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In continuum mechanics, conventional theory of elasticity fails to model structures, where the inner substructure starts affecting the material response. An intuitive explanation for this phenomenon relies on the length scale of the geometry, macroscale, and the inner substructure, microscale. As the ratio of macroscale with respect to the microscale approaches one, and as both length scales lead to the same order, the effects of the substructure shall be incorporated and we call this structure related material system metamaterial. Modeling of metamaterial incorporates additional parameters and it is indeed possible to do computations by using the finite element method [1], [2], [3], as long as we know all parameters. Therefore, we need an approach leading to a unique determination of all parameters. For an isotropic and centrosymmetric metamaterial, there are seven parameters to determine. It is challenging to define experimental studies for obtaining all of these parameters. As these parameters result after a homogenization approach by involving the inner substructure, we can acquire these parameters purely based on computations at the microscale. By using the finite element method for detailed computations at the microscale for seven distinct cases, we masterfully generate a way to determine the seven material parameters uniquely [4]. In this talk, this method is exploited and a practical application has been studied in order to present its capability for modeling the metamaterial response.

References

A MODEL OF HYDRAULIC FRACTURED HORIZONTAL WELL FOR DEBIT COMPUTATION OF SLANGED GAS AND OIL

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The purpose of work is to make mathematical model and finite difference algorithm for 3-dimensional dynamic model for debit and pressure computation in a region of hydraulically fractured horizontal well and compare results with commercial simulators. The composite model of hydraulic fractured horizontal well divides reservoir into three main flow areas: hydraulic fractures distributed along the horizontal well with different length and conductivity, but the fractures propagation is limited and obeys Darcy’s law; stimulated reservoir volume SRV: natural fractures are opened and connected. SRV is made up of matrix and micro-fractures and can be described with dual porosity model. The permeability of matrix system is very low compared with micro-fracture system. So, the inter-porosity flow between them is pseudo-steady and it can be determined only by pressure difference between matrix and micro-fracture system; unstimulated reservoir: the matrix characteristics are the same in unstimulated and stimulated reservoir. It has the same permeability and porosity. Assuming fluid flow in the hydraulic fractures obeys Darcy’s law, the pressure is equal on the boundary of fractures and matrix. The mathematical model for hydraulic fractures is given by analog of heat equation, initial and boundary conditions. The algorithm is based on solving heat equation with finite implicit methods on rectangular greed. These methods were chosen because of absolute convergent and second-order accuracy in time. Boundary condition can be used conditions of first (isolation) and third (non-transitory) types. Numerical computational algorithm realized on Python using numpy and matplotlib packages. This language was used because of simplicity of future integration into existing program packages.
GRADIENT & FRACTIONAL/FRACTAL MODELS FOR ELASTICITY, DIFFUSION, PLASTICITY AND DISLOCATIONS: APPLICATIONS TO LIBS AND DMCS

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Hooke’s law of elasticity and Fick’s law of diffusion are routinely used for theoretical interpretations of chemomechanical behavior and design of new materials and processes. The same is true for the use of classical plasticity and dislocation theories. However, the new experimental tools developed recently and associated computational methods suggest that the aforementioned “classical laws” often fail to interpret observed behavior. The lecture will show that a new possibility for sustaining the validity of the classical laws is to enrich them with nonlocal gradient, fractional and fractal terms. Physically unacceptable singularities predicted from classical elasticity for dislocations and cracks are eliminated within its gradient and fractional/fractal counterparts. Similarly, diffusion penetration profiles in nanopolycrystals and plasticity size effects in micro/nano pillars that could not be interpreted by classical theories can effectively be captured by their nonclassical counterparts. Examples will be chosen from the fields of Lithium-ion batteries and disclinated microcrystals fabricated by electrodecomposition under mechanical steering.

References

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PHASE-CHANGE IN NANOSCALE CONFINEMENT

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A two-dimensional (2D) material placed on an atomically flat substrate can lead to the formation of surface nanobubbles trapping different types of substances. This observation for graphene was first reported by group of A.Geim, along with modeling based on continuous theory of elastic membranes (Nature Communications, 2016). In our paper graphene nanobubbles are studied using atomistic and continuous multiscale modeling that allows direct numerical monitoring of phase change of the matter trapped inside nanobubbles (Scientific Reports, 2017; Nanotechnology, 2019).

All modeled graphene nanobubbles except for the smallest ones exhibit a universal shape, i.e., a constant ratio of a bubble height to its footprint radius, which is in an agreement with experimental studies and their interpretation using the elastic theory of membranes. MD simulations reveal that argon does exist in a solid close-packed phase, although the internal pressure in the nanobubble is not sufficiently high for the ordinary crystallization that would occur in a bulk system. The smallest graphene bubbles with a radius of 7 nm exhibit an unusual “pancake” shape. Previously, nanobubbles with a similar pancake shape were experimentally observed in completely different systems at the interface between water and a hydrophobic surface.

This research clearly demonstrates the possibility that nanobubbles in heterostructures can be used to investigate the fundamentally interesting phenomenon of phase transition in confined systems.
The paper presents an approach to kinematic synthesis of a leg mechanism for biped walking robots. The mechanism used is a six-bar, Watt-I type linkage. Selection of the kinematic scheme was based on the requirement to have the overall shape of the mechanism resemble the human leg outline shape. In addition, the Watt-I scheme is known for having three floating links connected in series, which in turn provides added flexibility toward obtaining complex coupler curves from the middle floating link. By using design heuristics and qualitative principles, a preliminary design synthesis is conducted first to obtain a rough set of the linkage dimensions. This stage only ensures that the mechanism generates a rough approximation of the desired walking gait. Further refinement of the design is carried out interactively using a relaxation synthesis method. By this method, we relax the linkage constraints by removing the input crank link hence making the mechanism a two-degrees-of-freedom (DOF) one. With the two DOF, we now can guide the ankle point of the leg along the prescribed desired path. By doing so and observing the paths traced by points of the floating link to which the crank was connected initially, we select a coupler point whose path is closest to circular. The found approximate circular path is studied to estimate its radius and center point, after which step the removed crank is then re-established as a link that connects the path’s center with the tracer point. The resulting one-DOF mechanism generates a better approximation of the desired path of the ankle.

The proposed design procedure is not limited to obtaining a prescribed path of the ankle point; it also includes certain requirements toward the positions (orientations) of the leg during stance and swing phases. The work demonstrates the capacity of interactive synthesis in solving practical problems that often require tedious numerical solutions.

**DOUBLE AGING OF HEAT-TREATED ALUMINUM ALLOY OF (7075) AND (6061) TO INCREASE THE HARDNESS NUMBER**

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The present study was undertaken to investigate the effect of double-aging and parameters (i.e. time, temperature and quenching media) on the mechanical properties of two aluminum alloys (i.e. AA7075 and AA6061), to find out the differences in response to the double-aging.

At first the specimens have been heat treated and tested using micro-Vickers hardness test, after that they are artificially aged at 150°C for various aging periods, then quenched in water and oil, after that they are retested to determine the optimum time and cooling rate that will give the maximum (peaking) hardness. This procedure has been repeated on the specimens with double aging at 185°C to find out which alloy will respond to double ageing more significantly. The experiment shows that the best results achieved for aluminum alloy 7075 better than the 6061 aluminum alloys, where the hardness increased from 135.66 HV to 150.61HV.

**MODELING FOR A CRACK IN AN ELASTIC PLATE WITH A V-SHAPED NOTCH**

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We developed a 2D plane strain numerical model of a thin plate with a v-shaped notch and a crack at its vertex. The plate is made of an elastic brittle material. The v-notch is statically loaded with a pressure distributed over the v-notch surfaces. The load controls the underlying crack growth. Initially an infinitely small crack at the vertex of the v-notch starts to propagate only if a critical value of a stress intensity factor is reached at the tip of the crack (assuming linear elastic fracture mechanics theory). We showed that depending on the plate thickness and the load applied, the resulting crack length can be predicted. For the system of a v-notch and an associated underlying crack there are three critical regimes: no influence of the rear plate surface is associated with a KI decrease with the crack length increase; the crack...
system close to a rear surface scenario is associated with an increase of a K1 with the crack length increase; transient mode with a flat dependency of a K1 to the crack length. Using the developed approach we parametrically estimated the crack lengths sensitivity to the plate thickness, v-notch shape, material properties and the load applied. We demonstrated that this approach can be used to predict the crack through and an arrested crack scenarios. The model allows us to take into account various extra factors including superimposed bending, chemically or thermally induced stresses.

**MODELING OF THE HYDRAULIC FRACTURING BY ENERGIZED FLUIDS AND FOAMS**

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Pseudo-three-dimensional cell-based model for hydraulic fracturing by energized fluids and foams is developed. The presence of gas phase in the fracturing fluid strongly affects its rheology and compressibility factor. Both effects are taken into account in the presented model and their influence on the fracture growth in a layered rock formation is investigated using pseudo-three-dimensional fracture geometry approach. It is assumed that gas phase processes are isothermal and empirical relation for the compressibility factor of real gas is applied. The rheology of foam is modeled by known correlations based on the experimental data. A method of coupling model equations with proppant transport model is developed in order to predict proppant distribution in the fracture during foam fracturing.

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**EXPERIMENTAL INVESTIGATION OF THE POLYURETHANE AGING UNDER DIFFERENT LOADING PROGRAMS**

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Polymers and polymer-based materials are intensive implemented in almost all areas of engineering practice: industry, construction, aircraft, rocket science, shipbuilding and medicine. These applications frequently have a very high performance demand, which makes their long-term characteristics of paramount importance. At the same time, they were subjected to degradation due to environmental factors, including light, temperature, stress, and others. Because of aging process, the physical and mechanical properties of these materials are significantly changed [1-2]. The effect of hardening and embrittlement of these materials during long-term aging is observed. So the investigation of aging processes in these materials is needed.

The research program includes experiments on alternating of fatigue, creep, long-term climatic and deformation aging of polyurethane specimens. Experiments were carried out on round specimens with the diameter of 4 mm. Fatigue experiments were conducted under conditions of repeated tension at a given amplitude variation of displacement and with loading frequency of 10 Hz on a desktop servo-hydraulic fatigue testing machine Si-Plan SH-B. On creep, specimens were tested at room temperature at different load values on Shimadzu AGX-50 plus tearing machine. Experiments for alternation of cyclic loadings and climatic aging during one year of the unloaded specimens are carried out. Results have shown the effect of considerable hardening and embrittlement during the aging process. Therefore, the number of cycles to fracture for the aged specimens was increased on more than by four times. Some specimens tested for this program, are additionally climatic aged during two years on a next step of investigations. Then these specimens were tested on creep. For aged specimens the time to fracture was increased on average by three times compared with specimens without aging.

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**References**


EVALUATION CRITERIA FOR THE WEAR RESISTANCE OF HIGH-CHROMIUM STEELS

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Currently, there is an increase in requirements for dimensional accuracy and quality of machined parts, which leads to the preferential use of machining processes in the final stages.

In modern machining production, more and more widespread use is found in expensive automated machine tools with microprocessor control. The operation of such equipment is characterized by a sharp increase in machine-minutes, toughening of the working conditions of the cutting tool, an increase in the consumption of tools per unit of output, which amounts to 5–10% of the total costs of cutting. Thus, the role of the cutting tool, which largely determines the efficiency of machining, increases markedly.

The most important indicator of the operation of the cutting tool is the performance, which characterizes the state of the tool in which it is able to perform its functions, having a working surface wear that is less than the criteria value. The following main consumer requirements for metal cutting tools can be distinguished: performance and reliability.

The performance depends on the processing modes (feed, speed and depth of cut), the geometry of the cutting part of the tool, the physicomechanical properties of the material of the workpiece and the tool material. Indicators of reliability of metal-cutting tools is its durability and reliability.

In this paper it is considered the issues of assessing the quality of tool material, as an important factor determining the performance of the cutting tool [1].


MOVING MATERIAL AND DYNAMIC PROBLEM OF AERTHERMOELASTIC VIBRATIONS AND INSTABILITY

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The study is devoted to the analysis of the travelling panel submerged in axially flowing gas medium taking into account the thermomechanical actions caused by the panel heating. In order to accurately model the dynamics and stability of a lightweight moving material, the interaction between it and the surrounding air must be taken into account somehow. The light weight of the material leads to the inertial contribution of the surrounding gas to the acceleration of the panel becoming significant. The approach described in this study allows for an efficient semi-analytical solution, where the reaction pressure of the gas flow is analytically represented by an added mass model in terms of the panel displacement function. Then the panel displacements accounting also for the gas-structure interaction are analyzed with the help of the weak form of the governing partial differential equation, and a Galerkin method of solution. In the first part of this study we represent the travelling panel by a single partial differential equation (in the weak form) using an added-mass approximation of the exact gas reaction. In the second part we apply a Galerkin method for dynamic stability analysis of the panel and present an analytical investigation of static stability loss (divergence, buckling) based on the added-mass model.

The work was supported by the Russian Science Foundation (project 17-19-01247).

MAXWELL AND OTHER MATRIX COMPOSITE HOMOGENIZATION SCHEMES IN AGEING LINEAR VISCOELASTICITY

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This work aims at showing how homogenization schemes concerning a matrix embedding ellipsoidal inhomogeneities such as Maxwell, Mori-Tanaka-Beveniste, Non Interaction Approximation and dilute schemes can be transposed from
A ROTATING of Automation and Control Processes

AND DISPLACEMENTS IN several taper, we study the stress media elasticity or conduction. low. Stresses, reversible and irreversible deformations, displacements are – rotational speed, and braking are investigated. In the case of ideal plasticity and the Tresca the Maxwell scheme. This allows to put in evidence that the so-called elastic contribution tensors have their counterparts in the ALV framework. The ALV Maxwell scheme can then formally be expressed by means of the latter after a reasoning transposed from elasticity or conduction. A special attention is then paid on the implementation of the schemes on composite materials made up with an isotropic ALV matrix embedding ALV spheroidal particles so that the Walpole formalism devoted to transversely isotropic media can be exploited. From a practical point of view, expressions based on Volterra products or inverses cannot be analytically calculated but a numerical discrete procedure based on a trapezoidal rule is used. This procedure transforms strain and stress histories in vectors, Volterra kernels in matrices and Volterra operations in matrix operations. Several examples are then treated. The method is first validated on non ageing cases using comparisons with results obtained from the exploitation of the Laplace-Carson transform and is finally applied on ALV materials. The ageing effect, the choice of the homogenization scheme as well as the influence of the aspect ratio of the spheroidal particles are particularly put in evidence on creep or relaxation curves.

SOLID MECHANICS MODELS IN OPHTHALMOLOGY

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Solid mechanics-based models have been used in recent years as tools to describe, for example, the stress-strain state of the eye shell under encircling band; to build a biomechanical model of the choroidal detachment, to depict the different mechanical aspects of the development of glaucomatous atrophy of the optic nerve fibers and the behavior of Lamina Cribrosa—circular or closed to circular plate, where the optic nerve fibers pass. In the present talk some of these models are reviewed.

Intravitreal injections are performed by the amount of fluid (drug) brought into the eye and are applied widely as a treatment for a variety of eye’s diseases. Estimation of the short time effect of intravitreal injections on the intraocular pressure (IOP) elevation has been performed with the help of shell-theory based models. It is shown that the absolute value of the difference between IOP readings before and right after the injection depends not only on the injection volume and the eyeball parameters, but also on the type of the tonometer used for the IOP measurements.

IOP, the fluid pressure inside an eye, is a key diagnostic parameter to determine the health of the eye. Therefore, accurate IOP estimation is important for proper management of the patients. The mathematical models for the several types of tonometers have been constructed and difference in the IOP readings before and after vision correction surgeries have been estimated.

DISTRIBUTIONS OF STRESSES, DEFORMATIONS AND DISPLACEMENTS IN A ROTATING ELASTOPLASTIC AND ELASTOVISCOPLASTIC DISKS

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Rotating discs are important details of many machines and devices. Calculations of rotating disks for strength were carried out repeatedly [1-3]. As a rule, discs operate under conditions that lead to the accumulation of irreversible deformations. Usually calculations are carried out at a fixed speed of rotation of the disk. It does not allow to investigate the stress state of rotating disks, which operate under varying operating conditions.

In this paper, we study the stress-strain state of elastoplastic and viscoplastic disks, rotating at varying speeds. The solution is obtained in the context of the flow theory for various plasticity potentials. Acceleration of the disc, deformation with a constant rotational speed, and braking are investigated. In the case of ideal plasticity and the Tresca yield criterion an analytical solution of the problem is obtained. Finite-difference schemes are constructed for the von Mises yield criterion and viscoplastic flow. Stresses, reversible and irreversible deformations, displacements are calculated. The laws governing the elastoplastic boundaries are obtained.

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EXTENDED KINETIC THEORY FOR COLLISIONAL SHEARING OVER AND WITHIN AN INCLINED, ERODIBLE BED

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Extended Kinetic Theory, a kinetic theory of granular gases in which the roles of velocity correlations, friction and particle stiffness are taken into account, is able to reproduce the results of Discrete Element Method (DEM) simulations of soft and hard spheres in steady, homogeneous shearing flows at volume fractions both less and greater than a critical, above which rate-independent components of the stresses develop (Berzi & Jenkins 2015). In steady, homogeneous shearing, the boundaries play no role. A striking advantage of kinetic theory over any other proposed model of granular flows is that it permits the derivation of boundary conditions at solid surfaces (Richman 1988) and phase interfaces (Jenkins & Askari 1991; Pasini & Jenkins 2005), using arguments of statistical mechanics in the energy and momentum balances. Those conditions are required when numerically solving the system of partial differential equations that govern granular flows in realistic geometries. The use of appropriate boundary conditions has permitted extended kinetic theory to be successfully tested also against discrete numerical simulations of steady, inhomogeneous shearing flows of frictionless spheres between bumpy planes in the absence of gravity (Vescovi et al. 2014); and inclined, gravity-driven, free surface flows of frictional spheres over rigid, bumpy planes, with and without flat, frictional sidewalls (Gollin et al. 2017). In those flows, the solid volume fraction was always less than a critical. Here, we apply extended kinetic theory to steady, inhomogeneous shearing flows in which the solid volume fraction may exceed the critical value for the development of rate-independent components of the stresses in steady, homogeneous conditions. An example is the steady, gravity-driven, free surface flow of frictional, soft spheres between flat, frictional sidewalls, when a sufficient number of particles is fed to the system. In this case, the flow takes place over an erodible bed in which the particles creep (Komatsu et al. 2001; Richard et al. 2008).

References

EFFECT OF CRACK BRIDGING ON THE TOUGHENING OF CERAMIC/GRAFENNE COMPOSITES

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A model is proposed describing the effect of crack bridging on the fracture toughness of ceramic/graphene composites. The dependences of the fracture toughness on the graphene content and the sizes of the graphene platelets are calculated in the exemplary case of yttria stabilized zirconia (YSZ)/graphene composites. The calculations predict that if crack
bridging prevails over crack deflection during crack growth, the maximum toughening can be achieved in the case of long graphene platelets provided that the latter do not rupture and adhere well to the matrix. The model shows good correlation with the experimental data at low graphene concentrations.

**BOUNDARY-ELEMENT MODELLING OF A SLOW COMPRESSIONAL WAVE IN POROVISCOELASTIC MEDIA**

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It is known that in porous medium due to the presence of a fluid phase, two kinds of compressional waves exist. The first one is similar to an elastic wave, and called a fast wave, with a small amount of attenuation. The second wave is with a much slower propagation speed and highly dissipative, and is called a slow wave. The slow wave is more difficult to detect, as its amplitude is considerably smaller than that of the fast longitudinal wave.

The presented work is dedicated to modeling of a slow compressional wave in poroviscoelastic media by means of boundary-element method. Biot’s theory of porous media is extended to poroviscoelasticity by means of the elastic-viscoelastic correspondence principle. Standard linear solid model is employed in order to describe viscoelastic behavior of the skeleton in porous medium. The boundary-value problem of the three-dimensional dynamic poroviscoelasticity is written in terms of Laplace transforms. Direct approach of the boundary integral equation method is employed. The boundary-element approach is based on the mixed boundary-element discretization of surface with generalized quadrangular elements. Subsequent application of collocation method leads to the system of linear equations, and then to the solution in Laplace domain. Numerical inversion of Laplace transform is used to obtain time-domain solution.

A problem of a Heaviside-type load acting on a poroviscoelastic column is considered. The slow compressional wave appearance is demonstrated on the solutions for displacements at the point of the load application, pore pressure at the center of the column and fluid flux at the loaded end. An influence of permeability of porous material on dynamic responses is studied.

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**A CONTINUOUS MODEL OF DAMAGED MEDIA AND ITS REALIZATION IN STATIC AND DYNAMIC PROBLEMS OF MECHANICS OF DEFORMABLE SOLIDS**

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The main degradation mechanisms of initial strength properties of structural materials (metals and their alloys) under static and dynamic modes of thermal-mechanical loading are considered.

In the framework of mechanics of damaged media (MDM), mathematical models are developed, which describe processes of inelastic deformation and damage accumulation under various (static and dynamic) modes of thermal-mechanical loading. The formulation of the model consists of three interrelated parts:

– relations defining inelastic behavior of the material, accounting for its dependence on the failure process;

– equations describing damage accumulation kinetics;

– a criterion of strength of the damaged material.

The version of the relations of viscoplasticity is based on the notion of a loading surface and the principle of orthogonality of the inelastic strain rate vector to the surface at the loading point. The present version of equations of state describes the main effects of the viscoplastic deformation process of the material for arbitrarily complex loading trajectories.

The construction of kinetic equations of damage accumulation is based on analyzing physical stages of the development of microdefects, using energy-based principles, and accounts for the effect of the type of the stressed state and the degree of accumulated damage on the processes of nucleation, growth and merging of micro-discontinuities.

The condition where the damage degree reaches its critical value is taken as the failure criterion.

Experimental-theoretical methodologies for determining material parameters and scalar functions of the defining relations of MDM are developed.

The model of MDM has been assessed using the numerical modeling method and by comparing the obtained results with the test data, which made it possible to draw the conclusion about the reliability of the defining relations and the developed methodology for determining material parameters used in the above relations. The following issues have been studied:

– the effect of average deformation on the fatigue life of metals;
– nonlinear summation of damage under block-type loading regimes;
– the effect of the type of deformation trajectory on the fatigue life of metals;
– thermal-cyclic life of heat-resistant alloys under combined thermal-mechanical loading;
– long-term strength of metals under simple and complex loading.

The results of numerically modeling the fatigue life of elements and units of load-carrying structures in a number of applied problems are presented. The following characteristics have been evaluated:
– fatigue life of a stripe with circular perforations under low-cycle loading;
– thermal-cyclic life of a model of flame tubes of gas-turbine engines with various inclinations of the cooling channels;
– carrying capacity of a NPP vessel in the conditions of a hypothetical emergency;
– strength of structural elements in the form of spherical and closed cylindrical shells with flat and hemispherical bottoms under a single pulse of explosion loading.

This work was supported by a grant from the Government of the Russian Federation (contract No. 14.Y26.31.0031)

**CONCENTRATED NANOPARTICLE SUSPENSION: 2D SIMULATIONS BY STOCHASTIC DYNAMICS**

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Development of new technologies to produce highly promising ceramics needs the application of ever smaller particles of starting materials. Among a number of preparation methods for nanosized particles, laser synthesis is particularly promising, since it yields perfect, highly pure, weakly agglomerated, spherical nanoparticles with a narrow size distribution [1]. Such nanoparticles could lead to excellent ceramic materials, if one can learn how to transform them to nanocrystalline, fully dense thin films and ceramics. Among others colloidal methods of tape, slip castings and electrophoretic deposition are commonly used to fabricate the films and ceramics.

In colloidal compaction methods, the density of the final compact and the probability of voids formation are determined by the rheological characteristics of the suspension. With an increase in the concentration of particles in a suspension, the aggregation process is facilitated, and a system characterized by aggregative stability can become unstable. The aggregation process of nanoparticles is complex and depends on many factors: the properties of the solvent, the material of the particles, their size, the presence of surface-active substances, the hydrophilic-lipophilic balance, the mechanisms for preparing the suspension, etc. Therefore, the phenomenon of formation of aggregates (and, accordingly, pores in ceramics) known from experiments still remains outside the framework of modern theoretical constructions, although it is fundamentally important for the creation of porousless ceramics.

In the present work, monodisperse ensembles of nanoscale particles suspended in a liquid medium are studied by the method of stochastic dynamics [2]. The particles are perfectly spherical in shape; their diameter varies in the range of 10–1000 nm. For clarity, calculations are carried out in a two-dimensional formulation. The model cell is a square in the Oxy plane, on the cell sides the periodic boundary conditions act. The number of particles inside the model cell is about 104. Interactions between suspended particles include: van der Waals attraction [3], elastic repulsion of particles with direct contact (Hertz’s law), and electrostatic repulsion due to the formation of an electrical double layer on the surface of suspended particles [4]. In the framework of numerical modeling, the process of aggregation of nanoparticles is analyzed: the rate of change with time of the monomers fraction, the maximal cluster size, the average coordination number in the ensemble, etc. The influence of particle size on the rate of aggregation and the stability conditions of the suspension is investigated.

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GRAIN BOUNDARY SLIDING AND ROTATION AS THE MAIN MECHANISMS OF HIGH-STRAIN-RATE PLASTICITY IN NANOCRYSTALLINE SOLIDS

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When the grain size of material decreases down to a nanometer range, the mechanisms of plasticity dramatically change [1,2]. In fine-grained nanomaterials, the main mechanism of plasticity is usually the grain boundary sliding (GBS) [3] accompanied by grain rotation [1], instead of the intragranular dislocation gliding typical for normal coarse-grained materials. In our previous works [3-5], we have proposed a mechanical model for GBS as the only mechanism of plasticity and have defined the yield stress [3] and the characteristic relaxation time [6] parameters for a few nanocrystalline metals. In the present work, we suggest a new constitutive model comprising intragranular dislocation plasticity and grain boundary rotations as the additional to GBS mechanisms of nanocrystalline materials’ plasticity. In doing so, we discuss interrelations between the dislocation mechanisms of plasticity and GBS in nanocrystalline solids under high-strain-rate deformation conditions. Plasticity mechanisms at strain rates $10^{-2}-10^3$ s$^{-1}$, which are usually created during the impact experiments, and $10^5-10^9$ s$^{-1}$, that are typical for molecular dynamics (MD) simulations, are in the focus of our consideration. The model correctly predicts a transition point, corresponding in copper to the grain size of about a few nanometers [7], below which the shape of nanograins remains spherical after the deformation process. The energy of partial dislocations with stacking faults has been calculated for two cases usually observable in MD simulations.

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HIGH-SPEED DEFORMATION AND DESTRUCTION OF BRONZE

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To calculate the strength of structures experiencing intense dynamic effects, knowledge of the physicomechanical properties of structural materials is necessary in a wide range of strain rates from $10^2$ to $10^6$ 1/s. Currently, to study the deformation properties and strength characteristics in the range of strain rates $10^2$–$10^5$ the Kolsky method and its modifications are most often used. Higher strain rates are obtained in a plane wave shock experiment.

The paper presents the results of a study of the dynamic properties of BraZhNMs bronze under tension, carried out using the Kolsky method, as well as the results of determining the spall strength obtained using a VISAR laser interferometer.

Experiments using a split Hopkinson bar were carried out in the range of strain rates 900–1800 1/s. In experiments, dynamic strain diagrams were obtained, over which the yield strength $\sigma_{0.2}$ and the tensile strength were determined. The yield strength of bronze increases with increasing strain rate from 500 MPa to 600 MPa. The tensile strength of bronze under uniaxial tension (temporary tensile strength) also increases from 700 MPa to 1000 MPa with increasing strain rate. The limiting plastic characteristics of the destruction of bronze (relative elongation and relative narrowing after rupture) are practically independent of the strain rate.

In plane-wave experiments, the spall strength of bronze was studied in the range of strain rates of $2 \times 10^4$–$3 \times 10^4$ 1/s. The
obtained values of the spall strength lie in the range of 1.6 - 2.5 GPa, which significantly exceeds the value $\sigma_B = 650 \text{ MPa}$, obtained under static loading and the values obtained in experiments using the Kolsky method, which is apparently due to the influence of the strain rate, and with the influence of the volume stress state in a plane-wave experiment.

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**SEISMIC BARRIERS: THEORY AND NUMERICAL SIMULATIONS**

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The basic idea of a seismic barrier is to protect an area occupied by a building or a group of buildings from seismic waves. Depending on nature of seismic waves that are most probable to appear in a specific region, different kinds of seismic barriers are suggested. For example, vertical barriers resembling a wall in a soil can protect from Rayleigh and bulk waves. The performed FEM simulation reveals that to be effective, such a barrier should be (i) composed of layers with contrast physical properties allowing “trapping” of the wave energy inside some of the layers, and (ii) depth of the barrier should be comparable or greater than the considered seismic wave length. Another option is the utilization of horizontal barriers. Horizontal barrier can be constructed modifying the properties of the surface layer preventing the corresponding surface wave from propagation. Such a barrier is especially effective against Love waves, at the same time assuring good protection of the area from the approaching Rayleigh waves. The last of the considered options is the utilization of discrete seismic barriers. One of the examples of discrete barriers is the system of piles (columns in soil) surrounding the area to be protected. Construction of discrete barrier is usually associated with lower cost as comparing to vertical barrier. At the same time, the performed numerical simulations testify that in many cases discrete barriers can secure a level of protection comparable the one achieved using vertical barriers.

**NEW ANSATZES FOR SOLUTION OF NONLINEAR NONAUTONOMOUS KLEIN-FOCK-GORDON EQUATION**

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Methods of finding of exact analytical solutions $U(x, y, z, t)$ of nonlinear nonautonomous Klein-Fock-Gordon (KFG) equation are offered [1,2]. We are finding solutions in the form of composite function $U=f(W)$. The function $f(W)$ satisfies the nonlinear ordinary differential equation of the first or second order. This function can be found in the form of an integral for arbitrary nonlinear right hand part of the nonlinear KFG equation. If the corresponding integrals can be inverting, then $f(W)$ is in an explicit form.

The argument $W(x, y, z)$ is named ansatz. It can be found on the basis of methods which were developed for constructing functionally invariant solutions of the wave equation [3,4]. New methods of definition of ansatz are offered $W$. It is shown that ansatz $W(x, y, z, t)$ can be constructed in the form of composite function of one variable

$$W = \Psi(\theta), \quad \theta = \{\tau(x, y, z, t), \lambda(x, y, z, t), \nu(x, y, z, t), \tau\lambda, \nu\lambda, ..., \}$$

or two variables

$$W = \{\Psi(\tau, \lambda), \Psi(\tau, \nu), \Psi(\lambda, \nu), ...\}$$

Exact analytical solutions of the nonlinear nonautonomous KFG equation are found for the each ansatz $W$. They allow to construct the new solution of the nonlinear nonautonomous KFG equation. The found solutions are illustrated and discussed.

The nonautonomous KFG equation, unlike autonomous, more adequately describes physical processes as it allows to consider heterogeneity of real media in which the corresponding physical phenomena take place. It is possible to hope that the found solutions will be useful at the description and modeling of these phenomena and processes.
HEATING AND DESTRUCTION OF BIOLOGICAL TISSUE BY HIGH-INTENSITY FOCUSED ULTRASOUND

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Recently high-intensity ultrasound (HIFU) has been increasingly used for the treatment of tumors of various nature, competing with both traditional surgical methods and other non-invasive technologies of biotissue destruction [1]. The evolution of technological equipment expands the capabilities of HIFU applications for processing a given tumor volume within a minimal time interval. The process of thermal necrosis requires a specific irradiation program: the choice of parameters of ultrasound pulses (the number of pulses, their intensity and duration) and the spatial and temporal localization of the focal areas within the tumor volume. The application of HIFU leads, on the one hand, to the tumor tissue necrosis, and on the other hand, to an undesirable effect on healthy tissue. A comprehensive study (obtaining the data on the spatial-temporal evolution of necrosis areas and temperature fields in tissues) of the processes of destruction of biological tissue is now possible only with the use of computer simulation technologies. The paper presents the results of three-dimensional modeling of the non-stationary process of heating and ablation of biotissue by HIFU pulses based on the solution of the bioheat transfer equation (BHTE) [2]. The computer code was developed for simulations and the computation resources were provided by the supercomputer center of Peter the Great St. Petersburg Polytechnic University. The influence of ultrasonic radiation parameters on the process of tissue necrosis has been studied. The effect of blood perfusion on the process of heat transfer during tumor therapy has been discussed. The possible spatial-temporal schemes of tumor therapy have been analyzed.

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EXPERIMENTAL AND NUMERICAL STUDIES FOR A SHEAR MODE PIEZOELECTRIC ACTUATOR APPLIED TO INKJET PRINTHEADS

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This paper proposes a novel actuating design adopting the shear deformation of a lead zirconate titanate (PZT) actuator to deflect the diaphragm with the application to various microfluidic systems. The deflection of diaphragm and resulting volume displacement in the pressure chamber is examined by analytical and numerical method. To estimate the maximum actuating force and deflection of shear mode piezoelectric actuator, we investigated the actuating characteristic curve for actuator, which represents the inverse proportion of central deflection to the anti-deflection force under certain actuating voltage. The direct proportion relation for diaphragm central deflection and action force can be also determined from the diaphragm central deflection curve. Afterwards, we can obtain both linear relations including diaphragm central deflection and volume displacement with respect to the actuating voltage and diaphragm central deflection. Besides, this study compared the numerical solutions with measured data for verification of the theoretical model, revealing acceptable agreement. The application of this proposed design is realized in a micropump or an inkjet printhead.
EFFECTS OF WEIGHTS ON VERTICAL NONLINEAR OSCILLATIONS

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A nonlinear energy sink is treated as an example to examine dynamic effects of weights on vertical nonlinear oscillations. Reference search documents that all available works assumed the weights balanced by the forces of static deflection. A fundamental problem is investigated to explore if the weight can be counteracted by the resulting static equilibrium in vertical nonlinear oscillations. The present work highlights dynamic effects of the weight on the vibration of a structure coupled with a nonlinear energy sink, which is modeled as a 2-degree-of-freedom system. Free vibration is numerically examined. Forced vibration is analytically explored via the method of harmonic balance with numerical validations. The numerical and the analytical results are compared with the experimental ones. The modeling, the analysis, the simulations, and the experiment yield the following conclusions: (1) The account of the weight results in an additional linear coupling term and an additional quadratic stiffness term in dynamic equations; (2) For free vibration of a structure with a nonlinear energy sink with its mass reasonably large, if the NES weight is considered, both the numerical and the experimental investigations demonstrate that the vibration frequency of the couple system is larger than the natural frequency of the primary structure, while the frequency of the couple system is smaller if the weight is neglected. In both cases, the frequency changes are small; (3) For harmonically forced vibration of a structure with a nonlinear energy sink, there are both quantitative and qualitative differences between the cases with and without the weight. Quantitatively, both the analytical and the numerical investigations found that in the case with the weight, the steady-state response of the primary structure is smaller, while the quantitative difference decreases with the increase of the excitation amplitude. The results considering the weight are closer to the experimental ones. Qualitatively, the numerical simulations indicate that, in the case with the weight, there may be period-2 motion or chaotic motion, while in the case without the weight, there is period-1 motion or regular motion with the same parameters. Therefore, for a nonlinear mechanical system moving vertically, its weights cannot be ignored together with the initial deformations due to the static equilibrium.

MODELING OF THE SUPERELASTIC BEHAVIOR OF CUALNI - SINGLE CRYSTALS ACCOUNTING ANISOTROPY OF ELASTIC PROPERTIES

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Microstructural modeling of functional and mechanical properties of CuAlNi shape memory alloy single crystals has been performed. The lattice deformation tensor for $\beta_1 \leftrightarrow \beta_4$ martensitic transformation was calculated from crystallographic data available in literature and maximal possible shear strain (the crystallographic resource of the transformation) was estimated to be equal 13%. As the Cu-base shape memory alloys demonstrate strong orientation dependence of the elastic properties, the anisotropy of the elastic moduli in austenitic state was taken into account. Matrices of the elastic moduli and elastic compliances were written based on the available experimental data. The simulated stress-strain curves obtained for superelastic austenitic and pseudoplastic martensitic CuAlNi samples are in a very good qualitative agreement with literature experimental data for single crystals with different orientations. The orientations of the single crystal when the maximal superelastic strain is close to the crystallographic resource of the transformation were determined.

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TSALLIS DIVERGENCE IN THE STATISTICAL LINEARIZATION OF DYNAMIC SYSTEMS

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Statistical linearization techniques have taken an appreciable place among approaches concerned with solving different problems related to investigation of mechanical systems; and papers [1-5] and others may serve as an evident confirmation. Within this branch, the present paper proposes an approach to the statistical linearization of dynamic systems, based on Tsallis divergence [6] as a measure of stochastic dependence. The statistical linearization of input/output system mappings is just a non-linear identification problem, whose solution is considerably determined by a dependence characteristics of input and output processes of a system under study. At
At the same time, existing approaches to the statistical linearization are based on the conventional linear correlation, which may lead to construction models, where the output variable will be identically equal to zero. In particular, such a possibility is shown in the present paper, in which an approach is proposed aimed to remove conventional correlation technique drawbacks.

Applying conventional correlation measures of dependence directly follows from statistical linearization problem statements themselves, when these are based on the conventional mean square criterion. Their main advantage is convenience of the use involving both a possibility to derive explicit analytical expressions under determining required system characteristics, and relative constructing their estimates involving those of based on availability of dependent observation data. Nevertheless, the main drawback of linear correlation dependence measures is a possibility of their vanishing even if there exists a deterministic dependence between the random values [7, 8]. To remove such a drawback, more complex, non-linear, measures of dependence are applied. Among them, a particular place is taken by consistent ones. In accordance to A/N/ Kolmogorov terminology [9], a measure of dependence between two random variables is referred as consistent, if it vanishes if and only if the random values are stochastically independent.

Within the present paper information-theoretic approach a problem statement is considered concerned with the statistical linearization of multi-input/multi-output discrete time dynamic systems. Such an approach is based on applying quadratic Tsallis divergence under construction a statistical linearization criterion. When one of the two densities is the joint probability distribution density of the random values (vectors, and the second one is the product of their marginal densities, a corresponding divergence becomes a measure of dependence that in the present case is natural to be referred as quadratic Tsallis mutual information.

From a computational point of view, especially under calculations by use of sample data, Tsallis divergence is more attractive than that of Kullback-Leibler since the latter involve the "integral of logarithm", what is commonly recognized as more complex in the comparison with Tsallis divergence, where the logarithm is absent at all.

Within the present paper approach, the statistical linearization criterion is the condition of coincidence of the mathematical expectations of the output processes of the system and model; and the condition of the coincidence of quadratic Tsallis mutual information of input and output processes of the system and quadratic Tsallis mutual information of the input and output processes of the model. Expressions to determine matrix-valued weight function coefficients of the linearized model are obtained. Meanwhile, the expressions obtained are based on quadratic Tsallis mutual information and define a measure of stochastic dependence being consistent in the Rényi sense.

Remark. In comparison to pointed out . . . terminology[9] mentioned, a measure of dependence is natural to be referred as consistent in the Rényi sense, if it meets Rényi axioms [7]. It is clear that the class measures of dependence consistent in the Rényi sense is narrower than that of measures of dependence consistent in the Kolmogorov sense, while constructing measures of dependence consistent in the Rényi sense is a particular problem, whose solution is not evident.

**LOCALIZED AND SOLITONIC PLANE WAVES IN 2D CUPRATE-LIKE LAYERS**

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The evolution of a landscape of density of oxygen particles in a two-dimensional CuO$_2$ layer is studied by means of numerical simulation when localized and other similar waves propagate in the layer. The cuprate-like layer is considered as a two-component lattice formed by two interconnected quadratic sub-lattices, one consisting of motionless copper atoms and the other consisting of oxygen atoms free to oscillate. Both types of atoms are modeled as point particles such that O and Cu units interact via Morse potential forces. A wave of compression of O-particles is initiated by either an initial kick to one particle in one row along one of axes of the sub-lattice or a plane soliton-line wave with a front perpendicular to one of such axes is excited by an appropriate choice of initial conditions. Wave characteristics (velocity, lifetime) and their changes are estimated for a range of misfit of the Cu-O-bonds when increasing/decreasing doping.

**BEYOND THE PEYRARD-BISHOP-DAUXOIS MODEL OF DNA: BUBBLES AND DISCRETE BREATHERS**

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A modified nonlinear model of DNA developing the well known Peyrard–Bishop–Dauxois model has been created to describe more accurately process of breathers’ forming and bubbles’ nucleation. Influence of nearest to nearest neighbors of each nucleotide pair on the pair’s opening is taken into account in study of dynamics of DNA molecule performed by numerical simulation. The nucleation length of the denaturation bubble was shown to be dependent of the many parameters of the model. There are sets of parameters providing that the optimal nucleation bubble length with the appropriate minimal energy of nucleation exists. There are conditions at which energy of nucleation of more short bubbles is higher than one of long bubbles. Also conditions for propagating of discrete mobile breathers excited by initial velocities and coordinates perturbations in a small group of nucleotide pairs located at the end of DNA are studied. It is shown that a length of trajectory of mobile breathers moving along a molecular chain may be long.

**WHAT IS THE DISTANCE IN THE ARENA OF SCIENCE AT WHICH THE ANALYTICAL SOLUTION TO THE NAVIER-STOKES EQUATION BECOMES AVAILABLE?**

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The Navier–Stokes equations, named after Claude-Louis Navier and George Gabriel Stokes in the year 1822, is a system of nonlinear partial differential equations. An analytical solution to the Navier-stokes equation does not exist in the literature. A set of principles as per which get defined a set of rules, to test any given claim of the existence of an analytical solution beyond doubt does not exist.

The presentation discusses the regime in which the Navier-Stokes equation exists, how its mathematical nature connects to other areas of Physics, how deep are the theoretical implications? An analysis of these lines brings forward a declaration on how a set of principles can be searched for by which would emerge a set of rules as per which any claim towards an analytical solution can be tested, this once achieved obtaining an analytical solution becomes the easiest task.

The presentation gives a detailed brief on the exciting industrial arena which emerges, once the analytical solution is achieved and the class of industrial data which becomes possible.

On the said lines, while attempting to obtain an analytical solution to the problem, industrial data achieved over years, as would be expected once an analytical solution for Navier-stokes equation is achieved, has been presented.
Sonic and phononic crystals based on the localized resonant principle have been proposed and studied in the last twenty years. In particular, periodic materials with heavy, stiff inclusions with a soft coating embedded in a stiff matrix have been demonstrated to have broad spectral gaps at low frequency. These intervals of frequency inside which no waves with real wavenumber can propagate can have different applications especially in vibration isolation.

In this contribution, we exploit the two-scale homogenization approach to compute explicitly these band gaps for out-of-plane wave propagation in ternary locally resonant metamaterials (LRM) with two-dimensional periodicity. The considered inclusions are cylinders, modelled as rigid, coated by a very compliant material. The homogenization approach, recently developed by the authors for binary LRM, leads to the definition of the dynamic effective mass density, depending on the frequency, that becomes negative near the resonant frequencies of the inclusions. The intervals of negative effective mass give the band gaps. These explicit solutions put in evidence the dependence of the spectral gaps on the geometric parameters of the unit cell and on the mechanical properties of the three constituent materials and can be useful for the design of the metamaterial. In particular, the key role of the coating thickness is highlighted.

The range of frequency where the asymptotic homogenization approach is equivalent to the Bloch-Floquet theory is also established and confirmed by numerical simulations.

NEW SOLUTION OF THE CUBIC COMPLEX GINZBURG-LANDAU EQUATION

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The cubic complex Ginzburg-Landau equation i \( u_t + p u_{xx} + q |u|^2 u = \gamma u \) (\( u(x,t), p \) and \( q \) complex, \( \gamma \) real, \( \text{Im}(q/p) \) nonzero) possesses up to now four closed form solutions due to Pereira and Stefano 1972, Nozaki and Bekki 1983 and 1984, Bekki and Nozaki 1985.

We present a new one and explain the method which allowed us to find it.

RECENT ADVANCES IN MICROSYSTEMS AND PRINTED SENSORS

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Micro Electro Mechanical Systems are the subject of active research pushed by the increasing number of their applications. These include: IOT, self driving cars, miniaturized biomedical devices and advanced monitoring of structures and infrastructures.

The purpose of the lecture will be to present and critically discuss recent research activities in the field of innovative Microsystems. After an overview of recent activities, the presentation will focus on: recent advances in Frequency Modulated gyroscopes [1], auxetic metamaterials in Microsystems [2], [3], additive manufacturing and wet metallization for the fabrication of uniaxial and multi-axial accelerometers [4].

Clay-rich rocks are considered as potential host rocks for high-level radioactive waste repositories in several industrial countries. These geological formations are highly heterogeneous at multiple scales and with regard to the complexity of their organization, the prediction of engineering properties from microstructure is clearly a challenging task. These engineering or effective properties inferred by homogenization theories are used as inputs of numerical codes, often based on the finite elements method, for engineering purpose. All the homogenization approaches used to estimate these effective properties are based on the paramount concept of Representative Elementary Volume (REV) in 3D or Representative Elementary Area (REA) in 2D.

This paper provides new estimates of REA sizes of two clay-rocks actively studied in the framework of deep disposal of radioactive waste: the Callovo-Oxfordian (COx) claystone from the underground research laboratory in Meuse/Haute-Marne (Eastern France) and the Toarcian argillite from the experimental station of Tournemire (Southern France). The REA sizes, named $l_{\text{REA}}$, have been obtained from two mineral maps following the classical “counting box” (CB) method and a statistical approach which introduces the concept of “statistical” REA. Following this approach, the “statistical” REA shown here is related to the microstructure and to the properties of each component. The precision of the estimation of the effective property is given, and depends on the number of realizations that one is ready to generate. The probabilistic concept of realization is presented, in a practical viewpoint, as a sub-domain of the studied mineral map in which apparent morphological or mechanical properties have to be calculated. In this study, the apparent elastic moduli of sub-domains have been estimated by using two micromechanical models. The first micromechanical model consists in an inclusion-based model for which spherical non-clay grain is embedded in a clay matrix, and for which values of its transverse isotropic stiffness tensor have been taken from literature. The second micromechanical model is an isotropic inclusion-based model for which spherical non-clay grain is embedded in a clay matrix which elastic moduli values have been inverted by a Monte-Carlo approach from engineering moduli of both shales under study. Our calculations have shown the following results: (i) the statistical morphological $l_{\text{REA}}$ considering surface clay fraction are of the same order of magnitude than those measured for other shales, and those obtained by the simple CB method with values of threshold between 5 and 10 %, (ii) the mechanical $l_{\text{REA}}$ associated with bulk modulus and shear modulus are significantly greater than morphological $l_{\text{REA}}$, (iii) the mechanical $l_{\text{REA}}$ estimates of shear modulus are greater than that of bulk modulus.

**ON REYNOLDS DILATION IN SHEAR BANDING OF METALLIC GLASSES**

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Metallic glasses, due to long-range disorder of atoms, expand locally or globally in response to shear, bearing a resemblance to Reynolds’ dilation of granular media. It has been widely accepted that shear flow in metallic glass must accompany local dilation, and the shear-dilation coupling is its intrinsic feature. In this talk, we first give a short review on available microscopic flow theories or models from a viewpoint of the dilation. Then we demonstrate how the dilation governs shear band formation and evolution in metallic glasses. We show that the coupling of dilation softening and thermal softening governs shear band emergence in metallic glasses, where the dilation (or free volume) softening plays a dominant role and the thermal softening plays a secondary role. Furthermore, we find that there is a linear correlation between the dilation and shear band evolution degree, and the accumulation of dilation leads to a transition from ductile shear band to brittle shear band in metallic glasses.

**EFFECT OF SURFACTANTS ON THE POLYMORPHISM OF IRBESARTAN GENERATED DURING DISSOLUTION**

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Irbesartan presents the phenomenon of polymorphism “desmotropie” and exists in two forms: crystalline form A and
form B which has no therapeutic activity. This product is characterized by a limited low absorption and dissolution rate limited. Improving its biopharmaceutical characteristics can increase its absorption and oral bioavailability. The objective of this work is to improve its solution using surfactants as binary physical mixtures (Irbesartan / surfactants) to delay the onset of the inactive form. The different mixtures were prepared by varying concentrations of surfactants (SDS, Poloxamer 188, Tween 20, Tween 80, tetradecyltrimethylammonium bromide and hexadecyltrimethylammonium bromide). The prepared systems were characterized by X-ray powder diffraction analysis to detect any formation of amorphous or polymorphic compound. The differential scanning calorimetry offers the possibility to evaluate the enthalpy and the melting temperature of the active ingredient (Irbesartan), surfactants and mixtures. Infrared spectroscopy was used to identify the active and surfactants. Scanning electron microscopy to determine the external appearance of active ingredient and different preparations. The study of the dissolution of the drug is realised in aqueous solutions: purified water (pH = 6.8) and gastric medium (pH = 1.2), gastro-intestinal (pH = 3.6). The results of dissolution have shown that there is a transition of Irbesartan to form inactive therapeutic perspective in acid medium and the presence of some surfactants not only helped improve the dissolution of the active ingredient but also delay the onset of form B.

Differential scanning calorimetry allowed us to identify two crystalline forms of PA and the amorphous form and show the presence of an interaction between the active ingredient and Cetrimid tetradecyltrimethylammonium bromide and hexadecyltrimethylammonium bromide. This interaction is characterized by a melting endotherm at a temperature below the melting point of the two components of the binary system. These depend strongly on the crystal lattice of the binary mixture which was confirmed by X-Rays diffraction.

Acknowledgments
We think Biopharm industry for Irbesartan.

APPLICATION OF DISCRETE ELEMENT METHOD (DEM) SIMULATIONS TO SUPPORT THE INVESTIGATION OF GAMMA ALUMINA PHASE TRANSFORMATION INDUCED BY MECHANICAL MEANS

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The current work has applied the Discrete Element Method (DEM) simulations in combination with experiments to study the effect of two different mills, an attritor and a planetary ball mill, on the transformation of γ alumina into α alumina.

Aluminium oxide $\gamma-Al_2O_3$, or alumina, is used for a variety of applications because of its beneficial properties such as thermal and chemical stability, wear-resistance, good strength and electric and thermal insulation [1, 2, 3]. Alumina exists under several allotropic forms (k, γ, θ, δ, α) with α alumina being the thermodynamic stable phase. This can be obtained by calcination of γ alumina at temperature over 1200°C [4]. γ alumina can be transformed in α alumina either by thermal effects, raising the temperature, or by suppling mechanical energy at much lower temperatures [5, 6, 7]. Several studies reported in the literature have used high-energy ball mills to induce phase transformation at room temperature but only some of them were successfully. From these studies it was highlighted that the best conditions for the conversion from the γ phase into the α phase were: a high ball-to-powder ratio, large grinding media and media with high hardness [5].

In the current work, the simulations employed the open source DEM code LIGGGHTS (DCS computing, Linz, Austria) adopting the standard Hertz-Mindlin contact model to solve normal and tangential contacts. The motion of the grinding media, in both an attritor and a planetary ball mill, was modelled by DEM for a variety of conditions (speed, grinding media size). This allowed the study of additional information on the collision frequency and the impact velocity of the grinding media that was not possible measure from the experiments. The DEM particle information was then used for the calculation of both the average stress energy and the average specific energy, which represent the maximum energy theoretically transferable by the media to the alumina during milling. High speeds and large grinding media were selected for the milling experiments to obtain high stress energy within the mill. The material was milled up to 4hr with a ball-to-powder ratio equals to 10 and then characterised for particle size measurements by laser diffraction and X-Ray diffraction measurements.

DEM simulations revealed that the planetary ball mill achieved stress energy levels two orders of magnitude higher than the attritor mill. This was in perfect agreement with the experiments that showed transformation of the alumina from γ to α phase at room temperature only for the planetary ball mill, inferring that for the latter case the stress energy was probably high enough to overcome an activation energy barrier. In fact, in the planetary ball mill first signs of phase
transformation were detected by XRD diffractograms already after 1hr of milling. In contrast, in the attritor mill the XRD diffractograms did not show any phase transformation not even after 4hr milling. The simulations pointed out that the media diameter is the most important parameter in order to maximise the energy per impact. Further, they showed that achieving a high energy per impact is more important than having a high global energy within the mill. Therefore, from these experimental results it can be hypothesised that an energetic barrier exists, and a minimum energy should be transferred to the material before inducing the transformation. This assumption was fully supported by the DEM modelling calculations of the stress energy done by simulations and it will be covered in the conference presentation, highlighting the ability of modelling to provide useful insight in complex processing systems.

Bibliography

SIMULATION OF HEAT PROPAGATION IN A SCALAR TRIANGULAR CRYSTAL LATTICE

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The classical thermal conductivity model, which is described using the Fourier equation, is applicable to materials that do not have a periodic crystal structure. Modern technology allows you to create materials with nanostructures. In such an environment, the process of heat propagation has a ballistic nature. In this connection, it is necessary to describe the processes of heat distribution in ideal crystal lattices. This paper analyzes the thermal conductivity of a two-dimensional triangular crystal lattice in various directions. As a model, a scalar harmonic lattice is chosen - the particles oscillate along a direction perpendicular to the lattice plane, the pair interactions between the particles are described by a quadratic potential. The proposed numerical experiment simulates the interaction of crystal particles and makes it possible to trace the evolution of the temperature field. The simulated temperature field is compared with theoretical predictions. The initial temperature field is a one-dimensional sinusoidal distribution in a given direction. The dependence of the amplitude of the temperature distribution on time is studied. The results of a numerical experiment reproduce analytical dependencies. A comparison of the results for the two main directions shows the anisotropy of the heat-conducting properties of the crystal lattice.

EFFECT OF DISCRETE BREATHERS ON MACROSCOPIC PROPERTIES OF NONLINEAR CHAINS

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Discrete breathers (DBs) are spatially localized, large-amplitude vibrational modes in defect-free nonlinear lattices. The effect of DBs on macroscopic properties of nonlinear lattices has not been thoroughly analyzed. In this talk, the effect of discrete breathers on heat capacity, thermal expansion and elastic modulus of different nonlinear chains will be reported. The FPU chains, as well as the chains with the on-site potentials, are investigated. In our simulations DBs appear in the chains as a result of modulational instability of the zone-boundary mode. The lifetime of such DBs can be very long but eventually they radiate their energy and system reaches thermal equilibrium. The mentioned above macroscopic properties are calculated during the evolution of the system allowing to determine the contribution from DBs. This study is important, for example, for the solid state physics, since direct observation of DBs in crystals is a challenge and they could be detectable from indirect measurements if their effect on the macroscopic properties of crystals would be known.
DEVELOPMENT OF THE LEGS FIXATION MECHANISM FOR LOKOMAT THERAPY TRAINING DEVICE

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The aim of our project is to find structural concepts to eliminate impact of significant weight bearings on the knee joints; equip the leg support with a toe-lift mechanism to avoid discomfort during maintenance, reduce the injury risks and speed up the rehabilitation process.

In the course of the work we have designed mechanism model including leg fixation mechanism and toe-lift mechanism. This construction allows performing biomechanically secure and correct movements. It will also eliminate tipping and slipping.

After settling structural analysis and topological optimization calculations the prototype was manufactured in FabLab Polytech. In the manufacturing process the following digital production was used: CNC milling machines, 3D printer.

MATHEMATICAL MODELING OF LARGE DEFORMATIONS OF A PLANE WITH A CRACK FOR HARMONIC MATERIALS

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The analytical solutions of nonlinear problems of elasticity for a homogeneous plane with a crack are obtained. Elastic properties are modelled by two types of harmonic materials: semi-linear and John’s. These materials allow us to use the methods of complex functions when solving nonlinear plane problems and to find exact analytical solutions. The deformations of a plane with a free rectilinear crack under given constant stresses at infinity are investigated. Formulas for nominal stresses, Cauchy stresses and displacements are obtained. Asymptotic expansions of the stresses at the vicinity of the crack ends are constructed. The stress intensity factors and the crack disclosing formulas are found. It is established that for two models of materials (John’s material and semi-linear material), the nominal stresses have a root singularity. Cauchy stresses do not have singularities at the ends the crack. The SIF for two models of materials in nonlinear and linear problems completely coincide. For John’s material, the nonlinear and linear problem crack disclosing formulas are the same. For the model of a semi-linear material, the crack disclosing formulas differ by a constant factor from the formulas in a similar linear problem.

RELAXATION OF SPACE PERTURBATIONS IN COUPLED DIFFUSION-RHEOLOGICAL SYSTEM, ITS ASYMPTOTICS AND CORRESPONDING STRUCTURAL MODELS

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The model of interdiffusion in metal alloys with accompanying rheological and chemical processes is required to describe the processes of surface treatment of details by plasma ion implantation, chemical corrosion of metal alloys in the presence of stresses, transformations in solid and powder metal materials with intense plastic strains. The relaxation times of the perturbation of the homogeneous steady-state solution of the model equations and their asymptotics are studied for a qualitative understanding of the processes.

The equations of isothermal interdiffusion with accompanying viscous volume and shear flow mechanisms and elastic deformations in metal are considered. We consider a model problem in which the equilibrium equations are satisfied identically, while one-dimensional unsteady diffusion-rheological processes can develop. The behavior of small perturbations of the homogeneous steady-state solution of the system of two nonlinear parabolic equations of the model with an arbitrary wavelength $\lambda$ along the coordinate is studied.

Consideration of elastic deformations leads to the appearance of a second relaxation time in the system. When $\lambda \rightarrow \infty$, the first relaxation time corresponds to Darken’s interdiffusion mechanism, while the second corresponds to the non-diffusion (viscous) mechanism. When $\lambda \rightarrow 0$ and $\beta / \eta \neq 0$, both relaxation times are controlled by volume viscosity where $\beta$ and $\eta$ are volume and shear viscosity modules. When $\beta / \eta = 0$ and $kT / GV_m \ll 1$, the asymptotics for $\lambda \rightarrow 0$ of the first relaxation time correspond to thermal interdiffusion by a mechanism different from
the Nazarov-Gurov mechanism, and the second correspond to fast diffusion mechanism. When \( \beta / \eta = 0 \) and \( kT/GV_m < 1 \), the asymptotics for \( \lambda \to 0 \) of the second relaxation time correspond to Darken’s thermal diffusion mechanism, and the first is slow diffusion mechanism. In the absence of shear viscosity, the asymptotic behavior of the first relaxation time at \( \lambda \to 0 \) and \( kT/GV_m << 1 \) corresponds to Darken’s mechanism. Each asymptotic behavior of the relaxation times of coupled diffusion-rheological processes in metal alloys can be compared with a structural scheme linking the diffusion structural elements into a whole. Viscous flow can moderate diffusion flow or it can provide a parallel mechanism of relaxation of perturbations. Elastic strains can control the fast or slow diffusion that accompanies the interdiffusion at the thermal fluctuation mechanism.

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**ON THE ONE APPROACH TO SOLVING OF NONSTATIONARY ONE-DIMENSIONAL BOUNDARY PROBLEMS IN HETERO MODULAR ELASTICITY**

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For one-dimensional nonlinear dynamics of heteromodular elastic medium, the paper proposes an algorithm for the approximate solving of nonstationary boundary value problems with the effects of the onset, propagation and interaction of strong discontinuities of strain. Modeling of heteromodular behavior of the medium is carried out in terms of the physically non-linear model [1] with the elastic moduli depended on the deformed state type. In the one-dimensional case, the model relations take a piecewise-linear form but the influence of the initial non-linearity is saved in the equations of the one-dimensional strong discontinuities dynamics [2] and, accordingly, in generalized solutions of nonstationary boundary value problems. To solve such problems, we propose to use the piecewise linear approximation of nonlinear boundary conditions in addition to piecewise linearization of model relations; then we pass to the associated sequence of quasistatic problems with exact solutions. The totality of obtained analytical solutions is an approximation for a nonlinear solution of the original problem. Using this approach, we solve a nonstationary boundary-value problem on the dynamic deforming of a heteromodular elastic half-space in a tension-compression mode. We analyze the evolution of the parameters of a one-dimensional plane shock wave interacting consistently with slow strong discontinuities which create a piecewise-smooth pre-stretching field. It is shown that the compression deformation "remembers" the information on the preliminary tension; that should be considered an important feature of the heteromodular medium dynamics.

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**References**


**CALCULATIONAL-EXPERIMENTAL METHOD OF PIPELINE DEFECT DIAGNOSTICS**

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Lately more often scientists face with a problem of increasing operating capacity of oil and gas machinery. Appearance and growing of operational defects in pipeline may cause disruption in system availability. That is why problem of timely complex state diagnostics of tube elements considered to be an actual question.

The research is dedicated to eigenfrequency diagnostic method development for pipeline elements. Theoretical aspects of the problem were studied. Finite element modeling was held with shell and 3D theory, and shell case applicability was shown for solution of this problem. Boundary condition influence on the eigenfrequency change due to defect occurrence was investigated, on free tube it is harder to see the change, than on console and fixed tube. To make the detection more useful, longitudinal eigenfrequencies are chosen to monitor. Approximation by basic mathematical functions was made and regularities were discovered. Dynamic research was made for console fixed tube, and eigenfrequency change due to defect was shown.
MICROSTRUCTURE-BASED SIMULATIONS FOR DEFORMATION BEHAVIOR OF ADDITIVELY MANUFACTURED ALUMINUM ALLOYS

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Additive manufacturing (AM) is an innovative technology which enables producing structural components of complex geometry. Although considerable progress in this field has been attained in the past few years, many problems remain to be unsolved yet. Particularly, there is still a great deal to learn about the deformation and fracture mechanisms developing in AM materials since their microstructure and mechanical properties are much different from those of as-received materials. The numerical analysis with explicit consideration of the material microstructure seems to be a reasonable tool for analyzing the AM material behavior which is difficult to be predicted within macroscopic models. This paper presents a computational approach to investigate the deformation behavior of aluminum alloys produced by selective laser melting with an explicit account of the grain structure. In order to construct the microstructure models two approaches are used. First approach relies on the mathematical description of the microstructure evolution during AM, taking into account physical processes involved. The numerical solution is based on a combination of the finite difference method for modeling AM thermal processes and the cellular automata method for describing the grain growth. Another approach provides fast generation of synthetic 3D microstructures typical for AM aluminum alloys, using the method of step-by-step packing. The grains are associated with the crystal plasticity-based constitutive models taking into account the microstructure and texture effects. The microstructural constitutive models are then used as input data in the boundary-value problem. The combined effects of the grain structure, texture and loading conditions on the evolution of the microscale stress-strain fields in AM aluminum alloys are analysed.

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2D AND 3D ELASTIC BEAM LATTICE STRUCTURES AS MICROPOLAR SHELLS AND SOLIDS

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We discuss the modelling of elastic beam lattice structures made of few families of fibers rigidly connected to each other. The discrete models are presented and their continual counterparts are discussed. We derive the continuum models of this class of beam lattices using the constitutive relations of micropolar solids and shells. The specific constitutive equations for shells and solids are presented. These relations inherit the properties of a single fiber. The relation with other continual models based on strain gradient elasticity is discussed.

NONLOCAL SURFACE ELASTICITY AND ANTI-PLANE SURFACE WAVES

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Recently with developments in the nanotechnologies the interest grows to modelling of microstructured coatings. Among various examples of such coatings we have super oleo- and hydro-phobic coatings used for manufacturing of self-cleaned and bactericide surfaces. Here we discuss a new class of anti-plane surface waves in an elastic half-space with surface stresses. Here we consider a surface elasticity within stress-gradient and strain gradient models. For these models we have non-classic dependence between surface stresses and surface strains. Some relations with microstructured coatings as mentioned above are discussed. Unlike known and widely used Gurtin-Murdoch model we have long range interactions, so the presented models constitutes strong and weak nonlocal models of surface elasticity. For anti-plane motions the problem is reduced to the wave equation with nonclassical dynamic boundary condition. The dispersion relation is derived. The influence of nonlocality is analysed.
The work is devoted to the determination of bending stresses in steel samples by the method of acoustoelasticity using the Rayleigh surface wave.

The effect of acoustoelasticity consists in the dependence of the velocity of propagation of an elastic wave in a material on stresses.

With the help of expansion-contraction and shear volume waves, the stresses caused by tensile or compressive effects are well measured, but the stresses caused by the bending of the sample cannot be tracked by these waves. Waves show the stress state averaged over the sample thickness. But if a sample of a material was bent, then all its longitudinal fibers that are above the midline of the cross section will stretch, and all the longitudinal fibers that are below the midline will be compressed. In this case, body waves will show that there are no stresses in the sample, but this is not the case. Therefore, to determine the stresses caused by bending, it is necessary to use such waves, which show not the average value over the cross section, but the maximum values of the stresses. The maximum values of bending stresses will be on the surface of the sample, and such stresses should allow measuring the surface Rayleigh wave.

The sample was fixed in the grips of the Tinius Olsen testing machine, which allows an impact force of up to 100 KN (approximately 10 tons).

But first it was necessary to determine the mechanical characteristics of the material. The stress state was created in a calibration sample from steel 20 with dimensions of 370 * 8 * 30 mm. The sample was fixed in the grips of the testing machine, allowing the impact of up to 100 KN (approximately 10 tons). On the testing machine, a sample stretch diagram was obtained, from which it follows: the tensile strength is 463 MPa, the modulus of elasticity is 211.0 GPa.

The Rayleigh surface wave was created by piezoelectric transducers (PT) at an oscillation frequency of 2 MHz. The wavelength at a propagation velocity of approximately 3000 m/s is equal to 1.5 mm, which makes it possible to use it to control the bending stresses on a sample of 8 mm, since the depth of penetration of the surface wave into the material is 1.5–2 wavelengths.

The radiating and receiving PT were installed at a fixed distance from each other using a special mechanical device. The excitation of the radiating PT was excited using a flaw detector, and from the receiver PT, the signal arrived at the time interval meter, for which an oscilloscope with a time resolution of one nanosecond was used.

The relationship between the propagation time of the Rayleigh wave and the bending stress, which was to be determined, was established. Thus, it was possible to show that the method of acoustoelasticity has great potential than is commonly believed, that is, if you use not bulk, but surface waves, the method allows you to determine not only tensile-compressive stresses, but also bending stresses.

Today, the method of acoustoelasticity is successfully used in the diagnosis of rocket and aviation equipment, surface and underwater ships, oil and gas pipelines. Improving this promising method is very important.

**MODELING OF MARTENSITE REORIENTATION IN FeMn-BASED SHAPE MEMORY ALLOYS WITH AN ACCOUNT OF THE THREEFOLD SYMMETRY OF HCP MARTENSITE**

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Microstructural modeling of stress-induced reorientation in FeMn and FeMnSi shape memory alloys has been performed. The FCC-HCP transformation can occur by one of the three shears \((1/6) < 1, 1, -2 >\) on each second close-packed plane \{111\}. The common threefold symmetry of the FCC and HCP lattices results in the fact that the three shears \((1/6) < 1, 1, -2 >\), \((1/6) < 1, -2, 1 >\) and \((1/6) < -2, 1, 1 >\) produce the same martensite, though the deformations corresponding to these shears are different. Thus, all 12 possible variants of the FCC-HCP transformation can be divided into four triplets (zones), each zone characterized by the choice of the original \{111\}_{FCC} plane. In the present model it is supposed that the easiest and, moreover, the only possible way of martensite reorientation is the transition from one martensite variant into another belonging to the same zone. Such transition is realized by a shear on the basal \((0001)_{HCP}\) plane. It is also supposed that (1) the reorientation occurs when the correspondent generalized thermodynamic force reaches some critical value; (2) the reorientation of martensite in a grain can occur only if the grain is purely martensitic and (3) the reorientation leads to minimization of the Gibbs’ potential. The model also describes microplastic deformation caused by the inter-phase stresses due to the incompatibility of the phase deformation. For this a set of internal variables for deformation defects is introduced. Fracture is supposed to appear when a special stress-strain criterion is reached. It is shown that the model allows describing the mechanical behavior of...
FeMn-based shape memory alloy specimens and their fracture both at unidirectional and cyclic mechanical loading. This research was supported by the grant of Russian Foundation of Basic Research 19-01-00685.

MATHEMATICAL MODELLING OF SEDIMENTATION PROCESS OF NANOPARTICLES IN THE VESSEL OF INFINITE DEPTH

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In this work we deals with the sedimentation process of spherical nanoparticles occurring under the influence of gravity in a glassful with liquid taking into account the Brownian diffusion. As object of research we take an arbitrary glassful with liquid contains particles with different sizes. A massive particles have settle to the bottom, a light particles have stay at the surface and they have distributed over the depth and creating a gradient medium. In this case we will investigate sedimentation of particles considering the depth of glassful as infinite. Using the equation of convective diffusion, the particle flux density and the initial and boundary conditions for that we consider the size distribution function in the task of sedimentation of particles taking into account the time of sedimentation for different sizes of particles. Using the methods of mathematical modelling like mathematical analysis, differential equations and inverse Laplace transform method the solution of convective diffusion’s equation has received and investigated analytically at the moment using Wolfram Mathematica system.

MODELLING, EXPLORATION AND MITIGATION OF PARTIALLY LIQUID-FILLED TANKS USING VARIOUS PASSIVE ENERGY ABSORBERS

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This study treats oscillations of a liquid in partially filled vessel under horizontal harmonic ground excitation. When exposed to external disturbances, the liquid is divided into two portions: oscillating sloshing portion, and a ‘static’ non-sloshing portion, located at the bottom of the tank. Such excitation may lead to hydraulic impacts applied by the sloshing mass on the tank walls. Different equivalent mechanical models are suggested to mimic the liquid sloshing mass motion and essential dynamical regimes of the overall tank-liquid system, such as a series of pendula or mass-spring-dashpot systems which can impact the vessel walls. We use parameters of the equivalent mass-spring system for the well-explored case of cylindrical vessels. The hydraulic impacts are modelled by high-power potential function. Finite-Element (FE) method is used to determine and verify the model parameters and to identify dominant dynamical regimes, natural modes and frequencies. The tank failure modes and critical locations are identified. Mathematical relation is found between degrees-of-freedom (DOFs) motion and the mechanical stress applied in the tank critical section. This is the prior attempt to take under consideration large-amplitude nonlinear sloshing and tank structure elasticity effects for design, regulation definition and resistance analysis purposes. Both linear (tuned mass damper, TMD) and nonlinear (nonlinear energy sink, NES) passive energy absorbers (PEAs) contribution to the overall system mitigation is firstly examined. Dominant sloshing regimes, such as moderate amplitude, and vibro-impact (VI) violent sloshing are studied and described using reduced-order models and analytical methods.

ENDOCHRONIC MODIFICATIONS OF THE BUGAKOV, KACHANOV AND RABOTNOV APPROACHES IN MODELING OF STRENGTH AND ELASTOVISCOPLASTICITY

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The work is devoted to the analysis and development of one of the fundamental directions of well-known prominent scientists in the field of linear and nonlinear hereditary chronomechanics of a solid deformable body, using generalized time. In connection with the 90th anniversary of the birth of senior researcher I.I. Bugakov and the 105th anniversary of the professor, head of the theory of elasticity of Leningrad State University L.M. Kachanov and Academician of the USSR of the Academy of Sciences, Head of the Department of Plasticity Theory of Moscow State University Yu.N. Rabotnov. Since 1969, the author studied under Ilya Izrailevich and Lazar Markovich, performed various scientific topics under their supervision, and studied the works of Rabotnov. Bugakov paid great attention to the principles of hereditary mechanics of deforming rheological complex media, building endochronic models of elastic-viscous plasticity with “simple” and “complex”, mainly horizontal, time scaling, using different physical, chemical and
References

Viscoelastic deformation of the fused silica cylinder under gravity in the presence of beta-cristobalite layer growth at the silica surface

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This paper reviews the problem of the viscoelastic deformations of the long thin-walled fused silica cylinder under the gravity force at high temperatures ~1400°C. This cylinder is typically called muffle and its purpose is to protect the optical fiber preform from outside contamination during thermal treatment. The muffle constantly deforms under the gravity force due to the relatively low silica viscosity at high temperatures, which is undesirable, because excessive deformations can lead to the muffle ineligibility. Simultaneously, the layer of beta-cristobalite, which is elastic at the considered temperatures, starts growing at the muffle surface. Once the cristobalite layer thickness reaches the certain “critical” value, it becomes strong enough to prevent further muffle sagging without cracking or buckling.

This paper reviews two problems. The first one is estimating the critical cristobalite layer thickness, so that it can support the muffle under gravity without breaking. The second problem is creating the optimal time-temperature schedule, that will help to build the critical cristobalite layer at the minimal time without excessively deforming the muffle. The cristobalite growth rate, in general, increases with temperature, but higher temperature leads to low silica viscosity and higher deformation rates, which can lead to unacceptable muffle shape. This paper proposes the criteria for the critical cristobalite layer thickness based on the basic elastic theory and the Eulerian buckling theory. Criteria for the continuous cristobalite growth without cracking was proposed based on the Maxwell viscosity material model and crystal growth considerations. The method of creating the efficient time-temperature schedule for building the critical cristobalite layer was developed and the example of such a schedule for an abstract muffle is provided.

Funnel flow of a Navier-Stokes-fluid with potential applications to micropolar media

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In this work foundations are laid for a future solution of a fully coupled flow problem for a micropolar medium undergoing structural change in a funnel-shaped crusher. Initially the fundamental equations of micropolar media are
revisited and the "crusher problem" is explained. The matter is modeled by a visco-elastic material. In the context with this example, it is also clear that the traditional material way of describing the movement of solids is no longer adequate and must be replaced by a spatial description. The necessity of using numerical methods of fluid mechanics is emphasized. The study of the problem of a two-dimensional fluid flow is based on an implicit finite difference scheme. Numerical results are presented for the velocities, the stresses and the dependence of the pressure of the funnel-shaped flow. The correctness of the algorithm is checked by specializing in the case of a Navier-Stokes fluid flow through a constant section tunnel under the action of gravity, for which an analytical solution is available.

APPLICATION OF BIONIC PRINCIPLES FOR DESIGN OF CYLINDRICAL FUSELAGE STRUCTURE OF CIVIL AIRCRAFT

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Implementation of composite structures based on semi-monocoque structure layouts, (conventional for metallic aircraft structures) to high-loaded parts of civil aircraft structures, resulted in low-effective solutions in terms of weight saving, as compared to existing metallic analogues. The main reason of low weight efficiency of such structures is caused by low impact resistance of current composite materials.

One of the perspective directions of development of high-loaded composite structures is searching novel structure layouts based on unidirectional composite elements. The main load-bearing element of such structures is composite rib, instead of laminated composite skin, used in today’s composite airframes. At the moment there can be defined several types of such structure layouts. The most well-known one is regular lattice composite structures, developed and realized for axisymmetric cylindrical shells. These regular structures have better weight efficiency as compared with both metallic and composite semi-monocoque structures. Typical examples of such lattice structures are adapters of rocket-carrier, having weight saving up to 50%. Lattice structures with regular lattice grid are rational for compartments of space rockets, subjected mainly to compressive loads. What about application of the lattice structures in aircrafts, where the main loading factor is bending, the lattice structures with constant parameters of the lattice grid give a lot less weight benefits.

In the present work application of bionic principles of design is proposed in order to increase the efficiency of the lattice composite structures, aiming to more optimal topology of the lattice grid and harmonization of stiffness and strength parameters of lattice structure elements.

The requirements of harmonization of stiffness and strength parameters of ribs of the lattice grid are driven by the specific features of load transfer in composite structures, where relaxation of disturbance factors, appearing in the zones of concentrations, is realized on a significantly larger distance (10-20 times) than in metallic structures.

The main factors, being the obstacles of realization of such structures based on bionic driven design are:
- absence of reliable and lightweight structure solutions for regular zones of the lattice and the zones of ribs’ intersections;
- absence of affordable methods for manufacturing of such structures based on 3D printing.

In the present work the approaches to solution of these problems are shown, based on:
- realization of high-density stacking sequence in ribs’ intersections, supported by the special wrap layers
- creation of protective impact-resistant layer for ribs, made of lightweight filler;
- excluding skin from sustaining bending loads, making it non-load-bearing element;
- creation of harmonized lightweight metal-composite based on integration of wingding composite technology and metallic additive manufacturing methods.

KINETICS, BLOCKING AND STABILITY OF STRESS-ASSISTED CHEMICAL REACTION FRONTS

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We present solutions of a number of boundary value problems for solids undergoing chemical transformations and demonstrate how external stresses and stresses induced by the transformation strain can accelerate or retard the reaction. The reactions with sharp reaction fronts like silicon oxidations or silicon lithiation which are accompanied by large
transformation strains, or intermetallic formation in lead-free solders are implied. Consideration is based on the concept of a chemical affinity tensor, which normal component determines the chemical reaction front velocity (see, e.g., [1]). We demonstrate how mechanical stresses can accelerate, retard or block the reaction front propagation (see, e.g., [1,2]). Then we focus on blocking the reaction front by stresses, and construct forbidden regions in strain space formed by strains at which the chemical reaction front cannot propagate [3]. We discuss the analogy and differences between phase and chemical equilibrium and study analytically and numerically the stability of the transformation front in the vicinity of the equilibrium. We note that the loss of the front stability may be the source of further damage.

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EXPLANATION OF INHOMOGENEOUS DISTRIBUTION OF HYDROGEN BY MEANS OF THE COSSERAT-TYPE THEORIES OF CONTINUA

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This research is concerned with investigation of hydrogen distribution inside metal samples. According to experimental data obtained for metals and alloys placed in aggressive environment, hydrogen concentration in the vicinity of the lateral surface significantly exceeds the volumetric concentration. According to our assumption, it can be caused by occurring of empty spaces within a thin boundary layer, which, in turn, initiate the seepage of hydrogen from the external environment. Thus, the uneven distribution of hydrogen can be explained by the existence of a lengthwise displacements increasing the intergranular space in the vicinity of the boundary. To find the dependence of the displacement on the distance from the boundary we solve a boundary-value problem for a cylindrical metal sample within the framework of the micropolar theory of elasticity, which makes it possible to introduce additional degrees of freedom for body particles. Lattice defects on the metal surface can lead to micro-crack formation which can be modeled by means of the distributed couple stress on the boundary surface. Also we take into account that the lateral surface is traction-free. We consider both the Cosserat and pseudo-Cosserat continua (micropolar continuum with constrained microrotations). In both cases we obtained that the stress-strain state near the boundary can be specified by application of the micropolar theory. The difference is that solution obtained on the base of the pseudo-Cosserat media depends on one additional material constant appearing in micropolar theory, whereas solution for the general case depends on a few material constants. So, comparison of theoretical results with the experimental data on the width of the boundary layer makes it possible to estimate one material constant in the first case and their ratio in the second one. Both results make it possible to predict hydrogen concentrations in metal samples with different shape, as well as to use the values of the material constants to solve any other mechanical problems. The other important difference between the results obtained for the general micropolar continuum and continuum with constrained microrotations is that the stress tensor and couple stress tensor have different structure and, therefore, the stress intensity varies. This, in turn, means that it is necessary to use the stress-strain state obtained for the general case to check the plasticity and fracture criterions.

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**A POSTERIORI ERROR ESTIMATES FOR PLATES AND SHELLS**

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Report is devoted to latest results of implementation of the functional approach to a posteriori error control for Reissner-Mindlin plates and Koiter’s shells. The functional approach [1-3] is based on rigorous mathematical methods (Functional Analysis, Calculus of Variations, PDE’s theory). The approach provides reliable error majorants — upper bounds are guaranteed for all conforming solutions of problems without additional restrictions on a class of methods used for numerical implementations. This property is very attractive for coupling of error estimators and indicators with commercial software for engineering. We consider practical aspects of implementations of adaptive algorithms for Reissner-Mindlin plates (see, for example, [2-7] for some general references, and [3, 8, 9] — for the latest results concerning mesh adaptations based on functional-type error estimators). A generalization of the theory to linear Koiter’s shells is also considered [10].

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**EFFECTS OF STEEL PIPE SEGMENT STRAIGHTENING ON TENSILE AND FRACTURE MECHANICAL PROPERTIES OF RESULTING SEMIPRODUCTS**

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Fracture mechanics specimens relating to pressurized pipelines are usually produced from flat sheets obtained from press straightened pipe segments. There is however scepticism about the validity of fracture toughness values gained from straightened specimens due to the occurrence of plastic strains which may be induced in the straightened semiproducts during the press straightening process. In order to clarify a substantiation of this scepticism, we have carried out fracture mechanical tests on CT specimens manufactured from a CSN 411353 steel pipe 266 mm in diameter and 8 mm in wall thickness by a common procedure, i.e. from a pre-straightened sheet, as well as on curved CT specimens which to some extent simulate stress conditions in a pipeline wall loaded by internal pressure. Examination of R curves for flat (straightened) and curved CT specimens has shown that, besides differences in the curve slopes and a lower position of the R curve in the J-∆a diagram for the curved CT specimens, the fracture toughness parameters J_{0.2} and J_{0.5} for the curved CT specimens were smaller by less than 3% as compared to the flat CT specimens. Moreover, we have also performed basic stress-strain tests on circumferentially oriented straightened and non-straightened tensile specimens taken from L360NB steel pipe 530 mm in diameter and 8.6 mm in thickness. Examination of the stress-strain diagrams for the straightened and non-straightened tensile specimens has shown that press straightening does not influence the behaviour of steel above the yield stress, including the U.T.S., since the stress-strain curves practically coincide above the yield stress. The only change induced by straightening is the removal of the Lüders region, and a subsequent change in the yield stress magnitude.
CONSIDERATION OF VISCOSITY AT DIFFERENT STAGES OF DEFORMATION OF ELASTIC-PLASTIC MATERIAL OF A HOLLOW SPHERE

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In the framework of the mathematical model of small elastic-plastic deformations, a one-dimensional boundary value problem of deformation of a hollow sphere under the action of an all-round pressure changing over time is considered. With the growth of mechanical pressure on the hollow sphere in it, stresses increase, leading to the production of irreversible deformations. Originally this process is slow and viscous, leading to the appearance of irreversible creep deformation. With a further increase in the pressure on the material, the stress states come to the loading surface, which leads to a change in the mechanism of production of irreversible deformations to a rapid plastic one. In the process of the plastic flow of the material, its viscous properties are also taken into account. When unloading the material of a hollow sphere, the sequence, on the contrary, changes from fast plastic to slow viscous. To ensure the continuity of irreversible deformations when changing the mechanisms of their production, a coordinated task of creep and plasticity potentials is necessary. In this case, we indicate the agreement of the creep law of Norton and the plasticity conditions of Mises, generalized in the case of viscous properties of materials.

An example of technological practice is such a technological method as cold forming. In this process, irreversible deformations accumulate due to the slow creep process, however, it is possible the emergence of local areas of plastic flow in the deformable material. The processes of the creep and viscoplastic flow at increasing all-round pressure, viscoplastic flow at constant pressure and environment unloading at decreasing pressure are considered. The regularities of the elastic-plastic boundaries advance are established in the hollow sphere material. The parameters of the stress-strain state of the environment are calculated, and the stress relaxation is investigated after complete unloading.

The work was partially supported by the Russian Foundation for Basic Research (18-01-00038).

INVESTIGATION OF PLASTIC DEFORMATIONS IN METALS USING ANGULAR DIAGRAMS OF ACOUSTIC ANISOTROPY

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There are two main certified industrial non-destructive approaches to estimate the stress-strain state of technical structures. Strain gauge methods are based on measuring surface deformations. The method of acoustoelasticity is based on measuring acoustic anisotropy [1], which is defined as the relative difference between velocities of bulk transverse waves of mutually perpendicular polarization. It is the only one integral method for measuring internal stresses in structures.

Theoretical relations for the method of acoustoelasticity were obtained on the basis of Hooke’s law for the case of elastic deformations. According to the industrial approach, it is necessary to provide orientations of shear waves along and across axes of the principal stresses \( \sigma_1 \) and \( \sigma_2 \). In this case, the possibility to estimate stress-strain state was confirmed experimentally [1]. At the same time, the case of accumulation of plastic deformations or damage has the greatest interest. Despite this, there are no approaches to control plastic deformations and damage using acoustic anisotropy. The existing theory for the acoustoelasticity method is based on the Murnaghan nonlinear elastic model [2] and on use of the Y.H. Pao - M. Hirao relation for dependence of acoustic anisotropy on small plastic deformations [2].

The aim of this work is the experimental investigation of the dependence of acoustic anisotropy on plastic deformations in metals in a wide range up to destruction. The method based on obtaining angular diagrams of acoustic anisotropy was applied instead of the standard technique. It allows to obtain information on local acoustic anisotropy for various orientations of system of orthogonally polarized shear waves.

Corset specimens from cold-rolled aluminum industrial alloy were investigated. In this case, the initial acoustic anisotropy caused by texture was comparable to the contribution of mechanical stresses. The nonmonotonic dependence of acoustic anisotropy on plastic deformations was established. It was observed on all specimens made along and across the direction of rolling. This effect cannot be described by the nonlinear elastic Murnaghan model [2]. Also, it was found that use of angular diagrams makes it possible to determine direction of rolling and orientation of the axes of principal stresses.
It was found that changes in acoustic anisotropy can tend to zero with a monotonic increase in deformations in the case when axes of principal stresses are non-collinear with directions of shear waves polarization. Thus, it was shown that estimating of plastic deformations by measuring acoustic anisotropy is possible only with use of angular diagrams. The obtained results have a great importance for non-destructive testing of plastic deformations of metals using acoustic anisotropy.

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ON THE COLLECTIVE MOTION OF A POPULATION OF MICROSWIMMERS

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Nature is full of swimming organisms, from bacteria to algae, with sizes typically ranging from one to one hundred micrometres. In the past few years, artificial microswimmers are also being designed and manufactured for applications in, for example, medicine, as vehicles of targeted therapies. There are many models of microswimmers in the literature, ranging from very detailed biological models to simple mechanical toys. Nevertheless, the collective behaviour of microswimmers and, particularly, how they affect each other characteristics is less studied, mainly because the computational cost is enormous. In this work, we define a simple microswimmer in two dimensions. The microswimmer is characterised by its size, swimming strategy and natural frequency. Under these conditions, the microswimmer is able to move at a characteristic speed. In the limit of low Reynolds number, the Navier-Stokes equations reduce to the Stokes equations, which are linear in velocity, so we propose a stokeslet description via the Oseen tensor, followed by a dipole expansion of the flow field originated by its motion. After the full individual model is analysed, we characterise the hydrodynamic interaction between two microswimmers and how this interaction affects their speed and mutual alignment. This analysis allows to understand under which conditions phase synchronisation and flocking between them occur. Finally, we extend the study to the collective behaviour of a population of microswimmers with different inherent features: identical, random and Gaussian distributed frequencies. We focus on their phase synchronisation and alignment and analyse how both collective behaviours affect each other.

STATIC AND ACOUSTIC PROPERTIES OF ARCHITECTURED MATERIALS AND METAMATERIALS BY HOMOGENIZATION METHODS

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Recent advances in additive manufacturing technologies have led to a new paradigm in the design of materials and the emergence of a new class of artificial materials with static and dynamic properties that are unparalleled in nature, so called metamaterials, of which the study of certain static and acoustic properties is the subject of this presentation. The term metamaterials refers to discrete topology architectures that give rise to exceptional effective properties, like auxetic materials (also called anti-rubbers because of their high volume variation capacity) that undergo transverse expansion under traction, contrary to conventional materials that contract. Auxetics have proven benefits in terms of shock absorption capacity and impact and have also excellent acoustic absorption properties. More recently, the need has arisen to create highly anisotropic architectures in terms of mechanical properties, in particular with a view to generating large volume changes than isotropic patterns that cannot be achieved; the Poisson’s ratio, which serves as a metric of properties for isotropic materials, is no longer sufficient to characterize the latter. So-called anti-auxetic materials (strongly positive Poisson coefficients are obtained in certain directions) are also in great demand, for example as ligament and tendon biosubstitutes, the latter having much higher Poisson coefficients (close to 6-7) at the theoretical limits than those of isotropic materials. We will show in particular based on a perturbative method that the anisotropy induced by large pre-deformations and the non-reciprocity in the sense of Maxwell-Betti are efficient control mechanisms of propagation of the waves within architectured environments.
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The role of anisotropy on the static and wave propagation characteristics of two-dimensional architectured materials under finite strains. H. Reda et al., 2018. Materials & design, 147.

EXPERIMENTAL INVESTIGATIONS OF 3D-DEFORMATIONS OF ADDITIVELY MANUFACTURED PANTOGRAPHIC STRUCTURES

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New macroscopic experimental techniques have been developed in the recent past with the objective of making generalized continuum theories technologically useful. So-called pantographic structures, which can be characterized as a generalized metamaterial, are going to be introduced and investigated experimentally: Samples of different materials and dimensions are subjected to large deformation loading tests (tensile, shearing, and torsion) up to rupture, while their response to the deformation is recorded by an optical measurement system. 3D-digital image correlation is used to calculate the deformation with respect to the reference plane by the help of a two-camera system. Results show that the deformation behavior is strongly non-linear and that the structures are capable to perform large (elastic) deformations without leading to complete failure. This special behavior makes those structures very attractive to serve as an engineering material for technical applications in lightweight and medical industries.

MECHANICS OF DEFORMATION OF DISCRETE MATERIALS WITH MOBILE MICROFRAGMENTS

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It is known that rocks are broken by weakened surfaces on separate blocks interacting among themselves. The blocks have relative mobility. Thus the contact area of adjacent blocks does not remain constant and varies in the deformation process. The mobility of separate microfragments is important property of rocks and granular medium. For studying the main properties of materials with mobile blocks we used the face-centered packing of elastic spheres interacting in accordance with the Hertz solution. Motion of a single ball in cooperation with neighboring particles is investigated. It is shown that the equation of motion of the ball in this case coincides with the standard form of the Mathieu equation for which is realized phenomenon of parametric resonance. This means that the granular medium must have the property of selectivity - suppress one frequency and amplify the other frequencies. Dynamics of a chain of balls with variable contact surface is considered. We derive the differential equation of motion and nonlinear differential analog. It is shown that under certain conditions the deformation of the chain are unstable. The phenomenological generalization of the model for 3-D continuous media implies that strain measure is nonlinear and extends the Green strain tensor. The difference between the Green strain tensor and the strain measure developed by the model consists of a coefficient before the nonlinear terms which depends upon the initial deformation of the medium. Because the coefficient before the nonlinear term is large the contribution of that nonlinear term to deformation becomes significant. The contribution of the nonlinear term increases if the consolidation of the medium decreases.
COMPREHENSIVE MECHANICAL STUDIES OF RUBBER MICRO-AND NANOCOMPOSITES PROMISING FOR THE TIRE INDUSTRY. UNIAXIAL AND BIAXIAL TESTS

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Studies of the mechanical properties of composites based on SBR-1500 styrene-butadiene rubber vulcanizate with various micro and nanofillers (which are already used or intended to be used in the tire industry) were carried out [1]. These are white soot (WS), micro (MS) and nanoshungite (NS), diatomaceous sorbent (DS), and products of rice husks pyrolysis RHW and RHB, consisting of amorphous silica and graphite (RHW 98%, SiO₂ 2% C; HRB 35% SiO₂, 65% C). The mass concentration for all fillers was 65 phr.

Atomic force microscope was used to determine the averaged characteristic sizes of filler particles and their distribution over the volume of material. It was found that in all samples, the inclusions are located in the matrix fairly uniformly, which indicates a good quality of their manufacture.

All composites were tested for strength under uniaxial tension. The best results were shown by NS and WS (7, 8-fold hardening), MS and DS (4 times), RWB and RHB (approximately 1.5 times).

For rubbers filled with MS, NS, WS and DS, studies of their viscoelastic properties were carried out during uniaxial cyclic testing – load-unloading with amplitude increasing at each step and stops for relaxation when changing its direction. All experiments were conducted until the final sample rupture.

It was found:
1) During cyclic testing of unfilled rubber, the load and unloading curves almost coincided, that is, the material behaved as elastic. The ultimate stresses and strains were also close to those obtained under monotonic tension.
2) The material becomes viscoelastic after filler input: a hysteresis loop appeared, its area (dissipative losses) enlarged with increasing amplitude of cyclic deformations.
3) Ultimate stresses and strains values in filled elastomers under cyclic loading were lower than with uniaxial tension. Internal damage was accumulated in the samples.

Biaxial loading tests were performed for composites filled with MS, NS, WS, DS, RHW and RHB. The four-vector test bench Zwick/Roell was used for this. The test program consisted of four cycles: two cycles of load-unload (with stops for relaxation), then two more such cycles in the perpendicular direction.

Experiments made it possible to study the effects of softening and the occurrence of induced anisotropy in filled elastomers under the action of a biaxial load. In the case of pure rubber, they are practically absent. A different picture is observed for filled systems. In almost all cases, the filler contributed to the appearance of a hysteresis loop on the cyclic loading curves, i.e. viscosity occurred in the composite. The greatest hysteresis was observed for the WS, for this composite the loading along the first axis caused softening in the perpendicular direction. For other materials, loading on one axis had a weaker effect on their mechanical behavior in the other direction, and hysteresis was approximately of the same order.

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NUMERICAL ANALYSIS OF THE LEAFLET ELASTICITY EFFECT ON THE FLOW IN THE VENOUS VALVE

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Venous hemodynamics is studied to improve the methods of diagnosis and treatment of venous diseases and life-threatening thrombotic complications [1-4]. It is known that ageing makes venous valve leaflets more rigid, thereby preventing the valve from normal functioning. Numerical simulation provides a lot of information about the flow in the venous valve and helps to analyze the effect of the leaflet elasticity on the stagnant zones behind the valve, where thrombus is likely to form. The purpose of this work is to study the effect of the venous valve leaflets elasticity on the stagnant zones formation.
This work investigates a 2D symmetric model of a valve in the popliteal vein based on clinical measurements. The variation of the bulk velocity over the cycle time, obtained from the Doppler measurements, was imposed at the inlet boundary, and a constant pressure was specified at the outlet boundary. Rheological Newtonian model was implemented. The flow was laminar. The approximation of rigid walls was used as their movement is slight for the popliteal vein. Young's modulus of the valve leaflets ranged from 0.2 to 2 MPa.

The fluid flow was calculated using the fluid-structure interaction (FSI) technology, which is implemented as a simultaneous solution of the fluid mechanics equations (Navier-Stokes) and the solid mechanics equations using the arbitrary Lagrangian-Eulerian (ALE) methodology. Hydrodynamic calculations were performed in the Ansys Fluent software package, mechanical calculations were performed in the Ansys Mechanical Transient software package. The stagnation zone is observed in the sinus (expansion behind the valve), where fluid rotates with a relatively small velocity. The vortex size and its center position change during the cycle. An intense jet is formed between the leaflets. The results of the venous valve leaflets movement numerical simulation were compared with clinical data during the cycle time. An increase in the leaflets elasticity increases their oscillations amplitude and decreases the size of the stagnant zone behind them.

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STEADY-STATE KINETIC TEMPERATURE DISTRIBUTION IN A TWO-DIMENSIONAL HARMONIC SCALAR LATTICE LYING IN A VISCOUS ENVIRONMENT AND SUBJECTED TO A POINT HEAT SOURCE

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We consider heat transfer in an infinite two-dimensional square harmonic scalar lattice lying in a viscous environment and subjected to a heat source. The basic equations for the particles of the lattice are stated in the form of a system of stochastic ordinary differential equations. We perform a continualization procedure and derive an infinite system of linear partial differential equations for covariance variables. The most important results of the paper are the deterministic differential-difference equation describing non-stationary heat propagation in the lattice and the analytical formula in the integral form for its steady-state solution describing kinetic temperature distribution caused by a point heat source of a constant intensity. The comparison between numerical solution of stochastic equations and obtained analytical solution demonstrates a very good agreement everywhere except for the main diagonals of the lattice (with respect to the point source position), where the analytical solution is singular.

We also present the preliminary results for the analogous problem formulated in the case of graphene lattice. In the latter case we get the deterministic differential-difference equation describing non-stationary heat propagation in the lattice using an alternative approach, and obtain its analytical solution in some particular cases.

KAPIZA RESISTANCE IN BENCHMARK ONE-DIMENSIONAL MODELS OF HEAT CONDUCTIVITY

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It is commonly accepted today, that one-dimensional lattice models can belong to three universality classes with respect to the heat transport. The first class (e.g. lattices with linear interactions) is characterized by heat flux that is proportional to temperature difference rather than to the temperature gradient. The second class includes models with size-dependent heat conduction coefficient (e.g. Fermi-Pasta-Ulam model and similar nonlinear chains with conserved
momentum). The third class includes the chains that can be characterized by well-defined convergent heat conduction coefficient in the thermodynamic limit (e.g. Frenkel – Kontorova model or chain of rotators). There exist some quarrels and contradictions on classification of various exotic chain models, but the universality classes themselves seem well-established.

The talk will address the well-known phenomenon of Kapiza resistance (KR) in non-homogeneous chain models belonging to different universality classes. This phenomenon (sharp step in the temperature profile) readily reveals itself if one considers either isolated isotopic or link defect in the homogeneous chain, or interface between two chain fragments with different characteristics. In both settings the KR demonstrates similar properties. Main finding to discuss it that these properties strongly depend on the universality class with respect to the heat conduction, to which the considered chain model belongs. In linear chains, the KR does not depend on the chain length in the thermodynamic limit, but substantially depends on the characteristics of thermostats used in the simulations. In the models with size-dependent heat conduction coefficient, the KR also is substantially size-dependent, despite strong localization of the Kapiza step. Finally, in the models with normal heat conductivity the KR is also normal, i.e. size- and thermostat-independent in appropriate limit.

**EFFECTIVE ELECTRICAL CONDUCTIVITY OF ANISOTROPIC ROCKS: APPLICATION TO MUDSTONES**

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The paper addresses the problem of calculation of the electrical conductivity tensor of a transversely isotropic material containing inhomogeneities of arbitrary orientation. For this goal, we first construct the electrical conductivity contribution tensor for an arbitrarily oriented isolated ellipsoidal anisotropic inhomogeneity embedded in a transversely isotropic matrix.

The general case of an orthotropic ellipsoidal inhomogeneity non aligned in an anisotropic matrix with different class of symmetry may be taken into account. This solution is used then as the basic building block of various homogenization techniques: Mori-Tanaka-Benveniste scheme, Maxwell scheme, and differential scheme.

The approach is illustrated by an application to a transversely isotropic mudstone rock composed of a clay matrix containing non clay inhomogeneities (calcite and quartz). We analyze the origins of the extent of anisotropy of the effective conductivity tensor distinguishing between shape, orientation distribution, and anisotropy of the inhomogeneities on the one hand and anisotropy of the matrix on the other hand. The novelty of the approach, for heterogeneous rock materials such as argillites and mudstones, is the account of the first source of anisotropy.

Numerical results show that orientation distribution of the inhomogeneities significantly affects overall anisotropy in the case of low aspect ratio(s). Limiting cases of aligned and randomly oriented inhomogeneities provide bounds of the extent of anisotropy for the overall electric conductivity tensor. More accurate results may be obtained by considering ODF (Orientation Distribution Functions).

**EFFECT OF RESIDUAL STRESSES IN METAL OBJECTS ON THE LASER GENERATION OF ACOUSTIC OSCILLATIONS**

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Laser ultrasonic and photoacoustic (PA) methods are successfully used to obtain information on the mechanical, thermoelastic, and thermophysical properties of bulk materials, solid-state structures, and thin films. Of particular interest is the application of laser PA microscopy techniques for evaluating residual stresses in various materials.

It was experimentally shown that internal and external mechanical stresses in metals significantly affect the characteristics of the PA signals, especially in areas with a complex rheological structure. In this paper, we studied the relationship of the PA signals and stresses in metals using an example of a model problem for which the stress distribution is well known. The object of the study was a metal plate with a hole, near which the stress distribution is...
known and is determined by the solution of the Kirsch problem. A comparison of the experimental data with the existing models of thermoelastic generation of elastic oscillations showed that the usual approach, taking into account only thermal expansion, does not allow a correct description of the dependence of the PA signal on internal stresses.

In order to correctly describe the generation of a photoacoustic signal in metals, it has been proposed to take into account electronic processes that depend both on temperature and deformations. To this end, forces depending on the pressure gradient of the electron gas are added to the equation of motion. The pressure changes are associated with the delocalization of electrons at the levels of lattice defects close to the Fermi energy (or chemical potential) of the degenerate electron gas. It is shown that under certain conditions the theoretical PA signal increases with compressive stresses in accordance with the experimental data.

The theoretical and experimental results show that the photoacoustic method in combination with the drilling method can be used to estimate the mechanical stresses in metals.

**WHAT CAN POLAR SEA ICE TELL US ABOUT THE MECHANICS OF COMPOSITE MATERIALS?**

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Polar sea ice is a key component of Earth’s climate system. As a material it exhibits complex composite structure on length scales ranging over ten orders of magnitude. A principal challenge in modeling sea ice and its role in climate is in linking scales, that is, relating behavior and structure on small scales to effective or homogenized behavior on larger scales, and estimating parameters controlling small scale processes from large scale observations. Similar issues are central to the development of advanced composite materials. I will give an overview of how we are using theories of composite materials and statistical physics to link behavior on various scales in the sea ice system. These mathematical advances, motivated by sea ice, tell us more generally how to analyze and compute the effective properties of a broad range of composite media, and how to address the inverse problem of reconstructing composite microstructure from effective property measurements. In particular, we address fundamental questions in sea ice homogenization, including fluid flow through the porous brine microstructure, effective properties of polycrystalline materials, the mechanical interaction between ocean waves and the sea ice pack, advection enhanced diffusion, and the evolution of melt ponds on Arctic sea ice. This work is helping to advance how sea ice is represented in climate models, and to improve projections of the fate of Earth’s sea ice packs and the ecosystems they support.

**ELASTIC WAVE PROPAGATION IN SMART LAYERED PERIODIC STRUCTURES**

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Nowadays composite materials and smart structures are used extensively in the aerospace industry, mechanical and civil engineering, and many high-performance products due to their enhanced properties. Additionally, a novel class of composites providing unique properties and called metamaterials is now being intensively introduced into practice. Metamaterials are composites periodically engineered to have special properties arising from the consolidation of several material components. Wave propagation in acoustic/elastic metamaterials or phononic crystals is intensively studied to manipulate mechanical wave propagations. Thus, acoustic metamaterials are able to provide required acoustic properties, e.g. wider band-gap, specific resonances or negative refractive index. Accordingly, the dynamic behaviour of complex three-dimensional structures made of acoustic metamaterials should be efficiently simulated and understood.

In this report, the results of studies of wave motion in layered phononic crystals composed of elastic, functionally graded and piezoelectric layers with imperfect contact and electrodes connected by electrical circuits are presented. Infinite periodic structures and structures composed of a finite number of unit-cells surrounded by two elastic half-spaces are considered. A semi-analytical method is developed to simulate and analyse the wave fields in a layered phononic crystal of finite thickness in the case of oblique incidence. Influence of material and geometrical properties of the layers on wave transmission through various kinds of layered phononic crystals is investigated using Bloch theorem, the developed semi-analytical method and the transfer matrix method.

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RESEARCH OF SI-AU AND SI-AL NANOPARTICLES CRYSTALLISATION

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Silicon nanoobjects are very interesting for nanophotonics due to unique optical properties depending on the atomic structure. Moreover, their optical properties can be tuned by changing the phase composition and doping by metal atoms. Thus, it is a great interest in study the structural features of these particles, such as the grain size and the distribution of metal (Au or Al) atoms in crystal grains and between them.

The influence of cooling rate on Si-Al and Si-Au nanoparticles (NPs) structures was studied in this work for different NPs sizes and metal concentrations. The molecular dynamics simulations were carried out in the quasi-2D case: diameter of NPs was up to 80 nm and thickness of cell was about 10 nm with periodic boundary conditions. In turn this may result smaller grain sizes in simulation in comparison to the experiment. That’s why, additional one-dimensional simulations were performed to study the grain size dependence on the Au or Al concentration in NP. The movement of the crystal grain boundary and changes in the gold and aluminum distribution during crystallisation were investigated. The common features of Si-Au and Si-Al NPs structures were analysed.

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EFFECT OF STRUCTURE PARAMETERS ON THE TRIBOTECHNICAL CHARACTERISTICS OF FIBROUS COMPOSITES

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Fibrous composite materials are a relatively soft matrix in which there are more rigid fibers. An example of such composites are carbon-carbon composites (carbon fibers are located in the carbon matrix), which are used in the manufacture of brake discs.

To calculate the wear characteristics of such composite at the macro level, the wear contact problem with the wear coefficient variable over the surface was formulated and solved based on the method developed in [1]. This coefficient describes the wear rates for the fiber, matrix and transition layer between the fiber and the matrix. Based on the results of the mathematical modelling, it was concluded that the initially smooth surface of the composite becomes wavy during wear process, and the geometrical parameters of the worn surface are determined by the geometrical and tribotechnical parameters of the carbon matrix and carbon fibers.

The wear process was analyzed for different values of the ratio of matrix and fiber wear coefficients. It was concluded that if the fibers are characterized by a lower wear coefficient than the matrix, the fibers protrude above the surface of the matrix in wear process. Under certain conditions it can lead to their separation from the surface. This case is typical, in particular, for carbon-carbon composites with carbonized fibers. In the case when the fibers are characterized by a higher wear coefficient than the matrix (this case, in particular, corresponds to the carbon fiber composite with graphitized fibers), as the simulation results showed, the fibers lie below the matrix level on the worn surface or almost at the same level with it.

The simulation results are in a good agreement with the experimentally measured microgeometry of the worn surface of such composite materials. The analysis of the effect of the structural parameters of the fibrous composites on their effective wear rate was also carried out. The results of the study can be used in the design of the fibrous composite materials to improve their tribotechnical characteristics.

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DELAMINATION OF PLAIN ADHESIVE JOINT UNDER COMBINED DYNAMIC ACTIONS

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In this article explores the problem of destruction of layered media under combined dynamic load. The research is aimed at the influence of background harmonic oscillations on the amplitude of the main force pulse. In previous works,
results were obtained for a simple one-dimensional model - a string on an elastic base. As a result, it turned out that it is possible to significantly reduce the value of the critical amplitude of the destructive effect due to the correct selection of the excitation frequency. This effect is observed even at low intensities of the background field. The criterion of incubation time was used as a condition for breaking the adhesive layer. In this paper, we will also investigate the features of the fracture as a consequence of the combined effect of the force and the external harmonic field. However, the results obtained in this paper will be presented for a two-dimensional model - a circular membrane on an elastic base. You will notice that there is a similar effect, as in the case of strings. External background field tuned to a certain frequency can significantly reduce the value of the critical amplitude of the separation of the adhesive layer. The incubation time criterion will also be used as a destruction criterion.

LINEAR HOMOGENEOUS ISOTROPIC ELASTIC CONSTRAINED REDUCED COSERAT MEDIUM: AN ACOUSTIC METAMATERIAL

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We consider a special kind of the reduced Cosserat medium, a constrained isotropic linear elastic reduced Cosserat medium. In such a medium there exist particle rotations (microrotations) and translations, but the strain energy does not depend on the gradient of the microrotation (therefore the medium is reduced), and also the microrotation equals macrorotation (vortex translational deformation of the particle neighbourhood). In such a medium the couple tensor is zero, the stress tensor is asymmetric, but its antisymmetric part must be determined from the dynamic equations (due to the existence of the kinematical constraint). The dynamic equations of such a medium look similar to those of a classical material but with an additional “pseudoinertial” term where apart from second derivative in time, derivatives in space are also present. Constrained Cosserat continua is a popular model, in particular, in geophysics, and we will investigate its dispersion properties. For the isotropic case, only the shear-rotational wave is influenced by the nonclassical term. It occurs to be a single negative acoustic metamaterial for large frequencies.

SURFACE STRESS EFFECTS IN THE PROBLEM ON AN INTERACTION OF EDGE DISLOCATIONS WITH A PLANAR INTERFACE

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The study of elastic fields induced by dislocations located in the vicinity of a traction-free surface or interface is one of the significant parts of dislocation theory. A lot of analytical solutions concerning the interaction of dislocations with surface/interface have been obtained within the framework of the classical theory of elasticity. The value of these solutions is that they are fundamental (Green functions) and so are used for the analysis of different fracture mechanics and inhomogeneity problems with the boundary element method involving the construction of a boundary integral equation. If a dislocation is in a subsurface layer of a nanometer thickness, the classical continuum mechanics needs to be modified to account for the surface energy and surface stress effects that are intrinsic to the nanomaterials having at least one dimension in the range of 1-100 nm. More general and widely used mathematical framework incorporating the effects of surface tension and surface elasticity into continuum mechanics was developed by Gurtin and Murdoch (GM). The aim of the present work is to investigate the stress field produced by the interaction of a single edge dislocation or dislocations array with a planar interface between two dissimilar elastic materials incorporating interfacial stresses. It is supposed that the bimaterial is under the plane deformation and the dislocations can reach the distance to the interface up to several nanometers. The solution of the corresponding 2-D boundary value problem with the generalized Young-Laplace boundary condition at the interface is based in the work on application of Goursat-Kolosov’s complex potentials, Muskhelishvili’s representations and the GM surface elasticity model that leads to the hypersingular integral equation. In the case of the dislocations array, this integral equation have been evaluated in terms of the Fourier series with coefficients determined by quadratures, as it was done in [1, 2]. Using derived formulas, the numerical results have been obtained for the stress field and image force acting on the edge dislocations with dependence on the dislocations position. Burgers vector orientation and the elastic properties of the bulk materials. The surface stress effect on the elastic field around the dislocations and at the interface and on the image force has been analyzed.

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ON HYDROGEN DIFFUSION MODELS IN STEELS

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Hydrogen embrittlement of metals depends on the amount of hydrogen in the metal. Experimental results show that the distribution of hydrogen in steel largely varies from the distribution of gas in other solids as the result of the bulk diffusion. In addition, the diffusion may depend on stress-strain state and material parameters of the solid body, which also reflects in various experimental results.

In this work, a model based on Truesdell and Prigogine approach is proposed. The two-component system is considered, the diffusion flux of hydrogen through the steel is defined as proportional to the gradient of chemical potential. The chemical potential of gas is taken in its classical scalar definition; as the chemical potential of the solid Eshelby energy-momentum tensor is taken. In this work, there are not considered any mechanisms of trapping or atomic diffusion.

As the example of the model applying, the distribution of hydrogen in axisymmetric solid body is achieved depending on a stress-strain state of the solid material. The dependences of hydrogen distribution on time, coordinates, temperature and material parameters are investigated. Results are compared to the known experimental data.

MICROSCALE MECHANICAL MODEL OF THE MAIN STRUCTURAL ELEMENT OF BAZHENOV FORMATION ROCKS

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A microscale model of the main structural element (“bearing” layers) of kerogen-clay-carbonate-siliceous of the Bazhenov formation rocks is proposed. The model describes the structure of the “bearing” layer as a composite material based on an inorganic clay matrix with different concentration (from <5% to 20-25%) of organic matter inclusions and micropores filled with light hydrocarbon fractions. Within the framework of the proposed model, the mechanical behavior of the main element of the microstructure of the “bearing” layer was studied by numerical simulation of the triaxial compression of microscale samples. The magnitude of the applied pressure varied in accordance with the typical P-conditions of occurrence of the rock. The simulation was carried out using the original numerical method of hybrid cellular automata. The results of computer simulation showed that the "bearing" layers of considered rock are characterized by a pronounced anisotropy of inelastic mechanical properties. The most important result is that the anisotropy of properties is expressed only in quantitative characteristics (parameters of the yield function), while the patterns of inelastic behavior are common to different directions of deformation. Thus, the mechanical behavior of the sample at pressures that meet the conditions of occurrence is satisfactorily described by rock plasticity models with two-parameter plasticity functions. As such a function, it is proposed to use the Mises-Schleicher function, which takes into account the contributions of the local pressure and stress intensity in the linear approximation.

The work was carried out within the project “Development of geological, mathematical and physical models of a fluid-saturated elastic-plastic fractured-pore collector in high-carbon kerogen-clay-carbonate-siliceous rocks (mixtites of bazhenite and domanikite types)” of the Comprehensive Program of Fundamental Researches II.1 of SB RAS.

FATIGUE RELIABILITY OF STRUCTURES: METHODOLOGY OF ASSESSMENT AND PROBLEMS

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Fatigue reliability assessment of metallic structures in various applications according current design codes is based mostly on S-N criteria with uncertain characterization of fatigue properties of a particular material and the assumed damage. In case the crack is detected residual service life as recommended may be estimated by applying the Linear fracture mechanics techniques, again, with incomplete defining conditions of the crack growth and exhaustion of life.

Proposed earlier procedure of simulation the fatigue process based on the due finite element modeling of the affected area of a structure, application of the damage summation technique and appropriate criterion for fatigue failure of material allowed assessment of fatigue life from the onset of service loading up to development of a critical state, e.g. of
the through crack in a structural component. Also, it was shown that the simulation scheme was capable of account the heterogeneity of the material structure fatigue resistance, the crack closure effects and elastic-plastic material response when the Strain-life criterion for fatigue failure was applied.

However, selection of the criterion for fatigue failure of material is but a straightforward decision: it is shown that S-N criterion even attributed to the same structural steel class as the Strain-life one does not provide in analysis of the fatigue process even an approximate convergence. This is mostly due to fairly indirect considering the inelastic properties of fatigue damage in S-N criteria and the methodology of fatigue testing specimens aimed at evaluation of S-N and e-N criteria.

Further, the approach would need in more comparisons of simulated and test data in different structural applications.

**3D ANALYSIS OF CRACK PROPAGATION IN HUMAN DENTIN BY X-RAY MICROTOTOMOGRAPHY**

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Dentin is a natural porous material with a hierarchical structure [1–3]. It contains quasi-cylindrical microchannels (called tubules) with 3–5 µm diameter spaced apart a distance of 10 µm. Substance around them has a rather complex structure. Dentin has specific strength and toughness properties and thereby human teeth maintain long time loads. The reasons for dentin’s resistance to damage are not clear so far. The aim of this work is to observe and discuss the formation and development of microcracks in plate-shape dentin specimens tested in uniaxial compression applied in the direction across a plate. The observations were performed with phase contrast tomography.

Nowadays two ways to implement x-ray tomography are available: conventional absorption and phase contrast modes. In the absorption mode, tomography has a serious limitation in studying micrometre-size objects in materials. In coherent light provided by a third generation synchrotron radiation (SR) source the image of a microobject can be determined only by the phase. Phase contrast (or ‘micro’) tomography can be a tool for visualizing microstructure in the interior of the dentin sample.

Microtomography was performed on SR source with monochromatic 25 keV x-rays. Three-dimensional (3D) images were reconstructed from tomography data by a commercial algorithm. Dentin samples were plates of size ~5x3 mm² cut out from roots of caries free human teeth perpendicular to the vertical axis of a tooth. No treatment with an acid was necessary. The plate had a thickness of ~0.2–0.5 mm.

We have established that in the samples with 0.5 mm thickness cracks appear when the compression stress is 370 MPa. Dominant and satellite cracks are formed. They begin on the loading surface and extend into the depth of the sample. A crack extension and propagation depend on the applied load. No cracks were observed for samples with 0.2 mm thickness.

3D visualization of the directions and locations of the dentinal tubules and cracks showed that the cracks go through the tubules. This conclusion seems natural, since the latter are stress concentrators. It is known that the propagation of dominant cracks in dentine is accompanied by the formation of satellite cracks, separated by areas of non-damaged material [4]. In the course of this experiment, it was shown that the development of cracks of both types is associated with the direction of the dentinal channels. We assume that the process of crack opening occurs through successive movements of its tip from one tubule to another in the plane of action of maximum local shear and tensile stresses. A qualitative model of this process for a mode II crack is suggested and discussed in detail.

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**References**


**GAS FLOW MECHANISM IN SHALE MATRIX NANOPORES**

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Shale gas reservoir has become an important source of natural gas, and a significant portion of gas in the reservoir exists in an adsorbed state. The permeability of shale matrix is ultralow. The main reason is that the pore diameters of shale...
matrix is mainly distributed in 2–10 nm. Due to the existence of nanopores in shale matrix, Darcy equation can’t describe gas flow in such narrow flow path. Besides, adsorption gas in nanopores can also affect gas flow mechanism. In this paper, firstly we studied gas existence state in shale matrix nanopores by simplified local-density model (SLD). Gas adsorption affecting factors which include temperature, pressure, pore type and diameters were studied quantitatively and systematically. Secondly, based on local gas density in nanopores obtained by SLD method, gas flows in shale matrix nanopores were described. Gas in shale nanopore can be divided into three layers. The first layer has the highest density and is about the radius of methane molecule from the pore wall; the second layer is the medium density layer, which has a slightly higher density than bulk gas, and the third layer has the lowest density. Gas density in third layer is the density of bulk gas. Gas flow in nano-pore can be divided into three stages. Thirdly, we derived an equation to describe gas flows in shale nanopores considering both gas flow flux caused by pressure gradient and by diffusion. The factors that affect gas flow in shale matrix nanopores were also studied, including temperature, pressure, nanopore type and diameter. Finally, the following conclusions were obtained: The total gas flow rate decreases with the increase of temperature. With the increase of temperature, both diffusion flow rate and viscous flow rate increase, and the effect of temperature on absolute diffusion flow rate is greater than that on viscous flow rate; with the increase of outlet pressure, the total mass flow rate decreases, and the total mass flow rate and outlet pressure show a non-linear relationship. The higher the pressure, the faster the flow decrease rate; the size and type of pore also affect the distribution of methane gas in nano-pore and the flow of gas. The smaller the pore size, the greater the influence of pore type on gas flow rate.

NANOSCALE HOMOGENIZATION OF THE VISCOELASTIC PROPERTIES OF POLYMER NETWORKS

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The development of new materials for advanced structural solutions with reduced noise and vibration levels is an active area of research due to concerns in various aspects of environmental noise pollution and its effects on health. Excessive vibrations can in many cases reduce the service life of the structures and limit the fields of their use. Access to materials that are both structural (have a reasonable stiffness) and able to cut noise or damp unwanted vibration is highly desirable but it is a technological challenge to develop such materials. Here we describe our recent work on the micromechanical design and manufacturing of such composite materials. Damped natural vibrations of viscoelastic Bernoulli-Euler beams and Kirchhoff plates are considered and, using the viscoelastic corresponding principle, a refined figure of merit for selecting best performing materials is derived. Optimum microstructural vibration damping design of coated sphere filled viscoelastic composites is performed (using a combination of classical n-layered spherical inclusion model and direct finite element calculations) and it is ascertained that by optimizing the thickness and the properties of the coating layers, substantial improvements can be achieved in the vibration damping characteristics of viscoelastic beams and plates. Then it is proved that samples can be manufactured to this specification (comprising a polymer reinforced by glass spheres with a thin, sub-micron viscoelastic coating), and that their experimentally measured viscoelastic properties closely match the predictions. It is shown that such novel materials can significantly reduce the amplitude decay time for the damped free vibration of viscoelastic plates, as compared to similar plates made from a pure polymer or a polymer reinforced with uncoated spherical beads. Plotting the properties of the new materials on an Ashby plot of loss factor vs storage Young’s modulus, shows the new materials to fall well above the trend line of all existing polymer materials and their composites, thus escaping the Ashby limit and offering a new route for manufacturing advanced composite structures with markedly reduced noise and vibration levels.

MISFIT STRESS RELAXATION BY DISLOCATION LOOPS IN CORE-SHELL NANOWIRES

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Core-shell nanowires (CSNWs) has attracted much attention in recent years due to their potential applications in optoelectronics [1–4], energy storage devices [5], heat conversion [6], solar cells [7], etc. However, the unique functional properties of CSNWs can strongly be affected and deteriorate by misfit strains, caused by the lattice mismatch of core and shell materials, and misfit defects which are generated in CSNWs and partly relax these misfit strains. Two kinds of misfit defects are commonly observed in CSNWs, which are straight misfit dislocations (MDs)

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parallel to the CSNW axes and prismatic loops of MDs surrounding the CSNW cores [8]. The first ones provide strain/stress relaxation in the cross sections of CSNWs, while the second ones provide axial relaxation in CSNWs. The principal questions to answer in this respect are (i) what is the critical condition for the onset of MDs and (ii) what is the equilibrium density of MDs at the core-shell interface? Until now, only the first question has been studied in a number of theoretical works [9-12]. In the present work, we revisit the problem of circular prismatic loops of MDs in CSNWs to answer both the questions. First, we solve the boundary-value problem in the classical theory of elasticity for a circular prismatic dislocation loop in an elastically isotropic cylinder by the Lurie method [13] different from those [10, 11] used before for solving this problem. Based on this solution, we find both the self strain energy of the loop and the interaction energy for a pair of such loops. Then we apply these results to calculating the critical conditions for nucleation of a circular prismatic MD loop in a CSNW. Finally, we calculate the change in the total energy of the CSNW in a partly relaxed state, with an infinite row of MD loops periodically distributed at the core-shell interface along the CSNW axis, per unit period of this row. Minimizing this energy change by the row period, we find the equilibrium distance between the MD loops and compare it with results of direct experimental observations of MDs in InAs-GaAs CSNW [8]. Our theoretical results (8.35–9.05 nm) well correspond to the experimental data (7.0–8.5 nm).

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References

INHOMOGENEOUS DISTRIBUTION OF THERMAL CHARACTERISTICS IN THE HARMONIC CRYSTAL

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In this paper, we consider a model of a uniform harmonic chain of particles [1–4] for the analysis of non-stationary thermal effects in an ideal crystal system. The exact solution for the particle system is presented and the temperature is calculated as a measure of the average kinetic energy of the particles. The corresponding energy averaging is performed over the initial distribution of the displacements and velocities of the particles, provided that they obey the Boltzmann principle. Simple analytical formulas are presented for all energy derivatives with respect to time at the initial time and for the first derivative with respect to the number of particles. Over a small time interval, the temperature was shown to depend monotonically on the number of particles. This means that the non-uniformity of thermal characteristics distribution, i.e. dependence on the number of particles, occurs in the system without additional assumptions about the structure of the initial conditions on a macroscopic scale. The obtained formula for the distribution of kinetic energy is presented through Bessel functions. The functional dependence on the number of particles is shown to appear in the index of Bessel functions, and the parity of the number of particles affects the temperature distribution. The distribution of the kinetic energy for a large time was asymptotically analyzed, and the exit to the stationary value was shown to depend essentially on the particle number.

References
OXIDE DILATOMETRY CONTAINING THERMALLY EXPANDED GRAPHITE

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The objective of the summary is the dilatometric study of oxides containing thermally expanded graphite. The dilatometric measurements made along the longitudinal (R) and transverse (Z) directions in the temperature range 30-800 °C showed the presence of strong anisotropy. $\Delta L/L_R$ is 25 times larger than $\Delta L/L_Z$. Relative variations in both directions change slope at the same temperature.

The coefficients of thermal expansion $\alpha_R$ and $\alpha_Z$ have the same behavior at low temperature. The dilatometric curves each contain an anomaly whose intensity and temperature of appearance differ from one direction to another. The intensity of the anomaly in the direction (Z) is 18 times greater than that in the direction (R).

The appearance of the DSC calorimetric curve shows no significant change. It varies monotonously. On the other hand, the representative curve of the weight loss has a plateau from ambient temperature up to 300 °C. At 320 °C, the behavior of TG varies slightly decreasing. From 620 °C, the slope changes abruptly and the shape of the curve TG becomes practically vertical.

ON COUPLED ELECTROMAGNETIC-TERMOMECHANICAL MODELING OF ELECTRIC MOTORS: THEORY AND APPLICATION

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Driven by environmental and sustainability considerations, new developments in the transportation industry rely heavily on electric propulsion, thus requiring a careful rethinking of electric motor designs. In particular, future developments of lighter, more compact and more powerful motors imply higher stresses, currents and electromagnetic fields. Strong couplings between mechanical and electromagnetic aspects may consequently arise and a consistent multi-physics modeling approach is required. Current simulations typically involve a stepwise process, where the resolution of Maxwell’s equations provides the Lorentz forces which are subsequently used as the external body-forces for the resolution of Newton’s equations of motion.

The work presented proposes a multi-physics model for electric motors. Using the direct approach of continuum mechanics, a general continuum model that couples the electromagnetic, temperature and mechanical fields is derived from the basic principles of thermodynamics and electromagnetism. As a first application, the theory is then employed for the modeling of an idealized asynchronous motor for which we simultaneously calculate the electromagnetic, stress and temperature fields as a function of the applied current and output mechanical torque.

INFLUENCE OF THE SPERM VELOCITY ON FERTILIZATION CAPACITY IN THE OSCILLATORY MODEL OF MOUSE ZONA PELLUCIDA

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Considering the fertilization process as an oscillatory phenomenon, based on mechanotransduction theory of sperm–oocyte interaction, influence of sperm velocity and their specific arrangement on outer surface of oocyte-Zona pellucida (ZP) relative to the oscillatory behavior of ZP was studied using discrete continuum oscillatory spherical net model of mouse ZP. For the calculated favorable impact angles of spermatozoa by using generalized Lissajous curves, a parametric frequency analysis of oscillatory behavior of the knot molecules in the mouse ZP spherical net model is conducted. In order to mimic successful fertilization in physiological conditions in this numerical experiment, velocities
of the progressive and hyperactivated spermatozoa were used. The resultant trajectories of knot molecules in mouse ZP spherical net model, in the form of generalized Lissajous curves, are presented. Influence of the sperm velocity and its arrangement on the resultant trajectory of the corresponding knot molecules are discussed. Component displacements in the meridian and circular directions of the knot molecules of ZP are in the form of multi-frequency oscillations. Symmetrical arrangements of spermatozoa having effective velocities are more favorable for achieving a favorable oscillatory multi-frequency state of mZP for a successful fertilization. Determining the optimal parameters of spermatozoa impact that will induce a ZP favorable oscillatory state opens the possibilities for more complete explanation of the fertilization process.

PHOTO-SWITCHABLE CHEVRON TOPOGRAPHIES OF GLASSY NEMATIC COATINGS

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Azobenzene-containing nematic glasses are highly cross-linked liquid crystal polymer networks with elastic moduli as high as a few gigapascals. Exposed to ultraviolet (UV) light, they contract and expand respectively in the directions parallel and perpendicular to the director due to trans-cis isomerization of the azobenzene moieties. The deformation can be reversed when illuminated by visible (VIS) light. Such a property of photo-responsivity makes the nematic solids very appealing in many innovative applications where reversible shape transformation is desired. Of interest is the fabrication of smart surfaces which can switch topography upon illumination so as to change the performances of adhesion, wetting, and light diffraction. In comparison with thermal and electrical actuation which require embedded heating sources and electrodes, using light as a trigger for topographic switch is particularly attractive as it allows for wireless control and miniaturization. In this work, we report a strategy to create photo-switchable chevron topographies via buckling of glassy nematic coatings on soft elastic substrates. The idea is the use of zig-zag director distributions in the coating so that desired buckling mode can be triggered upon uniform illumination. For verification, detailed numerical simulations are performed. The results indicate that the inclination angle of the chevron patterns is not in accordance with the director orientation. The phenomenon is proven to be well quantified by the stress state within the coating just before buckling.

BISTABLE DESIGN OF FUNCTIONALLY GRADED CARBON NANOTUBE-REINFORCED PLATES

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A bistable design technique is proposed for functionally graded carbon nanotubes reinforced composite (FG-CNTRC) plates with single-walled carbon nanotubes (SWCNTs) as reinforcements. The SWCNTs are assumed to be aligned and straight with a uniform layout in plane but functionally graded (FG) across the thickness direction of the plates by following a power law. A bistable FG-CNTRC plate can be obtained by varying the distribution types, the volume fractions and the volume fraction exponents of SWCNTs. A simple analytical model considering a Von Kármán-type of kinematic nonlinearity is used to study the bistable behavior of FG-CNTRC plates, and a higher-order Rayleigh–Ritz model is presented to investigate the bistability and the buckling behaviors of the proposed FG-CNTRC bistable plates. The analytical results are compared with nonlinear finite element (FE) results for the validation of studies. The analytical results show that increasing the initial curing temperature, the length of the plate can impel the occurrence of the bistability of the FG-CNTRC plates when the volume fraction of SWCNTs are relatively low. Besides, larger exponent in the expression of the FG distribution of the FG-CNTRC plate is beneficial for the occurrence of the bistability. By modifying the exponent and designing the distributing way of SWCNTs, the bistability of the FG-CNTRC plate can also be obtained with relatively lower volume fraction of SWCNTs. Thus, the bistable behaviors of FG-CNTRC plates can be obtained by designing parameters, including the distribution of SWCNTs and the FG-CNTRC plate’s dimensions.
The issue of heat transfer in particle systems has been widely encountered in many engineering and scientific applications, for instance, in porous media, soil, food processing; designing of energy systems; and geo-mechanics. The heat-transport mechanism in a granular system is more complex than transport through a pure solid material because of the effect of interstitial fluid in the voids between the particles. This study presents three topics about the heat transfer behaviors in particle systems. The first topic is about the thermal-diffusion mechanisms of particles with fluctuant motion in a vibrated dry granular system. Granular beds with different intensities of particle self-diffusion were produced by exerting vertical vibration-driving forces of different strengths. The effective thermal diffusivity was determined by solving the problem of inverse transient heat conduction. This study contributed important new observations of the thermal-diffusion mechanisms in a non-static granular system. The second topic is about heat transfer behaviors of granular medium in a rotating drum. The main purpose of the thermal treatment of the rotating drums is to raise the temperature of the material to the target temperature. The heat transfer in the rotating drums/kilns strongly depends on the combined transport of mass and heat within the granular material. Thus, there may exist obviously different heat transfer behaviors in case particles and rotating drum have different characteristics. This is because that the dynamics of granular flow in the drum may be changed by different control parameters. In this study, the effects of particle size and sidewall conditions of the drum on the heat transfer behaviors were was experimentally investigated. The heat transfer coefficient between the side wall and the granular material in indirect-heated rotating drum was also calculated. The third topic is about the hydrodynamics and heat transfer phenomena that occur in a fast pyrolysis system using rice husk/silica sand and nitrogen as biomass fuel/bed material and fluidizing gas, respectively. A simple two-dimensional computational fluid dynamics model was developed to investigate the gas-solids flow characteristics in a bubbling fluidized-bed reactor. Accordingly, various aspects such as pressure, solid volume fraction, solid mixing, granular temperature, thermal temperature, and surface heat transfer mechanisms together with the effect of biomass particles’ size on them were studied in this research.

ASYMMETRIC ELASTIC METAMATERIAL AND ITS APPLICATION TO ELASTIC CLOAKING DESIGN

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Asymmetric elastic metamaterial with elastic tensor losing minor symmetry is believed to be impossible without introducing artificially body torque. We demonstrate here that such material is feasible by ingenious microstructure design: the rotational inertia of the microstructure during wave loading breaks naturally the equal shear theorem, and the moment induced by the unequal shears is balanced at any instant with the rotational inertia without resort to hyper-stress or body torque. This concept is illustrated through a realistic mass-spring model and the corresponding band structure analysis. It is found that the rotation of the microstructure plays a key role in forming this asymmetric elastic metamaterial, the traditional elastic material (symmetric) is recovered in a static case. Asymmetric elastic metamaterial was utilized to construct a mathematical perfect matched layer (PML) to mimic an infinite space for elastic wave analysis. More interestingly, this hypothetical material could also provide a route to construct elastic wave cloak. With the designed asymmetric elastic metamaterial at hand, an elastic wave cloak is designed with help of transformation method. A lattice elastic cloak built with asymmetric elastic metamaterial is then constructed, its performance is validated by finite element method. The asymmetric elastic metamaterials pave the ways for designing elastic PMLS and elastic transformation devices.

A NEW SOFTWARE "AMS" FOR STRUCTURAL MODELING, ANALYSIS AND DESIGN OF MULTI STOREY BUILDINGS

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AMS is a software package we are developing for three dimensional structural modeling and for performing structural design of multi storey buildings. It is based on the finite element method (FEM), in terms of carrying out static, dynamic and seismic analyses, and it is written in C#. The most important characteristics of the program are the possibility of simultaneous modeling all structural
components (i.e., beams, columns, shear walls, slabs, frames), in one model. On the other hand, the AMS has a 3D graphical environment that shows the structure and all elements in an easy and obvious way (plan view, elevation view, 3D view) within the program interface.

Also, AMS provides many tools for creating calculation notebooks and for creating detailed sheets for structural elements according to practice requirements in Russia. Furthermore, the BIM technology is supported in AMS program. Many international designing standards will be included in AMS design options such as Russian (GOST), Euro and American codes. The program menus will support both Russian and English languages. The outputs of AMS are expected to apply in the field of structural, seismic, and mechanics studies.

This program provides an accurate and easy tool for analyzing and design of multi-storey buildings (in accordance with the standards demands) in short time and low cost.

Target users are:

- students of structural engineering universities;
- offices and structural engineering companies;
- interested people in the field of construction mechanics.

**DYNAMICS OF THE MICRORESONATOR IN THE REGIME OF SUPERCRITICAL COMPRESSION**

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In this work we research microresonator consisting of an elastic element in the form of a beam located between stationary electrodes. One end of the beam is rigidly clamped, and the other one is elastically fixed in the longitudinal direction. Longitudinal movement of the elastic fastening creates a longitudinal force in the elastic element of the microresonator.

The mechanical model of an elastic element is considered as Bernoulli-Euler beam in the transverse direction and as a linear straight rod in the longitudinal direction, using appropriate boundary conditions. The equations of motion are obtained using Galerkin mode-projection method. The result is a system of ordinary differential equations for time-dependent modal coefficients. They are supplemented by equations of electrical circuits containing sources of electromotive force and capacitors of variable capacitance formed by fixed electrodes and the elastic element of the resonator.

Equilibrium positions depending on the longitudinal displacement of the elastic fastening mechanism are obtained in the presence of a longitudinal compressive force and one or two sources of constant electromotive force. A significant difference of bifurcation diagrams in the absence of constant electromotive force sources and when it is turned on was revealed. With different switched on sources of constant electromotive force either two or three critical values of the force are possible, which differ from the Euler force.

We considered forced oscillations of the resonator with supercritical longitudinal compressive loads in different regimes, in which the average amplitude coincides with one of the stable or unstable equilibrium positions. Resonance curves were constructed with characteristic jump phenomena during the transition from one regime to another. A positive feedback scheme for the excitation of self-oscillatory modes was proposed. The conditions for the existence of self-oscillatory regime were established. The dependence of the frequency of self-oscillations on the parameters of the system — the magnitude of the longitudinal compressive force, the gain and the time constant of the capacitor charge circuits — was investigated.

**DYNAMICAL STABILITY OF RUNNING SOLITARY WAVES IN FLUID-FILLED ELASTIC MEMBRANE TUBES**

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We examine the problem of stability of solitary waves, propagating in a fluid-filled membrane tube. We consider waves with speeds starting from those given by the linear dispersion relation (it is known that there may exist four families of solitary waves having such speeds), i.e., the waves of a finite amplitude bifurcating from the quiescent state of the system. It is shown that if a solitary wave speed is bounded away from zero the solitary wave itself is orbitally stable, when the fluid is initially at rest (the mean flow is absent).

The governing equations for quasi-one dimensional motion of the perfect fluid in the axisymmetric membrane tube
were obtained in [1] by means of a straightforward derivation. Study of spectral stability of a branch of steady solitary-wave solutions (so-called aneurysm solutions) in the absence of the fluid inside the tube (pressure-controlled case) is given in [2]. A bifurcation parameter was the inflation pressure, and the authors found that all family of solitary waves is always spectrally unstable (i.e. a perturbation of a wave form exponentially grows with time). In [3] stability of the whole branch aneurysm solutions is studied when the fluid inside the tube is present, but a mean flow (a constant speed of the fluid at infinity) is zero. It was found there that the aneurysm is still unstable, but the presence of fluid has a strong stabilizing effect. The authors of [4] undertook a stability analysis of aneurysm solution in the presence of the mean flow and found that if a speed of the fluid at infinity is bounded away from zero, then the aneurysm is spectrally stable. Here we examine the problem of stability of solitary waves, propagating with a non-zero speed in a fluid-filled axisymmetric membrane tube. In this case a bifurcation parameter is not the inflation pressure any more (it may take arbitrary values), but a solitary wave speed.

**References**


**PERTURBATION METHOD IN THE PROBLEM OF OBLIQUE IMPACT ON THE BOUNDARY OF A NONLINEAR ELASTIC HALF-SPACE**

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Continued interest in the solid medium dynamics under the action of intense short-time boundary loads is associated with natural and anthropogenic geodynamic processes, the need for their mathematical description, and the engineering tasks of high-speed impact treatment of materials and structures. In addition to practical purposes, the study of solids shock deformation has an important theoretical value, since nonlinear modeling of the continuous solids properties is a relatively new subject area. The perturbation method is one of the most effective [1] for these purposes. Previously, it was used in the shock deformation problems which are related to a single surface of strong discontinuities [2–4]. The paper presents the solution of a one-dimensional nonstationary problem about oblique impact on the boundary of a nonlinearly elastic isotropic half-space obtained by the method of matched asymptotic expansions. The analysis of the relevant evolution equations is carried out for each of the two shock waves. The solution behavior behind the leading edge of a quasi-transverse shock wave is considered in more detail. For such a wave, we obtained that the preliminary volume deformation creates in the medium properties the inhomogeneity effect acting differently for each of the various boundary loads. We showed that the action area of the evolution equation for a quasi-transverse wave is determined by several interim inner problems of the small parameter method. These tasks depend on the preliminary volume deformation affecting the distortion of characteristic coordinates and the leading front of the quasi-transverse process. Therefore, the transition to the evolution equation of quasi-transverse waves occurs with the simultaneous change of all independent variables of the boundary value problem. For some types of the problem edge conditions, we have shown a transition to the region distant from the loaded boundary and the evolution equations appearing in this case for longitudinal and quasi-transverse waves.

THE IMPACT OF PRESTRESS IN A GROWTH LAYER ON BONE REMODELING

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Bone is an adaptive tissue which optimizes its structure in accordance with changes in external loadings. According to statistics the number of persons suffering from various bone diseases, such as osteoporosis and Paget's disease, increases every year. The majority of bone diseases are caused by the disorder of the adaptation process, also termed remodeling which consist of the growth and resorption phase. Mainly bone remodeling takes place on the surface of trabeculae and can be considered as surface growth and resorption. Many experiments show that the adaptation process can be controlled by the mechanical stimuli. Therefore, biomechanical modeling of growth and remodeling processes is the tool for the treatment of many diseases. However, despite the fact that the growth problem is one of the most important area of biomechanical research, there is still no a commonly accepted model of the adaptation process.

The aim of this research is to analyze the influence of the mechanical factors on growth and remodeling processes and to develop the biomechanical model of process. In the context of a present paper note approaches to growth driving forces developed in [1,2] (see also reference therein). The present microscale model considers the trabeculae bone part and is based on the expression of the configurational force derived from fundamental laws and entropy inequality similar to derivations for stress-assisted propagating chemical reaction front, see [3] and reference therein, where it was shown that the reaction front kinetics is determined by the normal component of the chemical affinity tensor. Special attention in the present research is paid to the new layer arising in the growth process. These layer may occur with prestress which can significantly affect the adaptation process. Various types and values of prestress are considered on the base of developed model. And it is shown that the bone growth is controlled by the normal component of growth driving tensor that depends on stresses/strains and the concentration of the incoming matter transported to the growth surface. In addition, attention is paid to the choice of the stress dependent supplying function which controls the amount of the matter incoming into the bone volume. Since stresses depend on the current bone configuration, this provides coupling between stresses, growth rate and the matter supply. Based on the developed model, surface growth and resorption of bone are simulated for various initial configurations of growing bodies and various mechanical loadings.

References

KINETIC THEORY FOR A DENSE, INCLINED, GRANULAR FLOW OVER AN ERODIBLE BED

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We outline the derivation of the equations for the balances of mass, momentum, and energy for dense, inhomogeneous, steady, granular shearing flows of inelastic, frictional spheres in the context of a kinetic theory which has been extended to incorporate the influence of velocity correlations on the rate of collisional dissipation. We then focus on flows in which the volume fraction is greater than 0.49, above which a first order phase transition to an ordered collisional state is possible in an equilibrated elastic gas. In this regime, the dependence of the transport coefficients on the volume fraction can be replaced by a dependence on the particle pressure and the strength of the particle velocity fluctuations. Associated with the resulting differential equations of balance are boundary conditions for momentum and energy that permit boundary-value problems to be phrased and solved in terms of known functions or simple quadratures.

We indicate the form of such a problem for a dense, inclined shearing flow over an erodible bed. This flow develops a denser region of slow, shearing, or creep at its base, in which the diffusion of energy is balanced by its collisional dissipation. We relate such a formulation to those of Kamrin and coworkers (e.g., Phys. Rev. Letts. 108, 178301, 2012) and highlight the similarities and differences of the two approaches. Finally, we provide solutions to the balance equations in terms of known functions, and show profiles of the mean particle velocity, the particle concentration, and the strength of the particle velocity fluctuations in a typical flow.
MONTMORILLONITE REINFORCED POLYIMIDE COMPOSITE AEROGELS AS MULTIFUNCTIONAL ABSORBENTS

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In recent decades, crude oil spills and chemical leakage from industrial accidents have caused serious environmental problems on marine and aquatic ecosystem. Hence, the development of efficient methods for oil spillage cleanup and oil-water separation has been a worldwide task. And the novel materials that can effectively and circularly separate oil–water mixtures are in urgent demand. Compared to traditional materials, aerogels are the good candidates for oil-water separation and absorption materials. Aerogels are one kind of ultra-light and porous materials that obtained by extracting the solvent of wet gels through appropriate drying methods. And the processes allow to replace the solvent with a gas and to maintain the three-dimensional network and initial volume. Aerogels have the characteristics of porous structure, low density and high specific surface area. Developing advanced aerogels with multifunctional properties has becoming increasingly important. Polyimide (PI) is an important widely applied engineering plastic for construction industry and aerospace, because of its superior mechanical properties, thermal stability, and corrosion resistance. Moreover, the PI aerogels have attracted a large number of domestic and foreign researchers, and show a promising prospect in the application of lightweight and high-performance material. Herein, the composite aerogels based on PI and montmorillonite (MMT) were fabricated through the eco-friendly freeze-drying method and followed by a thermal imidization process. The PI aerogel can stand stably on the top of a flower without any deformation, which is attributed to the low density (0.039 g•cm⁻³). In addition, the pure PI aerogel is an obvious layered structure. With the addition of MMT, the PI/MMT composite aerogels exhibit honeycomb-like, porous 3D network structures with continuous macro-pores of hundreds of micrometers. The addition of MMT would increase the solution viscosity and block the ice growth, therefore the network structure can be formed. The resulting PI/MMT aerogel has robust mechanical properties, with the addition of MMT nanoparticles. In detail, the compressive strength of pure PI aerogel is 27.1 KPa. Compared with the pure PI aerogel, the highest compressive strength of PI/MMT aerogel is 65.9 KPa. And after three loading-unloading cycles with a maximum strain of 60%, the PI/MMT aerogel exhibited no significant plastic deformation which indicated the robust structure. The improvement of compressive strength is attributed to the increase of the interfacial force between PI and MMT. The MMT nanoparticles could disperse uniformly in PI matrix. Thus, under the synergistic interaction with coupling agent KH550, the PI/MMT composite aerogels have excellent elasticity and toughness. What’s more, the PI/MMT composite aerogels are certainly ideal candidates for oil spill cleanup, because of the cyclically stable and efficient absorption capacity to various oils or organic solvents. Furthermore, the PI/MMT aerogels show multifunctional properties such as acid resistance, low and high temperature capabilities. This work provides an environmentally friendly method to prepare the multifunctional PI/MMT aerogel, which has a great potential for the environmental protection including oil spillage cleanup and oil-water separation.

PREFERRED MOTION OF ENANTIOMIC SMALL MOLECULE WALKERS UNDER AN EXTERNAL FIELD

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The area of research known as molecular motors has become a topic of significant interest due to various applications in biology, chemistry and nanotechnology. These molecular motors (or machines) under certain conditions are capable of a net unidirectional motion, and the physics behind this effect is well understood. Here we shall discuss, as a prototypical system, molecular walkers standing on two or more “feet” on an anisotropic periodic potential of a crystal surface, and shall investigate their ability to perform a Brownian motion at the surface-vacuum interface along a particular dimension. In thermal equilibrium the molecules move with equal probabilities both ways along this direction, as expected from the detailed balance principle, well-known in chemical reactivity and in the theory of molecular motors. Molecules that possess an asymmetric potential energy surface (PES) may perform as Brownian ratchets since under a
certain external field their preferential motion in a single direction can be realised. We propose a generic method based on the application of a time-periodic external field that would enable the molecules to move preferentially in a single direction. To illustrate this method, we consider a realistic synthetic chiral molecular walker, the 1,3-bis(imidazol-1-ylmethyl)-5(1-phenylethyl)benzene, diffusing on the anisotropic Cu(110) surface along the Cu rows. As unveiled by our kinetic Monte Carlo simulations based on the rates calculated using ab initio (electronic structure) density functional theory, that molecule moves to the nearest equivalent lattice site via the so-called inchworm mechanism in which it steps first with the rear and then with the front foot. As a result, these molecules diffuse in a two-step fashion, and due to their inherent asymmetry, the corresponding PES is also spatially asymmetric. Taking advantage of this fact, we show how the external field can be tuned to separate molecules of different chirality, orientation and conformation. These calculations are also supported by a simple analytical rate-equation model that will also be considered. The consequences of these findings for molecular machines and the separation of enantiomers will also be discussed.

**MULTI-SCALE EXPERIMENTAL ANALYSIS AND SIMULATION OF ELASTIC PROPERTIES OF RANDOM FIBRE POLYMER COMPOSITES**

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In this study multiscale analysis of random fibre composites with an average length of about 12 mm, 6 mm, 0.7 mm and 120 microns is done. One of the main characteristics of random fibre composites is fibre orientation distribution (FOD). FOD is of great importance because it defines materials microstructure and a number of mechanical properties of the entire material. The materials were scanned in a micro-computed tomography machine. Fine resolution of scans and high-performance computing resources are required, when FOD is calculated with identification of fibres as individual objects from micro-CT images. One of such high-fidelity methods consists of measurements of the elliptical parameters of fibres on a cross-section of a specimen and calculations of the orientation angles of individual fibres. However, there are global measurement methods to calculate FOD, the methods based on structure tensor analysis that defines local anisotropy of the material. Consequently, fibre orientation distributions from micro-CT scans are retrieved by two different methods: a high-fidelity method with identification of individual fibres and structure tensor analysis that is implemented in VoxTex software (KU Leuven). The high-fidelity method serves for validation of the global but fast structure tensor method.

Further, using the obtained FOD, finite element models of representative volume elements (RVE) for each type of the materials are created. With ABAQUS software, homogenized elastic properties of RVEs are predicted. Mechanical tests on Instron machines were carried out to obtain experimental data of elastic properties of the materials. These mechanical elastic properties are compared with the simulated RVE tests (tensile, compression and shear).

**MODIFICATION VARIABLES OF PROPAGATION OF THE ELASTIC-PLASTIC WAVES THROUGH THE MEDIA PRELIMINARY SUBJECTED TO EXPOSURE WITH THE WEAK MAGNETIC FIELD**

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Experimental study of features of propagation of the elastic-plastic wave performed. We initiated the waves by the intensive mechanical action and propagated them through the media preliminary exposed with the weak magnetic field. Such magnetic exposure alters as it is well known the quantum state of the dislocations and their motility. So it also affects macroscopic parameters of the media, for instance, the Hugoniot elastic limit.

We put the short-timed mechanical loading pulses under consideration in our study to make the hydrodynamic mechanism the prevailing one among the mechanisms of the wave attenuation. This mechanism lies in the fact that attenuation of the loading pulse is carried out by the discharge waves of elastic nature which velocity is higher than the velocity of the plastic waves. So it allows discharge wave to run after the plastic loading wave.

The process of reversion of parameters altered by the magnetic field to their initial values investigated. Outcomes of the study analysed from the point of view of their application as the base to develop the techniques the high-rated intensive mechanical processing of the materials.
DYNAMIC FRACTURE OF LINEAR ELASTIC OSCILLATOR CHAINS

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The work addresses dynamic fracture of discrete mechanical systems subjected to various static and dynamic loads. One-dimensional linear oscillator chains with arbitrary finite number of equal masses and springs is considered. The motion of this system is described by a system of second order differential equations which is solved analytically. Different initial and boundary conditions were studied including static loading with a subsequent load release and arbitrary dynamic load applied to the chain. Discreteness of the system resulted in fracture effects which are not observed in corresponding continuum models: even subcritical load parameters (initial deformation for the static preload case or pulse amplitude for the dynamic loading case) can cause the system failure. These effects were investigated both analytically and numerically. The studied effects can be accounted for when systems with essentially discrete structure are regarded such as composite multilayer materials or full-scale construction objects.

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF DYNAMIC FRACTURE OF PMMA SPECIMENS DUE TO IMPACT

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The work considers experimental and numerical investigation of dynamic fracture of PMMA (polymethyl methacrylate) plates due to impact. Steel cylinders served as projectiles which were accelerated using a gas gun facility. Both initial (Vi) and residual (Vr) velocities of the projectile were registered using magnetic coil device and high-speed photography. This way, Vr-Vi dependence and a ballistic limit could be experimentally established for the studied targets. The experimental tests were conducted for the PMMA specimens with three thicknesses: 4mm, 6mm and 10mm. The conducted experiments were then simulated using finite element method with a explicit time integration scheme. LS-DYNA software was used as a solver and incubation time model was applied as a fracture criterion. This model relies on the incubation time parameter – a material characteristic that can be experimentally assessed. The incubation time value for the PMMA is known from previous experimental works. Numerical simulations of the experiments revealed robustness of the developed numerical approach and the scheme was used in order to predict ballistic limit of a PMMA plate with the fourth thickness of 5mm.

EXPERIMENTAL ATTESTATION OF THE MODEL OF PLASTIC DEFORMATION AND FRACTURE OF SHEET METAL UNDER ITS FORMING AND SIMULATION OF SOME TECHNOLOGICAL PROCESSES

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The technique and results of experimental identification of the model of plastic deformation and fracture of anisotropic sheet steel in the processes of cold sheet forming are presented. The conditions of occurrence of defects in products caused by plastic strain localization and folding are discussed in terms of using the forming limit diagram. To formulate a mathematical model of cold sheet stamping of thin-walled products, an experimental technique is proposed to identify the constitutive equations of plastic flow and the criterion for the plastic failure of anisotropic sheet low-carbon steel. At room temperature, uniaxial tensile tests of samples in the form of strips with parallel edges cut from the sheet at angles of 0, 45 and 90° relative to the direction of rolling are carried out: a) with unloading to determine the modulus of elasticity, b) stretching up to 30% to determine the yield point, the strain hardening curve and the plastic anisotropy coefficient, and c) tensile to failure with a mesh applied to the sample to determine one point of the forming limit curve. On the basis of the data obtained, the parameters of the Berlat’s yield function Yld 2000-2d, the law of isotropic strain hardening and the point of the forming limit curve for each orientation of the tensile axis relative to the anisotropy axes were identified. The experimental data are best described by an isotropic hardening model when considering yield stress with a proof strain of 0.005%. A six-parameter approximation was proposed for the hardening curve with yield area. It is established that the coefficients of plastic anisotropy practically do not depend on the
deformation up to 30% elongation, at which the inhomogeneities of the working width of the sample increase by an order of magnitude. The forming limit curve is defined by the Marciniak – Kuczyński method which associates the limit state with a critical growth of strain localization under biaxial deforming of dual-zone sample. It was done with the aid of the experimentally attested plasticity model and the experimental data on the limit strains under uniaxial tension. Numerical calculation of the existing technological operations was performed in LS-DYNA package. Conditions for the occurrence of product defects were analyzed. New effective technological operations of drawing and bulging of a cup, stamping of a handle and forming of the panel with stiffeners are designed with the aid of numerical modeling in collaboration with Lysva Plant of Enameled Cookware and Lysva Plant of Household Appliances. The work is executed at support of RFBR grant No. 17-08-590310.

A BEAM - JUST A BEAM IN LINEAR PLANE BENDING

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We derive one-dimensional, static theories from the three-dimensional theory of linear elasticity by a power-law expansion of the displacements in non-dimensionalized width \( (\xi_2 = X_2 / \ell) \) and height \( (\xi_3 + X_3 / \ell) \) direction

\[
\begin{align*}
\mathbf{u}_i(\xi_1, \xi_2, \xi_3) &= \sum_{j=0}^{\infty} \sum_{m=0}^{\infty} a_{ij}^{m} \xi_2^j \xi_3^m.
\end{align*}
\]

(length of the beam \( \ell \), height \( h \), width \( b \); \( \xi_1 \): length direction). We compute the linearized strains, calculate the strain-energy density and obtain the strain energy per unit of length by integration with respect to the cross-sectional area. The potential of external forces is treated similarly. Application of the variational principle leads to a second order ODE system for the unknown coefficients \( a_{ij}^{m} \). We could show the following [1]

- the infinite ODE system is equivalent to the equations of linear elasticity
- if the cross-section is at least double symmetric, the material behaviour at least orthotropic and the loads are splitted in symmetric and antisymmetric sets, the one-dimensional problem decouples (also in the boundary conditions) into 4 sub problems:
  - tension/compression of a bar
  - torsion of a shaft
  - bending of a beam with respect to the \( \xi_3 \)-axis
  - bending of a beam with respect to the \( \xi_2 \)-axis.

Due to the integration with respect to the cross-sectional area, smallness parameters pop up as

\[
\begin{align*}
\mathbf{c}^2 &= \frac{h^2}{12 \ell^2}, \quad \mathbf{d}^2 = \frac{b^2}{12 \ell^2}; \quad \mathbf{e}^2 = \mathbf{c}^2 \quad \text{and/or} \quad \mathbf{d}^2,
\end{align*}
\]

and the elastic potential appears as power-law series in \( \mathbf{e}^2 \). If we truncate the elastic potential, e. g.,

\[
\Pi = \left[ ( ) e_o + ( ) e^2 + ( ) e^4 + O (e^6) \right]
\]

we can further show that [2]

- the error between the approximation of an \( N \)-th order theory considering all terms of the order \( e^{2N} \) and the exact solution is of order \( e^{2(N+1)} \).

Considering the plane bending sub-problem, we obtain the following results [3]:

- the zeroth-order approximation admits only rigid body translations and rotation
- the first-order approximation delivers exactly the Euler-Bernoulli beam theory (transverse displacement \( w \), bending stiffness \( EI \), transverse load \( Q \)), as

\[
\begin{align*}
\mathbf{E}^4 \mathbf{w}^IV &= \mathbf{q} \mathbf{\ell}^3 + O (\mathbf{e}^4),
\end{align*}
\]

with boundary conditions

\[
\begin{align*}
\mathbf{M} &= -\frac{\mathbf{E}^4}{\ell^4} \mathbf{w}^* + O (\mathbf{e}^4) = \mathbf{M}^* \quad \text{or} \quad \Psi = \Psi^*
\end{align*}
\]
The second-order approximation delivers a Timoshenko-type theory
\[
EIw^{IV} = \ell^3 \left( q - \frac{6}{5} (2 + \nu) c^2 \ell^2 q^{\nu} \right) + O(\varepsilon^6)
\]
with boundary conditions
\[
M = -EIw^{\nu} - \frac{6}{5} (2 + \nu) c^2 \ell^2 q + O(\varepsilon^6) = M^* \quad \text{or} \quad \psi = \psi^*,
\]
\[
Q = -EIw^{\nu} - \frac{6}{5} (2 + \nu) c^2 \ell^2 q^{\nu} + O(\varepsilon^6) = Q^* \quad \text{or} \quad w = w^*.
\]
where \( w \) and \( \psi \) are energetic averages in the Timoshenko/Reissner sense of the transverse displacement \( W \) and the slope \( \psi \), respectively.

The ODE (1) deviates from the Timoshenko theory
\[
EIw^{T} = \ell^3 \left( q - \frac{6}{5} (2 + 2\nu) c^2 q^{\nu} \right)
\]
only by a factor
\[
\frac{6}{5} c^2 \nu q^{\nu},
\]
which is due to the influence of the transverse normal stress \( \sigma_{33} \), which is neglected a priori in the Timoshenko theory.


**THE MODEL OF THE DOME TO ELIMINATE DEEP-SEA LEAKS**

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Due to the increase in deep-sea mining of hydrocarbon deposits in the oceans increases the probability of oil spills. The good examples of such spills are Ixtoc-1 and Deepwater Horizon platforms in the Gulf of Mexico. They showed the unpreparedness of modern methods for obtaining emergency underwater leakage. In this regard, there is a need to study the submerged jets, taking into account the mechanisms of hydrate formation, which is typical for large depths. To describe the flow of the jet is used the integral Lagrangian method of control volume.

To eliminate leaks, it is proposed to use a special dome-separator device. The dome is fixed above the leak and accumulates inside the hydrocarbons, which are pumped through the tubes into the tanker. This method eliminates leakage and collects hydrocarbons for future use.

The study of submerged jets will allow to obtain the distribution of thermal parameters of the jet from the vertical coordinate. These dependencies will allow to simulate the accumulation of hydrocarbons in the dome. The paper
considers the flow of submerged jet taking into account the salinity of the surrounding water, the dissociation of bubbles, the interaction of bubbles and oil droplets, the process of hydrate formation. The flow of the surrounding water has a great influence on the jet. Under the action of the flow, the jet may deviate, its flow pattern may change. The paper supplemented the integral Lagrangian method of control volume, the results were compared with experimental data. The reported study was funded by RFBR according to the research project № 18-31-00264.

**MODELING THE EVOLUTION OF A GRAVITATING BODIES CLUSTER BASED ON ABSOLUTELY INELASTIC COLLISIONS**

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Numerical simulation of evolution of a cluster of a finite number of gravitating bodies has been accomplished in the scope of classical mechanics taking into account accretion. The goal of the study was to reveal the basic characteristic phases of the intra-cluster distribution of material bodies. In solving the problem, the possibility of interbody collisions was taken into account. The collisions were assumed to be absolutely inelastic. Non-gravitational forces external with respect to the body cluster in question were ignored. Among all the internal force factors acting within the cluster, only the gravitational interaction was taken into account. To check the process of solution, the so-called "rotation curve" was used which presents a current radial distribution of orbital velocities of the cluster bodies. The Cauchy problem was considered. The issues of defining natural initial characteristics of the cluster bodies were touched upon. Conditions for commencement of rotation of gravitating bodies comprising the cluster about their common instantaneous center of mass were investigated. The numerical analysis showed that the characteristic shape of the "rotation curves" of stars of some galaxies depends only on the current configuration of the material body orbits. The "rotation curve" plateau characterizes the current redistribution phase of the intra-cluster matter. This means that invariance of radial distribution of star linear velocities in some of the observed clusters can be explained without considering the hypothesis of the "non-material gravitating dark matter" or modifying the classical Newton's Law on gravitational interaction between two material bodies.

**HIGH-FREQUENCY DIFFRACTION BY A CONTOUR WITH A JUMP OF CURVATURE**

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We address a long-standing problem of high-frequency diffraction of a plane wave by a contour having a jump of curvature, aiming at explicit construction of asymptotic formulas. Parameterizing the contour C by its arc length s measured from the point of jump O, we describe the curvature κ as follows:

\[κ(s) = g(s) + hH(s).\]

Here, g is a smooth function, h is the magnitude of jump, H is the Heaviside function: \(H(s) = \{1, s \geq 0; 0, s < 0\} \). Incident plane wave \(u^i\) is non-tangent and the Dirichlet boundary condition holds. Thus, the outgoing wave \(u^o\) satisfies the following problem:

\[\left(\Delta + k^2\right)u^o = 0, \left(u^o + u^i\right)|_s = 0,\]

with the large wavenumber \(k \to \infty\). According to Keller’s geometrical theory of diffraction [1], the outgoing wavefield at the illuminated region is given by a sum of geometrically reflected \(u^r\) and diffracted \(u^d\) waves:

\[u^o = u^r + u^d,\]

where the diffracted wave is a cylindrical wave with a certain pattern. In transition zone, that is in a specific neighborhood of the geometrically reflected from the point O ray, diffracted and reflected waves merge and the wavefield must be described by some special function. In contrast to earlier research (see, e.g., [2-5]) based on Kirchhoff’s method, we apply a rigorous version of the boundary layer approach, introducing in the vicinity of O stretched coordinates. In addition to description of the diffracted wave \(u^d\), we describe the wavefield in the transition zone in terms of the parabolic cylinder function \(D_{-3},\) which did not previously occur in the diffraction theory. We develop techniques applicable to several related problems such as diffraction by a contour with a Hölder discontinuity of curvature.

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FIBER-FREE ZONES AND THEIR IRREGULARITY IN STRUCTURALLY STITCHED NCF PREFORMS

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Combining different plies in one preform, through-the-thickness stitching is known as an effective way to reduce the lay-up time for textile or fibrous plies. Also, if the stitching is structural, i.e. produced using a relatively thick and firm yarn and thus forms a transversal reinforcement, a considerable improvement can be achieved in the interlaminar fracture toughness, in-plane shear, and out-of-plane strength.

However, stitching has some inherent properties, which are not favorable with respect to the processability and in-plane mechanical performance. One of these disadvantages is an uneven fibre distribution in the plies caused by the needle movement and tight stitching loops. As a result, the final structure has numerous fiber-free (called “openings” here) and fiber-rich zones in the plies, which affect the deformability of the preform, alter the resin infiltration, and increase stress concentrations.

The present study addresses the internal geometry (fibre-free zones) in fibrous plies in structurally stitched multilayer carbon-fibre preforms. Each layer is a multiaxial multiply non-crimp fabric (NCF) with a non-structural stitching. Two stitching methods are studied experimentally: sewing and tufting techniques with multifilament yarns, aramide (60 or 120 tex) or glass (204 tex), with square stitching patterns of 3×3, 5×5, and 7×7 mm. Experimental data (mean values, scatter,...) of the “openings” are presented and discussed for 12 stitching cases (2 yarns, 3 patterns, before or after RTM). The following is concluded (L and W are for the length and width of the “openings”):

- deviation of fibres from the initial global orientation can be considerable due to structural stitching;
- ratio L_{RTM}/L is higher in the surface plies, i.e. RTM reduces length of the “openings” in the surface plies in a lesser extent than in the inner plies;
- in contrast, ratio W_{RTM}/W is lower in the surface plies, i.e. RTM reduces width of the “openings” in the surface plies in a larger extend than in the inner plies;
- probably the transversal compression and deformation of the yarn loop is responsible for higher W_{RTM}/W ratios in the inner plies. In the same time this yarn deformation naturally has a much lower effect on L_{RTM}/L ratios;
- openings located in the surface plies are wider than the inner openings, and this observation of the surface provides an easy conservative criterion for a non-destructive evaluation.

In general, the meso-level geometrical characterization provides important input data for modelling of the permeability and mechanical properties of the preforms. This study is part of a broader effort to develop analysis methods and simulation tools for textile preformed composites, as well as to build up a physical understanding of their behaviour and hence to increase their usage.

ATOMISTIC SIMULATIONS OF PHASE AND STRUCTURE TRANSITIONS IN U-MO ALLOY

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Uranium is the main component of nuclear fuel. Due to high values of thermal conductivity and density, a metal nuclear fuel based on uranium alloys is the promising fuel for generation IV reactors. In addition, U-Mo fuel has high thermal conductivity, low thermal expansion, and high melting point.

Pure uranium has three different allotropes: a low-temperature orthorhombic α-U, a high-temperature body-centered cubic (bcc) γ-U, and an intermediate tetragonal β-U observed in a very small interval of pressures and temperatures. Among these phases, the γ-phase has the best technical properties for nuclear engineering due to cubic symmetry. The investigation of the structure details can provide the key to understanding several unusual peculiarities that are observed for γ-phase of pure U and γ-like phases of uranium alloys: anisotropy of lattice at low temperature; remarkably high self-diffusion mobility in γ-phase; decreasing of electrical resistivity at heating for some alloys.

The structure of U-Mo alloy γ-phase is similar to body-centered tetragonal (bct) lattice with a displacement of central...
atom at basic cell into [001] direction. Such displacements have opposite orientations for part of the neighbouring basic cells. In this case, such ordering of the displacements can be designated as antiferro displacement. Formation of such complex structure may be interpreted through forming of short U-U bonds. At heating, the tetragonal structure transforms into cubic $\gamma$-phase, still showing ordering of central atom displacements. With rise in temperature, $\gamma$-phase transforms to $\gamma$-phase with a quasi body-centered cubic (q-bcc) lattice. The local positions of uranium atoms in $\gamma$-phase correspond to $\gamma$-phase, however, orientations of the central atom displacements become disordered. Transition $\gamma \rightarrow \gamma$ can be considered as antiferro-to paraelastic transition of order-disorder type. The work is supported by the Basic Research Program of the Presidium RAS “Condensed matter and plasma at high energy densities” (coordinated by Fortov V.E.).

SYSTEM-LEVEL MODELLING OF MEMS ACCELEROMETER NONLINEAR DYNAMICS

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In this article the dynamics of single-mass micro-vibratory accelerometer is being investigated with the respect to: elastic suspension’s anisotropy and significant nonlinearity of ponderomotive forces. Computational model for this accelerometer is being deployed combining control scheme with its physical properties. The control scheme is built via MatLab Simulink. Physics of the system is being solved via finite element methods with the results of it being extrapolated for different states. An analytical model is built and solved utilizing asymptotic methods of nonlinear mechanics and numerical parameter continuation. Dynamic characteristics are obtained. The method of Reduced Order Modeling is being used to simulate nonlinear dynamical models of accelerometer. Comparison of analytical and numerical solutions is performed in order to verify applicability of considered modeling methods. Both analytical and numerical solutions are a subject to experimental verification. Built models give an opportunity for a fast MEMS designing and testing consuming a little to nothing of computational and human resources.

ABOUT OF THE METHOD OF DECREASE RAIL TRANSPORT IMPACT NOISE IN LOW FREQUENCY RANGE

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The application of railway wheel noise compensation method is considered. The system of standing waves in the interval d by an antiphase pair of sources with coherent components in the basic frequency 31.5 Hz and odd harmonics is formed. It takes away some energy from the general energy radiating by shock fluctuation running waves. The spectrum of such noise reaches a maximum in an octave strip of 31.5 Hz and sharply decreases approximately on 50 dB in a strip of 8000 Hz. The method of decrease impact noise between of wheel pairs rail transport and rails joint being main sources of noise is analyzed. The practical implementation dipole effect can be received by formation a non coherent pair of the knock impulse sources when the direction of acoustical axes is along the railway under small (15…20) angle. The compensatory effect when one rail joint for example right moves according left joint in other rail on the distance d having half of wave length of the basic low-frequency tone of shock impulses is reached. This effect providing antiphase shift between sources of noise is registered. The new additional effect of noise reduction by replacement the rectangular rail joint edges on the oblique-angled rail joints is carried out. The spectrograms considerably differed from rectangular edges in rail joints and oblique-angled in rail joints in low frequency band are analyzed. As the result the moving of sound pressure extreme value of the basic tone of shock impulses 31.5 Hz from low-frequency range to mid-frequency in spectrograms is reached. The compensation effect with the sound level meter installed on the distance 1 m from rail joints in marine cargo port was investigated. Only half of sound wave length on the distance d between sources the best railway noise compensation effect is confirmed. The distance d is depending on the speed of train and promotes the correlation interconnection between excited acoustical pulses. The intensity wheel knock spectrograms corresponding of different distance between rail joints registered by the microphone are estimated. The result of practical using the acoustic noise compensation method is proved.
Carbon Fiber Reinforced Plastic (CFRP) composite materials have an enormous potential of application in high-loaded structure elements. The most beneficial applications are connected with aerospace and aircraft structures, where perfect weight/strength ratio of CFRP is of an important demand. Lightweight designs of advanced load-bearing composite aircraft and aerospace structures are based, as a rule, on the unidirectional CFRP composite elements, which can provide the possibility to use high potential of the carbon fibers. Development and design of lattice aircraft structures, based on unidirectional CFRP elements (ribs), is a quite specific complex task, due to complicated local stress-strain state of resin in cross-sections of ribs, that has significant influence of global strength characteristics of the lattice structure.

Consequently, there is a high necessity of building up fast and reliable methods of numerical modeling, capable of carrying out complex strength analysis of the novel lattice structure layouts. Such methods should provide good balance between high speed of calculations and the accuracy of the results.

A fast method of building special parametric “box” finite element (FE) model for strength analysis of lattice composite structures was proposed in the present work. The main idea of the method is that a composite unidirectional rib is modeled by a spatial box structure, consisting of flanges and webs modeled by means of 2D membrane FE. The obtained FE model utilizes common 2D membrane finite elements, that provide fast detailed analysis of local stress-strain state of ribs. The properties of the FE model (thicknesses of webs and flanges, FE material properties) are calculated automatically from the condition of equality of stiffness characteristics of the box model and the real structure element. At that, the number of flanges and webs are parameters, defining how detailed the model is.

Based on the method, an automated algorithm of building “box” FE model for cylindrical fuselage barrels was built. In frames of the algorithm there is a capability of solving global and local strength tasks both for the whole lattice fuselage structure and separate ribs, using standard commercial FE solvers.

The numerical investigations, carried out using the algorithm have shown that the proposed modeling method gives not less than 40% time saving as compared with detailed 3D FE analysis, keeping high accuracy of both global and local strength analyses (error do not exceed 5%).

In this work, the results of validation of the method are presented. The validation investigations included both numerical and experimental investigations, carried out in TsAGI within the frames of a number of domestic research projects and European Framework projects FP7 ALaSCA and FP7 PoLaRBEAR . The experimental results were obtained on the full-scale lattice composite fuselage barrel, having 6m length and 4m diameter, tested at the special test facility, built in TsAGI for experimental investigations of lattice composite fuselage barrels.

The problem of improving the methodology and tools for measuring the rheological properties of physiological fluids is associated with the need to improve the accuracy and speed of measuring devices, as well as expand their functionality by collecting and analyzing a large amount of experimental data, identifying structures and significant patterns in them. The solution of the problem is part of a set of measures to solve the larger problem of diagnosing and treating socially significant diseases, the presence of which can be determined by changing the properties of physiological fluids. The main contradiction of the problem being solved is due to the fact that the overwhelming majority of methods for quantitative determination of rheological properties implemented in industrially produced devices require a priori knowledge of the type of rheological model of the test liquid. The goal of this study is partial or complete resolution of the contradiction. As the main approach of mathematical modeling of the movement of physiological fluids, continuum mechanics is used. More precisely, the momentless mechanics of continuous media, in which the stress, strain, and strain rate tensors are symmetric, and the properties of an isotropic medium are characterized by elastic and viscous state functions, including the dynamic viscosity coefficient. To take into account non-Newtonian properties, these quantities are considered as functions of the intensity of shear deformations, the intensity of shear deformation rates, pressure and temperature. This method of modeling non-Newtonian environments is one of two classic ways in rheology. The experimental part of the study is related to the measurement of the motion characteristics of the hard torus and the non-Newtonian fluid that fills it in real time. The geometrical parameters of the installation and the experimental regime will ensure uniformity of the fields of shear deformations and shear rates of deformations on the
The work presents an analysis of propagation of plane shock waves in graphene and boron nitride in both zigzag and armchair directions. It is known that existence of quasi-one dimensional crowdions in this structure cannot be realized due to the rigidity of covalent interatomic bonding and intensive Cherenkov radiation. However, one can consider the transfer of energy in such systems in the form of plane waves. Shock waves in graphene and boron nitride were induced by initial energy impact exceeding some critical value $E_0$. The establishment of the wave mode occurs roughly after 0.5 ps after the wave initiation moment. It was shown that stable plane solitary wave can exist in both zigzag and armchair directions. In all cases the velocity of the soliton was found out to be much higher than the sound velocity of the material. The analysis of the plot of soliton energy as a function of soliton velocity have shown a good coincidence for zigzag and armchair directions for the case of boron nitride while for graphene the propagation along armchair direction is characterized by higher energies for the same velocity values.

Analysis of the soliton energy radiation as a function of time revealed that the greatest stability is demonstrated by the energy of a soliton moving in a boron nitride in the zigzag direction. Features of shock waves propagation in different directions and reasons for their differences are discussed.

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propagation in the damped-driven, granular lattice mounted on a linear elastic foundation which assumes the general type of strongly nonlinear, inter-site potential and subject to an external harmonic forcing in the form of a traveling wave. To the best of authors knowledge this is the first theoretical study which addresses the damped-driven response of the granular lattice mounted on elastic foundation and is given to the special type of resonant external loading in the form of a traveling wave. Assuming the limit of small amplitude excitation and using the regular multi-scale analysis, we derive the discrete, damped-driven p-Schrödinger equation. In the first part of the talk we will focus on the analysis of slowly evolving, moving breather solutions forming in the non-driven - dissipative chain. Then in the second part of the talk we will present the analysis of non-linear wave solutions i.e. flat solutions as well as spatially localized (discrete breather) solutions emerging in the damped-driven granular lattice. This work was supported by Russian Foundation for Basic Research according to the research project no. 18-03-00716.

THE INTERACTION BETWEEN COAXIAL CIRCULAR PRISMATIC DISLOCATION LOOPS IN AN ELASTIC SPHERE

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Dislocation loops are typical elements of solids, which play a significant role in the physics and micromechanics of crystalline materials [1]. 3D theoretical modeling of structure and mechanical behavior of real solids requires the knowledge their elastic fields and strain energies. In particular, the elastic behavior of prismatic dislocation loops is of special interest in many cases. For instance, nowadays there are a number of strict analytical solutions describing the stress state caused by circular prismatic dislocation loops (CPDL) in solids with spherical boundaries [2-4]. In paper [4], the CPDL stress components are presented in the most appropriate form in terms of Legendre polynomials series for the following three types of such solids: an elastic sphere, an infinite elastic medium with a spherical pore, and an elastic spherical layer. The corresponding solutions have been applied for analyzing the initial stages of stress relaxation processes through the formation of CPDLs in bulk [5] and hollow [6] core-shell nanoparticles, in icosahedral [7] and decahedral [8] small particles. These theoretical models give results which are in good agreement with experimental data [9]. However, the aforementioned models dealt with individual CPDLs only. Meanwhile, in many real cases a number of similar CPDLs can nucleate and develop in tight interaction with each other, which requires the development of suitable mathematical means for studying these situations. One of such means is the energy of pair interactions between CPDLs. In the present work, we consider the pair interaction of coaxial CPDLs arbitrary placed in an elastic sphere. Using the strict solution of the boundary-value problem for a CPDL in an elastic sphere [4], we find an analytical form for the interaction energy and illustrate this result by energy maps built in the space of the radii and the axial positions of CPDLs. Our results will be used for analysing the theoretical models of stress relaxation processes in core-shell nanoparticles and pentagonal particles, which occur through the formation of dislocation ensembles.

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References
Icosahedral nanoparticles (IcNPs) are characterized by high residual stresses caused by the existence of fifth-order symmetry axes [1], which can relax by the formation of various defects, such as dislocations and disclinations, pores, gaps, misfit of crystal lattice, whiskers growing on the surface, etc. [2-6]. Of the greatest interest are the initial stages of the relaxation occurring through the formation of single defects, in particular, circular prismatic dislocation loops (PDLs).

A theoretical model is presented which describes the relaxation of residual stresses in IcNPs by generation of an individual PDL in both homogeneous and composite core-shell IcNPs. Within the model, the stress state in single-crystalline IcNPs is described by the Marks-Ioffe continual model of a distributed stereo-disclination [7]. In the case of a core-shell IcNP, the misfit stresses caused by the lattice mismatch of the core and shell materials are taken into consideration as well. It is shown that the nucleation of circular PDLs becomes an effective channel for the residual stress relaxation in both the homogeneous and composite IcNPs when the sizes of the latter reach certain values which depend on material properties. By varying such material parameters as the energy of the dislocation core and the Poisson ratio, it is possible to achieve both greater stability and higher flexibility of IcNPs with respect to the nucleation of PDLs. It is also shown that the optimal radius of the PDL depends on the IcNP size. Formation of PDLs in relatively large core-shell IcNPs is generally more likely in the case when the ratio of the core and shell radii is about 0.6. The results are also compared with those for decahedral and single-crystalline core-shell nanoparticles.

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References

WAVE AND DIFFUSIVE HEAT PROCESSES IN ULTRAPURE MATERIALS

Various types of heat transfer in crystalline defect-free materials are analyzed. Explicit formulae and equations for ballistic heat transfer are obtained on the bases of the exact solution for the lattice dynamics equations. Influence of the atomic interaction laws and peculiarities of the crystalline structure on the heat processes are analyzed. Analogy with ballistic mass transfer in rarified gases is demonstrated. Transfer to the diffusive heat propagation initiated by microbreaks of the crystalline structures is described. Application of the presented methods to description of the stochastic wave processes at different scale levels is discussed.

THE FIRST INTEGRALS AND THE GENERAL SOLUTION FOR EQUATION OF SURFACE WAVES IN A CONVECTING FLUID

A method for finding exact solutions and the first integrals is presented. The basic idea of the method is to use the value of the Fuchs index that appears in the Painlevé test to construct the auxiliary equation for finding the first integrals and exact solutions of nonlinear differential equations. It allows us to obtain the first integrals and new exact solutions of
some nonlinear ordinary differential equations. The main feature of the method is that we do not assign a solution function at the beginning, we find this function during calculations. This approach is conceptually equivalent to the third step of the Painlevé test and sometimes allows us to change this step. Our approach generalizes a number of other methods for finding exact solutions of nonlinear differential equations. We demonstrate a method for finding the traveling wave solutions and the first integrals of the well-known nonlinear evolution equation for description of surface waves in a convecting liquid. The general solution of this equation at some conditions on parameters and new traveling wave solutions of the fourth-order equation are found.

THE BRITTLE FRACTURE OF SOLIDS IS AN ANALOGUE OF A FIRST-ORDER PHASE TRANSITION

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A microscopic approach to the problem of the initial stages of destruction of brittle solids is described. It is shown that in the process of elastic stretching of a solid brittle body, an ensemble of vacancies is formed in it [1]. It has been proven that, under certain conditions, a vacancy ensemble can begin the process of condensation of vacancies into pores. Based on thermodynamic analysis, it was shown that the process of condensation of vacancies is a first-order phase transition. In this case, the dimensionless quantity \( \sigma/\kappa_B T \) in which \( \sigma \) is the normal component of the stress tensor in a solid, \( \kappa_B \) is the Boltzmann constant, \( T \) is the temperature, plays the role of the driving force of the pore condensation process and is analogous to the supersaturation during first-order phase transition. The formula for the critical pore size is derived, which essentially generalizes the classical Griffith formula for the critical crack size. The system of equations describing the nucleation and further evolution of micropores up to their coalescence with the formation of a crack has been derived and solved. As a result of solving this system, the size distribution functions of micropores are calculated, the rate of micropore nucleation and their critical size are calculated. The time dependences of the rate of accumulation of micro damages in solid brittle bodies under stress are established. The effect of temperature on micropore nucleation was studied. The criterion of accumulation of Zhurkov’s damageability is essentially generalized. A strict physical explanation is given to Zhurkov’s durability formula. A new energy criterion for the onset of fracture of brittle materials has been derived. A microscopic reason for the difference in the nature of the destruction of solids when exposed to shock and stationary loads is identified. The mechanisms of pore formation in an optical fiber when the fiber is irradiated with UV light from pulsed and CW lasers are studied experimentally and theoretically [2]. The heating temperature of the core of the germanium-doped fiber is determined. Thermal mechanical stresses arising in the fiber during its irradiation are calculated. The theory of the nucleation of pores and cracks in the fiber under the action of high-power laser pulses was constructed. The pore size distribution function, the pore nucleation rate, the pore growth rate, and the dependence of the pore density on the laser pulse exposure time are calculated. A new mechanism is proposed for the formation of refractive index gratings (Bragg gratings of type IIA) in a fiber when the fiber is irradiated with UV light from a high-power pulsed laser.

References

UNSTEADY BALLISTIC HEAT TRANSPORT IN HARMONIC CRYSTALS WITH POLYATOMIC UNIT CELL

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We study thermal processes in infinite harmonic crystals having a unit cell with arbitrary number of particles. Initially particles have zero displacements and random velocities, corresponding to some initial temperature profile. Our main goal is to calculate spatial distribution of kinetic temperatures, corresponding to degrees of freedom of the unit cell, at any moment in time. An approximate expression for the temperatures is derived from solution of lattice dynamics equations. It is shown that the temperatures are represented as a sum of two terms. The first term describes high-frequency oscillations of the temperatures caused by local transition to thermal equilibrium at short times. The second term describes slow changes of the temperature profile caused by ballistic heat transport. It is shown, in particular, that local values of temperatures, corresponding to degrees of freedom of the unit cell, are generally different even if their
initial values are equal. Analytical findings are supported by results of numerical solution of lattice dynamics equations for diatomic chain and graphene lattice. Presented theory may serve for description of unsteady ballistic heat transport in real crystals with low concentration of defects.

ASYMPTOTIC RESPONSE OF SYSTEMS AND MATERIALS WITH HYSTERESIS

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Hysteresis is a pervasive phenomenon which appears in a wide array of mechanical problems [1]. In this talk, dynamic systems with hysteresis across different material scales will be discussed including vibration absorbers [2,3] and carbon nanotube nanocomposite materials [4-5]. A model of hysteresis for carbon nanotube/polymer nanocomposite materials is discussed and implemented in the context of nonlinear nanocomposite beams subject to resonant excitations [6]. The focus of the talk is on the asymptotic treatment of the equations of motion to unfold the nonlinear dynamic behavior and bifurcations of these systems.

References

FEATURES OF DYNAMIC TESTING OF BRITTLE MEDIA

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Brittle media – concretes, rocks and bricks belong to a class of materials whose response under dynamic loading is actively studied. A tool to study the behavior of such materials at strain rates of 102-103 s-1 is the Kolsky method and some of its modifications. The use of these techniques is possible at observance of certain prerequisites and assumptions, the key of which is the uniformity of the stress-strain state of the sample and the absence of dispersion in the propagation of waves along the measuring bars. Otherwise, the dynamic strength of the materials may be incorrectly estimated. The presented report provides an analysis of the phenomena occurring in the process of testing brittle media using the classical Kolsky method. The study was conducted on the example of fine-grained concrete, class for the strength under the axial compression B22.5. The experiments were carried out with the use of a loading pulse shaper - a copper tablet placed on the impact end of the loading bar, and without it. The processing of experimental data was performed using the dispersion shift procedure of pulses in measuring bars, which is based on the direct solution of the Pochamer-Cree frequency equation and without its application. Based on the comparison of experimental results, the discrepancy between the obtained strength properties of fine-grained concrete when using a pulse shaper, the dispersion shift procedure and without the use of these tools is estimated.

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OVERALL ELASTIC PROPERTIES OF COMPOSITES WITH COALESCING CYLINDRICAL CAVITIES

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We recently studied the temperature and heat flux distributions around two nonconductive (separate or intersecting) circular holes in a plane system [1]. The obtained results have been used to construct the second-rank resistivity contribution tensor, which allows assessing the effective thermal properties of a composite including circular inhomogeneities.

In the present work, that study is extended to assess the overall elastic properties of an isotropic elastic matrix with two separate circular cavities or a cavity obtained by two overlapped circular holes of generally different diameters. A bipolar cylindrical coordinate system is employed for the description of the problem [2]. A Fourier series expansion of the Airy stress function is performed for separate holes, whereas Fourier transform are employed for overlapped holes. Once the displacement field \( \mathbf{u} \) has been calculated, the extra strain \( \Delta \varepsilon \) due to the inhomogeneity is assessed according to

\[
\Delta \varepsilon = \frac{1}{2V} \int_{\partial V} \left( \mathbf{u} n + \nu \mathbf{u} \right) dS,
\]

being \( n \) the normal vector and \( V \) the volume reference. Finally, the extra strain is used to work out the fourth-rank compliance contribution tensor varying the size of the circular holes.

References

CALCULATION OF THE NORMAL AND SHEAR COMPLIANCES OF A THREE-DIMENSIONAL CRACK TAKING INTO ACCOUNT CONTACT BETWEEN THE CRACK SURFACES

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The calculation of effective mechanical properties of materials with cracks is a long-standing problem in micromechanics. Usually each crack is modeled by a mathematical cut with traction free surfaces. In this case, the normal and shear compliances of crack are approximately equal. Then the effective elastic properties of the material with randomly located and arbitrary oriented cracks are orthotropic. If partial contact between crack surfaces is taken into account, then normal and shear compliances are generally different, and the effective properties are no longer orthotropic. This work proposes a three-dimensional model for estimation of the effect of contacts on the normal and shear compliances of the crack. An infinite flat crack is considered. Surfaces of the crack are connected by a doubly periodic system of identical contacts. Each contact has the shape of a rectangular parallelepiped. The centers of the contacts form a square lattice. The influence of contact sizes and distance between contacts on ratio of the normal and shear compliances of the crack is investigated. The compliances are calculated numerically using the finite element method. Calculations are carried out for a periodic cell containing a single contact. It is shown that in all considered cases, the normal compliance of the crack is less than shear compliance. Difference between the compliances increases with increasing contact height. A comparison with similar results obtained in a two-dimensional formulation is carried out. It is shown that in two dimensional case the ratio of compliances is larger than in three-dimensional case.
CLUSTER RECOMBINATION METHOD AS A WAY TO ACCELERATE
THE GRAVITY SYSTEMS’ CALCULATIONS

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It is difficult to imagine modern mechanics without methods of molecular dynamics – since continuum theories require a large number of assumptions. Also in some areas it is too tricky to use them. One such area – simulation of cosmological systems’ formation. One of the leading theories about the formation of the solar system states that there was a protoplanetary disk – the system of particles with big density. Continuum theories work good on this stage because the distribution can be considered continuous. But during the planetary formation the distribution become more and more heterogeneous.

The weak point of molecular dynamics theory is the need of using very powerful special computers to complete the calculation of the system containing a large number of particles in an short time. Therefore, development is underway to reduce the complexity of this task. This problem is partially solved by using of the hierarchical methods, but they do not work properly at the final stages of calculation – when the heterogeneity of the particle distribution becomes extremely significant.

My work is aimed to develop a method of reducing the number of particles in clusters while maintaining physical properties and behavior. It works because cluster (planet) is a very localized particle system, so it does not matter how much particles it contains.

The algorithm includes following steps:
1) Approximation of the cluster by ellipsoid;
2) Filling-in the ellipsoid by new particles;
3) Adjust the potential of short-range interactions and set the initial velocity to preserve maintaining physical properties and behavior.

NANOPARTICLE MASS DETECTION USING SUSPENDED MICROCHANNEL RESONATOR WITH ACCOUNT FOR INTERNAL FLUID FLOW

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In this paper, we construct and study a mathematical model of a suspended microchannel resonator (SMR) resonator with an electrostatic principle of actuation, designed to determine the mass of nanoparticles located in the fluid flowing through the channel of the resonator. The problem of small oscillations of a resonator in the vicinity of a non-trivial equilibrium state is investigated. The dependence of the natural frequencies of the resonator on the flow rate of the liquid, the magnitude and location of the nanoparticle in the channel, the strength of the electric field is determined. The problem of elastic stability of a resonator is investigated in the presence of non-conservative forces. An algorithm is proposed for determining the mass of a nanoparticle from the recorded changes in the spectral properties of the system.

The creation of analytical systems for the study of biological objects in their natural state is one of the rapidly developing areas of nano application - and microsystem technology. The key elements of alike systems are microfluidic devices used for manipulations of micro- and nanoobjects in canals with liquid. The development of microfluidics has led to the appearance of devices where the reproducible control of nano- and picoliter volumes of liquid is carried out. One of the important functions of microfluidic chips is the determination of nano- and microparticles mass. Suspended microchannel resonators (SMR) can be used to achieve this goal. It performs elastic oscillations under controlled external excitation.

We have constructed and studied a mathematical model of a beam (SMR) with an electrostatic principle of excitation of oscillations. It is designed to determine the mass of nanoparticles moving in the stream of liquid flowing through the resonator channel.

The nonlinear equations oscillations of the resonator were derived, taking into account the following: its distributed elasticity; the presence of Coriolis and centrifugal forces acting on the resonator from the flowing liquid; the concentrated inertial load from the nanoparticle as well as the ponderomotive forces of the electrostatic actuator. Both methods of modal discretization of nonlinear distributed systems and numerical methods of bifurcation theory are used for qualitative study of the problems of dynamics and stability of the considered coupled electro - hydroelastic system. The problem with small oscillations of the resonator in the vicinity of a nontrivial equilibrium position was investigated. The dependence of the resonator eigenfrequencies on the fluid flow rate, the size and location of the nanoparticle in the
channel, the electric field force was determined. The problem of elastic stability of the resonator in the presence of nonconservative forces was inspected. An algorithm for determining the mass of a nanoparticle from the recorded changes in the spectral properties of the system was proposed.

**DESIGN AND SIMULATION OF AN ACOUSTIC METAMATERIAL PLATE INCORPORATING TUNABLE SHAPE MEMORY CANTILEVER ABSORBERS**

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Metamaterials are materials having artificially tailored internal structure and unusual physical and mechanical properties. Due to their unique characteristics, metamaterials possess great potential in engineering applications. This study proposes a tunable metamaterials for the applications in vibration or acoustic isolation. For the state-of-the-art structural configurations in metamaterials, the geometry and mass distribution of the crafted internal structure is employed to induce the local resonance inside the material. Therefore, a stopband in the dispersion curve can be created because of the energy gap. For the conventional metamaterials, the stopband is fixed and unable to be adjusted in real-time once the design is completed. Although the metamaterial with distributed resonance characteristics has been proposed in the literature to extend its working stopband, the efficacy is usually compromised. In this study, the incorporation of tunable shape memory materials (SMM) via phase transformation into the metplate structure is proposed. Its theoretical finite element formulation for determining the dynamic characteristics is established. The effect of the configuration of the SMM cantilever absorber in the metplate for the desired stopband in wave propagation is simulated by using finite element model. The result demonstrates the tunable capability on the stopband of the metplate under different activation controls of the SMM absorbers. The result of this study should be beneficial to precision machinery and defense industries which have desperate need in vibration and noise isolation.

**THERMODYNAMIC DISLOCATION THEORY**

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This paper proposes the thermodynamic dislocation theory (TDT) for nonuniform plastic deformations, which takes into account the redundant and excess dislocations and the effective disorder temperature. With a small set of physical parameters, which we expect to be approximately independent of strain rate and temperature, we are able to simulate the stress-strain curves for single crystals and polycrystals, which are subjected to simple shear, tensile/compression and torsion tests over a wide temperature and strain rate range. We are developing large-scale least squares analysis to identify material parameters from experimental stress-strain curves. We show the size and Bauschinger effects of accumulating excessive dislocations, and the sensitivity of stress-strain curves to strain rate and temperature due to redundant dislocations. Finally, we extend the theory to finite deformations and apply it to the finite strain constrained shear of single crystals.

**VISCOMETRIC FLOW OF A CYLINDRICAL LAYER MATERIAL UNDER THE CONDITIONS OF ONE-SIDED MATERIAL SLIPPING AND THE ROTATION OF THE EXTERNAL BOUNDARY SURFACE**

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In the modelling of the technological processes of material treatment because of slow regime of creep (e.g. cold forming) [1], it is necessary to take into account the consecutive accumulation of large irreversible creep and plastic strains [2].

In the framework of the theory of large strains [2, 3], a boundary value problem on the deformation of the cylindrical layer of an incompressible elastoviscoplastic material is solved. The material is deformed under the rotation of the external cylinder with sequentially increasing, constant, decreasing and zero velocity. The contact between the material and boundary surfaces is initially carried out in the adhesion conditions. From the very beginning of the deformation process, irreversible strains accumulate due to the slow creep process. We assume that an increase in stresses in the medium leads to the development of plastic flow and material slipping in the neighborhood of the internal cylindrical surface.
The equations of the constructed mathematical model describing the change of the stress-strain state in the medium are numerically solved with the help of Scilab software. The work was partially supported by the Grant of the Russian Foundation for Basic Research (№18-01-00038).

References:

THE INFLUENCE OF NONLINEAR ELASTICITY OF A BASEMENT ON LOCALIZED WAVES PROPAGATING IN TIMOSHENKO BEAM

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In modeling the processes of interaction between vehicles and elastic guides, problems of bending oscillations of a beam are often considered, taking into account shear deformations and inertia of rotation of the cross section (Timoshenko’s model) lying on an elastic foundation. The movement of modern high-speed trains is accompanied by an intense vibration, both of the railway itself and in the surrounding ground, which leads to rapid wear of the railway and can cause the train to go off the rails. Therefore, in the construction of railways, especially on soft soils, the rigidity of the soil is increased, and this, in turn, makes it necessary to take into account the nonlinearity of the elastic base in the calculations.

In this paper, we study the propagation of bending waves in a homogeneous beam fixed on a nonlinearly elastic base. The dynamic behavior of the beam is determined by the technical Tymoshenko’s theory. It is shown that the evolution equation is a modified Ostrovsky equation with an additional cubic non-linear term. For the evolution equation, exact soliton solutions from the class of stationary waves in the form of a kink and antikink are found. It has been established that taking into account nonlinearity in an elastic base corresponds to a more accurate description of bending waves.

THE INFLUENCE OF NONLINEAR ELASTICITY OF A BASEMENT ON LOCALIZED WAVES PROPAGATING IN TIMOSHENKO BEAM

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THE SIMULATION OF THE EVOLUTION PROCESS OF HYDRAULIC-FRACTURING FLUID LAG IN PREEXISTING CRACK

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The phenomenon of fluid lag in hydraulic fracturing was first proposed by Russian scientists Khristianovic and Zheltov[1], and later this phenomenon was confirmed in many experiments under the condition of small in-situ stress[2,3]. This means that this phenomenon is real in hydraulic fracturing, but it is directly ignored in many articles or directly given a initial ratio between lengths of fluid lag and crack[4] and stress intensity factor is obtained by calculation of whole stress field of the rock, which requires a lot of calculation and is not accurate. Besides, such assumptions lead to an inaccurate initial condition for hydraulic fracturing simulation.

In our article is given out the whole evolution process of fluid lag until the crack grows forward and the numerical relationship between crack contour, fluid velocity and rock toughness. This result will provide a good basis and a relatively accurate initial conditions for early-time hydraulic fracturing simulation.

References

IMPROVED FAST MULTIPOLe METHODS FOR INHOMOGENEOUS MEDIA WITH FAR-RANGE INTERACTIONS

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There are wide classes of theoretical and applied problems, involving systems with long-range interaction between their elements. Such are systems with Coulombian or/and gravitational forces in molecular dynamics, systems considered in polar micromechanics, and systems arising after spatial discretization equations of continuum mechanics when using the potential theory. In all these problems, the interaction matrix, describing pair-wise interactions between elements, is fully populated. In numerical modeling, the matrix is repeatedly multiplied by a vector. This requires N^2 multiplications. When modeling a system with large number N of DOF, the time expense becomes immense. To overcome the difficulty, accelerated methods, reducing the computational complexity to NlogN, at most, have been developed to perform the multiplication. Among them, the fast multipole methods (FMM) are of special significance due to their applicability to geometrically irregular physical systems or meshes. The universal kernel independent (KI) form of the FMM attracts presently growing attention since it is easily implemented in codes simulating a wide variety of problems. This work is focused on improving the KI FMM by further increasing its efficiency. The improvement concerns with the key concept of the KI FMM: representing far-fields of a group of sources by the effect of p equivalent sources on an equivalent surface. Since p ≪ N, matrix-to-vector multiplications, involving p sources, are much less expensive than those for N unknowns. The multiplications are repeated in traversing the hierarchical tree and on iterations of solving a problem. Each of them has the complexity p^3. Thus it is of prime significance to make the number p minimal without loss of the accuracy. We reach the goal by a proper choice of equivalent surfaces. Instead of conventional surfaces of cubes, we employ spherical equivalent surfaces. The latter, in contrast with the conventional surfaces, which have singular lines (12 edges) and points (8 vertices), are smooth. It is expected that removing the singularities will favorably affect the accuracy and its acceptable level will be achieved with the smallest number p of equivalent sources. The work presents implementation of this approach and its thorough testing.

Firstly, the problems of appropriate approximation of (i) surface elements, (ii) densities on them and (iii) developing appropriate quadrature rules are considered. We solve them by using special spherical elements, which exactly represent the sphere. For such an element, efficient integration of an arbitrary density is suggested and implemented into a
procedure of general use. With this prerequisite, it is established that merely 6 congruent elements with the total number \( p = 26 \) of nodes only are sufficient to provide the accuracy of calculations on the level of three significant digits. To have the same accuracy, when employing conventional surfaces of cubes, the number of nodes should be 96. Since the complexity is proportional to \( p^2 \), using the spherical surfaces provides 13-fold gain in time expense.

The key parameters of the improved KI FMM are established on the basis of specially designed numerical experiments. The results confirm the increased efficiency of the KI FMM developed as compared with that of the KI FMM with conventional equivalent surfaces. The exposition is illustrated by examples and numerical results obtained by the authors for a number of benchmark and applied problems.

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**MODELING PANEL FLUTTER IN THE FRAMEWORK OF THE ASYMPTOTIC THEORY OF VISCOUS GAS FLOWS**

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The processes of a strong local viscous-non-viscous interaction in a flow around a flexible surface area are investigated. Linear and nonlinear processes of flow interaction in a laminar boundary layer with an external supersonic flow are studied.

As a result of the study, the following conclusions can be drawn.
1. For the linear mode, unstable modes always exist, with an increase in the wave number the maximum growth increment decreases according to a linear law. This means that unstable long waves grow faster than unstable short waves.
2. There is a criterion for choosing the main oscillation modes associated with the oscillation energy, and it is these modes that contain more than 99 percent of the oscillation energy. Knowing these modes, you can control the oscillation of the plate.
3. The system has an internal resonance between the first two modes due to the nonlinearity of the system.
4. With an increase in the amplitude of the perturbations of the extrusion thickness of the boundary layer and a decrease in the cylindrical rigidity, irregular vibration behavior is observed due to the nonlinearity of the term at the second derivative of the plate deflection.

**THRESHOLD EFFECTS OF FRACTURE UNDER COMBINED PULSED AND HIGH-FREQUENCY LOADING**

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The adhesion zone strength is investigated under the complex effect of force fields. The adhesive zone is modeled using models based on the “string” and “beam” approximations. An impulse of infinite and finite duration, applied in the center of the adhesive zone under the action of an external vibrational field, is considered as an external load. To determine the critical force required for delamination, the incubation time criterion is used. It is shown that the background harmonic field at certain frequencies can significantly reduce the amplitude of the pulse effect necessary to break the adhesive zone. Knowledge of this effect can contribute to solving the problem of managing the delamination process. In addition, the question of the influence of the values of the parameters of the problem on the threshold amplitude of the main load is investigated. An increase in the flexural stiffness or modulus of the elastic base increases the value of the critical frequency, at which the minimum value of this amplitude is observed. A decrease in the pulse duration leads to an increase in the difference between the amplitudes of the critical and noncritical forces.
MODELLING OF DEFORMATION AND FAILURE OF COMPOSITE MATERIALS WITH STRESS STATE DEPENDENT PROPERTIES

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The analysis of the results of experimental studies of deformation properties of composite materials shows that of their properties depend on loading conditions. Thus, the mechanical properties of these materials are not invariant to the loading condition but depend on the stress state type that is caused by heterogeneous structure of composite materials, which particularly is displayed in the stiffness difference of composites under uniaxial tension and uniaxial compression, and under other biaxial and three axial loading conditions, too. This effect is most prominent for fabric-based composites and especially for woven carbon-carbon composites or carbon composites with three axial weaves. The values of elastic moduli of these composite materials under tension can be sometimes greater in comparison with elastic moduli under compression. The fibers are tightened up under tension but they can buckle under compression. Thus, the mechanisms of deformation are quite different for these loading conditions. The bending stiffness of fibers is much lower in comparison with the tensile one. Therefore, instead of a set of constant elastic coefficients, it is necessary to use a set of anisotropic functions of the stress state parameter and constitutive relations become nonlinear ones. Other types of nonlinearity of the behavior of composite materials are concerned the nonlinear response to shear loading, damage accumulation, strain rate effects. Theoretical models to describe different types of nonlinearity are proposed [1,2]. The theoretical dependencies obtained on the base of proposed models are compared with the results of experimental studies and good correspondence of them is shown.

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MICROMECHANICS OF FIBROUS COMPOSITES BASED ON MICRO-CT IMAGES

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The last decade saw a rapid growth of micro-CT applications for textiles and textile composites. This growth was in line with the fast development of the micro-CT hardware. The micro-CT with a suite of software tools for quantification of the image is becoming a common tool in advanced experimental mechanics of fibrous and composite materials.

The description of a fibre reinforced composite microstructure involves the identification of individual yarns/fibrous plies and the definition of local parameters of the fibrous geometry: local fibre directions, local fibre volume fraction and description of the amount and morphology of voids. The methods and the software, developed at KU Leuven (VoxTex), analyse X-ray micro-computed tomography (micro-CT) images, producing a description of the fibrous microstructure as an array of volume elements (voxels), each element carrying information of the fibre directions and fibre volume fraction in it. Apart from that, the amount and morphology of voids in the composite are characterised. The methods are based on a two-parameter analysis of the image: the local grey scale value and the anisotropy, the latter defined via the structure tensor of the grey scale field.

This voxel description of the material allows direct calculation of micromechanical properties/ behaviour based on the micro-CT image. This involves problems, unusual for micromechanical modelling, based on the ideal micro-geometry: weak periodicity of the nominally periodic representative volume element, local errors of the identification of fibre directions, artefacts of the micro-CT image reconstruction etc. The paper discusses application of the “CT-micromechanics” to textile reinforced composites for modelling of elastic behaviour and damage initiation and development.
EQUILIBRIA FORMS BRANCHING FOR INITIALLY CURVED ELASTIC ELEMENTS OF MEMS

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Nowadays, technologies and devices which combine electronic and mechanical components of microscale (MEMS - microelectromechanical systems), become more and more popular. In connection with the development of industrial production MEMS, now they are widely used in various spheres of human activity: medicine (for example, pacemakers), energy (control systems for permissible vibration levels, technological robots), various systems navigation in the automotive and petroleum industries, etc.

Regardless of the purpose of the MEMS, sensitive elements commonly undergo an initial curvature imperfection, due to the microfabrication process. Initial curvature imperfection significantly affects the mechanical behavior of microplates, beams, membranes, etc. For example, initially curved microbeams loaded by concentrated or distributed transverse forces may exhibit bistability (the existence of two different stable equilibria under the same loading). The transition between two stable states in these structures is commonly referred to as a snap-through buckling.

The basic sensitive elements were chosen for the analysis—a nonlinearly elastic string, initially curved clamped-clamped and cantilever beam in the formulations of Bernoulli-Euler and Timoshenko, initially curved round membrane and plate. Equilibria forms branching for various configurations of electric field and initial curvature was investigated utilizing model order reduction technique (MOR) and numerical continuation methods. In addition to the bifurcation diagrams, natural frequencies of the above mentioned structures were also considered, and their dependency on the magnitude of the electric field and the parameters of the geometric nonlinearity of the system was analyzed.

Finite element modeling of the above mentioned problems of electroelasticity was carried out in the ANSYS software system and conclusions were drawn on the degree of applicability of FEM and ROM-FEM methods under various conditions.

NONLINEAR DYNAMICS OF MICROBEAM RESONATORS UNDER PERIODICAL AND PULSE OPTO-THERMAL EXCITATIONS

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The principle of laser thermo-optical exposure to a deformable medium is increasingly used in the tasks of non-destructive testing of equipment and structures, determining the physicomechanical properties of materials, studying the geometric and physical parameters of objects and structures at the nano- and microscale level, in biomedicine, as well as in the industry of nano and microsystems. One of the important directions of development and research in this area is laser thermo-optical generation of oscillations of moving elements of microelectromechanical systems for various purposes (sensors, signal processing systems).

Problems of analytical research related thermoelastic vibrations are considered in a large number of monographs and articles. In a number of studies, thermal and mechanical processes are studied in the beam structural elements under non-stationary temperature effects. This paper is devoted to the construction and study of mathematical models of the dynamics of a micromechanical beam resonator under pulsed and periodic localized thermo-optical action. The considered model of the resonator is based on the laser thermo-optical principle of generating bending oscillations of a beam-like movable element and the electrostatic principle of removing the output signal.

At not too high power of the incident light, the action of a laser pulse on the surface of the beam is reduced to the appearance of a thermal front propagating through its volume. The localization and nonstationarity of the temperature field both in thickness and in the length of the beam in general leads to the appearance of a bending moment and axial force.

The stationary periodically varying temperature field was found by solving the heat conduction equation for a rectangular region in neglect of the small dilatation term responsible for thermoelastic sound absorption. The time-varying temperature moment and axial force acting on the beam are calculated.

Nonlinear resonator dynamics with harmonic thermal effects is investigated using asymptotic methods of nonlinear mechanics (the multi-scale method, the theory of linear operators) with due regard for the coupling of longitudinal and transverse motions. The amplitude-frequency characteristics of the system are constructed in the regions of the main and secondary resonances.

In studying the case of impulse action, the solution was obtained numerically using the finite element method in a geometrically non-linear coupled thermoelastic formulation, as well as by finite-difference approximation of non-linear integro-differential equations with consideration of two mechanical models — Bernoulli-Euler and Timoshenko shift
model.
The study of the constructed mathematical model of the resonator allowed us to directly link the dynamic characteristics of the system with its geometrical and physicomechanical properties, as well as the parameters of the laser thermooptical effect. As a direction for further research, the question of the degree of influence of thermoelastic dissipation on the resonant properties of a moving element, as well as the whole problem of determining the optimal impact parameters from the point of view of the required operational characteristics of the device, should be noted.

ON ROLE OF SURFACE RELATED EFFECTS IN MICROMECHANICS OF COMPOSITES

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The problem of surface-related effects estimations in modeling of the effective properties of microcomposites in the framework of the classical theory of elasticity and thesecond-gradient theory of is considered. Preliminary analysis of the existing continual adhesion models is given, and is shown that the spectrum of adhesion models, their generality depends on the choice of the degree of generality of the continuum model. It is shown that the well-known adhesion models in the mechanics of materials can be extended as a result of the use of gradient second-order elasticity models with the correct construction of adhesion models.

We try to show that generalized adhesion models are nontrivial, and make it possible to expand the class of studied scale effects that can be important with the micromechanics of composites. Their role in the micromechanics of composites can be quite significant. We shown in specific examples that non-classical adhesion models elaborated within the framework of second-gradient elasticity make it possible to take into account effects that are difficult or impossible to evaluate in the framework of conventionally classical adhesion models.

Examples of qualitative estimations of the role of surface-related scale effects in problems of heat conduction and thermoelasticity are considered. The special role of extended models of adhesion in description of the effects of the thermal resistance of Kapitza is established. Numerical-analytical comparative estimations of the role of the size of inclusions, their shape and interfacial effects are given during modeling of the effective thermoelastic properties of composites with micro-inclusions. Percolation type of effects are predicted concerning the local heat flux at the microscale level, depending on the scale effects and coupled effects.

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VARIATIONAL MODELS OF COUPLED GRADIENT THERMOELASTICITY AND THERMAL CONDUCTIVITY IN MICROMECHANICS OF COMPOSITES

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We develop the variational gradient model of the coupled thermoelasticity and thermal conductivity based on a generalized model of media with the dilatation defects fields. Variational model of the coupled dissipative thermodynamic processes is constructed by introducing non-integrable variational forms describing the spectrum of dissipation channels.

In the general case, an extended model of surface-related interactions is taken into account, which generalizes the Gurtin-Murdoch and Steigmann-Ogden models, and includes a special model of gradient adhesion, which is extremely important in heat conduction problems.

In the general case, the unified model includes parameters that are responsible for mechanical and temperature size-dependent effects. The analysis of boundary problems of the general coupled model is given and it is shown that gradient thermal conductivity and thermoelasticity make it possible to simulate thermal resistance effects and size effects. Theoretical and numerical modelling show that only a specific gradient adhesion model adequately describes the thermal resistance of Kapitza on the boundary of the contact phase. Therefore, we are possible to describe both effects: anomalously high effective thermal conductivity and extremely low effective thermal conductivity of micronanocomposites, depending on the interfacial properties of the bounds.

For a coupled thermomechanical problems for composites with micro-nanostructures, anomalous effects of percolation and separation of local heat fluxes in the composite were found, depending on the relative orientation of the force loading and heat flux vectors and size of inclusions.

This work was supported particularly in the part of numerical modelling and analysis by the Russian Foundation for
We consider transition to thermal equilibrium in infinite face-centered cubic (FCC) lattice with harmonic and Lennard-Jones interactions. Initially particles have zero displacements and random velocities. The system has uniform spatial temperature distribution. Initial kinetic temperatures, corresponding to different spatial directions, are not equal. A transition to thermal equilibrium is accompanied by two physical processes: oscillations of kinetic temperatures and redistribution of temperature among spatial directions. The oscillations decay in time as $1/t^{3/2}$. At large times, the kinetic temperatures tend to equilibrium values. These values are equal for Lennard-Jones interactions and different in harmonic case. Formulas describing behavior of temperatures in harmonic FCC lattice were derived. Analytical results were shown to be consistent with numerical solution of lattice dynamic equations.

The urgency of search for the simplest and most effective algorithms of the kinetics of phase boundaries related to the first-order phase transitions in the Ehrenfest classification is determined by not only practical problems of the metal melting and crystallization but also by design of unique structures, for example, cryogenic dams, foundations of oil platforms and piers from ice for arctic operations. One of the main features of the simulation of similar structures is a necessity of taking into account possibility of abrupt change in physical properties of the bodies of dam, pier or platform foundation when passing from frozen state (ice) to unfrozen one (water). As a result, one of the problems concerning the model formation is determining the boundaries of frozen and unfrozen areas of the structure under consideration. When simulating the similar phenomena, there are two primary approaches to solving the problems with phase interface: through computation and explicit selection of the phase interface. The methods of the first line are capable to identify the important features of the thermal processes in cases of phase transitions, however, a description of local temperature fields and dynamics of the phase transition boundary position is impossible under this approach. As a rule, the numerical methods of the second approach are characterized by high accuracy of the interphase boundary identification but they become algorithmically highly complex in cases of multiphase and multi-dimensional problems or in case of temperature cycling at the boundary when several non-monotonically advancing fronts exist and some of them can merge or disappear. Among the most common techniques are the methods of front catching into the grid node, adaptive grid methods, methods of front straightening and fractional steps. The method of front catching into the grid node has two variants of realization when the time step is defined and the three-dimensional grid is selected such that the front turned out to be in the node and vice versa when the time step is selected such that the front turned out to be in the node of the stationary three-dimensional grid. Both variants are limited to the case of only one monotonically varied front. When using the adaptive grid methods, the sophisticated problem arises to construct the “good” grid at every time (temporal) layer, in what connection, the task of the grid construction for complex areas can exceed in complexity the original problem. The methods of front rectification are based on the substitution of the spatial variable in order that the original problem in the area with curved boundary turned already into the other problem defined in the rectangular area. The method has also restrictions in respect of the number of fronts. The numerical method offered in the present article presents a certain symbiosis of through methods and method of front catching into the grid node. The method can be applied for the case of any number of fronts in both one-dimensional and multi-dimensional problems.
INFLUENCE OF MATERIAL PARAMETRS ON THE REFLECTIVE PROPERTIES OF A DIELECTRIC SUBSTRATE COATED WITH GRAPHENE

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A two-dimensional sheet of carbon named graphene is attracted attention for many applications. It is a material with a unique mechanical, electronic and optical properties. Its electronic excitation at low frequencies demonstrate the linear dispersion relation, nonzero energy gap and chemical potential at any temperature. A two-layer structure of dielectric substrate covered by graphene of a great interest for mechanical engineering and telecommunication applications.

We present the results of numerical modelling of the reflectance of this structure taking into account energy gap and chemical potential. The used model based on formalism of Polarization Tensor and the Dirac model. It allows calculation for any material plate coated with real graphene on the basis of first principles of quantum electrodynamics.

We will demonstrate that at the fixed frequency of an incident wave an increase of the chemical potential and the energy gap affect the reflectance in opposite directions. The reflectance approaches unity at low frequencies and drops to that of an uncoated plate at high frequencies.

Possible applications will be discussed.

LOCALIZED DEFORMATION WAVES IN A NONLINEAR ELASTIC CONDUCTING MEDIUM, INTERACTING WITH A MAGNETIC FIELD

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The problems of interaction of deformation, electromagnetic and thermal fields in electrically conductive bodies in the presence of a constant strong magnetic field have traditionally received much attention of researchers from various scientific schools. The relevance of such research is associated with the development of methods for non-destructive testing of materials, approaches of electrodynamic excitation and reception of acoustic waves.

The importance of this range of tasks is also determined by the development of technologies for the thermo-mechanical treatment of large-sized products. Through warming up of materials is one of the technological operations, it reduces the stiffness of the material before it is processed by pressure, during sintering of powders and composites. Placing the sample in a strong magnetic field creates additional possibilities for the even distribution of heat sources, leading to a leveling of the temperature field and an increase in the heating rate during induction processing. Surface currents interact with the magnetic field, which leads to the generation of acoustic oscillations in the medium, which, in turn, cause the induction currents in the medium and the associated quasistationary electromagnetic fields. Viscous and Joule energy dissipation of coupled acousto-electromagnetic oscillations leads to the formation of additional volume-distributed heat sources.

Most of the problems of magnetoacoustics are considered in the linear approximation and one-dimensional formulation. Accounting for nonlinearity, as a rule, is limited by the nonlinearity of the interaction of the elastic medium and the electromagnetic field and the nonlinearity associated with temperature stresses.

The work is devoted to the study of the propagation of magnetoelastic waves in a three-dimensional nonlinear elastic medium. The problem of the influence of a magnetic field on the localization of deformation wave was previously considered by the authors in a one-dimensional (rod) and two-dimensional (plate) arrangement. The possibility of forming a spatially localized magnetoelastic wave in a three-dimensional elastic medium was demonstrated and wave parameters from the intensity and orientation of the magnetic field.

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NONSTATIONARY OSCILLATORY DYNAMICS OF THE SINE LATTICE

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We discuss energy localization and energy exchange in the sine-lattice of finite length, without any restrictions on the amplitudes of oscillations. The significant applications of this fundamental model comprise numerous physical systems. In the infinite and continuum limit the considered model is reduced to integrable sineGordon equation or certain non-integrable generalizations of it. However we will consider the limit of short chains where the long-length approximation
is not applicable since the number of degrees of freedom is not very high and the spectrum is not quite dense. The main goal of this paper is to study the nonstationary dynamics of an essentially nonlinear system, the sine-lattice, undergoing arbitrary oscillation amplitudes. We apply to the problem the approach based on the Limiting Phase Trajectory (LPT) concept in combination with a semi-inverse method. We check the applicability of our method and demonstrate the energy transfer along with energy localization in the system. At first, we consider the spectrum of the NNMs in the framework of an asymptotic semi-inverse method. Then, by analyzing the resonant interaction of NNMs, we study the stability the instability of the modes as well as the transition to energy localization in some domain of the lattice. The analytical predictions of the conditions providing transition to energy localization are confirmed by numerical simulation.

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RAYLEIGH WAVES INDUCED BY INTERIOR INITIAL CONDITIONS

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The talk is focused on the Rayleigh wave field induced by initial displacement and velocity patterns, prescribed over the interior of an elastic half-space. The stress field is calculated in an unbounded space due to the prescribed initial conditions. It results in discrepancies at the free surface of the half-space. Then, hyperbolic-elliptic asymptotic model [e.g. see, Kaplunov and Prikazchikov, 2017] is applied to obtain the analytical approximate solution for the Rayleigh wave contribution. The example for a sinusoidal variation along a horizontal interior line of the initial vertical velocity is presented.

Reference

THE USE OF CARTOGRAPHIC DATA IN THE OPTIMIZATION OF THE MOTION OF AN UNMANNED BOAT

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Our work is dedicated to solving the problems of route planning for water transport, taking into account the factors that limit the possibilities of its movement. When solving the problem, we used a simplified physical model of the vehicle. The inputs to the algorithm are nautical charts in a raster graphic format. Images are recognized by two base colors, using the HSV color representation and linear interpolation for color saturation values. The resulting matrix of values, taking into account the parameters of the ship, is interpreted into a matrix of hazard coefficients with decreasing discretization. The areas, the movement in which is dangerous for the ship, are transmitted to the route planning system in the form of closed second-order curves. Dijkstra's algorithm is used to construct the route taking into account the danger zones.

HYBRID METAL-COMPOSITE FRAME STRUCTURES FOR MECHANICAL AND CIVIL ENGINEERING APPLICATIONS

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At the present time a significant number of constructions (domestic buildings, shopping malls, sport arenas) with large dimensionality are designed and built. Increase of dimensions of the objects lead to the necessity of creation of more complex structures used for their ceilings. Effectiveness of application of beam metallic structures, typically used for such ceilings, drops significantly with increase of dimensions of an object. By this reason for such objects it would be rational to use frame structures, which make it possible the effective concentration of the material along the main force flows.
Metallic frame structures are used in the constructions where it is necessary to realize overlaps of significant sizes without using additional struts. There is a considerable experience of their applications in high constructions: transmission towers, communication stations, bridges etc.

Frame structures are also used in a number of aircraft structures: tail booms of helicopters, primary structure of Buran space shuttle, a set of fuselage structures of regional aircrafts with small passenger capacity and other. Despite of their merits, the current metallic frame structures have a number of shortcomings, which are limiting significantly their applications. The main shortcomings are:

1. High weight of steel elements, making difficult their production, transportation, assembling and repair, that gives additional constraints and decrease weight and cost efficiency of the structures.
2. High cost of structures of lightweight alloys, which, anyway, do not allow to increase significantly the weight efficiency.
3. Necessity of regular maintenance of the primary structure for its protection against corrosion.

An alternative to the described above metallic structures is the frame structures based on hybrid metal-composite rod elements, consisting of axisymmetric composite body and metallic ends (attachments), providing the possibility of a bolted joint for the rod. The direction of fibers on the composite package of the body is close to the longitudinal axis. Such direction of fibers allows to use to a maximal extent high strength characteristics of carbon fibers and provide significant increase of weight efficiency as compared to metallic frame structures.

In the present work the method for strength analysis and design of hybrid frame structures on the basis of two-level approach is described. Special protective layers for the rod elements are considered and their influence on strength and weight characteristics of rods is investigated. Increase of weight efficiency is substantiated and the manufacturing realizability is shown for a number of hybrid structures. The results of validation investigations of the method, carried out in frames of Russian and International projects, are shown.

The application of the method for the preliminary design of a number of hybrid frame aircraft structures is also shown.

SOFTWARE FOR FAST CALCULATION OF THE CONTRIBUTION OF INHOMOGENEITIES TO THE EFFECTIVE PROPERTIES OF ELASTIC MEDIA

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Software destined for fast calculation of the contribution of an individual inhomogeneity of one of two types (cracks and solid inclusions) in an infinite elastic medium to the overall effective properties is developed. The necessary data for the calculations consist of the shape of the inhomogeneity (given by either an explicit equation or a stereolithography (.stl) file) and the Young moduli and Poisson ratios of the matrix and the inhomogeneity.

For the solution of the proposed problem, an efficient numerical mesh-free method based on Gaussian approximating functions is proposed. First, the problem is reduced to a system of 2D integral equations for the crack opening vector or 3D volume integral equations for the stress field inside the inclusion. Than the 2- or 3D region of interest is covered by a regular node grid. For discretization of the integral equations, Gaussian approximation functions centered at the nodes are used. The matrix of the discretized system turns out to have the Toeplitz’s structure and no numerical integration is required for its construction. It is possible to use the Fast Fourier Transform algorithms for calculation of the matrix-vector products in the process of iterative solution of the discretized problem. Once either the crack opening vector or the stress field inside the inclusion is found, the contribution tensor to the effective elastic properties is calculated in straightforward way.

The developed software even in its current early alpha stage is expected to be faster and easier to use than the commonly used Finite Element Method. The software may be used for various purposes. One may apply it for the filling of the proposed database of inhomogeneity shapes. It is possible to use this software for didactic purposes. Finally, “blocks” dedicated to the solution of more complex problems (interaction of multiple inhomogeneities, calculation of stress intensity factors, crack propagation, etc.) may be added to the developed kernel with ease.
THREE-DIMENSIONAL BEM APPLIED FOR WAVE PROPAGATION IN ANISOTROPIC LINEARLY ELASTIC HALF SPACE

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In this work, we employ a three-dimensional direct boundary element formulation in Laplace domain to study wave propagation in anisotropic linearly elastic semi-infinite regions. Absence of the body forces and zero initial conditions are assumed. The boundary element approach is based on the regularized boundary integral equations for displacements. These integral equations are weakly singular which is advantageous compared to the conventional strongly singular formulations. For spatial discretization mixed boundary elements are employed. The geometry of the boundary on each element is approximated with quadratic functions. Displacements and tractions are interpolated using the linear and constant shape functions, respectively. Since anisotropic elastic dynamic fundamental solutions for displacements and tractions are not available in analytic closed form special attention is paid to numerical scheme of their calculation. To obtain the time-domain solutions a numerical method for inverse Laplace transform is employed. Finally, we present results of boundary-element modeling of the propagation of waves in an anisotropic elastic half space with cavity.

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NUMERICALLY MODELING HIGH-RATE DEFORMATION AND PROGRESSIVE DAMAGE OF INHOMOGENEOUS COMPOSITE SHELLS OF REVOLUTION UNDER EXPLOSIVE LOADING

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Structurally inhomogeneous composite materials are a promising class of structural materials meeting the requirements to modern technological structures. The optimal way of studying the laws of nonlinear deformation and progressive damage of layered inhomogeneous composite materials and structural elements is numerical modeling, which makes it possible to analyze in detail the information about stress fields and contributions of various damage mechanisms when evaluating carrying capacity of structural elements. The key issue in numerical modeling is the development of adequate models and methods for analyzing stressed-strained states without assuming any a priori force or kinematic hypotheses. The processes of high-rate deformation of multilayered shells of revolution made of hybrid composite materials are mathematically described in the framework of a non-classical theory of shells in a fully three-dimensional formulation, accounting for complex stressed states, viscoelastic and elastoplastic deformation, as well as for the effect of deformation rate on the rigidity and strength characteristics of the layers of the material of the shell. An energy-conformed resolving system of dynamic equations of hybrid metal-plastic shells of revolution has been derived by minimizing the functional of full energy of the shell as a three-dimensional body. To analyze strength of structurally inhomogeneous composite materials, a model of volatility of the rigidity and strength characteristics has been developed, which account for their evolution both due to damage of some of the elementary layers of the multilayered package, and as a function of deformation rate. To analyze the formulated initial boundary-value problems of nonlinear dynamic deformation and progressive damage of inhomogeneous shells of revolution, effective numerical methods and parallel algorithms, adapted for computations on the “Lobachevski” supercomputer, have been developed and software-realized. The reliability of the proposed methodology for analyzing dynamic strength of hybrid metal-plastic shells of revolution was assessed by analyzing the problem of nonstationary deformation and progressive damage of a two-layer metal-plastic shell loaded by a pressure pulse imitating an explosion of a spherical explosive charge in the center of the shell.

The model of deformation was developed with financial support by the Federal Targeted Program for Research and Development in Priority Areas of Development of the Russian Scientific and Technological Complex for 2014-2020 under the contract No. 14.578.21.0246 (unique identifier RFMEFI57817X0246), development of the failure model – with financing from Grants of RFFI (No 18-08-01234, No 19-08-00828).
ON IDENTIFICATION OF STRESS-CONTRAST BY USING PUMPING HISTORY

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References

ESTIMATION OF ROCK DESTRUCTION INCUBATION TIME FOR HIGH STRESS-RATE EXPERIMENTS

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References
Surface quality is an important attribute of glass products. One approach of reducing surface roughness is fire polishing. During this process glass is heated which enables capillary force to smooth micro imperfections of the surface. Fire polishing is a fast process which causes high temperature gradient. Nonuniformity of temperature field implies variability of glass viscosity and affects the rate of attenuation of roughness amplitude.

In this work we consider a half-space domain filled with viscous fluid. Its boundary is assumed to be perturbed at the initial time. We presents an analytical solution of Stokes equations with assumption of exponential viscosity growth in the direction perpendicular to the free surface. The approach allows us to describe dynamics of perturbation relaxation. In particular, we give relaxation rate as a function of defect width. Overall, the system was found to be similar to the case of isoviscous finite-depth layer of thickness equal to depth of exponential increasing of viscosity. Quantitative results are given for a few particular types of surface perturbations.

TRANSFER BY A MANIPULATOR WITH A THREE-FINGER GRASP OF A BRITTLE CYLINDER

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We consider the problem of the brittle cylinder grasping by the n fingers of the robot-manipulator [1] - [5]. Each finger contacts the cylinder in a single supporting point with Amontons-Coulomb or for two footholds spinning friction. Using numerical simulations and analytically, possible locations of contact points on the cylinder, for which there is a kinetostatics problem solution when the cylinder is moved by three fingers, are received. There is an analogy of the equilibrium of a three-legged robot on a cylinder for the problems of transfer by a manipulator with a three-finger grasp of a cylinder or for a robot on a surface which legs suspension points are on a cylinder. For n=3 the existence of the solution is related to the three square inequalities by parameter p. Where p is the difference reaction components along cylinder axis. Note that for arbitrary surface the structure and the properties of these inequalities preserves. The boundaries between different regimes can be determined analytically. Using numerical simulations we explain the reaction distribution problem existing and build this problem solution existing fields for given footholds and holding the main reactions point A.

Overall, robot can move along the cylinder changing one, two and three-footholds phases. And for example the humanoid robot with five arm fingers can hold the object by one and grasp by two or three-fingers. Let we give some examples. If one finger out the cylinder, the center mass of an object is up the finger. And the angle between the weight and the normal not exceed friction angle. Robot can hold the cylinder by two fingers on one diameter. Robot can hold the horizontal cylinder by three fingers. Let one of the points is in the vertical plane containing cylinder axis and another are in the plane orthogonal to the axis. Without friction, the cylinder center of mass has to be in the vertical plane that contain the cylinder axis. The supporting points are on the external surface of the lower semi-cylinder and the center mass of the cylinder is in the footholds triangle.

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References:
TRANSFER OF DISLOCATION GLIDE ACROSS GRAIN BOUNDARIES IN METAL-GRAFHEINE NANOCOMPOSITES

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Due to its large surface area, excellent mechanical and electrical properties, and high thermal conductivity, graphene has excellent prospects for use as a filler in various composite materials [1–7]. High elastic moduli, high tensile strength and low density make graphene an ideal reinforcing material for metal matrix composites [8, 9]. In metal-graphene composites (MGCs), graphene inclusions (graphene plates) usually consist of 10–40 monolayers. It is assumed that these thin plates retain the desired properties of single-layer graphene, such as high surface area and excellent mechanical, electrical and thermal properties [10]. In MGCs, graphene inclusions are most often located at grain boundaries (GBs) and, as a rule, can have an arbitrary orientation. Recently, Ovid’ko and Sheinerman [11] theoretically investigated the transfer of plastic deformation through graphene layers in the situation when monolayer or multilayer graphene sheets intersect the entire composite. They demonstrated that the transfer of plastic deformation through inclusions of graphene can occur due to the formation and expansion of dislocation loops in the stress fields of dislocation clusters in adjacent metal layers.

In the present work, we develop a theoretical model describing the transfer of dislocation glide across GBs in metal-graphene nanocomposites (MGNCs) in the general case, when graphene inclusions are randomly distributed along GBs. It is assumed that, in the most favorably oriented grains of the matrix metal, under the action of the applied shear stress, dislocation slip begins in the form of the formation of primary sliding dislocation loops. The expansion of such loops occurs as long as they do not abut in the nearest GBs. It is also assumed that platelets of reduced graphene oxide (rGO), distributed over such GBs, serve as additional obstacles for the transfer of plastic deformation through the GBs. Within the model, in GBs containing rGO platelets and the segments of initial dislocation loops, new dislocation loops are generated. Similar 3D models were proposed earlier for the description of slip transfer in nanometals [12–14] and nanoceramics [15]. Here, this approach is extended to the case of MGNCs, in which the secondary loops should bypass rGO platelets. It is shown that rGO platelets increase the critical stress for the generation of such dislocation loops, thus increasing the yield strength of MGNCs.

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References

ANALYTICAL MODELLING AND DYNAMIC STRENGTH ESTIMATION IN SPALL FRACTURE

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Experimental studies of dynamic tensile strength under high strain rate are mainly carried out in spall fracture tests. These tests allow one to create high strain rates in materials and vary the parameters of shock pulses. In most research works the spall strength is determined using the pullback velocity, obtained from the free surface velocity profile. However, such method of strength calculation may produce incorrect results even in the case of purely acoustic behaviour of a linear elastic material.
In this study, we consider a solution of a one-dimensional wave problem in an elastic approximation which allows us to calculate a stress-time dependence in a spall section and determine the real fracture stress. Calculation results show that for some profile of the loading pulse the spall strength significantly exceeds the real fracture stress. Such an overestimation of the material strength can lead to serious mistakes, for example, in engineering problems. Moreover, an evaluation of strength by one critical stress parameter does not permit to reveal temporal features of dynamic fracture. For example, in some spall test the effect of fracture delay is realized. In this case, the fracture occurs at the stage of local tearing stress drop, i.e. the material withstands the maximum peak of tensile stress. In this work, we also represent an analytical model of spall fracture using the incubation time approach. The model predicts the abovementioned fracture delay effect and shows that, in addition to the strain rate, the whole history of the shock pulse influences essentially on the ultimate fracture stress. Thus we show that the developed incubation time approach allows one to predict and evaluate most of the principal temporal effects of dynamic fracture in the condition of spalling.

**MISFIT DISLOCATION LOOPS IN COMPOSITE SPHERES WITH AXISYMMETRIC TRUNCATED SPHERICAL INCLUSIONS**

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The development of composite nanoparticles is an urgent issue in modern nanotechnologies. In particular, of special interest are core-shell nanoparticles (CSNPs) [1-3]. The phase composition heterogeneity of CSNPs leads to the appearance of residual elastic strains and stresses caused by the lattice misfit and different thermal expansion coefficients of components. According to existing theoretical models [4, 5], different misfit stress relaxation mechanisms are possible in CSNPs, which include the formation of misfit dislocations (MDs) around the core, prismatic and glide dislocation loops in the shell, cracks in the core or shell, core-shell separation, and core displacement from the CSNP center. Approximate calculations [5] showed that the MD formation is energetically more favorable than cracking or core-shell separation. In recent years, a number of theoretical models have been suggested to calculate the critical conditions for the onset of MDs in CSNPs [5-8]. However, all these calculations were done for spherical CSNPs with centered spherical cores although in practice CSNPs demonstrate rather different architectures [1-3]. Recently, the boundary-value problem in the theory of elasticity for an axisymmetric truncated spherical inclusion arbitrary placed in an elastic sphere has been solved and applied to the case of so-called Janus particles [9]. This solution is used in the present work to describe theoretically misfit stress relaxation by generation of circular prismatic loops of MDs in CSNPs with axisymmetric truncated spherical cores. In doing so, we consider different positions of the core in such a CSNP and different locations of the MD loop at the core-shell interface. We also vary the core shape and sizes. Based on these studies, we conclude about the core-shell architecture and sizes which form the less stable system with respect to the misfit stress relaxation by MD generation. For every configuration of the CSNP, we also find the optimal position of the MD loop in the core-shell interface.

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**References**

Two remarkable phenomena, namely, the superfluidity and the superconductivity, are results of collective movement of \(^3\)He atoms and Cooper electronic pairs, respectively. Because of their collective movement, \(^3\)He atoms must be scattered by boundary walls of a certain channel simultaneously and, since this process is extremely improbable, the \(^3\)He fluid, ore more precisely the condensed fraction of it, flows without any apparent friction. Similarly, the collective movement of Cooper electronic pairs prevents their scattering by impurities, dislocations, grain boundaries, and lattice vibrations (phonons). As a result, the electric current can flow through superconductors with no resistance at all. Both the \(^3\)He atoms and Cooper electronic pairs have the total spins equal to zero, i.e. they are bosons, and their possible states are governed by the Bose statistics. The system of such particles would undergo at some very low temperature \(T_0\) a phenomenon known as the Bose condensation. Below this temperature a finite fraction of bosons occupy a single state with lowest energy, and these bosons are described by a single coherent quantum mechanical wave function, and, as a result, they can move collectively, i.e. as a whole. As the temperature is lowered, the fraction of condensed boson particles increases, and at the absolute zero temperature all particles of the system are condensed. Thus, the classic superfluidity of \(^3\)He atoms and the superconductivity of Cooper electronic pairs are essentially quantum phenomena existing near the absolute zero temperature.

One can ask: Is it possible to force fluid particles to move collectively without quantum Bose condensation? After all, atoms and molecules of most liquids are not bosons, and most liquids composed of bosons have the freezing temperature higher than the Boson condensation temperature \(T_0\). It is obvious that this can not be implemented in a bulk phase of any liquid because of a chaotic motion of its atoms (molecules). However, in the case of a strong confinement inside a certain nanochannel with boundary walls having the crystalline structure, this structure can induce a spatially ordered liquid one. Under action of an external driving force this spatially ordered fluid should move as a whole, and this collective movement of fluid particles can exhibit some semblance of the superfluidity. Carbon nanotubes(CNTs), which attract a huge interest of the international research community during the last 20 - 30 years, seem to be as most suitable candidates for the role of such nanochannels.

Using molecular dynamics (MD simulations, we have investigated argon atom flows through carbon nanotubes with circular and rectangular cross sections. It has been found that there are two regimes of such flows. In the first regime, when the external driving force \(f_e\) which mimics an action of the pressure drop through such nanotubes, is lower than a certain critical value \(f_{ec}\), the argon atom flows through carbon nanotubes have finite flow velocities and the retarding force acting on argon atoms from the boundary walls is different from zero. In the second regime, when the external driving force \(f_e\) exceeds \(f_{ec}\), the retarding force acting on argon atoms from boundary walls drops to zero and average flow velocities can be infinitely high. Thus, the second regime of argon atom flows through carbon nanotubes resembles the phenomenon of superfluidity.

### STRESS RELAXATION AT THE BOUNDARIES OF A HOLLOW CYLINDRICAL INCLUSION OF FINITE HEIGHT BY GENERATION OF RECTANGULAR PRISMATIC DISLOCATION LOOPS

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Nanoscale inclusions of foreign materials, which are embedded in various matrices and often called ‘quantum dots’ (QDs), have been the subject of extensive studies since the beginning of 1990-s due to their potential use in optical networks, lasers, solar cells, and other various optoelectronic systems [1-7]. Spherical, cylindrical, ellipsoidal, pyramidal and conical QDs have already been discovered experimentally. They may have a different structure, but all of them are characterized by the presence of residual elastic strains and stresses caused by the difference in their crystalline lattices and properties from those of matrices. Upon reaching the stresses and strains of certain values, one can notice a change in the functional properties of the QDs. On the other hand, the residual stresses and strains can relax by generation of various defect structures. The aim of the present work was to find the residual stress fields of an inclusion in the shape of a hollow cylinder of finite height, placed in an infinite matrix with the same elastic moduli, and to study the peculiarities of the stress relaxation by generation of rectangular prismatic dislocation loops (PDLs) at the inclusion boundaries. Based on the recent solution for a cylindrical inclusion in an infinite elastic medium [12], we calculated and analyzed the stresses, caused by a three-dimensional homogeneous dilatation mismatch between the matrix and the
It is shown that inside the hollow inclusion, in the cavity filled by the matrix, the level of normal radial, hoop and axial stresses is much (by an order of magnitude in the case studied) lower than in the inclusion wall. As a mechanism of stress relaxation, we considered the formation of small rectangular PDLs in different places of the rectangular section of the inclusion wall. We draw the maps of changes in the total energy of the system by the formation of a PDL at three characteristic points of the section. Based on the analysis of these maps, the critical values of the misfit parameter for these types of PDLs were determined and compared with each other. As a result, we can conclude that the minimum value of the critical misfit parameter corresponds to the case of PDL-1. Therefore, the generation of PDL-1 is the most preferable channel of stress relaxation in the system. Among various shapes of PDL-1, a rectangular elongated along the inner boundary of the inclusion is the most favorable. The corresponding value of the critical misfit parameter increases with the inclusion height.

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References

DRUG DELIVERY FROM POLYMER-BASED NANOPHARMACEUTICALS — SIMULATION OF THE DIFFUSION PROCESS

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Knowledge about the release behavior of drugs into the human body is essential for correct long-term medication. Many factors can influence release kinetics. Various drug carriers have been developed and tested for drug delivery and related applications. For polymeric materials, drug release mechanisms are usually directly related to the diffusion, dissolution and degradation of the carrier matrix. The key parameters determining the kinetics of release are the location of the drug in the matrix and the solubility of the drug. Therefore, it is necessary to conduct experiments and determine these parameters in order to predict the release of the drug in various situations. As an example, the release of gentamicin (GM) in a polylactic acid matrix (PLA) is considered, see Macha et al. 2019.

In this paper, four models are proposed for describing drug release: the classical Fick diffusion equation with a constant diffusion coefficient, the classical Fick diffusion equation with a modified boundary condition, the diffusion equation with different kinds of production term. In these models, one of the parameters that determine the kinetics of release is the diffusion coefficient, which is found by comparing the experimental graph and simulation data obtained using the finite volume method. The paper also discusses the advantages and disadvantages of the models.

THE IMPACT OF LOCAL PROPERTIES OF AN ELASTIC TWO-PHASE SUBSTRATE ON A STRUCTURE OF DEPOSITED PLASMA COATING

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Plasma treatment changes the physical, mechanical, chemical and geometric surface features. A certain combination of properties of a soft polymer substrate and treatment conditions, the surface relief can acquire a wrinkled structure. This phenomenon is related with the loss of stability of the coating as a result of internal stresses arising in the stiff layer. The studies of such wrinkled structures increase rapidly in various applications (metrology, stretchable electronics, antibacterial properties, etc).

Polyurethanes, due to the broad range of thermomechanical properties, are widely used in many areas. This is a two-phase system consisting of soft and hard blocks. The structure and fraction of the hard phase depend both on formulation and production features: these can be linear or globular structures in the amorphous or crystalline state. Plasma treatment of these polymers is important, in particular for biomedical purposes.
In this work, the effect of plasma treatment (pulsed magnetron sputtering of a graphite target) on the properties of the elastic polyurethane surface was investigated. Depending on the duration of treatment and the properties of the substrate (phase composition, stiffness and surface roughness), various wrinkled structures were obtained and studied. The work is supported by the RFBR grant 17-48-590057_r_a.

**NON-UNIQUENESS IN THE LINEAR PROBLEM OF FORWARD MOTION OF BODIES IN A TWO-LAYER FLUID**

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The classical linear problem of ship waves appears in the framework of the surface wave theory and describes forward motion of rigid bodies with a constant speed in an unbounded heavy fluid having a free surface. Most studies of the model deal with the homogeneous fluid, but cases of fluid’s stratification have also attracted interest of researchers because of the presence of phenomena related to internal waves generation. In this work the fluid consists of two layers of different density. We consider the two-dimensional statement of the corresponding boundary value problem and the case when the contours of bodies are totally submerged in one of the layers. For an arbitrary given geometry of bodies, it is known (Motygin, 2003) that the problem is uniquely solvable for all values of the speed except a possibly empty set of isolated values (depending on the geometry and the ratio of densities). The technique of proof only allows description of basic properties of the set of exceptional values and the question of their existence was open. In this work we give a positive answer and construct examples of non-uniqueness developing the ideas suggested by Motygin, McIver (2009) for bodies of arbitrary shape moving in the homogeneous fluid. The approach is based on boundary integral equations of the potential theory, introduction of two compact self-adjoint operators and investigation of some functionals on their eigenfunctions. The existence of non-uniqueness examples at isolated values of forward velocity (depending on the geometry and the ratio of densities) in both regimes of motion — subcritical (with superposition of surface and internal waves) and supercritical (with only surface waves at infinity downstream) — is discovered numerically and discussed. For the configurations under consideration, numerical computation of the wave resistance is also performed. The developed theoretical methods are also applicable for the three-dimensional case of the problem which assumes further generalization of the present results.

**THERMODYNAMICS AND HYPERBOLICITY**

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The field equations of thermodynamics may be made symmetric hyperbolic by the application of the entropy principle, provided that the Lagrange multipliers are used as variables. The equations of the kinetic theory of monatomic gases furnish an example. The applicability and usefulness of thermodynamics of hyperbolic equations is shown by light scattering experiments.

**THENCE THE MOMENT OF MOMENTUM!**

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50 years ago Clifford A. Truesdell wrote two essays entitled “Die Entwicklung des Drallsatzes” [1] and “Whence the Law of Moment of Momentum?” (in [2], pp. 239-271). He poses a seemingly innocent question: Is the balance for the moment for momentum independent of Newton’s Lex Secunda. Both articles were written during the renaissance of modern higher continuum theories of the Cosserat type, which emphasize rotational degrees of freedom of the material point independently of its translational momentum. Then, on the continuum mechanics scale, an independent balance for the spin is postulated. The situation is analogous to the case of total energy, which consists of a part for the kinetic energy and another one for the internal energy invisible on the continuum level. However, in contrast to angular momentum nobody claims that the balance of kinetic energy suffices to describe the energy contents of continuous matter nor that the balance of momentum can be used to obtain the balance of internal energy. Truesdell’s analysis culminates in radical conclusions:

- Physicists suffer from the misconception that Newton’s Second Law can be used to derive the balance of angular momentum. They are also unwilling to realize the need for their independence.
• Physicists embrace Newton’s verbally expressed notions on motion uncritically. They ignore the fact that there are two independently valid laws of motion first clearly formulated by Euler.
• Physicists are also unaware about the development of generalized continuum theories, which consider internal rotational degrees of freedom independently of translational ones.

Truesdell substantiates his claims using the monographs by Joos [3] and by Sommerfeld [4], two textbooks well known to physicists. He also refers to the Principia and Manuscript V [5] as evidence that Newton did not really think in terms of moment of forces and did not grasp the importance of a dynamic law for the angular momentum. He presents the work of Euler [6] where the two laws of motion are clearly stated in mathematical form. 50 years after his essays it is time to draw a resumé:
• What is the status of the law of moment of momentum in today’s physics education?
• What is the current status of generalized continuum theories and how is the independence seen, expressed, and used for problem solving now?
• Did Newton truly disregard the notion of angular momentum and did he not consider extended (rigid) bodies?
• Did Euler really claim and emphasize that the balances of momentum and angular momentum are not related? Did he really distinguish between moment of momentum and total angular momentum?

Moreover, we will present examples and show that generalized continuum theories are alive (in particular in St. Petersburg) and useful for today’s engineering technologies.

References

TRANSITION TO THERMAL EQUILIBRIUM IN A DEFORMED CRYSTAL

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An analytical description of the transition to thermal equilibrium in infinite nonlinear crystals after initial deformation is presented. Previous papers [1,2] have shown that the thermal oscillations with a monotonically decreasing amplitude are realized in the infinite one-dimensional harmonic crystal after the instant thermal perturbation. Nonequilibrium thermal processes in crystals are described in these papers using the method of covariance analysis. The temperature oscillations in the crystals after some deformation were not considered before the present time. The virial theorem allows us to calculate the only equilibrium crystal temperature after the transition process is completed. In the present paper the dynamics of this process is investigated.

Initially the crystal is in an equilibrium state such that kinetic and potential energies are equal. Then the crystal is deformed under some load. After loading, the temperature of the crystal rises sharply. Using the approach based on the covariance analysis we describe the transition process to a new equilibrium state. Analytical expressions describing the crystal temperature at an arbitrary moment of time are obtained. These results are supported by numerical simulation of the crystal dynamics (Figure 1) and they are accordance with the virial theorem.
Figure 1. Oscillations of kinetic temperature in the infinite crystal after loading at zero moment of time. Numerical (circle) and analytical (solid line) solutions are presented.

**Biography**


**SPEED-UP METHODS FOR THE EXPLICIT TIME INTEGRATION SCHEME IN PLANAR3D MODEL**

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The hydraulic fracturing increases oil production in oil-bearing formations. Tasks of simulation hydraulic fracture propagation become more and more relevant nowadays primarily due to the development of computer technologies. In this paper we consider the Planar3D model for a multi-layered rock. To solve the system of linear differential equations in each time step, we use explicit time integration scheme. Some of the advantages of using explicit schemes are the simplicity of modeling various physical effects, no need to inverse matrices, and the simplicity of parallelization. The methods described below allow us to speed up calculations when using the explicit integration scheme and to compensate for the need to choose a significantly smaller time step compared to implicit schemes.

The implemented explicit scheme of integration involves the pressure calculation as a multiplication of the permanent influence matrix and the opening in the crack. This matrix-matrix multiplication can be accelerated by using Fast Fourier Transform (FFT) technic. Influence matrix can be transformed to a circulant form by setting the periodic boundary conditions, so we can store in memory only the first column of the influence matrix (influence vector). To calculate pressure, we apply FFT on the influence vector and the vectorised opening, element-wise multiply these two vectors and take the inverse FFT of the result. With large grids this give the advantage in calculations due to the complexity of the method $O(N \log N)$, compared to the direct multiplication $O(N^2)$.

Increasing the computational grid step allows us to use a larger time step without losing the stability of the scheme. The grid can be scaled without recalculating the influence matrix, if we first perform the corresponding normalization of the quantities. Combination of explicit and implicit integration schemes (IMEX) also provides bigger integration time step. The use of universal asymptotes and the statistical method for tracking the crack front can significantly reduce the computation time for both explicit and implicit schemes.

Additional acceleration can be achieved by including special compilation flags, using multi-core systems and high-performance math libraries.

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FINITE ELEMENT ANALYSIS OF EFFECTIVE PROPERTIES OF THERMOELASTIC TRANSVERSELY ISOTROPIC MATERIAL WITH NANOSIZED POROSITY

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Recently, there has been an increased interest in the problems of nanomechanics. Numerous studies have revealed a scale effect, which consists in changing the effective stiffness and other material moduli for nanoscale bodies in comparison with the corresponding values for bodies of macro-dimensions. A number of theories have been developed to explain the scale factor. One of such widely used theory is the model of surface elasticity. There are a number of reviews devoted to research on the surface theory of elasticity and its applications. In turn, among the theories of surface elasticity, the most popular is the Gurtin-Murdoch model. The use of this model actually leads to the fact that the boundaries of the nanosized body are covered with elastic membranes, the internal forces in which are determined by surface stresses. Elastic membranes can be placed on the interphase boundaries inside the body with nanoscale inclusions, which also allows to model imperfect interface boundaries with stress jumps.

In this paper, we study the effective thermomechanical properties of nanoporous thermoelastic materials of hexagonal syngony class or transversely isotropic materials with random and close porosity structures. Porous material is considered as a limiting case of a two-phase mixed composite, when the material of inclusions has negligibly small stiffness moduli. The nano-dimensionality of the pore boundaries was taken into account using the Gurtin-Murdoch model of surface stresses and he highly conducting model. This work is a continuation of the author’s researches. In the development of earlier investigations, the scale factor is associated with pore sizes and the influence of the structure of porosity on the effective properties of the composite is studied.

Finite element packages ANSYS and ACELAN-COMPOS were used to simulate representative volumes and to calculate the effective material properties. This approach is based on the theory of effective moduli of composite mechanics, modelling of representative volumes and the finite element method. In accordance with the effective moduli method we solve in the constructed volume the static thermoelastic and thermal problems with linear essential boundary conditions. Homogenization problems are solved numerically by the finite element method.

We used the regular cubic representative volumes with hexahedral thermoelastic finite elements and random and granular distributions of inclusions. To take into account the nanosized internal structure, the contact boundaries between material and pores were covered by the surface membrane thermoelastic elements. We also specified transversely isotropic material properties for the membrane elements, in accordance with the location of the element coordinate systems and the anisotropy type of the volume elements in these coordinate systems. Next, we calculate the averaged stresses and thermal fluxes, which determine the effective thermoelastic moduli.

As an example, the models of nanoporous material have been examined with different values of surface moduli, porosity and number of pores. The calculation results allowed us to analyze the dependence of the effective moduli on porosity and surface elements.

The work was done in the framework of the Ministry of Science and Higher Education of Russia project No. 9.1001.2017/4.6 in part of the analysis of algorithms for creating granular composite structures and in the framework of the RFBR project 16-58-48009 IND_omi and DST in part of analyzing the effective properties of nanostructured porous thermoelastic composites.

ANALYSIS OF BEHAVIOR OF STRUCTURAL ELEMENTS MADE OF FUNCTIONALLY GRADED CARBON NANOTUBES REINFORCED MATERIALS

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A mathematical model employing the concept of the energy-equivalent inhomogeneity [1] combined with the method of conditional moments [2] has been applied to analyze short-fiber composites with different interphase models. The basic idea of the energy-equivalent inhomogeneity to replace the inhomogeneity and its interphase by a single equivalent inhomogeneity (combining properties of both) is similar to previously proposed developments but the criterion of equivalency is entirely different. It is based on Hill’s energy equivalence principle, and is developed for cylindrical inhomogeneity of finite length with Gurtin-Murdoch surface model and spring layer model of interphases [3]. To evaluate the effective properties of short-fiber reinforced composites a statistical method, the method of conditional moments, has been employed which describes random distribution of fibers. Closed-form formulas for the components
of the effective stiffness tensor of short-fiber reinforced composites have been developed which, in the limit, compare well with the results available in the literature for infinite parallel fibers with Gurtin-Murdoch interphase model and spring layer model. Influence of fiber length on contribution of the surface effects to the effective properties of the material containing cylindrical cavities and glass fibers has been analyzed for all five independent components of its stiffness tensor. Formulas for the properties of equivalent inhomogeneities associated with Gurtin-Murdoch and spring layer models of interphases can be utilized to obtain the properties of equivalent inhomogeneities for multi-component interphases [3]. It was shown that in the case of energy equivalent definitions of equivalent inhomogeneities introduced recently by the present authors this can be achieved by direct superposition of the solutions associated with each component separately.

Inclusion of multiple mechanisms in the description of interphases is applied to the Carbon Nanotube (CNT)-reinforced materials. In this case the CNT can be modeled as a cylindrical high-stiffness surface, and Gurtin-Murdoch model is very adequate for its mathematical description. Outside of CNT, however, there exists a zone of rather weak bonding with the matrix (typically polymer) and various techniques are used to improve that bonding (so-called functionalization). Such a weak (or soft) zone surrounding the CNT can be modeled by a spring layer of some thickness \( h \). In this case, one Gurtin-Murdoch and one spring layer models would need to be combined. The properties of CNT-reinforced polymers will be analyzed and compared with experimental results available in the literature.

A composite plate weakened by a hole under uniaxial load will be considered. It is assumed, that the plate made of the polymer with randomly distributed and disoriented CNTs. Analysis of how various special distributions of CNT concentration affect the response of this plate under different type of loading will be performed.


DYNAMIC ANALYSIS AND DESIGN OF GYRO-ELASTIC STRUCTURES WITH APPLICATIONS

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In this talk, we discuss the dynamics of a variety of micro-structured media possessing gyroscopic properties. In particular, we will focus on the transient behavior of an elastic lattice formed from rods connecting periodically placed masses that are supported by an array of gyroscopic spinners [1]. Such media have been paving new ways in designing innovative structured materials due to their novel wave-rerouting capabilities [2-7], which have applications in civil engineering.

We present an asymptotic transient model characterising the interaction of a spinner with a mass embedded in the truss system, extending the result of [2] obtained in the time-harmonic regime. Several examples are then provided illustrating the transient features of special dynamic phenomena such as unidirectional interfacial waves and highly localised waveforms in finite gyro-elastic systems [4, 7]. Further, we demonstrate that these systems can be employed in the design of efficient structured topological insulators and cloaking devices for discrete media.

References


Pathological fractures of proximal femur are often caused by tumor-like lesions and/or a decrease in mineral bone density due to osteoporosis. One of the methods of fracture preventing is implanting in particular with endoprostheses, screw and blocking implants.

The aim of this study is to estimate the ultimate load on the femur under the action of a person’s own weight after fixation with intramedullary nails based on a finite element modeling. Two fixation cases were simulated, including the isoelastic and telescopic implants, attached in the proximal femur part. Design of implants were developed in Novokuybyshevsk Central City Hospital. The finite element model of the femur is reconstructed based on CT-images.

The elastic moduli, shear moduli and Poisson’s ratios of cortical bone varies nonlinearly along the anatomical axis of the femur. The load along the biomechanical axis of the femur is applied to simulate the action of a person’s own weight. Assessment of the ultimate load on was carried out using the finite element damage parameter. The ultimate load on femur may increase approximately from 20% to 30 % after installing telescopic or isoelastic implant, respectively. This results can be used in medical practice while forming recommendations for implanting the diaphysial part of femur to increase its bearing capacity.

Experimental evaluation of viscoelastic material properties to be utilized for prediction of material behaviour is still a challenge from both the practical and the scientific points of view. The relaxation modulus function and the creep compliance function are related through the well-known convolution integrals. However, in practice both are measured independently using special experimental setup. In this paper, a new approach to determine both material functions from a single experiment is presented. The essence of the approach is to test specimens at different loading rates. The proposed approach is expected to be able to correctly predict the material behaviour in a wide range of loading rates from quasistatic to extreme dynamic loading conditions.

The excellent mechanical properties of nacre and bone are attributed to the unique brick-and-motor architecture, which is becoming a source of inspiration for fabricating biomimetic nanocomposites with robust mechanical behaviors. The principle of flaw tolerance reported by Gao et al, (2003) and his collaborators have addressed why nanoscale and structural hierarchies are important for the overall strength optimization. In this talk various stress-strain curves of the regularly staggered and randomly staggered brick-and-motor structures with the motor being elastic-perfectly-plastic material under uniaxial stretch are calculated using the shear-lag model. The combined effects of brick arrangement, the yielding zone length of the motor and the aspect ratio of the bricks on the elastic modulus, strength, toughness of these stagger structures are discussed. This provides a biomimetic design guideline for such nacreous composites.
STRESS FUNCTION APPROACH IN MICROMECHANICS

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The classical Airy stress function has been around for over 100 years and is a powerful tool for solving 2-D elasticity problems. However, the majority of the usage of the Airy stress functions is in fracture mechanics and it appears that applications of the Airy stress function to micromechanics (composites) are non-existent. Christensen and Lo showed a procedure to obtain the stress field for a three-phase material in which a single inclusion is surrounded by another concentric inclusion outside which lies an infinitely extended matrix medium subject to uniform strains at infinity. However, their solution is incomplete short of closed form and it was not the purpose of the paper to obtain the exact stress field for the three-phase materials.

In this paper, the classical Airy stress function method is employed to derive the elastic fields of three-phase media analytically. The Airy stress function consists of two independent analytic functions defined for each phase. The two functions are sought in Taylor/Laurent series. The coefficients of the series are determined to satisfy the continuity conditions of the displacement and traction across the phase as well as the prescribed boundary condition at the far field.

The use of a computer algebra system makes it possible to solve for the unknown coefficients in closed form with all the relevant parameters.

The obtained result is used to derive the effective properties of the composites which provide better prediction than the conventional self-consistent approximation.

MEANDERING FLOW BETWEEN TWO PARALLEL FLAT PLATES IN A UNIFORM FLOW

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Meandering flow appears under a high speed train. This flow causes uncomfortable lateral vibration on the train in tunnels. Flow between two parallel flat plates in a uniform flow was investigated in a water channel, as a simple model to clarify the generation mechanism of the meandering flow. The plate size was 1 m in length, 25 mm in width and 2 mm in thickness. Distance between the parallel plates, h, was set within a range of 5 to 30 mm. Uniform flow velocity was 30 mm/s. The velocity distribution of the flow between the two plates was measured by the PIV method. The result shows as follows: When the distance between the two plates is large (h ≥ 20 mm), the influence of the fluid viscosity is small, so the flow between the plates is similar to the uniform flow. When 10 ≤ h ≤ 15 mm, the flow velocity between the plates decreases toward the downstream due to the fluid viscosity. Then, the difference between the flow velocity in the space between the two plates and the flow velocity outside the plates increases. This results in generating clockwise and counterclockwise vortices on the each side of the plates. These vortices interact each other in the space between the two plates and meandering flow appears. When h ≤ 5 mm, the flow between the plates stagnates due to the fluid viscosity, so no meandering flow appears.

CONTINUUM APPROACH TO HIGH-CYCLE FATIGUE

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In this talk we consider new approach for stochastic fatigue analysis, based on the continuum approach to high-cycle fatigue, introduced by Ottosen, Stenström and Ristimaa in 2008 [5]. This topic is under active research. The idea of the method is to define the so called endurance surface in the stress space. The movement of the stress space is governed by the so called evolution equation. The movement of the surface is related to the growth of fatigue. The advantage of the method is, that it is based on theory of differential equation i.e. any cycle counting methods are not needed. This phenomena makes it easy to extend on several directions.

First we recall all needed basics of the theory. Then we consider step-by-step finite and infinite life-time cases. In both cases we have natural statistical interpretation for a results. We demonstrate the method by computing some numerical examples.

This talk based on our papers:

MECHANICAL MODELING OF THIN CNT FILMS WITH THE PARALLEL MESOSCOPIC DISTINCT ELEMENT METHOD

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We present a computational study of the mechanics of thin CNT films under in-plane loading. For the first time we present a numerical modeling of mechanics of representatively large specimens with realistic micro- and nanostructure. Our simulations utilize the scalable implementation of the Mesoscopic Distinct Element Method (MDEM) within waLBerla Physics Engine framework. In our modeling approach, CNTs are represented as chains of interacting rigid segments. Neighboring segments in the chain are connected with elastic bonds, resolving tension, bending, shear and torsional deformations. These bonds represent a covalent bonding within CNT surface and utilize Enhanced Vector Model (EVM) formalism. Segments of the neighboring CNTs interact with realistic coarse-grained anisotropic vdW potential, enabling relative slip of CNTs in contact. These advances in simulation technique allowed us to qualitatively match the mechanical behavior of CNT film observed in a numerical simulation and one observed in experiment.

A NEW CLASS OF OPTIMIZATION PROBLEMS RELATED TO CONTACT INTERACTION

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The design parameters in structural optimization are usually defined as material moduli, structure size, shape and topology characteristic parameters, supports, loads, inner links, reinforcement Banichuk [1]. Several classes of optimization problems have also been considered in the paper [2]. The numerical solutions have been obtained by applying a special iteration process using also the concept of partially controlled contact pressure [3]. In this lecture a new class of optimization problems is formulated. It is required that at the same boundary point (or points) of a structure, the displacement and force are prescribed. To achieve this condition, the punch contact pressure action is applied at some location on the structure boundary. Then, the punch force and its location should be specified, combined with specified contact pressure distribution and required contact shape, satisfying the constraint set on the maximal contact pressure and the stress level at contacting material interfaces. This problem can exist in the design of robot elements, such as clippers and gardening or plantation tools for mechanical processing. In other words, the problem is reduced to a local displacement control in a structure subjected to service loads, such as an assembling robot gripper. It is assumed that materials of the contacting bodies are linearly elastic, displacements and strains are small. The supporting constraints set on a structural element are most important in specifying a proper controlling punch action. This problem solution will be demonstrated by treating several support and control cases for beam structures, namely 1. cantilever beam clamped at its end and loaded at point Q by the force F, 2. beam and its support allowed to execute a rigid body vertical displacement, 3. free beam.

The punch is designed by specifying contact pressure distribution $p_n$ subject to the constraint on the beam normal stress not exceeding the value $\sigma_u$, that is $\sigma \leq \sigma_u$.

Using the Green function for the beam, the displacements can easily be expressed for different forces and contact stresses. In these contact optimization problems, the initial gap (shape form of the contact surface) is the unknown function. The problem is discretized and the calculation of the contact shape can be performed by applying the iterative
procedure described in [2,3].

The examples presented demonstrate effectiveness of the proposed method. It can be used in the mechanical technological process.

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INVESTIGATION ON THE SELF-SIMILARITY SOLUTIONS OF FRACTURE PROPAGATION EQUATIONS IN THE PSEUDO3D MODEL

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The presented work is devoted to the modeling of hydraulic fracturing (HF). Hydraulic fracturing is the main operation to effective recover hydrocarbons in low-permeability reservoirs. The key feature of this operation is the injection of high-viscosity fluid under high pressure into the reservoir in order to create fractures in the rock. To prevent the fracture from closing, a proppant is added to the fracturing fluid. Thus, a highly conductive channel is created in the formation to increase oil or gas flow to the well.

Modeling fracture growth is a computationally expensive task; therefore, the use of accurate models is impossible to optimize hydraulic fracturing operations for a large number of wells within one field. Hence, it is necessary to develop simplified and fast calculation methods suitable for engineering use in the field. To do this, the hydrofracturing equations are analyzed in order to determine the properties of their solutions and obtain a simplified form of the solution.

In this research, the problem of fracture propagation is considered in the Pseudo3D model. The medium in which the crack propagates is homogeneous in elastic moduli with a given piecewise-uniform stress distribution. The length of the crack is assumed to be much greater than the height of the hydraulic fracture. The height and distribution of fracture opening is determined from the solution of the 2D problem of brittle fracture mechanics. Fluid flow is considered one-dimensional along the length of a crack. Fluid leak-off into the reservoir is considered negligible. The paper presents that under certain boundary conditions the problem has a self-similar solution. The length and the fracture surface area depend on time according to a power law. This solution can be used in fast optimization calculations.

INFLUENCE OF PRESTRESS ON THE FREQUENCY OF NANOBAMS BASED ON MODIFIED STRAIN GRADIENT THEORY

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With transition to nanomechanical structures, many classical theory starts violating the continuum level assumption, hence, the size effects become significant. To capture size effects in bending/transverse vibration of nanomechanical beams, non-classical theories such as non-local elasticity theory, modified strain gradient theory (MSGT), and coupled stress theory (CST), etc. Although, these theories have been used by many researchers to capture different size effects, scaling in MSGT and CST theory is different from that in non-local elasticity. In this work, we analytical solve the above equations without prestress, and validate the solution with available literature. After validating the procedure with available results, we obtain the solution of MSGT, CST, non-local elasticity by including the prestress. All the solutions are compared for different values of beams thickness. On comparing the solutions, we found that MSGT solutions are most accurate in capturing size effect under different prestress. The formulation presented will be very in capturing size-related effect in nano and sub-micron structures.
ANALYTICAL AND NUMERICAL MODELLING OF SURFACE ACOUSTIC WAVES IN ROTATING PIEZOElastic MEDIA

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This work presents results of analytical and numerical research of surface acoustic waves propagation process in rotating piezoelastic media, taking into account the coupling of physical fields. Various wave parameters such as frequency, phase velocity, wave mode are analyzed and their dependencies on angular velocity is investigated. The results obtained can be used to develop microelectromechanical devices in the field of navigation and signal processing. The relationship between phase velocity and rotation was determined without simplifying assumptions and was compared with previously obtained results from the literature. Dependencies were found for materials of ST-quartz and Lithium niobate (LiNbO$_3$). Based on the obtained analytical solutions, the numerical solution in COMSOL was verified. There is a great difficulty in solving such problems with rotating media by the finite element method, due to required numerical precision and necessity to solve eigenvalue boundary problem for non-self-adjoint linear operator. Equation-based COMSOL solver was used as a numerical method for such problems. The solution of the initial equations by the method of finite differences was also obtained.

CRACK INITIATION TOUGHNESS OF PMMA UNDER DYNAMIC LOADING

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There have been several reports in literature indicating that the fracture initiation toughness of the polymer polymethyl methacrylate (PMMA) increases drastically with loading rate. The reported increase has been over ten times that of the quasi static fracture initiation toughness. In this work a detailed experimental cum numerical study is performed to understand the reasons behind this behavior. To this extend, single edge notched specimens of PMMA were loaded dynamically using a single polymeric incident bar under the three-point bending (TPB) configuration. The dynamic event of fracture initiation was imaged in real time using an ultra high speed camera at framing rates in excess of 600,000 frames per second. From the images the exact time of crack initiation was obtained. The different approaches used in the literature for detection of the instant of crack initiation were i) time corresponding to peak load, ii) fracture gages installed on the surface and iii) time corresponding to peak strain recorded by a strain gage. Numerical simulations using realistic rate dependent constitutive models were performed from which the time history of the energy release rate (J) was obtained. Further details can be obtained from [1].

The results of the study indicated that each of these different methods of detecting the instant of crack initiation leads to different levels of error which in turn reflects in the calculation of the initiation toughness. Detecting the time of crack initiation from the peak load and using the peak load in calculating the fracture initiation toughness resulted in maximum error. In this case the error increased with increase in loading rate. At lower loading rates the time to fracture $t_f$ was large and the initiation toughness calculated from maximum load provided reasonable estimates. However at higher loading rates, $t_f$ was smaller and small errors in crack initiation time measurement lead to higher level error in the calculated initiation toughness.

The high speed images indicated that crack extension started in the middle of the specimen thickness and then spread along the crack front. Use of surface mounted crack gages or strain gages will sense crack extension only when cracking reaches the surfaces. The time delay between start of crack extension at the middle of the specimen to it reaching the surface scales with the specimen thickness and was 3-4 microseconds in our experiments. This resulted in error in the measured initiation toughness; however the level of error was not as high as that when using the peak load as an indicator of crack extension. The study therefore brings to light the artifacts involved in the measurement of crack initiation toughness at high loading rates.

References
NONLINEAR ROTATIONAL WAVES IN A BLOCK GEOMEDIUM

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Recent data of geological and geophysical research argue that the Earth’s crust consists of non-point particles-blocks that are able to rotate. On the base of assumption that the rotational movements of the chain of the crust blocks and the corresponding rotational waves characterizing the redistribution of tectonic stresses are described by the sine-Gordon equation with dissipation, the dispersion properties of this equation are analyzed. The presence of anomalous dispersion has been revealed for all values of the dissipation factor. It is shown that the dispersion is manifested in the low-frequency range at high values of the dissipation factor, and the greater is the dissipation factor, the larger is the dispersion at low frequencies. The features of propagation of the stationary shock (seismic) wave in a geomedium with account of dissipation have been investigated. It has been found that the shock wave front width is directly proportional to the nonlinear wave velocity and to the dissipation factor of the medium, but it is inversely proportional to the nonlinearity coefficient. The obtained research results can be used for the study of geodynamic processes in various fields of the Earth and for improvement of earthquake forecasting methods.

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THE INFLUENCE OF PLASTIC STRAINS ON A CHEMICAL REACTION FRONT PROPAGATION IN SPHERICALLY-SYMMETRIC PROBLEMS

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Silicon-based Li-ion batteries may have very high energy density, since silicon has one of the highest known specific capacity to store lithium atoms. But the lithiation of silicon yields large volumetric expansion that generates high mechanical stresses, which affect the kinetics of the chemical reaction between silicon and lithium and can lead to massive cracking and subsequent capacity fading. The influence of mechanical stresses on the reaction front kinetics was examined by many researchers. Stress effects have been modelled via stress dependent chemical reaction parameters: surface reaction rate, diffusivity of a diffusive constituent, viscosity of the reaction product, but the dependencies of these parameters on stresses were introduced heuristically. Another set of models is based on the use of a scalar chemical potential that was introduce for deformable constituents of the reaction by analogy with chemical potentials of gases and liquids.

A present paper is based on the approach based on the expression of the chemical affinity tensor and on the kinetic equation with a reaction front velocity dependence on the normal component of the affinity tensor (see, e.g., [1]). This allows to incorporate stresses into the model by a thermodynamically motivated way. The approach was used to study spherical reaction fronts for linear elastic solid constituents [2] and nonlinear viscoelastic constituents for the case of finite strains [3].

In the present work we focus of the effects of plasticity on the reaction front. We consider a sphere subjected to a homogeneous external all-round loading. The chemical reaction starts from outer surface of the sphere and is localized at a spherical reaction front dividing the sphere into two parts occupied by the initial linear elastic material and transformed elastoplastic material. The diffusive constituent is delivered to the reaction front by the diffusion through the transformed material and fully consumed at the front by the reaction. We study the front propagation for elastoplastic material at various loading conditions. We study in detail interconnections between the reaction front propagation and the evolution of plastic deformations domain, and discuss differences between the front behaviours in the cases of various constitutive models of the reaction product.

Acknowledgments

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QUANTUM NANOMECHANICS: A NEW APPROACH

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In the last few decades, advances in the integrated-circuit fabrication techniques allowed the production of microelectomechanical (MEMS) and nanoelectromechanical (NEMS) systems with sizes ranging from micrometers to nanometers. It is common knowledge that MEMS and NEMS devices are increasingly used in optical and cellular communications, etc. Upon shrinking MEMS dimensions to submicrometer level, the van der Waals and Casimir forces induced by the electromagnetic fluctuations come into play. These forces act between uncharged material surfaces and become dominant at separations several hundred nanometers. All of this gave impetus to boost efforts to create MEMS and NEMS devices driven by the Casimir force.

We will present the theoretical foundations and the practical realization of the Fabry-Perot resonator with characteristic size of a few hundreds nanometers, driven by the light pressure and Casimir force. Operation of such a “charge-free”, purely mechanical device is determined by the laws of quantum mechanics. The periodical mechanical movements of one of the material parts of such a device are several nanometers, and the characteristic oscillation time are few milliseconds. We will report the technical parameters and practical applications of the device.

FRACTURE AND STRUCTURAL TRANSFORMATIONS: STATICS VS DYNAMICS

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Experiments on the dynamic fracture of solids, liquids, conductors, and insulators caused by fast intense actions of the environment or directed energy fluxes reveal a number of effects indicating a fundamental difference between the fast dynamic rupture (breakdown) of materials and a similar process under slow quasi-static actions. For example, one of the basic problems in testing the dynamic-strength properties of materials is associated with the dependence of the limiting characteristics on the duration, amplitude, and growth rate of external action, as well as on a number of other factors. Whereas a critical value is a constant for a material in the static case, experimentally determined critical characteristics in dynamics are strongly unstable, and as a result, their behavior becomes unpredictable. In this paper, we analyze examples illustrating typical effects inherent in these processes, which show principal importance of accounting the structural time nature of the fracture and structural transformations under dynamic loading. We propose a unified interpretation of these effects using the structural-time approach based on a concept of the incubation time.

THE EXACT EXPLICIT FORMULAE FOR RECONSTRUCTION OF PLASTIC STRAIN DISTRIBUTION IN SURFACE TREATED PLATES AND CYLINDRICAL SAMPLES

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To increase fatigue life and resistance to wear of machine parts they are subjected to surface treatment via mechanical, chemical or thermal methods. To predict the fatigue life it is necessary to take into account surface layer with tangential compressive residual stresses. There are methods of reconstruction of residual stress fields in bodies of simple geometry. But such fields cannot be used in numerical simulations of bodies of complex geometry because residual stress field must be self-balanced. Instead, plastic strain field which doesn’t need to satisfy any conditions can be used. One can reconstruct plastic strain field for body of simple geometry treated in the same way and then use it in numerical simulation of body of complex geometry to induce residual stress field. In the framework of linear theory of elasticity with induced plastic strain field, the following results for plate and cylindrical sample were obtained.

The equilibrium of an infinite force-free plate with plastic strain field which is homogeneous in plane of plate i.e
depends only on depth coordinate is considered. The formulae for residual plastic strain field as a function of residual stress field and vice versa are derived. For N.N. Davidenkov method was derived formula of reconstruction of the plastic strain field by deflection as a function of thickness of removed layer. For X-ray diffractometric analysis was derived formula of reconstruction of the plastic strain field by residual stresses field known only in hardened layer. It has shown that the deflection of the surface treated plate does not depend on width of the plate.

The cylindrical sample is considered infinite along its axis, free from loading and plastic strain field depends only on radial coordinate. The formulae for residual plastic strain field as a function of residual stress field and vice versa are derived. For N.N. Davidenkov method was derived formula of reconstruction of the plastic strain field by diameter of the cut ring as a function of thickness of removed layer.

For both plate and cylindrical sample cases surface treatment is considered anisotropic i.e. main plastic strains in surface plane can differ.

To validate obtained formulae the experiment was performed. Steel plates 100x19x1.3mm was treated by shot peening. Then plastic strain and residual stress fields were reconstructed via Davidenkov method using APOON setup and via X-ray diffractometric analysis using Xstress 3000 setup.

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HEAT TRANSPORT IN ONE-DIMENSIONAL SYSTEMS

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Transport properties of one-dimensional systems are reviewed, based on the analysis of (nonlinear) microscopic classical models. I start by revisiting the definition of heat-flux to introduce a quantity which describes correctly energy fluxes down to microscopic (spatial and temporal) scales.

Numerical and theoretical (self-consistent mode coupling, fluctuating hydrodynamics) approaches are exemplified in paradigmatic models (nonlinear oscillators, the hard point chain, rotors, stochastic systems with conservative noise) with the goal of illustrating the universality properties of anomalous heat conductivity (i.e. divergence with the system size). The origin of the nonlinear shape of the temperature profile is also discussed together with still open problems, presumably related to the presence of strong finite-size effects.

In the second part, I discuss setups characterised by the transport of more than one quantity (e.g., energy and mass). Linear-response theory (namely, Onsager formalism) is invoked to provide a general description of thermo-mechanical effects both in rotors and in the discrete nonlinear Schroedinger (DNLS) equation. Phenomena such as the emergence of non monotonous temperature profiles are briefly discussed.

Finally, I illustrate a DNLS setup where strong deviations from local equilibrium spontaneously emerge: the presence of a pure dissipation acting in one of the two chain edges induces the formation of a “wall” separating a finite-temperature from a basically empty phase. The wall intermittently arises and self-destructs, inducing a strongly fluctuating energy flux.

COMPUTATIONAL MODELLING OF STRESS-AFFECTED LOCALISED CHEMICAL REACTIONS

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The analysis of the stability and the kinetics of phase boundaries has a long history in continuum mechanics. More recently there has been an emergence of interest in mechanochemical processes, focusing on describing the influence of mechanical stresses on the kinetics of localised chemical reactions that take place at a surface inside a solid body [1]. In both cases, the interface (phase boundary or chemical reaction front) can be at an equilibrium state, the configurational stability of which depends on the stress conditions. For materials with complex rheology undergoing large deformations, the analysis of the stability must be performed computationally.

When the standard Finite-Element Method (FEM) is applied to problems with moving interfaces, the geometry should be remeshed each time the interface moves. Such technique requires using an extremely fine mesh for achieving a sufficient accuracy and additional computational resources for performing remeshing. Furthermore, the automation of the remeshing process can be a non-trivial task. An alternative way of treating such problems is a computational method that allows the interface to cut through the elements and to move independently of the mesh, the so-called CutFEM approach [2]. In this talk, a generalisation of CutFEM to large deformations and arbitrary constitutive behaviour of
In the proposed method, the interface conditions (e.g., the force equilibrium and the displacement continuity for mechanics) are enforced weakly by using a Nitsche-like approach. To address the ill-conditionality of the problem related to the interface partitioning the elements into highly unequal spatial fractions, an inter-element stabilisation is added. The total energy functional is formulated, from which the weak form of the problem is derived. It is demonstrated that the proposed implementation of the method has the same convergence rate with respect to the mesh size as the standard FEM.

The method is used to simulate the kinetics of phase boundaries and chemical reaction fronts in hyperelastic bodies undergoing large transformation strains. An approach to an equilibrium configuration is modelled and several case studies of configurationally stable and unstable interfaces are considered. To benchmark the method, a comparison with the standard FEM with remeshing for capturing the interface movement is performed for small strains.

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References
Surface waves in a pre-stressed elastic half-space are discussed within the framework of plane-strain assumption, see e.g. [1, 2]. The presented analysis extends the asymptotic theory for the Rayleigh waves induced by prescribed surface stresses exposed in [3], incorporating the effect of pre-stress.

The consideration starts from the representation of the surface wave field in terms of a single plane harmonic function, see e.g. [4], which is then perturbed in slow time. The leading order analysis gives the surface wave eigensolution, whereas the correction provides a hyperbolic-elliptic model. As a result, the vector problem in elasticity is reduced to a scalar one for a pseudo-static elliptic equation, with the boundary condition on the surface in the form of a 1D wave equation. In addition, the effect of incompressibility is addressed [5], with the coefficient in the right hand side of the hyperbolic equation on the surface blowing up near the bounds of stability of surface wave.

As might be expected, the resulting approximation for the surface wave field is of interest when the contribution of the studied wave is dominant compared to that of the bulk wave, including far-field or near-resonant regimes. As an example, the obtained formulation is implemented to a problem for a concentrated impulse load, moving steadily at a constant speed along the surface, allowing a straightforward approximation for surface wave field in terms of elementary functions.

Finally, further generalisations are discussed, including general anisotropy, accounting for the action of embedded sources, as well as inhomogeneity of the media.

References

ON CRACK PROPAGATION IN A TWO-COMPONENT THERMALLY REINFORCED PIPE

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The losses induced by cracks propagation in oil and gas pipelines may be minimized by creating conditions for cracks arrest and controlling their trajectories. One of the effective approaches to the retardation of cracks in pipes was introduced in [1]. For the manufacture of pipes it is proposed to use periodically thermally reinforced rolled sheet. The phase boundaries in the crack path reduce the rate of its propagation and change its trajectory. The direction of the crack propagation may be controlled by the configuration of these boundaries. The paper presents experimental and theoretical results concerning the crack propagation near the strengthened strips in steel sheets and model pipes. The angles of inclination of the strengthened strips with respect to generatrix of the pipe’s cylindrical surface are determined, contributing to the most effective reduction of the destroyed part of the pipe. Some possible dynamics effects are discussed.

References
THE PROBLEM OF RELAXATION IN RAREFIED GAS

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The incompleteness of the modern theory, in our opinion, consists on the formulation of equilibrium conditions. Therefore, we suggest another view on them than the classical view of the problems description of continues medium and rarefied gas [1-3]. The present study is associated with the formulation of conservation laws as conditions of equilibrium of angular momentums and forces, while usually formulated in terms of balance of force. The Ostrogradsky-Gauss theorem is used for a fixed volume in deriving the conservation laws. The theorem is a consequence of the application on the integration in parts of the spatial case for continuous function. The out integral addend answers for the rotation. In reality, gas and liquid move and not only translational, but also rotate. Non symmetric tensor that we received early answers this effect. It was found that the stress tensor is non symmetric for structureless particles. Examples were given to demonstrate the contribution of the non symmetric part of the stress tensor of the simplest problems in the theory of elasticity and the boundary layer. The extra-integral term is difficult to introduce into the differential equation. Therefore, to account for all components of the motion, it is proposed to use an integral formulation. We investigate the role of the discreteness of the description of the medium in the kinetic theory and the interaction of the discreteness and "continuity" of the media is investigated. The question of the relationship between the discreteness of a medium and its description with the help of continuum mechanics arises due to the fact that the distances between molecules in a rarefied gas are finite, the times between collisions are finite, but on definition under calculating derivatives on time and space we deal with infinitely small values. The important role of the angular momentum at the point of appearance of the gradient of the physical quantity and at the beginning of the movement is proved. It is proposed to take into account the role of the angular momentum in determining virial coefficients for moderately compressible gases. The role of the angular momentum is reduced to a change in the magnitude and direction of the velocities of the molecules, which changes the pressure values. Analysis of the recording of the Lagrangian function for the collective interaction of the particles with the change of the center of inertia of the moving particles and the influence of effect angular momentum were made in more early work. The moving of the inertia center is main reason for appearance the angular momentum which go to rotating of the elementary volume. This too reason is to origin collective potential for charge particles. The results of numerical and analytical studies of certain problems of the boundary layer, the interaction of gas flow with the crystal surface for the gas that is moving near the solid surface, the simplest problems of elasticity were discussed early. In this paper, the conditions for the occurrence of the stress tensor are mathematically analyzed.

Reference

ROCK FRACTURE DURING OIL WELL PERFORATION PROCESS

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The rock stress field in the near wellbore of an oil well zone during perforation is studied numerically. Factors that influence the stress field of rocks to be modified during perforation are identified. It is shown that during pressure reduction in a well, tangential stresses at the border of the well and reservoir increase significantly while radial stresses decrease. The dynamic stress field formed in the near wellbore zone causes degradation of reservoir properties and annular zones of rock fracture formed around a production wellbore.

The stress state of the fractured fluid-conducting reservoir was modeled using FEM in the ANSYS taking into account the distribution of reservoir pressure over the radius. It has been shown that the jet-slotting perforation reduces the normal and increases the tangential stresses, ensuring conditions for an annular fracture zone to be formed contributing to an increase in reservoir properties and well productivity. An enlargement of the zone of plastic deformations around a production well over time was detected via ISAMGEO software.

Jet-slotting perforation has an intensive influence on the distribution of crack opening and change in permeability. The impact of a fluid jet on a barrier during perforation was assessed. The intensity of the impact of a fluid jet on the rock
was determined using differential pressure. The fluid jet outflow from the nozzle and its impact on the casing are simulated. It is shown that fracture of porous rocks by a jet of pure liquid is an effective reservoir stimulation method. Presence of solid particles in the liquid increases the process efficiency. The analysis of hydraulic perfection of various types of perforation holes and slots was performed. It is proved that the stress state of the production string with a long slotted channel along its axis approaches to the stress state of an infinitely long drill-string. Investigations on the effect of environmental pressure, porosity, rock permeability and flow parameters of the jet substance on effectiveness of the jet-slotting perforation were also carried out.

CAVITY FLOW OF NEMATIC LIQUID CRYSTALS - A PARAMETER STUDY

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This paper presents a parameter study of the flow of nematic liquid crystals which possess both viscous and elastic properties. The underlying general equations are stated and subsequently simplified for non-isothermal and steady state conditions. The flow situation of a two-dimensional lid-driven cavity is analyzed. Hence, the equations are specialized for the case of two-dimensional flow. For numerical calculations the complete boundary value problem is formulated and then expressed in dimensionless form. Several dimensionless parameters are identified and their impact on the solution is analyzed. Furthermore, the temperature rise due to viscous dissipation is analyzed, which is frequently ignored in the mechanics community. The finite element method is employed using the software package FeniCS. Therefore, the resulting weak forms of the equations are presented. In addition to the cavity flow the steady state Couette flow is considered as a reference problem. Using an analytical solution for the Couette flow, a convergence analysis is performed in order to assess the quality of the numerical method.

RELATIONSHIP BETWEEN MECHANICAL AND ADHESIVE CHARACTERISTICS OF ELASTIC MATERIALS

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The model of adhesive interaction of contacting solid elastic bodies is proposed. The models of adhesive interaction of elastic bodies, which are currently used by the mechanics of a deformable solid, are based on the idea of the non-local interaction of their surfaces. The basis for constructing or choosing a model of deformable solids for the description of their adhesion is the following assumption. When adhesion, the material fibers of the joint body, which cross the contact surface, retain their integrity and smoothness during its deformation. The assumption reflects the statement that in real materials during adhesion, the atomic lattice of one of them continues the lattice of the other or is coherent with it. The basis of the proposed model is the idea of non-local pair and triple potential interactions of the components of their infinitely small particles. In this, it differs from the existing models. When building a model, attention is focused on the differences and connections of the results of using the principles of locality and non-locality. The local version of the model is built independently of the non-local. It is based on the complexity of the structure of the classical stress tensor. The possibility of transition from a non-local description of the adhesive interaction to a local one made it possible to express the parameters of the interparticle potentials through the characteristics of the elastic state of the interacting materials. It turned out that the requirement of preserving the smoothness of material fibers crossing the contact surface necessitates the use of a gradient model of a solid. This, in turn, allows for calculations of the adhesion of specific materials on the basis of information about these characteristics without additional experiments. An example of using the proposed model of adhesion for its particular case - the model of adhesive contact of Derjaguin, Muller, Toporov, is given in the paper.
Functional nanoceramics are widely used in various industries, such as, for example, power engineering. In particular, new ceramic nanocomposite based on yttrium stabilized zirconia (YSZ) with the filler in the form of graphene layers is a promising material which has both ionic (oxygen) conductivity, inherent in YSZ ceramics, and electron conductivity due to the formation of clusters of graphene in the intergranular space [1, 2]. Such material can serve as a basis for creating an efficient molecular oxygen pump with possible applications in power engineering, engine building, fine chemical synthesis technologies and design of new medical equipment. At the same time, the desire to achieve better functional properties (such as strength, hardness, response to the concentration of oxygen in the gas phase over a wide range of temperatures through more intensive grain refinement or usage of new filler materials) often leads to degradation of mechanical properties of fabricated samples [3]. A purposeful search for ways to improve the functional properties of nanoceramics and ceramic nanocomposites, without sacrificing their mechanical characteristics, requires the development of theoretical models describing the mechanisms of strength and plasticity of such materials.

In the present work, we represent our first results on computer modeling of mechanical behavior of YSZ ceramics/graphene nanocomposites within the molecular dynamics approach. Our model was a YSZ crystal with a deformable graphene inclusion. The interaction between the graphene and the YSZ ceramics was described by various potentials of atomic interactions. The Tangney-Scandolo dipole model potential [4] was used to describe the interaction between yttrium, zirconium, and oxygen atoms, which was optimized for the cubic and tetragonal YSZ phase. The Tersoff potential [5] was used to describe the interaction between carbon atoms. The Lennard-Jones potential [6] was used to describe the interaction between yttrium and carbon atoms. In this parametrization, the bond breaking energies and the distance between the atoms of various elements are completely reproduced. The 2NN MEAM (the second nearest-neighbor modified embedded atom method) potential was used to describe the interaction between zirconium and carbon atoms, and oxygen and carbon atoms. Based on our results in modeling these objects with LAMMPS software package, we consider the dynamics of the structure evolution and the mechanical behavior of a separate graphene nanoinclusion, and discuss the possibility to transfer these data to the behavior of real nanocomposites.

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References

SHEAR BANDING LOCALIZATION PHENOMENA IN STEEL AND COPPER

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We study the features of shear banding self-organization phenomena in steel and copper undergoing the dynamic loading. Starting from mathematical model which allows one to take into account strain hardening, thermal softening and dipolar effects we present new numerical approach that can be used to simulate the shear banding phenomena from initial to final stage of localization. To prove the accuracy and efficiency of the following method we give solutions of several benchmark problems. Next, using our algorithm, we study the stress and strain waves propagation in metals considered. We focus our attention on statistic properties of shear bands formation in dipolar materials. To be specific we obtain statistical distributions of the width of localization zones and distance between them using the Parsen-Rosenblatt method. We show that dipolar effects significantly change the width of localization zones and distance between them. The localization time is also affected by these effects and increases with an increase of the magnitude of
the dipolar parameter. Much attention is paid to compare the obtained results with the results for nonpolar case.

**FRACUTRE TOUGHNESS OF MATERIALS WITH HIERARCHICAL MICROSTRUCTURE**

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Importance of structural hierarchy with regard to mechanical behavior of materials with periodic microstructure is well known. While the impact of hierarchy on the material strength and stiffness is the subject of many research papers, the fracture toughness performance is significantly less investigated. The reason is a high computational cost of the corresponding multiscale problems with non-periodic stress state, which include the length scales defined by the periodicity at each hierarchical level and the length scale related to a macrocrack employed for the fracture toughness evaluation. A novel method based on the discrete Fourier transform enabled to reduce the volume of calculations thanks to the replacement of the analysis of a large periodic domain with non-periodic stress state by multiple analysis of a single period.

Two-dimensional materials with a microstructure generated by a periodic system of voids in a homogeneous parent material are considered. The second order hierarchy with cubic symmetry of voids layout at both hierarchical levels is addressed, and fracture behavior of two different hierarchical materials is examined. In the first case, hollow macrovoids are surrounded by a porous microvoided material, while in the second one the microvoided material fills macrovoids, which embedded in solid material. The brittle fracture behavior is investigated by analyzing the stress field in the macrocrack tip vicinity. For the voided material this field is non-singular, and the fracture toughness is determined in the framework of critical stress criterion.

The influence of material redistribution between the hierarchical levels with fixed overall density constraint was examined. For the hollow macrovoids material it is found that for the low and moderate values of porous constituent relative density (microdensity) the fracture toughness enhances with the microdensity increase. With the further microdensity increase above 0.5 the toughness first becomes insensitive to the parent material division between the hierarchical levels, and then a certain decrease takes place. This phenomenon can be explained by the fact that small microvoids become stress concentrators. For the material with filled voids in the considered densities range in most cases, there is no significant influence of material distribution on the fracture behavior. In addition, for this material the sensitivity of the fracture toughness and effective elastic properties of hierarchical material to the microdensity variation for the fixed macrovoids size is examined. As expected, in the case of large voids (small macrodensity) even a small increment of microdensity significantly improves all the material characteristics, and it appears that for the fracture toughness the effect is more pronounced.

**EXPERIMENTAL STUDY OF VIBRATIONAL THERMAL CONVECTION OF LIQUID IN A ROTATING THICK CYLINDRICAL LAYER**

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The convection exited by the transverse vibrations in liquid stably stratified in a centrifugal field is investigated. The cylindrical layer with the boundaries of different temperature rotates about its axis of symmetry. In the case of more heated inner boundary, under the action of centrifugal force of inertia, the liquid in the layer is in a state of mechanical equilibrium. It is found that the vibrations perpendicular to the axis of rotation are able to disturb this quasi-equilibrium state in the case when the frequency of vibrations is close to one of rotation. In a resonant area, heat transport through the layer non-monotonically depends on the frequency ratio. The maximal values of heat flux are observed when the frequencies are slightly (about 5 %) mismatched, while at strictly equal frequencies there is a local minimum. It is also found that heat transport monotonically increases with an increase in the amplitude of vibrations and the frequency of rotation. The structure of convective flows responsible for heat transport is studied using PIV method. It is shown that the appearance of the convective flows in the layer is determined by the inertia force field, which violates the axial symmetry of the centrifugal one. The analysis of the result is curried out from the point of view of vibrational hydromechanics. The governing parameters are the centrifugal and vibrational Rayleigh numbers.

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To the analysis of plastic deformation of structurally inhomogeneous materials we apply the method of numerical modeling, based on the theory of the orthotropic elastic-plastic Cosserat continuum with a plasticity condition taking into account both shear and rotational nature of irreversible deformation. Within the assumption of a blocky structure of a material with elastic blocks interacting through pliable plastic interlayers, this condition limits the tangential components of an asymmetric stress tensor, which characterize shears, as well as the couple stresses, which limit values lead to an irreversible change in the curvature of deformed state of a continuum. The equations of translational and rotational motion together with the constitutive relationships of the model are formulated as a variational inequality that correctly describes both the state of elastic-plastic deformation under active loading and the state of elastic unloading. For numerical implementation of the mathematical model, a parallel computational algorithm and author’s software package for multiprocessor computing systems of the cluster architecture are used. With the help of developed computational technology we study the problem of compression of a rectangular blocky rock massif of the type of masonry by a rough undeformable plate making a uniformly accelerated rotational motion. The influence of the yield strengths of pliable interlayers during shear and bending on the stress-strain state of the massif is analyzed. Along with the fields of displacements, stresses, couple stresses and angle of rotation of the structural elements, the field of plastic dissipation of energy is studied. A detailed analysis of numerical solutions shows that the couple stresses and the associated curvatures have a small influence on the final macroscale deformed state of a massif, which is characterized by the main quantities – displacements and corresponding stresses. Distribution of the couple stresses takes a cellular structure, reflecting the inhomogeneity of a material and the change of inhomogeneity in the process of loading. Therefore, unlike usual stresses, they should be associated with a mesoscale level of deformation of a structurally inhomogeneous material. Chaotic distribution of the energy of plastic dissipation due to a change in curvature in the whole volume of a medium confirms the hypothesis that the plastification of a material at the meso-level is because of rotational degrees of freedom of the particles.

THE DAMAGE PARAMETER CHANGES DURING HIGH-TEMPERATURE CREEP

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The damage conception that was introduced in the mechanics of materials to describe long-term strength under conditions of high-temperature creep, have been developed in the fundamental works of Kachanov [1] and Rabotnov [2]. In their works, to describe the brittle region of the experimental long-term strength curve, the conception of damage was introduced, the simple kinetic equation for the damage parameter was proposed, and the long-term strength criterion was formulated. The next stage on the creep and damage problem solution relates to the work of Rabotnov [3], in which a system of two interrelated equations for creep deformation and damage parameter was introduced. When the interrelated creep and damage equations was formulated, the physical content of the damage parameter should be given. In particular, irreversible changes in volume (loosening) [4] or density [5] were considered as a damage parameter. This parameter is the most representative characteristic of damage. In work [6] the system of equations for rate of creep and damage parameter written through damage parameter for the compressible medium was considered.

In this paper, we propose to determine the damage parameter changes according to the experimental curves of high-temperature creep. Only one kinetic equation for creep rate for compressible medium, recorded using the damage parameter is formulated. From this equation, the damage parameter is determined, depending on the creep rate and the creep deformation. Similarly, the value of the damage parameter is determined according to the Rabotnov solution. To describe the experimental creep curves various empirical dependences in the form of power, exponential, and mixed functions are used. Theoretical damage curves are plotted. The long-term strength criterion is obtained under the condition, when damage parameter is reached the critical value. The corresponding theoretical long-term strength curves are constructed. For the case of a compressible medium, a more intensive damage accumulation and, accordingly, the fracture processes are observed, compared with the Rabotnov solution.

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References


MICROMECHANICS OF CONCRETE: OVERVIEW OF CHALLENGES AND CONTRIBUTIONS FROM EDF R&D

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To manage the long term operation of power plants civil engineering facilities, EDF has adopted an integrated approach combining inspection, structural analysis and material aging knowledge. This allows to monitor the degradation of civil works and optimize maintenance, to ensure a safe operation.

The assessment of concrete aging plays a fundamental role in this process. Relevant constitutive behaviors are obviously required as inputs of FEM computations. For inspection techniques relying on indirect measurements, material modeling aims at providing reliable relations between quantities of interest (e.g., water content) and measured properties (e.g., electric conductivity or dielectric permittivity). In short, the physical properties, and transport and mechanical constitutive behaviors of the concretes making up the structure at stake are required.

As extracting core samples from structures or lab recreating decades-old concretes is rarely feasible, EDF R&D is developing a "virtual lab" to investigate and estimate aging of cementitious materials. This contribution proposes an overview of challenges raised by such an approach, and of our recent works to address them.

The aim of this "virtual lab" is to estimate, from the knowledge of both the initial mix design and the aging conditions in the structure, properties and behavior of concrete. To be predictive and adaptable to the wide range of concrete mixes found in EDF plant fleet, these models clearly have to be as much physics-based as possible. Concrete being a highly variable, multi-scale material, where multi-physics processes occur, multi-scale models represent an appealing option. Indeed, these micromechanics-based approaches are able to bridge the scale where the physical processes occur to the scale of interest for the engineer. This contribution is restricted to mean-field homogenization, used at either the cement paste or concrete scale.

Microstructure plays a key role in the homogenization process, and its evolution allows to relate mechanical properties to degradation processes. A morphological model of hydrating cement paste is first proposed and validated against experimental stiffness data. Then, the influence of two degradation mechanisms on the effective elasticity is investigated. First, a purely chemical mechanism is considered: leaching of cement paste, involving dissolution of some hydrates. Second, damage development and propagation in matrix surrounding expanding (due to alcali-silica reaction or neutron irradiation, for example) aggregates is investigated.

The delayed behavior of concrete is affected by both the intrinsic viscoelastic nature of the C-S-H gel and microstructure evolutions. The latter yields aging creep. The influence of cement hydration is investigated as an example.

The last case considers concrete as an unsaturated porous media, and proposes a simplified model to relate the effective permittivity (measured by non destructive techniques) to the liquid saturation degree (which influences concrete properties and durability).
In the present work, on the basis of non-central power and moment interaction between atoms, a discrete model of a nanocrystalline linear chain of atoms is constructed and, further, during the consideration of long waves, its continual one-dimensional model is constructed by the limit transition. It is shown that the constructed continual one-dimensional model is identical to the previously constructed applied theory of a micropolar elastic beam with independent fields of displacements and rotations. Based on the energy reasons, all the present elastic constants for the specified theory of micropolar elastic beam are determined by the parameters of the atomic discrete chain model. Based on the constructed micropolar beam model, a structural (discrete-continual or beam) approach is proposed for studying the deformations of nanocrystalline materials, replacing interatomic connections with micropolar beams.

CRYSTALLOGRAPHIC ORIENTATION AND DELAY TIME INFLUENCE ON THERMAL FATIGUE STRENGTH OF SINGLE-CRYSTAL NICKEL SUPERALLOYS

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Single-crystal nickel based superalloys [1] are widely used as structural materials for production of gas turbine engines (GTE) [2]. The thermal-fatigue strength of such materials with a pronounced anisotropy and a sensitivity of mechanical properties to the temperature is currently not fully studied. For investigation of thermal fatigue durability under a wide range of temperatures with and without delay times the experiments are carried out on different types of samples, including corset (plane) specimen on the installation developed in NPO CKTI [2]. Fixed in axial direction by means of two bolts with a massive foundation the corset sample (see Fig. 2) is heated periodically by passing electric current through it. The aim of the research is determinate numerically a stress states of the corset specimen under cyclic electric loading and to study systematically the effect of a delay time at maximum temperature and crystallographic orientation (CGO) on a thermal fatigue durability on the base of the deformation criterion [3-5] for single crystal superalloys using the results of finite element (FE) simulation and an analytical approximation.

Modeling of inelastic cyclic deformation of corset samples under cyclic thermal loadings was carried out using finite element (FE) program ANSYS. Thermal fatigue destruction with different orientations and delay times was calculated with help of FE program PANTOCRATOR which based on the application of micromechanical (physical) models of plasticity and creep of single crystals. These computations were carried out for superalloy ZHS32. Modeling of processes of heating and thermal fatigue fracture of alloys was carried out for temperature modes: 150-900 °C and 500-1000 °C. The results of multivariate computations in program ANSYS for full-scale model allow to define the equivalent length of the simplified model of sample, which was found for the alloy ZHS32 was equal to 40-52 mm. In the FE formulation in PANTOCRATOR, the length of the specimen for alloy was taken to be 40 mm. CGO [001], [011] and [111] were considered.

The comparison of the results of FE simulations and an analytical approximation demonstrates a good agreement with the experimental results for the number of cycles before the formation of the macrocrack with delay times for the alloy. Calculations showed that the thermal fatigue durability of samples from superalloy ZhS32 with CGO <001> exceeds the thermal fatigue durabilities of CGO <011> and <111> (fig. 9) for all considered loading programs.

References
HEDE MODEL VS INNER PRESSURE MODEL IN CALCULATING THE STRENGTH OF HYDROGENATED METALS

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It is well known that hydrogen, which causes embrittlement and destruction of steel, is a serious problem for the oil and gas, construction and transport industries. Sensitivity to inner hydrogen especially increases with increasing material strength and makes significant adjustments in the application of high-strength steels. In a hydrogen environment, metals lose their strength, ductility, toughness, and fail at much lower loads than hydrogen-unsaturated materials. Hydrogen saturation of steel occurs mainly in the process of its production (due to the presence of water in charge materials, in ligature and other materials used in steel production) and because of its being in a corrosive environment.

There are several hypotheses which describe the mechanism of hydrogen embrittlement, but this process remains poorly understood. In this paper, two models are analyzed: the hydrogen enhanced decohesion model (HEDE) and the inner pressure proposed by the ANSYS software system for engineering finite element analysis.

According to the HEDE model, interstitial hydrogen expands the metal atomic lattice, thereby reducing the cohesive strength of the atoms. This reduces the energy barrier crack propagation. It will occur in places of stress concentration, where the stress intensity factor is particularly high. For example: in internal corners, holes, grooves, or on the tips of a crack or notch. According to HEDE, hydrogen lowers the critical value of the stress intensity factor in these areas below the local voltage level caused by the application of a load. In other words, the concept of a critical hydrogen concentration is postulated, at which the critical stress value necessary for the start of crack development is equal to the applied stress, because of which destruction occurs.

Consider the second case - an equation embedded in the ANSYS engineering complex. The geometric and physical parameters of the model, the applied loads were taken as for HEDE model. At the stage of the associated structural-diffusion analysis, the total deformation consisted of two components: the elastic part that described by Hooke's law, and the inner pressure part. This part determines the dependence of the stress intensity factor on the hydrogen concentration. The quantity of hydrogen influence coefficients was chosen empirically.

Comparison of simulation results shows that the current hypotheses describing the mechanism of hydrogen embrittlement really allow us to simulate the growth and development of cracks in samples, but they have significant drawbacks. For the first case HEDE model, they are related to the fact that the relations used in the calculation of the process are empirical and have no physical justification. For the second inner pressure model, we had to use parameters that have a non-physical value.

Therefore, further research into the phenomenon of hydrogen embrittlement is necessary.
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STRUCTURAL-TEMPORAL CHARACTERISTICS OF THE METAL MULTILAYER COMPOSITE GLARE

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Responses of the aluminum multilayer composite to dynamic loading are described by the relaxation model of plasticity. Deformation dependencies of GLARE composite with an effect of the stress drop, related to the process of fracture of the glass fiber and delamination, is calculated. Dynamic effect of yield drop phenomenon of Al 2024-T3 sheet metal is predicted. A comparative analysis of the characteristic time parameters of GLARE (glass laminate aluminum reinforced epoxy) composite and its component (Al 2024-T3 sheet metal) is given. It is shown that the relaxation model of plasticity is capable to effectively predict a wide spectrum of aluminum multilayer composite responses to fast and slow dynamic loading. Relations between the rate sensitivity of the multilayer composite, parameters of the dynamic loading and the strain rate sensitivity of its components are established. It is shown that estimates of the rate sensitivity turned out to be higher for GLARE composite in comparison to the rate sensitivity estimates for its component.
NUMERICAL SIMULATION OF DYNAMIC DEFORMATION AND FRACTURE OF POLYCRYSTALLINE ALUMINUM

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Aluminum alloys are widely used in aircraft building, shipbuilding and aerospace industry. During operation process, these alloys are exposed to thermomechanical effects in a wide range of loading rates. To obtain a reliable prediction of the deformation behavior of aluminum alloys it is necessary to use the mathematical models that taking into account the temperature and velocity sensitivity, as well as the features of the polycrystalline structure of the material.

Three-dimensional micromechanical model including thermo-mechanical relaxation constitutive equation for multidimensional flow is developed to describe dynamic deformation and fracture of metal. This work aims at studying the influence of polycrystalline structure on the stress-strain localization arising near grain boundaries and fracture of the polycrystalline aluminum at different strain rates and temperatures.

It was established that polycrystalline structure is responsible for earlier plastic strain localization in the regions of grain boundaries and triple grain joints, while the homogeneous sample was still at the elastic stage of deformation. At the same time, when the entire homogeneous sample experienced significant plastic deformation there were still local regions of elastic deformation in polycrystalline sample. Accounting for the polycrystalline structure of the samples leads to low values of the macroscopic flow stress. With deformation rate increasing, the places of origin of primary cracks change, the fraction of the fractured material increases, and the multiple cracking of the sample is realized.

HETEROGENEOUS MATERIALS WITH ANISOTROPIC MATRICES

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We focus on calculation of the overall elastic and conductive properties of heterogeneous materials with anisotropic matrix. The basic building block of any homogenization process is construction of the property contribution tensors. We show that conductivity and resistivity contribution tensors allow closed form representation for any orientation of an ellipsoidal inhomogeneity embedded in an anisotropic matrix. Exact solutions for stiffness and compliance contribution tensors can be obtained in closed form in some special cases only – when matrix material is transversely isotropic and axis of symmetry of a spheroidal inhomogeneity coincides with the axis of elastic symmetry. This class of solutions can be substantially extended by approximations. We show how overall elastic properties of a transversely isotropic material containing multiple randomly oriented circular cracks can be obtained. For this goal, we propose a new methodology based on the observation that crack opening displacement tensor for an arbitrarily oriented crack in a transversely-isotropic material of elliptic type is almost independent on the crack orientation if the coordinate axes are associated with the symmetry axes of the matrix. We then use replacement relations to extend our results to the case of arbitrarily oriented oblate platelet in a transversely-isotropic matrix. We then use various homogenization techniques (Mori-Tanaka scheme and Maxwell scheme) to calculate the overall elastic and conductive properties of the materials with anisotropic matrices. Finally, we show how these results lead to explicit cross-property connections for such materials.

TRANSCENDENTAL FIRST INTEGRALS OF DISSIPATIVE SYSTEMS WITH MANY DEGREES OF FREEDOM

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In the problems of dynamics, mechanical systems with many degrees of freedom with dissipation (position space, multidimensional manifold) are studied. The tangent bundles of these manifolds become their phase spaces. Thus, for example, the study of an n-dimensional generalized spherical pendulum in a nonconservative field of forces leads to a dynamic system on the tangent bundles of an (n – 1)-dimensional sphere, and the metrics of special form on it are induced by an additional group of symmetry [1, 2]. In this case, the dynamic systems describing the motion of such a pendulum are characterized by alternating dissipation, and the complete list of the first integrals is composed of transcendental (in the sense of complex analysis) functions, which can be expressed through a finite combination of elementary functions.

Let us also define the class of problems about the motion of a point over a multidimensional surface, the metrics on
which are induced by the Euclidian metrics of the overall space. In some cases, it is also possible to find the complete list of the first integrals composed of transcendental functions in systems with dissipation. The results obtained are especially important in the sense of the presence of just a nonconservative field of forces in a system.

In this work, the integrability of some classes of dynamic systems on the tangent bundles of a multidimensional manifold is demonstrated (for similar studies on the tangent bundles of two-, three, and four-dimensional manifolds, see [3–5]). In this case, the force fields are characterized by so-called alternating dissipation and generalize the fields considered earlier (see also [6]).


TEMPERATURE RISING AND FAILURE BEHAVIORS OF GLASS SPHERE SUBJECTED TO IMPACT LOADING

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The dynamic compression responses of four glass spheres are investigated by the multi-point infrared temperature method based on the modified split Hopkinson pressure bar device (SHPB). The results show that the deformation of the glass spheres is dominantly elastic-brittle and the slight plasticity mainly concentrates around the contact area. The formation and growth of the shadow areas observed at the impact end and the support end in the spheres are the main causes of the catastrophic failure. The movement of the plane-like fronts of the shadow areas is activated and driven by local velocity gradients. Dynamic breakage of the spheres is then analyzed by the temperature rising behavior. The results show that there are two main temperature rising stages in the process of sphere breakage, e.g. the fast rising stage and the stable stage. In order to investigate the transition of these two temperature rising stages, a thermal-mechanical coupling model is preliminarily established on the local velocity gradients and temperature rising behavior of the plane-like fronts. The model shows both good simulations to the experimental data and obvious the transition process of two temperature rising mechanisms. The scaling laws and the strain rate effects of breakage strength are then discussed. The results are helpful for the controlling of pulverization for brittle particles.

STRESS-STRAIN DIAGRAMS ON PHASE TRANSFORMATION PATHS: EQUILIBRIUM TWO-PHASE MICROSTRUCTURES AND OPTIMAL COMPOSITE MICROSTRUCTURES

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We relate two problems which arise from different branches of mechanics of materials: construction of limiting phase transformation surfaces in strain space and stress-strain diagrams for stress-induced phase transitions and optimal design of two-phase 3D-composites in the sense of minimizing its energy. In [1], for the case of isotropic phases, it was shown that, given a new phase volume fraction and depending on average strain, the strain energy of a two-phase linear-elastic composite is minimized by either direct or inclined simple laminates, direct or skew second-rank laminates or third-rank laminates. Then these results were applied for the construction of direct and reverse transformations limiting surfaces in strain space for elastic solids undergoing phase transformations by additional minimization with respect to the new phase volume fraction and finding the strains at which minimizing volume fraction equals zero or one. In a present paper we construct stress-strain diagrams on various straining paths at which a material undergoes the phase transformation [2]. We demonstrate that phase transformations may result in stress softening and stress hardening effects on stress-strain diagrams. We also demonstrate that an additional degree of freedom – a new phase volume fraction – may crucially result in instability of two-phase microstructures even if the microstructures are energy minimizers for composites with given volume fractions of phases. On the other hand, a two-phase microstructure may minimize the energy with respect to the new phase volume fraction but be not an optimal microstructure at the minimizing volume fraction. This in turn may lead to incompleteness of monotonic phase transformations and broken
stress-strain diagrams. We study how such a stress-strain behavior depends on a loading path and chemical energies of the phases.

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References


DESIGN OF A PIEZOELECTRIC CANTILEVER BEAM FOR ENERGY HARVESTER FOR USE IN BICYCLES

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This article describes the modeling and testing of a piezoelectric cantilever beam as an energy harvesting system for use on bicycles. The cantilever beam consists of an Aluminum beam and a piezoelectric layer, with a magnet at the end of the cantilever. The cantilever beam is excited by the repulsive magnetic force between the magnet at its tip and other nine magnets fixed on the bicycle’s wheel. When the bicycle is ridden, the cantilever beam is excited via a periodic triangular wave type of force. To have an efficient energy harvest, the piezoelectric cantilever beam must be resonantly excited at its first normal mode. Therefore the piezoelectric cantilever beam is designed so that its first resonant frequency can be easily reached at typical bicycle speeds. Experimental results show that if the cantilever’s first structural resonance frequency is an integer multiple of the triangular wave forcing frequency, the cantilever beam will vibrate at the resonance frequency and can generate power more efficiently than at other forcing frequencies. To be more specific, when forcing frequency is equal to one fold, one half, one third and one fourth of cantilever’s structural resonance frequency (corresponding to riding speed at 17.3, 8.4, 5.6 and 4.2 km/hr), cantilever beam will vibrate at resonance with larger power generation efficiency. The maximum power generated by harvester can be up to 135 μW at 8.4 km/hr speed.

EFFECT OF GRAIN BOUNDARY SLIDING ON FRACTURE TOUGHNESS OF CERAMIC/GRAFHE COMPOSITES

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A model is suggested that describes the effect of grain boundary (GB) sliding on the fracture toughness of ceramic/graphene composites. Within the model, GB sliding near the tip of a large mode I crack initiates the formation of a new nano- or microcrack at an adjacent GB. The new crack merges with the pre-existent one, thus providing crack propagation. For the situation where the suggested crack growth mechanism restricts the fracture toughness of ceramic/graphene composites, we calculated the dependence of the fracture toughness on grain size and lateral dimensions of graphene platelets. It appeared that GB-sliding-controlled fracture toughness decreases with a decrease in the grain size and/or increase in the graphene platelet length. In the case of alumina/graphene composites, GB sliding can reduce the fracture toughness of the composite if the grain size of the ceramic matrix is smaller than several micrometers. The effect of fracture toughness reduction associated with GB sliding near crack tips becomes stronger with a decrease in the grain size and/or increase in the graphene platelet length (as long as the graphene platelet length is smaller than the GB length). The results of the calculations agree with the experimental data on the fracture toughness of alumina/graphene composites.

The work was supported by the Russian Science Foundation (grant 18-19-00255).
At the current moment, a various number of mathematical models of the hydraulic fracturing are presented in scientific literature. Analytical or semi-analytical models, like the Perkins-Kern-Nordgren model, the Khristianovich-Geertsma-de-Clerk model and the Radial model, have a high evaluation speed, but the limited application field due to their simplicity. Pseudo3D model, which is, in fact, one dimensional, is fast enough to the practical application, but still is not valid into highly heterogenic reservoirs.

Planar3D model, in contrary, is valid for all types of planar fractures, including the fractures into the highly heterogenic reservoirs, but has comparatively low evaluation speed for the practical purposes. Thus, the Planar3D model application should be limited only by the cases, which cannot be numerically simulated with the proper accuracy by the other existing models. The main criteria for the analytical models applicability is the ratio between fracture length and height. If the ratio is high, the Pseudo3D model is valid, if the ratio is low – the KGD model should be used. In case of homogeneity of the reservoir conditions, the radial model should be used.

Furthermore, the existing criteria based on the parameters, which themselves are not the initial conditions of the problem, but the results of the numerical simulation. Therefore, conclusion about the model applicability can be made only after numerical modeling, which does not fit to the field applications. For that purposes, a dimensionless conditions on the initial parameters are needed. Moreover, since the analytical models were developed before the more general Planar3D model, the connection between the Planar3D model and the analytical models have not been rigorously proven yet. The main problem is that the transition between two-dimensional Planar3D model and one-dimensional Pseudo3D models are not obvious, and, as it shown into the work, does not require only the length/height ratio.

In the proposed work the dimensionless formulation of the Planar3D model was obtained, and the full set of the dimensionless parameters of the equation was derived. Using different set of conditions of small dimensionless parameters into the original equations of the Planar3D, the transition to the Pseudo3D model and analytical model was proven. Thus, the Pseudo3D model appeared to be the limit of the Planar3D model in case of low ratio between

**STUDY ON MECHANICAL CHARACTERISTICS AND DAMAGE MECHANISM OF THE LONGMAXI FORMATION SHALE IN SOUTHERN SICHUAN BASIN, CHINA**

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During the development of shale gas reservoirs, the shale mechanics parameters are greatly significant to guide reservoir drilling design, reservoir stimulation, scheme design and wellbore stability evaluation. Compared with conventional reservoirs, the mechanical properties of shale rocks are more complex and lack of the comprehensive understanding. In this study, the uniaxial and triaxial compression experiments of the Longmaxi shale in south China were conducted to understand the mechanical characteristics and damage mechanism of shale rocks. Combined with the characteristics of shale microstructure, the effects of the shale mechanics properties such as mineral composition, the deformation, stress-strain and fracture damage characteristics of shale were analyzed and discussed. The results show that the stress-strain curves of shale are two main types of elastic deformation and elastic-plastic deformation. There is a significant difference in effective pressure of yield platform in different shale post-peak deformation. The effective pressure of rigid shale is 60 MPa, and that of other shale is 30 MPa. With the increase of effective pressure, the increase of peak compressive strength decreases gradually, and the effect of effective pressure on compressive strength decreases gradually with the transition from the brittleness to the ductility. The higher the effective pressure of the brittleness to the ductility is, the greater the change of compressive strength with effective pressure is, and the smaller the compressive strength under low effective pressure is, the smaller the variation with pressure is. Shale rocks with relatively high brittleness under different effective pressures are mainly characterized by brittle split fracture dominated by tensile fracture, while the shale with low brittleness is dominated by single shear fracture plane.
DYNAMICS OF A FLEXIBLE BEAM FALLING ON A RIGID SURFACE

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An analytical solution is presented for a dynamic behavior of a flexible beam falling on the rigid surface. The developed model aims to analyze multiple collisions of the beam with the surface and clattering. The Bernoulli-Euler theory is applied to describe the motion of the beam. It is assumed that a contact of the beam with the surface is carried through end points of the beam. The contact is simulated by linear springs. The whole process of the beam falling is divided into simple regimes: no contact with the surface; one contact point; two contact points. For each regime the solution is represented by a sum of eigenmodes. The complete solution has the form of sequence of the regimes. The developed approach allows us to evaluate trajectory and process time, bending modes, stresses and contact force from the beam-surface contact. The simulation could be performed for the arbitrary orientation and initial velocities (both translational and rotational) of the beam.

In this study we estimated effect of flexural stiffness, mass, internal damping, contact stiffness and initial conditions to the dynamic response of the beam. Possible application of the model includes but not limited to a free fall event of a flexible object or a system or a device. The approach can also be used to design and evaluate for a shock absorbing system.

ENERGY ABSORPTION IN FRAGMENTED SOLIDS AND STRUCTURES

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Fragmented solids are discontinuous or heavily fractured solids, whose fragments are not joined together by any binder or connector and the integrity of these solids is only kept by compression applied at their boundaries. Mechanical behaviour of these solids is controlled by the shapes of the fragments and the properties of interfaces between them. Fragmented solids and structures are encountered in many engineering and natural systems from mortarless structures to blocky rock masses. The main features of the fragmented structures are enhanced fracture toughness, elevated energy absorptiveness and higher design flexibility. Due to the inherent discontinuity, strong stress dependence and variable internal architecture, the mechanical behaviour of fragmented structures is essentially different from that of continuous solids. In this study, we investigate the energy absorbing capacity of fragmented structures subjected to static and dynamic loads.

The ability of separate fragments to move and rotate independently within the geometric constraints imposed by the neighbouring fragments sets up the energy absorption mechanism in fragmented solids. The fragments are not bonded to each other and under application of external loads can partially lose contact (the blocks/fragments get detached at a part of their contact area forming a process that we called delamination). The compression applied at the boundaries of the fragmented structure restores these contacts and brings shifted blocks back to their place dissipating energy on friction and local contact non-linearity. In order to assess the energy absorbing capacity of a fragmented structure, we develop a non-linear continuum model that accounts for the delamination between the fragments. We introduce bending stiffness depending on the extent of this delamination, which is governed by the acting bending moment and pre-compression stresses.

We apply this model to the analysis of fragmented beams assembled of interlocking blocks and subjected to various loading conditions. We consider two cases of the boundary compression: posttensioning by tendons passed through the neutral axes of the beam cross-section and prestress provided by predefined displacement of the beam supports. We verify this model experimentally and also compare the obtained results with the finite element solution. We use all these models to investigate the influence of the interface geometry and friction on the bending behaviour and energy absorbing capacity of the fragmented beams. Simulations of cyclic loading tests demonstrate hysteretic behaviour, which results from the relative sliding of blocks. The decrease in the friction coefficient of the interfaces increases the ability of the beams dissipate energy. We also observe that the rotations of blocks increase the force in the tendon. We demonstrate that the posttensioning level controls the behaviour of the assembly.
SIMULATION OF THE DYNAMIC BEHAVIOR OF ZR-NB ALLOYS

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The results of the development of a physical-mechanical model for predicting the mechanical and deformation properties of Zr–Nb in a wide range of strain rates are presented. Mechanical behavior of Zr–1%Nb and Zr–2, 5 % Nb alloys (Grades E110, E625, E125) was studied in strain rate range from 0.001 to 1000000 1/s by the numerical simulation method. The model was used to study the mechanical behavior of coarse-grained and ultrafine Zr-Nb alloys under quasi-static and dynamic loading conditions. The model took into account the multiphase state of Zr–Nb alloys, different resistance of α, β and ω phases to plastic flow. Simulation of plastic flow, evolution of damages and destruction of alloys at uniaxial tension and compression of samples in quasi-static conditions, loading of samples by plane shock waves was carried out. It was shown the strain rate sensitivity of the flow stress of alpha Zr–1%Nb in the range from 0.001 to 100 1/s is less then at strain rates above 1000 1/s. The creation of the three-wave configuration was predicted in Zr–1%Nb due to polymorphous α → ω transition at ~11 GPa. The Hugoniot elastic limit (σHEL) and spall strength of Zr–x%Nb alloys strongly depends on beta phase concentration. Calculations have shown that increasing of the dynamic yield strength σsd = 1.5σHEL(1 – (cb/cl)^2) can be caused by an increase in the volume concentration of the beta phase in Zr–x%Nb alloys (cb, and cl are the bulk and the longitudinal sound velocity, respectively). The increase in the β phase concentration at elevated temperatures causes an increasing of the dynamic yield strength of Zr–1%Nb alloys. It was shown that ZrFe3 and βNb precipitations in Zr–2.5%Nb caused increasing of σsd and the spall strength. It was shown that the creation of bimodal grain structures in Zr–Nb alloys caused increase the flow stress while maintaining the ductile fracture in a wide range of strain rates. It was shown the strain rate sensitivity of the yield stress of Zr–Nb alloys strongly depends on the concentration of Nb. The results can be used in engineering analysis of designed technical systems for nuclear reactors.

THE MECHANICAL BEHAVIOR OF MAGNESIUM ALLOY Mg−3Al−1Zn AT HIGH STRAIN RATES AND ELEVATED TEMPERATURE

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The paper presents the results of experimental and numerical simulation studies of the mechanical behavior of the Mg–3Al–1Zn alloy at high strain rates at room and temperatures up to 673 K. The flat samples with a smooth working part and with notches with radius of 10 mm, 5 mm and 2.5 mm were used. Experimental studies were carried out on the high-velocity servo hydraulic test machine Instron VHS 40/50-20. Heating the samples with flat ceramic infrared emitters to the set temperatures took on average from 60 seconds to 160 seconds. Temperature control in the working part of the samples was carried out in real time using a K-type thermocouple (chromel–alumel). It was found that the value of tensile strain to fracture of magnesium alloy is decreased twice when stress triaxiality factor increased from 0.33 to 0.5. This effect is realized in a wide range of strain rates and homologous temperatures T/Tm from 0.32 to 0.73 (Tm=923 K is the melting point of magnesium alloy Mg–3%Al–1%Zn). The yield strength of MA2-1 magnesium alloy under tension increases almost twice within strain rates growth from 100 to 1000 1/s in temperature range from 473 K to 673 K. The obtained experimental data made it possible to determine the material parameters of modified Zerilli-Armstrong model for MA2-1 magnesium alloy. This model possesses to describe the dependence of the strain before the destruction of the MA2-1 magnesium alloy on the strain rate, temperature and the stress triaxiality factor. The results obtained can be used to develop computational models of the mechanical behavior of structures made of magnesium alloys, which are subjected to dynamic effects, plastic deformations at elevated temperatures.
The paper focuses on the calculation of the effective viscoelastic properties of a flake reinforced composite. The orientation distribution of the flakes varies from perfectly aligned fibers to randomly oriented ones. Both matrix and fibers are assumed to be isotropic. Property contribution tensors [1] are used in the context of homogenization problems to describe contribution of a single inhomogeneity. In the context of the effective elastic properties, one can use compliance contribution tensor of an inhomogeneity $H$ that gives the extra strain produced by introduction of the inhomogeneity into the otherwise uniform stress field or stiffness contribution tensor $N$ that gives the extra stress due to inhomogeneity when it is placed into the otherwise uniform strain field (1).

$$\varepsilon = \frac{1}{V} H : \sigma^- ; \quad \sigma = \frac{1}{V} N : \varepsilon^-$$

Their viscoelastic behavior is described using fraction-exponential operators of Scott Blair-Rabotnov [2]. We used Laplace transform to solve problems for linear viscoelastic materials. Results are obtained in explicit closed form. The analytical results are verified by comparison with finite element model calculations. A particular case of a viscous matrix containing randomly oriented viscoelastic inhomogeneities, allow determining the viscoelastic properties of blood.

References:

Excellent functional properties of composite core-shell nanowires (NWs) make them attractive for designing modern optical and electronic devices [1, 2]. Reliability of the devices is largely determined by the state of the NW interface boundaries including their shape, lattice mismatch and presence of defects [3, 4]. In this respect, for searching the ways of preventing the deterioration of NWs quality, it is important to create theoretical models which describe the strain relaxation processes. Most of such models treat the core-shell NWs as axisymmetric cylindrical heterostructures that makes it much easier to calculate the critical conditions for generation of misfit dislocations (MDs) [5-7]. However, such models do not consider the effect of a real polyhedral shape of NWs on the stress relaxation process [8]. Recently, we have solved a boundary-value problem in the classical theory of elasticity for cylindrical matrix containing their shape, lattice mismatch and presence of defects [3, 4]. In this respect, for searching the ways of preventing the deterioration of NWs quality, it is important to create theoretical models which describe the strain relaxation processes. Most of such models treat the core-shell NWs as axisymmetric cylindrical heterostructures that makes it much easier to calculate the critical conditions for generation of misfit dislocations (MDs) [5-7]. However, such models do not consider the effect of a real polyhedral shape of NWs on the stress relaxation process [8]. Recently, we have solved a boundary-value problem in the classical theory of elasticity for cylindrical matrix containing an inclusion in the form of a long polyhedral prism subjected to a three-dimensional eigenstrain [9]. This solution allows us to consider the critical condition for the onset of misfit stress relaxation in a composite core-shell NW with taking into account a real polyhedral shape of the core. We presume the nucleation of rectangular prismatic dislocation loops (PDLs) on both the free surface and interface in core-shell NWs with cores having the forms of long triangular, square and hexagonal prisms, and of circular cylinders as well. The energy changes due to PDL nucleation in such NWs involve the following terms: the strain energy of rectangular PDLs [10], the dislocation core energy [11], and the interaction energy between PDLs and misfit stresses. It is shown that in the case of PDL nucleation on the NW free surface and expansion into the shell, the most stable are the NWs with cores of triangular cross section, while the NWs with cylindrical cores are the least stable. In contrast, for PDL nucleation on the interface and expansion into the core, the most stable are the NWs with cylindrical cores, while the NWs with cores of triangular cross section are the least stable.

References


EVALUATION OF CRITICAL STRESSES FOR QUASI-BRITTLE MATERIALS AT VARIOUS LOADING RATES

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Engineering practice shows that the design of modern structures and technique components requires the adaptation of existing methods for testing materials to conditions of dynamic loads. On the one hand, critical stresses in materials under quasi-static loads can differ greatly from critical stresses in dynamics. However, analytical and numerical models usually use the quasi-static parameters, which can wittingly lead to erroneous predictions of the structures or products life. On the other hand, there is no generally accepted unified approach to determining the dynamic strength of materials. There are various techniques for dynamic testing of material strength. The results of these methods often lead to different or even to contradictory results. This talk will discuss the experimental and theoretical basis for determining and predicting critical stresses in quasi-brittle materials (concrete, rocks, and organic glass) over a wide range of loading rates provided by different test methods. Standard tests for compression, tension (splitting) and bending will be presented. The structural-temporal approach will be considered as a unified approach to determining the dynamic strength of materials. It will be shown that the critical stresses in the materials under a wide range of dynamic loads can be estimated based on just two parameters.

DIGITAL MODELS FORECASTING THE EFFECTIVENESS OF STRATEGIES FOR ENHANCING OIL RECOVERY

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The effectiveness of different strategies of oil recovery can be evaluated using digital models for the strategies thus enabling to choose the strategy enhancing recovery.

The mathematical models for displacement instability and viscous fingering simulations were developed making it possible to consider these processes while developing digital model for oil extraction. A criterion evaluating displacement front non-uniformity was developed. The capillary forces being the key element of seepage flows were investigated in model experiments both in artificial and natural porous media to validate digital models of seepage flows. The digital system for flow instability visualization and comparing metadata with model experiments was developed.

For simulating hydraulically driven fracture interaction with non-uniformities of the medium a modification of boundary elements numerical method was suggested, which uses displacement discontinuity method in 3-D space. The advantage of the current method is in essential decrease of computational elements number in 3-D space because final elements are placed only on the surface of a fracture simulating the discontinuity of elastic medium. Thus, the dimension of the problem is decreased. The new fundamental solutions were developed based on double layer potentials. The method proved to be effective for hydraulic fractures modeling and their interaction with natural faults in host rock formations.

The model for simulating the effectiveness of hydraulic fracture cleaning and displacing the fracturing fluid were
developed. It was demonstrated, that in relatively long fractures fracturing fluid could be entrapped thus shortening the effective length of the fracture used for collecting oil. As a test problem, the displacement of oil by water fed through a well into a horizontal oil-bearing layer is considered. The producing well at the same time may contain or not contain a fracture. It is shown that such a crack intensifies the process of oil production, but in the end, it does not lead to a total increase in oil recovery from the reservoir, but shortens time of recovery.

The digital models for core flows simulation at a microscale were developed. To develop the digital model of the core the method for extracting the system of channels and pores in the core material from the data processing of the X-ray tomography of the core sample are presented. Based on the developed pores structure numerical 3-D simulations of viscous incompressible fluid flow in this system and evaluating of porosity and permeability of this structure were performed.

EXPERIMENTAL INVESTIGATION OF BALLISTIC HEAT CONDUCTION IN SUSPENDED GRAPHENE

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Unique properties of graphene which were discovered recently in the last decade have made it a very attractive object for microelectronic applications. Due to miniaturization and increasing dissipative powers the problem of heat withdrawal became a crucial issue of designing new devices. One of the possible solutions are electrodes made of graphene which is not only good electrical conductor but also can guide excess heat to the heat sink due to it’s high thermal conductivity (reported heat conductivity above 3000 W mK⁻¹). Heat processes on such submicron level requires special treatment. When size of the structure is comparable with phonon mean free path the heat conduction reaches ballistic regime. It differs from the classical diffusive processes observed at a macrolevel. Recent experimental investigations of the ballistic heat conduction present values of coefficient of heat conductivity derived from the Fourier law and indicate heat conductivity’s size dependence [1, 2]. More advanced approach was presented recently in a study of the transient heat conduction [3]. In this work a thermal grating technique was used. It allows to create a sinusoidal heat perturbation on the surface and achieve 1D heat flow. Recent theoretical studies of lattice dynamics made it possible to introduce an alternative to the Fourier law. Such new approach describes transient ballistic heat conduction in wide range of harmonic models (1D, 2D scalar lattices) [4, 5] and proposes an original model for description of heat conduction in perfect low dimensional structures. Investigation of 1D ballistic heat conduction within the framework of phenomenological thermodynamics [6] allowed to overcome challenges occurring with wave-like heat conduction. In the current work we plan to use Scanning Thermal Microscopy to measure the steady temperature profile in the suspended circular graphene membrane which is heated in the center by a laser. As obtained in the recent numerical and analytical calculations the ballistic heat conduction causes anisotropic heat profile in the circular graphene disc [5]. The goal of the planned experiment is 1. qualitatively detect anisotropy of temperature profile and 2. distinguish it quantitatively from the Fourier law. Second task is more challenging since the description of the sample-tip contact in case of ballistic heat conduction in non-trivial. In [7, 8] a quantitative explanation of sample-tip contact is presented in detail. By using these results, we expand such technique for measuring temperature profiles in monoatomic 2D layer in order to validate the model of ballistic heat conduction in perfect low dimensional structures proposed in [4, 5].

References:
NUMERICAL SOLUTIONS OF CRACK PROBLEMS IN SECOND GRADIENT ELASTICITY

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Regularization of solutions for the bodies with cracks is one of the opportunities that is provided by the high order elasticity theories. Non infinite values of stresses in the crack tips, at the sharp edges and at the corners of the bodies allow one to use a failure criteria approaches for the prediction of strength of structures with non-smooth geometry. Implementation of gradient elasticity theories in the finite element systems and its theoretical and experimental validation is an important step for the further involvement of gradient theories in engineering practice.

In the present work we implemented the second gradient elasticity theory in the Comsol Multiphysics. Simplified constitutive models with reduced number of additional length scale parameters are involved. Accurate satisfaction of the high order equilibrium equations and accounting for the boundary conditions are checked by using exact analytical solution for the smooth and non-smooth geometry of the models, namely, we use the solutions of the inclusion problems and the solutions for the crack problems of the mode I, II and III. Influence of the mesh size on the predicted stress and strain concentration around crack tip is studied. Interaction between several cracks in the frame of gradient theory is investigated by using numerical simulations. Possibility of identification of the models additional materials constants based on the fracture test with brittle materials is studied, namely, the relations between fracture toughness parameters of fracture mechanics and the length scale parameters of second gradient elasticity is discussed.

CRYSTAL PLASTICITY ANALYSIS OF PLANE STRAIN DEFORMATION BEHAVIOR FOR PURE MAGNESIUM

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A rate-dependent elastic–viscoplastic constitutive model is proposed to research the plane strain deformation behavior of pure magnesium. The hardenings caused by slip, compressive twinning (CT) and tensile twinning (TT) are distinguished to better describe their effects on the whole deformation. The uniform parameters are calibrated with experiment data in single crystal cases. The plane strain numerical schemes of seven different orientations for loading and fixed boundary are considered and their various mechanisms and characteristics of plastic deformation are discussed. These computational predictions are carefully compared with their corresponding macroscopic experimental observations. The geometrical model of polycrystalline magnesium is developed based on the Voronoi diagram approach. The compression deformation of polycrystalline magnesium has been investigated. The results of simulation prove that it is necessary to distinguish different twinning systems and their associated hardening laws for the plastic deformation of magnesium and its alloy.

MICROMECHANICAL GLASS MODELING IN LS-DYNA

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In general glass is treated as a brittle material with a purely elastic behavior. At a micro level, however, a molecular dynamic (MD) modeling predicts that glass may demonstrate non-linearity like plastic material response at some stress-states. MD simulation allows carrying out a variety of simple material tests to define glass yield surface. The aim of this work is to develop a glass material model for finite element (FE) analysis that can accurately reflect the glass behavior at micro-scale level. FE method can be used for problems of any scale and can help to define conditions of glass contact cracking. Due to the lack of suitable material models in commercial software, the material model is implemented as a user-defined subroutine in LS-DYNA as elastic-perfectly plastic material with parabolic yield criteria. Material model performance is evaluated with a glass indentation model. The finite element modeling results compared with available
Berkovich indentation experimental data and modeling results obtained with the Von Mises and the Drucker-Prager plasticity models.

**DAMPED DRIVEN RESPONSE OF GRANULAR CHAIN, PART 2: PARAMETRIC EXCITATION**

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Regimes of resonant energy transfer remain one of intensively studied topics of both applied physics and engineering sciences. These regimes are manifested by either weak or strong energy exchanges between the different parts of coupled oscillatory models and are ubiquitous in a wide variety of physical and engineering problems. In the vast majority of the previous studies, less attention has been paid to the effect of essentially nonlinear coupling and parametric forcing on the dynamics of non-stationary regimes manifested by intense energy transfer in low and higher dimensional models. We initiated the current study with consideration of a nonstationary response emerging in the parametrically forced and nonlinearly coupled two-oscillator models. In the former model, we assumed some general coupling form, weak dissipation and parametric forcing applied on each oscillator. The main focus of the first part was the analytical description of nonstationary regimes exhibited by both models as well as the analysis of intrinsic mechanisms governing their formation and destruction. This work has been further extended to the parametrically driven, granular like oscillatory chains subjected to periodic boundary conditions and assuming essentially nonlinear coupling of a general type. In this part of the study, we present the analysis of three special regimes namely a regime of nonlinear beats, as well as the regimes of standing and moving breathers. Results of analytical study are in good agreement with the numerical ones.

**CHARACTERISATION OF HOLLOW STEEL COLUMN UNDER COMPRESSION**

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In underground mines safety of the men and materials is of prime importance. Standing mine supports are often used as passive support. This supports i.e. props are made up of hollow mild steel columns. Before installation in the mine these supports are simulated as per mining condition by applying the required compressive load in laboratory. The hollow steel column is of the same outer diameter and length but different wall thicknesses show the buckling behavior in different manner in the fix-fix end condition. After theoretical and experimental comparison it was seen that the behavior of the column is in good agreement with Rankine’s formula. Additionally, there is a very strong relation between actual buckling load and buckling load by Rankine’s formula. An extensive studies were conducted in the CSIR-CIMFR laboratory at Dhanbad. After comparing the characteristic curve and on the mathematical calculations it was observed that there is some difference between the theoretical and actual buckling load which may be due to geometrical defect, crack generation during loading, chemical composition and formation of eccentricity. The prop made up of steel hollow columns show that the variation of differences between actual and theoretical buckling load with respect to wall thickness which is parabolic in nature.

**ON KEPLER’S THIRD LAW OF 3-BODY SYSTEM**

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In 1619, ten years after the publishing of his first two laws, Kepler proposed his third law, which captured the relationship between the period T and the semi-major axis a of the motion of celestial bodies: \( T^2/a^3 = K \), where K is a constant. Kepler found these by analysing the astronomical observations of Tycho Brahe, rather than by way of mathematical deduction. Newton, who discovered the universal law of gravitation, found that the planets’ orbits conform approximately to Kepler's laws because of the small masses in comparison to that of the Sun, and hence slightly improved upon Kepler’s model by mathematical derivation. Kepler’s third law of two-body problem can also be expressed in modern notations as:
Where \( E \) is the total energy of the system that contains two gravitationally interacting point masses, \( m_1 \) and \( m_2 \), and \( G \) is the gravitational constant. Kepler’s third law has a wide range of applications, which range from the motion of artificial Earth satellites to the planets in the solar system, including the calculation of the stellar mass in the faraway universe.

There is a perfect analytical solution for the two-body problem. However, if there are more celestial bodies in the system, even one more? it would culminate in the three-body and n-body problems in celestial mechanics, which are age-old and challenging puzzles that Newton, Euler, Lagrange and Laplace have already studied. Until 1890, Poincaré determined that there is no analytical solution for a three-body problem in general, and its motion is usually non-periodic, which might explain why only five special solutions have been found under restricted conditions for over 300 years. These special solutions are now known as liberation points or Lagrange points.

Benefiting from the substantial improvement of computer ability, Moore [1] found the famous figure-eight periodic orbit for a three-body problem in 1993. In recent years, Šuvakov and Dmitraš inoviè [2] made a breakthrough in finding 13 new distinct planar periodic orbits for the special three-body problem, containing three equal masses in a plane with zero angular momentum. Li and Liao successfully gained 695 families of periodic orbits in the same three-body system and furthermore, more than 1000 periodic orbits for a similar system with unequal masses were found by using a new numerical method in Li et al.[4,5]. Moreover, based on the statistical analysis of the derived periodic orbits, Dmitraš inoviè and Šuvakov [3], Li and Liao, and Li et al [4,5]. proposed that: similar to the elliptical motion of the two-body problem, there may be a relation in the form

\[
T \left| E \right|^\frac{3}{2} = \text{constant}
\]

for the periodic motion of the three-body problem.

Does the three-body and/or n-body system have a similar Kepler’s third law for the two-body system? Recently, Bohua Sun [6] investigated this problem with the dimensional analysis, the method that Galileo and Newton had adopted, and for that which were widely recognized after Buckingham in 1914. Bohua Sun [6] proposed a complete conjecture on Kepler third law of the three-body periodic orbits by using the mass product symmetry of Newtonian gravitational field:

\[
T \left| E \right|^\frac{3}{2} = \frac{\pi}{\sqrt{2}} G \left[ \frac{m_1 m_2}{m_1 + m_2 + m_3} \left[ \left( \frac{m_1 m_2}{m_1 + m_2} \right)^{3/2} + \left( \frac{m_1 m_3}{m_1 + m_3} \right)^{3/2} + \left( \frac{m_2 m_3}{m_2 + m_3} \right)^{3/2} \right] \right]
\]

The Sun’s conjecture for classical n-body system gives results in good agreement with computations based a great number of periodic planer collisionless orbits for \( N=3 \) of [4,5]. Since the publication of, it has received good attentions [7,8,9,10]. An surprising results from Semay even found that the quantum supports Sun’s conjecture [10,11].

In this article, we will review the process of discovery and results of quantum Kepler’s third law [11].

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THE INFLUENCE OF BALCONY GREENING OF HIGH-RISE BUILDINGS ON URBAN WIND AND THERMAL ENVIRONMENT: A CASE OF AN IDEAL CITY

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In recent years, with the rapid development of urbanization around the world, buildings in the urban have a trend of high-rise and high-density development, thus the urban wind environment is shielded, which in turn aggravates the urban heat island effect. Many cities have begun to develop a vertical greening model that uses roofs, balconies, and walls to increase greening space so as to achieve the purpose of carbon reduction and to help mitigate the urban heat island effect as a countermeasure. The early built balconies were mostly within 2m in depth; these balconies mainly plant herbs or shrubs. However, there has been a new trend to build balconies with over 3m in depth and to plant trees on these balconies, such as the vertical forests in Milan, Ruo-Shan Apartment I in Taiwan and so on. However, does balcony greening really help to improve the urban wind environment and thermal environment? It is worth further discussion.

This study is based on the ideal city model of 66-high-rise-building proposed by Hang et al. (the rectangular configuration of 11 buildings × 6 buildings), in which each volume is with 30m (length) × 30m (width) × 80m (height). Based on the above-mentioned Ideal City Model, this study used two different variables of the “depth of balcony” (none, 3m-depth) and varying “green coverage rate of balcony” (0%, 50%, and 100%), and then used ANSYS Fluent 18.0 software to perform CFD numerical simulations to investigate the impact of high-rise buildings’ balconies depth and their green coverage on wind speed and air temperature on the pedestrian wind field(height: 1.75m) and urban wind field (height: 50m).

The main findings are as follows: 1. Adding a 3m-depth balcony will reduce the wind speed of the streets perpendicular to the wind direction in the central block, but increase the wind speed of the streets parallel to the wind direction slightly. 2. Adding a 3m-depth balcony will cause the temperature of the farther urban area away from the main wind direction to rise partially. 3. Increasing the green coverage of the balcony has the effect of slowing down the urban wind speed of the high-rise buildings. 4. Adding the green coverage of the balcony can effectively reduce the urban temperature.

Overall, the addition of a 3m-depth balcony to urban high-rise buildings may result in a slight increase in the wind speed on the streets parallel to the wind direction and a slight decrease in the wind speed on the streets perpendicular to the wind direction, and may cause a local increase in the temperature of the farther urban area from the main wind direction. However, when the 3m-depth balcony increased green coverage rate of the balcony (up to 50% or 100%), it was found to simultaneously achieve the obvious effect of slowing down the urban wind speed and reducing the urban temperature. It can reduce the problems of strong winds around high-rise buildings and high temperature on the leeward side of the buildings to improve the comfort of urban environment.

LARGE EDDY SIMULATION OF FLOW AROUND TWO ELONGATED PARALLEL PLATES IN A UNIFORM FLOW

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Aerodynamic vibration of high speed trains in tunnels have become a subject of discussion concerning ride comfort in Japan. Previous studies showed that the meandering flow under the train body interfered with the tunnel wall, causing pressure fluctuations on the side of the vehicle and causing the train to vibrate. However, the mechanism by which the flow under the vehicle meanders does not have been well understood. Recently, Okura et al. succeeded in reproducing this meandering flow experimentally using a simple model. They placed two elongated parallel plates in a water tank, simulating the space between the ground and the car body, and measured the flow field around it using the PIV method. Their results indicated the flow velocity difference between inside and outside a space between the plates made the flow unstable and caused the meandering flow. However, the detailed mechanism of generating the meandering flow has not been clarified.

Therefore, in this study, we carried out a numerical flow simulation around the two plates in order to clarify the mechanism. The unsteady three-dimensional Navier-Stokes equation was used as the governing equation and Large eddy simulation was performed using the Smagorinsky model. By simulating the experiment of Okura et al., two flat plates of 2.5 h in width and 100 h in length were set in parallel at an interval of h in a uniform flow. The Reynolds
number based on h is 1000. The results shows that the velocity distribution is in good agreement with the experimental result. The computed flow field clearly displays the process of generating the meandering flow as follows: As the boundary layer develops along the plates, the flow velocity difference with the outer region increases. Then, the flows becomes unstable at the boundaries on both sides of the space between the plates. The unstable flow interferes through the space between the plates, creating an alternating vortices on the left and right sides of the plates.

**THERMODYNAMICS OF HYPERELASTIC MATERIALS WITH RELAXING HEAT FLUXES**

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This work deals with hyperelastic materials under finite strain conditions. The mass density of free energy is represented as a sum of equilibrium and non-equilibrium components. The equilibrium component is a function of temperature and strain ratios. The nonequilibrium part also depends on the heat flux. The law of energy balance and the second law of thermodynamics formulated in the form of the Clausius–Duhem inequality are initial basis for the mathematical processing. The classical approach, based on the study of the independence of the laws of thermodynamics on the choice of an inertial reference system, is used to obtain consequences.

As a result of the carried out analysis of the equations specific expressions for the Cauchy stress tensor and the mass density of entropy are obtained. They are calculated using the expression for the mass density of free energy. An important result is the inequality that must be satisfied by the relationship between the heat flux, the time derivative of the heat flux, and the temperature gradient. The first and second laws of thermodynamics are valid only if this inequality is fulfilled. The law for relaxing heat flux proposed by J. C. Maxwell in 1867 and C. Cattaneo in 1948, is satisfied this inequality. The modified Fourier law proposed by A. M. Krivtsov in 2015 also satisfies this inequality. The heat conduction equation is derived as a consequence from the laws of thermodynamics of hyperelastic media with relaxing heat flux. It is established that the specific heat capacity in this case is a function also including the heat flux as additional argument. This may lead to a significant increase of temperature in a non-equilibrium state in some areas of the material and its subsequent change towards equalization. Consideration of this factor is important in solving problems of nanomechanics. Simple calculations allow us to obtain well-known conclusions about the impossibility of creating perpetual motion engines of the first and second kind for the materials under consideration.

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**RESONANT EXCITATION OF THE ROTATING PREDOMINANTLY TANGENTIAL WAVES IN THE ANNULAR DOMAINS**

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According specifications of resonant acoustic rotating waves in circular and annular domains [1], there are two classes of resonant rotating waves, namely, predominantly tangential and predominantly radial, in terms of predominance of tangential or radial components of the vectors of vibrational velocities and displacements. At that all predominantly tangential resonant angular velocities $\omega_{kr}/kR/c$, $i = 1, k = 1, 2, 3,...$ for all values of $\rho$, where $\rho$ is the ratio of the inner radius of the annular domain to its outer radius $R$, are assembled into the self-isolating single low-frequency branch, whereas predominantly radial ones, $i = 2, 3,...$ fill the entire high-frequency region very densely. This provides a simple effective way for resonant excitation of the rotating predominantly tangential waves in annular domains.

The device operates as follows [2]. It uses a continuous steady-state operation. When the rotor revolves, its impeller and/or external blower ensure that the working medium is fed into the internal cavity of the rotor axially, i.e. in the direction of its axis of rotation. Next, through the $k$ uniformly arranged windows along the circumference of the rotor, the working medium under pressure enters radially the resonant annular chamber – the concentric area between the outer surface of the revolving rotor and the inner surface of the stator, thereby creating the rotating acoustic load in the form of $k$ angular rays, or "spokes", corresponding to the rotor windows. The acoustic load rotating with the rotor excites resonant oscillations in the form of rotating waves inside the annular chamber when the rotational frequency of the load coincides with the abovementioned self-isolating single low-frequency branch for all predominantly tangential resonant waves. At resonance optimal conditions are created for pumping the energy of an external source into a mechanical oscillatory system with distributed parameters, namely, acoustical system, because the vibrational velocity and pressure in the working medium – compressible gas or fluid, become in-phase. The condition for occurrence of the resonance, namely, the coincidence of the frequency of the external load with the natural frequencies of vibrations of the system, or, which is the same for this device, the coincidence of the angular velocity of rotation of the acoustic load with the cited single self-isolating low-frequency branch of the angular velocities of rotation of the natural waves.
\[ \omega_{ik}/kR/c, \ i = 1, \ k = 1, 2, 3, \ldots, \] must be strictly fulfilled with the proper rpm choice of the rotor.

References:

**ASSESSMENT OF THE INFLUENCE OF NON-SPHERICAL INCLUSIONS ON EFFECTIVE MECHANICAL PROPERTIES UTILIZING THE REPLACEMENT ESHELBY TENSOR APPROACH**

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The presence of inclusions within an otherwise homogeneous material affects all kinds of mechanical properties, being extensively treated in the field of continuum micromechanics. Eshelby’s fundamental solution, allowing the assessment for stress and strain fluctuations provoked by an individual ellipsoidal inclusion in the course of loading, became an integral part of a wide range of homogenization approaches covering mechanical properties such as elastic behavior, strength and flow characteristics.

The present contribution discusses the extension of these approaches to non-ellipsoidal inclusions by applying the replacement Eshelby tensor approach recently proposed in [1]. The key concept of this approach is the modification of the Eshelby tensor by two adjustment factors characterizing the inclusion shape. The latter are obtained by one finite element simulation determining the influence of a single inclusion on the elastic material response. At first, the application of the approach for homogenization of elastic and plastic properties is outlined. Secondly, the effect of non-ellipsoidal inclusions on flow properties such as the effective viscosity is targeted. Therefrom obtained effective properties for selected inclusion morphologies are compared to direct numerical simulations.


**ACOUSTOELASTIC EFFECT IN METALS WITH DAMAGE**

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Acoustic anisotropy is the relative difference between velocities of bulk shear waves with orthogonal polarization. It is one of the main characteristics of the acoustoelastic effect. The linear relationship between the velocities of ultrasonic waves and mechanical stresses was experimentally found by P. W. Bridgman [1] and explained in later work [2]. The theoretical description of acoustoelastic effect in weakly anisotropic and textured metals [3] was confirmed experimentally [4].

The classic approach to study of acoustoelastic anisotropy is based on the linearization of mechanical characteristics along the direction of propagation of acoustic wave [4]. This approach was applied on specially prepared metals. In this case, contribution of elastic deformations is in range from 0% to 0.3% of acoustic anisotropy and contribution of inelastic deformations is in range from 0% to 8%. For the case of plastic deformations, the non-monotonic dependence of acoustic anisotropy on deformations was observed. Moreover, the nonlinear macroscopic distribution of acoustic anisotropy was observed along the axis of destroyed specimens. This effect cannot be described using theory [4].

The aim of this work is to study the additional contribution to value of acoustic anisotropy that leads to appearance of residual nonlinear waves of acoustic anisotropy. These waves were observed in specimens after destruction. It was experimentally established that acoustic anisotropy of the surface layer of metal has a significant contribution to integral value of the acoustic anisotropy. It was observed on steel and aluminum specimens from industrial alloys after monotonous stretching and cyclic loading. Mechanical removal of the surface layer has a significant influence on value of integral acoustic anisotropy. It allows to separate the contribution of mechanical stresses from contribution of other factors. For example, measurements on weakly loaded parts of structures were previously required to evaluate the intrinsic acoustic anisotropy. Thus, one of the main problems of non-destructive testing with the use of acoustic anisotropy can be solved.

The obtained result allows to extend the method of estimating stress-strain state using acoustic anisotropy for the case of plastic deformations of structures.

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We consider formation of an intermetallic compound (IMC) composed of tin (Sn) as a base of a lead-free solder and copper (Cu) as a substrate. Although the presence of the IMC layer is one of the requirements of a reliable solder joint, the excessive formation of a brittle IMC may lead to interconnection deterioration [1]. The growth of an IMC layer is often accompanied by an accumulation of cavities (Kirkendall voids) in the vicinity of the interface between the IMC and pure materials [2,3]. This leads to the reduction of an effective cross-sectional area in the IMC zone and, as a result, to the amplification of a current crowding effect. In turn, the current crowding may lead to the failure of a solder joint due to heat release. Thus, the lifetime of a solder interconnect depends on cavities formation.

The cavities near the interface form due to diffusion of vacancies that occurs due to diffusion of Cu in the process of the IMC growth. In the present work we take into account that the diffusion rate if affected by the electric field, considering the phenomenon of electromigration (EM) (see, e.g., [4]), and by the chemical reaction rate of IMC growth. The chemical reaction rate is affected additionally by mechanical stresses at the reaction front.

The influence of the mechanical stresses on the reaction rate is considered based on the chemical affinity tensor concept (see, e.g., [5]). The approach to modelling the influence of mechanical stresses on the IMC formation via the influence on the reaction rate was utilized in [6]. In the present paper we also focus on the role of the electric current. We relate the kinetics of the IMC growth under the action of the stress and electric fields with the kinetics of the cavities formation at the interface. Finally, the estimation of a solder interconnect life expectancy is proposed based on the idea that the open circuit failure happens upon reaching the critical volume of cavities at the interface between the IMC and pure materials.

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The article deals with solving the inelastic deformation problem of a continuous medium as applied to the description of floor heaving of rocks in workings. This is the ubiquitous manifestation of rock pressure in single mine workings, both in coal and ore deposits. It is expressed in the form of the ground raising, reaching significant values comparable to the size of mine workings and leading to its functionality loss.

Floor heaving is a process stretched in time for weeks, months, or even years. It should be noted that so far it has not been constructed an adequate description of such floor heaving process. Theories of elasticity, plasticity, granular medium in their various versions and modifications do not include the time parameter in their ratios, and therefore are not acceptable in this situation. The concept for solving the problem under consideration within the framework of continuum mechanics, which is usually used in solving various problems of geomechanics, is a hereditary theory of creep. At the present time it is considered that the most acceptable theoretical approach is the hypothesis about the loss of the elastic-plastic stability of the rock mass in the vicinity of a single working.

However, the deformation of the mine working contour is not only due to the floor heaving. Side wall divergence can also reach tens of centimeters, often leading to a complete overlap of its opening. Such a strain at the existing in an array level of load is difficult to associate with a loss of rock massif stability with such a complex shape of a deformed boundary, which indicates a different mechanism of deformation during heaving.

In the article, the construction of the floor heaving problem solution is carried out within the framework of the theory of viscoplasticity. This approach may also reflect the time dependence of the deformation process, since the equations of state are formulated in terms of increments or strain rates. Creep deformation is characterized by a deformation rate, which generally is a function of the stresses, time and, possibly, temperature. Bearing in mind the deformation of rocks in situ, the influence of the latter value can be ignored.

The form of this function can be constructed experimentally for each specific material as a result of numerous experiments on samples followed with statistical processing of the results obtained. However, in theoretical studies a variety of simplified analytical dependencies, mostly of a power type, are used. The article discusses different options for the numerical calculation of a viscoplastic deformation both with a constant deformation rate over time, and with a decreasing rate, when the total deformation reaches a constant level after a certain period of time.

From practice it is known a phenomenon of forming a rift in the soil; that is when, together with raising the soil along its center line, a tensile crack passes along. Analysis of the stresses in the soil rocks shows that their horizontal component is tensile, despite the compressive initial stresses in the rock massif.

To preserve the working capacity of the mining working, disrupted and squeezed into the mining working layer of soil, is removed after a certain time. It is known that action of such kind usually produced 2-4 times, after which the floor heaving on this site completely stops. Within the framework of the viscoplastic model, the main regularities of the processes occurring during the disruption of the soil are considered.

The most studies on dynamic fracture of brittle materials can be divided on two distinct types. The first one involves theoretical and experimental investigations aimed to explore fracture mechanism of material with macroscopic defects like a crack. The scope of the second type is analyzing fracture of intact matter without pre-cracks or inclusions etc. The most phenomena of dynamic fracture under high strain-rate load in whole are similar for both intact materials and ones with macroscopic cracks. The strain-rate dependency on strength and the fracture delay phenomenon (a fracture occurs during constant or descending stage of local force field) are among them. It is developed that the delay phenomenon which observed experimentally either in spall test of intact matters or dynamic fracture tests of cracked materials can be explained in the framework of incubation time approach.
VIBRATION TECHNOLOGY RESEARCH ACHIEVEMENTS OF THE MEKHANOBR SCIENTIFIC SCHOOL AND THEIR INDUSTRIAL APPLICATIONS

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Vibration effects play a special role in the processing of natural and technogenic materials. Vibration alters material properties and enables modification and streamlining of process flows. When designing and improving vibration equipment and technology, a number of unique new problems of mechanics and the theory of nonlinear oscillations emerge. It becomes increasingly urgent to improve the analytical and numerical methods for studying the effects of vibration on various systems and media and to research respective vibration excitation methods and workflows. The report provides an account of the main developments in these areas, ensured mainly by the Mekhanobr Institute. The achievements of recent years are considered in detail.

The main theoretical works cover the discovery and development of the theory of self-synchronization of rotating bodies, the development of the theory of vibrational displacement, the creation of new analytical approaches to studying the effects of vibration on nonlinear systems and media, vibrational mechanics and vibrational rheology; the discovery and research into a number of nonlinear vibration effects, the development of the theory of vibrational classification, and the creation of process and strength design methods for machines.

The main applied developments include the creation of a set of laboratory vibration equipment and a unique experimental base, including the universal vibration stand.

The industrial applications for the research cover the design of a new class of highly efficient vibration machines, such as crushers, screens, separators, flotation machines, etc.

STRESS CONCENTRATION AND DISTRIBUTION IN CERAMIC COMPOSITES WITH TRIPLE JUNCTION PORES

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Most of ceramics and ceramic composites contain pores, which are considered as one of the main features in the structure of ceramic materials [1, 2]. The type, size and distribution of pores in ceramics strongly depend on the technology used for their synthesis and further processing. The common place is the presence of pores at grain boundaries (GBs) and their triple junctions (TJs). In these cases, pores make a great contribution to the brittleness of ceramics because they play the role of stress concentrators and sources for intergranular cracking. Therefore, the study of stress concentration due to the presence of pores located at GBs and TJs is of primary importance for developing theoretical models of stress relaxation, plastic deformation and fracture in ceramics under external loading.

In work [3], the perturbation method was used to solve the problem of a solid with a nearly circular hole. These results can be extended to a more complex problem of stress distribution, for example, in the vicinity of a TJ pore. In the present work, we attack this problem by both the analytical and numerical means. In doing so, we use the Goursat – Kolosov complex potentials, the Muskhelishvili representations and the universal boundary perturbation technique as well. Following Muskhelishvili [4], the complex potentials are found out in terms of power series in small parameter. In each-order approximation of the boundary perturbation method, the problem is reduced to solving the independent Riemann – Hilbert boundary problems. An algorithm for finding any-order approximation expressed in elementary functions is suggested. The analytical results are given in an explicit form for the first-order approximation. To solve the described problem numerically, we use the finite-element method. The analytical and numerical results are compared and discussed in detail.

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SIMULATION OF HYDROGEN THERMO-DESORPTION SPECTRA FOR CYLINDRICAL IRON SAMPLES

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Hydrogen critically affects the mechanical properties of materials. The diffusion of atoms and molecules in a solid, as a phenomenon, also most often concerns the transport of hydrogen. Other substances diffuse in metals much slower and this diffusion leads to practical results, mainly at high temperatures.

Under close to normal conditions, hydrogen is practically the only element with high diffusion mobility in solid metals. Thus, the diffusion of hydrogen is the most important mechanism of its influence on the mechanical properties of metals.

Hydrogen is located inside the metal in traps of various nature, from which it is redistributed using the “diffusion channel”.

The most famous and popular method for studying these traps and diffusion is the Thermo-Desorption Spectra (TDS) method. Samples of a metal with a hydrogen charge are slowly heated in a vacuum or in an inert gas. The heating rate is constant. The traps are emptied, diffuse and release hydrogen through the surface of the sample.

The total flux of hydrogen from the sample is fixed by the measuring device. The time dependence of the hydrogen flux is called the TDS spectrum. The presence of several maxima in such a spectrum is unambiguously related to the presence of traps of different nature inside the sample.

We obtained new data that with standardized charging of metals with hydrogen there is a thin surface layer, in which the concentration of hydrogen is about 100 times greater than inside the sample.

The task of the study was to establish the effect of this surface layer on TDS. The simulation was carried out for a cylindrical sample with a diameter of 8 mm. The thickness of the surface layer was chosen to be 100 μm.

As the hydrogen diffusion model, the standard Fick model was chosen, with the diffusion coefficient depending on temperature exponentially according to the Arrhenius equation. A linear variation of the sample temperature was simulated. Standard iron values of all parameters were selected.

Modeling using the diffusion temperature analogy in the ANSYS package did not allow us to obtain an adequate result, since the integration resulted in time-oscillatory solutions associated with the instability of the integration scheme. It was written its own code that implements the integration scheme with an implicit time integration method.

An extraction curve was obtained with two maxima, which are not associated with different binding energies of hydrogen, but with its uneven distribution after charging of metal samples. This result allows us to explain the multiple discrepancies in the values of the hydrogen binding energies in the traps of the same nature, which were obtained using the standard TDS method.

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ON THE METHOD OF VARIABLE INTERVAL

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The present paper is devoted to the development of a method, firstly proposed by L.I. Slepyan, for searching an approximate solution of a nonstationary problem. The application area of this approach is extended to linear systems of equations including both hyperbolic and parabolic types. For solving boundary value problems we often use integral transformations that allow to reduce a partial differential equation to an ordinary one. As a result the problem consists in restoring the original function by the given image, when it is necessary to integrate expressions with singular points on the real axis or branch points. Even if it can be overcome, the resulting expressions usually contain special functions and are inconvenient for further research. Greater difficulties arise in the analysis of nonlinear equations when from the very beginning one has to reflect about using numerical approaches, which in most cases do not allow to isolate the region of parameters providing the transition of the system to the desired state and to estimate the duration of this transition. Thus, we often need a clear method of obtaining approximate analytical expressions, which gives the possibility to predict the dynamics of the system and to separate the physics of the process from the effects introduced by numeric procedure.

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REPLACEMENT RELATIONS FOR A VISCOELASTIC MATERIAL CONTAINING MULTIPLE INHOMOGENEITIES

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Classical replacement relations provide a connection between elastic properties of a porous material and the same material with fluid or solid infill of the porous space. We derive such relations for the case when both skeleton and infill materials are viscoelastic. For this goal, we use formalism of compliance/stiffness contribution tensors that lead to replacement relations for anisotropic elastic materials that, in the case of isotropy, coincide with classical Gassmann equation (Gassmann, 1951). We rewrite these relations using creep and relaxation contribution tensors that describe effect of individual inhomogeneities on the overall viscoelastic properties of a heterogeneous material. Explicit analytical expressions are obtained using elastic-viscoelastic correspondence principle and Laplace transform. It becomes possible when viscoelastic properties are expressed in terms of fraction-exponential operators of Scott Blair–Rabotnov. Results are obtained in closed explicit form.

NUMERICAL AND EXPERIMENTAL STUDY OF DYNAMIC YIELDING

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Numerical and experimental study of dynamic yielding is performed for Taylor impact test. The experimental scheme was originally proposed to evaluate dynamic yield stress of material in accordance to conventional von Mises approach. A cylindrically-shaped specimen impacts rigid anvil for a range of initial velocities. The simplest analysis based on the change of the specimen length makes it possible to evaluate critical yield stress as a function of the loading rate. However, numerical simulations of Taylor test utilizing von Mises approach with yield stress calculated according to usual procedure does not provide a good correspondence to the final specimen shape received experimentally. At the same time, other approaches (ex. based on Johnson-Cook or Zerilli-Armstrong plasticity models) give much better coincidence of the specimen final shape. However, they are much more complicated and contain a big number of fitted constitutive parameters with unclear physical meaning. Thus, the choice of a plasticity model for analysis of a rather simple processes is not evident. It will be demonstrated that von Mises approach can be applied with including friction and given beforehand a strain-rate dependency of yield stress. The study of specimens with various length to diameter ratio demonstrated that the utilized value of the yield stress should provide good coincidence between the predicted and the real specimens final length and diameter simultaneously. Then obtained strain-rate dependencies of the yield stress are in good correspondence to analytical predictions based on the incubation time criterion. Moreover, specimens with higher length-to-diameter ratio give values of yield stress that are much closer to the calculated ones. Thus, Taylor test could be a method to evaluate the incubation time for the process of dynamic yielding. On the other hand, von Mises approach enhanced with the incubation time makes it possible to numerically simulate dynamic yielding in the simple case of Taylor impact test.

MUDSTONE CREEP EXPERIMENT AND NONLINEAR DAMAGE MODEL STUDY UNDER CYCLIC DISTURBANCE LOAD

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To study the creep characteristics of mudstone under disturbed load, creep rock triaxial compression disturbance tests under different disturbance amplitudes and frequencies are conducted using a self-made triaxial disturbed creep test bench for rock. The influence of different factors on the creep deformation law of each stage is analyzed. The results show that the disturbance effect has a significant impact on the creep properties of mudstone, and various factors have different effects on the creep stages. The instantaneous creep variable, creep decay time and steady creep rate change exponentially with the increase in axial pressure, and increase linearly with the increase in disturbance amplitude and disturbance frequency. The disturbance amplitude has a more significant effect on the instantaneous creep, steady-state creep rate, and accelerated creep. According to the analysis of the test results, a nonlinear disturbance creep damage model based on Burger’s model is established. The model is identified and calculated by the improved least squares
method based on pattern search. The influence of different disturbance factors on the creep parameters is analyzed. The model fitting results and experimental results are compared to demonstrate that the model is used to simulate different disturbances. It was observed that rock creep under certain conditions exhibits certain adaptability.

**NONCOVALENT INTERFACE BETWEEN MELAMINE AND GRAPHENE OXIDE: ATOMICSTIC MECHANISM AND DESIGN OPTIMIZATION**

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Noncovalent interactions, due to the features of breaking and reforming, as well as the potential mechanisms of cooperativity and anticooperativity, play important roles in the performance and design of interface-governed materials and devices. However, the complex nature of noncovalent interactions always overshadows their advantages to material design. The commonly assumed low strength of noncovalent interactions also weakens their tunable ability in the interface-dominated materials at atomistic scale. Recently, we found that the melamine–GO interface exhibits a remarkable noncovalent binding strength up to ~1 nN, even comparable with typical covalent bonds. This feature makes the noncovalent interface a promising candidate for maintaining a balance between the strength and the toughness of graphene-based artificial nacreous materials. The first-principle calculations revealed that the anomalous O–H···N hydrogen bonding, formed between the triazine and the hydroxyl group, is found cooperatively enhanced by the amino–π interaction, which is responsible for the strong noncovalent interface. The large-scale molecular dynamics simulations illustrated that the inter-layer shear strength can be greatly improved by tuning the content of melamine molecules between GO bilayer. Combining with the nonlinear shear-lag model, we can engineer the strength and toughness of melamine–GO nacre-like paper through the content of melamine and the size and oxide degree of GO. Our investigation deepens the understanding on the chemo-mechanical behaviors within the melamine–GO interface, which is expected to provide new potential strategies in designing high-performance graphene-based artificial nacreous materials.

**VIBRATION CHARACTERISTIC ANALYSIS OF VISCOELASTIC SANDWICH CYLINDRICAL SHELL**

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The inherent characteristics of viscoelastic laminated cylindrical shells has carried on the theoretical calculation. Use two calculation methods with freedom and spring constraints to calculate the experimental model of literature. The results of spring constraint method are more relatively close to experimental measured results of these two calculation methods, confirmed the correctness of the calculation method. In addition, Ansys simulation is carried out on the model calculation results calculated results are consistent with the theory of free constraints.

Cylindrical shell is a common structure form, its shape characteristic is the thickness of the size of the shells than the other two directions on the order of magnitude small. Because of the cylindrical shell with small thickness, light quality, material consumption, good performance, therefore they are widely used in aviation, aerospace, shipbuilding, civil engineering and machinery and other industries. Such as container and the supply of oil, chemical industry, aviation, aircraft skin in the aerospace industry, shipbuilding industry in the submarine's yacht, an instance of the cylindrical shells are applied to engineering.

With the rapid development of industry and shell structure is widely used, people on the performance of the cylindrical shell are also put forward higher requirements. The traditional single material performance of a single cylindrical shell, poor controllability, already cannot satisfy the complex environment the demand for its static and dynamic characteristics. With the development of materials science and mechanical manufacturing technology progress, people will be two or more materials together with physical and chemical method, a composite structure. It on the physical properties of various components of the material is different, each component has obvious interface between materials. Is actually a kind of composite structure material, composite material of various materials on the performance of complement each other, each other to produce synergistic effect, make the comprehensive performance is better than that of the original composition of composite materials and meet the different requirements. Composite laminated cylindrical shells with light weight, high strength, and the advantages of good design, so more and more widely used in modern engineering structures.

Through the comparison of theoretical calculation and experiment proved the correctness of the theoretical calculation method. This method can be used to solve the natural frequency of other size and material of viscoelastic laminated
cylindrical. At the same time, by comparing the theoretical calculation results, the simulation results and experimental results can prove the correctness of the simulation method, that provides a method to solve natural frequency of the complex structure of viscoelastic laminated cylindrical shell.

**HIGH-TOUGHNESS Zr$_{61}$Ti$_{3}$Cu$_{25}$Al$_{12}$ BULK METALLIC GLASS: FAILURE UNDER TORSIONAL LOADING AND MODE III FRACTURE TOUGHNESS**

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From torsional tests of cylindrical samples, we have determined the torsional properties of high-toughness Zr$_{61}$Ti$_{3}$Cu$_{25}$Al$_{12}$ (ZT1) bulk metallic glass (BMG), including its shear yield strength, $\tau_y=950$ MPa, its shear elastic strain limits, $\gamma=3.0\%$, and its shear modulus, $G=31.5$ GPa. Under torsional loading, the BMG fails via a major shear band, without obvious macroscopic plasticity on the specimen surface. The shear band maintained stable propagation by a distance of $\sim300$ $\mu$m ($\sim20\%$ of cylinder radius) before final catastrophic failure, owing to the constraint of stress gradient along the radial direction. The intrinsic mode III fracture initiation toughness is measured for the Zr$_{61}$Ti$_{3}$Cu$_{25}$Al$_{12}$ BMG, which is known to have a high mode I fracture toughness ($K_{IC}$). The plastic strain intensity factor $\Gamma_{pl}$ was used as a measure of the fracture resistance under elastic-plastic conditions. The intrinsic mode III fracture initiation toughness of ZT1 BMG, $\Gamma_{III}$, is found to be $29$ m, equivalent to a $K_{III}$ of $51$ MPa$m^{1/2}$. The corresponding fracture energy release rate is similar to or higher than that of conventional engineering metals such as high-strength aluminum alloys and some steels. The subcritical crack growth in ZT1 prior to catastrophic fracture is characterized by an extension of a microscopically zig-zag crack front. ZT1 exhibits a relatively low ratio of $K_{III}/K_{IC}$ of $\sim0.39$, indicating that the material is more susceptible to mode III fracture. In engineering design with BMGs, the mode III fracture toughness is thus a useful baseline to ensure the reliability of structural components.

**THE CONTACT PROBLEM FOR A SYSTEM OF PUNCHES AND THE ELASTIC BASE**

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The model for study of the effect of fragmented rigid coating in contact interaction of the rigid punch with coated elastic base is proposed. This problem arises as a result of fragmentation of solid surface which is used in various tribojunctions. For example, in the work [1] authors showed that the surface nanolayer at the boundary of polyurethane implants can be cracked after ion-plasma treatment.

The general method to study two-dimensional contact problems at different types of boundary conditions in the contact region and examples of solutions of particular problems are presented in [2, 3]. 2-D periodic problem for a system of punches with a flat base and the elastic half-plane in the presence of adhesion and slippage zones in the contact region is solved in [4].

In this paper the contact problem for the limited system of punches with flat base and the elastic half-plane under the conditions of full adhesion is investigated. The system is loaded by forces modeling the effect of rigid body indentation. The method of solving the contact problems under consideration is based on consideration the contact problem for a single punch taking into account the loads acting outside of the contact area due to the influence of the neighboring punches on the indentation of a single one [5]. The influence of the density of the punches on the contact and internal stresses arising in interaction and on the delamination of the punch surface from the half-plane is analyzed. Obtained results allow us to compare the characteristics of the contact interaction in the cases of solid and fragmented coatings.

The work was supported by the Russian Science Foundation, grant 18-19-00574.

**References**


THERMAL ANALYSIS FOR AN X-AXIS FEED DRIVE SYSTEM

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The feed drive system is one of the key parts in precision machine tools. The improvement of high-speed feed drive systems has been a principal subject in the machine tool industry for the past few decades. In particular, the errors coming from thermal expansions of the machine elements attributable to heat sources are the most important concerns affecting the accuracy of machine tools. This study devised a coupled thermal-structure model via the finite element method (FEM) to accurately predict the transient temperature and thermal deformation fields of an X-axis feed drive system. We then compared the FEM predictions against the measured temperatures at the saddle and axial deformations at the screw of feed drive for validation of the computational model. This paper further explores the thermal behavior of the X-axis feed drive system at different feed rates and screw stroke lengths. From the simulation results, the friction at the contact areas from the screw stroke, bearings and motor can produce enormous heat, causing thermal deformations for the deterioration of machine tool accuracy. It should be also noted that the thermal deformations of the X-axis feed drive on the rear motor side are greater than those on the motor side. This can be attributed to the higher heat generation from bearings of the rear motor side and greater stiffness on the motor side. The studied results can facilitate better understanding of the thermal responses and estimate of the deformations for the X-axis feed drive system.

ON THE FINITE ELEMENT ANALYSIS IN GENERALIZED MECHANICS

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Various finite element implementations have been proposed in the literature for computation in generalized mechanics involving higher order space derivatives of displacement, see for example [1]. As experimental observations are challenging in generalized mechanics [2], a purely computational benchmark problem is beneficial to highlight the differences or even validate a novel approach. We present a relatively simple analytic solution and validate two methods for the numerical implementations of strain gradient elasticity.

The first one is a mixed-type finite element implementation based on a penalty approach [3]. The mixed FEM utilizes the standard C0 Lagrange shape functions; however, not only displacements but also displacement gradients are used as nodal degrees of freedom. Kinematic constraints between displacement gradients are enforced via a penalty term. The second implementation of strain gradient theory is based on the isogeometric analysis (IGA) [4]. The employed IGA possesses several advantages, the most appealing thing in the context of strain gradient theory is the usage of globally higher-order continuous basis functions. Both approaches are implemented by using open source packages developed under the FEniCS project.

References
THE SCATTERING OF SH WAVES BY A CIRCULAR CAVITY IN INHOMOGENEOUS MEDIUM

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Based on the principle of homogenization, harmonic dynamic stress of the radially inhomogeneous medium with a circular cavity can be investigated by using the complex variable function method. The shear modulus in the medium is a constant. In polar coordinates, the density is only positively correlated with the radial direction. Due to the continuous change of the density, the governing equation of SH waves propagation in the unbounded space is a Helmholtz equation with variable coefficients. It can be equivalently transformed into a standard Helmholtz equation by applying conformal transformation method (CTM). Then, the displacement fields and stress fields in inhomogeneous medium can be obtained. Finally, the distributions of dynamic stress concentration factor (DSCF) around the circular cavity in radially inhomogeneous medium can be obtained. The change in density parameter of the medium is found to affect the dynamic stress concentration factor (DSCF) around the circular cavity.

DYNAMICS OF DISK-BASED MEMS CORIOLIS VIBRATING GYROSCOPE

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In the present work, a micromechanical wave solid-state gyroscope with a disk resonator is investigated. An analytical formulation of the problem of free oscillations of a disk in the absence of rotation is considered. The decision is based on article [1]. The solutions are compared with the thin ring problem [2]. The frequencies and vibrational shapes of a disk on a fixed platform are determined analytically using MATLAB-BVP and numerically in ANSYS. When solving in ANSYS used the condition of the type "cyclic symmetry". A comparison of numerical and analytical results. Frequencies and vibration modes of a disk on a fixed platform taking into account Coriolis inertia forces are obtained analytically using MATLAB-BVP and numerically in ANSYS. The effects of centrifugal inertia forces on the frequencies and modes of vibration are studied. The problem of free oscillations of a rotating disk is considered with allowance for centrifugal and Coriolis inertial forces. A numerical solution of the problem was carried out using MATLAB and ANSYS. A comparison was made of the results of their interpretation. An analytical discrete model of a wave solid-state gyroscope with a disk resonator was constructed on the basis of the article [3]. An analytical study of the basic oscillator model with two orthogonal degrees of freedom, which oscillates in a rotating plane, is carried out. The solution of the problem of small oscillations is obtained. The dependence of frequencies and modes of oscillations on the magnitude of the angular velocity of rotation is investigated.


MODELING HIGH-RATE DEFORMATION AND FRACTURE OF METAL RINGS BY THE MAGNETIC PULSE TECHNIQUE

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Description of the behavior of the material under extreme conditions is an urgent task of modern research. It’s of great importance for engineering practice. The experiment of ring specimens provides a unique opportunity to determine homogeneous deformation at fracture, rather than localized. The magnetic-pulse methods has several advantages for modeling dynamic loads in the laboratory. High rates of deformation of materials is one of conveniences this technique. Samples are investigated under conditions of pure tension. This fact allows to exclude the effect of reflected waves that there is during impact. Thus, the proposed technique is able to conduct a series of controlled experiments on the fracture
of materials over a wide range of strain rates.

Based on the results of numerous experiments carried out using the developed methods of magnetic-pulse loading, deforming and fracture of thin metal ring specimens in a wide time range, the previously proposed mathematical models for calculating the circumferential stress function were improved. Due to this it became possible to describe the change of circumferential stress over time at various stages of loading in a wide range of strain rates. The construction of the model is given from the standpoint of the dislocation dynamics. The three most typical situations of the relation between the velocity of mobile dislocations and their density as functions of stress and strain are considered.

1. The law of dislocations multiplication in the case of small deformations $N_m = N_0 + \alpha \gamma$, where $\alpha$ - coefficient of dislocation multiplication, $\gamma$ - shearing plastic strain, $N_m$ - density of mobile dislocations, $N_0$ - original density of dislocations. The relation between dislocation rate and shear stress is linear (viscous trapping of dislocations)

$$v_d = (\tau - \tau_0) b / B,$$

where $\tau$ - shear stress, $\tau_0$ - characteristic stress, $b$ - value of Burgers vector, $B$ - coefficient of dislocations trapping.

2. The law of dislocations multiplication in the form of Gilman $N = (N_0 + \alpha \gamma) \exp(-H \gamma / \tau_s)$, where $H$ - coefficient of material strengthening, $\tau_s$ - maximum shear stress. The rate of mobile dislocations is selected in the from $v = v_{dm} \exp(-\tau_0 + H \gamma / \tau_s)$, where $v_{dm}$ - maximum rate of mobile dislocations.

3. The law of dislocations multiplication $N = (N_0 + \alpha \gamma) \exp(\gamma' / \tau_s)$, where $\gamma'$ - rate of shearing plastic strain. The rate of mobile dislocations $v_d = v_{dm} \exp(-\tau_0 + H \gamma / \tau_s)$.

**MODEL OF THE EFFECT OF LOW NATURAL CONCENTRATIONS OF HYDROGEN ON CYLINDRICAL STEEL SAMPLES**

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Small amount of hydrogen concentration impact appears significantly in material fatigue and cracks propagation. Resonant effect is observed at fatigue. This effect was described by a model of bicontinuous medium containing hydrogen [1] and was detected experimentally later [2].

Significant impact of small diffusion – mobile hydrogen concentration to metal fatigue was observed in non-cyclic static and dynamic loading. Hydrogen embrittlement areas were localized. Hydrogen embrittlement sites were formed during metal fracture. Model HELP (Hydrogen-enhanced localized plasticity) is generally used to describe the observed phenomena [3]. The base physical mechanism couldn’t be represented in the critical hydrogen concentration, which could be observed experimentally. This and calculation complication are major weak points of the model.

During the testing it had been found that hydrogen was concentrated in a thin boundary layer at the surface of a metal specimen [4]. A model describing the degradation of properties only in a thin boundary layer were prepared, and there was no significant effect on the deterioration of the physicomechanical characteristics, according to the data in [5]. To simulate a significant deterioration of the physicomechanical properties of the model, similar to what is happening in the experiments, a model with varying bilinear elastic-plastic properties is proposed, corresponding to the saturation of hydrogen after its accumulation in the actual structure for several years.

The finite element method used to simulate the effect of degradation of the mechanical characteristics of the entire sample caused by hydrogen saturation. The simulation carried out for the case of cylindrical corset samples, for which there are extensive experimental data.

Analysis of the calculation results shows that the behavior of the material under the influence of hydrogen occurs not only in the zone of elastic deformations. It is noticed that the degradation of the mechanical characteristics of the metal under the influence of hydrogen leads to a significant change in deformation and strength. The material model used for the entire sample allows one to describe experimentally observed effects.

The financial support of the Russian Foundation for Basic Research, grants 17-08-00783-a and 18-08-00201-a, is acknowledged.

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GENERALIZED CUBIC QUINTIC MODIFIED KDV EQUATION IN NONLINEAR WAVE MECHANICS

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We study a nonintegrable modified KdV equation containing a combination of 3rd and 5th degree nonlinear terms that simulate waves in a three-layer fluid, as well as in spatially one-dimensional nonlinear-elastic deformable systems. It is established that this equation passes the Painlevé test in a weak form. It is shown that, in a traveling wave variable, this equation reduces to a generalized equation for the Weierstrass elliptic function, the right side of which is determined by a 6th order polynomial in the dependent variable. Depending on the structure of the polynomial roots, the general solution of the equation is expressed in terms of the Weierstrass elliptic function or its successive degenerations — rational functions depending on the exponential functions of the traveling wave variable or directly on traveling wave variable. The classification of exact solitary-wave and periodic solutions is carried out, the ranges of parameters necessary for their physical feasibility are revealed. An approach is proposed for analytically constructing approximate solitary-wave and periodic solutions of generalized Weierstrass equations with a polynomial right-hand side of high orders.

NUMERICAL SIMULATION STUDY ON CASING STRENGTH OF UNDERGROUND GAS STORAGE AND AN OPTIMIZATION METHOD OF CASING

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The casing of underground gas storage is under complex stress conditions because of the injection-production alternating loads and the influence coming from the intensive injection and withdrawal of injection-production wells. It is crucial for the long-term safety of injection-production wells of underground gas storage to conduct casing optimization and to decrease casing stress. A three-dimensional parametric finite element model of injection-production well of underground gas storage was built by employing the finite element software ABAQUS and the PYTHON scripting language. The whole process of model building was recorded by the PYTHON scripting language. It is very easy to automatically build a different model by editing and running the PYTHON script file. The model includes casing, cement sheath and formation. The spiral perforation completion was conducted in the model. The injection-production process was simulated by adopting the data coming from a field injection-production well of underground gas storage. The temporal and spatial distribution of von Mises stresses of the model was obtained from the simulation results. In order to check if the casing stress can meet relevant safety requirements, the von Mises stress of the casing was checked by employing the fourth stress strength criterion. A study on the influence of the model parameters was carried out by changing the parameters one by one, as a result of which the optimal structure and dimensions of the casing were obtained.

TUNABLE ASYMMETRIC ELASTIC WAVE PROPAGATION IN PRESTRESSED TENSEGRITY METASTRUCTURE

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Tensegrity is prestress-controlled structure with its shapes and stiffness determined by the stretched string components and therefore, possesses tunable static as well as dynamic properties. In this presentation, a prismatic tensegrity
structure with axial-torsional-coupling effect is first investigated with a theoretical model. Then, tensegrity metasstructures are designed to demonstrate the interesting wave selection and conversion between the compression-dominated and the torsion-dominated elastic waves, which are further utilized to achieve asymmetric wave propagations in the tensegrity metastructures. Moreover, it is demonstrated that by just changing the prestress distribution in a periodic tensegrity chain, the asymmetric wave propagation can be readily realized without any structural design, which can lead to the in-situ tunable elastic wave devices. Finally, nonreciprocal wave propagation is achieved by applying the time-space modulated prestress on the tensegrity metastructure. The proposed prestress-controlled tensegrity metastructure could be useful in the applications of directional wave reflectors and vibration isolators.

**MECHANICAL INVESTIGATION OF BIOSYNTHESIZED BACTERIAL CELLULOSE NANOCOMPOSITES THROUGH MULTISCALE MODELING**

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Cellulose-based nanomaterials have emerged as a new generation of sustainable materials with promising applications in materials science and engineering, in which the cellulose nanocrystal plays an important role due to its excellent mechanical properties and tunable surface chemistry at nanoscale. Therefore, understanding of the mechanical behavior of cellulose nanocrystals and associate underlying mechanisms at nanoscale should be crucial for promoting the bottom-up design of cellulose-based nanomaterials with tailored properties. Recently, Yu and his co-workers reported a general and scalable biosynthesis strategy to achieve 3D bacterial cellulose (BC) nanofibril networks, which can also be used to obtain high-performance functional bulk nanocomposites within the co-deposition process of various kinds of nanoscale building blocks. The biosynthesized BC nanocomposites exhibit extremely high mechanical strength compared with common polymer composites reinforced by carbon nanotubes or reduced graphene oxide. Here, we perform molecular dynamics simulations and finite element analysis through multiscale modeling to understand the effects of inter-fiber hydrogen bonding and complex 3D network on the final mechanical properties of biosynthesized BC nanocomposites. We also consider the modification of mechanical properties of cellulose nanocrystal with shear-lag model to improve the multiscale modeling.

**CALCULATING ACTIVATION ENERGIES OF TITANIUM, MANUFACTURED WITH 3D PRINTING TECHNOLOGY, USING MULTICHANNEL HYDROGEN DIFFUSION MODEL**

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The most popular method for calculating activation energies of hydrogen is the method of thermo-desorption spectra (TDS). The disadvantage of this method is that it does not consider diffusion inside the metal. Essentially, only surface sorption and desorption can be adequately studied using this method. All this leads to large variations of experimentally evaluated activation energies for the same materials.

In the paper a method for calculating activation energies, based on experiment data, is offered. The measurements were done on an industrial mass-spectrometric hydrogen analyzer AV-1, which uses hot vacuum extraction. The authors of the paper suggest using step heating in a vacuum to measure the activations energies of hydrogen in titanium. Meaning, that a certain extration temperature is set, which remains constant throughout the analysis. After the background flows of hydrogen settle, the studied sample is moved from the cold part of the vacuum extractor into the analytic part, where the amount of hydrogen, released from the sample at this temperature, is calculated. When the flow of hydrogen from the sample becomes comparable to the background flows, the analysis is terminated. To do this, the sample is moved back to the cold part of the extractor, where it cools down in a vacuum. Afterwards, the next extraction temperature is set and after the background flows settle, the analysis repeats. The advantage of the suggested method is the ability to subtract the background flows, which can be greater than the flow from a sample.

The mathematical model was based on the model of multichannel diffusion of hydrogen. The calculations of hydrogen flows and their time integrals, which characterize integral experimental results on every temperature step, were done using a program written in Fortran. The parameters of the sample and the experiment conditions were entered into the program. The integration was done using the explicit fourth-order Runge-Kutta method. As a result, the activation energies of hydrogen diffusion were calculated. Using these activation energies a graph of discrete thermo-diffusion spectrum was plotted, which was then compared to the graph obtained during the experiment. The work was done with the support from the grants: RFBR № 18-31-00329, 18-08-00201, 17-08-00783.

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BASIC PROPERTIES OF MODEL GRANULAR MATERIALS, WITH OR WITHOUT COHESION

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A review is presented of some recent research results on the rheophysical behaviour of granular materials, with some emphasis on cohesive systems. It focusses on the model systems for which a micromechanical approach exploiting grain-scale numerical simulations has been carried out, with systematic comparisons to laboratory experiments.

The critical state, in the sense of geomechanics, i.e., the state reached after large monotonically imposed strains, in which the material quasistatically flows at constant density under constant deviator stress, has proved a very fruitful concept, leading to significant progress in the understanding of dense granular flows and suspension rheology. The characterization of the state of the flowing material by the inertial number (a non-dimensional form of shear rate accounting for inertial effects) and some generalizations thereof, proved a particularly efficient approach. In the presence of adhesive forces, the second most influential control parameter is the ratio $P^*$ of applied stress to tensile contact strength (put in dimensionless form using the grain diameter).

The resistance to shear is strongly increased by adhesive forces as $P^*$ decreases, and we show how a macroscopic cohesion, in the Mohr-Coulomb sense, can be estimated from micromorphological parameters.

Cohesive materials, of which wet granular assemblies, endowed with capillary cohesion, are a convenient example, may be stabilized with very low densities, forming loose and tenuous contact networks similar to colloidal particle clusters. Those loose states, the structure of which depends on the aggregation process, tend to collapse irreversibly under increasing stress. This plastic compression process has been studied and its dependence on some micromechanical features such as rolling resistance characterized. These results are discussed in the context of the classification of static granular packing states, and perspectives on more complete rheological modeling are evoked.

FLOW OF GRANULAR MATERIAL: FROM THE COLLAPSE OF AN ANTHILL TO THE DESTRUCTION OF THE ANTARCTIC ICE SHEET

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Granular media, with a large number of unconnected grains, form, and can flow, in many natural and industrial situations, from anthills through rockfalls, volcanic eruption outputs, grain silo collapses, demolition of large buildings through to dislodgment of giant ice bergs from the edge of an ice sheet. The talk, which will be illustrated by a series of desk-top simulations, will discuss granular collapse in either air or water resulting in a propagating gravity current and/or a different steady structure. Despite the presence of small-scale volcanic eruptions, building collapses and huge ice berg formations on the front desk during the colloquium, the audience is guaranteed to be safe.

ELABORATION AND ANALYSIS OF FUNCTIONAL FOREARM PROSTHESIS WITH NEURO-PHYSIOLOGICAL CONTROL SYSTEM

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The analysis of advanced developments in the field of upper limb prosthetics is given. The anatomy of the human hand is analyzed. The problem of the minimum necessary functional of the prosthesis is analyzed. The developed and created model of prosthetic is given. The kinematics and dynamics of each finger module of prosthetic was investigated. Equation for calculation of the trajectories of finger phalanges was derived. Equation for calculation of force on every phalanx of the finger was derived. The trajectories of finger phalanges for the created prosthesis were calculated. A prosthetic control system is being developed. It based on the registration of neurophysiological signals. Results of prosthesis tests on a real patient were carried out.
STABILITY PROBLEMS IN MECHANICS: MULTIPHYSICS & MULTISCALE ASPECTS (A MECHANICIAN’S PERSPECTIVE...)

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Stability is a fascinating topic in solid mechanics that has its roots in the celebrated Euler column buckling problem, which first appeared in 1744. Over the years advances in technology have led to the study of ever more complicated structures first in civil and subsequently in mechanical engineering applications. Aerospace applications, most notably failure of solid propellant rockets, led the way in the 1950s. Problems associated with materials and electronics industries came on stage in the 1970s and 1980s, starting with instabilities associated with thin films and phase transformations in shape memory alloys (SMA’s), just to name some of the most preeminent examples. In a parallel path, starting in the late 19th century, mathematicians studying nonlinear differential equations, developed the concept of a bifurcation (term coined by Poincare) and created powerful techniques to study the associated singularities, followed by advances in group-theoretical methods that exploit the problem’s underlying symmetries. Amazing progress has been made since the early days of structural buckling problems and continues to be made in this field, with applications ranging from atomistic to geological scales. With the advent of new materials, the number of applications in this area continues to progress with an ever-increasing pace.

In this plenary talk we present selected applications of stability problems involving phenomena a) across spatial scales and b) driven by multiphysics coupling. In the first class of applications we visit – by decreasing the size of the underlying scale – the instabilities occurring in fiber reinforced composites, honeycomb and crystal lattices (shape memory effects). In the second class, we present stability problems in magnetoelastic thin films, liquid crystals and step-bunching in epitaxial thin film deposition. In all these applications, we use both continuum description of the problem at hand or appropriate micromechanical models and the mathematical tools of bifurcation theory and symmetry groups.
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