Abstracts

Onishchenko E. O., *Zin'kovs'kyi A. P.*, *and Kruts V. O.* **Determination of the Vibration Diagnostic Parameters Indicating the Presence of a Mode I Crack in a Blade Airfoil at the Main, Super- and Subharmonic Resonances** // Problems of Strength. – 2018. – No. 3. – P. 5–13.

The paper presents the results of numerical calculations to determine the regularities underlying the influence of the characteristics of a mode I breathing fatigue crack on the leading edge of the aircraft gas turbine engine blade airfoil – that is responsible for the nonlinearity of the vibratory system – on its flexural forced vibration behavior. Their comparison with similar data for the rod of a rectangular cross section has shown satisfactory agreement. The calculation of the vibration diagnostic parameters indicating the presence of damage is performed using the developed finite element models of the investigation objects whose forced vibrations were excited by the kinematic displacement of fixed edge elements. The breathing crack is modeled as a mathematical cross section, the non-penetration of its faces is ensured by solving the contact problem of their interaction. The problem of the system forced vibrations is solved using the Newmark method and fast Fourier transformation. The obtained amplitude-frequency characteristics of the undamaged and damaged blade airfoil are indicative of the increase in the energy dissipation in the system in the presence of a breathing crack. The change in the resonant vibration frequency of the cracked object of investigation and the amplitude ratio of the dominant harmonics of displacements and accelerations (the ratio of the former to the latter at the superharmonic resonance and the latter to the former at the main and subharmonic resonances) were chosen as the vibration diagnostic indicators of damage. The amplitude ratio of the dominant harmonics of accelerations at the superharmonic resonance and that of displacements at the subharmonic resonance is found to be the most sensitive indicator of the presence of cracks.

Shakeri Mobarakeh P., *Grinchenko V. T.*, *and Soltannia B.* **Effect of Boundary Form Disturbances on the Frequency Response of Planar Vibrations of Piezoceramic Plates. Analytical Solution** // Problems of Strength. – 2018. – No. 3. – P. 13–26.

The general solution of the boundary problem of planar vibrations of piezoceramic plates in the form of parallelogram is constructed. The solution is presented as infinite series, with each term satisfying the motion equations of the piezoceramic plate element. The series coefficients are determined with functional equations, generated by the boundary conditions of the problem. These equations can be solved using the two approaches: approach based on minimization of the standard deviation and collocation method-based approach. In the case of practical application of finite sums, both approaches lead to the search of solving the systems of linear algebraic equations. Quantitative estimates of the dynamic characteristics of piezoceramic plates are obtained, their analysis permits of evaluating the plate geometry effect. This method provides high accuracy of calculation results.

Bulat A. F., *Dyrda V. I.*, *Lysytsya M. I.*, *and Grebenyuk S. M.* **Numerical Simulation of the Stress-Strain State of Thin-Layer Rubber-Metal Vibration Absorber Elements under Nonlinear Deformation** // Problems of Strength. – 2018. – No. 3. – P. 27–36.

Stress-strain state components of thin-layer rubber-metal elements are investigated. The compression level of a thin rubber layer under the action of vertically applied stress is calculated. For simplified hypotheses the relationship between the rubber layer thickness reduction and its radius-thickness ratio was analytically derived. The problem was solved under linear-elastic deformation of a rubber layer vulcanized onto the metal plates. For numerical calculations, weak rubber compressibility was simulated with the moment finite element scheme for weakly compressible materials, involving the triple approximation of displacement fields, strain components, and a volume variation function. The numerical solution was obtained by the finite element method for different layer radii and thicknesses under geometrically nonlinear elastic and viscoelastic deformation of the rubber material. The geometrical nonlinearity is described by the nonlinear strain tensor. Viscoelastic rubber properties are simulated by the hereditary Boltzmann–Volterra theory with the Rabotnov relaxation kernel. Nonlinear boundary problems are solved by the modified Newton–Kantorovich method. The calculation is effected for the two cases of curing the rubber layer onto the metal elements of the structure. The first case assumes that the rubber layer is vulcanized onto the metal plates, in the second one, it can freely slip over their surface. For the first case, numerical results are compared with the analytical solution. The effect of geometrical nonlinearity and viscoelastic rubber properties on the rubber layer thickness reduction was examined.

Hobiny A. D., *Abbas I. A.*, *and Berto F.* **Finite Element Analysis of Thermoelastic Fiber-Reinforced Anisotropic Hollow Cylinder with Dual-Phase-Lag Model** // Problems of Strength. – 2018. – No. 3. – P. 37–48.
In the present paper, we have constructed the equations for generalized thermoelasticity of a fiber-reinforced anisotropic hollow cylinder. The formulation is applied in the context of dual-phase-lag model (DPL). An application of hollow cylinder is investigated for the outer surface is traction free and thermally isolated, while the inner surface is traction free and subjected to thermal shock. The problem is solved numerically using a finite element method. The results of displacement, temperature and radial and hoop stress are obtained and then presented graphically. Finally, the comparisons are made between the results predicted by the coupled theory (CT), Lord and Shulman theory (LS) and dual-phase-lag model (DPL) in presence (WRE) and absence of reinforcement (NRE).

Gorik A. V. and Kaval'chuk S. B. **Solution of a Transverse Plane Bending Problem of a Laminated Cantilever Beam under the Action of a Normal Uniform Load** // Problems of Strength. – 2018. – No. 3. – P. 49–63.

The paper presents an exact direct solution of a transverse plane bending problem of a laminated cantilever beam of small width under the action of a uniformly distributed load under the absolutely hard contact between the layers. The solution has been constructed with the aid of linear elasticity theory equations: to take into account the heterogeneous structure of the laminated beam, piecewise constant functions of elastic characteristics, which have been described analytically by means of shifted Heaviside functions, have been introduced into the Hooke's law relation-ships. During the solution of problem, the normal stresses were expressed from static equations in terms of an unknown function of tangential stress distribution over the cross-section height. The use of the obtained expressions in the Hooke's law relationships and Cauchy equations for linear strains made it possible to establish relationships between displacements and tangential stresses. The Cauchy equation that remained for angle strains gave a defining integro-differential equation, from which differential equations for the unknown tangential stress function and for all unknown integration functions have been derived. The solution of the derived equations is possible for the entire packet of layers without considering an individual layer, the final relations for stresses, strains and displacements describing the stress-strain state of the entire packet of composite beam layers. The constructed solution satisfies the boundary conditions and the conditions of the absolutely hard contact of the layers and is exact if the load distribution corresponds to the determined stress distribution. Using this solution, we have carried out a theoretical study of the stress-strain state of a three-layer beam. The obtained relation allow one to predict the strength and stiffness of multilayer structural composite elements and to construct application solutions for other elastic bending problems of laminated beams.

Li N., *Ding J. F.*, *Xuan Z. Y.*, *Huang J. M.*, *and Lin Z. P.* **Contact Deformation Behavior of an Elastic Silicone/SiC Abrasive in Grinding and Polishing** // Problems of Strength. – 2018. – No. 3. – P. 64–70.

An elastic abrasive of the new type having the advantage of effectively controlled contact pressure and uniform deformation was developed. It provides complete lamination of the surface, effective treatment of the curved mold cavity, as well as improves the processing efficiency. It permits of fine cavity surface finishing. These soft elastic abrasive composites are based on silicone as the matrix material and modified SiC microparticles as the reinforcing element. Mechanics and contact deformation behavior of the abrasives were studied by examining sizes of reinforcing particles and their content (53.5, 59.3, and 65.4%). Mechanical compression behavior of the composite is characterized by the concave power function index. Contact deformation analysis shows that the network connectivity produced by cross-linking of silicone and a curing agent propagates through the void spaces of the crystal lattice of abrasive particles on pressure application. Elastic extension and compression of composite net chains guarantee the complete lamination of the processed surface, and hard abrasive particles introduced into the net chain spacing complement the structure of the material.

Buketov A. V., Dolgov N. A., Sapronov A. A., and Nigalatii V. D. **Adhesive Pull and Shear Strength of Epoxy Nanocomposite Coatings Filled with Ultradispersed Diamond** // Problems of Strength. – 2018. – No. 3. – P. 71–78.

In this work, epoxy diane oligomer ED-20 is used to form nanocomposite materials, polyethylene polyamine is used as a hardener, ultradispersed diamond with a particle size of 4–6 nm is used as a filler. The epoxy diane resin ED-20 was heated to 353 K. Then the ED-20 oligomer and the nanofiller were subjected to hydrodynamic mixing and subsequent ultrasonic treatment of the obtained composition. The effect of the concentration of diamond nanoparticles on the adhesion properties of composites was studied. The adhesion pull strength of materials was studied by measuring breaking stresses of cylindrical specimens glued by the nanocomposite adhesive. The adhesive shear strength was evaluated by the breaking stress of the lap joints of flat metal specimens glued by the nanocomposite adhesive. In both types of specimens, the glued sections had the same area. It has been found that the incorporation of nanoparticles in the concentration from 0.010 to 0.025 parts by weight per 100 parts by weight of ED-20 epoxy oligomer yields the adhesive pull strength of 25.0–26.3 MPa. The optimal concentration increases the latter value by a factor of 1.5 (to 34.3 MPa) and the adhesive shear strength – by a factor of 1.3 (to 10.8 MPa). The further increase in the concentration (0.075–1.0 parts by weight) is shown to deteriorate the adhesion strength. The nanocomposite coating–metal substrate bond breaking surface has been investigated. It is experimentally proved that the coatings with the cohesive nature of failure have the maximum adhesive pull strength, while those with the mixed (adhesive-cohesive) mode of failure exhibit an improved adhesive shear strength.

Rizov V. I. **Fracture Analysis of a Three-Dimensional Functionally Graded Multilayered Beam** // Problems of Strength. – 2018. – No. 3. – P. 79–90.

Delamination fracture behavior of the three-dimensional functionally graded multilayered crack lap shear (CLS) beam configuration was studied analytically in terms of the strain energy release rate with linear-elastic fracture mechanics methods. The CLS under consideration can consist of an arbitrary number of layers, each having different thickness and material properties. The material of each layer is functionally graded along its width, thickness, and length. A delamination crack is arbitrarily located along the beam height. The strain energy release rate was derived by analyzing its density in the beam cross section ahead and behind the crack front. It was additionally analyzed using the strain energy release rate was performed by using the beam strain energy for verification. The effect of the material gradient and crack location along the beam height on the delamination fracture behavior was evaluated.

Knysh V. V., Solovei S. A., Kir'yan V. I., and Bulash V. N. **Increasing the Corrosion Fatigue Resistance of Welded Joints by High-Frequency Mechanical Peening** // Problems of Strength. – 2018. – No. 3. – P. 91–97.

The cyclic life of butt- and T-welded joints in as-welded condition and after strengthening by high-frequency mechanical peening has been studied. The welded joint specimens were made from a 12 mm thick rolled sheet of commonly used weathering steels 10KhSND and 15KhSND. The fatigue tests were carried out in air and in a corrosive medium (in a 3% NaCl solution) under pulsating tension with a frequency of 5 Hz. It has been found that high-frequency mechanical peening as a method for the plastic surface deformation of the joint metal near the fatigue damage localization sites increases the cyclic life of welded joints in air by a factor of over 10. It has been confirmed that in tests in a corrosive medium, the short-time fatigue strength of welded joints both in initial and in strengthened condition decreases. It has been shown that as a result of strengthening by high-frequency peening, the corrosion fatigue resistance characteristics of butt-welded joints of 15KhSND steel are significantly improved: the cyclic life increases by a factor of 4–10 depending on the level of applied stresses, the short-time fatigue strength, based on $2 \cdot 10^6$ cycles, increases by 85%.

It has been found experimentally that in a 3% NaCl solution, strengthening increases the cyclic life of T-welded joints of 15KhSND and 10KhSND steels by a factor of 4–10 and 3.5–4, respectively, and that the short-time fatigue strength increases by 114 and 80%, respectively. Most strengthened specimens failed in the base metal, far from the fusion line; the unstrengthened specimens failed only in the transition area between the weld metal and base metal.

Timoshenko O. V., *Koval' V. V., Babak A. M.*, *Dik Quan Fam*, *and Sidorenko Y. M.* **The Influence of Plastic Deformation on the Low-Cycle Fatigue during the Burnishing of Holes in Flat Specimens of D16chT Steel** // Problems of Strength. – 2018. – No. 3. – P. 98–104.

The paper deals with one of the most important problems of such closely related industries as mechanical engineering and aircraft manufacturing, involving the determination of the service life of components and structures operating under cyclic loading conditions. The presence of local structural and manufacturing stress concentrators greatly complicates the determination of the predicted life of components and structures at their design stage. The burnishing technique, namely, the method of plastic deformation of walls of the hole, aimed at achieving the amount of the residual plastic strain on their surface, is used to strengthen components with holes. The results of low-cycle fatigue tests conducted in repeating tension are presented for flat laboratory specimens of an aircraft aluminum alloy D16chT with a central cylindrical manufacturing hole hardened by burnishing. The burnisher geometry that ensures the required value of the residual plastic strain level (1, 2, and 3%) on the hole surface is calculated. The cyclic tensile loading of specimens at the stresses in a pulsating load cycle was performed in the range of 150 to 270 MPa at a frequency of 3 Hz using the equipment Bi-02-112. The influence of the amount of plastic strain in the burnished hole of the specimen on its cyclic life and fracture as a function of the load value is observed. It is found that due to plastic strain hardening of the surface of manufacturing holes, a local area of compressive residual stresses occur, causing the stress concentration around the manufacturing hole to decrease and the level of limit loads to increase. It is shown that the specimen, having a manufacturing hole hardened by burnishing (up to a plastic strain of 3%) and being cyclically loaded by a tensile stress to 170 MPa, failed not at the hole (the stress concentrator). Both the onset of the microcrack initiation and its further propagation take place in a solid region of the specimen. This is indicative that with a certain amount of residual stresses in the burnished hole, the specimen fracture under low-cycle fatigue becomes insensitive to the presence of this concentrator.

Karpyuk V. M., *Kostyuk A. I.*, *and Semina Yu. A*. **General Case of Nonlinear Deformation-Strength Model of Reiforced Concrete Structures** // Problems of Strength. – 2018. – No. 3. – P. 105–118.

The paper considers a nonlinear deformation-strength model of a rebar structure. Within framework of the reinforced concrete mechanics, it allows one to take into account the specific features of the joint operation of concrete and reinforcement components at all loading stages, including failure, in the structure cross sections under the general stressed state conditions. The model is found to be instrumental in practical applications due to the possibility of its application at the design or strengthening of beams, cross-bars, columns, elements of girder frames with the rectangle cross section, as well as at the check of bearing capacity of existing reinforced concrete bar structures, which operate under conditions of complex stress-strain state, including low-cycle pulse loading. The assessment algorithm of the bearing capacity of a reinforced concrete bar (rebar) cross sections under multiaxial stress conditions is proposed. The general physical dependencies for such cross section are reduced to the stiffness matrix. The proposed algorithm includes the input data block, main block, supplementary subprograms of load vector increment check and exhaustion of the bearing capacity, as well as the output data printout block. At each computation stage, all iterations are executed until the accuracy of determining all components of strain vector reaches a certain preset value. The variation patterns of normal and tangential stresses, generalized linear and angular strains are considered. The equilibrium equations of a concrete rebar operating under multiaxial stress conditions are derived.

Jutas A., *Mockiene J.*, *Vaiciukynas V.*, *Zaldarys G.*, *and Cinelis G.* **Deformability Behavior of St3 Steel Used in the Profiles of High-Voltage Poles** // Problems of Strength. – 2018. – No. 3. – P. 119–133.

The reasons for the difference in mechanical properties of cold-rolled angles made of low-carbon St3 steel used in old designs of high-voltage poles are established. Several kinetic curves for mechanical properties were investigated in terms of tangential and plastic moduli as the most appropriate tool since the integrating parameters can present some strength and deformability differences much more clear at any stage of deformation. The original quantitative characteristics were presented to eliminate the manufacturing quality effect of pole elements and demonstrate the importance of deformation behavior in explaining the microstructural variety. The microstructural phenomena may affect stress levels at the points of yielding, ultimate strength, and fracture.

Strizhalo V. O. and Stasyuk S. Z. **Special Features of Metal Lamination in hydrogen Sulfide Absorber of Catalytic Reforming Unit and Hydraulic Cleaning** // Problems of Strength. – 2018. – No. 3. – P. 134–144.

The paper analyzes the technical state of the hydrogen sulfide absorber of the catalytic reforming unit and hydraulic cleaning containing hydrogen and hydrogen sulfide with its operation time of 168,000 hours (21 years, operation conditions). 17G1S manganese-silicon steel is used in the absorber structure. In operation, in the vessel shell, a cone-shaped region of subsurface metal lamination is developed across the entire periphery. The region is under constant observation using the methods of nondestructive testing. In case the region of the damaged metal intersects the longitudinal welded joint, the vessel shell is being repaired. A low-temperature (to the boiling point) hydrogen-related fracture of metal in the petroleum refining due to hydrogen saturation and its accompanying cracking are considered to be the most critical types of corrosion of oilfield equipment. In view of this, a set of laboratory tests using specimens of metal templates cut out of the damaged shell region has been performed to evaluate the serviceability of the absorber, as well as to determine the effect of hydrogen sulfide on the structure and mechanical characteristics of the metal. It is found that the process of lamination is detected inside the metal intersection and is caused by the macro-inhomogeneity of rolled metal, i.e., the axial segregation zone, which is the most critical region of the deformed metal. X-ray phase analysis lends credence to the metallurgical nature of lamination of the shell plate. The results of metallographic examination imply that the subsurface hydrogen-induced cracking is caused by aggregation of brittle refined nonmetallic inclusions, mainly of MnS, and it propagates chiefly over sulfide films along the rolled metal direction. The results of experimental investigations on the specimens are provided. From the fractographic investigations on the fractured surface of specimens after mechanical testing it is established that the process of fracture is ductile occurring via microvoids coalescence in the fracture of bridges between them. The key mechanism of microvoids formation is the inhomogeneity of the plastic strain in the microvolumes around the nonmetallic inclusions.

Vorob'ev E. V. **On the Accuracy in Determination of the Mechanical Material Characteristics at Low Temperatures** // Problems of Strength. – 2018. – No. 3. – P. 145–152.

The paper considers the processes related to the specimens and loading device in the tensile testing of metals in strain-controlled mode, including under the conditions of cryogenic temperatures up to 4.2 K. It is demonstrated how the potential elastic energy accumulation and its subsequent relaxation in the development of the specimen strain affect the process of kinetics. The strain rate dependencies on the strain value and stiffness factor (relation between the values of stiffness of the specimen and the machine) are obtained. Noteworthy is that the values of initial and nominal strain rates can differ by an order of magnitude in case of the machine compliance. To obtain the strain rates that are similar for different machines at the initial stage of the process, the formula is proposed allowing one to calculate the required nominal rate. At the temperatures lower than 30 K there is a dramatic increase of the influence of the machine stiffness, dimensions and shape of the specimens on the obtained characteristics, which requires the special measures in the process of testing. Some international and national standards are considered. It is shown that, at present, the process of standardization for tensile testing of metals is inadequate, and the requirements of the current regulatory documents are the minimum, which are not in agreement with the development paces of testing equipment. To significantly enhance the level of accuracy of the obtained mechanical characteristics, it is required to employ the urgent measures as the machine compliance limitation, as well as the decrease of the dimensions range for the specimens together with the standardization of the permissible range of the stiffness factor, and the required selection of the nominal strain rate considering the latter.

Kowalik M., *Mazur T.*, *and Trzepiecinski T.* **Assessment of the Depth of the Deformed Layer in the Roller Burnishing Process** // Problems of Strength. – 2018. – No. 3. – P. 153–165.

This paper presents the methods used to determine the depth of the plastically deformed top layer in the roller burnishing process. An analytical method was developed for determining the depth of the plastically deformed layer on the basis of the Hertz–Bielayev theory. The depth of deformation was obtained as a function of the process parameters: burnishing force, material strength and roller radius. The analytical solution has been verified using an original method based on the measurement of the face profile of rings. A mathematical model for a theoretical solution and a plan for experimental tests have been developed. The numerical simulation of the depth of the plastically deformed layer was carried out based on the finite element method. The results of deformation depth as a function of roller force, material strength and roller geometry show a good agreement between analytical and experimental methods.

Sheng L. Y., *Du B. N.*, *Zan S. P.*, *Lai C.*, *Jiao J. K.*, *Gao Y. B.*, *and Xi T. F.* **Optimization of the Microstructure and Mechanical Properties of a Laves Phase-Strengthened Hypoeutectic NiAl/Cr(Mo,W) Alloy by Suction Casting** // Problems of Strength. – 2018. – No. 3. – P. 166–178.

A niobium (Nb)-doped NiAl/Cr(Mo,W) hypoeutectic alloy was prepared by conventional and suction casting methods. Its microstructure and compression properties were studied to evaluate the effect of a manufacturing process. A coarse primary NiAl phase and NiAl/Cr(Mo) eutectic cell are demonstrated to be the main components of a NiAl/Cr(Mo,W)–Nb hypoeutectic alloy. The Nb addition promotes the formation of a Cr_2Nb Laves phase along the eutectic cell boundary. The suction casting significantly refines a NiAl/Cr(Mo) eutectic cell, primary NiAl phase, eutectic lamella, intercellular region, and Cr_2Nb Laves phase. This casting provides the uniform distribution of a Cr_2Nb Laves phase and increases the solid solubility of the alloy. At room temperature, the suction casting alloy reaches its yield strength, compression strength, and ductility of 1495 MPa, 2030 MPa, and 36%, respectively, which are approximately 50, 30, and 100% higher than those of the conventional casting alloy. A significant improvement of the mechanical properties at room temperature may be ascribed to optimization of the microstructure by suction casting. At 1273 K, the above alloy exhibits almost similar mechanical properties, which is mainly associated with an enlarged intercellular region.