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“Advanced Problems in Mechanics”

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BOOK OF ABSTRACTS

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General Information

The International Conference "Advanced Problems in Mechanics – 2015" is the forty third in a series of annual summer schools held by Russian Academy of Sciences. The Conference is organized in commemoration of its founder, Ya. G. Panovko by the Institute for Problems in Mechanical Engineering of the Russian Academy of Sciences (IPME RAS), Peter the Great St.Petersburg Polytechnic University (Institute of Applied Mathematics and Mechanics), Scientific Council on Solid Mechanics (RAS) (chairman N. F. Morozov), Russian National Committee on Theoretical and Applied Mechanics (chairman I. G. Goryacheva) under the patronage of the Russian Academy of Sciences (RAS). The main purpose of the meeting is to gather specialists from different branches of mechanics to provide a platform for crossfertilisation of ideas.

The list of problems under investigation is not limited to questions of mechanical engineering, but includes practically all advanced problems in mechanics, which is reflected in the name of the conference. The main attention is given to problems on the boundary between mechanics and other research areas, which stimulates the investigation in such domains as micro- and nanomechanics, material science, physics of solid states, molecular physics, astrophysics and many others. The conference "Advanced Problems in Mechanics" helps us to maintain the existing contacts and to establish new ones between foreign and Russian scientists.

Young scientists' school-conference "Modern Ways in Mechanics" (MWM), which is held within the annual international conference "Advanced Problems in Mechanics" (APM), is meant for broadening scientific outlook of young researchers in the field of mechanics and also for organizing their scientific dialogue. It is supposed that students, Ph. D. students and young Ph. D.'s under 30 (date of birth is later than 12/31/1984) from different all over the world, specializing in the sphere of theoretical and applied mechanics become the main participants of the conference. In order to attract the largest possible number of various scientific areas and schools, organizing committee suggests a partial compensation for the costs connected with participation in conference, as well as extensive cultural program. One of the major purposes of conference is transfer of scientific experience from well-known scientists to their young colleagues.

History of the School

The first Summer School was organized by Ya.G. Panovko and his colleagues in 1971. In the early years the main focus of the School was on nonlinear oscillations of mechanical systems with a finite number of degrees of freedom. The School specialized in this way because at that time in Russia (USSR) there were held regular National Meetings on Theoretical and Applied Mechanics, and also there were many conferences on mechanics with a more particular specialization. After 1985 many conferences and schools on mechanics in Russia were terminated due to financial problems. In 1994 the Institute for Problems in Mechanical Engineering of the Russian Academy of Sciences restarted the Summer School. The traditional name of "Summer School" has been kept, but the topics covered by the School have been much widened, and the School has been transformed into an international conference. The topics of the conference cover now all fields of mechanics and associated into interdisciplinary problems.

Scientific Committee

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The conference is organized with help of our service agency “Monomax PCO”: www.monomax.ru

Scientific Program

Presentations devoted to fundamental aspects of mechanics, or spreading the field of applications of mechanics, are invited. We are particularly keen to receive contributions that show new effects and phenomena or develop new mathematical models. The topics of the conference cover all fields of mechanics, including, but not restricted, to

- mechanics of media with microstructure, phase and chemical transformations
- nano-and micromechanics
- computational mechanics
- wave motion
- nonlinear dynamics, chaos and vibration
- solids and structures
- fluid and gas
- mechanical and civil engineering applications
- aerospace mechanics

Accompanying Events

[MS1] Minisymposium "Engineering dynamics of structures in interaction with solids, fluids and moving loads" (charman: A.V. Metrikine , TU Delft, The Netherlands)
[MS2] Minisymposium "Continuum physics and discrete mechanics applied to astrophysical phenomena (charmen: A.M. Krivtsov, SPbPU, IPME RAS, Russia and V.H. Mueller, Technical University of Berlin Faculty V, Institute of Mechanics, Chair of Continuum Mechanics and Materials Theory, Germany)

Four different forms of presentations are offered, namely, plenary lectures (45 minutes), presentations at minisymposia and short communications (20 minutes), and posters.
The working language for oral presentations is English. Regrettably we can not provide simultaneous translation, and due to the international nature of the conference all the oral presentations must be in English.
The working languages for poster sessions are English and Russian.
Attention: each participant may only give ONE oral presentation. The number of posters for each participant is not limited.
The Summer School – Conference has two main purposes: to gather specialists from different branches of mechanics to provide a platform for cross-fertilization of ideas, and to give the young scientists a possibility to learn from their colleagues and to present their work. Thus the Scientific Committee encouraged the participation of young researchers, and did its best to gather at the conference leading scientists belonging to various scientific schools of the world.
We believe that the significance of Mechanics as of fundamental and applied science should much increase in the eyes of the world scientific community, and we hope that APM conference makes its contribution into this process.
We are happy to express our sincere gratitude for the help in organization to Russian Foundation for Basic Research, Russian Academy of Sciences (RAS). This support has helped substantially to organize the conference and to increase the participation of young researchers.

Day 1 – Monday, June 22

08.30–09.45	REGISTRATION
09.45–10.00	OPENING CEREMONY
10.00–11.30	PLENARY LECTURES – I
	COFFEE BREAK
11.50–13.20	PLENARY LECTURES – II
	LUNCH BREAK
14.15–15.15	MWM OPENING
15.15–16.40	MWM PRESENTATIONS
	COFFEE BREAK
17.00–18.30	MWM POSTERS, POSTER SESSION

18.30 WELCOME PARTY

Day 2 – Tuesday, June 23

ROOM I

10.00–11.30	PLENARY LECTURES – III
	COFFEE BREAK
11.50–13.50	MECHANICS OF MEDIA WITH MICROSTRUCTURE, PHASE AND CHEMICAL TRANSFORMATIONS – I
	LUNCH BREAK
14.50–16.50	MECHANICS OF MEDIA WITH MICROSTRUCTURE, PHASE AND CHEMICAL TRANSFORMATIONS – II
	COFFEE BREAK
17.10–18.30	MECHANICS OF MEDIA WITH MICROSTRUCTURE, PHASE AND CHEMICAL TRANSFORMATIONS – III

EXCURSION

ROOM II

11.50–13.50	NONLINEAR DYNAMICS, CHAOS AND VIBRATION
	LUNCH BREAK
15.00–16.50	SOLIDS AND STRUCTURES – I
	COFFEE BREAK
17.10–18.50	SOLIDS AND STRUCTURES – II

EXCURSION

Day 3 – Wednesday, June 24

ROOM I

10.00–11.30	PLENARY LECTURES – IV
	COFFEE BREAK
11.50–13.10	ENGINEERING DYNAMICS OF STRUCTURES IN INTERACTION WITH SOLIDS, FLUIDS AND MOVING LOADS – I
	LUNCH BREAK
14.50–16.50	ENGINEERING DYNAMICS OF STRUCTURES IN INTERACTION WITH SOLIDS, FLUIDS AND MOVING LOADS – II
	COFFEE BREAK
17.10–18.10	ENGINEERING DYNAMICS OF STRUCTURES IN INTERACTION WITH SOLIDS, FLUIDS AND MOVING LOADS – III

ROOM II

11.50–13.10	FLUID AND GAS
	LUNCH BREAK
15.00–16.50	COMPUTATIONAL MECHANICS – I
	COFFEE BREAK
17.10–18.30	COMPUTATIONAL MECHANICS – II
	BANQUET

Day 4 – Thursday, June 25

ROOM I

10.00–11.30	PLENARY LECTURES – V
	COFFEE BREAK
11.50–13.20	PLENARY LECTURES – VI
	LUNCH BREAK
14.40–16.10	MECHANICAL AND CIVIL ENGINEERING APPLICATIONS – I
	COFFEE BREAK
16.30–17.50	MECHANICAL AND CIVIL ENGINEERING APPLICATIONS – II
	SPORT ACTIVITIES

ROOM II

14.50–16.10	NANO- AND MICROMECHANICS – I
	COFFEE BREAK
16.30–17.50	NANO- AND MICROMECHANICS - II
	SPORT ACTIVITIES

Day 5 – Friday, June 26

	ROOM I		ROOM II
10.00–11.30	PLENARY LECTURES – VII		
	COFFEE BREAK		
11.50–13.20	PLENARY LECTURES – VIII		
	LUNCH BREAK		
14.15–16.00	CONTINUUM PHYSICS AND	14.20–16.00	WAVE MOTION
	DISCRETE MECHANICS APPLIED TO ASTROPHYSICAL PHENOMENA - I		
	COFFEE BREAK		
16.20–18.00	CONTINUUM PHYSICS AND		
	DISCRETE MECHANICS APPLIED TO ASTROPHYSICAL PHENOMENA – II		
18.00	**CLOSING CEREMONY**		

Day 6 – Saturday, June 27

EXCURSION

Day 1 – Monday, June 22

08.30–09.45 **REGISTRATION**

09.45–10.00 **OPENING CEREMONY**

10.00–11.30 **PLENARY LECTURES – I**

Chair: D.A. Indeitsev.

10.00–10.45 ***A.M. Krivtsov.*** One-dimensional crystals and heat superconductivity.

10.45–11.30 ***W.H. Müller.*** Mechanics of celestial bodies: An old but long neglected branch of the mechanics community.

11.30–11.50 **COFFEE BREAK**

11.50–13.20 **PLENARY LECTURES – II**

Chair: A.M. Krivtsov.

11.50–12.35 ***A.V. Metrikine.*** Dynamic stability of structures interacting with generalized flows

12.35–13.20 *M. Wang, X. Gao, S. Li, E.A. Zimmermann, C. Riedel, B. Busse,*

V.V. Silberschmidt. Fracture processes in cortical bone: effect of microstructure.

LUNCH BREAK

14.15–14.30 **MWM OPENING**

Chair: A. Kuznetsova.

14.30–15.15 ***M.L. Kachanov.*** Rough fractures versus traction-free cracks: similarities and differences.

15.15–16.40 **MWM PRESENTATIONS**

Chair: A. Kuznetsova.

16.40–17.00 **COFFEE BREAK**

17.00–18.30 **MWM POSTERS, POSTER SESSION**

18.30 WELCOME PARTY

Day 2 – Tuesday, June 2

ROOM I

10.00–11.30 **PLENARY LECTURES – III** *Chair: A.B. Freidin.*

10.00–10.45 ***R. Kienzler,*** *P. Schneider.* Consistent Plate Theories.

10.45–11.30 ***V.A. Babeshko,*** *O.V. Evdokimova, O.M. Babeshko, E.M. Gorshkova, I.B.Gladskoi.* Directed antenna for block structure.

11.30–11.50 **COFFEE BREAK**

11.50–13.50 **MECHANICS OF MEDIA WITH MICROSTRUCTURE, PHASE AND CHEMICAL TRANSFORMATIONS – I** *Chair: A.D. Sergeyev.*

11.50–12.20 Key-note lecture. ***S. Rudykh.*** Multiscale design of functional composites.

12.20–12.50 Key-note lecture. ***A.B. Freidin,*** *S.E. Petrenko, E.N. Vilchevskaya.* Kinetics of chemical reaction fronts in elastic and inelastic solids.

12.50–13.10 *E.A. Ivanova*, ***E.N. Vilchevskaya.*** Formulation of dynamic problems for the micropolar continuum in Eulerian description.

13.10–13.30 ***A.L. Korzhenevskii.*** Strain induced incommensurate structures in vicinity of the reconstructive phase transitions.

13.30–13.50 ***E.L. Aero,*** *A.L. Korzhenevskii.* Theory of plane stress structures in crystals experiencin austenite-martensite phase transformation.

LUNCH BREAK

14.50–16.50 **MECHANICS OF MEDIA WITH MICROSTRUCTURE, PHASE AND CHEMICAL TRANSFORMATIONS – II** *Chair: E.N. Vilchevskaya.*

14.50–15.10 ***C. Liebold,*** *W.H. Müller.* Generalized continua and size effects in elastostatic bending experiments.

15.10–15.30 ***L.L. Sharipova,*** *A.B. Freidin.* Kinetics of phase transitions in elastic and inelelastic solids.

15.30–15.50 ***V. Bratov,*** *E. Borodin.* Comparison of dislocation density based approaches for prediction of defect structure evolution in aluminium and copper processed by ECAP.

15.50–16.10 ***A.L. Glazov,*** *K.L. Muratikov*. Photoacoustic thermoelastic imaging of indented areas in metals.

16.10–16.30 ***E.V. Shishkina,*** *S.N. Gavrilov.* Scale-invariant initial value problems with applications to the dynamical theory of stress-induced phase transformations.

16.30–16.50 ***A.I. Shveykin,*** *P.V. Trusov, E.R. Sharifullina, T.V. Ostanina, P.S. Volegov*. The multilevel model of inelastic and superplasticity deformation of polycrystalline metalls.

16.50–17.10 **COFFEE BREAK**

17.10–18.30 **MECHANICS OF MEDIA WITH MICROSTRUCTURE, PHASE AND CHEMICAL TRANSFORMATIONS – III** *Chair: V. Bratov.*

17.10–17.30 ***P.S. Volegov,*** *D.S. Gribov, A.Yu. Yanz, D.G. Selukov, A.I. Shveykin.* Multilevel modeling of deformation of polycrystals with a small grain size under complex loading.

17.30–17.50 *V Lalin,* ***E. Zdanchuk.*** The strong and the weak form of the initial boundary-value problem for the linear reduced Cosserat continuum.

17.50–18.10 ***S.N. Shubin,*** *A.B. Freidin.* Elastomer composites with phase-changing fillers in sealing application.

18.10–18.30 ***A.D. Sergeyev,*** *D.A. Indeitsev.* The local criterion to simulate long-wave dynamics penomena in a regular multi-body chain by means of the 1D-continuum dynamics.

Day 2 – Tuesday, June 23

ROOM II

11.50–13.50 **NONLINEAR DYNAMICS, CHAOS AND VIBRATION**

Chair: D.Yu. Skubov.

11.50–12.10 ***M.A. Guzev.*** The system of inverted pendulums.

12.10–12.30 ***I.I. Blekhman,*** *L.I. Blekhman, L.A. Vaisberg, V.B. Vasilkov, K.S. Ivanov, K.S. Yakimova.* Nonlinear vibration-induced effects in mechanisms, fluids, loose and combined media: new results.

12.30–12.50 *N.V. Naumova, V.S. Sabaneev,* ***P.E. Tovstik,*** *T.P.Tovstik.* Vibrations of thin elastic body in contact with an incompressible fluid.

12.50–13.10 ***A.B. Morgulis,*** *K.I. Ilin.* Steady streaming in a vibrating container at high Reynolds numbers.

13.10–13.30 ***F. Maurin,*** *A. Spadoni.* Wave propagation in buckled-beams.

13.30–13.50 ***M.V.Shamolin.*** Multidimensional pendulum in a nonconservative force field.

LUNCH BREAK

15.00–16.50 **SOLIDS AND STRUCTURES – I**

Chair: V.V. Silberschmidt.

15.00–15.30 Key-note lecture. ***A. Roy,*** *V. Nekouie, V.V. Silberschmidt*. Indentation study of mechanical behaviour of Zr-Cu-based metallic glass.

15.30–15.50 *V. Flambaum, G. Martin,* ***B. Pavlov***. A resonance mechanism of earthquake.

15.50–16.10 ***M.B. Babenkov,*** *A.M. Krivtsov, D.V. Cvetkov*. Initial value problems for the heat transfer process in ideal crystals.

16.10–16.30 ***Yu. Vetyukov***. Buckling and supercritical behavior of axially moving plates.

16.30–16.50 ***A.Y. Zemlyanova.*** A new model of fracture with a curvature-dependent surface tension.

16.50–17.10 **COFFEE BREAK**

17.10–18.50 **SOLIDS AND STRUCTURES – II**

Chair: E.A. Podolskaya.

17.10–17.30 *M.M. Dannert,* ***V.A. Kuzkin.*** Dynamic buckling of a column under constant rate compression: analytical solution and finite element study.

17.30–17.50 ***A.R. Dehadrai,*** *I. Sharma, S.S. Gupta.* Dynamics of a large ring-shaped structure towed via a heavy rope.

17.50–18.10 ***A.P. Kiselev.*** Non-plane surface waves in anisotropic layered medium.

18.10–18.30 ***G.V. Kostin,*** *V.V. Saurin*. A projection approach to vibration analysis of elastic beams with the triangular cross section.

18.30–18.50 *A.H. Sargsyan,* ***S.H. Sargsyan.*** Geometrically nonlinear static theory of thin elastic micropolar shallow shells.

EXCURSION

Day 3 – Wednesday, June 24

ROOM I

10.00–11.30 **PLENARY LECTURES – IV**
Chair: I.E. Berinskii.

10.00–10.45 ***S.A. Lurie,*** *P.A. Belov, N.P. Tuchkova, E.D. Lykosova.* Role of superficial effects in modeling of behavior of superthin scale- depend structures: beams, plates and shells.

10.45–11.30 ***S. Bordas,*** *L. Beex, E. Atroshchenko, K. Miller, P. Kerfriden.* Adaptive multi-scale methods for fracture, CAD, image as a model and digital twins.

11.30–11.50 **COFFEE BREAK**

11.50–13.10 **ENGINEERING DYNAMICS OF STRUCTURES IN INTERACTION WITH SOLIDS, FLUIDS AND MOVING LOADS – I**
Chair: A.V. Metrikine.

11.50–12.10 ***E. Lourens,*** *T.S. Nord, O. Øiseth.* Ice load identification on the Nordströmsgrund lighthouse.

12.10–12.30 *J.M. de Oliviera Barbosa,* **W.G. Versteijlen,** *K.N. van Dalen, A.V. Metrikine.* Method for extracting equivalent Winkler model of a 3D dynamic soil-structure interaction model for large-diameter offshore monopile foundations

12.30–12.50 ***A. Tsouvalas,*** *A.V. Metrikine.* Structure-borne wave radiation generated by offshore pile driving.

12.50–13.10 ***J.S. Hoving,*** *A.V. Metrikine.* A mixed time-frequency domain method to describe the non-smooth dynamic behaviour of a nonlinear medium bounded by a linear continuum.

LUNCH BREAK

14.50–16.50 **ENGINEERING DYNAMICS OF STRUCTURES IN INTERACTION WITH SOLIDS, FLUIDS AND MOVING LOADS – II**
Chair: A.V. Metrikine.

14.50–15.10 ***S.N. Gavrilov.*** The paradox of a discontinuous trajectory for a mass particle moving along a string revisited.

15.10–15.30 ***T. Lu,*** *A.V. Metrikine.* On the existence of a critical speed of a rotating ring under a stationary point load.

15.30–15.50 ***C. Keijdener,*** *A.V. Metrikine.* A simple discrete element model of a dynamic geometrically nonlinear Timoshenko beam.

15.50–16.10 ***A. Jarquin Laguna,*** *A. Tsouvalas*. A semi-analytical impulse response method for transient laminar flow in hydraulic networks.

16.10–16.30 ***J. Barbosa,*** *Y. Qu, E.M. Lourens, A.V. Metrikine.* Influence of a plane boundary on the response of a freely vibrating cylinder in uniform flow.

16.30–16.50 ***R. van Vliet,*** *A.V. Metrikine.* Derivation and validation of a discrete model for a vibrating plate, based on Mindlin-Reissner theory.

16.50–17.10 **COFFEE BREAK**

17.10–18.10 **ENGINEERING DYNAMICS OF STRUCTURES IN INTERACTION WITH SOLIDS, FLUIDS AND MOVING LOADS – III**
Chair: A.V. Metrikine.

17.10–17.30 ***P. van der Male,*** *K.N. van Dalen, A.V. Metrikine.* Simulated nonlinear aerodynamic excitation of a rotating aerofoil.

17.30–17.50 ***M. Zhao,*** *K.N. Van Dalen, A.V. Metrikine.* 3D scattering of seismic waves at a cylindrical cavity in an elastic half space.

17.50–18.10 ***F.W. Renting,*** *K.N. van Dalen, J.M. de Oliveira Barbosa, A.V. Metrikine.* Interaction of a 2-D acoustic waveguide and an Euler-Bernoulli beam.

BANQUET

Day 3 – Wednesday, June 24

ROOM II

11.50–13.10 **FLUID AND GAS**

Chair: S.A. Chivilikhin.

11.50–12.10 ***E.V. Prozorova.*** Influence the effects of delay and dispersion in mechanics.

12.10–12.30 ***D.V. Voronin.*** Modeling of the flow ignition in a planar vortex chamber.

12.30–12.50 ***I.K. Marchevsky,*** *S.R. Grechkin-Pogrebnyakov.* Vortex element method adaptation for flow numerical simulation using GPU.

12.50–13.10 ***S.A. Chivilikhin,*** *P.A. Pavutets.* The calculation of planar stokes flow with free boundary in homobaric approximation.

LUNCH BREAK

15.00–16.50 **COMPUTATIONAL MECHANICS – I**

Chair: I.A. Brigadnov.

15.00–15.30 Key-note lecture. *A. Schiavone,* ***L.G. Zhao.*** Modelling of stent deployment and deformation in diseased arteries by considering vessel anisotropy.

15.30–15.50 ***A. Le-Zaharov.*** A study of thermal conductivity in crystal structures using particle dynamics approach.

15.50–16.10 ***E.Yu. Vitokhin.*** Numerical analysis of temperature distribution in a layer heated by the short laser impulse with regard to a heat flux relaxation constant.

16.10–16.30 ***V.F. Nikitin,*** *N.N. Smirnov.* Computation of hydrogen-air mixture detonation with OpenMP multiprocessing on a supercomputer.

16.30–16.50 ***V.D. Sulimov,*** *N.N.Smirnov.* Hybrid global optimization for computational diagnostics of hydromechanical system.

16.50–17.10 **COFFEE BREAK**

17.10–18.30 **COMPUTATIONAL MECHANICS – II**

Chair: L.G. Zhao.

17.10–17.30 ***I.A. Brigadnov.*** Engineering estimation of bearing capacity of solids.

17.30–17.50 ***A.V. Zaitsev,*** *I.Yu. Zoubko, O.Yu. Isaev, D. V. Smirnov, I. A. Sudakov.* Inelastic Deformation of Flexible Graphite O-Ring Seals and Seal Packs under their Exploitation in Stop Valves.

17.50–18.10 ***N. Kazarinov,*** *V. Bratov, Y. Petrov, L. Witek, A. Bednarz.* Numerical simulation of ceramic plate penetration by cylindrical plunger.

18.10–18.30 ***A.I. Dmitriev,*** *W. Österle.* Possible impact of nanoparticles on polymer matrix properties.

BANQUET

Day 4 –Thursday, June 25

ROOM I

10.00–11.30 **PLENARY LECTURES – V**

Chair: V.A. Kuzkin.

10.00–10.45 ***T. Shimada,*** *T. Kitamura.* Multi-physics properties in low dimensional Ferroic nanostructures from quantum-mechanics calculations.

10.45–11.30 ***A.M. Linkov,*** *L. Rybarska-Rusinek.* Numerical simulation of seismicity induced by mining.

11.30–11.50 **COFFEE BREAK**

11.50–13.20 **PLENARY LECTURES – VI**

Chair: E. Pavlovskaia.

11.50–12.35 ***V.A. Levin,*** *T.A. Zhuravskaya.* Detonation stabilization in a supersonic flow of a gas mixture in the channel of a special shape without any energy input.

12.35–13.20 ***P. O'Brien.*** From Fundamental Research to Commercial Reality.

LUNCH BREAK

14.40–16.10 **MECHANICAL AND CIVIL ENGINEERING APPLICATIONS – I**

Chair: R.A. Arutyunyan.

14.40–15.10 Key-note lecture. ***E. Pavlovskaia,*** *A. Postnikov, M. Wiercigroch.* Modelling of vortex induced vibrations.

15.10–15.30 ***B.E. Melnikov.*** Mean stress evolution in irregular cyclic loading of aluminium alloy.

15.30–15.50 ***S.V. Petinov.*** Aspects of fatigue crack growth assessment.

15.50–16.10 ***I. Smirnov,*** *G. Volkov, Yu Petrov, L. Witek, A. Bednarz, N. Kazarinov.* Threshold erosion fracture of aero engine blades.

16.10–16.30 **COFFEE BREAK**

16.30–17.50 **MECHANICAL AND CIVIL ENGINEERING APPLICATIONS – II**

Chair: S.V. Petinov.

16.30–16.50 ***R.A. Arutyunyan.*** High temperature damage and creep fracture of metallic materials.

16.50–17.10 ***V.F. Koshelev,*** *B.Z. Amusin.* A method of back analysis for rock mass inelastic parameters estimation.

17.10–17.30 ***M.G. Zeitlin,*** *A.N. Fedorova.* From Localization to Zoo of Patterns in Complex Dynamics of Ensembles.

17.30–17.50 ***A.N. Fedorova,*** *M.G. Zeitlin.* Fast Modeling for Collective Models of Beam/PlasmaPhysics.

SPORT ACTIVITIES

Day 4 –Thursday, June 25

ROOM II

14.50–16.10 **NANO- AND MICROMECHANICS - I**

Chair: O.S. Loboda.

14.50–15.10 ***I.E. Berinskii,*** *A.Yu. Panchenko, E.A. Podolskaya.* Modeling of elastic properties of molybdenum disulfide using a torque interaction potential.

15.10–15.30 ***B.E. Abali,*** *W.H. Müller, V.A. Eremeyev.* Numerical investigation of thin films with strain gradient elasticity.

15.30–15.50 *F. Ruiz-Botello,* ***A. Castellanos,*** *E.F. Grekova, M.A.S. Quintanilla, V. Tournat.* Sound propagation in fine magnetic powders: effect of the magnetic field in the assembling procedure.

15.50–16.10 *O.V. Privalova, L.V. Shtukin,* ***D.Yu. Skubov.*** Nonlinear dynamics of nano- mechanical systems in quasi-stationary electromagnetic fields.

16.10–16.30 **COFFEE BREAK**

16.30–17.50 **NANO- AND MICROMECHANICS – II**

Chair: I.E. Berinskii.

16.30–16.50 ***M.A. Grekov,*** *S.A. Kostyrko, Yu.I. Vikulina.* Effect of surface and interface roughness at the nanoscale.

16.50–17.10 ***S. Melin,*** *P. Hansson.* Indentation at the atomic scale.

17.10–17.30 ***S.V. Bobylev,*** *I.A. Ovid'ko.* Plastic deformation modes mediated by grain boundaries in nanomaterials.

17.30–17.50 ***M.V. Simonov,*** *A.M. Krivtsov.* Energy oscillations in a harmonic one dimensional crystal.

SPORT ACTIVITIES

Day 5 –Friday, June 26

ROOM I

10.00–11.30 **PLENARY LECTURES – VII**

Chair: V.I. Erofeev.

10.00–10.45 ***A. Corigliano.*** Non-linear mechanics and numerical simulations in microsystems: recent advances and applications.

10.45–11.30 ***A.V. Porubov.*** Localized nonlinear waves in lattices: modeling, generation and control.

11.30–11.50 **COFFEE BREAK**

11.50–13.20 **PLENARY LECTURES – VIII**

Chair: S. Rudykh.

11.50–12.35 ***F. dell'Isola.*** Microstructured n-th gradient continuum models and some applications.

12.35–13.20 ***E.F. Grekova.*** A class of continuous acoustic metamaterials.

LUNCH BREAK

14.15–16.00 **CONTINUUM PHYSICS AND DISCRETE MECHANICS**

APPLIED TO ASTROPHYSICAL PHENOMENA – I

Chair: A.M. Krivtsov.

14.15–15.00 ***W.H. Müller.*** *W.Weiss.* Large strain theory applied to self-gravitating bodies: A numerical Lagrangian approach.

15.00–15.20 ***P. Lofink,*** *W.H. Müller.* Finite Element investigations of the gravitational and rotational deformation of the Earth.

15.20–15.40 ***F. Reich,*** *W.H. Müller.* A review of electrodynamics and its coupling with classical balance equations by means of continuum mechanics.

15.40–16.00 ***S. Glane,*** *F. Reich, W.H. Müller.* Kinematic fluid dynamos examined by toroidal-poloidal decompositions - An example of combining continuum mechanics and electrodynamic field theory.

16.00–16.20 **COFFEE BREAK**

16.20–18.00 **CONTINUUM PHYSICS AND DISCRETE MECHANICS**

APPLIED TO ASTROPHYSICAL PHENOMENA – II

Chair: W.H. Müller.

16.20–16.50 ***A.M. Krivtsov.*** Origin of Earth – Moon system: dynamical and evolutional consideration.

16.50–17.20 ***E.N. Slyuta.*** Mechanical problems related to the lunar program.

17.20–17.40 ***O.V. Trifonov,*** *A.G. Tuchin, D.A. Tuchin, V.S. Yaroshevsky.* Hardware-In-The Loop Modeling system of flight control of te spacecraft "Luna-Glob" at the stage of the automatic landing on the Moon.

17.40–18.00 ***A.S. Murachev.*** Equilibrium dust and gas clouds with evaporable particles.

18.00 CLOSING CEREMONY

Day 5 –Friday, June 26

ROOM II

14.20–16.00 **WAVE MOTION**

Chair: A.V. Porubov.

14.20–14.40 ***V.I. Erofeev.*** Nonlinear localized deformation waves in the continuum with internal oscillatory degrees of freedom.

14.40–15.00 ***Yu. I. Meshcheryakov.*** Multiscale relaxation in steady shock wave.

15.00–15.20 ***M. G. Zhuchkova,*** *D. P. Kouzov.* The effect of a fluid stratification on the low frequency vibrations of a semi-infinite floating elastic plate interfaced with a rigid vertical wall.

15.20–15.40 ***I.E. Keller.*** Some new types of unstable generalized-viscous media.

15.40–16.00 ***M.V. Wilde.*** A cylindrical surface wave in a half-space with mixed boundary conditions on its surface.

Day 6 – Saturday, June 27

EXCURSION

Co-Chairmen and Plenary Speakers

Professor Dmitry A. Indeitsev (Co-Chairman)

Country: Russian Federation

Positions:

- Director of Institute of Problems in Mechanical Engineering, Russian Academy of Sciences
- Head of the Mechanics and Control Processes department at Peter the Great St. Petersburg Polytechnical University
- Professor of the Elasticity Theory Department at Mathematical Mechanical Faculty of St.Petersburg State University

Awards: Professor Indeitsev was awarded by St. Petersburg Government for the Higher and Secondary Professional Education

Scientific associations:

- Member of GAMM.
- Member of EUROMECH.
- Member of the Russian National Council of Theoretical and Applied Mechanics.

Research Interests:

- Mechanics of solids.
- Wave dynamics.
- Hydroelasticity.
- Theory of non-linear wave processes in elastic and elastic-acoustic media with inclusions.

Professor Anton M. Krivtsov (Co-Chairman)

Country: Russian Federation

Positions:

Peter the Great St.Petersburg Polytechnic University (SPbPU):

- Head of Dep. of Theoretical Mechanics
- Scientific supervisor of Center for scientific and technical creativity of the youth (CSTC) and Fab Lab Polytech
- Head of laboratory "Applied fracture micromechanics",

Institute of Problems of Mechanical Engineering, Russian Academy of Sciences:

- Head of laboratory "Discrete models in mechanics"

Activities:

- Member of Russian National Committee for Theoretical and Applied mechanics.
- Member of the Academic council of the Institute of Applied Mathematics and Mechanics, Peter the Great St.Petersburg Polytechnic University.
- Member of the Academic council of the Institute for Problems in Mechanical Engineering, Russian Academy of Sciences.
- Member of 2 committees for PhD and Doctoral degrees judgment.
- External expert for Russian Foundation of Basic Research.
- Scientific secretary of the Program for basic research of the Presidium of the Russian Academy of Sciences "Fundamental problems of mechanics of interactions in technical and natural systems, materials and mediums".
- Co-Chairmen of annual international conference "Advanced problems in mechanics".
- Member of editorial board of Journal of Mechanical Engineering Science.
- Member of the Scientific Committee of International conference "Recent Advances in Numerical Simulation of Hydraulic Fracture" (HYDROFRAC2014).
- Member of the Scientific Committee of International conference "Nonlinear Dynamics in Engineering: Modelling, Analysis and Applications" (UK, 2013).
- Member of the Steering Committee of Sixth EUROMECH Nonlinear Dynamics Conference (ENOC 2008).
- Chairmen of the Local Organizing Committee and member of the Scientific Committee of EUROMECH Colloquium 468 "Multi-scale Modelling in the Mechanics of Solids" (Russia, 2005).

Research Interests:

Particle and molecular dynamics, Mechanics of mediums with microstructure, Nanomechanics, Geomechanics, Computer methods in mechanics, Continuum mechanics, Multibody dynamics, Nonlinear oscillations, Dynamics of centrifuges, Percussive drilling, Astrophysics.

Academician Vladimir A. Babeshko

Country: Russian Federation

Position: Head of department of mathematics and mechanics, Southern Scientiific Center RAS

Former President of Kuban State University in Krasnodar, Russia

Honours, Awards:

- Honoured Scientist of the Russian Federation, Kuban, and the Adygei Republic.
- The State Prize in the field of science and technology (2001).
- The Sign of Honor order.
- The People’s Friendship order.
- The Vavilov Medal.
- The medal of Kuban Hero of Labor.
- The Rector of the Years 2004, 2005.
- Honorary Senator of the Berlin University of Applied Sciences.

Scientific associations:

- VAK, ASA.

Field of expertise:

Mechanics and applied mathematics, seismology, geophysics, environmental sciences.

About publications:

Academician Babeshko is an initiator of several lines of research, the author of five monographs, and over 300 articles and inventions, including pioneering research publications.

Professor Stéphane Bordas

Country: Luxembourg

Positions held: Professor of Computational Mechanics, University of Luxembourg

Editorial responsibilities:

- Editor “Advances in Applied Mechanics.”
- Co-Editor “Asia Pacific Journal on Computational Engineering”.
  Editorial Board Member of journals Journal of the Mechanical.

  Behavior of Materials, Advances in Engineering Software, Computers and Structures, Proceedings of ICE journal Engineering and Computational Mechanics
- EUROMECH Solid Mechanics Conference Committee 2014-2018.
- Editorial Board/Advisory Panel Member International conference ECT2008, ECT2011, TCNCAE2008, International ECCOMAS conference XFEM2009, ECT2012, XFEM2013, ECCOMAS YIC2013.

Professional associations and boards:

- Scientific Committee, The first International Conference on Biomedical Technology 2013.
- EUROMECH Solid Mechanics Conference Committee 2014-2018.
- Conference National Committee (1st UK National Conference on Patient-Specific Modelling (PSM) and Translational Research).
- Representative Association for Computational Methods in Engineering (ACME) representative for board of scientists under 40.
- Association for Computational Methods in Engineering (ACME) Executive Committee Co-opted member (2012-2014).
- Member of Wales Institute for Mathematical and Computational Sciences.
- Member of the Engineering Professor’s Council.
- Member of the UK Higher Education Academy (HEA)
- Member of the International Association of Computational Mechanics (IACM), French and UK antennas: CSMA, ACME.
- Honorary member of the Industrial TECHNET Alliance for computational mechanics regrouping CEOs and Academics.

Academic Area(s): Aerospace & aeronautics engineering / Civil engineering / Computer science / Materials science & engineering / Mechanical engineering / Multidisciplinary, general & others / Surgery.

Research Topics: Computational Mechanics, Fracture and durability, High performance computing, Surgical simulation real-time.

Professor Alberto Corigliano

Country: Italy

Position: Full professor of Department of Civil and Environmental Engineering at Politecnico di Milano, Italy

Award: February 2006: Bruno Finzi Prize for Rational Mechanics, Istituto Lombardo Accademia di Scienze e Lettere.

Scientific associations:

- Chairman of the ESMCC (European Solid Mechanics Conference Committee).
- Member of the IUTAM (International Union of Theoretical and Applied Mechanics) Symposia Panel for Solid Mechanics.
- Member of the AIMETA (Italian Association of Theoretical and Applied Mechanics).
- Member of the GIMC (Italian Group of Computational Mechanics).
- Member of the EUROMECH (European Mechanics Society).
- Member of the IGF (Italian Group of Fracture).
- Member of the Eurosime Technical Committee (Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems).
- Member of the IEEE.

Journal editorial activities:

Associate Editor

- European Journal of Mechanics A/Solids.
- Advanced Modeling and Simulation in Engineering Sciences.
- Frontiers in Materials – Mechanics of materials.

Current research interests and activities:

- Composite and advanced materials:
  characterization of the mechanical behaviour, interface models for delamination, numerical approaches to damage of composites.
- MEMS:
  design of on chip test devices for the mechanical characterization of polysilicon at the scale of micron. Fracture and fatigue at the micro scale. Electrostatic and thermo-mechanical actuators. Multi-physics and multi-scale modelling. Accidental drop modelling. Spontaneous adhesion phenomena. Resonant accelerometers. Micromagnetometers. Micro energy harvesters. Micro gyroscopes.
- Advanced modelling and simulation by means of domain decomposition and model order reduction techniques.

Professor Francesco dell'Isola

Country: Italy

Positions:

Full Professor of Mechanics of Solids and Structures

Career and Teaching Activity:

1986 : Graduate in Physics.

1992 : Ph.D. in Mathematical Physics (Università di Napoli Federico II).

Administrative Responsibilities:

1998 - to present: Member of the "Collegio dei Docenti" of the Doctoral School in Theoretical and Applied Mechanics Università di Roma La Sapienza.

2000 Visiting Associate Professor, Lectures on Theory of Elasticity at Virginia Polytechnical Institute and State University.

2003 - to present: Scientific Responsible "Laboratorio Strutture e Materiali Intelligenti of Cisterna di Latina" (Italy).

2005 Professeur invité à l'Université de Versailles.

2012 – to present: Member of the Executive Committee of the International Research Center M&MoCS, University of L'Aquila.

2014 – 2018: Membre du Conseil scientifique de l'Institut des sciences de l'ingénierie et des systèmes – CNRS.

Editorial Board Membership:

2014 – to present: PNRPU Mechanics Bulletin.

March 2013: Guest Editor (with Samuel Forest) of the Special Issue of Continuum Mechanics and Thermodynamics.

2013 – to present: Editor of Continuum Mechanics and Thermodynamics.

2012 - to present: Mathematics and Mechanics of Solids.

2012 – to present: Co-Founder of Mathematics and Mechanics of Complex Systems (M&MoCS).

2012 – to present: The Book series of Modern Mechanics and Mathematics.

2002 – to present: International Journal of Electromagnetics and Mechanics.

2000 – to present: Research in Nondestructive Evaluation (RNDE).

Research Topics:

- Mechanics of solids and structures and Vibration Control. Modeling of compressible fluid flow in deformable porous media. Saint-Venant's problem and Almansi problem for elastic micro-structured solids, for piezoelectric materials in linear and non linear contexts (by means of the Signorini's perturbation method); Vibration control in beams connected to electric transmissions lines by means of PZT actuators). Mathematical Foundations of Continuum Mechanics. Variational Principles. Generalized Continua and their applications to Architectured materials. Systems with inextensible fibers and applications to composite mechanics. Mechanics of living tissues and their mathematical modeling. Mathematical models for phase transitions, capillarity and interface phenomena.
- Co-author of 124 papers on international journals and co-author of an US-patent 6546316, Two dimensional network of actuators for the control of damping vibrations. Net-Control systems of structural vibrations;
- Invited as speaker in 70 seminars and organizer of 16 International conferences and Schools.

Dr. Elena F. Grekova

Country: Russian Federation

Position: Senior researcher, Institute for Problems in Mechanical Engineering of Russian Academy of Sciences, St. Petersburg

Awards: The prize from Russian government "For active participation in realization of scientific programmes and creative approach in solution of scientific problems", 1999.

Scientific associations: Member of the research group "Electrohydrodynamics and cohesive granular media" of the University of Seville.

Keywords to the fields of interest:
Polar and multipolar media, generalised continua, metamaterials, magnetic materials, geophysics, powders and grains, nonlinear elasticity, constitutive theory, wave propagation.

Professor Mark L. Kachanov

Country: USA

Positions: Professor, Department of Mechanical Engineering,
Tufts University

Research Interests

Professor Kachanov's research is focused on micromechanics of materials and its applications to various materials systems, as well as on piezoelectrics. Many of his works are done in cooperation with industry.

- Mechanics of heterogeneous materials; Multiple cracking and damage
- Rough contacts: Mechanics and conductance
- Geophysics and rock mechanics; Applications to oil exploration
- Industrial Applications :
  - Thermal barrier coatings
  - Porous ceramics (fracture under compression, thermal loading)
  - Oil exploration (multiple fractures, anisotropy, rough surfaces, wavespeeds)
  - Nano-indentation of piezoelectrics

Career Highlights

- Science Citation Index (Web of Science): 2,800 +, H-index: 31
- Distinguished Fulbright Chair
- Von Humboldt Research Award for Senior Scientists (Germany)
- Editor-in-Chief of International Journal of Engineering Science
- Five of former students/postdocs won professorships at US Universities

Professor Reinhold Kienzler

Country: Germany

Position: Professor and Chair of Technical mechanics and Structural mechanics, University of Bremen, Germany

Scientific associations:

- Honorary Member of the Polish Society of Theoretical and Applied Mechanics.
- Honorary Member of the Hellenic Society of Theoretical and Applied Mechanics.

Journal editorial activities:

- Editor-in-Chief of «Archives of Applied Mechanics».

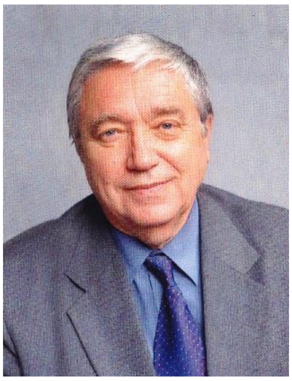
About publications:

The list of publications counts 7 books and about 200 scientific papers in Journals and Proceedings with Review procedure.

Current research activities:

- Plates and Shells
- Configurational Mechanics
- Fracture and Damage Mechanics

Academician Vladimir A. Levin



Country: Russian Federation

Positions:

- Head of department of Computational Mechanics at the Faculty of Mechanics and Mathematics, Lomonosov Moscow State University, Russia.
- Head of research laboratory, The Institute of Mechanics, Lomonosov Moscow State University, Russia.
- Head of research laboratory, Institute of Automation and Control Processes Far Eastern Branch of RAS.

Honours, Awards

State prizes:

- The medal of the order "For Merits before the Fatherland" of the II degree (1999).
- The State Prize in the field of science and technology (2002).
- The Honor order (2011).

Scientific prizes:

- The Chaplygin Prize (1976).
- The Zhukovsky Prize with silver medal (1984).
- The Lomonosov Prize, I degree (1991).
- The Keldysh Medal (2009).
- The Nyuma Manson Medal by the Institute for the Dynamics of Explosions and Reactive Systems (2013).
- The Cherny Prize (2014).
- The honoured Professor of Lomonosov Moscow State University (2015).

Scientific associations:

- The member of the bureau of the department of power and mechanic engineering, fundamental mechanics, control processes of RAS.
- The member of Presidium of Far Eastern Branch of RAS.
- The member of the bureau of Explosion and Combustion Research Council RAS.
- Russian National Committee on Theoretical and Applied Mechanics.
- European Hypersonic Association.
- Chairman of the Academic Council.

Field of expertise: Gas dynamics of explosion and reacting systems, initiation and propagation of blast and detonation waves in combustible gas mixtures, supersonic aerodynamics, plasma aerodynamics and problems of wave drag reduction, mechanics of natural processes.

About publications: The list of publications counts over 300 scientific papers and 16 inventions and patents. Vladimir Levin is a teacher: more than 30 candidates of science, 5 Doctors of Science.

Professor Alexander M. Linkov

Country: Russian Federation

Positions:

- Chief Scientist, Department of Mathematical Methods in Mechanics of Materials and Structures; Institute for Problems in Mechanical Engineering of Russian Academy of Science
- Laboratory of Numerical Models in Mechanics of Materials and Structures; Institute for Problems in Mechanical Engineering of Russian Academy of Science

Honors, Awards:

- *International Schlumberger Award* for Fundamental Researches in Rock Mechanics - International Society for Rock Mechanics, 1994.
- *Prize* of the Journal of Applied Mathematics and Mechanics (Russian Academy of Sciences) for the best paper published in 1999, Russia, 2000.
- *Salamon Award* - SANIRO, South Africa, 2002.
- *Marie Curie Professorship* - University of Liverpool (UK), 2005.
- *Honoured Scientist of the Russian Federation* - Award by the President of the Russian Federation, 2008. **Scientific associations:**
- Member of St.-Petersburg Scientific Society (Russian Academy of Sciences).
- Member of Int. Assoc. for Boundary Element Method.
- Member of the American Geophysical Union.
- Member of New York Academy of Sciences.
- Member of Society of Petroleum Engineers.

Specialization:

- **Main field:**
  Solid, fracture and computational mechanics.
- **Other fields:**
  Fluid dynamics, integral equations.
- **Current research interests:**
  Micromechanics, homogenization problem, hypersingular equations, singular points, blocky and layered systems, fracture propagation, synthetic seismicity, hydraulic fractures.

Discovery: Discovery No 337 "Regularity of underground fracture of rocks", 1988, State Committee on Discoveries, USSR.

About publications: The list of publications counts 9 books and over 300 scientific papers.

Professor Sergey Lurie

Country: Russia

Position: Head of laboratory Non classical models of composite materials of Institute Applied Mechanics of Russian Academy of Sciences

Awards:

- Honorary research fellow of The Centre for Micro- and Nanomechanics Aberdeen University (CEMINACS).

Scientific associations:

- Member of Consul Group on Composite Materials Mechanics of Russian Academy of Sciences.
- Member of Russian National Committee on Theoretical and Applied Mechanic.
- Member of GAMM (International Association of Applied Mathematics and Mechanics).
- Member of ESIS (european structural integrity society).
- Member of EUROMECH.

Research/visiting positions:

- Institute for Static and Dynamics of Aerospace Structures.
- University of Stuttgart (1993-1994 and 1995-1996).
- United States Air Force Research Laboratory (2002).
- Federal of University of Rio de Janeiro (2003, 2004, 2006).
- Brazil Aberdeen University.
- Centre Micro and Nanomechanics (2006), UK.
- Sheffield University (2006).
- Zurich University -ETH (2007, 2010).

Research interests:

Prof. Lurie has over 25 years of experience in working with composite structures, multi-scale modelling of damage in orthotropic laminates under multi-axial in-plane loading, fracture of composites. He has made significant research contributions in developing of nonlocal theories of elasticity, fracture mechanics and modelling of mechanical physical properties composites and heterogeneous structures across the length scale. Some of the applied gradient models for composites, ceramics, metal- matrix composites and fracture models he developed have been implemented in commercial computer design packages, used successfully by industry and academia. Refined and corrected nonlocal theory of elasticity, nano-mechanical modelling in framework of continuum mechanics and extended thermodynamics determine his scientific interests for the last few years. Professor Lurie research work has appeared in more than 180 publications including 5 books and over 110 journal papers (19 journal papers are the solo contributions). He made over 70 technical presentations at international conferences and gave over 17 invited talks at leading universities in the Russia, UK, USA, Australia, Germany, Swizeland, Brazil, chaired more then 10 technical sessions at the International Conferences.

Professor Andrei V. Metrikine

Country: The Netherlands

Positions:

- Antoni van Leeuwenhoek Professor at the Faculty of Civil Engineering and Geosciences, TU Delft, The Netherlands;
  Chair Dynamics of Solids and Structures
  Section Head Offshore Engineering
- Adjunct Professor of Arctic Marine Civil Engineering at the Faculty of Engineering Science and Technology of NTNU,
  Trondheim, Norway

Scientific associations:

- Receiving Editor and Deputy Editor-in-Chief and of the Journal of Sound and Vibration.

Current research interests and activities:

- Dynamics of offshore pipelines focusing on the flow-induced instabilities such as divergence and flutter induced by axial flows and vortex induced vibration in currents.
- Dynamics of structures in ice centering on ice-induced vibrations of bottom-founded structures and interaction of level ice with floating structures.
- Dynamics of high-speed trains and railway lines with the emphasis on the effect of soil on the global dynamics of the train-railway-subgrade system.
- Dynamics of offshore wind turbines focusing on the installation, including noise generation during piling, and on the dynamic interaction of offshore turbine foundations with soil.

Professor Wolfgang Müller

Country: Germany

Position: Professor and Chair of Continuum Mechanics and Materials Theory, Technical University of Berlin, Germany

Awards from:

- SMTA,
- CNRS,
- The Senate of Berlin.

Scientific associations:

- Member of ASME (American Society of Mechanical Engineers).
- Member of ASTM (American Society for Testing and Materials).
- Member of DHV.
- Member of GAMM (German Society of Applied Mathematics and Mechanics).
- Member of STMA.

Current research interests and activities:

- Continuum theory and modeling of the performance and behavior of advanced materials and technical structures.
- Fracture and damage mechanics, in particular "fracture electronics".
- Numerical mathematics and computer simulations.
- Mechanics and thermodynamics of advanced materials (composites, ceramics, glasses, solders, steels, and alloys).
- Experimental determination of micro-mechanics parameters.
- Thermodynamics and materials theory Modelling of sports materials.

Dr. Patrick O'Brien

Country: United Kingdom

Position:

Chief Executive of the Industry Technology Facilitator (ITF), United Kingdom

Scientific associations:

- Fellow of the Royal Academy of Engineering (FREng).
- Honorary Professor of Engineering at the University of Aberdeen.
- Adjunct Professor of Engineering at the National University of Ireland, Galway.

Current research interests and activities:

Subsea riser mechanics, riser design and flexible pipe technology.

Professor Alexey V. Porubov

Country: Russian Federation

Positions:

Institute of Problems of Mechanical Engineering, Russian Academy of Sciences:

- Leading Research Fellow in the laboratory “Micro-mechanics of materials”

Peter the Great St.Petersburg Polytechnic University (SPbPU):

- Part-time Professor in the Chair of Theoretical Mechanics

St. Petersburg State University (SPbU):

- Part-time Professor in the Chair of Computer modeling of multi-processor systems

Activities:

- Member of EUROMECH (European Mechanics Society).
- Member of the Russian Acoustic Society.
- Co-Chairmen of numerous mini-symposiums at the annual international conference “Advanced problems in mechanics”.

Research interests:

- Nonlinear waves in solids, fluids and discrete structures.
- Mechanics of media with microstructure.
- Solutions to nonlinear partial differential equations.
- Computer methods in mechanics.
- Nonlinear mechanics of lattices.
- Control of nonlinear wave processes.

Professor Takahiro Shimada

Country: Japan

Position: Assistant Professor, Department of Mechanical Engineering and Science, Kyoto University

Awards:

- JSME Best Presentation Fellow Award, The Japan Society of Mechanical Engineers (JSME), 2005.
- JSME Miura Award, The Japan Society of Mechanical Engineers (JSME), 2006.
- MD Award, The Society of Materials Science, Japan (JSMS), 2007.
- JSME Best Presentation Award, he Japan Society of Mechanical Engineers (JSME), 2008.
- JSME Medal for Outstanding Paper, The Japan Society of Mechanical Engineers (JSME), 2012.
- JSME Young Engineers Award, The Japan Society of Mechanical Engineers (JSME), 2013.
- Best Poster Nominee, Best Poster Nominee, Materials Research Society (MRS), Materials Research Society (MRS), 2013
- The Young Scientists' Prize (The Commendation for Science and Technology by the Minister of Education), Ministry of Education, Culture, Sports, Science and Technology (MEXT), 2014.

Fields of research:

- Material Strength.
- Low-dimensional Nano-structures.
- Ferroelectricity
- Magnetism.
- Multi-physics Properties.
- Multiferroics.
- First-principles (Ab-initio) Calculations.
- Molecular Dynamics (MD) Simulations
- Phase-Field Modeling.

Professor Vadim Silberschmidt

Country: United Kingdom

Position: Professor of Mechanics of Materials at Loughborough University, Leicestershire, UK

Awards:

- A.V. Humboldt Foundation (Germany) Fellowship (1992-1994).
- Best Paper Award, 8th CIRP International Workshop on Modeling of Machining Operations, Chemnitz, Germany, 2005.
- Best Paper Award, 10th CIRP International Workshop on Modeling in Machining Operations, Reggio Calabria, Italy, 2007.
- President of Tokyo University of Science Prize, 2012**.**

Scientific associations:

- Member of the EUROMECH (European Mechanics Society).
- Member of the International Association for Computational Mechanics.
- Member of the European Structural Integrity Society.
- Member of the GAMM (German Society of Applied Mathematics and Mechanics).
- Member of the DGM (German Materials Science Society).
- Fellow of the Institution of Mechanical Engineers.
- Fellow of the Institute of Physics.

Journal editorial activities:

- **Editor-in-Chief**
  - Mechanics of Advanced Materials and Modern Processes(Springer).
- **Associate Editor**
  - Journal of Engineering Materials and Technology(ASME).
  - Journal of Vibration and Control (SAGE).
- **Journal editorial board memberships:**
  - International Journal Materials Science and Engineering A: Structural Materials: Properties, Microstructure and Processing (Elsevier).
  - Computers, Materials & Continua (Tech Science Press).
  - International Journal of Automotive Composites (Inderscience).

    - Shock and Vibration (Hindawi).
    - Advanced Manufacturing: Polymer & Composites Science (Maney Publishing).

Current research interests and activities:

- Multi-scale models of damage and fracture evolution in microstructured materials.
- Finite-element analysis of complex deformational behaviour, damage and fracture of advanced materials under various loading conditions.
- Impact fatigue.
- Analysis of ultrasonically assisted machining.
- Mechanics of composites and nanocomposites.
- Micromechanics and reliability of microelectronic packages.
- Mechanics of bones and biomaterials.
- Mechanics and micromechanics of nonwoven materials.
- Modelling of sports materials.

About publications:

Professor Silberschmidt has co-authored four research monographs and more than 370 peer-reviewed scientific papers (including some 220 journal papers) on mechanics and micromechanics of deformation, damage and fracture in advanced materials.

Poster Session

1. **Argunova T.S., Gutkin M.Yu., Mokhov E.N., Nagalyuk S.S., Je J.H.** Micro-structural evidence of crack prevention in ALN crystals grown on gradually decomposing sic substrates.

2. **Arutuynyan A.R.** Consumption of fracture energy in speed and frequency experiments.

3. **Astafurov S.V., Shilko E.V., Dimaki A.V., Psakhie S.G.** Theoretical investigation of influence of multimodal internal structure on mechanical characteristics of intermetallic alloys.

4. **Aleshchenko S.P., Freidin A.B., Vilchevskaya E.N., Korolev I.K.** FEM simulation of a chemical reaction front propagation round the stress concentrators in an elastic solid.

5. **Argunova T.S., Gutkin M.Yu., Kohn V.G., Lim J.H.** Micromechanical interpretation of micropipes morphology in bulk SiC crystals

6. **Arutyunyan A.R.** Damage and fracture of aged elastic-viscous media

7. **Astafurov S.V., Shilko E.V., Kolubaev E.A., Dmitriev A.I., Nikonov A.Yu., Psakhie S.G.** Development of discrete element approach for computer-aided simulation of the dynamics of friction stir welding process

8. **Astafurov S.V., Shilko E.V., Psakhie S.G.** Development of models of interfaces for numerical simulation of materials with multimodal internal structure

9. **Astankov K., Rumyantsev S.A.** The Non-harmonic Oscillations for Vibratory Pile Driving

10. **Begun A.S., Kovtanyuk L.V., Lemza A.O.** Rotational movement of the material under conditions of creep and plasticity

11. **Boltachev G.Sh., Chingina E.A., Maximenko A.L.** Influence of micro-characteristics on macro-properties of nanopowders in compaction processes

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4. **Alfimov A.V., Aryslanova E.M., Chivilikhin S.A.** Theoretical study of orientation effects during the multi-particle diffuse double layer interaction in monodisperse aqueous zinc oxide nanocolloids

5. **Aligozhina K.A., Knyazeva A.G.** Numerical investigation of difference materials joining by means of shs welding

6. **Anisimova M.A., Knyazeva A.G.** The Model of Crystallization of Composite Coating

7. **Aryslanova E.M., Alfimov A.V., Chivilikhin S.A.** Theoretical modeling of aluminum oxide growth during anodization

8. **Bibossinov A.Zh., Iskakbayev A.I., Bekbauov B.E.** Modelling and study the size and shape of plastic zone around blunt and sharp plane cracks

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11. **Grigoriev A.S., Shilko E.V., Skripnyak V.A., Bragov A.M., Psakhie S.G.** The numerical study of the features of dynamic response of heterogeneous brittle solids

12. **Grigoryeva P.M., Vilchevskaya E.N., Mueller W.H.** Stress-assisted chemical reaction front propagation in deformable solids

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14. **Grishchenko A.I., Semenov A.S., Getsov L.B.** Modeling inelastic deformation of single crystal superalloys with account of γ/γ' phases evolution

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18. **Krasnitskii S.A., Gutkin M.Yu., Kolesnikova A.L., Romanov A.E., Dorogin L.M., Vikarchuk A.A.** Stress relaxation in icosahedral particles by generation of prismatic dislocation loops

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34. **Smirnov A.M., Gutkin M.Yu., Kolesnikova A.L., Krasnitskii S.A., Romanov A.E.** Misfit stress relaxation in hollow and solid core-shell nanowires via generation of prismatic dislocation loops

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48. **Zinovieva O.S., Zinoviev A.V., Ploshikhin V.V., Romanova V.A., Balokhonov R.R.** Cellular Automata Simulation of Microstructure Evolution in Additive Layer Manufacturing Processes

NUMERICAL INVESTIGATION OF THIN FILMS WITH STRAIN GRADIENT ELASTICITY

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Thin films are applied in micro-electro-mechanical systems (MEMS). Copper (Cu) is often used for producing thin films due to its high conductance and specific strength. Interestingly, its mechanical response changes on micrometer length scale. Especially for Cu thin films this phenomenon has been observed experimentally, see for example [1] and [2]. Such a change of the mechanical behavior is referred to as the size effect. The ordinary theory of elasticity fails to characterize it. Thus, this theory needs to be refined. In order to calculate the mechanical behavior of thin films we propose to implement the so-called strain gradient elasticity. There have been various variants of the strain gradient elasticity, see for an overview [3, Chap. 90]. We give a brief outline of our version based on rational continuum mechanics and then perform a numerical study of Cu thin films.

First, we start with the balance equations of linear and angular momentum. Their flux terms are known as the stress tensor and the couple stress tensor for a non-polar medium, such as Cu. Second, we present a suitable method to obtain necessary constitutive equations for the stress and couple stress tensors. By closing the balance equations by the constitutive equations we obtain the field equations. Third, we employ a variational formulation for generating a weak form out of the field equations. This weak form can be computed by using numerical solution techniques. We use the finite element method for space discretization and finite difference method for time discretization. Then we solve the weak form by using open-source packages developed under the FEniCS project [4]. We compute Cu thin films with our version of strain gradient elasticity, perform a numerical study of different thicknesses, and observe qualitatively the same phenomenon as in experiments.

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THEORY OF PLANE STRESS STRUCTURES IN CRYSTALS EXPERIENCING

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Analytical approach is developed to describe the plane stress and strain structures in crystal plates experiencing austenite-martensite transformations. In the model translational symmetry of the sublattices mutual displacement is explicitly taken into account by means of the inclusion of periodic potentials into the energy density. The general nonlinear equations of motion are derived from the variational principle. It is shown that not only long range but also short range topological order is destroyed in the intermediate heterophase structure. Theoretical recommendations are offered to be used in the engineering practice.

FEM SIMULATION OF A CHEMICAL REACTION FRONT PROPAGATION ROUND THE STRESS CONCENTRATORS IN AN ELASTIC SOLID

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We develop a procedure for the numerical simulation of a stress-assisted chemical reaction front propagation. The reaction similar to the oxidation of silicon is sustained by the diffusion of a gas constituent through the transformed material. The analytical model of this phenomenon is based on the expression of chemical affinity tensor [1,2]. The normal component of the chemical affinity tensor acts as a configuration force and drives the reaction front.

We implement the model using ANSYS software supplied by special means of internal programming language. Numeral simulation allows us to examine the reaction front kinetics near the stress concentrators: a semicircular groove and a cylindrical hole. It is found that applying of different external stresses causes different scenarios of chemical reaction front propagation. Thus, it is demonstrated that applying the tensile external stresses leads to the formation of a "helmet-shaped" oxide front, while applying external compressive stresses leads to slow oxide growth. The quantitative investigation shows that the tensile external stresses increase the oxide growth rate all over the reaction front, while the applying of compressive external stresses leads to decrease of the one. This effect is stronger at the zone of a stress concentrator. This dependence takes place for all range of values of analyzed external stresses: from -400 to 400 MPa.

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THEORETICAL STUDY OF ORIENTATION EFFECTS DURING THE MULTI-PARTICLE DIFFUSE DOUBLE LAYER INTERACTION IN MONODISPERSE AQUEOUS ZINC OXIDE NANOCOLLOIDS

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Nanotechnology is among the fastest growing fields of applied research in the past few decades. An important group of nanomaterials that have found a wide industrial, commercial and scientific application are those based on nanoparticles as their primary structural units. These materials include nanocolloids, aerosols, nanoceramics, etc. and demonstrate a high dependency of bulk material properties on those of the individual nanoparticles [1].

It is important to note that physical and chemical properties of particle-based materials and, therefore, their fate and transport, biological activity and behavior in the human body are also dependant on the morphology and stability of the particle assemblages [2, 3] in the form of agglomerates and aggregates (terms used in accordance with ISO 14887). Although the agglomeration of nanoparticles has been a subject of extensive studies, only a few works to date have focused their attention on the formation of nano-agglomerate spatial structure [2].

The presented work is devoted to the theoretical study of nanoparticle agglomeration in aqueous colloids that allows to explicitly describe and predict the morphology of forming particle assemblages. To achieve that, an original multi-particle electric double-layer (EDL) interaction model first introduced by the authors in [4] was used. The model is developed in the framework of the DLVO (Derjaguin, Landau, Verwey, Overbeak) theory and uses the well-known linear superposition approximation of the Poisson-Boltzmann problem along with an improved version of the original linear charge regulation model accounting for the nanoparticle surface charge redistribution during their interaction. The model was qualitatively verified by studying the predicted probability of attachment between a nanoparticle and an agglomerate as a function of the agglomerate's size.

The suggested theoretical approach is suitable for the identical spherical amphoteric nanoparticles with low surface potential interacting in the aqueous solutions of low ionic strength. Thus, the zinc oxide nanoparticles were chosen for the modeled system of this work due to their unique semiconductor and chemical properties wide use in customer products.

The derived analytical expression for the multi-particle EDL interaction potential energy allowed us to study the dependence of the potential barrier energy on different collision geometries between a primary ZnO nanoparticle and an agglomerate of varied size and morphology. The results indicated that the long-range electrosteric repulsion between colloid nanoparticles makes it more energetically favorable for them to form linear structures. However, after the agglomerate is formed it might become subjected to compaction due to attractive van der Waals forces, reorientation due to crystal lattices mismatch, structural changes and fluctuations due to the interaction with the carrier medium, etc. Hence, the resulting morphology of a nano-agglomerate can be described as the product of a balance between the initial preference for a linear structure formation and further compaction, reorientation and interaction with the medium.

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NUMERICAL INVESTIGATION OF DIFFERENCE MATERIALS JOINING BY MEANS OF SHS WELDING

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The modern technologies often require the use of materials that can be operated at very high temperatures. Generally, such materials as ceramics and ceramic matrix composites are applied. However, the problem with the joining of the ceramic to itself and to metals exists. Among the technologies that are able to solve this problem the SHS welding has a row of advantages such as energy efficiency, simplicity of facilities and high quality of products.

In spite of so attractive features of the technology the high rates of heating, the fast course of the reaction and great temperature gradients make the processes of combustion problematical to control, therefore the mathematical modeling gains in importance.

Mathematical model, which is a basis for numerical investigation of the problem, represents two-dimensional three-layer coupled thermal conductivity problem with chemical heat release source in a middle area. Chemical reaction is described by simple summary scheme. Boundary conditions in the interface are formulated assuming that the contact between connective materials and reagent is ideal. Initiation of the reaction is realized with help of short heat impulse from the surface. That leads to combustion wave formation and its further propagation in the direction of initial substance.

The problem includes chemical kinetic equation, thermal conductivity equation for reagent consisting an additional term which characterizes the heat source effect, thermal conductivity equation for connection materials, as well as boundary and initial conditions corresponding to described situation.

In order to decrease a number of variables and amount of necessary numerical calculations we solve the problem in dimensionless form. To go to dimensionless variables scales typical for combustion problems were used.

Numerical implementation of the model was carried out with the help of implicit difference scheme, coordinate splitting and linear double-sweep method.

In this work parametric investigation in a wide parameter space was carried out. The effect of several process parameters, such as width of the reagent layer, initial temperature, thermophysical properties relations between connecting materials and adhesive composition on the temperature and the conversion extent profiles as well as some energetic characteristics behavior.

It was detected that inert materials can both promote and retard the reaction development. Therefore, it is necessary to thoroughly choose the size of conjugated materials correspondingly to the size of the area occupied by the reagent, when the SHS welding of two different materials is carried out.

THE MODEL OF CRYSTALLIZATION OF COMPOSITE COATING

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In the modern technologies composite materials and coatings, properties of which depend on the conditions of their production, became widespread. For example, the conjugate heat transfer conditions can lead to the peculiarities of the structure and properties of the final product due to emergence of unwanted temperature gradients.

So, the various nature of the heat transfer between overmold coating and ambient environment, between coating and substrate, and also the properties of the substrate surface (non-uniform surface structure), leading to local inhomogeneities, plays a major role in the distribution of the phases in the coating.

The influence of conjugate heat transfer on the properties of the final product can be studied by means of mathematical modeling of typical experimental situations.

In this paper, we propose a model of cooling and crystallization of the overmold composit coating. The results of its research are used to evaluate the properties of the coating.

It is assumed in the thermophysical model that the filler particles may be irregularly distributed in the coating due to the effect of force of gravity and of different sizes and masses of particles, which is given by dependence of the concentration of inclusions on the coordinates.

The shape of the substrate surface (its roughness) affects the cooling and crystallization conditions, that described by introducing of nonuniform thermal resistance of boundary materials.

The problem was solved numerically using implicit difference scheme of splitting to the coordinates and the standard method of coordinatewise sweep.

Effective properties of inhomogeneous coating are evaluated on the basis of the approach known in the mechanics of composite materials.

MICROMECHANICAL INTERPRETATION OF MICROPIPES MORPHOLOGY IN BULK SIC CRYSTALS

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Due to the improvement of the production technologies, SiC single crystals are gradually becoming one of the main materials for high current - high power electronics. Diameter of commercial SiC ingots has recently grown from 50 to 100 - 150 mm. The density of defects therein decreased by several orders. In particular, the density of micro-pores threading along the entire length of ingot, i.e. dislocated micropipes, has become less than 1 cm^{-2}. However, not all the features of their formation explained and further study is required to eliminate these defects.

We report on theoretical and experimental investigations of micropipe morphology in SiC single crystals grown by the sublimation technique [1]. Micropipes were imaged by means of phase contrast technique in Synchrotron radiation (SR) with photon energy greater than 10 keV. Unmonochromated x-rays had the spatial coherence of $L_s = 42$ µm. The computer simulation of phase contrast images [2] allowed the determination of 3D micropipe morphology from only one 2D projection. We measured the micropipe parameters in the three directions: parallel and normal to the x-ray beam and along their axis. Remarkable effectiveness of the simulation approach made it possible to detect instabilities in their shapes and sizes.

A theoretical model of transformation of threading lattice dislocations into micropipes through the nonequilibrium processes of pipe diffusion and coagulation of vacancies is suggested. The model includes the following main stages: (1) heterogeneous formation of dislocations elongated along the *c* axis and reaching the front of the crystal growth; (2) pipe diffusion of vacancies from the surface into the crystal bulk through the cores of these dislocations; (3) coagulation of these vacancies around the dislocation lines; (4) forming a continuous cavity (micropipe) around dislocations and leveling its surface by surface diffusion of vacancies. Under this scenario of micropipe formation, the formation of oblate micropipes can be explained by their trend to comprise some dislocations (dislocation bundle) at once with minimizing the micropipe surface. The largest size of the micropipe cross section is then approximately equal to the distance between the farthest dislocations in the bundle. If the dislocation bundle is a self-screened ensemble of dislocations, from a dipole to an arbitrary multipole, then the driving force of the dislocation agglomeration inside one micropipe is total annihilation of dislocations there, while the main limitation of such agglomeration is that the bundle size cannot be larger than its critical size d_c. If the dislocation bundle consists of dislocations of the same sign (or of opposite signs but when the number of dislocations of one sign differs from the number of dislocations of the opposite sign), then the driving force of the dislocation agglomeration within one micropipe is a decrease in the strain energy density near the bundle. The main limitations in this case are that (1) the Burgers vector magnitudes of the residual dislocations must be larger than a critical value b_c and (2) the transverse size of the bundle of residual dislocations (the largest distance between them) must be in the range between two critical values d_{c1} and d_{c2}, which is determined by the value of b. Our numerical estimates of critical values d_c, d_{c1} and d_{c2} are in good accordance with the sizes of oblate micropipes observed in our experiments.

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DAMAGE AND FRACTURE OF AGED ELASTIC-VISCOUS MEDIA

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Structural polymeric materials and composites based on them are widely used in various fields of modern engineering practice. In actual operating conditions they are subjected to the influence of complex mechanical, physical and chemical factors. Internal physical and chemical processes occurring as a result of these actions lead eventually to a change in there rheological properties. Together, these processes determine the aging of the material. It is possible to distinguish two types of aging: climatic and deformation. In the case of there combinations there are significant changes in the mechanical characteristics that are observed in our experiments performed on alternating active and cyclic loading and aging on specimens of polyurethane at different times of climatic and strain aging. In particular, in experiments with strain aging it is observed that material is hardened considerably, as compared with the specimens tested after climatic aging. To describe them the elastic viscous models of Maxwell and Voight, expressed in the scale of the effective time, are used. These equations are supplemented by a kinetic equation that determines the evolution of the damage state of the media. Functions and parameters of the proposed equations are specified and analytical relations for the damage parameter and criteria of long durability with and without account of aging processes are received and the corresponding theoretical curves are constructed.

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HIGH TEMPERATURE DAMAGE AND CREEP FRACTURE OF METALLIC MATERIALS

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The work is aimed at the development of investigations impotent scientific and technical problem of damage and high-temperature creep fracture of metallic materials. This problem is demanded in such areas of modern engineering as the thermal and nuclear power plants, aircraft and spacecraft and others. In this regard, intensive studies on this problem are carried out. It has been found that under the prolonged action of stresses and high temperatures metallic materials embrittled due to development of damage (cracks, pores etc.). These effects have been studied in detail by the methods of physics and materials science. For engineering applications, it became necessary to develop mechanical models of creep damage and fracture. The first such models have been proposed in the works of G. Hoff, L.M. Kachanov, Yu.N. Rabotnov. In these models incompressibility condition is assumed, which is contrary to the very concept of damage. This contradiction can be overcome, if we assume that the material is compressed and formulate the creep fracture criteria, taking into account the law of conservation of mass. Taking into account these propositions and remaining within the concept of damage mechanics, interrelated equations of creep, damage, and long-term strength are formulated. The proposed approach does not contain the mentioned contradictions and can be considered as the basis for a more accurate description of the deformation and strength processes occurring in metallic materials and structural elements, especially during long action of relatively low stresses and high temperatures.

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THEORETICAL MODELING OF ALUMINUM OXIDE GROWTH DURING ANODIZATION

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Currently, the development of nanotechnology and metamaterials requires the ability to obtain regular self-assembled structures with different parameters [1-2]. One such structure is porous alumina films, which are self-organizing structures that consist of hexagonally packed cylindrical pores. Pore size and the distance between them can be varied depending on the anodization voltage, the electrolyte and the anodization time (pore diameter - from 2 to 350 nm, the distance between the pores - from 5 to 50 nm).
In this paper we describe an analytical model of the growth of anodic alumina. We consider the motion of the interfaces between the electrolyte-Al_2O_3 (dissolution) and between the Al_2O_3-aluminum (oxidation).
We consider the dynamics of moving boundaries and the change of small perturbations forms of these boundaries. In each of the areas under consideration Laplace equation for the electric potential is solved. The process of growth of porous alumina is described by the theory of small perturbations. In zero approximation boundaries are considered flat and the speed of their movement proportional to the current density at these boundaries. The first approximation takes into account the small perturbations of the interface, which lead to small changes in the potentials and currents at these boundaries. The evolution of small perturbations of the interface is defined as a perturbation of the current density at the borders, and the process of surface diffusion.

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DEVELOPMENT OF MODELS OF INTERFACES FOR NUMERICAL SIMULATION OF MATERIALS WITH MULTIMODAL INTERNAL STRUCTURE

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Currently, the design of advanced materials is in many respects based on theoretical results obtained with computer simulation. The necessity for computer simulation in modern materials science and mechanical engineering has promoted a rapid development of numerical methods and generated a need for the development of methodologies and approaches of multiscale modeling of material deformation and fracture. It should be noted that regardless of the chosen approach developed multiscale numerical models should take into account (explicitly and implicitly) the contribution of deformation mechanisms of spatial and structural scales, lower with respect to the considered one, to the mechanical response of the material at the considered scale. This actually means the requirement for taking into account the internal structural and rheological features of basic structural elements at different scales, first of all, at the nano- and microscale. The basic elements of the internal structure are not only grains and inclusions of other phases but also interfaces between them and discontinuities whose deformation ability and evolution play a crucial role for a wide range of materials and, for example for materials with so-called multimodal internal structure. The term "multimodal internal structure" means that material has multiscale structure in which the size distribution of grains or phases is characterized by the presence of several different-scale maxima. So, the key point in describing the mechanical response of materials with multimodal internal structure at the meso-, micro- and nanoscale is to take into account the role of grain boundaries and phase interfaces. The geometric and physical and mechanical properties of such interfaces depend on the characteristic size of the structural elements separated by interfaces as well as on the conditions of material production. Particularly, the characteristic width of grain boundaries does not exceed a few nanometers, whereas the width of phase interfaces may vary within several orders of magnitude and reach a few micrometers. The "wide" phase interfaces have a pronounced gradient of the internal structure and mechanical properties in transition from one phase to another.

This paper is devoted to development of multiscale numerical models for simulation of deformation and fracture of materials with multimodal internal structure in the framework of discrete element method (DEM). Two representatives of this type of heterogeneous materials produced by powder metallurgy methods are considered in the paper. These materials are chosen to demonstrate the possibilities of the developed DEM-based models, first, due to their multiscale internal structure in which grain boundaries and phase interfaces are key elements and, second, due to high industrial demand in them as materials for turbine blades (intermetallic compound Ni3Al) and cutting tool components (TiC-particle-reinforced Ni-Cr matrix composite).

This work was supported by the Russian Science Foundation (grant 14-19-00718).

DEVELOPMENT OF DISCRETE ELEMENT APPROACH FOR COMPUTER-AIDED SIMULATION OF THE DYNAMICS OF FRICTION STIR WELDING PROCESS

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Friction stir welding (FSW) is a relatively new method of obtaining non-detachable joints of materials. Recent year studies have shown that FSW is an effective way to obtain high quality joints for structures of various dimensions and shapes, including sheets, 3D profile structures, and pipes. Possessing the broad technological capabilities for obtaining permanent joints of details or units, it can be used as an alternative to riveted joints, electric arc welding, electron beam and laser welding as well as for welding the dissimilar materials. Thus, FSW becomes a perspective technology that has a great potential in various industries, including aerospace area.

The FSW technology is based on the friction of the rotating cylindrical or specially shaped tool between two connected or overlapped faces (ends) of metal plates. The rotating tool is introduced into the joint of two metal plates to a depth approximately equal to their thickness. As a result of sliding friction (while rotating of the tool) a frictional heating the metal takes place. This leads to plastic deformation, flow and mixing of the material and, consequently, to formation of welded joint. The main problem when using FSW technology for producing of welded joints is the determination of an optimal regime (optimal parameters) of the rotating tool movement (in particular, the ratio of the angular and traslational velocities of the tool). These parameters are determined by a wide range of factors, among which are the physical and mechanical properties of welded materials, the thickness of the connected plates, etc. Note, that incorrect determination of welding parameters is likely to cause of a large amount defects at different scales (pores, microcracks, etc.) in a weld seam and, consequently, to decrease of the quality of the joint.

Experimental determination of the parameters of FSW process is quite difficult task, because it requires obtaining and analysis of large amounts of data. In this regard, it is promising to use computer-aided simulation of process of formation of the welded joint. Since FSW processes are inseparably linked with the intensive formation of discontinuities, the generation of structural defects of different levels, the mass transfer, etc. the most preferable one is to use methods of discrete description of the simulated technology. In this paper, the dynamics of the FSW process of duralumin plates was investigated on the base of computer-aided simulation by the movable cellular automaton method.

To achieve the objectives of the paper the two-dimensional model of elastic-plastic interaction of cellular automata is used. This model is based on the use of many-particle potentials/forces of interaction of cellular automata. An incremental theory of plasticity of isotropic medium with von Mises plasticity criterion was used to model deformation of intermetallic alloy. Radial return algorithm of Wilkins was adopted for this purpose. Using the developed approach allowed to investigate the features of the dynamics of of formation of welded joint. It is shown, in particular, that in a certain range of the ratio of the angular and traslational velocities of displacement of the rotating tool it is possible to obtain a welded joint with a minimum content of pores and microcracks.
The work has been supported by RF Ministry of Education and Science (project ID RFMEFI57814X0045) on"Improving the technology of friction stir welding by ultrasonic treatment to form permanent connections ofhardened aluminum alloy for aerospace and transport industry" and by Program for Basic Scientific Research of theState Academy of Science on 2013–2020.

THE NON-HARMONIC OSCILLATIONS FOR VIBRATORY PILE DRIVING

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To improve the efficiency of overcoming point resistance of piles in cohesive soils a new design of dual-frequency vibratory pile driver and its operation scheme to generate oscillations of two different types is proposed. The device can work by two modes: in differential up and down speed and in differential driving force acting upwards and downwards.
The operation scheme of the vibratory pile driver is based on cooperation of two pairs of eccentric masses with different rotation speed, static moments and initial phases for different eccentric mass pairs. The basic parameters and components of the vibratory driver are represented.

INITIAL VALUE PROBLEMS FOR THE HEAT TRANSFER PROCESS IN IDEAL CRYSTALS

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In work [1] the equations for the heat flux and kinetic temperature are analytically derived for one-dimensional defect-free harmonic crystals based on the correlation analysis and the long-wave approximation. Unlike equations of the hyperbolic heat conduction [2, 3], the equation [1] is time-reversible and has only one independent parameter, i.e. the speed of sound "c".

Analytical solutions of this differential equation are obtained for various initial and boundary conditions, namely: a thermally insulated half space heated by an instantaneous point source located at its edge, the cooling of an evenly heated half space under the boundary conditions of the first kind, heating of a half-space and a layer with a short laser pulse distributed in the media according to the Beer–Lambert–Bouguer law. The solutions are obtained both in the closed form and in a form of a series. The detailed analysis of the obtained solutions is conducted: we have built the envelope curves for the solution profiles, studied the asymptotic behavior of the solutions and plotted the temperature with respect to time at the both ends of the heated layer. All the obtained results are compared with the analogous solutions within the classical Fourier and Cattaneo-Vernotte (MCV) hyperbolic heat transfer models. The analytical results are confirmed by computer simulations.

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DIRECTED ANTENNA FOR BLOCK STRUCTURE

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It was shown earlier that varying the form of a punch one can achieve a directional radiation of surface waves. A directional radiation is necessary while solving many applications, for example during calculation of acousto-electronic piezoelectric devices on surface waves or during the allocation of hard vibrating equipment, when it's necessary to shade different objects having directed the radiation to a safe side.
In seismic prospecting and defectoscopy the problem of creating a directional radiation of volumetric waves is relevant. Directional seismic antennas are even more widely used during the vibratory examination of the earth's crust and upper Earth mantel, but the optimal characteristics of antenna elements (amplitudes and burden phases) are being determined only empirically, and the use of acoustic antenna theory, formulated to create ideal acoustic circumstances, in case of elastic stratificated circumstances causes great errors. In order to obtain the results, used practically, also the calculation of vertical inhomogeneity and block structure of circumstances realized in this work is important.

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INFLUENCE OF A PLANE BOUNDARY ON THE RESPONSE OF A FREELY VIBRATING CYLINDER IN UNIFORM FLOW

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Though power cables transporting energy from off-shore wind farms to shore are expected to be buried, it may happen that due to sand migration and scour some parts of the cable are uncovered and therefore subjected to flow. Being that the case, it is important to assess if the free span of the cable may be subjected to vortex-induced vibrations (VIV) and what implication that may have in the operational lifetime of the cable.
Works were performed in the past whose intent was to study the behaviour of cylindrical structures when subjected to flow. Nevertheless, studies that consider the influence of a plane boundary in the response of the cylinder are scares, and therefore the motivation of the work that is herein presented.
This presentation is composed of two parts: first, report is made to experiments on stationary and free-vibration cylinders that are exposed to uniform flow and that are placed at varying distance from the rigid bottom of an open flume; secondly, it is explained how the existing wake-oscillator model is enhanced in order to accommodate the features observed the experiments.

ROTATIONAL MOVEMENT OF THE MATERIAL UNDER CONDITIONS OF CREEP AND PLASTICITY

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The model of elastoplastic body assumes the independence mechanical properties of materials from time. However, the mechanical properties of many modern technological materials changes considerably over time. The phenomenon of creep is expressed either in increasing strain over time at a constant load, or in decrease stresses at a constant strain. The accumulated strains in the body resulting from creep can distort or even destruction of the body. Thus, the study of the creep process is important and phenomena associated with the process of creep, are of considerable interest to the modern theoretical and applied sciences.
In this paper we study the nonlinear elastic and viscous properties of the material, which is located between two rigid coaxial rotating cylinders. The solution is constructed using the model of the large elasticviscoplastic deformation that takes into account both the viscous properties of the plastic flow stage and before it [1, 2]. The reversible and irreversible deformations are determined from differential transport equations. The velocity of the irreversible deformation is determined in the area of plastic flow by means of the associated flow law, in area of elastic-creep strain it is determined by Norton creep law. The process is studied with increasing, decreasing and constant load. For calculating fields of the stress and strain system of differential equations with partial derivatives was obtained in areas of viscoplastic flow and in areas with elastic-creep deformations. The implicit finite-difference scheme was built for solve the system of equations.
This work was supported by the Grant of the President of the Russian Federation (project no. MK-2879.2014.1).

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MODELING OF ELASTIC PROPERTIES OF MOLYBDENUM DISULFIDE USING A TORQUE INTERACTION POTENTIAL

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Elastic behavior of single-layer molybdenum disulfide ($SLMoS_2$) is studied. A potential describing the interaction between atoms of material was developed. This potential includes the torque interaction in addition to the classical force interaction. It was demonstrated, that both Mo-Mo and S-S interactions could be regarded as pair Morse force interactions with the sufficient accuracy. The parameters of Morse potential were determined for both types of interaction. Four out of six parameters of torque potential were obtained for Mo-S bond using information about the elastic moduli and phonon spectrum available in the literature. These parameters allowed to predict the elastic behavior of infinite $SLMoS_2$ crystal in a basal plane. The remaining two parameters for Mo-S bond, which are responsible for bending and torsion stiffnesses of the bond, can be identified from the indentation test. A good agreement is observed between the proposed model and both the experimental and numerical data on elastic moduli, phonon spectrum and indentation test.

ON THEORY OF THERMOPRESSING OF CONIC SHELLS FROM FIBROUS COMPOSITES

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The general idea is the following: the impregnated composite tapes are placed on the mould made of material with relatively great value of TEC(thermal expansion coefficient), then the shell made of material with relatively small value of TEC is placed over composite, and from the side of big base of the cone the relative position of moulds is fastened. On heating the clearance between moulds decreases and pressure of composite is realized.

MODELLING AND STUDY THE SIZE AND SHAPE OF PLASTIC ZONE AROUND BLUNT AND SHARP PLANE CRACKS

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In the development of technological processes of manufacturing and design elements with the specified functional properties of the material necessary to ensure the appropriate structure, which determines its mechanical and physical properties. In the structural mechanics of fundamental role is simulation of the interaction of various scales in the process of deformation and failure to improve the operational properties of product (durability, strength, fracture toughness). [1].

Influence of microdefects to the physical and mechanical properties of the material is studied by Irwin theory of strength, in which the defect is modeled by mathematical cut with ability to spread. In this case, there are singular points at the ends of the cut where stress tends to infinity by the asymptotic law. In Griffith's fracture mechanics study of the influence of defects on the properties of materials comes to a boundary value problem in plane deformation of a body having elliptical shape cutout.

In this paper, by using the structural strength criterion of Neuber – Novozhilov [2], obtained a formula of the critical load for plane blunt and sharp cracks.

According to the obtained formula is carried out modeling of sharp crack as a thin ellipse with a ratio of small and major semi axes one to ten.

With application a software package OpenFOAM [3], based on the finite volume methods, by creating a solver for small elastoplastic deformation, we found the shape and size of plastic zone around the blunt and sharp cracks.

A size of plastic zone based on calculation results satisfactorily agrees with the experimental data in researches of Hahn and Rosenfield [4], and shape – with data of Tuba [4].

The results allow evaluating the impact of the microstructure to ductile material and on the behavior of structures made from such materials.

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NONLINEAR VIBRATION-INDUCED EFFECTS IN MECHANISMS, FLUIDS, LOOSE AND COMBINED MEDIA:NEW RESULTS

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The article contains a summary of the main results of the research representing the fundamental basis for the creation of new vibration processes and devices, with specific focus on the radically new findings and their practical applications.

A brief review of the main areas of the research (regarding vibration effects on mechanisms, rotor synchronization, vibrational displacement, and vibrorheology) is followed by the results of new developments. These include:

1. Development of a common approach to the study of high-frequency effects on dynamic systems (oscillatory strobodynamics) and its elaboration.
2. Studies of vibration effects on physical processes, chemical reactions, and biological systems.
3. Studies of the separation of granular materials, identification of the vibration-induced diffusion separation effect, elaboration of the respective theory.
4. Development of models for the vibrational screening process, using the results to create new vibratory separators.
5. Studies of the behavior of oscillating bodies near

the interface between two media, identification of the increased buoyancy effect, suspension of particles in near-wall turbulent flows.
6. General studies of vibrational antigravity processes, the two simplest models.

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PLASTIC DEFORMATION MODES MEDIATED BY GRAIN BOUNDARIES IN NANOMATERIALS

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This presentation gives an overview of theoretical models which describe special modes of plastic deformation, the namely modes mediated by grain boundaries in nanomaterials. We describe several classes of theoretical models treating grain boundaries as defects highly contributing to plastic flow in nanomaterials. First, we discuss the class of dislocation emission models where grain boundaries act as sources of mobile lattice dislocations. In doing so, low-angle, high-angle and amorphous grain boundaries in nanomaterials are considered. Second, we discuss theoretical models dealing with stress-driven movement of grain-boundaries. In particular, we consider stress-driven migration and rotation of grain boundaries as special modes of plastic deformation in nanomaterials. Special attention is paid to deformation-distorted grain boundaries as defects specific to nanocrystalline and ultrafine-grained materials fabricated by severe plastic deformation methods. Finally, we discuss theoretical models based on the approach of nanoscale ideal shear mode (the so-called nanodisturbance deformation mode) developed by our theoretical group. The mode represents formation and evolution of nanodisturbances - nanoscopic areas of ideal plastic shear with tiny shear vectors – in nanomaterials with various geometries and chemical compositions. Results of all the models under consideration are compared with the corresponding experimental data.

INFLUENCE OF MICRO-CHARACTERISTICS ON MACRO-PROPERTIES OF NANOPOWDERS IN COMPACTION PROCESSES

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The processes of cold compaction of nanopowders are simulated by the granular dynamics method [1, 2]. Model systems with a diameter of particles of 10 nm, which correspond to the oxide nanopowders having weak and strong tendency to agglomeration, are investigated. The interactions of the particles, in addition to commonly used contact interactions such as Hertz law and Cattaneo-Mindlin law, involve the dispersion forces of attraction and the possibility of the formation/destruction of solid bridges between particles. The solid bridges result from strong pressing of particles to each other which is initiated an action of high dispersive interactions or the compaction process. The influence of such micro-characteristics of powder as elastic properties of particles (the Young modulus, Poisson's ratio) and the energy parameter of dispersive interactions on macro-properties of the powder body is analyzed. In particular, it is revealed that values of particles elastic modules have weak influence on compaction curves, when monotonous loading takes place, but substantially define behavior of nanopowder when decreasing external pressure, i.e., at stages of unloading. At condition of pure shear deformation of model cells the effect of a positive dilatancy is found: the examined systems tend to increase their volume under the pure shear stress. In simulation results (at constant volume), this fact is reflected by positive values of the hydrostatic pressure.

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COMPARATIVE ANALYSIS OF NON-CLASSICAL THERMAL CONDUCTIVITIES OF THE MCV AND GNIII TYPES

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We studied two thermal conductivity models, namely Cattaneo-Vernotte [1] and the Green-Naghdi [2] as a special case of two-temperature model of heat propagation in metals [3].

Dispersion curves were built for the Green-Naghdi and Cattaneo-Vernotte heat equations. The decay coefficient, phase and group velocities dependences of the frequency were compared within each theory. We found asymptotic values of the phase and group velocity and decay coefficient for the Cattaneo-Vernotte thermal conductivity; their absence were shown in the Green-Naghdi thermal conductivity, which means the Green-Naghdi heat equation is parabolic.

The branches of the phase and group velocities of the Cattaneo-Vernotte thermal conductivity emerge from the origin, but the branches of Green-Naghdi theory emerge from the non-zero velocity value.

Within the Cattaneo-Vernotte thermal conductivity the decay coefficient branches emerge from the origin at the right angle (as in the classical Fourier heat conduction), but in Green-Naghdi thermal conductivity this angle is 0 degrees.

We conclude that the Cattaneo-Vernotte thermal conductivity significantly corrects Fourier's law at high frequencies, but the Green-Naghdi thermal conductivity corrects Fourier's law at low frequencies.

We concider a problem of a thin metal layer irradiated by a short laser impulse adopting the two-temperature model [3]. The interaction of a slab with a laser beam was modeled by the internal heat sources, assuming that the intensity of the laser radiation is absorbed by the medium according to the Beer–Lambert law. The temperature distribution over the layer thickness was plotted at different moments of time. The obtained solution was compared with each of the three special cases of the two-temperature model [3] : the Green-Naghdi [2] , Cattaneo-Vernotte [1] and classical Fourier heat conductivity. The temperature on the back side of the irradiated layer was plotted versus time.

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ADAPTIVE MULTI-SCALE METHODS FOR FRACTURE, CAD, IMAGE AS A MODEL AND DIGITAL TWINS

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The presentation focuses on recent advances in multi-scale methods for fracture of heterogeneous materials. We focus on two approaches: model order reduction and homogenisation.

The need for multi-scale methods is motivated by the requirement to understand and predict the behaviour of heterogeneous, adaptive, smart and sentient materials whose micro-structure is increasingly complex and whose behaviour entails not only mechanical, but also thermo, hydro, magneto, electric and excitations. It is clear that it is impossible and perhaps unwise to even attempt to model the full complexity of the material over scales of engineering relevance, which has motivated approaches to reduce computational expense for such problems.

Such methods can be decomposed into two classes:

- model order reduction based on algebraic arguments
- physics-based reduction based on averaging (homogenisation)

Standard hierarchical homogenisation methods fail as soon as material loses stability. In this case, representative volume elements cease to exist and hierarchical methods must be coupled to concurrent methods which represent the microstructure explicitly.

The second approach consists in reducing the multi-scale problem algebraically, i.e. through (offline) pre computations which are hoped to capture some of the behaviour of the material and structure. The difficulty here is that such methods fails as soon as non-linearities arise, in particular when those are strongly localised, for example during damage and fracture.

It therefore seems that the two approaches available face the same hurdle, in other words the lack of correlation between solutions in the region of interest, where fracture takes place.

The presentation will review recent advances in this field and touch upon advanced discretisation methods to simplify the interaction of the user with the model: CAD as a model and Image as a Model.

STUDY OF TWO RAPIDLY SOLIDIFIED AL-5CR-2ZR (WT.%) ALLOYS

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The development of aluminium alloys with improved elevated temperature properties using rapid solidification routes has been a major research goal of the aerospace industry. The strength normally increases with the volume fraction of second phases located in the matrix. For high-temperature applications, mechanical properties can be enhanced by stable and finely distributed dispersoids within the α-aluminium matrix. Among the most successful developments is the Al-Cr-Zr alloy which owes its elevated temperature strength to fine particles formed in the matrix as a result of heat treatments. The obtained products of Al-5Cr-2Zr (wt%) such as atomised powder and melt spun ribbons underwent some degree of evaluation of microstructure and thermal stability by the means of the complementary techniques of characterisation such as optical microscopy, scanning electron microscope (SEM), transmission electron microscope (TEM), Microhardness measurements and X-ray diffraction. The microstructure of these products contain, in addition to α-aluminium matrix and Al13Cr2 precipitates, a new type of precipitates which exhibits fivefold symmetry and it appears to be thermally stable.

COMPARISON OF DISLOCATION DENSITY BASED APPROACHES FOR PREDICTION OF DEFECT STRUCTURE EVOLUTION IN ALUMINIUM AND COPPER PROCESSED BY ECAP

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Three known dislocation density based models are compared to each other, and to available experimental results. All three models were embedded into ANSYS finite element (FE) software and firstly utilised to predict aluminium and copper transformations (dislocation density evolution and the resulting grain size) in a result of a single pass of equal channel angular pressing (ECAP). It is demonstrated that for the studied problem dislocation density evolution under severe plastic deformation (SPD) can be precisely predicted utilizing simple classical model. One of the models was utilized to predict defect structure evolution for the series of ECAP passes. Simulations have revealed that within the framework of the proposed model the increase of the dislocation density on ECAP pass is proportional to yield strength increment on the previous pass for both studied materials. This fact gives grounds to a proposal of a semi-analytical approach, predicting dislocation density evolution in a result of consequent ECAP passes on the basis of a numerical simulation of the two first passes. The utilized kinetic model for dislocation density evolution separates between densities of mobile and immobile dislocations. Employing the idea of separation of dislocations into mobile and immobile, a new approach for dynamic recrystallization coupling dislocation density and the size of grain formed in metal is proposed. The proposed approach for dynamic recrystallization appeared to be applicable for the whole range of grain sizes.

HYBRID MATERIAL AND SPATIAL DESCRIPTION FOR SATURATED POROUS MEDIA

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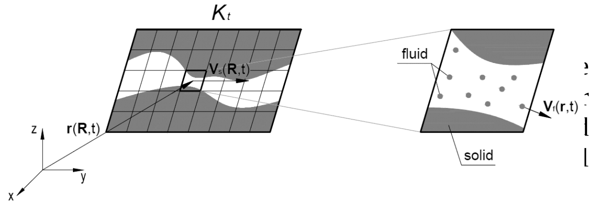
Fluid flow through deformable porous solid matrix is rather wide problem. Flow conditions can be very different. They depend on type of fluid, its density, viscosity, typical velocities and sizes and opportunity of chemical reaction or phase transition between solid and fluid. The first difficulty of this problem is stress and strain definition in the solid and fluid phases. For the solid continuum material approach is traditionally used whereas for the fluid continuum – spatial. Material approach is limited for fluid due to particles mixing. Spatial approach is embarrassing for the solid media because of configuration evolution description.
The second problem is fluid-solid interaction modeling. Usual interaction laws includes only viscous effects (Darcy’s law, Fick’s law). Though in some cases the elastic effects have a great influence on both of the components.
In this work, physically based approach is introduced. It consists in material description for the solid phase and spatial description for the fluid phase. For the solid phase the reference volume connected with referential coordinates was introduced. Fluid motion through solid matrix motion is described using spatial description relatively the same reference volume. Note that this kind of spatial description differs from classical approach because of the reference volume.



The energy balance equation for two-phase continuum was constructed. Further to the solid and fluid energy, we consider interaction energy. Using Zhilin's approach entropy and temperature were incorporated in the equation system. They are assumed to be conjugated in terms of the energy. The energy balance equation is obtained in reduced form. This allowed writing constitutive equation for elastic components of stress tensors and interaction force and moments. Constitutive equations for inelastic components are found using the second law of thermodynamics.

ENGINEERING ESTIMATION OF BEARING CAPACITY OF SOLIDS

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The problem of an estimation of bearing capacity of a solid is considered in the current configuration, which may be as the *reference* (undeformed) or the *actual* (deformed). We propose an original variational approach to the problem for stresses in selected subdomains, in which, depending on different engineering considerations, average integral values of different component of stresses are estimated and from their aggregate the bearing capacity of the current configuration of a solid is estimated regarding to given external influences. In each of the selected subdomain the weakest stress field is obtained which is globally balanced with external influences. In reality, the body can to balance significantly more intense external influences. Thus, a lower bound for the bearing capacity of the current configuration of a solid is estimated for given external influences and selected subdomains. Previously a method has been proposed for estimating the bearing capacity of the reference configuration of nonlinear elastic solids on the basis of limit analysis [1].
The proposed approach is fundamentally different from the classical method of rigid-plastic analysis of bearing capacity of the only reference configuration of a solid in which the only point criterion of maximum intensity of shearing stresses is used [2]. The principal disadvantage of this method is the uncertainty of the stress field in hard subdomains of the body. In the proposed approach, depending on different engineering considerations, average integral values of any component of *allowable* stresses in *various subdomains* are estimated and from *their aggregate* the bearing capacity of the *current* configuration of the solid is estimated. For example, the assessment of the average integral hydrostatic pressure is needed for study of bearing capacity of geomaterials.
At the end, an analytical example is presented, clearly showing the richness of the proposed original approach.

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SOUND PROPAGATION IN FINE MAGNETIC POWDERS: EFFECT OF THE MAGNETIC FIELD IN THE ASSEMBLING PROCEDURE

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In previous experiments on the propagation of sound wave in cohesive powders we studied the ballistic velocity of ultrasound waves at consolidations above 1.25 KPa and solid fraction above 0.47. In this study we use a new experimental setup that allows us to investigate sound propagation by resonant methods at lower consolidations, and in the presence/absence of magnetic fields in the vertical direction. We erase the powder memory in order to have a reproducible initial state. The method consists in introducing a flow to break all contacts, then cutting off the gas flow and wait for the sample to settle under gravity before measuring sound wave velocity. We may apply the magnetic field during the fluidization state and/or in the sediment. In this work we report the experimental results for sound propagation for the application of the magnetic field during the fluidization state. In the fluidization stage the magnetic field allows dipoles to be oriented in preferred chains along the magnetic field. The sedimentation of the vertical chains produces a quite different contact network, compared to the sedimentation of aggregates in the absence of magnetic fields. Sound is able to detect this anisotropy of contacts. The results show the important role of cohesive forces (van der Waals and magnetic interparticle forces) in the network of contacts in these loosely consolidated fine powders, and how affect sound wave propagation in the sediment.

THE CALCULATION OF PLANAR STOKES FLOW WITH FREE BOUNDARY IN HOMOBARIC APPROXIMATION

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The Stokes flows of high-viscosity liquid with free boundary attracted the attention of researches due to many applications - from glass formation to lava draining [1, 2]. The planar models let us to investigate the qualitative effects which appear in these flows [3, 4]. In [5] was described the method of planar Stokes flow calculating based on the expansion the pressure in a complete system of harmonic functions. The structure of this system depends on the topology of the region. Using the pressure distribution, we calculate the velocity on the boundary and investigate the motion of the boundary.
In homobaric approximation pressure distribution assumed homogeneous and equal to average pressure over the region.

This approach allows obtaining a simple analytical expression for the velocity of the boundary. The resulting law of evolution of the interface is in qualitative agreement with the exact law. In case of capillary forces the law of perimeter decreasing obtained in homobaric approximation is a strict upper bound of the true law of perimeter evolution.

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NON-LINEAR MECHANICS AND NUMERICAL SIMULATIONS IN MICROSYSTEMS: RECENT ADVANCES AND APPLICATIONS

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Microsystems (or Micro Electro Mechanical Systems, MEMS) are devices, like e.g. micro accelerometers, micro gyroscopes, pressure sensors and micro pumps, whose dimensions are in the range of fractions of micrometers to millimetres with sensing and actuating functions. The great versatility and the reduced unit cost have been the basic ingredients for the large diffusion of microsystems in various fields like the consumer and automotive markets, structural monitoring and biomedical devices. They are one of the key ingredients in the Internet of Things (IOT) incoming world. The purpose of this talk is to describe the microsystems complexity from a mechanical perspective. The focus will be on some aspects of the non-linear mechanical behaviour and on coupled, multi-physics phenomena strictly connected to the microsystem world, which deserve particular care in the study, design and final testing of the products. Starting from examples studied in strict collaboration with a major industrial partner, the presentation will deal in particular with the dynamics of resonant devices in linear and nonlinear regimes and on advanced techniques for multi-physics numerical simulations.

DYNAMIC BUCKLING OF A COLUMN UNDER CONSTANT RATE COMPRESSION: ANALYTICAL SOLUTION AND FINITE ELEMENT STUDY

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Buckling behavior of a column rod beam under kinematic loading is considered. The buckling is caused by the motion of the column ends towards each other with constant velocity. Simple model with one degree of freedom simulating static and dynamic buckling of a column is presented. Analytic expression for the critical buckling force as a function of compression velocity and initial disturbance is derived. It is shown that in a range of compression rates typical for laboratory experiments the dependence can be accurately approximated by a power law with an exponent equal to 2/3. Strong influence of the initial disturbance on the time required for buckling and on the critical buckling force is demonstrated. These theoretical findings are supported by results of available laboratory experiments and finite element simulations carried out in the present paper.

DYNAMICS OF A LARGE RING-SHAPED STRUCTURE TOWED VIA A HEAVY ROPE

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We aim to investigate the in-flight motion of a large ring-shaped structure towed via a heavy rope. The ring is assumed to be suspended at its center by a single rope. The first objective is to use the exact rod theory [1] to derive the governing equations for the rope-ring system. The aerodynamic loads will be included in an appropriate manner by assuming arc and length elements of, respectively, the ring and the rope, to be infinitesimal cylinders in crossflow, and then employing available lift and drag models. The governing equations will then be solved numerically via finite element method. Our second objective will be to investigate the stability of the system. A linear stability analysis following perturbations of the equilibrium equation will be performed. Such an investigation will help point the way towards better designing and controlling strategies for such underslung loads.

The ring's mass is much less than that of a typical helicopter, hence we ignore its effect on the dynamics of helicopter. This means that the effect of the helicopter on the ring may be reduced merely to a specification of the three-dimensional motion of the point of attachment of the ring to the helicopter. Further, assuming that the ring lies well below the helicopter, the effect of the rotor's downwash on the it may also be ignored. While underslung loads from helicopters are well studied, [2-4], a detailed stability analysis of such structures is sparsely investigated.

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MICROSTRUCTURED N-TH GRADIENT CONTINUUM MODELS AND SOME APPLICATIONS

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Composites and living tissues show many interesting similarities: they have a complex behaviour at macro-scale which is usually related to their micro-structure. One can also easily establish which are the most relevant differences between these two class of materials: both differences and similarities deserve to be carefully considered and studied as understanding them will allow a serious advancement of knowledge. Indeed composites and living tissues share many features in their respective multiscale structure and both show at micro-level high contrast in physical and geometrical properties. On the other hand living tissues are able to change their constitutive equations by means of re-modelling processes, which are controlled by tissue resorption and tissue formation as driven by mechanically driven biological stimuli.

Some numerical, theoretical and experimental results which were recently obtained will be presented showing that fibrous fabrics must be modelled by means of second gradient continua (at least) and that one can conceive to design new and efficient metamaterials whose performances can be really exotic. In particular some microstructured fabrics constituted by fibres having bending stiffness (pantographic sheets) and nearly-inextensible are carefully studied using microscopic and macroscopic models. These examples show that: i) macro-models cannot belong to the class of Cauchy first gradient continua ii) some fabrics whose micro-structure is really simple may have a very complex macro-behaviour, iii) the dynamical response of pantographic sheets can be really unexpected and iv) some delicate experimental set-ups are needed to measure their main physical properties.

We show also how growth of reconstructed bones can be greatly influenced by the microstructureof bone tissue and reservable material (which again can be modelled by means of second gradient models) and therefore we suggest that the lattice pantographic microstructure conceived to design aforementioned metamaterials could be fruitfully used to conceive bone scaffolds.

A digression on the concept of generalised contact forces in higher gradient continua and on the boundary conditions naturally arising in the theory of generalised continua will be necessary to consistently present the obtained result. This digression shows some of the the limits of standard continuum mechanics as conceived by Cauchy and motivates the conceptual effort (based on the Lagrangian Principle of Virtual Work) which has been started by Gabrio Piola, continued by Toupin, Mindlin and Germain and recently re-started by several research groups to found the correct conceptual frame for generalised continuum mechanics.

THE NUMERICAL STUDY OF A MECHANICAL RESPONSE OF WATER-SATURATED POROUS SAMPLES IN THE FRAMEWORK OF A COUPLED DISCRETE-CONTINUUM APPROACH

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We propose a numerical model of liquid-saturated porous material (brittle or ductile), based on a coupled approach combining the particle-based numerical method and finite difference method. In the framework of the model a porous solid skeleton is described with the discrete element method, named the "Method of movable cellular automaton (MCA)". An ensemble of discrete elements simulates processes of deformation of a porous solid and filtration of single-phase liquid in an interconnected network of "micropores" (pores, micro-channels and other discontinuities enclosed in the volume of a discrete element). We suggest, following the ideas of Biot, that stress-strain state of a discrete element is directly interconnected with a change of a volume of pores and pore pressure of a fluid in the "micropores". Mass transfer of a fluid between the "micropores" and "macropores" (the latter are considered as the areas between spatially separated and non-interacting discrete elements) is calculated on a finer grid superimposed on an ensemble of movable discrete elements. This approach allows description of a behavior of samples and systems with developed multi-scale porosity, like ceramics, coal seams, biological tissues etc.

The developed model has been applied to numerical study of a mechanical response of brittle samples with water-saturated pore volume. It has been shown that the strength of liquid-saturated samples is determined not only by strength properties of "dry" (unfilled) material and a pore pressure, but largely by sample geometry, deformation rate and characteristics of porosity of a material. Analysis of simulation results allowed us to suggest a generalized dependence of the uniaxial compressive strength of water-saturated permeable brittle material on the specific diameter of filtration channels, which is the ratio of the characteristic diameter of the filtration channels to the square root of the strain rate. Values of parameters of mentioned dependence are strongly connected with the character of the relation between pore volume and pressure of a liquid. Obtained results demonstrate the applicability of the developed model for studying of nonstationary processes of deformation and fracture of fluid-saturated materials under dynamic loading.

POSSIBLE IMPACT OF NANOPARTICLES ON POLYMER MATRIX PROPERTIES

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The method of movable cellular automata (MCA) was applied to simulate the stress-strain behaviour of a nanocomposite consisting of an epoxy matrix and 5 vol. % silica nanoparticles and for samples of pure components. The size of the elements used for modelling was fixed at 10 nm, corresponding approximately to the diameter of the filler particles. Modelling results were compared with tensile test results of both, pure epoxy as well as the epoxy-5 vol. % SiO2 composite. Since assuming bulk properties of the two constituents did not yield satisfactory results, slight modifications of the nanoparticle response functions and nanostructures were tested numerically. Finally, slightly increased strength properties of both constituents had to be taken into account for obtaining good correlation between experimental and modelling results. The tendency of model parameter adjustments corroborate expected changes of composite constituents compared to their respective bulk structures.

MOLECULAR DYNAMICS STUDY OF THE LOCAL FRICTIONAL CONTACT

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In the paper simulation of the behavior of copper crystallite under local frictional contact was carried out using the method of molecular dynamics. Loading was realized by the movement of hard indenter along the surface of the sample. Following configurations were considered: initially defect-free crystallite, structure with a symmetrical tilt grain boundary Σ5. Influence of the initial structure on the behavior of the crystallite under loading was analyzed. Nucleation of nanofragmentation of the surface layer was displayed. Atomic mechanisms of a process of nanofragmentation were investigated. A detailed analysis of the character of the atomic displacements in emerging blocks shown that they have a rotational nature. Further calculations showed that the amount of disorientation of formed nanoblocks along different directions is not more than 2 degrees. Despite what two limiting cases of arrangement grain boundaries in the material has been studied only, it can be assumed that the behavior of crystallites with defect disposed at an arbitrary angle relative to the free surface is a combination of processes that occur in these cases.

NONLINEAR LOCALIZED DEFORMATION WAVES IN THE CONTINUUM WITH INTERNAL OSCILLATORY DEGREES OF FREEDOM

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Materials with microstructure with high contrast in mass, stiffness, isolated and interconnected structural element such as in 3d woven materials demonstrate a number of complex phenomena under external excitationы, including formation and interaction of localized waves, transfer of energy from macroscopic oscillations to microscopic, energy dissipation, internal resonances e.t.c. Such diversity is related to the dynamical processes occurring at the microscopic level.
It is very important to be able to model such phenomena for practical applications. At same time it is an extremely complex task due to coupling between spatial and temporal scales and need to introduce very high spatial and temporal resolution.
An alternative approach is to consider an effective media with internal degrees of freedom. The existence of a carrying media is postulated and it is assumed that this media is described by equations on nonlinear elasticity theory. It is further assumed that infinite number of non-interacting oscillators is coupled with each point of the carrying medias [1].
It is shown that for one-dimensional wave processes the system of dynamics equations of generalized continuum is equivalent to the Korteweg-de Vries-Burgers equation. This equation has an analytical solution in the form of a spatially-localized wave. The influence of such parameters as stiffness, viscosity, and ratio of carrying media density to the oscillators' density on the magnitude, wave speed and the thickness of an impulse-like wave is studied. A non-stationary process of deformation wave localization is studied numerically.

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STUDY OF STRESS-STRAIN STATE IN AN ENSEMBLE OF INCLUSIONS OF DIFFERENT SIZES

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The paper presents the results of numerical studies considering structural stresses and strains for ensembles of inclusions that differ in size by a factor of ten and even more. The ensembles are embedded into an incompressible elastic matrix loaded at infinity by tensile stress. The analytic iteration method based on theory of functions of a complex variable function is used to evaluate the specific features of the structure of the composite material of interest. Incorporation of a small-sized inclusion into different areas of a large-sized inclusion allow us to observe an essential difference in the patterns around the small-sized inclusion. The heterogeneity of structural stresses around small-sized inclusions is pronounced more strongly than around large-sized inclusions. Hence, composites reinforced by inclusions of different sizes have a dimension hierarchy of concentrations, which triggers a dimension hierarchy of a damaged structure.

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FAST MODELING FOR COLLECTIVE MODELS OF BEAM/PLASMAPHYSICS

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We consider an application of modification of our variational-wavelet approach to some nonlinear collective models of beam/plasma physics: the Vlasov/Boltzmann-like truncation of general BBGKY hierarchy related to the modeling of the propagation of intense charged particle beams in high-intensity accelerators and transport systems. We use fast convergent multiscale variational-wavelet representations for solutions which allow to consider the polynomial and rational type of nonlinearities. The solutions are represented via the multiscale decomposition in nonlinear high-localized eigenmodes (waveletons). In contrast to different approaches we do not use perturbation technique or linearization procedures.

KINETICS OF CHEMICAL REACTION FRONTS IN ELASTIC AND INELASTIC SOLIDS

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We consider a reaction between gasous and solid constituents similar to the reaction of silicon oxidation. To take into account stress effects, we develop a theory of stress-assist chemical reactions basing on the notion of a chemical affinity tensor. We derive an expression of the chemical affinity tensor within the frames of mechanics of configurational forces as a consequence of the mass, momentum and energy balances and entropy inequality written down for an open system in which a chemical reaction takes place between diffusive gas constituent and a solid. Then we formulate a kinetic equation for a propagating reaction front as a dependence of the reaction front velocity on the normal component of the affinity tensor. In such a statement stresses affect the chemical reaction rate through the affinity tensor. Thus, to describe the reaction front kinetics one have to find stresses and strains, solve the diffusion problem and find the gas concentration at the reaction front, calculate the normal component of the affinity tensor and then calculate the front velocity. We solve a number of boundary value problems considering planar and spherical reaction front propagation. We study how stresses and stress relaxation can accelerate, retard and even block the front propagation. On the whole, we demonstrate the variety of the transformation front behaviors in dependence on reaction parameters, rheological models chosen for the solid constituents, material parameters, external and internal stresses and temperature.

THE STUDY OF STRUCTURE AND MECHANICAL PROPERTIES OFPOLYETHYLENE - SILICATE ACICULAR NANOFILLER AT THE MACRO AND MICRO LEVEL

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The microstructural and mechanical properties of polyethylene filled with different fractions of silicate needle-like inclusions (palygorskite) are studied. The macroscopic mechanical properties and stress toughness were investigated by the analysis of stress-strain curves. The microstructure and local mechanical properties of the composites were studied by the atomic force microscopy. The structural parameters were obtained by the novel methods of the analysis of local mechanical properties. The agglomeration of palygorskyte into secondary structures is observed. These structures look like bunches of several needles which are located close and parallel to each other. Examination of the microstructure of the composite under uniaxial tension showed that part of the needles becomes wave-shaped; at the same time the orientation of the filler along the axis of deformation is not observed.

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USING OF ATOMIC FORCE MICROSCOPY TO THE STUDY PRE-LOADED POLYMER SAMPLES (COMPUTER SIMULATION)

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It is well known that the filled elastomers are characterized by a complex mechanical behavior which caused by various reversible and irreversible structural changes occurring during deformation. Therefore, the creation of new composite materials with improved performance characteristics requires serious structural fundamental and applied studies at nano, meso and micro levels.

For today atomic force microscopy (AFM) is one of the most promising instruments of materials internal structure investigation. Its principal advantage is that the AFM allows to obtain information not only on the morphology of the inner structure of matter at the nanoscale, but also on its local physical and mechanical properties (which, as experience shows, may differ significantly from what we see at the macro level). The successful development of modern nanotechnologies in materials science is not possible without this knowledge. By learning to efficiently manage events and processes which take place at micro and nano scales, you can purposefully create materials with principally new consumer properties, unattainable within the framework traditional technology.

Atomic force microscopy can also explore the local mechanical properties of nanostructured materials. Appropriate experimental studies of the nanostructure of elastomers and elastomeric nanocomposites, pre-stretched at the macro level until prescission states were held in ICMM UB RAS (I.A. Morozov, V.N. Solodko). Experiments have shown that at the vertex microfractures can form a nanofiber-strands different from the mechanical properties of the base material and the interaction of the AFM probe with previously deformed surface differs substantially from that observed in samples unloaded.

Standard software supplied for the interpretation of the results of scanning atomic force, mainly based on models using the classical solution of the Hertz contact a rigid sphere and a plane linear elastic half-space. In our case they should be used with great caution for the following reasons:

Firstly, the Hertz solution takes no account that halfspace can be predeformed.

Secondly, investigated polymers are quite "soft" non-linear elastic materials, that is, an AFM probe can be pressed into the surface under study to a considerable depth (large deformation).

Thirdly, the contact of the probe and nano-strand occurs not normal to the surface, but at an angle, and it does not correspond to Hertz solution.

Model studies were next conducted to evaluate arising due to this errors in decoding results of AFM scanning. The contact boundary problem of pressing an AFM probe into a pre-deformed nonlinear elastic flat surface (Neo-Hookean) was solved. At calculations the sample was subjected to uniaxial tension (compression) before indentation probe. Pre-stretching deformation varied from 0% to 700%, pre-compression — from 0 to –55%. The problem was solved in a three-dimensional formulation, finite element method was used. As a result the dependencies between elastic reaction force on the indenter F, the indentation depth of the AFM probe into the material u and and pre-stretching deformation of the sample ε were built.

Also, a comparison of nonlinear elastic solution for the case of unstretched sample with classical Hertz contact problem were held.

It was established that these solutions can be considered close until the indentation depth of the AFM probe does not exceed 0.4 of the radius rounding of its vertices, then they begin to diverge (and non-linear elastic solution is below). It was established that these solutions can be considered close until the indentation depth the probe end does not exceed 0.4 of its top rounding radius, then they begin to diverge (and non-linear elastic solution is below). To study the same pre-deformed samples Hertz solution is not applicable.

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THE PARADOX OF A DISCONTINUOUS TRAJECTORY FOR A MASS PARTICLE MOVING ALONG A STRING REVISITED

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In 1883 Stokes considered the problem of the motion of a heavy mass particle along the bridge. The approximate model of a massless Bernoulli-Euler beam was used. Stokes showed that the limit vertical position of the mass particle at the end of the bridge generally is not zero, i.e. the trajectory of the mass particle moving along a bridge is discontinuous. It was suggested that this difficulty may arise because the inertia of the beam is neglected. In 1964 Smith considered the analogous problem for a string. Smith showed that in the case of a string the paradox is generally observed for both inertialess and inertial strings. Recently the paradox was rediscovered by Dyniewicz & Bajer, who proceed with the numerical calculations and claim that the paradox is observed in the case of an inertial string and an inertial Timoshenko beam and is not observed in the case of an inertial Bernoulli-Euler beam.

In this paper a new model is suggested to resolve the paradox in the case of a string.

VIBRATION AND WAVE PROCESSES IN VIEW OF NON-LINEAR DEFORMATION OF COMPONENTS IN AIRCRAFT ENGINE HYDRAULIC SYSTEMS

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Unpredictable failures in the course of operation of hydraulic automatic equipment of aircraft engines occur increasingly often. To predict them is a difficult and time-consuming task. It is true that failures may be related to the drastic increase of operation noise generated by hydraulic systems of aircraft engines, and therefore it might be suggested that they are brought about by cavitation effects in the pipelines caused by vibrations of the component walls. This paper is concerned with the possibility of modelling the cavitation effect during the operation of hydraulic automatic equipment.

We performed numerical studies of hydroelastic vibration and wave processes which included two approaches: one solving coupled problems in ANSYS CFX software package, and another using national algorithm for solving problems of hydroelasticity stated as a couple.

In ANSYS CFX package we constructed physical and mathematical models for computing experiment and performed numerical computations. In ANSYS CFX package we obtained results of computational modelling of cavitation effect caused by vibrations of the wall in a closed type (return-flow) pipe filled with fluid. We revealed the dependence between the cavitation parameters and the vibration parameters. We also have revealed that the cavitation effect was maximized at certain combinations of amplitudes and frequencies of oscillations and have constructed the domain (range) of influence of amplitudes and frequencies of vibration upon concentration of cavitation bubbles.

At present, with current sanctions against Russia, this is particularly important to develop national algorithms for solving complex interdisciplinary problems, including hydroelasticity.

To develop national algorithm for solving coupled problems of dynamic hydroelasticity we have constructed physical and mathematical models. To develop the original system of differential equations we chose one of the methods of finite differences - the particle-in-cell method. Based on the chosen method we developed the algorithm which included several stages. The initial stages were designed to solve the hydrodynamic problem, whereas the subsequent stages were meant to estimate parameters of the dynamic stress-strain state or tensely deformed condition of structure.

The use of this standardized algorithm for simultaneous solution of hydrodynamic problem and calculation of parameters of the stress-strain state of the structure is an innovation and makes it possible to study and reveal the physical entity of the occurrence and course of abnormal unpredictable hazardous processes and phenomena in case of the nonlinear interaction in the dynamic system using the united methodological tools. This will allow finding ways to ensure operability of expensive high-tech structures yet at the design stage.

Testing of the proposed algorithm for solving problems of dynamic hydroelasticity was conducted in MARS domestic package for the model problem “about the motion of piston in the fluid filled pipe”.

To verify the obtained numerical solutions analytical calculations for this model problem were made with the use of known analytical dependences. A comparative analysis of numerical and analytical solutions of the model problem. It has shown that their results agree very closely.

KINEMATIC FLUID DYNAMOS EXAMINED BY TOROIDAL-POLOIDAL DECOMPOSITIONS—AN EXAMPLE OF COMBINING CONTINUUM MECHANICS AND ELECTRODYNAMIC FIELD THEORY

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In 1919 LARMOR proposed that the magnetic field of large astronomical objects, such as the earth or the sun, is generated by fluid flow in the interior. This is due to self-excitation processes caused by a coupling of fluid- and electromagnetic fields, cf., [1]. This coupling is described by additional terms in MAXWELL's equations and the equation of linear momentum. The transfer of kinetic energy to electromagnetic energy can lead to an amplification of the magnetic field. This process is called dynamo action.

In general, a fully coupled multi-physics problem describes dynamo actions. A solution of this system of partial differential equations can, in general, only be obtained numerically. In many cases the magnetohydrodynamic approximations apply. These are, cf., [2]:

- the ratio of fluid velocity to the vacuum speed of light is much less than one,
- there is no polarization and magnetization,
- OHM's law for a moving conductor holds.

Using these assumptions, a scale analysis leads to a simplified MAXWELL system. If the velocity is specified and homogenous media are assumed, the magnetic field is governed by the induction equation:

$$\frac{\partial \boldsymbol{B}}{\partial t}+\frac{1}{\sigma\mu_0}\nabla\times\nabla\times\boldsymbol{B}=\nabla\times\left(\boldsymbol{v}\times\boldsymbol{B}\right).$$

This is the evolution equation for the magnetic field. As the velocity is prescribed, natural damping by coupling with the momentum equation is not considered.

Therefore, the induction equation is used as a tool to find velocity fields amplifying magnetic seed fields. In conclusion, by prescribing the velocity field the fully coupled problem reduces to a single field equation for the magnetic field.

Commonly, the equation above is decomposed into temporal and spatial components. This yields a generalized eigenvalue problem in space. In our paper, we consider the problem in spherical coordinates and assume a purely solenoidal velocity field, i.e., incompressible media. This motivates an ansatz of toroidal and poloidal series expansions for both spatial fields, cf., [3]. The coefficients of these series are unknown radial functions.

In order to determine these unknown functions, the induction equation must be projected so that the governing equations for the radial functions can be obtained. Our approach is to develop a convenient operator notation based on functional analysis. Therein, we exploit the orthogonality properties of spherical harmonics and show how a coupled STURM-LIOUVILLE type system of ordinary differential equations can be obtained. The coupling structure of this system is governed by the so-called ELSASSER and ADAMS-GAUNT integrals containing triple products of spherical harmonics, cf., [4]. This system is known as BULLARD-GELLMAN equations, cf., [5]. In our approach the projection method is presented in a straightforward, clearly arranged manner and thus may be extended to different problems.

Finally, the series is truncated leading to a finite number of modes. The coupled eigenvalue problem is commonly solved numerically using finite-differences in radial direction. Since the boundary conditions are non-trivial, a modification of the finite-difference scheme is necessary. Furthermore, the computation of ELSASSER and ADAMS-GAUNT integrals is not done using quadrature but rather by computing WIGNER-3j-Symbols. These symbols are known from quantum mechanics and obey 3-term recurrence relations which are exploited numerically, cf., [6]. The discretization yields a generalized algebraic eigenvalue problem consisting of a coupling matrix $\boldsymbol{C}_h$ and a so-called BESSEL operator matrix $\boldsymbol{B}_h$. The entries of the coupling matrix are inherently governed by the choice of the fluid velocity field. The generalized eigenvalue problem reads

$$\left(\boldsymbol{B}_h + Re_{\text{mag}}\boldsymbol{C}_h\right)\boldsymbol{v}_h = \lambda \boldsymbol{D}_h \boldsymbol{v}_h \ .$$

Recent works, tackling the solution of such problems are based on iterative eigenvalue computations using KRYLOV methods, cf., [7]. The goal is to study the behaviour of the eigenvalues λ and eigenmodes, i.e., $\boldsymbol{v}_h$, depending on the parameters of magnetic REYNOLDS number and prescribed velocity field. If the real part of an eigenvalue is positive, this indicates amplification of a seed field. Hence, a dynamo action may be possible.

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PHOTOACOUSTIC THERMOELASTIC IMAGING OF INDENTED AREAS IN METALS

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The application of the photoacoustic thermoelastic effect for the diagnostics of mechanical stresses is considered at present with growing interest. The main advantage of the photoacoustic method lies in its nondestructive and universal character and high spatial resolution. Photoacoustic microscopy methods are successfully used for the diagnostics of defects in the bulk and near subsurface layers of various materials. As to the problem of residual stress detection by photoacoustic methods, many important details are not solved up to now. In this work both experimental and theoretical investigations are presented to clarify the situation in this field.

Experimental investigations of the work are based on photoacoustic imaging of areas inside Vickers and Rockwell indentations in metal samples under external loading. These experiments are performed on titanium, instrumental steel amd other metals. It is shown, for example, that external normal and shear stresses influence on the behavior of the photoacoustic signal inside indented areas in metals. The obtained results can

be used for estimating sensitivity of the photoacoustic method to mechanical stress determination in metals.
The theoretical model of the photoacoustic thermoelastic effect in solids is proposed for the explanation of the obtained results. It is based on the modified nonlinear model of elastic body that takes into account a possible dependence of Young's modulus of a metal on temperature. The proposed model is applied for the explanation of the photoacoustic signal behavior in indented areas of metals and its modifications under residual and external stresses.

LOCALIZED NONLINEAR WAVES EVOLUTION IN INHOMOGENEOUS AORTA

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The nonlinear dynamical model for blood waves in inhomogeneous aorta is specified, and the model equation describing evolution of the walls of the aorta, is obtained. The case of inhomogeneities caused by treatment of the cardiovascular diseases, is studied numerically. The code within the Wolfram Mathematica is designed. It is found not only previously observed reflection of the waves from inhomogeneities but also generation of secondary localized waves. Use of the particular localized wave solution of the model equation allows us to suggest a procedure of estimation of inhomogeneity on the basis of the measurement of the wave amplitude, velocity and estimation of generation of secondary waves. It may be applied in acoustic diagnostics of inhomogeneities of the walls of the aorta.

NUMERICAL MODELING OF THE MOTION OF LIQUID FRONT IN INHOMOGENEOUS NANOPOROUS MEDIA

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In the last decade nanoporous materials have been a subject of great interest and various researches. Among them stands the transport process of fluids in nanoporous media, which is considerably more complex than the transport in homogeneous or even macroporous systems [1, 2].
We propose a numerical model, which simulates the motion of the front of the liquid, permeating two-dimensional inhomogeneous nanoporous media with altering permeability and pore size. Such model can be very useful in filtering, medicine, biophysics, etc.
In our work we use the continuity equation for incompressible flow and the approximation of Darcy's law [3]. The combination of those allowed us to numerically obtain the distribution of pressure in inhomogeneous nanoporous media, permeated by incompressible liquid, and through that - the transition of a liquid front. It also allows us to model various possible inhomogeneities of a front itself.
For such calculations two problems must be solved. Firstly, in every iteration it must be determined where a grid node lie: above the liquid front or below (grid nodes, which lie above the front, are located in the area, not permeated by liquid, and therefore should not be used in calculations). Secondly, the situation, when the liquid front crosses the grid not in the node, requires the specific set of calculations. Both problems have been successfully solved.
The numerical results for various nanoporous media with different parameters were obtained using the program, written both in MatLab and C++.

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A CLASS OF CONTINUOUS ACOUSTIC METAMATERIALS

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When speaking on metamaterials they usually refer to electromagnetic composite materials showing abnormal effective properties of wave propagation. Single negative metamaterials have frequency band gaps, and double negative metamaterials have frequency domains with negative group velocity but positive phase velocity. In the last case material has a negative refractive index. Mechanical analogues of these media, having the same properties for acoustic waves, are called "acoustic metamaterials". These materials can be applied for various purposes, for instance, to reduce vibrations or control wave beams, mask objects etc. Usually these are hand-made composite materials, and most of researchers consider them at the discrete level when investigating their properties.
We consider a certain class of enriched linear elastic continua and show that these media act as single negative acoustic metamaterials in some domains of frequencies (i.e. have band gaps) for certain type of waves. Some of them also behave as double negative acoustic metamaterials in other frequency domains (i.e. have a decreasing part of dispersion curve). Dynamics of these continua obeys Lagrange equation. Their point

bodies are described by two vectorial generalised co-ordinates, one of them acts as a "distributed dynamic absorber" due to the absence of the elastic reaction to its gradient in the medium.

We show some examples: "bi-rotational" elastic continua whose point body contains two infinitesimal rigid bodies, linear reduced Cosserat continua (Cosserat media that does not react to the gradient of turn of point-bodies), isotropic as well as with anisotropy of a certain type. We show that nonlinear reduced elastic Cosserat medium in the isotropic prestressed state also acts as single negative acoustic metamaterial with respect to linear perturbations. It can be considered also as a smart material: changing the pressure or tension in the prestressed state, we change the limits of the band gap.

EFFECT OF SURFACE AND INTERFACE ROUGHNESS AT THE NANOSCALE

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Influence of a surface irregularity on stress distribution in a subsurface and on stress concentration has been widely analyzed at the macrolevel. For example, stress concentration coursed by roughness of the surface and interface in macro composite film-substrate has been recently examined in [1, 2]. At the same time, it was observed [3] that mechanics of nanostructured elements, including nanoparticles, nanowires, nanobeams, and nanofilms, and heterogeneous materials containing nanoscale inhomogeneous defers notably from the general one. Unlike for bulk material elements, the elastic properties are highly depend on the size of the nanostructure. This size dependency of properties at the nanoscale can be understood by incorporating the effect of surface and interfacial stress (e.g., [4–7]).

The intent of this work is to examine the influence a shape of a surface/interface asperity at the nanoscale, elastic parameters of a body and of surface stress on the stress concentration and the local stress distribution along the surface and the interface. We consider composite containing two dissimilar elastic semi-infinite solids with slightly curved interface under plane strain conditions. In particular, the interface is reduced to the surface when elastic parameters of one of semi-infinite solids are equal to zero. We suppose that the composite is subjected to the uniaxial remote loading parallel to the interface.

To solve the boundary value problem, we use generalized Young-Laplace law and Gurtin-Murdoch surface elasticity model [8, 9]. Based on Goursat-Kolosov's complex potentials, Muskhelishvili's representations and the boundary perturbation technique, we reduce the solution of the problem to the solution of the hypersingular integral equations in each order approximation

$$\tau_n'(x_1) - \frac{M}{2\pi i}\int_{-\infty}^{+\infty}\frac{i\tau_n'(t)}{(t-x_1)^2}dt = F_n(x_1), \;\; x_1 \in (-\infty, +\infty) \quad (1)$$

Function F_n depends on all previous approximations and on the function $f(x_1)$ describing the shape of the interface, $F_0 = 0$, $\tau_n \; (n = 0,1,\ldots)$ are the coefficients of the power series of the surface stress τ in small parameter ε. Factor M is expressed in terms of bulk and surface elastic parameters.

For the periodic shape of the asperity when ε is the ratio of the maximum interface deviation to the period, it is carried out an algorithm which allows deriving an analytical solution of the integral equation (1) in the form of Fourier series. Numerical results have been obtained for the first order approximation. The influence of the surface stress on the stresses at the surface and interface is analyzed for various stiffness ratios of materials, elastic parameters and the shape of the surface/interface. In particular, the size-effect is discovered. It becomes apparent in stress dependence on the period of the interface roughness if the values of this period have the order of 10 nanometers.

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THE NUMERICAL STUDY OF THE FEATURES OF DYNAMIC RESPONSE OF HETEROGENEOUS BRITTLE SOLIDS

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It is known that material properties are determined not only by the features of the internal structure, but greatly depend on the load type and strain rate as well. Therefore, the determination of adequate methods for obtaining dynamic strength characteristics of materials is an important trend in mechanics and materials science. This is due to the fact that the effect of strain rate on the results of the experiment is observed even at low rates, while under the dynamic impact the influence of strain rate becomes determinative. Numerical simulation is an efficient way to reveal the influence of strain rate and applied boundary conditions on material behavior and mechanical properties under dynamic loading.
In the present work the numerical study of the dynamic response of brittle heterogeneous materials was conducted. Zirconium alumina concrete is used as an example of brittle material with a complex internal structure. This concrete is a composite material with reinforcing particles of electrofusion zirconium dioxide and barium-alumina cement binder.
The numerical study was carried out with use of the movable cellular automaton (MCA) method. The formalism of this method combines features of discrete element and cellular automaton numerical methods and makes possible simulation of the deformation and fracture processes of brittle materials including concretes. To take into account inelastic (quasi-plastic) behavior of concrete the Nikolaevsky’s plasticity model (non-associated plastic flow law with Drucker-Prager criterion) was implemented within the formalism of the MCA method. The deformation response of zirconium alumina concrete to the dynamic impact was studied in 2D problem statement within the approximation of plane strain state.
To construct macroscopic structural model of concrete the parameters of plasticity model were obtained within the quasi-static approximation. Determination of model parameters was carried out by numerical simulation of quasi-static uniaxial tension and compression tests of mesoscopic concrete samples (sample dimensions are close to the size of movable cellular automata used for further modeling of the response of macroscopic samples to dynamic loading). The inhomogeneities of the internal structure of mesoscopic samples including reinforcing ceramic particles and pores were explicitly taken into account. Parameters obtained by the series of numerical tests on samples with different configurations of the internal structure were averaged and used as input parameters for the simulation of macroscopic sample dynamic strength tests.
Using the developed model and the parameters obtained in the static approximation the features of mechanical response of macroscopic concrete sample to the dynamic impact were numerically investigated for wide range of strain rates. The applied scheme of the dynamic loading corresponds to the Kolsky method (split Hopkinson bar). Complicated internal structure of the concrete at the macroscopic scale was taken into account implicitly by specifying the strength and rheological properties of movable cellular automata derived from the study on the mesoscopic scale.
It is known that the kind of the stress state significantly affects the strength characteristics of brittle materials. In particular, the constrained conditions produce initial stresses in the sample. To study the deformation and fracture of materials under constrained conditions the modification of Kolsky method, in which the sample is placed in rigid jacket, is used. The influence of kind of stress state on the dynamic deformation response of the material is investigated.
The dynamic strength characteristics of zirconium alumina concrete at the mesoscopic and macroscopic scales were derived with use of numerical simulation. The dependence of the compressive strength of concrete on strain rate is discussed. The influence of the stress state kind on the features of the deformation response and fracture of the sample of concrete is analyzed.
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STRESS-ASSISTED CHEMICAL REACTION FRONT PROPAGATION IN DEFORMABLE SOLIDS

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In this work, an approach of Freidin and Vilchevskaya to modeling stress-assist chemical reactions between solid and gas constituents basing on the chemical affinity tensor was investigated. One of the simplest examples was studied: solid constituents are linear elastic; reaction front is planar and propagates along one of the axis. The model was developed analytically.
There was obtained a huge range of the reaction behavior; from the reaction rate changing up to locking

effect at some values of energy parameter and loads.
Also, there was considered a model of stress-driven diffusion and compared the results with the results of model with constant diffusivity. A range of parameters, for which we can neglect effects of non-constant diffusivity, was obtained.

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INVESTIGATION OF THE NEGATIVE THERMAL EXPANSION COEFFICIENT OF THE TWO-DIMENSIONAL CHAIN WITH THE PARTICLE DYNAMICS APPROACH

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In this work an effect of the negative thermal expansion coefficient of the two-dimensional chain with the longitudinal and flexural stiffness is investigated. Dependence of the pressure on temperature of the chain could be considered as linear. In the case of the linear dependence it is well described with the Mie–Gruneisen equations. However, with the critical compression the dependence of the pressure on the temperature is non-linear, so the equations of Mie–Gruneisen give inaccurate result.

In this work huge range of the dependencies of the pressure on the temperature is presented; dependencies are the result of the numerical experiments with the particle dynamics approach. These dependencies were obtained for the various values of deformations, when the an effect of the negative thermal expansion coefficient appears. Also, the limit of applicability of the Mie–Gruneisen equation for this chain is presented.

MODELING INELASTIC DEFORMATION OF SINGLE CRYSTAL SUPERALLOYS WITH ACCOUNT OF Γ/Γ' PHASES EVOLUTION

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The development of gas turbine engines (GTE) leads to the expanding use of single-crystal nickel-based superalloys. Their application for the turbine blades manufacture can significantly increase the operating temperature of GTE, which leads to increase economy of GTE.

At the microscopic level, the single-crystal nickel-based alloys are a structure consisting of two phases: γ'-phase, forming on the basis of Ni3Al, which is dispersed in a matrix of γ-phase, representing a solid solution alloying elements in nickel. The purpose of this research is the development of phenomenological models of creep and plasticity for the single crystal nickel-based alloys, predicting their behavior under high-temperature thermomechanical loading, taking into account the evolution of γ and γ 'phases. Micromechanical models of inelastic deformation, taking into account the presence of octahedral and cubic slip systems, are used to describe the behavior of each phase. On the basis of finite element homogenization the analysis of the influence of phase composition on the stress-strain diagram, as well as study the effect of the evolution of form γ'-inclusion, occurring during the formation of raft structures, on the creep curves are performed.

THE SYSTEM OF INVERTED PENDULUMS

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From the point of view of studying various physical processes the system of coupled pendulums is instructive model. The case of small linear oscillations in a vicinity of the stable equilibrium position is studied and described in the literature [1]. There are interesting features of the pendulum behavior in the unstable (inverted) position. For example, the upper vertical position of the pendulum might be stable when the driving frequency the vibrating suspension is fast [2],[3]. Pyotr Kapitza was the first to analyze this highly unusual phenomenon in 1951 [4].

Stability of two inverted connected pendulums was analyzed in [5]. The problem of a few inverted pendulums in a linear interaction is a challenge for researchers. In particular it is linked with the study of the domino-structure which plays an essential role in determination of rock brittleness and instability at failure [6].

This paper presents the mathematical 1D model of the inverted interacting pendulums. We considered the weak coupling between the pendulums on condition that the potential is assumed to be to linear with respect to distance between the pendulums. The corresponding equations of the discrete chain pendulums are obtained. It is found that in the case of two inverted pendulums the upper vertical position of the system has a critical behavior with respect to the dimensionless interaction parameter. For a finite number N of inverted pendulums investigation of the chain is carried out numerically. We calculated the critical value of the interaction parameter for which the system is unstable. It is shown that the critical value decreases monotonically with respect to N. The asymptotic formula of the critical value is obtained in the case of small values of the interaction parameter.

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INFLUENCE OF MATURATION ON THE EVOLUTION OF THE MAIN CHARACTERISTICS OF RESISTANCE, DUCTILITY AND MICROSTRUCTURE OF THE POLYCRYSTALLINE ALLOY 43100

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Having physical and chemical properties in general and particularly interesting mechanical, at both low and high temperatures, such as good tensile strength and fatigue resistance, high hardness, good corrosion resistance and low coefficient thermal expansion, the alloys Al-Si foundry are part of many industrial applications: cylinder heads, pistons for gasoline and diesel engine high performance, cylinder block, compressors and pumps etc.
The elaboration and mechanical characterization of a material is of great technological interest for the design and practical parts. Before use in a given application, it is necessary to undertake a preliminary study of its properties, which must fulfill its proper functioning in various embodiments to operate rationally and avoid, in some cases leading to disaster serious consequences.
In this study we investigated the influence of curing time, the addition of Mg and development by two different methods: sand casting and metal shell on the changing characteristics of elasticity, of plasticity and necking of the polycrystalline alloy Al - 10% mass. used in various embodiments in which it undergoes mechanical stress means. Parts developed from this alloy components are part of returning to various embodiments of the SNVI (Aluminium Smelter Unit of Rouiba) and Electro-Industries (Unit Engines Freha in Tizi-Ouzou), Algeria.
In this study we are interested in the mechanical properties of the alloy hypoeutectic Al - 10% mass. If for five different states (crude of casting noted: F, hardened condition noted: T, ripened noted: M12h). The three states are respectively matured each followed by artificial aging noted: T46. Measurements of the characteristics of strength and ductility were determined, respectively, at room temperature, using the traditional method of uniaxial tension. The analysis shows that maturation leads to changes in mechanical characteristics: rise and decline of the respective elastic and plastic characteristics. The observed variations are associated with the evolution of the microstructure: the presence of heterogeneities in the as-cast, removing the last during the homogenization and reduction of internal stress during maturation of the material.

THERMAL EXPANSION COEFFICIENT OF POLYETHYLENE CONTAINING NANOTUBES OF CARBON

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The reinforcement by introducing the nanotubes in polymeric materials could modify thermal and thermomechanical properties of composites considerably. Several works published in various scientific newspapers confirms the positive role of the carbon nanotubes in order to substitute heavy metal parts by cheaper light nanocomposite in different fields of industry such as medicine and the safeguard of nature.
The objective of this note is to study the dilatometric properties behaviour as a function of temperature □(T) of the polyethylene (PE) containing carbon nanotubes (CNT). To complete this work, we took pure polyethylene (0%CNT) high density into which we introduced three different concentrations X (X= 0.5, 1and 2.5% of CNT).
The Measurements were made along radial and longitudinal directions by using dilatometer NETZSCH 402C in the temperature range 20 - 110°C.
The obtained results show that the thermal expansion coefficient of nanocomposite PE + X%CNT, as a function of temperature, changes from the radial direction to the longitudinal direction whatever the concentration in carbon nanotubes.
Along the radial direction, α2.5 is higher than the three others in the whole of the temperature range. It presents a very intense peak located at 95°C which does not appear in the three others. At low temperatures, α0%,

α0.5%, α1% are practically over lopped. From 45°C, α1% is different from both others while decreasing on the remainder of the temperature domain. α0% and α0.5% overlap up to 110°C.
Along the longitudinal direction, the dilatometric behaviour of the nanocomposite changes completely. The pure material presents a thermal expansion coefficient very large compared to that of the three others. The four curves contain each one a peak located around 50°C. Its intensity depends on the concentration. When the quantity introduced into the matrix is about 1%. The dilatometric anomaly appears at 55°C with its intensity is the lowest compared the three others. When the concentration reaches 0.5% CNT, the dilatometric anomaly becomes intense compared to the preceding one and appears with 50°C. The passage of the concentration to 2.5% CNT makes the intensity three times compared to the first and its temperature of appearance becomes 52°C.
We notice that the thermal expansion coefficient as well as the intensity of the dilatometric anomaly of the nanocomposite PE + 1%CNT is the weakest compared to the three others whatever the direction of measurement.

A MIXED TIME-FREQUENCY DOMAIN METHOD TO DESCRIBE THE NON-SMOOTH DYNAMIC BEHAVIOUR OF A NONLINEAR MEDIUM BOUNDED BY A LINEAR CONTINUUM

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To minimize the calculation time required by numerical models that describe dynamic interactions involving nonlinear behaviour, it is useful to divide the model into two separate domains. One domain close to the interaction point, which consists of a sophisticated model capable of describing nonlinear phenomena, and another domain at a distance from the interaction point where only linear behaviour remains. The key issue in such numerical models is the coupling of the two domains. The presence of said nonlinear phenomena implies the necessity to work in the time domain rather than in the frequency domain. Nevertheless, frequency domain approaches are preferred as they allow for much faster calculations than time domain approaches. So-called hybrid models exist that attempt to maximize the use of frequency domain approaches for the modelling of nonlinear dynamic behaviour, but these models are often iterative, thereby increasing calculation times.
This contribution presents a non-iterative method to describe the non-smooth dynamic behaviour of a significantly nonlinear system coupled to a linear continuum. Although this method shows the potential to be particularly effective for applications in two- or three-dimensional media, this paper only treats the coupling of one-dimensional media to illustrate the concept of this method.

A SEMI-ANALYTICAL IMPULSE RESPONSE METHOD FOR TRANSIENT LAMINAR FLOW IN HYDRAULIC NETWORKS

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Transient analysis in hydraulic networks has been well recognized of high importance due to sudden changes in flow or pressure introduced by valve closures or component failures. Therefore, accurate and robust numerical models are necessary to analyse the travelling pressure waves as a result of such abrupt changes, i.e. waterhammer effects. This work presents the formulation of a semi-analytical impulse response method applied to transient laminar flow in hydraulic networks. The method is based on the exact solution of a two-dimensional viscous model in the frequency domain with various interface and boundary conditions. The numerical computations are based on the use of the fast Fourier transform and a discrete numerical convolution with respect to time. A numerical example is presented and the results are compared with the method of modal approximations which is widely used in practice. The results show that the proposed method is able to predict the transient behaviour with better accuracy and without the need of spatial discretization. Thus, it is expected that for large networks, the computational cost of the impulse response method will have a great advantage when compared to existing grid-space methods.

RESIDUAL STRESSES IN THE ELASTIC-PLASTIC INFINITE TUBE AT TEMPERATURE INFLUENCE

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There are residual pressure in the materials during manufacturing and hardening of metal products, negatively influencing on operating characteristics, causing distortion or even destruction. There are many examples of the destruction in the technique, caused by the big technological stresses; residual pressure in the pipelines is one of the main causes of their destruction: it can develop cracks length of several tens of kilometers. Methods developed to avoid residual stresses, for example, temperature annealing of finished products. The purpose of annealing is a reducing of the residual stresses in the blanks and products without significant changes of their

properties. The simulation of this process was carried out in [1].
In this work within the framework of mechanics of deformable solids are considered boundary value problems and describes patterns that are responsible for removal of residual stresses with temperature effects in an infinite tube. The level of accepted for the basis of accumulated stress are calculated in [2]. The modeling was carried out in [1] quasistatic process additional strain on slow heat exposure at a certain temperature, and the slow cooling. The stage considered taking into account creeping properties of materials [3-4]. Creep is described using Norton power law [5]. For power n=3 the analytical solution is reached.

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NUMERICAL SIMULATION OF CERAMIC PLATE PENETRATION BY CYLINDRICAL PLUNGER

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In this paper dynamic fracture process due to high-speed impact of steel plunger into ceramic sample is simulated. The developed numerical model is based on finite element method and a concept of incubation time criterion, which is proven to be applicable in order to predict brittle fracture under high-rate deformation. Simulations were performed for ZrO2(Y2O3) ceramic plates. To characterize fracture process quantitatively fracture surface area parameter is introduced and controlled. This parameter gives area of new surface created during dynamic fracture of a sample and is essentially connected to energetic peculiarities of fracture process. Multiple simulations with various parameters made it possible to explore dependencies of fracture area on plunger velocity and material properties. Energy required to create unit of fracture area at fracture initiation (dynamic analogue of Griffith's surface energy) was evaluated and was found to be an order of magnitude higher as comparing to its static value.

A SIMPLE DISCRETE ELEMENT MODEL OF A DYNAMIC GEOMETRICALLY NONLINEAR TIMOSHENKO BEAM

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This talk (no paper unfortunately) will explain a new simple methodology for designing discrete element models which mimics the behaviour of dynamic geometrically nonlinear Timoshenko beams. The model functions like a rod in axial direction and like a Timoshenko beam in the transverse and rotational direction and captures all coupling and nonlinear effects up to the order desired.
The methodology is used to derive a second order discrete model. This model is used to showcase the capabilities of the method by showing beams undergoing large deformations as well to perform buckling and post-buckling analyses, both static and dynamic.

ROUGH FRACTURES VERSUS TRACTION-FREE CRACKS: SIMILARITIES AND DIFFERENCES

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Rough fractures that have multiple contacts between crack faces are common in materials science applications. They are frequently confused with traction-free cracks. Although both produce displacement discontinuities, the microstructural parameters that control them are entirely different. These issues, as well as cross-property connections for contacting rough surfaces are discussed in detail.

SOME NEW TYPES OF UNSTABLE GENERALIZED-VISCOUS MEDIA

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It is known that autowaves propagating localization of deformation arise spontaneously in the elastic-viscous media with non-monotonic dependence of the stresses on the rate of the viscous deformation. To our mind, the existence of such nonlinear dissipative effects is determined the special types of rheology, enhancing the symmetry of the equations of mechanics. To search for these types of rheology, the two-dimensional equations of quasistatic motion of generalized-viscous medium have been written. The generalized-viscous relations were described by the proportional relationship of the stress tensor and the rate of viscous deformation tensor with arbitrary material functions of the invariants of these tensors. A class of functions discovered always has a singular point and does able to describe a stress intensity drop in a local interval of viscous deformation rate intensities or a viscous deformation rate intensity burst in a local interval of stress intensity. Localization deformation scenario under uniaxial tension of a one-dimensional elastic-viscous specimen were investigated, the possibility of checking up the correspondence of the described mechanism to experiments and the identification of the model parameters were discussed. A model with an internal variable and nonlinear evolutionary equation was formulated taking into account the hereditary properties of the material.

CONSISTENT PLATE THEORIES

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Using the uniform-approximation technique in combination with the pseudo-reduction method, a hierarchy of consistent plate theories is derived: After the introduction of non-dimensional quantities, the strain-energy and the dual-energy densities appear as infinite power series in the plate parameter that describes the relative thinness of the structure. The associated Euler-Lagrange equations deliver a countably infinite set of PDEs, where each PDE is an infinite power series with respect to the plate parameter. It is shown that the untruncated set of PDEs is equivalent to the problem of the three-dimensional theory of elasticity. Furthermore, an a-priori error estimation is given for the truncated, finite and therefore tractable PDE system. The error of the Nth-order two-dimensional theory decreases like the $(N + 1)$th-power of the characteristic plate parameter, so that a considerable gain of accuracy could be expected for higher-order theories. The resulting equations of a consistent 2nd-order plate theory are used to assess and validate theories established in the literature

NON-PLANE SURFACE WAVES IN ANISOTROPIC LAYERED MEDIUM

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In [1,2] a study of general non-plane waves in layered isotropic structures was launched. The general solution was dependent on an arbitrary solution of 2D "membrane" Helmholtz equation introduced first in [3]. The talk concerns a generalization of this theory to a rather arbitrary anisotropic structures. The technique is based on summation of plane surface waves.

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HYPERELASTIC STRUCTURAL-MECHANICAL MODEL OF FILLEDRUBBER. INFLUENCE OF FILLER DISPERSION AND INTERFACIAL PROPERTIES

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The model is represented by the volume filled with rigid spherical inclusions. Inclusions could be grouped into secondary structures (fractal clusters) and connected by damageable links representing the mechanical behavior of the elastomer in the gaps between filler particles. The mechanical response of the link depends on the initial gap between the pair of inclusions. The formation of the interfacial polymer layer (10 nm thick) is taken into account.

Microstructural parameters are obtained by analyzing the AFM-images of the filled rubber. The force response of links to deformation and their destruction points are calculated by applying the finite element method to the problem of pair interaction of two rigid inclusions in a hyperelastic matrix.

The computer model of the filled elastomer is a representative volume with thousands of inclusions connected by links. The volume is subjected to stepwise deformation. After each loading step, the equilibrium position of the inclusions is searched for provided that the energy of deformed links is minimal. Hysteresis losses under cyclic loading conditions are modeled by way of breaking links.

The influence of the microstructure (filler fraction, cluster/random filler distribution, amount of micropellets) and the properties of interfacial layers on the macroscopic characteristics of filled elastomers are discussed in the context of the developed model.

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TRANSFORMATIONS OF INITIALLY DISCLINATED GRAIN BOUNDARIES IN POLYCRYSTALLINE GRAPHENE AND ULTRAFINE-GRAINED METALS

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We suggest two models describing structural transformations of initially disclinated grain boundaries (GBs) in polycrystalline graphene and ultrafine-grained metals. These transformations of GBs occur through GB dislocation climb processes driven by a decrease in the elastic energy of GB defect ensemble.

The first model describes structural transformations of GBs containing partial disclination and located far from the edges of graphene layers or free surfaces of ultrafine-grained metals. Such partial disclinations at GBs are associated with experimentally observed structural irregularities of real GBs in graphene and ultrafine-grained metals. Within this model, we calculate the dependences of the equilibrium density of GB dislocations on the disclination strength, its location at the GB, and the screening length of the disclination stress field. We demonstrate that after dislocation climb, the distributions of GB dislocations in polycrystalline graphene and ultrafine-grained metals become highly inhomogeneous, in contrast to nearly uniform distributions of GB dislocations commonly observed at GBs.

The second model describes the structural transformations of GBs located near the edges of polycrystalline graphene or in subsurface areas of ultrafine-grained metals. This model considers a low-angle symmetric tilt GB that extends between a triple junction of GBs containing a wedge disclination and the lateral free surface of the examined solid. We calculate the dependences of the equilibrium density of GB dislocations on the disclination strength and initial density of dislocations. We demonstrate that the structural transformations of GBs near the edges of polycrystalline graphene or in subsurface areas of ultrafine-grained metals can result in either spatially inhomogeneous or homogeneous distributions of GB dislocations, depending on the geometric parameters of GB dislocation configurations and triple junction disclination.

COMPUTER STUDY OF THE MECHANICAL RESPONSE OF BRITTLE MATERIALS WITH GRADIENT POROUS STRUCTURE UNDER SHEAR LOADING

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It is known that strength and elastic properties of porous materials are substantially depended on their structure parameters, in particular porosity value and size of pores. Meanwhile the structure of many natural (bones) and artificial (ceramics) porous materials is characterized by the presence of a gradient in the spatial distribution of the pores. Depending on the purpose and usage conditions of material the law of spatial distribution of pores in it can be significantly different. Thus, it can change the mechanical response of the material. Therefore, in this paper numerical investigation of the influence of various laws of spatial distribution of pores in the material on its deformation, fracture, strength and elastic properties under simple shear was carried out. Calculations were based on multiscale approach, developed in the framework of the of movable cellular automaton method (MCA). Plane MCA-model of ceramic ZrO2(Y2O3), with a pore size comparable with the grain size and unimodal pore size distribution function was developed. Material with round pores was considered. Several laws of the spatial pore distribution over sample height, including linear and nonlinear one were considered. Calculations were performed in a wide range of porosity of material. On the basis of computer calculations the influence of the porous gradient structure of material on its mechanical response and effective strength and elastic properties were studied.

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NUMERICAL STUDY OF MECHANICAL BEHAVIOR OF THE CERAMIC COMPOSITES BASED ON NANOCRYSTALLINE METAL OXIDES UNDER COMPRESSION LOADING

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In the framework of movable cellular automaton method (MCA) a multiscale model of ceramic composites based on nanocrystalline metal oxides with phase transformations in their structure during mechanical loading was developed. On the basis of developed model the mechanical behavior of ceramic composites based on nanocrystalline oxides of zirconium and aluminum with different contents components under uniaxial compression was investigated. For numerical investigations 2D square specimens with the size 32 mkm were generated. The volume content of each component was varied from 10% to 90%. At the interface between components assumption of perfect contact conditions was made. Mechanical properties of the model material corresponded to that of nanocrystalline ceramics $ZrO_2(Y_2O_3)$ and Al_2O_3 with a porosity of 2%. Accounting for phase transitions in the model was carried out under the proposed phenomenological approach, implying the formulation of the law of inter-automaton interaction corresponding to the irreversible behavior of the material. This law has been chosen so as to correspond to qualitative and quantitative deformation diagrams of $ZrO_2(Y_2O_3)$ with structural transformations. To investigate the qualitative and quantitative impact of the polymorphic (T-M), transformation in the structure of $ZrO_2(Y_2O_3)$ on the mechanical response of the composite the additional structural parameter was introduced in the model. It determined the volume fraction of the matrix of the composite, which undergo a polymorphic transformation under mechanical loading of model specimens. For studied specimens it varies from 0 to 50%. An increase of fracture toughness of zirconia ceramics under implementation of phase transitions were taken into account by introducing a pair of automaton transition kinetics from the "linked" state to the "unlinked" one. To do this, the crack propagation rate parameter was explicitly introduced at the MCA method. It was capable to slow down the transition of automaton pair to "unlinked" state for several time steps. Usually in the MCA method this transition occurs at the one time step, which corresponds to crack propagation with the speed of longitudinal sound. In this model (for the pairs automata modeling phase transition), the value of crack propagation velocity was lower than the velocity of sound in the material. The speed of compression loading was 0.5 m/s. The problem was solved under plain strain conditions. Within the framework of the model constructed main mechanisms of deformation and fracture of composites were studied. The interrelation of structure, mechanisms of fracture and effective strength and elastic properties of the composite was shown.

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INVESTIGATION OF PECULIARITIES OF CRYSTAL STRUCTURE REARRANGEMENT DURING FRICTION STIR WELDING

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The aim of this investigation is to study the atomic mechanisms of crystal structure rearrangements of material subjected to severe plastic deformation using load scheme imitating the friction stir welding conditions.

The study was carried out by the method of molecular dynamics in the form of a software package LAMMPS. Interatomic interaction was described by the potentials calculated in the frame of embedded atom method.

Translational movement of the rotating absolutely rigid tool along the surface interface of two connected metal crystallites was simulated. Various combinations of the connection of two initial defect-free crystallites were considered: copper crystallites, copper and iron crystallites, two crystallites of identical solid solution of D16 (duralumin). It is found that movement of the rotating tool leads to disruption of the crystalline structure and consequent mixing of the surface atoms of the crystallites in their connection region. It is shown that under certain loading conditions after the tool movement the crystal lattice of specimens restores a regular order in their connection region. It is shown that the application of additional vibrational action to a moving tool leads to a more uniform depth distribution of embedded atoms of each of the crystallites in the opposite ones in their connection region. It is shown that an increase of the amplitude and frequency of the vibrational action increases the depth of penetration of atoms of one crystallite to another in a direction normal to the plane of connection of the crystallites. Increasing the speed of the tool increases the number of structural defects formed in the region of its movement.

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STRAIN INDUCED INCOMMENSURATE STRUCTURES IN VICINITY OF THE RECONSTRUCTIVE PHASE TRANSITIONS

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The general conditions for the incommensurate phases (IPs) existence in crystals undergoing reconstructive phase transitions (RPTs) are analysed. It is shown that there is a universal tendency for the IPs appearance in vicinity of the RPTs. The universality is stipulated for the improper higher order Lifshitz invariants that are allowed under broad symmetry conditions can be effectively reduced to ones bilinear in gradients of the critical displacements and deformations. Our approach offers the general mechanism of the “premartensitic” IPs formation as well as the origin of incommensurate structures that have been discovered in many chemical elements under high pressure.

A METHOD OF BACK ANALYSIS FOR ROCK MASS INELASTIC PARAMETERS ESTIMATION

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Rock mass mechanical parameters evaluation proved to be actual problem in underground mining. Its solving serves for efficient design and increasing reliability of the constructions. We present an approach based on analytical solutions of two problems of elastic-plastic deformation of rock mass around the underground opening. Both the solutions of plane axisymmetric and spherical symmetric problems reduced to the system of nonlinear algebraic equations with elastic and inelastic parameters as unknowns.

We focus on the particular case of the rock mass obeying associated flow rule with Mohr-Coulomb constitutive law. As input information for the back analysis and estimation of the inelastic characteristics of the rock mass we use data of field measurements of displacements in underground openings.

As a result, we confirm one empirical formula (Amusin, 2000), approximating displacement distribution into inelastic zone. According to it, relative displacement depends on the angle of internal friction only. We evaluate accuracy of the approximation. Some examples of comparison of our results with field measurements are presented.

Advantages of our approach as compared with conventional methods of identification, based on sophisticated computational instruments (e.g., FEM), are discussed.

A PROJECTION APPROACH TO VIBRATION ANALYSIS OF ELASTIC BEAMS WITH THE TRIANGULAR CROSS SECTION

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A projection approach based on the method of integro-differential relations and semi-discretization technique is applied to analyze natural variations of rectilinear elastic beams with non-symmetric triangular cross sections. A numerical algorithm is proposed to compose compatible approximating systems of ordinary differential equations. It is shown that the beam vibrations cannot be separated into four independent types of longitudinal, bending, and torsional motions if a non-symmetric cross section is considered. In this case, all these motions can interact with one another. Nevertheless, only one type of displacement and stress fields makes the largest in the amplitudes of the corresponding vibrations. Several eigenfrequencies and eigenforms of a beam with the isosceles cross section are presented and analyzed.

INFLUENCE OF THE ELECTRON GAS ON THE TEMPERATURE DISTRIBUTION IN THE METAL LATTICE DURING LONG AND SHORT LASER PULSES

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The problem of the heat transport in metals with the perfect lattice [1] heating by the laser emission with the presence of the electron gas is considered. A thermally isolated half-space is uniformly heated by the monochromatic laser pulse. Two different problems of the metal heating are studied within the well-known 2T-model [2,3]. The interaction of the media and the laser pulse is modeled by the inhomogeneity term in the heat transfer equation [1] that depends on time as Dirac-delta function and Heaviside function. The absorption of the laser pulse in the media is described by the Beer–Lambert–Bouguer law. Dispersion relations of the resulting equations are investigated. The solutions are obtained in the form of a series. The results are compared with the classical solution obtained in the framework of Fourier’s model. The heat propagation in metals is although compared with the heat propagation in dielectrics.

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STRESS RELAXATION IN ICOSAHEDRAL PARTICLES BY GENERATION OF PRISMATIC DISLOCATION LOOPS

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Metallic particles with a face-centered cubic (FCC) crystalline structure often take the form of polyhedra having fivefold symmetry axes. They are commonly called ‘fivefold twinned’ or, simpler, ‘pentagonal’ particles. These objects have been studied intensively over the last fifty years and still demonstrate new and unusual properties [1-3]. It is well known that pentagonal rods and particles are the subject of residual mechanical stresses and store the corresponding strain energy which is proportional to the particle volume. The residual stresses and the strain energy can relax in them through many different mechanisms involving the generation of various crystal lattice defects such as dislocations, disclinations, low-angle grain boundaries and microtwins, the formation of open gaps, misfitting layers and inclusions, the emission of whiskers, etc. [4-7]. The reason for the manifold manifestations of the stress relaxation in pentagonal particles still left unexplained. Perhaps some relaxation processes are developed consecutively with increasing the particle size, while others are combined with each other and occur simultaneously. What is evident, the onset of stress relaxation in pentagonal particles occurs through generation of single defects such as an individual circular prismatic dislocation loop (CPDL).

Recently we have solved a boundary-value problem in the theory of elasticity for a circular prismatic dislocation loop placed coaxially in an elastic sphere [8]. This has allowed us to consider rigorously the case of a CPDL generated in an icosahedral particle (IP), the stressed state of which is modeled by the Marks-Ioffe continuum disclination model [9]. We have calculated the energy change due to the CPDL generation with respect to its radius and axial position. It is shown that the most energetically favorable position of the CPDL is in the equatorial plane of the IP. The critical conditions of the CPDL generation strongly depends on the dislocation core energy contribution which is estimated by a parameter α taking the values in the range from 0.5 to 5 depending on the material [10]. For crystals with high core energy ($\alpha > 1.5$) such as semiconductor IPs, there is an energy barrier for the CPDL nucleation. In this case, the CPDL appearance is energetically favorable when its radius is larger than a critical one. On the other hand, for those IPs where the dislocation core energy is small enough ($\alpha < 1.5$) such as metallic IPs, the barrier-less CPDL generation is possible.

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SIMULATION OF HYDROTHERMAL SYNTHESIS OF NANOTUBES

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One of the methods for synthesis nanotubes is a hydrothermal synthesis. This process has input and output characteristics. The main characteristics of hydrothermal synthesis are distribution of velocity, temperature and concentrations. To make process of hydrothermal synthesis more efficiency need determine connections between input and output characteristics. Autoclave with optical window allows investigating early step of creation nanotubes. Understanding of this process allow found configuration of input characteristics for more efficient synthesis of nanotubes. To build model of hydrothermal synthesis of nanotubes at autoclave and get estimation characteristics of process suggests to use CFD package OpenFOAM. The first step to simulate hydrothermal synthesis is solve problem of free convection fluid at cavity. This problem describes via system of Navie-Stokes equations. The second step is solve equation of convection-diffusion. Distribution of velocity obtained at the first step is used to solve convection-diffusion equations. The result of the second step is a distribution of concentration. This distribution demonstrated critical area where the early steps of creation nanotubes more probably. The future steps of investigation are calculation of creation nanotubes via two-scale model. Distributions obtained at macro scale is a boundary conditions for nano-scale.

MODELLING PLASTICITY OF MATERIALS WITH A MICRO AND NANOSTUCTURE

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Materials with the nano and micro structural elements have many useful properties. The yield point and strength of nanomaterials are in the several times larger than that of conventional materials. It is necessary to simulate correctly its properties in the strength calculations for the use of nanomaterial in machines and in constructions. Some uncertainties reduce the opportunities for using of the dislocation model for the strength calculation and predictive modeling of the nanomaterials.
An important component of the self-energy is the energy of the surface tension of the grain of structural elements. Surface tension energy is a significant part of the elastic deformation energy for the nano scale. The article gives the calculation of the volume energy density of surface tension. The dependence of the melting point and yield point on the particle size of material may be interpreted as altering the surface tension. The results of calculations and their comparison with the experimental curves are presented. The proposed approach contains a minimum number of physical parameters. This approach makes it possible to predict the mechanical properties of materials.

DYNAMICAL INSTABILITY OF THE BERNOULLI-EULER BEAM ON AN INHOMOGENEOUS ELASTIC FOUNDATION

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The study concerns the localization phenomenon in continuous structures of finite and infinite lengths. An example of a compressed infinite beam has been used to investigate the localization of oscillations in the area of a defect in the foundation and to examine the features of buckling of the structure for this case. It has been shown that in addition to the continuous spectrum, the existence of trapped modes is also related to the appearance of a point spectrum that lies below the cut-off frequency of the structure. The dependence of the localized point frequencies on the compressive force has been obtained. It is shown that buckling mode changes with increasing the defective area. Critical force less than the Euler crtitical force is obtained. Parametric instability of the beam is as well investigated. The influence of existence of the discrete spectrum on the instability regions is studied.

HIGH-ORDER NUMERICAL SCHEME FOR ATTACHED VORTEX LAYER INTENSITY COMPUTATION IN 2D VORTEX ELEMENT METHOD

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Vortex Element Method that belongs to particle-type meshless Lagrangian CFD method, is very useful when solving number of engineering problems, especially fluid-structure interaction (FSI) problems, when the fluid domain varies in time and the flow can be considered incompressible.
In 2D case there are some approaches for solving the Navier-Stokes equations by using vortex methods, one of the most useful of them is Viscous Vortex Domains Method (VVD) which is based on the so-called ‘diffusive’ velocity computation for vortex wake evolution simulation. The accuracy of the flow simulation and aerodynamic loads computation depends on many factors. The most important factors are the following: 1) the accuracy of the airfoil approximation; 2) the accuracy of the free vortex layer intensity on the airfoil surface computation (as well as attached vortex and sources layers if the airfoil is movable or deformable); 3) the accuracy of the vortex wake approximation and its evolution simulation.
Normally in 2D Vortex Element Method, the intensity of free vorticity layer is computed as solution of singular boundary integral equation of the 1-st kind, and this approach sometimes leads to significant errors and even to qualitatively wrong results. However, there exists the alternative approach that corresponds to solving of the Fredholm-type integral equation of the 2-nd kind (if the airfoil is C2-smooth). The authors have developed this approach and it allows to raise the accuracy considerably.
But the further accuracy improvement is restricted to the accuracy of the airfoil approximation. In the present research the algorithm is developed and the corresponding quadrature formulae are derived which allows to take into account the curvature of the airfoil. This approach allows to consider the solution to be piecewise-linear or even piecewise-quadratic along every curvilinear part of the airfoil whereas in traditional approaches the solution assumed to be piecewise-constant along straight airfoil’s panels.
The mentioned ideas are very close to well-known ‘panel methods’ but there is also some significant differences. Firstly, we don’t assume the solution to be continuous along the airfoil – it is important for correct flow simulation around airfoils with angle points and

sharp edges. Secondly, in order to obtain the linear algebraic equations system we use least residuals method along the curvilinear parts of the airfoil instead of collocation-type conditions in separate control points. And thirdly, many integrals are computed exactly by using analytical formulae instead of series expansions which are normally used in panel methods. In concern to the influence of the straight panel with constant, linear and quadratic vorticity layer distribution on the arbitrary point as well as self-influence of the curvilinear airfoil part. The other integrals are calculated approximately, but their analytic approximation have at least O(h^2) error, so we need only 1-2 items in Taylor series.

The developed approach and numerical algorithm allow to raise to accuracy of vortex layer intensity computation when flow simulation in Vortex Element Method.

INVESTIGATION OF DEFORMATIONS PROPAGATION LAWS IN TH NONLINEAR ELASTIC MEDIUM

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The distribution features of shock disturbances in materials with nonclassical nonlinear elastic properties are studied. For most of natural and structural materials, it is experimentally proved that the dependence of the stress and strain is non-linear. The deformation behavior of such nonlinear elastic media is studied by formulating and solving boundary value problems of shock dynamics within the mathematical models which include various additional assumptions. Here elastic media with non-linear in compressibility [1], different resistance to tension and compression [2, 3] and unequal response to the multi-directional shifts [4] are considered. For each case, the ways of shock disturbances in nonlinear deformable elastic material are studied. It is shown that the solution of boundary value problems of deformation environment with limited mechanical properties are different from the well-known results of the linear theory.

For selected models the types and properties of waves (shock wave fronts and simple Riemann waves) which may arise in the process of dynamic deformation of nonlinear elastic medium were obtained. Velocities of these waves were calculated. Solutions of a number of one-dimensional boundary value problems with plane and spherical waves are built. These solutions clearly demonstrate the significant differences of the process of shock disturbances in media with complicated nonlinear mechanical properties from the well known results of the linear theory.

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DETONATION STABILIZATION IN A SUPERSONIC FLOW OF A GAS MIXTURE IN THE CHANNEL OF A SPECIAL SHAPE WITHOUT ANY ENERGY INPUT

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The numerical investigation of detonation propagation in a stoichiometrical hydrogen-air mixture flowing with supersonic velocity into a plane channel has been carried out with the purpose of determination of a channel shape that guarantees detonation stabilization in the flow without any energy input.

The possibility of stabilization of formed detonation wave without energy input in the combustible gas mixture flowing with supersonic velocity into the plane channel with narrowing has been determined. In case of detonation stabilization the considerable energy input in the domain containing the stabilized detonation front (or in a domain placed in front of detonation) was used for stabilization stability testing. It has been established that in spite of a disturbance of the stabilized detonation after energy release the energy input under consideration does not break the wave stabilization and does not chance the location of the stabilized detonation wave.

Besides for some Mach numbers of the incoming flow M0 the method of determination of the channel shape which gives detonation initiation and its stabilization in the flow without any energy input is proposed.

In addition a plane two-dimensional supersonic flow of the combustible gas mixture about the symmetrical semi-infinite plane obstacle placed along the stream was considered. In case of M0=5.5 the structure of the stabilized ahead of the obstacle detonation wave was studied. It has been established that the detonation wave is divided into three sections with different structures. So a part of the wave near the symmetry plane is overdriven detonation; with the increase of the distance from the plane of symmetry the left-running transverse waves (facing upstream) propagate along the detonation front; with the further distance increase the transverse waves of both sets (the left-running and the right-running) are formed and define a cellular structure that is qualitatively similar to a plane detonation wave structure.

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GENERALIZED CONTINUA AND SIZE EFFECTS IN ELASTOSTATIC BENDING EXPERIMENTS

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It is well known that the elastostatic deformation of micro-materials, whose mechanical properties may depend on its intrinsic structure, is size dependent, reflected in a stiffer or in a softer elastic response at the micro- or at the nano-scale [1-3]. In order to account for the size effect in the context of a static theory of elasticity for isotropic materials, different approaches of higher-order continua are investigated in this paper.

More specifically, generalized continua, such as the strain gradient-, micropolar- and surface theory of elasticity [4-6] are used in order to derive, first, analytical solutions for the Euler-Bernoulli beam model. This is useful in context with an inverse analysis: The corresponding additional material characteristics, a.k.a. material length scale parameters, of the various theories are identified by means of deflection experiments during which beam structures with decreasing thicknesses were deformed.

Second, a numerical approach to beam deflection based on a higher-order theory is presented. For this purpose we start from a cascade of principles of rational mechanics so that the constitutive relations can be derived: Extended balance equations, such as the independent balance of moment of momentum are presented and a variational formulation of the couple stress theory is derived by taking advantage of singularities on surfaces to indicate the jump condition for the element interfaces [7]. An implementation of the variational formulation into the open-source Finite Element code, FEniCS©, allows us to obtain numerical results of the problem.

Atomic Force Microscopy (AFM) investigations of engineering materials, such as nano-porous nickel alloys, epoxy, and SU-8 are performed. Force as well as deflection data is recorded in order to measure the bending rigidities of micro-beams. The forces F, deflections w, and thicknesses T of the micro-beams are in the range of $0.5\ \mu N < F < 250\ \mu N$, $50\ nm < w < 8.0\ \mu m$, and $2.1\ \mu m < T < 170\ \mu m$, respectively. Flexural vibration analyses of the material aluminum foam were carried out in order to quantify the size dependent material behavior of macro-samples of thicknesses $6.0\ mm < T < 40\ mm$. Fast-Fourier-Transformations (FFT) of the acoustic signal of the excited beam structures allowed to identify the lowest vibrational frequency, which is used to calculate bending rigidities as well. The data from experiments is evaluated with the help of the least square method, where the corresponding fit functions are defined by using the analytical solutions for the Euler-Bernoulli beam model for the different higher-order theories. As a result, positive and negative size effects are observed depending on the thickness as well as on the length. Additional material parameters are extracted by following the analytical as well as the numerical approach. They show good agreement. Material length scale parameters of the micro-samples are found to be in the range of some micrometers. A comparison to existing values from the literature [2] is performed whenever possible.

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NUMERICAL SIMULATION OF SEISMICITY INDUCED BY MINING

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Numerical simulation of seismicity in mines has been successfully developed and used for the two last decades. Presently, the general theory of modeling and the progress in computational techniques provide wide options for simulation of seismic and aseismic events with various source mechanisms accounting for blocky structure of rock mass, inclusions, faults, cracks, complicated contact conditions and various mechanical properties of rock. The output of numerical simulation, both in mechanical and seismological quantities, can be quite detailed, as well. For seismic events, it may include the location, time, type and energy, tensors of seismic moment and potency, seismic efficiency, source parameters, temporal characteristics of chains of events, dependence frequency-magnitude, etc. Meanwhile, in practical applications, the input data are commonly limited and often uncertain. The data on observed seismicity are also often limited with a few parameters, like coordinates and time, some of which are found with significant errors. Clearly, there should be a balance between the *input* parameters used in modeling and those available in a mine; a balance is to be also between the simulated *output* information on the events and the data provided by observations in practice. The present work aims to distinguish input parameters and output quantities which look optimal for case studies in the sense that being not excessive they agree with the recent progress in mining seismology. We single out three groups of output data which may serve for main applications. The first group includes the data on temporal and spatial distributions. These distributions are of special value for improving the input data on geometrical and structural features of the mined area. The second group employs the data on the magnitude of events. It includes distributions of the frequency-magnitude type. These distributions are of exceptional need when evaluating the risk of dangerous strong events. The third group includes the data on distributions of geometrical parameters of the source mechanism. It is especially important when establishing and using the connection between the stresses and seismicity. It serves for improving the input data on in-situ stresses and for better interpretation of observed seismicity. Features and applications of the distinguished distributions are illustrated by numerical examples for mining a tabular deposit.

FINITE ELEMENT INVESTIGATIONS OF THE GRAVITATIONAL AND ROTATIONAL DEFORMATION OF THE EARTH

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In this paper we investigate the deformation of Earth due to self gravitation and constant rotation. This problem is not completely new and has already been discussed by the masters of the old days, namely Newton [1,2], Sommerfeld and Klein [3]. However, there are still many open issues, since the previous, almost philosophical investigations were very abstract and highly theoretical. Many of the old papers do not even include equations but describe the scientific findings in terms of thought experiments and words. Nowadays, computational power is steadily increasing and numerical calculations enable new approaches toward this topic.
A first rough estimate of a rotating, self gravitating metal sphere using linear elasticity and infinitesimal strains shows that the deformations due to gravity alone are about 16 percent. These are comparatively large deformations. Consequently, we should apply the concept of finite deformations instead and solve the local balance equations for mass and linear momentum in the material configuration, using the second Piola-Kirchhoff stress tensor and the Euler-Lagrange strain tensor. The stress and the strain measures are related with an St. Venant-Kirchhoff constitutive law.
For this purpose, finite element calculations are conducted using the research tool FEniCS [4]. This allows for the great opportunity of specifying the governing equations directly and therefore allows for a complete control over the whole procedure. Results show that the pure gravitational displacements are about two magnitudes larger compared to the ones from centrifugal forces, which has an impact on the accuracy of the so-called flattening parameter. We treat this problem by a thorough dimensional investigation of the participating terms and therefore decouple the system of highly non-linear differential equations. We compare the results with previously conducted analytical approaches [5], and also with semi-analytical calculations using an infinite series technique. The latter approach is published in a different paper within the conference Proceedings.
Additionally to these analytical approaches we abandon the idealization of a constant mass density and adopt the density distribution presented in PREM [6]. This model approximates the mass density in each earth layer as a third order polynomial. The coefficients were derived from propagation velocities of seismic waves. This seems to have critical influence on the calculation of the

flattening parameter, since the core is much denser than the outer regions. In combination with the cylindrically symmetric rotational force this holds great potential for more accurate solutions in comparison to a homogeneous density. Finally we show results and recommendations for further studies.

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ICE LOAD IDENTIFICATION ON THE NORDSTRÖMSGRUND LIGHTHOUSE

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As an alternative to expensive load panel measurements on structures subjected to severe ice-induced vibrations, the ice forces can be identified from limited vibration response data of the structure. In this contribution, a model-based inverse approach is used to identify the ice loads exerted on the Nordströmsgrund lighthouse located in the Gulf of Bothnia, Sweden. The lighthouse was subject to an extensive measurement campaign during the winter seasons from 1999 to 2003 [1]. This provided valuable data for the full-scale validation of load identification techniques which have, up to now, only been tested using data from scaled structures in a laboratory setting [2].

The load identification is performed using a recently proposed joint input-state estimation algorithm [3]. The algorithm identifies the forces exerted on, and the states (displacements/velocities) of the lighthouse, based on 2 biaxial acceleration measurements and a reduced-order model of the structure. The model is constructed using only the eigenproperties necessary for modelling the prevailing dynamics, as these were calculated with a finite model. Results are presented for an event characterized by simultaneous ice failures and violent response of the lighthouse. The identified forces are validated by comparing them with the measured pressure panel loads, and a convincing agreement is found.

Apart from the force identification, the algorithm also allows for the extraction of spatially complete response information, i.e. at all unmeasured locations, from the measured accelerations. The identified global response of the structure during the event is visualized, thereby assisting our understanding of the ice-structure interaction.

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PARALLEL RKDG ALGORITHM FOR ASTROPHYSICAL PLASMA FLOW MODELING

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The process of magnetorotational instability (MRI) evolvement in accreting protostellar shell is considered. The model is constructed using a system of equations of ideal MHD in two-dimensional axisymmetric approximation.

In order to solve system of equations on triangular unstructured grids the second order RKDG method is developed. This method has a low dissipation level and provides a high quality of discontinuities resolution and instability detalization. The overview of magnetic field divergence-free condition realization methods during the numerical solution of 2D magnetohydrodynamical problems using the 2nd order RKDG method for triangular grids is provided. The procedures of numerical flow redistribution leading to magnetic field artificial divergence suppression are described.

The parallel numerical code that implements the method using technology MPI is created. The code is tested on the KIAM RAS K-100 cluster. The test computations showed good performance and scalability of the code. In Orszag – Tang test problem simulation using 256 processor cores the acceleration was 226 times.

The computational results show the evolution of MRI and the formation of large-scale vortex structures in accreting protostellar shell. Vortex structure of plasma flow leads to the redistribution of angular momentum from the axis of system rotation to the shell periphery. The computed magnetic field lines structure is in a good agreement with observational data.

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ROLE OF SUPERFICIAL EFFECTS IN MODELING OF BEHAVIOR OF SUPERTHIN SCALE- DEPEND STRUCTURES: BEAMS,PLATES AND SHELLS

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The continuum model of superficial effects such as a superficial tension, the meniscus, wettability and capillarity are modeled within the framework of the unified continuous description of adhesion scale effects in the mediums[1-5]. We consider the theory of media with microstructures with description of the spectrum of the superficial phenomena for the media with fields of defects in common case and also for pseudo-continuums with gradient properties. It was shown that the consistent gradient generalized adhesion models can be developed on the base of variation formalism using the formulation of the consequence gradient models of the pseudo-continuums.

Refined non-classical models of thin Timoshenko and Bernoulli– Euler beams are developed in framework of the correct gradient elasticity and generalized adhesion theory of Young–Laplace. Scale depend effects for these super thin structures are described with the aid one material length scale parameter and in general case, two additional length scale parameters linked to the surface energy. We show that the unusual behavior of super thin scale-depend beams depends mainly on superficial effects, but not on the length scale gradient effects. It is worthy to note that this new beam's theory gives results that are remarkably consistent with the available experimental data for all frequency range with appropriate choice of parameters.

At last, the gradient models of two-dimensional defectless medium is formulated. We developed new adhesion theories of plates and cylindrical shells, that are formulated without any additional kinematic hypotheses. Two problems for a graphene sheet and for the single walled nanotubes are examined as an example of such two-dimensional medium. We show that the characteristic feature of both problems are the fact that the mechanical properties of such structures are not defined by "volumetric" moduli but by adhesive ones.

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ON THE EXISTENCE OF A CRITICAL SPEED OF A ROTATING RING UNDER A STATIONARY POINT LOAD

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It is known that critical speeds exist for a constant load uniformly moving around an elastic ring, which is elastically connected to an immovable axis. However, in the inverted case, namely in the case of a rotating ring subject to a stationary constant load, the existence of such critical speeds is still being debated in literature. Various rotating thin ring/shell models are available in the literature. Especially active is the tire research community, which often employees the rotating ring/shell models to mimic vibrations of the tire tread of pneumatic tires. The theoretical predictions of the critical speeds made on the basis of existing models are not convincing and sometimes confusing. Properly formulated governing equations including the pretension due to rotation and a due linearization are needed to predict the critical speeds correctly. In this paper, a rotating thin ring elastically mounted on an immovable axis and subjected to a stationary point load is investigated. The governing equations are obtained by modifying one of the most widely used rotating ring models in order to describe the pretension in a more accurate way. The parameters are adopted from a pneumatic tire. Free and forced vibrations are investigated. Instability and stationary modes are found which were not reported in literature before. The results of the forced vibration clearly reveal that a critical speed of a rotating ring does exist. The deformation patters of the ring rotating at the sub-critical and super-critical speeds are shown and discussed.

VORTEX ELEMENT METHOD ADAPTATION FOR FLOW NUMERICAL SIMULATION USING GPU

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Vortex Element Method is meshless lagrangian CFD method which allows to solve complicated aerodynamic and aeroelastic problems for incompressible flows. In 2D case it can be used for simulation both viscous and inviscid media. The computational cost of unsteady flow simulation using Vortex Element Method usually is much smaller in comparison with other numerical methods (mainly mesh methods); furthermore, the computational cost of aeroelastic problem solving is nearly the same as for flow simulation around the fixed airfoil.

There are some approaches for numerical algorithms constructing in vortex element method; the authors have developed some new numerical schemes, which allow to raise the accuracy significantly.

The aim of the present research is to develop new algorithm of vortex element method for its execution on NVIDIA graphic processing units (GPU). Performance of modern graphical cards can be many tens of times greater than performance of central processors (CPU). However, due to some specific features of GPU effective algorithms development is non-trivial problem. The significant advantage of vortex element methods is low memory requirement for computations, so 100-150 Mbytes of DRAM on GPU is enough for solving of complicated unsteady problems. So all necessary data can be uploaded to GPU and there is no need to transmit data from GPU to computer and vice versa. All the steps of the numerical algorithm of vortex element method can be improved for their execution on GPU. All specific operators, which cannot be effectively executed on GPU, should be replaced by equivalent subroutines, adapted for the specific architecture.

The created numerical algorithm and the corresponding computer program can be executed both on personal computers and on high-performance clusters (in sequential mode) which are equipped with arbitrary CUDA-compatible GPU (capability version 2.0 or higher). Results of computations are exactly the same as on “classical” algorithms which don’t require GPU, but time of computation is many times smaller: for some particular model problem of vortex structures evolution simulation in viscous incompressible media the obtained acceleration is about 100 times, for flow simulation around thin plate (Blausius boundary layer) or around circular cylinder acceleration is about 60 times. The highest results were achieved on GeForce 970 and Tesla 2070 graphic cards, installed in personal computer and cluster K-100 (Keldysh Institute of Applied Mathematics) respectively. The obtained numerical solutions in model problems are very close to exact analytical solution and experimental data.

The developed algorithm allows to use number of numerical schemes for vortex element method, including the most effective and accurate, both for aerodynamic and aeroelastic problems. So it is possible to expand applications of vortex method and reduce computational cost of simulations significantly. Such model problems as airfoil vortex resonance unsteady simulation now can be solved using personal computers with graphical processors instead of high performance clusters with tens computational cores.

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A COMPUTATIONAL ANALYSIS OF PLASTIC STRAIN LOCALIZATION IN MATERIALS WITH MODIFIED SURFACE LAYER

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The deformation and fracture mechanisms in coated materials with varying coating thickness and coating-substrate interfacial curvature parameters are investigated. The plane-strain boundary-value problem was solved numerically, using the finite-difference method [1]. Constitutive models of the elastic-plastic behavior and elastic-brittle fracture were used to describe the mechanical responses of the substrate and coating materials. A wavy interfacial curvature of the needle-like and sinusoidal types was simulated. The value of stress concentration in the near-interface region is shown to increase with both a decrease in the coating thickness and increase in the sine amplitude. These dependences are found to have exponential character. An optimal coating thickness was found with the lowest stress concentration. The larger the period of the curvilinear coating-substrate interface, the lower the stress concentration and the higher the optimal coating thickness.

The work was supported by Russian Science Foundation, Russian Academy of Sciences and a program to increase the competence of Tomsk Polytechnic University.

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WAVE PROPAGATION IN BUCKLED-BEAMS

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Periodic buckled beams possess a geometrically nonlinear, load-deformation relationship and intrinsic length scales such that stable, nonlinear waves are possible. Modeling buckled beams as a chain of masses and nonlinear springs which account for transverse and coupling effects, homogenization of the discretized system leads to the triply-dispersive Boussinesq equation. Since the sign of the dispersive and nonlinear terms depends on the buckling level and support type (guided or pinned), compressive supersonic, tensile supersonic, compressive subsonic and tensile subsonic solitary waves are predicted and their existence is validated using finite element simulations of the structure. Elasticity properties of wave collisions are also investigated.

Large dynamic deformations, which cannot be approximated with a polynomial of degree two, lead to strongly nonlinear equations for which we propose closed-form solutions. For sufficiently high amplitude wave, compatons are obtained.

INDENTATION AT THE ATOMIC SCALE

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Technology involving nano-sized metallic components is today part of everyday life through entering a vast diversity of applications such as i.e. electronic or medical devices. With decreasing linear measures come difficulties in properly dimensioning such components subjected to mechanical loading since the mechanical properties at the nano-scale differs from those at the macro-scale. At the nano-scale experiments are sparse and often difficult to interpret. One way to gain a complementary understanding of the nature of the material response is through molecular dynamics simulations using the freeware LAMMPS. Indentation tests in fcc copper coatings, of thickness a few nano-meters only and resting on a much stiffer substrate, are simulated. Elastic and plastic properties are found from the force-displacement curve and individual atomic positions are monitored to pinpoint the reasons for irregularities in the curve. Also the evolution of the stresses beneath the indenter was followed and the centro-symmetry parameter, describing the lattice disorder in the film, was determined.

MEAN STRESS EVOLUTION IN IRREGULAR CYCLIC LOADING OF ALUMINIUM ALLOY

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The mean stress evolution was studied in program loading under strain limits control including fragments of excessive compression and extension. Cyclic stress-strain curves were continuously recorded and analyzed. An effective cyclic curve is suggested for generalization of the cyclic properties of the material. Specific character of the mean stress development is observed in transitions from fully-reversed segments of irregular loading to segments with cyclic tensile or compressive loading: the induced tensile mean stress increases in repetitive fragments of tensile loading following the material cyclic hardening. The induced compressive mean stress in respective loading fragments occurs almost unaffected by the cyclic hardening mechanisms.

THE INFLUENCE OF VIBRATION ON THE IMPURITY DIFFUSION AT A MATERIAL

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We obtain the extended equation of impurity diffusion in the material based on a two-component continuum model. This allows us to take into account the influence of the internal structure of material on its mechanical properties. As an example, redistribution of hydrogen in a one-dimensional metal rode under dynamic loading is studied. It is shown that a generalized rigidity of the rode decreases substantially with increase of the oscillation frequency (amplitude). The results are compared with experiments on the redistribution of hydrogen under the deformation of metal samples.

MULTISCALE RELAXATION IN STEADY SHOCK WAVE

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The numerous investigations on shock-wave propagation in solids show that dislocation mechanism of microplasticity alone doesn't provides a correct description of the shock-wave process. The presented paper concerns a propagation of steady shock-wave in a medium with three scales of plastic deformation: (a) dislocation scale, (b) mesoscale and (c) macroscale. To take into account collective mechanisms of microplasticity in response of solids on impact, meso-macro momentum exchange between mesoscale and macroscale is incorporated into constitutive equation. The intermediate collective mechanism of dynamic straining is grounded on the experimental evidence that particle velocity variation at the mesoscale is proportional to macroscopic strain rate. In the case of uniaxial shock-wave deformation this leads to the second order differential equation with square non-linearity. Analytical solution and simulation of this equation show that new approach provides a much more precise description of experimental steady wave temporal profile as compare to dislocation mechanism of plasticity.

DYNAMIC STABILITY OF STRUCTURES INTERACTING WITH GENERALIZED FLOWS

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In this talk an attempt is made to take a unifying look at the dynamic stability of such structures as railway tracks, pipelines and offshore platforms in interaction with, respectively, running trains, conveyed fluids/currents and ice flows. The latter three moving objects/media are referred to in the title as generalized flows.

The dynamic stability of a train-rail interaction is compared to that of a pipe conveying fluid. These two situations are similar being both related to the axial movement of the flow (trains and conveyed fluid) with respect to the axis of the structure. The physical reasons for the instability are discussed and compared to each other. Special attention is paid to the effects of the boundaries of the structure and continuity of the flow on the systems stability. Cross links are established between these two engineeringly different but phenomenologically similar situations.

The vortex-induced vibration of a submerged pipeline in a cross flow (marine current) is evaluated in comparison with the ice-induced vibration of a vertical offshore structure in contact with level ice. These phenomena are similar due to the normal incidence of the flows relative to the structure and due to the both spatial and temporal synchronization of the flows along the contact interface. The dissimilarities are related to a strong inhomogeneity of ice and its fracture process in interaction with the structure in comparison to a practically homogeneous character of sea water.

This talk is hoped to assist in transferring expertise from the relatively well-developed field of fluid-structure interaction to the fields of train dynamics and ice-structure interaction, in which the phenomena of instability has not been studied in detail as yet.

INVESTIGATION ON PULSED GAS DISCHARGE FORMATION AND ITS INFLUENCE TO THE SUPERSONIC AIRFLOW

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In this work the results of investigation of pulsed gas discharge formation and dynamics in quiescent gas and supersonic airflow are presented. Some features of significant mutual influence of pulsed gas discharge plasma and supersonic jet are revealed. Optical and spectral diagnostics of this interaction allowed us to determine the composition of the jet, to study the peculiarities of electrode matter ejection and flow ionization processes and to estimate the electron temperature.

STEADY STREAMING IN A VIBRATING CONTAINER AT HIGH REYNOLDS NUMBERS

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We consider incompressible flows in a variable container the variations of which are supposed to be prescribed and periodic with respect to time. It is supposed that there is neither flux nor the slip on the wall of container. In addition, it is supposed that characteristic magnitude of the displacements is small while the frequency is high, and the width of the Stokes layer is of the same order as the magnitude of the displacements. With these assumptions and with no additional ones we build the asymptotic expansions of the correspondent solution of the Navier-Stokes. In particular, we get an explicit form of the general equations and boundary conditions for the mean flow ('steady streaming'). The mean flow turns out to be relatively weak but able to bring the vorticity into the bulk of the fluid and to influence the long term mixing processes.

We use the general framework to treat a number of important particular cases. Special attention is paid to the 3D steady streaming in a round pipe due to the transversal deformation of the pipe wall spreading in the form of spiral waves. This time the mean flow is written explicitly and reveals some notable features such as reflux and counter rotation.

LARGE STRAIN THEORY APPLIED TO SELF-GRAVITATING BODIES: A NUMERICAL LAGRANGIAN APPROACH

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The problem of modeling the deformation, *i.e.*, the displacements, stresses and strains in self-gravitating telluric bodies by suitable constitutive equations for solids is rather old. In what follows we will restrict ourselves to solid spheres, so that the problem reduces to a fully radially symmetric case.

First attempts at finding such solutions were based on the linear theory of elasticity, *i.e.*, on the combination of the static balance of momentum with Hooke's law, formulated for small strains. A rather extensive exposition of this problem for a constant, homogeneous density, including also the effects of centrifugal forces, can be found in [1]. A corresponding analytical result for the radial displacement is presented in [2], Sect. 98. Most recently, results for this problem have been summarized in terms of concise formulae in [3]. In the sixties there was a revival of the problem, because, based on seismic measurements, more complex models of the density distribution of the Earth became available, *e.g.*, [4], [5].

Besides the assumption of an initially homogeneous mass density the review in [3] also showed that linear strain theory might be insufficient to describe the situation in rather massive telluric bodies, such as Venus and Earth, since the predicted strains turned out to be of the order of 10 percent and more. In fact, the same concern was expressed much earlier in [6] and [7]. Their analysis was based on Seth's approach to finite elasticity, which operates in current space, uses the Eulerian-Almansi tensor as a strain measure related it to the current Cauchy stress in terms of a quasi Hookean equation [9]. The numerical approach was based on using an infinite series for a displacement related quantity in context with a corresponding highly linear differential equation stemming from the static equation of momentum in the current configuration together with empirically motivated equations for the mass density and the corresponding self-gravitating force field.

In context with the latter papers several points of criticism apply. First, the convergence of the series has not sufficiently been discussed. Second, the mass density is a result of the modeling and should be calculated from the integrated form of the mass balance, once the displacement is known. Third, the use of the current configuration could be replaced with today's rational concepts of reference configuration and material description. In fact the need for a thorough description of the reference configuration for self-gravitating bodies was anticipated quite early in the papers of Jeans and Lord Rayleigh, [9] and [10], respectively, and has also received further attention more recently, *e.g.*, [11].

In this paper we will pursue exactly that approach: The balance of momentum will be specialized to its static form in the reference configuration using the first Piola-Kirchhoff tensor as a stress measure. The body force is given by the self-gravitating force, which will be that of an initially homogeneous sphere of constant reference mass density following Newton's general law of gravitation. As a strain measure we will use the Green-Lagrangian strain tensor. The second Piola-Kirchhoff stress will be related to that strain measure by using a law of the St. Venant-Krchhoff-type. The result is a highly non-linear second-order differential equation for the displacement, which can only be solved numerically. Special attention must be paid to its inherent singularity, which is already obvious in the analytical solution of its linear Hookean counterpart.

Three numerical techniques will be used for this purpose, namely, first, a Runge-Kutta approach with stiffness switching, second, the infinite series technique and, third, a finite-difference scheme. Pros and cons of the three methods will be discussed, followed by concrete numerical results for various telluric bodies, moons as well as planets. Moreover, the corresponding stresses will be calculated numerically and deviations from the linear-elastic case will be discussed. Finally, the resulting redistribution of the mass density will be determined and compared to the mass density distributions of the Earth stemming from experiments.

In conclusion recommendations for further studies of initially non-homogeneous Earth models in context with non-elastic stress-strain models will be made.

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EQUILIBRIUM DUST AND GAS CLOUDS WITH EVAPORABLE PARTICLES

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A simple model of the equilibrium of isothermal self-gravitating dust clouds is presented here. According to some models, gas and dust clouds can be formed at the early stages of planetary formation in protoplanetary disks. Due to the gravitational attraction, clouds of dust and gas can contract and form planet systems. The largest part of the gas can be expelled from the clouds during evolution process. It is shown that if the dust particles are completely covered with ice then the “radiation force” (which is interparticle repulsive force caused by the evaporation) can balance the self-gravitation, and the collapse can be halted. Term which is responsible for the repulsive force is derived from the radiative transfer theory. A modified equation of the hydrostatic equilibrium is used to find the distribution of the dust concentrations. The forces acting on each particle of cloud are described. It is shown a critical parameters, beyond which the dust cloud collapses and forms a solid planet shown, exist there.

STABILITY OF A LIQUID FILM ON A STRING

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The dynamics and stability of thin liquid films on rigid substrates is a well understood problem, see [1-3] and the references therein. Recent studies have extended the analysis to flexible substrates, see [4-12].

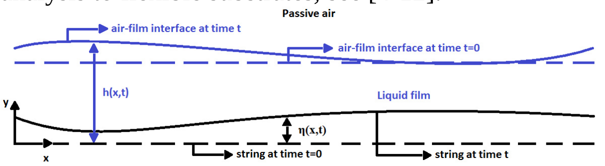

Figure 1: A sketch of a liquid film on a string

In the present study, we consider the dynamics and stability of a two-dimensional liquid film on a string, see Fig. 1. The string is a one-dimensional continuum and is considered to be uniform, flexible, and inextensible. It is infinite in length and has an initial horizontal configuration. It is assumed that the string undergoes only small transverse displacements. For the liquid film, lubrication approximation is employed to simplify the governing equations and boundary conditions. The dynamics of the fluid-solid interaction is governed by a set of three coupled partial differential equations for the film thickness, string tension and string displacement. Subsequently, a linear stability analysis will be carried out and the resulting equations will be solved numerically. The ultimate objective of this study is to understand the behaviour of thin film flows over translating structures such as strings and belts that may or may not be of finite extent.

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STATIONARY ENERGY PARTITION BETWEEN MODES IN THE ONE-DIMENSIONAL CARBYNE CHAIN

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Based on a simple mathematical model, taking into account central and noncentral interactions between carbon atoms, the stationary patterns of energy partition between thermal phonons in a one-dimensional carbyne chain at ambient temperatures are investigated. The study is carried out by standard asymptotic methods of nonlinear dynamics in the framework of classical mechanics. Within the first-order nonlinear approximation analysis the triple-phonon resonant ensembles of quasi-harmonic waves are revealed. Each resonant triad consists of a single primary high-frequency longitudinal mode and a pair of secondary low-frequency transverse modes of oscillations. In general, the carbyne chain is described as a superposition of resonant triads of various spectral scales. It is found that the stationary energy distribution in carbyne chains is roughly approximated by the Rayleigh-Jeans law, though differs from this one due to the presence of three-wave resonant processes. This study may be of interest for some applications of nanotechnology dealing with NEMS or delicate water purification sets.

COMPUTATION OF HYDROGEN-AIR MIXTURE DETONATION WITH OPENMP MULTIPROCESSING ON A SUPERCOMPUTER

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Detonation of hydrogen-air mixture was modeled in a 3D closed area with adiabatic non-permeable walls. The mesh was uniform with cubic elements; 2-order explicit numerical scheme is used. A multicomponent non-viscous perfect gas mixture model was used. The kinetic model consisted of 20 reversible reactions involving 9 species. The numerical method was based on the MUSCL interpolation of parameters onto cells interfaces, the AUSM calculation of fluxes on each internal interface, and the Rosenbrock method of calculating the kinetic fluxes in time. The initiation was modeled by injection of additional mass and energy in a small portion of the work area during a short time; the intensity of this injection was taken high enough to ensure straight detonation initiation. The time step calculation procedure was parallelized with OpenMP method keeping the serial version as well.

This problem is sensitive to the level of numerical viscosity, because the kinetic mechanism involves free radicals as transition agents between initial and final products of the main chemical reaction. Excess numerical diffusivity (proportional to the numerical viscosity) would bring to diffusion of those radicals ahead of the leading detonation shock, and initiation of reaction ahead of the main shock thus corrupting the theoretical results. The corrupted results look like a weak detonation with higher detonation velocity but lower shock pressure than the Chapman – Jouguet ones. Therefore the numerical scheme for the detonation problem must ensure the numerical diffusivity small enough not to launch the reaction at a big scale ahead of the shock.

Numerical calculations were performed on the meshes with various sizes for the same problem statement: 260 x 26 x 26, 500 x 50 x 50, 1000 x 100 x 100, and 2000 x 200 x 200. The last mesh consisted of 80 mln. cells. Those tests showed the influence of numerical viscosity on the process which is diminishing with the increase of the mesh size. For each mesh size, the weak detonation was not obtained for the 2-nd order scheme in space, and it was obtained for the corresponding 1-st order scheme with low resolution.

Other tests showed the dependence of the calculation time on the mesh size and the number of threads, which varied from 1 to 48 on a computer APK-1. The peak OpenMP acceleration was about 30 times from the serial variant of the program.

NUMERICAL MODELING OF RIVER SAND PIT

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Growth of capital and road construction in Russia promotes development of the market of nonmetallic materials. Its growth rates correspond to the growth of the construction market. Nonmetallic building materials industry has the following characteristics: a large number of sandpits spread their performance - from tens of thousands to several million cubic meters of mineral resources; - rigid connection of mining operations , mining at the sandpit. Most of the sandpits located along the river systems because the actual behavior is to build a bottom pits for successful planning, implementation and use of new mining sites of non-metallic materials with regard to hydrological and hydrochemical characteristics of the river reservoir. In this case , for a description of such processes using traditional two-dimensional hydrodynamic models , in the approximation of the shallow water equations, it is not correct, because the horizontal and vertical dimensions of sandpits are comparable. Thus, to solve these problems within the framework of the shallow water equations is only possible to estimate the change in velocity of the main stream and a very approximate estimate of the intensity of sandpit blur. For correct modeling of the described problems need to build three-dimensional models of currents and sediment transport in rivers. This paper presents the results of numerical modeling of the processes associated with the production of non-metallic materials under complex hydro chemical river regime. The simulation of flows arising in the presence of a sandpit depending on the depth of the river and the characteristic dimensions of the sandpits . The characteristics of the vortex occurring in the well, depending on the size of pit and the main flow velocity. Shows the time evolution of a sandpit in the water area of the object .

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A RESONANCE MECHANISM OF EARTHQUAKE

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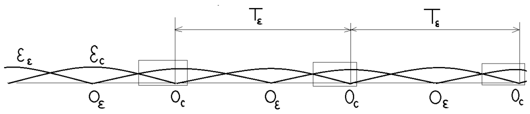
Beating of spectral modes in quantum dots was discussed recently in [1]. We guess that the manifestation of the phenomenon in classical analogs of quantum dots may bring new understanding to the study of seismo-gravitational oscillations (SGO) and pulsations(SGP) on tectonic plates, see [5], which are non-randomly (95%) registered prior to powerful earthquakes. Using the bi-harmonic model for relatively thin tectonic plates, we interprete SGO as spectral modes of the plates [8].The SGO dynamics is stable under stretching tension, see [7], but may be unstable ,[2], under contraction caused by additional pressure on localized active zones, due to arising new low frequency spectral modes localized on the zones, which may be in resonance with the modes of the complement on the tectonic plate or other active zones. Alternation of the modes in the perturbed dynamics similar to one of the Wilberforce pendulum, [9], was clearly registered as an energy migration between the corresponding unperturbed modes, prior to powerful earthquake (EQ) 26 September 2005 in Peru. Mathematical modeling of the alternation process is suggested in [3], based on zero-range approach [6], modified with regard of dissipation of energy, see [4], resulted the below diagram of the energy beating on the active zone and on the complement C.
Small rectangles mark time intervals with maximal energy on the active zone. The total energy is conserved.



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MODELLING OF VORTEX INDUCED VIBRATIONS

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In the first part of the talk, the vortex-induced vibrations of elastically supported cylinders capable of moving in cross-flow and in-line directions are discussed. Two approaches are adopted to analyse the considered system. First the amplitudes of cross-flow and in-line vibrations under variation of the fluid flow velocity are calculated using CFD for various mass ratio. It is shown that when a light cylinder is moving in the fluid flow (mass ratio is low), the in-line motion becomes significant resulting in the increase of the cross-flow displacement amplitudes, thus confirming the presence of the "supper-upper" branch earlier obtained in the experimental studies. Then a new two degrees-of-freedom wake oscillator model is proposed where vortex-induced lift and drag are modelled with two nonlinear self-excited oscillators of van der Pol type. Total hydrodynamic force is obtained here as a sum of lift and drag forces, which are defined as being proportional to the square of the magnitude of the relative flow velocity around the cylinder. The CFD results are utilised to calibrate the proposed wake oscillator model and to compare of the cross-flow displacement amplitudes obtain by CDF and using new wake oscillator model for different mass ratios.

In the second part of the talk, the fluid–structure interactions are considered by investigating a straight but slender pipe interacting with uniform water flow. Two configurations are studied, namely vertically and horizontally positioned pipes, which are modelled as an Euler–Bernoulli beam with flexural stiffness. The structure is assumed to be moving only in the direction normal to flow (cross-flow motion) hence its in-line motion is neglected. The external fluid force acting on the structure is the result of the action of sectional vortex-induced drag and lift forces and they are described using the model discussed earlier. The obtained coupled system of nonlinear partial differential equations is simplified employing Galerkin–type discretisation. The resulting ordinary differential equations are solved numerically providing multi-mode approximations of cross-flow displacement and non-dimensional lift coefficient. The comparison between the responses of vertical and horizontal structures will be presented and the influence of the wake equation coefficients, the fluid force coefficients together with the length of the pipe and pretension level will be discussed.

ASPECTS OF FATIGUE CRACK GROWTH ASSESSMENT

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The rules for fatigue assessment of welded structures recommend carrying out the crack growth analysis by using the concept of equivalent cyclic loading. The concept provides the irregular loading history reducing to the equivalent cyclic loading based on application of the linear damage accumulation rule. In reducing the S-N criterion is applied; the recommendations imply linear elastic deformation of material whereas at the crack tip develops plasticity effects of which on the stress intensity depend on the loading conditions. Presented is the analysis of influence of material plasticity on fatigue crack growth in the stress concentration area when the equivalent cyclic stress concept and the direct damage summation procedure are applied. It is shown that considering of material plasticity insignificantly influences short structural cracks in stress concentrations of structural components.

FORCED QUASI 2D TURBULENCE WITH GLOBAL REACTION: NEW INTERPRETATION

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In this report we presents the results of new interpretation of forced quasi 2D turbulence with global reaction. This model leads to a new phenomenons in comparison without the global reaction. The KLB (Kraichnan-Leith-Batchelor) theory 2D turbulence predicts the existence of two inertial ranges. Kraichnan (1967) discussed inverse cascade in a finite box in the absence of a large-scale dissipation mechanism. In physical space, the condensation appears as the formation of two strong vortices of opposite sign. The condensate state arising from the lack of dissipation at large scales results in the formation of large-scale vortices and a steepening of low-k spectrum.The influence of global reaction on inverse cascades is investigated. The characteristics of cascade for various parameters were obtained. The physical mechanism is corrected via data generated numerical-analytical simulations.

LOCALIZED NONLINEAR WAVES IN LATTICES: MODELING, GENERATION AND CONTROL

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Various approaches for nonlinear modeling of dynamic processes in lattices are considered: discrete, continuum and phenomenological. It is shown, how different continuum limits may be obtained for some discrete lattice models. Corresponding nonlinear continuum model equations are derived. Exact solutions in the form of traveling waves are obtained and studied for resulting model continuum equations. It is shown, that numerical study allows us to see how these solutions may resume from rather arbitrary initial conditions. Other input may destroy localization of the wave and give rise to various defects of the shape of the wave. To avoid it, an algorithm of the control with a feedback is developed. It provides keeping of the localized nature of the wave and suppresses undesired variations in the shape of the wave independent of the initial conditions.
The work was performed in IPME RAS, development of the control algorithm was solely supported by the RSF (grant 14-29-00142).

INFLUENCE THE EFFECTS OF DELAY AND DISPERSION IN MECHANICS

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The present study is associated with the formulation of conservation laws as conditions of equilibrium of angular momentums, while usually formulated in terms of balance of force. The equations for gas are found from the modified Boltzmann equation and the phenomenological theory. For a rigid body the equations are used of the phenomenological theory, but their interpretation changed. The angular momentum effects are investigated in classical case and for one-particle matrix of density in quantum case. Peculiarities of these processes were analyzed for gases and solids. The influence of angular momentum is investigated on exact solution for kinetic theory on some examples. Delay is investigated for kinetic theory.

ON GENERALIZATION OF THE LS-STAG IMMERSED BOUNDARY METHOD FOR LARGE EDDY SIMULATION AND DETACHED EDDY SIMULATION

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The LS-STAG method for viscous incompressible flows simulation combines the advantages of the MAC-method, immersed boundary methods and level-set method. This method allows to solve on the Cartesian meshes problems when domain shape is irregular or it changes in the simulation process due to hydroelastic body motion. For these reasons, the LS-STAG method is very useful for solving such complicated computational mechanics problems as coupled hydroelastic problems, biomechanic problems, problems of solid mechanics with deformable bodies.
However, the LS-STAG method, as all mesh methods has a significant limitation when simulating flows with high Reynolds number: it requires extremely small space and time steps. It leads to significant increase in computational cost. The traditional method of solving this problem is RANS, LES, DES etc. turbulence models usage.
In this research, the general approach to the application of the LS-STAG method for LES and DES is suggested. According to the concept of the LS-STAG method normal Reynolds stress components are sampled on the base mesh (similar to pressure discretization) and tangential ones - in the upper right corners of the base mesh cells. Thus, for the tangential Reynolds stresses an additional mesh (xy-mesh) is introduced. In case of Reynolds Stress (RSM) models, these meshes are used for transport equation solving for Reynolds stresses. The result then is taken into account in the Helmholtz equation for the velocity. In case of Eddy Viscosity (EVM) models eddy viscosity is sampled on the xy-mesh. It is very suitable that the eddy viscosity at solid boundaries vanishes, so the cut-cells discretization of the eddy viscosity equations and computation of Reynolds stresses becomes simple.
In this research the LS-STAG-discretization for convective and diffusive fluxes on the additional xy-mesh is developed. A software package is developed for the numerical simulation of the bodies’ motion in the viscous incompressible flow by using the LS-STAG method and its modifications. The C++ language and the paradigm of object-oriented programming are used. It allows to modify and to develop the package (for example, by including a mesh for non-Newtonian and turbulent stresses in addition to the staggered meshes "velocity-pressure") much easier in comparison with procedure-oriented programming paradigm. The developed software package can be used for computations with RANS, LES and DES in case of Spalart – Allmaras, Smagorinsky, k-w, k-e and k-w SST turbulence models.
To verify the developed LS-STAG method modifications and its implementations test problems of flow simulation past various non-moving and moving airfoils have been solved.

THE RAY METHOD FOR SOLVING OF THE AXISYMMETRIC PROBLEMS OF THE SHOCK DEFORMATION IN A CYLINDRICAL LAYER

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A large number of engineering technologies is based on a dynamic intensive details processing (forging, stamping, punching of apertures, etc.). All of these processes lead to the propagation of shock waves in solids or on their surfaces. Although today a large number of scientific researches are devoted to studying of shock waves in solids, many unsolved problems still remain in this area. In particular, the possibility of an exact solution of boundary value problems of impact deformation is practically absent. In general, the approximate analytical solutions belong to the problem of plane waves motion, or to one-dimensional problems in which only non-zero curvature shock waves propagate through the medium. In other cases, usually numerical methods are used, which are also not free from drawbacks. Approximate analytical methods have two important advantages: it is clarity and interpretability of results, and it is their universality regardless of the specific model constants. The most rapidly developing analytical methods today are the small parameter method and modification of the ray method for shock waves, proposed in the mid-eighties of the XX century. The modification of the ray series was based on the use of additional series by delta-derivatives for objects associated with the moving discontinuities surfaces. This method has been successfully applied in the analysis of one-dimensional dynamic problems when the initial stages of deformation for small post-impact times were described. The wave pattern included only the front edges leaving from the border and it was not necessary to obtain the solutions for the interaction of these fronts with other borders, further reflection and interaction leaving and reflected fronts among themselves.

In this paper efficiency of the ray method version, which was developed directly for the strong discontinuities waves (shock waves) is shown by an example of an axisymmetric problem of intense deformation of the cylindrical nonlinear elastic layer under the load action on the its external border. Several of the initial stages of the wave process, namely, the motion of the created shock waves to the inner border of layer, the reflection of a more rapid wave from the inner border, the interaction of the slow shock wave and the reflected shock wave with the formation of a new wave pattern is considered. The solution for each deformation stages is constructed using the modified ray series method.

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A REVIEW OF ELECTRODYNAMICS AND ITS COUPLING WITH CLASSICAL BALANCE EQUATIONS BY MEANS OF CONTINUUM MECHANICS

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In classical physics, NEWTON's laws govern the mechanical response of individual mass points. The principle of continuum mechanics extends these laws to bodies that are modeled with continuous properties, thus allowing problems in extensive bodies to be described by means of calculus. For example, EULER used this technique to formulate the equations of motion for rigid bodies.

In the last 100 years, continuum mechanics were rigorously mathematically reexamined and extended by the principles of thermodynamics. The objective is to find the fields: mass density ρ, velocity $\boldsymbol{v}$, and temperature T for each "particle", i.e., the average values for sufficiently many atoms. The governing balance equations and mathematical theorems to exploit them are presented in (Truesdell and Toupin 1960). The authors also show the fundamental principles to formulate constitutive equations that satisfy the 2nd law of thermodynamics and basic physical reasoning. Furthermore, they demonstrate the principles of electrodynamics by means of balance equations and derive MAXWELL's equations by mathematical reasoning therefrom.

In general, the governing equations of mechanics and the fields contained within are intuitively clear. In electrodynamics, however, it is often not easy to see what a field actually represents. Does it model the underlining physics? Or is it some mathematical tool? How do the governing relations change in moving matter? To resolve these questions, the modern approach by balance equations is advantageous. Following (Truesdell and Toupin 1960), a more recent treatise is given by (Kovetz 2000), who examines in detail how the classical balance laws for momentum and energy change when electromagnetic fields are present by means of the COLEMAN-NOLL method. Here, the electromagnetic momentum density follows for any given class of matter discussed. It is however possible to *define* an electromagnetic momentum density with appropriate flux terms that holds in general. This approach is also shown in (Truesdell and Toupin 1960), (I. Müller 1985), (W. H. Müller 2014), and by many others.

A recent modified approach to electrodynamics with mixture balance equations is examined by (Guhlke 2014), communicated by W. DREYER. The mixture balances allow for an even deeper insight into the nature of the fields and how constitutive relations can be obtained. The author also examines the transformation laws of the electrodynamic fields w.r.t. LORENTZ and EUCLID transformations, as do all previously mentioned authors. In classical physics, constitutive relations may only be formulated for objective quantities, i.e., physical processes and the involved fields must be invariant under change of observer.

The goal of this review is to show the concepts of electrodynamics as demonstrated by the authors above. First, the two elementary fields of electrodynamics, i.e., the magnetic flux density $\boldsymbol{B}$ and the electric field $\boldsymbol{E}$ are introduced by measurable forces. Second, the balance equation of the magnetic flux is analyzed, yielding two of MAXWELL's equations. Third, balance equations for mixtures are employed. This yields the balance of free electric charge as a corollary of the balance of mass. With the postulation of the balance law for total charge there also follows a balance of bound charges. The examination of the balances of total and bound charges with transport theorems and general surface flux balances yields a) the other two of MAXWELL's equations and b) relations that show how the densities of bound charges and bound electric currents can be calculated by constitutive relations. Fourth, the coupling of electrodynamics and classical thermodynamics is reviewed, i.e., electrodynamic production and supply in the balances of momentum and energy. Fifth, the transformation laws for the electrodynamic fields in the classical limit are reviewed. For a general description w.r.t. moving observers, objective quantities are defined. The classical balance laws are rewritten by means of flux derivatives in order to be purely represented by objective quantities. This formalism is directly applicable to problems of geophysics. For example, the earth's magnetic field is generated by dynamo action that can be modeled by coupled momentum and electrodynamic equations. The review closes with a brief outlook on how constitutive relations can be obtained.

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ON THE NATURE OF BOUNDARY CONDITIONS FOR FLUID FLOW IN TUBES

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The present research deals with the numerical solution to problems related to the complex nature of boundary conditions for fluid flow inside tubes. Our analysis is based on the numerical simulations performed by means of molecular dynamics method.
The performed investigations have demonstrated that the behavior of fluids confined in channels has a strong dependence on structure and form of the channel wall. The considered cases of fluid flow in nano channels have shown that the velocity profile is different from the classical one (by form and size). Also we have investigated various modes of fluid motion in carbon nano channels, such as rectilinear motion, stepwise movement, standing motion mode.
This work also analyzes the flow properties in macro channels with sophisticated edge. We have compared properties of fluid flow in nano channels with properties of fluid flow in macro channels with complex edge and have observed their differences.
We have investigated features of the tube walls and our simulations clearly indicated that they play key roles in the determination of fluid flow properties.

NUMERICAL SIMULATION OF CELL BEHAVIOR IN NARROW CHANNEL

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This study is devoted to the numerical solution to the problem related to the behavior of the cells in narrow channels. The flow behavior of cells is important in many applications in biology and medicine. For example, as it is known experimentally sick and healthy cells have different mechanical properties. The purpose of work was to study the shape and velocity of the cells depending on their mechanical properties.
We have developed a three-dimensional model for system consisting of streamlined cells in a narrow channel. Cells are modelled as elastic highly deformable membranes. Motion of the fluid flow was simulated by Reynolds equations.
Observed results of shape and velocity of the cells make it possible to create devices that distinguish between diseased and healthy cells.

INTERACTION OF A 2-D ACOUSTIC WAVEGUIDE AND AN EULER-BERNOULLI BEAM

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Semi-analytical solutions to dynamic interaction problems can be found in the case of relatively simple geometries. Such solutions are often computationally efficient, which is desirable when multiple loading scenarios need to be analysed, for example.
In this contribution, the solution of a two-dimensional acoustic waveguide interacting with a partially submerged Euler-Bernoulli beam is obtained in the frequency domain. To this end, the boundary integral formulation for the acoustic medium is combined with a set of orthogonal beam modes to describe the displacement and pressure at the interaction surface; finally, the associated modal coefficients are computed from a set of linear algebraic equations.
In similar problems, the in-vacuo modes of the structure are employed. The current paper addresses whether this is optimal for convergence. The associated criteria for convergence are not only the matching of the fluid and beam displacements but also the interaction pressure.

FINITE-ELEMENT MODELLING OF 3D ORTHOGONAL ULTRASONICALLY ASSISTED TURNING OF TI-6AL-4V

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Hybrid machining has gained sufficient prominence in the manufacture of various products since they demonstrate a beneficial combination of several processes. Ultrasonically assisted turning (UAT) is a hybrid machining technique, in which high-frequency, low-amplitude vibration is superimposed on the cutting tool’s movement, resulting in several advantages, including a substantial reduction in cutting forces (in some cases >70%) and improved surface finish amongst others [1].

Comprehensive machining trials are expensive and time- consuming, especially when a wide range of parameters affects complex thermo-mechanical processes that govern high-magnitude deformation in a process zone. As a result, mathematical simulations and, in particular, a finite-element (FE) technique is used increasingly in the machining research community.
In the present work, thermo-mechanically coupled three dimensional FE models of conventional and ultrasonically assisted orthogonal turning processes of a titanium alloy (Ti-6Al-4V) are presented. Nonlinear temperature-sensitive material models are incorporated into our numerical simulations. The simulation results obtained are compared for both conventional turning and UAT to elucidate the main deformation mechanisms responsible for the observed changes in the material's responses to the different cutting techniques. The obtained simulation results are in good agreement with our experimental data.

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INDENTATION IN SINGLE CRYSTALS

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Indentation size effect (ISE) is investigated using crystal plasticity modeling for three types of metal single crystals, namely, FCC copper, BCC Ti-64 and BCC Ti-15-3-3. The deformation behaviour of single crystals is characterized by both conventional single crystal plasticity (SCP) model and mechanism-based strain gradient crystal plasticity (MSGCP) model in order to investigate the effects of strain gradient on nanoindentation. For each type of single crystal, both sharp conical and spherical indenters are incorporated during indentation simulation. The simulation results indicate that the feature of ISE is significantly affected by indenter geometry and strain gradient. Indentation hardness decreases with depth for conical indenter but increases with depth for spherical indenter in the range of small indentation depth. Moreover, ISE becomes more significant due to the presence of geometrically necessary dislocations (GNDs) caused by strain gradient. It indicates that ISE of metal single crystals are determined by both the transition of elastic to plastic deformation and the density variation of GNDs through a parametric study. The two mechanisms responsible for ISE leads to the difference of ISE feature among three investigated single crystals.

INDENTATION STUDY OF MECHANICAL BEHAVIOUR OF ZR-CU-BASED METALLIC GLASS

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Modern high-tech industries rely on manufacture and synthesis of advanced materials that are stronger than traditional ones. Bulk metallic glasses (BMGs) have received much scientific and technological attention due to their significant mechanical properties such as high ratio of their elastic limit to Young's modulus and higher fracture toughness, when compared to crystalline counterparts of the same composition. This is typically attributed to the absence of a long-range order in their atomic structure and a lack of defects such as dislocations, which control ductility in traditional metallic materials. BMGs are brittle and exhibit zero plasticity in the macro-scale. Some recent experiments on sub-micron and nano-size metallic-glass specimens showed that a process of shear localisation became more stable and less catastrophic when compared to the response exhibited by large-size samples [1].
A significant amount of work was carried out to understand deformation mechanisms of such unique materials. In this study, a Zr-Cu-based BMG is characterised using a nano-micro indentation technique. A relatively new technique, namely, wedge indentation was also developed in-house to characterise shear-band formation and evolution in the material`s volume. A thorough structural characterisation of shear bands around the indented region was carried out to understand the nature of shear banding in BMGs.

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MULTISCALE DESIGN OF FUNCTIONAL COMPOSITES

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Nature actively uses sophisticated designs of microstructures to achieve astonishing material properties and functionalities. Thus, the microstructures give rise to the incredible toughness of mother of pearl. Another example is an octopus, an amazingly effective soft machine created by nature. The beast can squeeze its whole body through an extremely narrow space while preserving a large variety of functionalities. The nature created soft machine comprises highly deformable composites that are characterized by different microstructures and phase properties, depending on the required functionalities. Moreover, combinations of the sophisticated microstructures with the ability to sustain extremely large deformations give rise to the opportunity of controllable microstructure transformations. These cascade transformations on the microscopic length-scales change dramatically the macroscopic properties of the materials.

In this talk, I will specifically focus on the role of microstructures in the overall performance of deformable multifunctional composites. We will explore the behavior of *fiber composites* which are extensively used in a large variety of engineering applications (e.g., aerospace and automobile industry); these composites are also widely present in biological tissues (e.g., collagen). We will also examine the performance of *electroactive polymer composites* that gained the name "*artificial muscles*". These materials can undergo large deformations when excited by an external electric field. Next, we will turn to *bio-inspired flexible armor* which draws its design principles from fish's scale-tissue protective systems. As personal armor, these composites grant protection while preserving the flexibility so that the movement is not restricted. These materials can be potentially used for ergonomic and lightweight spacesuits. We will touch some aspects of the behavior of *magnetorheological elastomers* that deforms and modify their stiffness in external magnetic field. They can be used in a large variety of application such as sensor, actuators and noise and vibration dampers.

We will consider how large deformations and elastic instabilities can be used to trigger dramatic pattern transformations and control the large variety of functionalities. Analytical, numerical, and experimental results will illustrate the ideas.

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THE DISCRETE DISLOCATION-DISCLINATION DYNAMICS OF DISLOCATION WALL GENERATION IN METALS AND ALLOYS UNDER SHOCK COMPRESSION

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The study of microstructural changes in metals and alloys during plastic deformation is one of fundamental problems in the physics of strength and plasticity [1-4]. In recent years, an effective tool in theoretical modeling of the severe plastic deformation processes has become the approach of 2D discrete dislocation-disclination dynamics (the D4-approach) which describes the collective behavior of straight dislocations interacting with partial disclinations [5-7]. Recently we have shown that this approach can also be used for modeling the grain fragmentation in polycrystalline metals and alloys under shock compression [8, 9]. In view of highly nonequilibrium conditions of shock wave propagation, we assumed that at the boundaries of the simulation box, which model the subgrain boundaries in a metallic grain under shock compression, there were some jumps of misorientation angles. For tilt boundaries, the jump points are effectively described in terms of partial wedge grain-boundary disclinations. These disclinations can capture the dislocations of opposite signs gliding nearby within the subgrain and make them to form new dislocation walls – fragment boundaries. This process, in fact, represents the physical mechanism of fragmentation within pre-existing subgrains in shear bands in metallic materials under shock loading. If in the process of modeling, the distance between two dislocations of opposite signs becomes less than a critical distance, it is considered that the dislocations are annihilated. To simulate the motion of dislocations, we used the 2D D4-approach. In doing so, we took into account two new features as compared with our earlier works [8, 9]. First, we accounted for the temperature increase in the shear bands and used it for calculating the local drag coefficient β . Second, we considered the fact that on the subgrain boundaries, at the place of newly generated dislocations, new opposite-sign dislocations appear. Such dislocations create their own stress fields and strongly affect the dynamics of all dislocations in the simulation box. As a result, our new 2D D4 computer model clearly demonstrated the subgrain fragmentation. In comparison to results of previous works [8, 9], the modification of the boundary conditions made a significant impact on the final microstructure in the case of both fine and coarse initial subgrains. We obtained stable dislocation structures similar to those observed in experiments [10, 11] and showed that the typical shock duration is enough to complete the fragmentation process within the initial subgrain, and the necessary stress magnitude (0.5 GPa) well agrees with experiments [10, 11].

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GEOMETRICALLY NONLINEAR STATIC THEORY OF THIN ELASTIC MICROPOLAR SHALLOW SHELLS

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Micropolar thin shallow shells are considered, the elastic deflections are comparable to their thickness and at the same time are small in relation to the basic size, at the same time as the small angles of relation of the normal to the middle surface before deformation, and their free turns. Thus, in the strain tensor and tensor of bending-torsion takes into account not only linear but also the nonlinear terms in the gradients of displacements and rotation. The hypothesis method is developed and on this base static applied theory of micropolar elastic flexible shallow shells are constructed. Some practical problems are solved.

ANALYTICAL INVESTIGATION OF AIR FLOW THROUGH MINE AIRWAY JUNCTIONS OF ARBITRARY GEOMETRY

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Pressure losses in underground mines are divisible into two components: linear air resistances due to friction and local air resistances due to passing through local hindrances (wall stopping, mine airways junction, bend etc.). The local air resistances also are classified into flow compression-expansion, deflection and mixing. As follows from experimental measurements of potash mines, local air resistances often exceed 20% of the total pressure loss. The relative contribution of local air resistances ascends with the increase of the mine airways cross sectional area. It is necessary to take into account local air resistances while the calculation of air flow distribution in underground mine ventilation networks. At the moment, there is no algorithmically suitable and reasonably exact general technique of local air resistances determination for mine ventilation networks. Existing methods either give a pretty exact solution in a limited set of simple cases [1, 2], or give a general solution for the arbitrary junction with no consideration of some sufficient physical processes influencing on result pressure losses [3]. In this investigation we formulate the mathematical model of air flow through mine airways junctions of arbitrary geometry. Proposed model allow us to take into account pressure losses due to flow compression, expansion, deflection and mixing for arbitrary number of flows entering the junction. Also we consider the influence of wall roughness, which is important in case of local resistances accordingly to [2]. The comparison study of proposed formula and existing approaches of local aerodynamic resistance calculation is accomplished. Also we compare obtained formula with existing experimental investigations.

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THE LOCAL CRITERION TO SIMULATE LONG-WAVE DYNAMICS PHENOMENA IN A REGULAR MULTI-BODY CHAIN BY MEANS OF THE 1D-CONTINUUM DYNAMICS

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We consider the chain of rigid bodies. The adjacent bodies of the chain are connected by means of the Bernoulli-Euler inertialless elastic beams. Each rigid body of the chain has 6 degrees of freedom. The number of inertia elements is extremely large, and solve a system of ordinary differential equations is boring.

It is known that the longitudinal dynamics of such a chain may be simulated by means of partial equation as well as the rotation dynamics of the rigid bodies along the axis of the chain. However the transverse dynamics of the chains inertia elements does allow such type of simulating only for connections of a special kind.

We are presenting the criterion which gives a possibility to construct the continuum description for the long wave dynamical processes in the chains, formed of elastically connected equal rigid bodies. The possibility depends on the properties of the local elastic connections between adjacent inertia bodies.

We are showing, that the continuum description is impossible, if the behavior of the descrete regular 1D-lattice in accordance with a <<descrete>> scenario is energetically more favorable than its behavior in accordance with a scenario of a 1D-continuum. Then we give the example of the essentially discrete multi-element structure. There is no sense to find a continualization for this multi-element structure without the constraints of external fields.

Finally, we show that for the rigid body chain may be realized both scenarios. There exist degrees of freedom of the chain inertia element, which allow continualization, mean while for the other degrees of freedom of the bodies the long-wave continualization is impossible. It gives opportunity to consider the rigid body lattices as mechanical structures of so called dual nature.

MECHANICAL PROPERTIES OF FILLED ELASTOMERS SUBJECTED TO ALTERNATE LOADING ALONG TWO ORTHOGONAL AXES

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We present the results of an experimental study of the behavior of carbon black filled rubber and rubber with carbon nanofibers. Tests were carried out using a 4-vector test stand Zwick (biaxial testing machine), a uniaxial testing machine Testometric FS100kN CT and a dynamic mechanical analyzer DMA/SDTA861^e. Our investigations revealed the induced anisotropy of mechanical properties in the material with grain filler — stretching along one axis does not, in any way, affect mechanical properties along the other axis. It is shown that uniaxial stretching of an elastomer with nanofibers changes the structure and mechanical properties of the material in all directions.

The study was supported by RFBR and Perm Ministry of Industry of Innovations and Science (grant 13-01-96016 r_ural_a and grant 14-08-96013 r_ural_a), and the Ministry of Education of Perm Region under agreement C-26/627.

MULTIDIMENSIONAL PENDULUM IN A NONCONSERVATIVE FORCE FIELD

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In this activity, we systematize the results on the study of the equations of motion of dynamically symmetric multidimensional rigid bodies in nonconservative force fields. The form of these equations is taken from the dynamics of real lower-dimensional rigid bodies interacting with resisting medium by laws of jet flows where a body is influenced by a nonconservative tracing force; under action of this force, the velocity of some characteristic point of the body remains constant, which means that the system possesses a nonintegrable servo constraint.

In the earlier activities, the author has already proved the complete integrability of the equations of a plane-parallel motion of a body in a resisting medium under the jet flow conditions when the system of dynamical equations possesses a first integral, which is a

transcendental (in the sense of the theory of functions of a complex variable) function of quasi-velocities having essential singularities. It was assumed that the interaction of the medium with the body is concentrated on a part of the surface of the body that has the form of a (one-dimensional) plate. In the sequel, the planar problem was generalized to the spatial (three-dimensional) case, where the system of dynamical equations possesses a complete set of transcendental first integrals. In this case, it was assumed that the interaction of the medium with the body is concentrated on the part of the surface of the body that has the form of a planar (two-dimensional) disk.
Moreover, we study the dynamic part of equations of motion of a different four-dimensional dynamically symmetric rigid body where a nonconservative force field is concentrated on a part of the surface of the body, which has the form of a two-dimensional (three-dimensional) disk, and the action of the force is concentrated in the two-dimensional plane (one-dimensional line) perpendicular to this disk.
In this work, we discuss results, both new and obtained earlier, concerning the case where the interaction of the medium with the body is concentrated on the part of the surface of the body that has the form of a (n–1) -dimensional disk and the force acts in the direction perpendicular to the disk. We systematize these results and formulate them in the invariant form. We also introduce the additional dependence of the moment of a nonconservative force on the angular velocity; this dependence was distributed from the motion in lower-dimensional spaces.

KINETICS OF PHASE TRANSITIONS IN ELASTIC AND INELELASTIC SOLIDS

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In the paper we call attention to a problem for propagating phase boundaries in elastic and inelastic solids capable of undergoing stress-induced transformations of martensite type.
For small strains the problem is formulated by the following way

$$x \notin \Gamma: \quad \nabla \cdot \boldsymbol{\sigma} = 0, \quad \theta = \text{const},$$
$$x \in \Gamma: \quad [\![\mathbf{u}]\!] = 0, \quad [\![\boldsymbol{\sigma}]\!] \cdot \mathbf{n} = 0,$$
$$D = -\int_\Gamma \chi\, \upsilon^\Gamma \, d\Gamma \geq 0, \quad \chi \triangleq [\![f]\!] - \boldsymbol{\sigma} : [\![\boldsymbol{\varepsilon}]\!], \tag{1}$$

where ε and σ are the strain and stress tensors, respectively; θ is the temperature; **n** is a unit normal to the propagating phase boundary Γ; D is the energy dissipation during quasistatic propagation of the surface of discontinuity in deformations that must be nonnegative; υ^Γ is the velocity of Γ in the direction of the normal that is outward normal to the phase boundary from the phase “+”; χ≠0 is the thermodynamic force (Eshelby’s driving force, material or configurational force). The brackets $[[g]]=g_+ - g_-$ denote the jump of a function g across Γ. Conditions (1)–(2) are conventional equilibrium and boundary conditions for a joined body, inequality $(1)_3$ prescribes the law of propagation of the phase boundary. Bulk forces, thermoelastic stresses and surface energy are not taken into account.
For propagating phase boundaries from eq. $(1)_3$ it follows that the velocity υ^Γ is connected with the thermodynamic force χ by a kinetic equation

$$\upsilon^\Gamma = \Phi(\chi), \tag{2}$$

where Φ is some function of χ, and, in consequence of $(1)_3$, must satisfy $\Phi(\chi)\chi \leq 0$.
The system of equations $(1)_{1,2}$, (2) can be satisfied not for every deformation, the normal and the velocity. This brings to the introduction of the modified phase transition zone (PTZ) that is formed by all deformations which can coexist on the phase boundary advancing with a given velocity. This definition is an extension of the definition of the PTZ for equilibrium phase boundaries developed earlier, see [1] and references within. We construct the modified PTZ and with its help we show how a deformed state and plastic deformation influence on the rate of propagation of phase boundaries and the type of strain localization.
This work was supported by Russian Foundation for Basic Research (Grant No. 13-01-00687).

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RESEARCH OF STABILITY OF SELF-SYNCHRONIZATION VIBRATION EXCITERS, UNDER VARIOUS OPERATING CONDITIONS VIBRATION MACHINES

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The Ural State University of Railway Transport is actively engaged in research of vibration transport machines, operating on the principle of self-synchronization. While researching mathematical model is being used, based on a system of differential equations describing the nonlinear dynamics of the machine (in its various versions).
To verify the theoretical research, we have developed a test bench of the vibration transport machines, designed to conduct field studies of this machine motion with different parameters.
The article deals with the results of the experimental research of self-synchronization stability of vibration

exciters with the test bench developed by the authors The test bench allows to study the dynamics of transition processes at the time of launching (getting started) and switching off the vibromachine in case of both one-mass and two-mass configuration, as well as with one, two or three vibration exciters.
The experimental results provide an opportunity to identify ways to save energy and improve the design vibration transport machines.

THE ROLE OF ELASTIC VORTICES IN THE DYNAMIC PROPAGATION OF LONGITUDINAL SHEAR CRACKS

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Dynamic propagation of longitudinal shear (mode II) cracks has been widely studied experimentally and theoretically in the contexts of earthquakes, fracture of materials and friction. The main feature of the dynamics of unstable shear rupture is formation of the shear stress concentration (stress peak) ahead of the crack tip. The shear stress peak was an object of intensive study by different authors due to its governing role in shear rupture transition from conventional sub-Rayleigh to supershear (intersonic) regime. Despite this basic understanding of the mechanisms of longitudinal shear crack propagation, some fundamental questions concerning the material deformation in the vicinity of the crack tip are still not fully understood. In particular, the physical mechanisms of the formation of a stress concentration region ahead of the crack tip and its stability as well as necessary conditions for the intersonic crack propagation have not yet been completely understood. Presented study is devoted to the numerical analysis of this problem.
The study was carried out by means of numerical modeling using movable cellular automaton method. A two-dimensional slab containing infinitely thin low-strength interface (interface line) with initial crack was considered. Both parts of the slab were assumed to be made from the same high-strength linear-elastic material. Shearing deformation of the slab in the direction parallel to the interface line was modelled.
Simulation results have shown that a vortex-shaped motion pattern (hereafter referred to as elastic vortex) is formed in the vicinity of the shear crack from the very beginning of crack propagation. With progressing growth of the crack the elastic vortex involves more and more of the medium ahead of the crack tip. The propagation velocity of the elastic vortex quickly approaches the shear wave speed, while the crack advances at a velocity lower than the Raleigh wave speed. Therefore, during the course of propagation the vortex gradually moves away from the crack tip and finally detaches from it. After separation of the elastic vortex from the crack the new vortex start to form at the tip. Finally, mode II crack propagating in conventional sub-Rayleigh regime generates a chain of elastic vortices moving ahead of the tip at a shear wave speed. The most important feature of these elastic vortices is shear stress concentration in their frontal parts. The position of the maximum of shear stress distribution in the vortex corresponds to the position of the stress peak ahead of the crack as described by different authors. Analysis of the simulation results gives grounds to state that unsteady character of shear crack propagation in conventional sub-Rayleigh regime (including crack velocity oscillation) is explained by generation and emanation of elastic vortices. Note that the concept of vortex-related dynamics of unstable rupture is useful for general understanding of instabilities in brittle fracture.
Finally, the conditions under which the acceleration of a longitudinal shear crack to an intersonic speed takes place are discussed. It is shown that geometrical parameter governing such acceleration is the ratio (P) of the initial crack length to a parameter which may be called the “crack thickness”. If the initial crack is characterized by the magnitude of the geometrical parameter P>Pcrit (where Pcrit is the value, at which the peak stress at the interface ahead of the crack reaches the interface strength), the crack can overcome the Rayleigh wave velocity barrier and propagate in intersonic regime. The value of the critical parameter Pcrit depends of material elastic and viscous properties. Specific forms of these dependencies are discussed.

MULTI-PHYSICS PROPERTIES IN LOW-DIMENSIONAL FERROIC NANOSTRUCTURES FROM QUANTUM-MECHANICS CALCULATIONS

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Mechanical stress/strain strongly interacts with ferroelectric, ferromagnetic, and various electronic properties, i.e., "multi-physics" coupling. In particular, ferroic nanostructures exhibit novel properties distinct from the bulk counterpart. We present a series of quantum-mechanics studies on remarkable ferroic and multi-physics properties in low-dimensional nanostructures from the state-of-the-art first-principles density-functional theory calculations, which are essential for the nonlinear multi-physics couplings due the quantum mechanical effects. The novelty and complexity of ferroelectric nanostructures originate from combinations of the outer shape (e.g., thin films, nano-wires, tubes, and dots) and the inner understructure (e.g., grain boundaries, domain walls, and lattice distortions). Each shape or understructure alters spontaneous polarization or magnetization although the influence is restricted within a local area of several nanometers. The multi-physics coupling through mechanical stress/strain not only enhances their influence dramatically and entirely but also brings about novel and unusual ferroic properties, such as closure-nanodomains, polarization vortices, improper ferroelectricity, and absence of ferroelectric critical sizes. We first classify the nanostructures into fundamental elements and explain the interplay of them systematically, which provides deeper insights into multi-physics properties in nanostructures. Our studies simultaneously point out a new direction of "mechanics of materials", which pave the way of designing novel functionalities at the nanoscales.

STRAIN-ORBITAL INTERACTIONS IN OXYGEN-DEFICIENT FERROELECTRICS: UNUSUAL MULTIFERROIC TRANSITIONS

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The nonlinear interaction between mechanical strain applied to functional materials and electron orbitals that governs the properties of materials has attracted considerable attention owing to the potential ability to tailor the functionality, i.e., “strain-orbital engineering”. Here, we address this mechanical-quantum interaction using the state-of-the-art first-principles hybrid Hartree-Fock density-functional theory, and demonstrate the novel path toward realization of extra functionality which the host materials do never exhibit by taking one hot example of multiferroics that simultaneously possess both ferroelectricity and (anti-)ferromagnetism in one phase.
The control of the magnetization by an electric field in multiferroic materials makes the design and the integration of novel electronic devices possible. However, very few discoveries of multiferroic materials due to mutually exclusive mechanism between ferroelectricity and (anti-)ferromagnetism have prevented the innovation and progress in this field. Here, we demonstrate an entirely new route to multiferroics by the orbital symmetry engineering through the nonlinear defect-orbital and strain interactions in nonmagnetic ferroelectrics $PbTiO_3$. A misfit strain in epitaxial $PbTiO_3$ films activates local (anti-)ferromagnetism at oxygen vacancies via the orbital symmetry breaking and splitting of the defect electronic states. A nonlinear magnetoelectric effect is also present due to magnetic phase transitions coincident with ferroelectric polarization switching. The present results thus provide a new material design strategy for multiferroics and multifunctional oxides that exhibit magnetism coexisted with the host functionalities by engineering both defects and misfit strains

SCALE-INVARIANT INITIAL VALUE PROBLEMS WITH APPLICATIONS TO THE DYNAMICAL THEORY OF STRESS-INDUCED PHASE TRANSFORMATIONS

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We deal with the 1D non-stationary wave propagation in an elastic phase-transforming bar. The stress in the bar is assumed to be a piecewise linear function of the strain containing a “negative slope segment”, thus the strain energy is a non-convex function of the strain. It is known that the problem of elastostatics for such a kind of material can have solutions with discontinuous deformation gradients. In the framework of the model of stress-induced phase transitions, the surfaces of the strain discontinuity are considered as the phase boundaries, and the domains of continuity are considered as zones occupied by different phases of the material. The solution of both statical and dynamical problems are generally non-unique; therefore, an additional thermodynamic boundary condition at the phase boundary is required.
The comparative analysis for two types of problems is under consideration. The first problem is concerned with a new phase nucleation in a phase-transforming bar caused by a collision of two non-stationary waves. The second one is a new phase nucleation caused by an impact loading applied at the end of a semi-infinite phase-transforming bar. Both of the problem can be formulated as a scale-invariant initial value problem with additional restrictions in the form of several inequalities involving the problem parameters. The aim of the investigation is to determine the domains of existence of the solution in the parameter space.

DYNAMICS OF INCLINED VIBRATORY JAW CRUSHER

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A symmetrical flat inclined vibratory jaw crusher dynamic system that includes a carrying body (frame) with two jaws attached to it by means of torsion springs (torsions) is considered. An inertial vibration exciter is attached to the upper jaw. The crusher is intended for recycling of lengthy ferroconcrete designs (columns, bearing parts, cross ties, etc.) with receiving secondary crushed stone and standard scrap metal. As distinguished from the crusher conventional scheme, vertical symmetry axis of the inclined crusher forms a certain angle with vertical line. Also, the modernised crusher is driven by only one vibration exciter, attached to the upper jaw.

Differential equations of motion of the considered system with the five degrees of freedom are derived. The laws of forced oscillations of jaws have been formulated, as well as their amplitude-frequency and phase-frequency characteristics have been plotted. Ranges of out-of-phase jaws oscillations with same frequency and similar amplitudes have been determined. It is shown, that out-of-phase jaws motion is realized in low-frequency range (up to symmetrical resonance), as well as in high-frequency range (above skew-symmetrical resonance). Besides, there is a small inter-resonance frequency range, in which out-of-phase jaws motion may be realized. In the course of experimental investigations, the resonance frequency ranges (symmetrical and skew-symmetrical), as well as amplitude-frequency and phase-frequency characteristics of jaws have been determined, showing fine reproducibility of the theoretical results.

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SOME FEATURES OF REFLECTION AND REFRACTION OF THE PLANE LONGITUDINAL SHOCK WAVE WHICH INTERACTS WITH THE BOUNDARY BETWEEN TWO NONLINEAR-ELASTIC MEDIA

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The nonlinear elasticity models describes the relationship between stress and strain in the areas where the material is still exhibits elastic properties, but the Hooke's linear law does not work. For most materials, such area with a significant elastic deformation precedes the transition to the zone of plasticity. Effect of nonlinearity is shown most essentially at dynamic action on solids when surfaces of deformation discontinuities with combined change of volume and shear deformations appear [1]. The occurrence of similar effects does not observed of linear elasticity theory, therefore in the majority of cases the solving of boundary value problems of dynamics deformation of nonlinear elastic materials is carried out in an approximate way. In this paper some features which occur when the compression shock wave interacts with a plane interface between two elastic media are demonstrated on the basis of results of a series of computational experiments. The materials are described by the nonlinear five-constant model [2] (Murnaghan material). The wave intensity and the angle of incidence are given constant. An approximate solution is constructed using the finite difference scheme [3,4], specially designed for the dynamic plane problem of the deformation of the nonlinear elastic solid. It is shown that the reflected and refracted wave packets may include the surfaces of strong and weak discontinuities of deformations. It is found that there may be solutions, when the intensity of the first refracted shock wave exceeds the intensity of the incident longitudinal shock wave. In general, the appearance of such solutions depends on the mechanical properties of the conjugate materials, namely on the value of the third-order elastic constants.

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ELASTOMER COMPOSITES WITH PHASE-CHANGING FILLERS IN SEALING APPLICATION

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It has been estimated that about a quarter of the world hydrocarbon undiscovered reserves lays in the Arctic continental shelf and adjacent land areas. Hence development of new materials and adaptation of equipment design to low temperature is necessary for sustainable extraction of fossil fuels and minerals. In the present paper we consider sealing elements. The use of usual elastomer seals is limited at low temperatures due to big mismatch between the coefficients of thermal expansion of steel and rubber. A thermal shrinkage of an elastomer seal placed into its steel groove may leads to decrease of contact pressure twice or even more, depending on the temperature drop. This, in turn, may result in forming a leak path for the contained fluid. This paper is aimed to finding ways to enlarge the admissible operating temperature gap for elastomer-based composites to temperatures using special fillers.

We consider an elastomer composites with fillers made of a phase-changing material (PCM). Upon cooling at a certain temperature PCMs change from liquid to solid phases. The transformation is accompanied by volume expansion and heat release. PCM's expansion partially compensates the thermal shrinkage of the elastomer, and the latent heat release provides opportunity to slow down seal freezing. The research focuses on answering the following questions:
How does the volume fraction of fillers affect the thermal contraction, effective thermo-elastic properties and freezing time of the composite at abrupt temperature drop?
How does the contact pressure produced by the composite seal depend on temperature, the filler volume fraction and time?
What are local strains at the interfaces between rubber matrix and particles in such composites?

THE MULTILEVEL MODEL OF INELASTIC AND SUPERPLASTICITY DEFORMATION OF POLYCRYSTALLINE METALLS

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The deformation in superplasticity regime is a promising way of metal forming with complex shape. It allows to obtain high-quality large-sized parts with relatively low load level to pressing stamps. Empirical determination of efficient process conditions is highly resource-intensive, therefore the significant problem is to construct mathematical models for description not only the integral process parameters, but also the evolving material structure, which determines the quality of a product. At the same time models should be sufficiently general to describe superplastic deformation and "usual" elastoviscoplastic deformation as well as transitions between these deformation regimes. Multilevel models based on internal variable introduction and crystal plasticity theories are the most suitable to achieve the aim[1].
The previously developed two-level constitutive model of polycrystalline inelastic deformation is proposed as a basic model[1]. To describe grain boundary sliding, which dominates during structural superplastic deformation, additional scale level (intermediate level between meso- and macrolevel) is introduced. Resulting three-level model includes description of intragranular dislocation sliding, lattice rotation and grain boundary sliding. Schmid law is used to describe intragranular dislocation sliding, crystallite lattice rotation is determined by the model based on the incompatibility of dislocation sliding in the neighboring crystallites[1], grain boundary sliding is described by equations that take into account inflow of intragranular dislocations, changing of the boundary structure during grain boundary sliding realization and diffusion processes. Consistency conditions of scale levels[1] are used to precise geometric nonlinearity description in constitutive relations of macroscale level.
The numerical implementation algorithm of three-level model which describes the behavior of polycrystal representative volume is suggested. Also an algorithm for using this model as a material model to solve boundary value problems is proposed. It is based on the finite element method realization in package Abaqus.
With the model different computational experiments for representative volume of polycrystalline copper were conducted. The obtained results show that grain boundary sliding is important mechanism and must be taking into account for describing inelastic deformation processes.
The work was supported by the President Grant №MK-4485.2014.1, № MK-4917.2015.1, the Russian Federation Ministry of Education and Science (basic part of the state task PNRPU, №01201460535) and RFBR (grants № 14-01-00069-a, 15-08-06866-a).

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FRACTURE PROCESSES IN CORTICAL BONE: EFFECT OF MICROSTRUCTURE

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Understanding of bone fracture can improve medical and surgical procedures. Therefore, investigation of the effect of bone’s microstructure and properties as well as loading parameters on initiation and propagation of crack is of great importance. In this paper, several modelling approaches are used to study fracture of cortical bone tissue at various length scales and different types of loading. Two major problems are tackled: crack propagation under impact loading and bone cutting in surgical procedures.
In the former case, a micro-scale finite-element fracture model is suggested accounting for bone’s microstructure and using X-FEM for crack propagation analysis [1, 2]. Several formulations are used: effective homogeneous medium and three- and four-component heterogeneous one. The topology of a transverse-radial cross section captured with optical microscopy is used to generate the models in two last cases; extensive experimental studies provide necessary mechanical input data [3]. The effect of dynamic loading is analysed separately [4], employing both experimental analysis and numerical simulations. Two areas are covered: tensile impact tests to quantify a bone’s behaviour under impact loading, and a 3D finite-element model simulating these tests. In the first area the effect of three different parameters – a cortex position, a notch depth and an energy level – on

the bones tissue's response is investigated. Additionally, a 3D numerical model for the tensile impact test is developed using Abaqus/Explicit finite-element software.

The problem of bone cutting is treated within the framework of tool-bone interaction analysis [5, 6]. A two-domain approach is used, with a process zone treated using the smooth-particle hydrodynamics method. This zone is embedded in a continuum domain with macroscopic anisotropic properties obtained in experiments. This study is supported by analysis of damage induced by the interaction between the cutting tool and bone tissue using wedge and indentation tests and considering also the anisotropic behaviour of the bone. Indentation tests are performed on several anatomical positions of a bovine cortical bone to observe damage initiation and effect of mechanical anisotropy on damage characteristics. Each anatomical position is tested with a load ranging from 1 kg to 100 kg. The wedge testing provides a broader perspective on damage evolution, especially in the direction of tool motion.

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ENERGY OSCILLATIONS IN A HARMONIC ONE-DIMENSIONAL CRYSTAL

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In recent decades, the methods of mechanics of discrete media have widely been used to describe nonequilibrium processes in matter [1–3]. Interest in discrete approaches has especially risen in connection with the development of nanotechnologies [4, 5].

The analysis of nonequilibrium thermal processes in discrete media even for such a simple model as ideal crystals under classic (nonquantum) description remains a serious problem. For example, for one dimensional crystal the thermal elasticity equations can be derived in the adiabatic approximation [3, 6], however the description of heat transfer can diverge with the conclusions of classic heat conductivity theory [7, 8].

The aim of this study is to analyse the energy oscillations in one-dimensional harmonic crystal with nonlinear interactions between the particles.

The study of kinetic energy oscillations in one-dimensional crystal is done. The one-dimensional crystal with nonlinear interaction of particles (cubic nonlinearity in force) is considered. The dimensionless parameter characterizing the ratio of nonlinear to linear interaction between the particles in one-dimensional crystal is introduced to study the influence of nonlinearity interaction. Two type of initial conditions: uniform temperature distribution and sinusoidal temperature profile in one-dimensional crystal were considered.

For the first formulation of the problem the kinetic energy in the crystal and its dependence from nonlinearity parameter was investigated. Defined that variation of kinetic energy in one-dimensional crystal has an oscillatory character. With increasing the nonlinearity the rate of decay of kinetic energy oscillations is increases. The approximation of decay law for kinetic energy oscillation for various values of nonlinearity parameter is proposed. The proposed approximation gives a good compliance with kinetic energy oscillations for small nonlinearity.

A good compliance of the proposed approximation for small nonlinearity in the case of uniform temperature distribution indicate that the analytical solution for obtained in [9] is stability.

For second case of initial condition (sinusoidal temperature profile), the amplitude of temperature profile and its dependence from nonlinearity parameter were investigated. Defined that variation of amplitude of temperature profile in one-dimensional crystal also has an oscillatory character. With increasing the nonlinearity the rate of amplitude of temperature profile oscillations is increases. The approximation of decay laws for amplitude of temperature profile oscillation for various values of nonlinearity parameter is proposed The proposed approximation gives a good compliance for small nonlinearity. But if the nonlinearity is not small the discrepancy between approximation of decay laws and the real decay law is significant.

Graphics of the dependences of decay laws parameters from nonlinearity parameter for the two initial conditions (uniform temperature distribution and sinusoidal temperature profile). Shown that decay laws of kinetic energy and amplitude of temperature profile oscillations are difference.

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NONLINEAR DYNAMICS OF NANO-MECHANICAL SYSTEMS IN QUASI-STATIONARY ELECTROMAGNETIC FIELDS

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This investigation is devoted to solution of some new physical tasks of a nonlinear dynamics of conductive nano-systems placed into quasi-stationary electromagnetic fields. These solutions are carried out by methods of the theory of nonlinear oscillations, in particular, by the asymptotic method. These analytical and numerical solutions as far as possible were checked by real physical experiments. As well as theory and experiment opens the possibility of creating the new electromechanical systems, which are similar nano-systems.
The first common task of this study is to determine experimentally obtained and numerically confirmed quasi-stationary magnetic field in some electromechanical systems and comparison of these distributions qualitatively. The next is to obtain the expressions the ponderomotive forces as the functions of the generalized coordinates. These functions have been obtained based of distribution of electric and magnetic field. The corresponding Lagrange-Maxwell equations are derived and solved analytically and numerically. In some cases the asymptotical solution is possible, in particular, using the methods of separation of the motions – averaging method.
The approach proposed above is used to investigate some new physical tasks. The first one is a nanoresonator based on graphene layers, which is considered as an electromechanical system. This system can be used as an ultraprecise mass sensor. Three different ways to determine the spectral characteristics changing of this system are proposed. The first one is based on the jump of the stationary nonlinear oscillations. The second one is based on modulation of the beating oscillations and third is obtained symmetrical electromechanical system with pure parametrical resonance.
The aim of these electromechanical tasks is a determination of spectral characteristics of nano-layers, which can changed at sticking nanoparticle.

MISFIT STRESS RELAXATION IN HOLLOW AND SOLID CORE-SHELL NANOWIRES VIA GENERATION OF PRISMATIC DISLOCATION LOOPS

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Production and applications of composite nanoparticles, nanowires and nanolayers are extensive areas at the forefront of modern nanotechnology. These nanostructures have attracted significant interest due to their electronic, magnetic and optical properties which depend on their shape, size, chemical composition, crystal lattice type and presence of various defects. In particular, great attention is attracted to core-shell nanostructures like nanoparticles [1] and nanowires [2]. These nanoscale objects are composed of different materials and can find many applications in modern optoelectronics, photonics, spintronics, solar cells, sensors, data storage and transfer devices, catalysis, medicine, etc. As cores and shells consist of different materials with different lattice parameters and thermal expansion coefficients, the growth of such nanostructures is accompanied with appearance of residual elastic strains and stresses which can relax by different mechanisms. One of possible ways of the stress relaxation is the generation of misfit defects at the core-shell interface. These defects like misfit dislocations cause degradation in electronic, optical and other functional properties of composite nanostructures, which explains a special interest to this problem.

Recently, a number of theoretical models have been developed to analyze the critical conditions for onset of misfit defects such as rectangular [3-5] and circular [5-7] prismatic dislocation loops (PDLs) in core-shell nanoparticles [3-7] and other composite nanostructures [4]. It has been shown that in core-shell nanoparticles, the rectangular PDLs generated from the shell surface can sometimes develop and transform into the circular PDLs embracing the core [5]. However, the activation of this mechanism strongly depends on the model parameters.

In the present work, we extend the approach developed in work [5] to the case of core-shell nanowires with hollow and solid cores. With the assumptions that the nanowires are elastically isotropic and homogeneous, we derive strict analytical solutions for the energy changes accompanied the generation of rectangular PDLs on the shell surface and circular PDLs on the core-shell interface, and compare these cases in terms of critical shell thickness with account for the PDL shape. We show that the case of relatively small misfit parameter is favorable for either coherent state of nanowires or generation of circular PDLs in their interfaces, and that these circular loops can not be formed through the nucleation and subsequent expansion of the rectangular PDLs. In the case of relatively large values of the misfit parameter, the coherent state is unprofitable. With the growth of the shell thickness, one can first expect the appearance of rectangular PDLs, then the formation of circular PDLs with preserving of existing and newly generated rectangular PDLs, and then the gradual extension of rectangular PDLs and their transformation into circular PDLs. Finally, we show that hollow core-shell nanowires are more stable against PDL generation than the solid ones.

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THRESHOLD EROSION FRACTURE OF AERO ENGINE BLADES

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In this report we will discuss erosion fracture of aero engine blades due to impact of sand grains. A model of erosion wear at threshold velocities of incidence of abrasive particles will be presented. In the model the Hertzs classical impact theory is used for modeling the contact interaction of a particle with an elastic half-space. The incubation time fracture criterion is applied for predicting surface fracture. Energetically optimal modes of dynamic impact will be shown. In particular, it will be demonstrated that the energy input for fracture can be optimized so that the energy cost of the process is minimized.

SIMULATION OF IRON-GRAPHENE COMPOSITE MATERIALS

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Metal matrix composites are widely used in different areas of industry. Microstructure modification is powerful method of increasing the strength of materials. It was shown [1] that graphene contained in nanolayered composite consisting of alterlating layers of metal and graphene is effective in blocking dislication propagation across metal-graphene interface. In this work influence of graphene inclusions on metal matrix properties is investigated by using MD simulations based on paralled LAMMPS code. Multiple simulations of tensile experiments with suitably selected simulation boxes are performed until breakage of the sample. In particular, in these simulations the temporal evolution of lattice defects such as dislocations and possible nanocracks at the Fe-graphene interface is in the center of interest. Analytical studies for polycrystalline with single inclusion using Eshelby solution were carried out. Influence of orientation of graphene inclusion was investigated. Results obtained in MD simulations were in good conformity with analytical investigation. Further polycrystalline with a fixed grain size of about 10 nm with randomly distributed orientations is created, which due to the lattice mismatch at the grain boundaries have geometrically necessary dislocations. At this point tensile, shear and nanoindentation tests at different temperatures are performed until new dislocations formed. As a result of these simulations the mechanisms of the strength increase in the polycrystalline Fe-graphene are obtained. Relevant graphene orientation investigated such as crossing grain boundary, being inside a grain, or lying along a grain boundary.

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MODELLING OF BOND SATURATION IN COMPLEX MOLECULAR STRUCTURES

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Nowadays computer simulation is extremely powerful method of research of molecular systems [1]. Although quantum mechanics simulation remains the most accurate method for describing systems on electronic level it is still excessively computationally expensive. The Hamiltonian of such system can be described in terms of classical mechanics. Approaches combining quantum mechanics and molecular dynamics showed broad applicability for simulation of complex chemical systems [2]. Method using classical mechanics and empirical data obtained from quantum mechanics was developed. The atom is represented by a set of material points. Each material point represent center of mass of nucleus and centers of electron density of electron clouds. A modification of the model proposed by R.V. Vlasov, E.A. Ivanova, A.M. Krivtsov [3] is used. To describe the interaction between a material point representing the electron cloud and the nucleus it is proposed to use a linear elastic force. To describe the interaction between particles, representing the electron clouds of a single atom it is proposed to use the Coulomb force. The interaction of material points representing the electron clouds of different atoms must meet the following requirements. Electron clouds of different atoms should attract, but in the case when the distance between two clouds becomes small, the interaction of these clouds with other clouds becomes negligible, i.e. the bond will be saturated. The parameters for carbon and carbon hydrogen interaction are given. Qualitative and quantitative results are obtained. Examples of different molecule formation are given.

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NUMERICAL SIMULATION OF THE EFFECT OF SOFTENING IN MATERIALS ON CHANGES IN THE STRESS-STRAIN STATE OF ELASTOMERIC ARTICLES

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The paper explores the necessity of taking into account the effect of softening encountered in rubbers (Mullins effect) during physical and numerical modeling of industrial rubber articles. For more precise computations, the Ogden-Roxburgh model is modified by changing constants to functions found from the analysis of experimental data. The modified model implemented in commercial package ANSYS allows us to perform a comparative analysis of changes in the stress-strain state of a car tyre with and without taking into account the effect of softening in rubbers.

The study was supported by RFBR and Perm Ministry of Industry of Innovations and Science (grant 13-01-96016 r_ural_a and grant 14-08-96013 r_ural_a), and the Ministry of Education of Perm Region under agreement C-26/627.

MODELING VISCOELASTIC STRAIN AND CREEP FOR HARDENING STRUCTURES BASED ON CEMENT UNDER TEMPERATURE GRADIENTS

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During the hardening period, materials based on cement experience deformation due to heat generation and moisture movement or internal consumption of water by cement. All these processes influence the change of material volume. As a result, these factors can lead to water tightness problems, durability problems and damage due to frost, which means that numerical simulation of its properties is important problem. So, in order to predict and prevent these problems, a numerical model should be developed in a proper way. For example, accurate consideration of heat generation and heat loss should be incorporated to calculate the temperature distribution gradients. The first goal of the research is to present numerical model of temperature calculation and then using this data to estimate thermal dilation and autogenous shrinkage during the contraction phase. As is well known, creep also influences on stress state for hardening materials and is a relaxation factor during the cooling period. Finally, the aim is to model a creep effect.

SURFACE EFFECTS IN THE THEORY OF ELASTIC MATERIALS WITH VOIDS

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A model of a porous medium, which is obtained as a special case of the general theory of media with conserved dislocations proposed by Lurie S.A. [1], is considered. Statement of the model differs from the known theory of the materials with voids by Cowin and Nunziato [2] in the modified boundary conditions, which take into account the influence of surface effects. The model is an analogue of the Gurtin-Murdoch theory of surface tension [3] for materials with voids.
The analyzes of the variational formulation of the model and the treatment of the additional physical surface modulus are given. It is shown that surface effects are relate to the formation of a new surface (opening or closing of the porosity at the surface of the medium).
The solution of the problem of the beam pure bending with surface effects is given. Unlike to the Cowin and Nunziato statement [2], the model assumes that the gradient of changing of porosity volume fraction on the surface of the beam is not equal to zero. This difference determined by the additional surface stresses and surface parameters in the model. The analytical solution of the problem is considered. The analysis of the stability of solution depending on the values of non-classical parameters is conducted. As an example, we consider the media with typical physical and mechanical properites corresponding to ceramics. Additionally, we investigate the possibility of simulation of the effect of porosity closing due to the prolonged or cyclic heating, which is typical for the operating conditions of ceramic materials. Thus, the model takes into account the impact of stress field and temperature field on porosity volume content. The dependence of the porosity on the temperature assumed to be known from experiment. As result of solving such problem the analysis of stress-strain state of the beam as a function of time or number of cycles of heating is given.

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GRAVITY DRIVEN GRANULAR FLOWS OVER A FLEXIBLE BASE

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We study gravity driven flow of dense granular media employing discrete element simulations on a flexible bumpy base as shown in fig.1. We have used linear spring dash-pot system [1] to model particle interactions. The flowing particles are considered to be spherical, smooth, inelastic and cohesion-less [2, 3, 4]. The same spring dash-pot model is used in between wall particles to incorporate flexibility in the base. This allows us to simulate deformation of continuous media by employing discrete element method [5, 6]. For this simulation, we have considered flowing particles to be stiffer than the base. Also the base particle's size is taken smaller than the size of flowing particles.
In this study, we simulate granular flows over flexible base as a first step investigating flow over conveyor belts. The dimensionless value of stiffness constant for flowing particles is taken to be 2×10^5 mg/d and that for base is 4×10^5 mg/d, which is the actual stiffness value of conveyor belt. The minimum tensile strength of the conveyor belt is used to limit flexibility of the belt [7]. For various values of base stiffness and its inclination, we find forces exerted by granular flow on the flexible base and how these forces influence the base. The effect of having flexible base on the flow of granular material is also explained by analyzing velocity profile, kinetic energy and granular temperature of the flow. These properties are later compared with well-studied flow over an inclined rigid plane [8, 9].

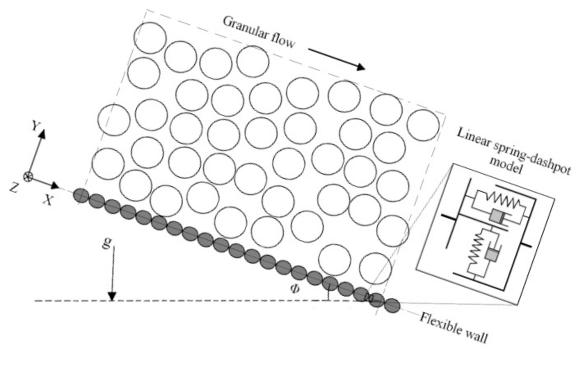

Figure 1: Granular flow over a flexible base.

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HYBRID GLOBAL OPTIMIZATION FOR COMPUTATIONAL DIAGNOSTICS OF HYDROMECHANICAL SYSTEM

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At the present time mathematical modelling is an integral part of most studies related to the safety and computational diagnostics of critical objects in the nuclear power industry. Main consideration is being given to problems of early detecting abnormal conditions of the coolant flowing throw the reactor primary circuit. Inverse problems of computational diagnostics are formulated for mathematical models of generalized gas-liquid flow. The relevant problem consists of studying the effects of the second phase inclusions on the dynamical characteristics of the flow. The solution of the problem suggests determination of anomalies in the state constitution of the coolant flow and location of corresponding gas-liquid area. As the normal state of the coolant and anomalous one are characterized by different spectra, then it is necessary to minimize simultaneously individual differences between spectral components. This is performed by use of numerical optimization methods. Incompleteness of measured spectral data and presence of multiple frequencies result in the error function of the extremal problem being non-convex and non-differentiable. Two novel hybrid algorithms with deterministic local search procedures for solving the corresponding global minimization problem are proposed. The first algorithm M-PCASGM combines the stochastic Multi-Particle Collision Algorithm (scanning the search space) and deterministic Smoothing Gradient Method (local search). The second algorithm M-PCADFPP implements the derivative-free proximal point (DFPP) method for local minimization. Results of successful computational experiments are presented to show the efficiency of the approach.

INTERNAL COMBUSTION ENGINE IGNITION OPTOELECTRONIC TRANSDUCER

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The invention refers to mechatronics, particularly, to contactless spark formation transducers and can be used in internal combustion engine ignition systems and other mechatronic systems of commutation, switch, distributors of automatic and remote control systems. Internal combustion engine ignition optoelectronic transducer comprises fixed stator and revolving inside it rotor. The stator is equipped with light source at its centre and n phototransistors uniformly distributed along the circumference, where n – the number of engine cylinders. The rotor bears cylindrical multislot shield periodically isolating the phototransistors from the light source. The special slot system allows providing:

1. permanent (uninterrupted in time) commutation between optical sensors,
2. multifold rotor rpm reduction and the same closed state time increase,
3. higher accuracy of the device,
4. reduction of vibration, heating and wear,
5. electrical and mechanical strength reliability.

AN ACCOUNT OF CURVATURE IN 1D HEMODYNAMICS MODEL

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Modeling of arterial wave propagation in large parts of arterial tree has a great value as source of knowledge about function of the cardiovascular system or prediction of the outcome of medical interventions. However, it is computational hard problem and with account of capability of actual computer systems, it can be solved only with reductive 0D and 1D models. In the latter compared to 0D model as like as topology a space shape of blood vessels (bends and forks) can be considered. However, the classic derivation of 1D hemodynamics equations is based on averaging in straight cylindrical segment. Assumed velocity profile in lateral section is critical at that, but even for most accurate approximations the results of 1D and 3D models turns out considerable different in the case of strong bending of vessel. In this study we consider more precise averaging of Navier-Stokes equation leads to dependence of solution on curvature of vessel. The comparison with classical 1D model as well as a validation by full 3D simulation was performed.

VIBRATIONS OF THIN ELASTIC BODY IN CONTACT WITH AN INCOMPRESSIBLE FLUID

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At the vibrations of plates and shells, which are found in contact with the liquid, the influence of liquid is connected, mainly, with an increase in the effective mass of system due to the apparent additional mass of liquid. Vibration damping due to wave emission is also possible. But if the liquid is located in the locked vessel and it fills with its pillar, then on the vibrations of walls of vessel are superimposed the limitation, which consist in the fact that the internal volume during vibrations does not change.

In the report the vessel in the form of the parallelepiped, one of faces of which is thin elastic rectangular membrane or plate, is examined, and remaining five faces are not deformed. Liquid is assumed to be ideal incompressible, and its motion be nonvortical. Vibrations are assumed to be small. The frequency spectrum of the free vibrations is built. Is investigated its dependence on the parameters of problem - the apparent additional mass of liquid, relationship of the sides of parallelepiped. The vibration modes of the membrane (or the plate) are found. The degenerate case, when apparent additional mass is not considered, however, limitation to the volume inside the vessel remains, is examined. The two-dimensional setting of the problem, with which the motion of liquid is plane, and the membrane or plate is substituted by string or beam is investigated . In all cases the exact solution, based on Rayleigh's method is constructed.

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STUDY THE INFLUENCE OF THE STIFFNESS OF THE LOADING SYSTEM ON THE SPACE-TIME INHOMOGENEITY OF SERRATED PLASTIC FLOW IN ALUMINUM-MAGNESIUM ALLOY

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The particular interest of researchers is related to the necessity of systematizing available data set and to obtain new knowledge on the special-time inhomogeneity of the plastic deformation of metals and alloys and to development of the test techniques of the complex experimental study of the effects of macroscopic localization processes of plastic flow.

The paper presents the results of the experimental study of the unstable plastic flow pattern evolution in the aluminum-magnesium alloy with allowance for stiffness of the loading system. It contains the data of the spatial-time inhomogeneity of plastic deformation due to the Lüders and the Portevin-Le Chatelier effects during uniaxial tension. There is shown the test procedure based on the use of the digital image correlation technique and the original specimens with complicated geometry. Two type of the specimens were used: the flat specimens with two L-shaped holes in the middle of the gage part, and the flat specimens with the additional deformable part. The special configuration provide managing the properties of the loading system. There were performed experimental studies of the specific features of plastic flow in the aluminum-magnesium alloy in dependence of the stiffness of the loading system from 55.8 up to 177.9 MN/m.

In this study, the 3-D DIC-measurement system Vic-3D [1-4] was used to estimate the inhomogeneous surface strain fields caused by the initiation and propagation of the strain bands. Mechanical tests were provided on the Instron 5989 electromechanical test machine at room temperature in conditions of kinematic and force loading.

Therefore, the test data (stress-strain curves, displacement and strain fields) illustrate the processes of the jerky flow, which are characterized by a high degree inhomogeneity of the strain fields by the existence of stages of relative levelling-off of the deformation over the specimen’s surface. The quasi-periodic character of the evolution of plastic deformation due to the PLC effect was analyzed [5, 6].

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THEORETICAL AND EXPERIMENTAL STUDY OF THE POSTCRITICAL DEFORMATION STAGE OF MATERIALS UNDER TENSION AND TORSION

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The paper is devoted to the theoretical and experimental investigation of materials behaviour on the postcritical deformation stage (or strain softening stage). This stage of deformation connects with dissipative processes of inelastic deformation, including the processes of structural failure and fracturing, and reflects on the deformation curve as descending section on a loading curve. On the postcritical deformation stage the formation of macro-destruction conditions takes place. These conditions, unlike the traditional view that defines the use of force or deformation criteria are not definitely related to the stress-strain state at the point of deformed body. During the transition from the equilibrium stage of damage accumulation to non-equilibrium stage of destruction, interaction of the deformed body with the loading system plays the key role. As a result, based on loading conditions, each point on the descending section of stress-strain curve can correspond to the moment of the loss of load-carrying ability as a result of transitioning from stable to non-equilibrium stage of the damage accumulation process [1-3].

When postcritical deformation stage is taken into account in adjusted computation, it allows a reserve of constructions load-carrying ability to be revealed. Questions of theoretical and experimental study of postcritical deformation mechanisms of materials attract attention of researches in connection with the questions of use of the deformation reserves of materials, the rise of load-carrying ability and survivability of materials, and the analysis of possibilities of failure processes management [1-9].

Results, which confirm theoretical justification of influence of the stiffness of the loading system on the possibility of obtaining of descending sections of strain curves, were got in set of test group. Uniaxial tension tests of specimens with different stiffness were carried out. Moreover, special test tool with variable stiffness was used in tests. In those cases, we had different ratio of stiffness of specimen test part to stiffness of the loading system that includes deformable parts of test machine, specimen parts outside of test part. In proportional tension-torsion tests of thin-walled tubular specimens were obtained stress-strain curves with postcritical deformation stages in conditions of plane stress state. Various ratios of axial strain to shear angle were realized in tests. In addition, tension with torsion tests at room and high temperature (up to 800 °C) were carried out.

In the tests were used solid cylindrical and thin-walled tubular specimens of set of structural steels, such as steel 20 (GOST 1050-88), 40X (GOST 4543-71) and other. Tests were carried out in Center of experimental mechanics on Instron 8850 biaxial servohydraulic test system (maximum load 100 kN, maximum torque 1000 Nm, cyclic tests with frequency up to 30 Hz).

It is shown that, with sufficient stiffness of loading system, equilibrium postcritical deformation of materials is possible, and destruction moment on the strain softening stage depends on the stiffness of the loading system. The test results of elastoplastic and postcritical deformation of steels in conditions of plane stress state were obtained. It confirms the possibility of postcritical strain realization at different types of stress-strain state and allows obtaining new data for creating models of softening medium mechanics.

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HARDWARE-IN-THE-LOOP MODELING SYSTEM OF FLIGHT CONTROL OF THE SPACECRAFT "LUNA-GLOB" AT THE STAGE OF THE AUTOMATIC LANDING ON THE MOON

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The Russian space program lunar exploration involves automatic soft landing on the moon surface of the spacecraft (SC) "Luna-Glob". On-board control system of motion SC is created to implement this task. Integrated on-board computer system is processed measurements of two sets of inertial units, velocity and range Doppler devices. The output parameters of computer system are using for control of SC jet engines: correction and brake, two engines soft landing, four engines correction and stabilization and eight engines stabilization. The HILM system of flight control enabled to begin debug stage of the automatic landing software prior to the creation and assembly of complete sets of equipment SC "Luna-Glob".

STRUCTURE-BORNE WAVE RADIATION GENERATED BY OFFSHORE PILE DRIVING

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This paper describes a three-dimensional semi-analytical pile-water-soil interaction model that is developed for the prediction of structure-borne wave radiation generated by offshore pile driving. The pile is described by a thin shell theory and the hammer is substituted by a force applied at the head of the pile. The soil is modelled as a three-dimensional elastic continuum and the water region is described by the linear acoustic wave equation. The responses of the shell and the acousto-elastic domains are expressed in terms of a complete set of eigenfunctions which satisfy the boundary and interface conditions along the vertical coordinate. The displacement compatibility and the force equilibrium at the pile-water and pile-soil interfaces are satisfied by using the orthogonality relations of the acousto-elastic and shell modes. In this framework, the importance of the evanescent modes of the exterior to the pile acousto-elastic domain is also highlighted.
With the developed model, the structure-borne wave radiation due to impact pile driving is analysed. The wave field in the water domain consists of pressure conical fronts that are generated by the supersonic waves propagating from the top to the bottom of the pile. In the soil domain, both shear and compressional waves are generated, with the former being much stronger than the latter. *Scholte* waves are also generated along the seabed-water interface, which induce low-frequency pressure fluctuations in the water column close to the seabed surface. The energy launched by the hammer into the water and into the soil is investigated for different soil types. The present work aims to provide the scientific and engineering community with an in-depth physical understanding of the main sources that can possibly contribute to the underwater noise associated with pile driving in offshore environments.

SIMULATED NONLINEAR AERODYNAMIC EXCITATION OF A ROTATING AEROFOIL

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The aerofoils of offshore wind turbines are the largest rotating elements existing. The ongoing aerodynamic excitation makes these elements prone to fatigue, while maintenance is not easily executed, given the size and the hostile environmental conditions. Therefore, an accurate estimation of the accumulated fatigue damage during the design stage is required.
For a detailed analysis of the structure, use can be made of CFD techniques, which allow for the rotational and vibrational motion of the aerofoil in the unsteady airfield. Given the computational costs of this approach, a need exists for a computationally cheap alternative that can be applied preliminarily and would allow for a swift assessment of the involved dynamics. To this end, a boundary approach is adopted, which addresses the nonlinear aerodynamic interaction of the rotating blade with a given aerodynamic field.
The work presents a model of a rotating aerofoil excited by an aerodynamic forcing. The model accounts for the geometry of an actual aerofoil, including the lengthwise-varying pitch angle. Moreover, the model

explicitly accounts for the rotational velocity and an additional pitch to control the aerodynamic performance of the aerofoil. The aerodynamic forcing represents both nonlinear drag and lift, based on the relative motion of the air flow with respect to the moving blade, implying the explicit inclusion of the structural response velocity.
After reducing the model to its principal undamped eigenmodes the structural response to the aerodynamic excitation is assessed. Due to both the varying pitch angle and the force definition, the flap and edge wise motions of the aerofoil are coupled. Moreover, a linearized analysis reveals the coupling of the modes as a result of the apparent damping in the system, introduced by the aerodynamic interaction. By comparing nonlinear and linear time-responses, the level of nonlinearity is assessed.
Apart the estimation of the modal coupling and the nonlinear forcing contribution, the work provides a starting point for the analysis of the dynamics of the rotor. Such a study would provide valuable insight in the apparent damping of a wind turbine, based on which the dynamics of the complete structure can be better understood.

MODELING OSCILLATIONS OF RESONATORS BASED ON CARBON NANOWHISKERS

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Nowadays nanostrucrures become more popular because of the new technologies and possibilities. But this part of science is not discovered well. The kind of nanostructures investigated in this work could be used in medicine, microbiology and in nanoelectromechanical systems.
The aim of this research is to model dynamics of whiskers to find the best parameters for each kind of nanostructure. Knowing the best parameters can help to make nanowiskers more long and strong, also to find right shapes of complicated structures like scalpel, fork and tuning-fork.
Investigation consists of five parts: oscillations of mechanical systems with two degrees of freedom, longitudinal oscillations of carbon beams, modal oscillations of nanostructures, transversal forced oscillations of nanostructures, modeling of nanoscales. This work has been made using 3D simulations in ANSYS, analytical solutions for mathematical models and Java-script animation.

DERIVATION AND VALIDATION OF A DISCRETE MODEL FOR A VIBRATING PLATE, BASED ON MINDLIN-REISSNER THEORY

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This presentation discusses a discrete lattice model, consisting of masses and springs, that was derived to describe out-of-plane deformations of thick plates and which matches the Mindlin-Reissner plate theory in the long wave approximation. Bending, shear and torsion are taken into account. The lattice model is validated against an analytical evaluation of eigenfrequencies of the unloaded plate and deflection and rotation of the plate under sinusoidal loading.
Compared to continuum models, this lattice model has a great benefit in modelling of plate failure by removing connections such that there is no need for re-meshing. In addition, there are no stresses in the lattice model, only displacements and forces, and therefore infinite stresses near a crack tip do not occur.

METHOD FOR EXTRACTING EQUIVALENT WINKLER MODEL OF A 3D DYNAMIC SOIL-STRUCTURE INTERACTION MODEL FOR LARGE-DIAMETER OFFSHORE MONOPILE FOUNDATIONS

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The magnitude of both the soil stiffness as the soil damping used in the design of large-diameter monopile foundations for offshore wind turbines are believed to be underestimated. For the stiffness related part, the wind industry relies on the “p-y” method, which no longer holds for the applied rigid-behaving, non-slender piles. The fact that the observed fundamental frequencies of installed structures are higher than designed for, confirms the underestimation of stiffness associated with the p-y method comprises.
For the damping related part, being it a more complex mechanism, there is even more uncertainty. As a result, conservative low damping ratios are assumed during design. Although it is less straightforward to measure the damping of installed turbines, the published values range from a factor of 1 to 4 with respect to the value used in design. In the 1970s and 80s, empirical relations were derived based on more advanced 2D and 3D models, in combination with field tests and the previously mention p-y curves. Again, these relations are restricted to flexible piles, where the pile tip is assumed to be fixed.
To capture the interaction for the current pile dimensions, it is necessary to simulate the 3D interaction between the pile and the soil, and perform

full scale tests. The latter are not yet available, but results of a few campaigns are expected in the near future. For the purpose of physical insight and for engineering applications, it is useful to extract a 1D equivalent model that can mimic the 3D simulation.
In this work, a linear elastic dynamic 3D FE model of a pile-soil system is used to extract the frequency dependent displacements. The FE domain is surrounded with perfectly matched layers (PMLs) that absorb the propagating waves at the boundaries for the relevant frequencies of excitation. The soil properties of a design location are used, which have been identified using seismic measurements.
A method for the derivation of a 1D equivalent dynamic stiffness (i.e., a Winkler model with distributed springs and dashpots) is thereafter derived. The results obtained with the 1D model, match those of the 3D FE analysis.

BUCKLING AND SUPERCRITICAL BEHAVIOR OF AXIALLY MOVING PLATES

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We consider a flexible plate moving across a domain, bounded by two parallel lines. Velocities of the plate, with which it is entering the domain and leaving it, are kinematically prescribed and may vary in space and time. The deformation of the plate is quasistatically analyzed using the geometrically nonlinear model of a Kirchhoff shell with a mixed Eulerian-Lagrangian kinematic description. In contrast to the formulations, available in the literature, neither the in-plane nor the out-of-plane deformations are unknown a priori and may be arbitrarily large. The particles of the plate travel across a finite element mesh, which remains fixed in the axial direction. This is achieved by additionally introducing an intermediate configuration in the mapping of the position vector from the undeformed reference state onto the actual one such, that just the displacement in the axial direction differs the reference configuration from the intermediate one. Mapping from the intermediate configuration onto the actual one features the out-of-plane displacement of the plate as well as its motion in the transverse direction.
The evident advantage of the approach is that the boundary conditions need to be applied at fixed edges of the finite elements. In the paper, we present the mathematical formulation and demonstrate its consistency by comparing the solution of a benchmark problem against results, obtained with conventional Lagrangian finite elements. In particular, we consider buckling of a trapezoidal plate with kinematically prescribed displacement of the inclined edge.

NUMERICAL ANALYSIS OF TEMPERATURE DISTRIBUTION IN A LAYER HEATED BY THE SHORT LASER IMPULSE WITH REGARD TO A HEAT FLUX RELAXATION CONSTANT

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In this paper we propose a numerical study of the thermoelastic waves propagation described by the equations of the Lord-Shulman theory. This model belongs to a class of the hyperbolic systems. The generalized Fourier law that incorporates the rate of the heat flow change is used to obtain the telegraph type heat equation. This equation contains the wave term with the heat flux relaxation coefficient. The magnitude of the relaxation time by different estimates varies from 10-6 to 10-12, and determines the time required to form the thermal front. Taking into account the wave term eliminates the paradox of infinite speed of heat propagation. This model can be of a particular interest if the body is heated at a very high speed, or the heat sources have the nanometer scale sizes, or if the heated matter itself has the micro/nano scale. The unbounded slab is subject to a short-term laser impulse. The temperature at the unconstrained (or constrained) boundaries of the slab is kept constant (or the boundaries are thermally insulated). To obtain the numerical solution we use the explicit finite difference method. The problem is considered in the coupled and semi-coupled statements. We compute the propagation velocities of the heat and acoustic waves and its peak values with respect to the heat flux relaxation time. The numerical and analytical solutions demonstrate a good match.

MULTILEVEL MODELING OF DEFORMATION OF POLYCRYSTALS WITH A SMALL GRAIN SIZE UNDER COMPLEX LOADING

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Starting from the second half of the 20^{th} century, understanding of the necessity to register the condition of material internal structure for correct description of its behaviour at macroscale level during the operation has enhanced. In plasticity mechanics, the attention to multilevel models clearly describing condition and changes in the material internal structure has enhanced in the recent decades. In particular, the so-called crystal plasticity models of polycrystalline metals in terms of this approach have been intensively developing in the recent 20 years; these theories clearly consider physical mechanisms of deformation at lower-scale level rather than the representative macrovolume levels. Particularly acute problem of describing inelastic deformation arise in the study of materials with unique properties – submicrocrystalline, nanocrystalline materials, materials capable of superplastically deformed. For further behavior in the operation of such materials is essential complexity of the loading process in their manufacture and production. In addition, the development of technological modes of severe plastic deformation (SPD) requires formulating and solving the corresponding boundary value problems of solid mechanics.

The main objective of this work is to develop mathematical models that describe the evolution of the grain and the defect structure of polycrystalline metals under intense inelastic deformations in a wide range of impacts, including the complex loading programs, efficient numerical methods and algorithms for the implementation of the model for the study of material processing and related software. The specifics of the work is to study the features of the deformation of materials with low and ultra-low grain size, which imposes additional restrictions on the model and the requirements for accounting for material for this kind of material mechanisms of inelastic deformation, accounting for the influence of grain size on the elastic and elastic-material properties.

One of the most important deformation mechanisms, determining the material behaviour at macrolevel, is the motion and interaction of defects and formation of a developed defect structure (first of all, dislocation structure) in the deformation process. In constitutive models based on crystal plasticity, the defect structure evolution is reflected first of all in the so called hardening laws. It is due to primary importance of the defect structure evolution consideration in hardening laws that there are many different approaches to hardening description in reference materials, including the approaches developed within the framework of crystal plasticity.

The work continued on the increasing complexity and refinement of additional terms in the law hardening describing the formation of dislocation barriers as a result of reactions to split dislocations; the corresponding expressions are modified to take into account in their different strengths emerging barriers and possibilities of destruction last at an advanced stage of plastic deformation. The dependence of the elastic constants of the material on the grain size, this approach was used molecular statics, identified the physical dimensions of a single crystal (grain), with a further increase which will not be a change of the elastic characteristics. The influence of grain size on the strengthening, including investigated the relationship between the intensity of grain boundary hardening and typical grain size in polycrystalline, as a result was able to qualitatively determine the area of the Hall-Petch law compliance.

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MODELING OF THE FLOW IGNITION IN A PLANAR VORTEX CHAMBER

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The problem of construction of engine based on detonation phenomenon is one of the widely studied in many research centers all over the world. There are many technological and scientific aspects here. Vortex chamber is one of the engine parts. The stability of the flow in the chamber is often interrupted by gas mixture self-ignition observed in experiments, although the value of mean gas temperature in the chamber (after the passage of initial pulse) is essentially lower than the value of self-ignition. The reasons of the effect are not quite clear. The recent paper is devoted to theoretical and experimental study of the problem.

The numerical calculations of the flow field in a planar vortex chamber have been performed. The model is based on conservation laws of mass, momentum and energy for non-steady two-dimensional compressible gas flow in case of swirl axial symmetry. The processes of viscosity, heat conductivity and turbulence have been taken into account. It was found that transition of kinetic energy of gas into heat due to processes of dissipation generates “hot spots” in boundary layers at the chamber walls. The gas temperature at the spots may exceed the temperature of gas ignition (T =1200 K), while the surrounding regions remain still cold. It may be the reason of cold gas self-ignition observed in experiments.

To appreciate the influence of turbulence on the gas self-ignition, the numerical simulations of laminar flow were performed on the base of Navier-Stokes equations at the same initial values of the problem parameters. For laminar flows the mixture self-ignition may occur as well. Although the maximum value of temperature in laminar hot spot T = 1370 K is significantly less than turbulent T = 2110 K at the same instant. So the flow turbulence may play decisive role in possibility of gas self-ignition.

ON THE PULSE PNEUMATIC TRANSPORTATION OF METAL RADIOACTIVE WASTE MATERIALS AT ATOMIC ELECTRIC POWER STATIONS

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Metal particles (as fragments of constructional materials) form significant share in radioactive waste materials, formed in factories on regeneration of nuclear fuels. One of the consuming and dangerous operations in technological process is the operation on transportation of solid radioactive particles, as it is necessary to take into account the danger of materials to an environment and their harmful influence on health of the attendants and population. The various devices for transportation are used. However pipelines become the most popular transport of solid radioactive particles recently. Pneumatic transportation with the help of compressed gas pulse allows sharply to locate a zone of distribution of radioactive particles, safely deliver them to a burial place or containers and to improve sanitary - hygienic conditions thus.

In the paper a problem of metal particles movement in a tube under action of a pulse gas flow was numerically and experimentally solved. Comparison of computational and experimental data was carried out. On the basis of researches the optimum characteristics of the work of pulse pneumatic transportation of metal radioactive waste materials are determined.

Modeling was performed within the framework of model of non-stationary two-dimensional motion of ideal compressible media on the basis of laws of conservation of mass, pulse and energy in case of axial symmetry. The thermodynamic flow field has been computed both in gas and solid phases. Processes of particles mutual interactions, coalescence, fragmentation, interaction with a tube walls and motion have been investigated in detail. Interface borders have been considered as contact discontinuity surfaces, where a condition of a continuity of normal to the surface component of a flow velocity vector and the continuity of normal component of tension tensor were satisfied. Modeling was performed numerically on the basis of the method of individual particles. The comparison of the computational and experimental data confirms the reliability of numerical algorithm. The optimum pipeline parameters (optimum nozzle diameter is 37 mm, pressure of gas in receiver chamber is about 8 MPa) are determined, at which the effective pulse cleaning of pipelines from metal wastes with the least expenses is possible. It was found that series of pulses is more effective mode of transportation than a single pulse, having similar total power.

A CYLINDRICAL SURFACE WAVE IN A HALF-SPACE WITH MIXED BOUNDARY CONDITIONS ON ITS SURFACE

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In this work, the problem of cylindrical surface waves in an isotropic elastic half-space is investigated. We deal with the generalization of classical Rayleigh wave [1] to the three-dimensional case and use cylindrical coordinates. It is assumed that the surface is free of normal traction and shear traction in circumferential direction and fixed in radial direction. Unlike the case of free surface (see, e.g. [2]), the problem considered don’t allow to construct an exact solution in Bessel functions. To explain that fact we turn to the analogous problem in Cartesian coordinates, which is solved in [3,4]. The solution shows that in the case of mixed boundary conditions the velocity of the surface wave depends on the propagation angle. In the case of cylindrical waves this angle depends on radial coordinate. Thus, we must assume, that the velocity of the surface wave in the case under consideration depends upon the radial coordinate. Such a wave cannot be described in Bessel functions like the wave in the case of free surface. To show that the cylindrical surface wave exists also in the case of mixed boundary conditions we construct a short-wave asymptotics based on the idea of JWKB approximation. As a result, we obtain a dispersion equation that can be solved analytically. So we obtain the approximate velocity that tends to the velocity of the shear wave as radial coordinate tends to infinity, and to the velocity of Rayleigh wave as radial coordinate tends to the turning point. This result corresponds to the dependence on the propagation angle for the waves with plane fronts [4]. The numerical data for the velocity and form of the found wave are presented.

The other case, when the boundary is free of shear traction in radial direction and fixed in circumferential direction, is investigated analogously.

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FATIGUE AND STRESS ANALYSIS OF COMPRESSOR BLADE SUBJECTED TO RESONANT VIBRATIONS

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In this work the crack propagation analysis of the compressor blade of aero engine was performed. During investigations the blade with mechanical defects (notch) was considered. In experimental analysis the blade was subjected to resonant vibration. During transverse vibrations, a high stress occurs in the blade. Pulsation of stress causes the fatigue of material. In results of proposed investigations the crack growth dynamics will be obtained for the blade working in resonance condition. Moreover the stress distributions in the vibrated blade were determined.

High-cycle fatigue (HCF) is often concerned with vibration of aero engine components. Compressor blades have a small bending stiffness and are particularly susceptible to HCF. During work of engine, blades are excited by an unbalanced rotor. The worst case is when the frequency of excitation overlaps with the resonant frequency of the blade. During resonance, large amplitude of stress causes the damage of the blade in relatively short time. The fatigue process is often accelerated by mechanical defects (notches) created during collision of rotated blade with hard objects suctioned from a ground. If a problem arises in the compressor section it will significantly affect the whole engine function and safety of the aircraft.

The broken blade could cause the puncture of the engine casing. Failures of any high speed rotating components (jet engine rotors, centrifuges, high speed fans, etc.) can be very dangerous to passengers, personnel and surrounding equipment and must always be avoided. The failure analysis of the compressor blade has received the attention of several investigations. The problem of fatigue fracture of the aero engine blades was described in the works [1-10].

The objective of presented investigation is to determine both the number of load cycles to crack initiation and also the crack growth dynamic for the compressor blade of aero engine (including artificially created mechanical defects), subjected to resonant vibrations. Created defects (notches) simulate the foreign object damage (FOD) of the blade. An additional aim of work is numerical determination of maximum principal stress values in the blade with the notch subjected to resonant vibration.

The high cycle fatigue tests of the blade were made using the Unholtz-Dickie UDCO TA-250 electrodynamic vibration system at Laboratory of Turbomachinery of Rzeszów University of Technology. In investigated blade a V-notch was created. The depth of notch was about 0.5 mm whereas the apex angle 90 degrees. The notch was located 3 mm above the blade lock.

The blade with a notch was horizontally mounted on the movable head of vibrator. Next the head of shaker was entered into harmonic vibration. The amplitude of blade tip (A=1.2 mm) was constant during main part of fatigue test. In the first step of analysis the resonance frequency was determined (for first mode of transverse vibration). During investigations two main parameters were periodically monitored: vibration amplitude of the blade tip and the size (or existence) of the crack. For control of amplitude the laser scanning vibrometer POLYTEC PSV H-400S were used. A nondestructive fluorescent penetrant method was utilized to measure the length of the crack.

Obtained results of experimental investigations showed that the blade with v-notch created by machining, needs $N = 12\times10^6$ total number of load cycles to crack initiation. The crack propagation process was much shorter. The crack needs $N = 1.87\times10^6$ number of load cycles for propagation from length a = 0 to final crack size a = 19 mm (at which the blade was broken). Thus, in presented case the crack initiation process ($N = 12\times10^6$) is a main part of fatigue life of the blade ($N = 13.87\times10^6$).

For definition of stress state in the blade subjected to HCF, the finite element analysis (FEA) was performed. In this analysis the first mode of transverse vibration was considered. To solve this problem, the Patran program was used for both geometrical and the finite element model preparation. In the notch vicinity the finite element mesh was concentrated. In the next part of work, ABAQUS software was used for stress and modal analysis of the compressor blade. The results of FEA showed that during the first mode of resonant vibration the blade is subjected to cyclic bending. All numerical results are obtained for constant vibration amplitude (A = 1.2 mm) and for a left blade deflection at which the maximum principal stress in the blade was observed. Results of numerical simulation showed that value of maximum principal stress in the zone located near the attack edge of blade is about 225-280 MPa. The area of maximum stress (771 MPa) is located in the notch vicinity. Maximum principal stress values in cross-section of blade (in fracture plane) showed that during left blade deflection the tension stress occured in the zone near concave surface of blade. Just in this region the crack propagate more quicly than in convex profile area. Obtained results of FEA showed that cyclic tension stress in blade cross section is a main reason for crack initiation and crack propagation of the blade subjected to resonant vibration.

In this study the experimental analysis was performed to investigate both the crack initiation and the crack propagation process of compressor blade with preliminary defect. This mechanical defect simulates the foreign object damage. The complex experiment was performed in resonance condition. In experimental investigation a modern vibration system and the laser scanning vibrometer were used. Moreover, in this paper the finite element analysis was used for stress calculation in the blade subjected to resonant vibrations.

As a result of performed work, the following conclusions were formulated:

1. Foreign object damage is very dangerous for the compressor blades. In most cases defects obtained in results of FOD (as V-notches) are potential crack origins. After phase of initiation, the crack propagates from notch inside the structure in relatively short time.
2. The crack in the blade working in resonance conditions (first mode of vibrations, A = 1.2 mm) initiates after about $N = 12\times10^6$ total number of load cycles.
3. The crack needs $N = 1.87\times10^6$ number of load cycles for propagation from length a = 0 to final crack size a = 19 mm (at which the blade was broken).
4. The crack initiation process (number of cycles for initiation of crack from a = 0 to blade damage) is a small part (about 13.5%) of total fatigue life of blade ($N = 13.87\times10^6$).
5. Maximum principal stress area in the blade is located on tip of notch. In the blade vibrated with amplitude 1.2 mm a maximum stress on the notch has a value of 771 MPa. This value is close to yield stress of blade material.
6. Maximum principal stress value (for left deflection) in the blade without defects is about 3 times lower then the local stress in the notch.

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STARTING OF VIBRATING MACHINES WITH UNBALANCED VIBROEXCITERS ON SOLID BODY WITH FLAT VIBRATIONS

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Expressions for vibration moments (additional dynamic loading caused by the vibrations of bearing body) during the passage of resonant zone by vibration machines with the flat vibrations of bearing body both with one arbitrarily located vibration exciter and with two self-synchronization vibration exciters for the different modes of starting are got in an analytical form by method of direct division of motions. Using approaches of vibration mechanics of I.I. Blekhman possibilities of improvement of process of running approach of vibration machines with unbalanced vibration exciters are demonstrated by using of methods the "double" (in case of one vibration exciter) and "separate" starting of electric motors (in case of two vibration exciters). It is shown that the first method is based on using semislow vibrations arising in the resonant zone. The necessary condition of the successful using of this method is motion on the rotor of exciter in the moment of the repeated including of engine of rotary-type vibration moment. The conditions when the separate starting is effective are shown. Conclusions and practical recommendations that allow to facilitate starting of vibration machines with an unbalanced drive are pointed.

THE STRONG AND THE WEAK FORM OF THE INITIAL BOUNDARY-VALUE PROBLEM FOR THE LINEAR REDUCED COSSERAT CONTINUUM

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An interest in the study of granular media has increased in recent decades: development of nanotechnology has become possible to create new artificial bulk materials, exposing a significant gap between the technology of new materials and possibilities of the theoretical prediction of their physical and mechanical properties. An introduction of these materials into practice requires knowledge of the dependence of physical and mechemical properties of the material from their

microstructure. One of such media is the reduced Cosserat medium.
It looks reasonably to use the reduced Cosserat continuum to describe granular materials. In this type of medium grain's size and a nearest-neighbour distance are roughly comparable, rotational degrees of freedom must be considered along with the translational. Grains have an ability to move one relative to the others like a liquid and couple stresses are not created inside the material. So in the reduced Cosserat continuum couple stress tensor is equal to zero in contrast to the classical Cosserat media.
The main goal of this work is to present the variational and strong forms of the initial boundary-value problem for the linear reduced Cosserat continuum and to prove the uniqueness of the solution of the problem.

FROM LOCALIZATION TO ZOO OF PATTERNS IN COMPLEX DYNAMICS OF ENSEMBLES

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A fast and efficient numerical-analytical approach is proposed for modeling the complex collective behaviour in complex plasma physics models based on the BBGKY hierarchy of kinetic equations. Our calculations are based on variational and multiresolution approaches in the bases of polynomial tensor algebras of high-localized generalized coherent modes generated by action of the internal hidden symmetry of the underlying functional space. We construct the representation for hierarchy of reduced distribution functions via multiscale decomposition in high-localized eigenmodes. Numerical modelling shows the formation of zoo of various internal symmetry-generated structures (patterns) which describe the (meta)stable/unstable type of behaviour in non-equilibrium ensembles.

A NEW MODEL OF FRACTURE WITH A CURVATURE-DEPENDENT SURFACE TENSION

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A new model of fracture mechanics which takes into account interfacial effects due to a curvature-dependent surface tension will be considered. This model is based on a physically valid assumption that the behavior of molecules near a surface of a material is significantly different from those in the bulk and depends on the local curvature of the material surface. The theory will be presented through several examples: a curvilinear non-interface and interface crack, and contact problems for a rigid stamp indentation into an elastic half-plane. It will be shown that the incorporation of surface effects on the crack boundary eliminates the power and oscillating singularities at the crack tips which are predicted by linear elastic fracture mechanics. The mechanical problems will be reduced to the systems of singular integro-differential equations. The regularization and numerical solution of these systems will be addressed and numerical examples will be presented. Potential direction for future research and connections with experimental results will be discussed.

MODELLING OF STENT DEPLOYMENT AND DEFORMATION IN DISEASED ARTERIES BY CONSIDERING VESSEL ANISOTROPY

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Experimental studies on human arteries highlighted the anisotropic behaviour of biological tissues [1]. State of the art of arterial constitutive modelling suggests the use of hyperelastic anisotropic models in computer simulation of stent deployment in diseased arteries. However, anisotropic hyperelastic models have seldom been used to simulate expansion and deformation of stent-artery system, and existing studies are dominantly limited to the use of isotropic models. In this paper, finite element simulation of stent deployment was carried out using an anisotropic model for the artery. In particular, the artery wall was considered to consist of three individual tissue layers, i.e., intima, media and adventitia. Each layer was modelled as a hyperelastic anisotropic material described by the Holzapfel-Gasser-Ogden (HGO) model [2]. The model parameters were calibrated against the experimental stress-stretch responses in both circumferential and longitudinal directions [1]. The results showed that, at the peak pressure, stent expansion obtained using the anisotropic model was much reduced when compared to that obtained using the isotropic model. However, after deflation, the finally achieved diameter for the anisotropic model is larger than that for the isotropic model, due to the significant reduction in recoiling for the anisotropic model. Also, the anisotropic model generated slightly higher levels of stress in the artery and the plaque than the isotropic model. High stresses were mainly located in the intima and adventitia layer as well as on the stenotic plaque surfaces. The media experienced the lowest stress level due to its relatively softer stress-strain response in the circumferential direction. Following deployment, deformation of the stent was also modelled by applying relevant biomechanical forces, such as bending, torsion and radial compression, to the stent-artery system. The results were utilised to interpret the mechanical performance of stent after deployment. In summary, it is strongly recommended to take into account the layered structure of the artery and the anisotropy of each layer to model expansion and deformation of the stent-artery system.

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AN EXPERIMENTAL STUDY OF MECHANICAL BEHAVIOUR OF POLY-LACTIC ACID (PLA) FOR STENT APPLICATION

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Biodegradable polymers have been widely studied for medical applications either in drug delivery system or bio-resorbable stents due to their biocompatibility and biodegradability. With considering the widely application of Poly (lactic acid) (PLA) in medical implants in the form of screws, plates, pins and rods, this research aims to understand, characterize the biomechanical behavior of PLA through processing and testing for stent application.

Uniaxial tensile tests were performed under different strain rates (1 s^{-1}, 0.1 s^{-1}, 0.01 s^{-1}, 0.001 s^{-1}, and 0.0001 s^{-1}). Creep tests were conducted at two different constant applied stresses (30 MPa, 40 MPa) at the loading rate of 1 MPa/s, and stress-relaxation tests were carried out with applying three different constant strains (0.01, 0.015 and 0.02) on the specimens at the loading rate of 0.01 s^{-1} for 200 minutes. Cyclic tests were performed to understand the deformation behavior of PLA under cyclic loading conditions: For load-controlled tests, three different stress ratios (0, 0.2 and 0.5) were considered while maintaining the maximum stress level at 40 and 50MPa, respectively. For strain-controlled tests, two different strain ratios (0.2 and 0.5) were considered while maintaining the maximum strain level at 2% and 3%, respectively. In addition, a multiple-step cyclic test was carried out by increasing the maximum strain level at each cycle while maintaining the minimum stress level at 0.1MPa.

The tensile stress-strain curves show that the strain rate has an effect on the stress-strain behavior of PLA, demonstrating the time-dependent deformation nature of the material that an increase of stress with the increase of strain rate. The creep curve under 40 MPa stress loading show all three stages of creep deformation but it broke around 3 hours. The stress-time curves show a rapid stress relaxation at very early stage, then the progressive drop of the stress as a function of time and finally tend to reach a saturation stage. The stress-strain loops show the strain ratcheting behavior that there is the accumulation of strain with the number of cycles; furthermore, the effect of stress ratio on strain accumulation is identified. The stress-strain loops indicate the tensile stress decreases with the increase of number of cycle. The multiple-step cyclic test result proves the behavior of cyclic plastic deformation at variable strain ranges, although very limited.

3D SCATTERING OF SEISMIC WAVES AT A CYLINDRICAL CAVITY IN AN ELASTIC HALF SPACE

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This paper addresses the wave scattering at an infinitely long cylindrical cavity in an elastic half-space. The cavity has a uniform cross section and its axis is parallel to the half-space surface. Excitation is considered by both the body and surface waves. The incidence angle is assumed to be arbitrary with respect to the axis of the cavity, which means that a three-dimensional scattering has to be considered.

The total wave field in the medium consists of the incident, reflected and scattered waves. The part of the scattered waves generated at the free surface are simulated using the image technique; i.e., through waves that propagate from the image of cylindrical cavity.

As the half-space and cavity surfaces possess different symmetries, the problem is not straightforward. In order to circumvent this difficulty, the physical domain is conformally mapped onto an auxiliary domain with a cylindrical symmetry, in which the half-space surface and the cavity surface are located at concentric cylindrical surfaces.

The solution of the original boundary value problem is finally obtained by solving a set of algebraic equations, and the convergence of the solution is tested. The accuracy of the present method is verified by comparing the numerical results with those available in the literature. Displacements and stresses are computed to investigate the effect of the depth of the cavity, and the frequency and the angle of the incident wave on the response of the half-space and cavity surfaces.

The presented method is semi-analytic, aimed at a significant reduction of the computational time and development of an unconditionally stable computational procedure.

THE EFFECT OF A FLUID STRATIFICATION ON THE LOW-FREQUENCY VIBRATIONS OF A SEMI-INFINITE FLOATING ELASTIC PLATE INTERFACED WITH A RIGID VERTICAL WALL

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To describe interaction of water waves in ice-covered stratified ocean with off-shore structures we consider a semi-infinite thin elastic plate of uniform thickness floating upon a two-layer fluid and interfaced with a rigid vertical wall. The upper layer of lighter (fresh) fluid is of finite thickness and lies on the surface of the main heavier (salty) fluid. Flexural-gravity waves of a low frequency and of a small amplitude propagate along the interface between the plate and the upper fluid layer and reflect from the rigid wall. We study the influence of the upper fluid layer on vibrations of the floating plate. Exact analytical solutions for the wave motion in the plate and in the fluid are found. The method of the derivation have been put forward in our paper [1]. The results received for various plate-wall junctions are compared with each other. The geometry of the model is shown in the Figure 1.

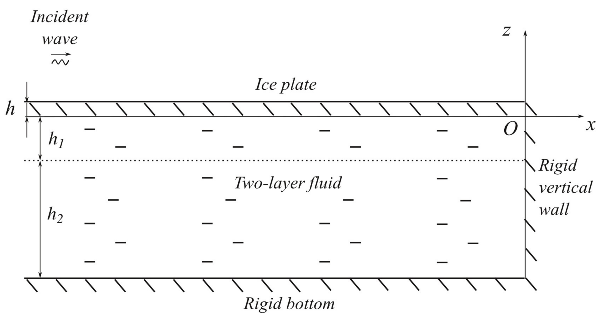

Figure 1

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CELLULAR AUTOMATA SIMULATION OF MICROSTRUCTURE EVOLUTION IN ADDITIVE LAYER MANUFACTURING PROCESSES

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Additive layer manufacturing (ALM) is a relatively new technology that has a potential to revolutionize many industrial fields (as, for example, aerospace, automobile industries) by reducing a component cost, lead time, material waste, etc. Currently ALM is not widely used due to several drawbacks induced by this method. One of the main problems is reported to be a wide heterogeneity of mechanical characteristics of structural components, which is associated with the heterogeneity of the grain structure at the mesolevel. In order to optimize the ALM technology, a thorough analysis of microstructure evolution in ALM processes is necessary to be done.

This work deals with the simulation of 2D polycrystalline structure evolution influenced by the thermal front during selective laser melting (SLM). For this purpose, a model based on the approach of Rappaz and Gandin was developed by implementing and coupling a cellular automata (CA) and finite difference (FD) methods. The implemented algorithm includes the following procedures: (i) calculation of the temperature field; (ii) grain nucleation; (iii) calculation of the solid phase increment. The grain growth algorithm is modified in such a way as to reduce the mesh anisotropy. When the whole computational domain becomes solid, we consider it as a polycrystalline substrate used in additive manufacturing. Then a focused beam of a high-power laser is considered generating a molten pool and melting injected powder, and we simulate microstructure evolution under these thermodynamic conditions. To describe a heat flow given by the focused laser heat source, we use the heat source model proposed by Goldak et al.

Using the approach developed, we simulated grain growth in SLM process, studied the effect of different depth of molten pools on grain morphology and analyzed the texture formation process. We considered the cases when a molten pool has the same horizontal coordinate during all laser passes across 2D plane and when a molten pool shifts horizontally. The simulation results were compared to experimental data, and found to be in good qualitative agreement.

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MECHANICAL ASPECTS OF MESOSCOPIC SURFACE ROUGHENING IN LOADED POLYCRYSTALS

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Heterogeneous plastic deformation is known to give rise to roughening at the free surface of loaded polycrystals. Evolution of the surface at the meso level, where the surface roughness is formed as a corrugation, ridging, roping, and quasi-periodic distribution extrusion and intrusion areas plays a particular role. The purpose of our study is to investigate the main aspects of the surface roughening in terms of mechanics and effect of

microstructure (texture, grain size), surface hardening and loading conditions on this phenomenon.
Construction of a microstructure-based constitutive model includes the microstructure design and development of constitutive relations for grains of polycrystal. We use a finite-difference model [1] where elastic properties and yield stress of grains vary to take into account the material inhomogeneity. Grain aggregates have been designed using SSP-method [2]. We consider aluminum alloy and steel as materials under study.
Stress-strain state responsible for the out-of-plane displacements on the free surface is analyzed. The conclusion is drawn about the stress tensor components that give rise to the surface roughening in polycrystalline materials. Dependencies of the surface roughness characteristics on the grain size, material texture, hardened surface layer, and loading conditions are established. Analysis of the stress-strain state is performed for all these cases. In order to evaluate the grain size effect on the roughness, the statistical analysis is performed. The simulation results are compared to experimental data and data reported in literature. Also we carried out numerical simulations using a simplified 2D single-inclusion model. Dependencies of the shape and amplitude of the surface roughness on the orientation, location relative to the free surface, and ratio of the elastic properties of the inclusion and matrix are determined. Reasons of the dependency characters are analyzed in terms of mechanics.
Support of Russian Foundation for Basic Research (Grant No. 14-08-00277-a) and a program to increase the competence of Tomsk Polytechnic University is gratefully acknowledged.

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MICROSTRUCTURE EFFECT ON DEFORMATION AND FRACTURE IN A MATERIAL WITH CERAMIC COATING

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The aim of the work is to investigate stress-strain localization and fracture in steel with ceramic coating. The simulated microstructure of the coated material (i.e. pores in coating, grains in substrate, and curvilinear coating-substrate interface) corresponds to that produced experimentally and is accounted for explicitly in the calculations. Polycrystalline microstructure generation model based on the cellular automata method was developed. The initial curvilinear finite-difference mesh was created using the original algorithm we developed previously [1]. The dynamic boundary-value problem in plain strain formulation was solved numerically, using the finite-difference method [2]. To simulate the mechanical responses of the substrate material, use was made of an elasto-plastic model accounting for isotropic strain hardening. To take into account the grain size effect on the initial yield stress, we used Hall – Petch relationship. To describe the fracture of the coating material, use was made of a maximum distortion energy criterion that accounts for crack initiation and growth in local regions experiencing bulk tension. Deformation and fracture of four specimens with an average grain size of 2, 5, 15, and 30 μm are investigated numerically. In the case of tension or compression, cracks are found to originate in the local regions experiencing tensile loading. For all types of loading, homogenized tensile strength values for the specimens with smaller grains are higher than those for the specimens with larger grains. In the case of compressive loading to the coating surface, the grain size contributes significantly to the coating fracture. The coatings of the specimens with larger grains (15 and 30 μm) fail and lose the functional properties at significantly larger deformation than those of the specimens with smaller grains (2 and 5 μm).

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MECHANICS OF CELESTIAL BODIES: AN OLD BUT LONG NEGLECTED BRANCH OF THE MECHANICS COMMUNITY PROPER

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Mechanical models describing the motion and deformation of the Earth, i.e., its spin, nutation, precession, self-gravitational state, and ellipticity have been presented for more than 400 years. This paper will look into their history and show that many issues are still under discussion today, in particular from the viewpoint of modern mechanics research.

Newton himself treated the problem of the precession of the Earth, a.k.a. the precession of the equinoxes, in Liber III, Propositio XXXIX of his Principia [1]. He takes the contribution due to the Sun and to the Moon into account and predicts a total duration of ca. 26000 years. This agrees fairly well with the experimentally observed value. However, the details of Newton's calculations remain obscure. Thankfully Chandrasekhar reveals them in Chapter 26 of his annotations to Newton's book [2]. He follows an approach suggested by Scarborough [3] starting from Euler's equations for the gyroscope and calculating the torques due to the Sun and to the Moon on a tilted spheroidal Earth. These differential equations can be solved approximately in an analytic fashion, yielding Newton's result. However, they can also be treated numerically using a Runge-Kutta approach allowing for a study of their general non-linear behavior. This paper will first show how and explore the intricacies of the numerical solution. A comparison the actual to actual measurements will also be attempted.

A second issue addressed in this paper concerns Earth's deformation due to self-gravity and rotation. It turns out that during modeling of the motion of the Earth's axis, the so-called flattening is a crucial parameter. We define the term "flattening" as the difference between the equatorial and polar radii of the Earth normalized by the equatorial radius. It can either be measured or predicted by means of suitable models for the spinning Earth. Newton was probably the first who suggested modeling the Earth as a liquid sphere, which during stationary spinning assumes the shape of an ellipsoid. However, in his famous Principia [1] he describes his method only verbally. Chandrasekhar [2] attempts to explain Newton's ideas in modern mathematical language and points out the various approximations. Modern fluid mechanics textbooks elaborate on this problem in their sections on rotational hydrodynamics, e.g., [6]. Alternatively to the fluid model the rotating Earth can be modeled as a Hookean solid. Thomson and Tait [7] were seemingly the first to report corresponding results, albeit in a rather archaic notation of linear elasticity. Finally, Klein and Sommerfeld compiled results from both models in their treatise [8]. In this paper we will first give a critical overview of the historical development regarding the modeling of Earth's flattening. Moreover, a complete, modern treatment of the fluid model, and its application not only to the Earth but also to other celestial bodies will be presented. We will compare the results to actual measurements and discuss reasons for discrepancies. Then we shall deal with the Hookean model of the Earth, which we will also state and solve in modern terminology. In particular, we will not only compute the flattening but also present a complete solution for the stresses in a self-gravitating and stationary spinning, linear-elastic sphere. We will discuss possible extensions of the models, such as a Hookean hollow sphere with a liquid core, or even more complicated onion-layered type of models. The discussion and outlook section of this paper is devoted to nonlinear theories of deformation, which will be presented in detail in another paper of these proceedings.

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NONLINEAR WAVES IN SQUARE LATTICE MATERIALS

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The purpose of this paper is to describe the dynamics of plane waves in the material that can be considered as a square lattice with the same type of particles at the micro level. We examined two types of square lattice: simple and stable, for which the equations of motion had been derived.

The dispersion analysis allows to select high frequency and low frequency oscillation spectra of particles. In the case of low-frequency oscillations, the graph of particles' displacement depending on time represents a smooth curve. In this case, the equation can be obtained by Taylor series expansion. This approach is called one-field model.

In the case of high-frequency oscillations the dependence of the displacement on the time is a rapidly varying function, so a standard procedure of the series expansion is not possible. However, if one divides all particles into even and odd and considers oscillations of these groups separately, Taylor series expansion will be feasible for each of them. This approach is called two-field model.

When the motion of particles in crystal lattices is examined, all particles are considered as mass points

connected with linear springs.
As a result of the research the equations of the plane waves propagation in materials with a square crystal lattice were obtained. The cases of long and short wavelengths were considered separately, and the research has shown the one-field model to be effective in the first case, and two-field model - in the second case. The comparison of the results obtained for stable and unstable lattices showed that qualitative differences in the solutions hadn't been observed.

INELASTIC DEFORMATION FLEXIBLE GRAPHITE O-RING SEALS AND SEAL PACKS UNDER THEIR EXPLOITATION IN STOP VALVES

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Flexible graphite (i.e. FG) is a unique composite material with temperature-independent high thermo-chemical durability, low coefficient of friction and high elastic properties. FG seals are easily breaking-in without erosive affection on the contact metal surfaces, fit for multifunctional usage in high-corrosive and high-reactive gas (i.e. oxygen, nitrogen, hydrogen, etc.) and fluid (i.e. solutions of acids, alkalis and salts, organic solvents, petroleum and petroleum derivatives, sweet and sea-water, etc.) media. FG o-ring seals and seal packs have high reliability, they do not require additional hermetization during long-term usage and work at temperatures up to 560 °C with pressures up to 40,0 MPa. Currently FG o-ring seals are greatly used in aerospace, metallurgical, oil-and-gas and chemical plants, power industry facilities, housing and communal service companies. Traditional experimental schemes (i.e. full scale in-situ experiments with structures and prototypes) for the development and optimization of seals are unreasonable due to a high risk of accidents with serious environmental and economic damage. Therefore, mathematical modelling makes it possible to predict thermophysical and mechanical properties of FG, describe mechanical behaviour and optimum design of o-ring seals and seal packs corresponding to survivability and safety usage.
A thermomechanics model for initial operation mode description of large-scale production seals (intended for plunger seal in the stop valves) is developed with the account of a cylindrical nature of anisotropy type of FG, obtained experimental data and results of numerical predictions by modification of particle method for elastic, friction, strength and thermophysiccal characteristics of FG. It was supposed that o-ring seal is a thick-walled, limiting homogeneous transversally-isotropic cylinder fixed in a oil-seal housing by sealing bush (i.e. in all points of an external surface radial, hoop and axial displacements are dropped out). On one of the end surfaces hermetization pressure has been set from a sealing bush, and on the other end surfaces – work pressure. Axial displacements that modelled plunger reciprocation in burn-in regimes in the direction of a closing ring and in the opposite side have been set on the internal lateral surface. The quasistationary mode of o-ring seal behaviour assumed absence of FG entrainment which was modelled by the set of the friction law for contact surfaces in the form of proportionality between radial and shear stresses. With consideration of given conditions analytical solutions for boundary-value problems have been received and stresses, strains and displacements have been defined.
The influence of thermoforce loading conditions on the character of stress-strain distributions along cross-sections of o-ring seals and seal packs has been investigated by the use of numerical FEM solutions of 3D stationary boundary-value problems. Calculations have been made of estimation of real damage mechanisms (i.e. damage from tension or compression in radial, hoop and axial directions, and from transversal and antiplane shear) affection on initial strength, of a comparison of different loading modes (i.e. reciprocating motion in sealing bush or opposite direction, and torsion of the rod), height and conditions on contact surfaces (i.e. ideal contact, friction or slip) between seals on the maximum values of radial, hoop, axial, and shear stresses.
The locations of damaged domains (i.e. red zones at Figure 1) obtained from computational experiments correspond with the results of o-ring seals experiene. That allows us to define an optimum hermetization pressure, justify recommendations to modify existing structures of o-ring seal packs and develop engineering techniques for refined strength analysis.

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PROBABILISTIC METHODS FOR THE ANALYSIS OF RANDOM STRESS AND STRAIN FIELDS IN 2D AND 3D MATRIX-INCLUSION COMPOSITES AND POROUS SINTERED POWDER MATERIALS

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Prediction of the effective deformation properties and definition of the statistical characteristics of random structures, stress and strain fields at components of fibre- (2D) and particle-reinforced (3D) matrix-inclusion composites and porous sintered powder materials are connected to finding the solutions of stochastically nonlinear boundary-value problems using various hypotheses on character of collective multiparticle interaction in the ensemble of reinforcement aggregates and porous. The conditional and unconditional multipoint correlation functions (CF) of different orders for random structures and elastic modules are required for construction of approximate solutions of the problems. Usually calculation of CF follow the 'traditional' algorithms which used to plot these functions experimentally by processing of microslices of fibreglass plastics. Realization of the algorithms have been supposed to usage of an additional co-ordinate net, definition of belonging each point of the net to one of the composite phases and required significant hardware and software cast even in the case of realization of height-performance parallel computational procedures. The results of CF calculation, which carried out on the height-performance cluster of Perm National Research Polytechnic University (64 nodes with peak performance up to 4,096 TFlops and total memory 12 Tbytes) have shown, that usage of 4 nodes (each node contains 2 Barcelona–3 processors) have been reduced the total solution cast up to 6 times and further increasing the number of nodes is inappropriate.

The new method for analytical calculation of CF for random structures, stress and strain fields in 2D and 3D matrix-inclusion composites and porous sintered powder materials was developed on the basis of the proven theorems for geometric sense of conditional probabilities. The general regularities of random fields were detected. Theorems on the derivative sign of conditional and unconditional correlation functions of the second and third orders at the points corresponding to zero values of arguments, and on the local isotropy of random fields were formulated and proved. Obtained derivatives, which are defined by a ration of the measures for the interphase surface and for the fragment, could be considered as one of a possible conditions for verification and a rejection of existing and developed models for random-structured media.

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INELASTIC DEFORMATION, STRAIN-SOFTENING, LOCALIZED FAILURE AND DILATATION IN SANDSTONE MEDIA UNDER TRIAXIAL QUASISTATIC LOADING

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The investigation of inelastic deformation and failure of sandstones is associated with the necessity to develop mechanical models for the correct description of the behaviour of damaged heterogene-ous rock media. Besides, there is a need to improve the procedures of strength analysis in order to take into account actual loading conditions and the evolution and character of the collective interaction in a system of defects which determines the instant of macrofailure, when the damage accumulation becomes unstable. Without understanding the regularities and mechanisms of damage accumulation, without evaluating its stability and determining the conditions of localization begining, the macrofracture of sandstones will remain latent and poorly predictable phenomenon of internal structure evolution of the heterogeneous rock media.

The two-level-phenomenological structural model for brittle sandstones was developed with the aim to study the character of collective multi-particle interaction in the defect ensemble, the general laws and the change in failure mechanisms and scale levels of damage evolution under combined triaxial quasistatic loading. A partial or complete loss of load-carrying capacity by structure elements is connected with violation of strength conditions and, as consequence, with jump-like changes of deformational characteristics. The model allowed us to describe the inelastic deformation accompanied by inclination and coarsening of defects as a multistage process of damage accumulation and to determine the instant of macrofailure of rock media as a result of loss of stability of this process. In the course of computational experiments, we found and analyzed such regularities of mechanical behaviour of sandstone media as the strains corresponding to the instant of macrofailure and the character of damage evolution in relation to the stiffness of the loading system, the effect of lateral pressure on strain-softening, the dilatation under uniaxial compression, the unequal resistance of heterogeneous bodies, and the self-supported accumulation of defects.

A nonlocal critical dimensional lengths constant for damaged solids is found to exist, which does not depend on the type of stress-strain state and quasistatic proportional. The constant determines the instant of transition from the stage of accumulation of disperse damage to a localized failure and to the strain-softening. The new nonlocal criterion allow one to determine a unique quantitative re-lation between the connection of damaged domains and the regularities in the behaviour of isotropic and anisotropic media.

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