Abstracts

A. L. Stel’makh, A. P. Zinkovskii, and S. N. Kabannik, “Rapid Method of Predicting the Subsonic Flutter Stability of AGTE Axial-Flow Compressor Blade Cascades. Part 1. Physical Backgrounds of the Method,” *Problems of Strength*, No. 2, 5–14 (2019).

Generalization of experimental investigation results for direct compressor cascades of blade profiles at a subsonic (continuous and separated) gas flow with bending, torsional, and bending-torsional vibrations created the basis for defining the physical mechanisms of subsonic flutter initiation in AGTE axial-flow compressor blade cascades. Such a combination of reduced frequencies and angles of attack is possible when the aerodynamic blade vibration decrement equals zero. At corresponds to the critical reduced vibration frequency value below which the aeroexcitation of blade vibrations and an increase in its level are observed, i.e., the dynamic subsonic cascade flutter loss is taking place. The rapid method of predicting the dynamic subsonic flutter stability for compressor blade cascades is described. The scheme of critical reduced blade vibration frequency data base generation is tabulated as the critical values at fixed geometric cascade parameters (pitch-chord ratio and deflection angle), angles of attack, and coefficients of bending–torsional coupling. An example of such a data base for specific compressor blade cascades is given.

A. F. Bulat, V. I. Dyrda, S. N. Grebenyuk, and M. I. Klimenko, “Determination of Effective Characteristics of the Fibrous Viscoelastic Composite with Transversal and Isotropic Components,” *Problems of Strength*, No. 2, 15–25 (2019).

The method of determining the parameters of the integral operator of the effective longitudinal elastic modulus of the first-kind composite material is proposed. The viscoelastic transversal and isotropic composite with a periodic structure was used as an object of study. The elements of its cell are the transversal and isotropic viscoelastic matrix and the elastic fiber, which are approximated by hollow and solid cylinders, respectively. The rheological matrix characteristics are described according to the Boltzmann–Volterra hereditary theory. The axisymmetric longitudinal stretching of the cell is considered. It is assumed that the radial displacements and stresses on the border between the matrix and the fiber are continuous, the lateral surface of the cell is free from stresses, and the axial deformations of the matrix and the fiber coincide. The Laplace transform is applied to solve the received boundary value problem. The similar problem in image space is solved for the homogeneous transversely isotropic viscoelastic composite. The effective instantaneous longitudinal elastic modulus and the relaxation kernel are determined due to the correspondence condition between the deformation of the composite and its components, namely the equality of their axial deformations. The proposed method allows us to determine the viscoelastic composite characteristics due to the corresponding characteristics of its elements and the volume fractions of the matrix and the fiber in the composite material.

P. A. Fomichev and A. V. Zarutskii, “Fatigue Life Prediction by a Local Stress–Strain Criterion for Hole-Containing Specimens after Precompression of Their Material,” *Problems of Strength*, No. 2, 26–35 (2019).

The fatigue life prediction method for structure elements with the material precompression in the bole vicinity is proposed. The method is a further step in evolving the approach to life prediction from a local stress-strain state that is based on the energy criterion of fatigue fracture. Residual stresses arising from the material compression in the hole vicinity were evaluated by the finite element method. The problem of contact interaction of the punch profile with corresponding specimen portions was solved in the physically nonlinear statement. The nonlinear behavior of the hole-containing strip material under elastoplastic deformation was simulated with the multilinear model including kinematic hardening. In life calculations, residual compression stresses were accounted for by introducing additional fictitious ones into the load cycle. The variation of fatigue material characteristics under asymmetric loading were considered by introducing the additional function derived from the test results for smooth specimens under symmetrical loading. Computational results were compared with fatigue test data. For this, D16AT and V95pchT2 aluminum alloy flat specimens with material precompression in the hole vicinity were tested under regular and program loading.

Regular loading was realized by a zero-to-tension stress cycle, the program one was effected witch the stepped program equivalent to the damage during the combined operation of a multi-purpose aircraft. Satisfactory agreement between calculation data and experimental results was noted.

L. B. Getsov, A. S. Semenov, A. N. Grudinin, and A. I. Rybnikov, "Fracture Behavior of Single-Crystal Alloys under Thermocyclic Loading," *Problems of Strength*, No. 2, 36–50 (2019).

Experimental study results for thermal fatigue fracture of sand-glass specimens from a ZhS32 single-crystal alloy with different crystallographic orientations are presented over a wide range of maximum and minimum cycle temperature variations. Crystallographic, fractographic, and finite element data were used to identify crystallographic and noncrystallographic fracture modes of a single-crystal alloy. The noncrystallographic mode is realized at high maximum cycle temperatures and comparatively narrow temperature ranges. It is characterized by mode I crack growth. The crystallographic mode is realized at lower maximum temperatures and a wide range of cycle temperature variations. It is characterized by combined I–II mode crack growth in crystallographic plane {111}. The chart of fracture mechanisms in the maximum temperature-temperature range coordinates is proposed. The boundary between the regions permits of approximation, corresponding to the Arrhenius equation.

P. Shakeri Mobarakeh, V. T. Grinchenko, B. Soltanina, and V. A. Andrushchenko, "Effect of Boundary Form Disturbances on the Frequency Response of Planar Vibrations of Piezoceramic Plates. Experimental Investigation," *Problems of Strength*, No. 2, 51–61 (2019).

Experimental results for forced planar vibrations of parallelogram-shaped piezoceramic plates are presented. The concept of this study is to evaluate the potentials of controlling the spectrum of natural frequencies and electromechanical coupling coefficients of plates by changing their shape. The results permit of supporting the data on analytical and numerical investigations of dynamics of piezoceramic plates and establishing the consistency between the physical properties of a real plate and the assumptions of the ideal computational model in the solution of practical problems. Comparison of calculated and experimental data for the spectrum of natural frequencies of the plate over their rather wide range can demonstrate this consistency. The experimental procedure was tested in studying the vibration behavior of SM111 ceramic square and parallelogram-shaped plates with different side slopes. The frequency range of investigations is limited from above with 140 kHz, which provides effective excitation of a sufficient number of natural vibrations. The structure of an experimental complex and excitation mode of vibrations at actual values of the quality factor permit of considering the external voltage source as the infinite power one. The excitation of asymmetric vibration modes on the change in geometry of a rectangular plate is natural. As was shown, high-order modes (very low electromechanical coupling coefficients in rectangular plates) can be effectively excited in parallelogram-shaped plates with maintaining a uniform electrode coating. It needs the traditional estimates of electromechanical coupling coefficients in piezoelectric plates to be refined with regard to inhomogeneous stress and strain fields.

M. A. Degtyarev, A. V. Shapoval, V. V. Gusev, K. V. Avramov, and V. N. Sirenko, "Structural Optimization of Waffle Shell Sections in Launch Vehicles," *Problems of Strength*, No. 2, 62–71 (2019).

A new approach to optimizing the waffle shell sections of the launch vehicle is proposed. The waffle cantilever cylindrical shells are considered under the action of the axial force that is lower than the critical load. The nonuniformity load coefficient is calculated based on the analysis of the static stress-strain state using the finite element method. Considering the calculation data and analytical relations that are successfully applied in the design of launch vehicles, the optimal parameters are chosen. For this purpose, the structural surface is conventionally divided into the main zones with the nonuniformity coefficients exceeding a certain predetermined value, and the weight reduction zones. Since the main zones are characterized by significant stresses, they are enhanced via the increase in finning and shell thickness. Low stresses are observed within the zone of weight reduction, therefore finning and shell thickness can be reduced, as well as the structure can be lighter. In this case, both the cross-sectional dimensions of finning and shell thickness are subjected to variation. The results of the optimization of the tail section of the Antares launch vehicle are presented. It has been established that the weight of the weight-reduced tail section is 188 kg less than the weight of the original structure, which is 18% of the total weight.

D. V. Breslavs'kyi, S. O. Pashchenko, and O. A. Tatarinova, "Stress-Strain State and Damage in Polymer Parts of Instruments Aboard Artificial Satellites," *Problems of Strength*, No. 2, 72–82 (2019).

The paper presents a method for determination of the stress–strain state and the level of accumulated damage in polymer parts of the devices aboard artificial satellites orbiting the Earth. A mathematical statement of the creep problem is put forward using the Lagrange approach. The methods involves the use of constitutive equations that include elastic, thermoelastic, and creep strains and damage due to cyclic actions of temperature fields and space radiation. Different types of damage are allowed for through the Yokobory hypothesis, and the equivalent stress is chosen by the Pisarenko–Lebedev criterion. The intensification of creep and the damage accumulation due to period changes in temperature stresses are taken into account by means of special constitutive equations derived by the methods of asymptotic expansion and averaging over the period of stress variation. A transient heat conduction problem is pre-solved in order to determine the temperature field. At each time step the boundary-value problem is solved by the finite-element method using a 3D eight-node element and a three-node element of a solid of revolution. The initial boundary value problem is solved by the finite-difference predictor-corrector method. By way of example, the thermal fields, stress state and damage accumulation are computed for a polypropylene component of a fiber-optic gyroscope. Based on the thermoelastic problem computations, the time dependence of the equivalent stress has been found, which is allowed for in the constitutive equations during the strain and damage calculations for the polypropylene component. The calculated data on the stress re-distribution, the increase in stress and damage are discussed for various cases of protection against space radiation.

S. B. Koval'chuk, A. V. Gorik, A. N. Pavlikov, and A. V. Antonets, "Solution to the Task of Elastic Axial Compression–Tension of the Composite Multilayered Cylindrical Beam," *Problems of Strength*, No. 2, 83–96 (2019).

The authors present an accurate solution to the task of elastic axial compression (tension) of the multilayered cylindrical beam with axial orthotropic layers surrounding a central core. The description of the geometry and structural framework of the beam requires the employment of the circular cylindrical system of coordinates where the mechanical characteristics of its inhomogeneous materials serve as the functions of the only variable. The task is solved via direct integration of the entire system of equations of the theory of elasticity within the selected system of coordinates upon the condition of rigid contact at the interfaces of the layers. The analytical relations for all the components of the features of the stress-strain state are obtained, their application is illustrated by the results of the solution to the test task of compression of the four-layered beam with the isotropic core.

I. V. Orynyak and Z. S. Yaskovets, "A Study of the Stress State of Underground Gas Pipelines in Mine Working Zones Using the Method of Internal Response Function," *Problems of Strength*, No. 2, 97–108 (2019).

The stress state of pipelines in mine working zones, where the main loading factor is longitudinal soil displacements caused by the gradual filling of mine voids, has been calculated. Differential equations of pipe deformation have been formulated, for the solution of which the method of internal response function is proposed, which takes into account the mutual displacement of the pipe and soil in each iteration using a classical three-part nonlinear model of pipe–soil interaction. The type of interaction is determined on the basis of the concept of the basic displacement of the pipe, which is refined using displacements calculated in the previous iteration. The procedure of refining the basic solution is an important component of the method, where the basic solution in the next iteration is found as the sum of the previous solution and the difference between the calculated and previous solutions, multiplied by the convergence-control factor of the iterative procedure. To check the convergence accuracy and rate of the proposed iterative procedure, a comparative analysis with other existing procedures and results, obtained with the aid of commercial finite element programs, has been performed. To diagnose the stress state of pipelines during the working of longwall faces, a system for their continuous monitoring has been created. The correctness of the results of the performed numerical modeling of the stress state of a gas pipeline and the effectiveness of the measures that are developed to reduce the high stress level in its individual zones have been confirmed by relevant monitoring data, which are important both for refining the physical characteristics of pipe–soil interaction and for further taking into account the relaxation of these relations in time.

N. V. Bondar and V. V. Astanin, "Effect of Hydraulic Liquid and Sea Water on the Mechanical Characteristics of Polymeric Fibrous Structures," *Problems of Strength*, No. 2, 109–118 (2019).

The degradation of the mechanical characteristics of typical composite materials under the action of the working liquid is studied. Polypropylene and epoxy specimens reinforced with a glass fabric with the warp fiber orientation 0, ±45, and 90° have been investigated according to the ISO 527-4 standard. The materials were a polypropylene composite based on stitched glass fabric and an epoxy-bonded glass fabric and carbon fabric reinforced composite. The basic mechanical characteristics of the materials under investigation have been determined. The specimens were kept in an AMg10 hydraulic liquid and in sea water for 910 h with periodic weighing. The characteristics of the process of adsorption of working liquids by the materials under investigation: adsorption rate coefficient and the maximum amount of the adsorbed liquid have been determined. An investigation to detect damages caused by the liquids adsorbed by materials has been carried out. The specimens with adsorbed liquids were held at 255–373 K with subsequent tensile test. It has been found that the liquid in the material causes its swelling owing to liquid pressure. It is assumed that the characteristics degrade in proportion to swelling pressure. The effect of the above liquids on the strength characteristics of the materials under investigation has been studied by keeping them in these liquids for different time intervals (0–840 h), followed by a tensile test. The effect of through-thickness stitching along the test direction 90° on the mechanical characteristics of a material with a liquid in comparison with other test directions has been studied. The laws governing the effect of the above liquids on the mechanical characteristics of materials in time have been established. Based on experimental data, a model of the behavior of the composite under investigation under the above conditions has been developed, and numerical calculations have been performed. The calculated curves give a fairly good fit to experimental data, which confirms the described approach to be correct.

V. I. Rizov, "Longitudinal Fracture Analysis of Nonlinear Elastic Circular Shafts Loaded in Torsion," *Problems of Strength*, No. 2, 119–128 (2019).

The longitudinal fracture of circular shafts loaded in torsion is analytically investigated. It is assumed that a longitudinal crack with a circular crack front is arbitrarily located to the radial direction of the shaft cross section. The shafts are made of nonlinear elastic material, which exhibits continuous inhomogeneity in the radial direction. The material nonlinearity is described by the Ramberg–Osgood stress-strain relation. The longitudinal fracture is studied in terms of the strain energy release rate. The developed analysis is applied to evaluate the longitudinal fracture behavior of a clamped nonlinear elastic inhomogeneous shaft loaded in torsion by a torque applied to a free end of internal crack arm. For the method verification, the strain energy release rate is also assessed by analyzing the energy balance in the clamped shaft. A parametric study is performed to assess the effects of material inhomogeneity, its nonlinearity, and crack orientation to the shaft radial direction on the longitudinal fracture behavior of the clamped shaft.

R. X. Huang, Z. Ma, W. Z. Dong, Y. Shen, F. M. Du, J. Xu, and M. Jin, "On the Adhesive Strength Quantification and Tribological Performance of the Multilayered Fe–Ni Coating Fabricated by Electroplating," *Problems of Strength*, No. 2, 129–141 (2019).

The present work studied the adhesive strength and tribological performance of the multilayered Fe–Ni coating fabricated by the electroplating. The adhesive strength was quantified by a novel modified Ollard method. The cross-section morphology and inherent mechanical properties of each layer were analyzed. The tribological performance of the developed coating was compared with the common used BP alloy cast iron. The effect of the treatment of dimple texturing coupling with the MoS_2 on friction reduction of the Fe–Ni coating was investigated. The results show that the adhesive strength between the Fe–Ni coating and the 42CrMo substrate is as high as 460 MPa. The repeatable results validate the applicability and stability of the developed adhesion quantification method. The initial layer, transition layer and hard Fe–Ni layer can be observed in sequence from the substrate to the coating surface. Accordingly, the hardness and residual stress in different layers varies with different layers. The tribological properties of the Fe–Ni coating are better than the common used BP alloy cast iron, such as the lower friction coefficient and less wear loss as well as much longer anti-scuffing time. The treatment of dimples textured surface and then filled with MoS_2 nano particles can even improve the tribological performance of the Fe–Ni coating due to the coupling effect of the dimples and MoS_2 particles.

Y. J. Zhao, Y. M. Su, M. Liu, Z. L. Hu, and P. Tang, "Ductile-to-Brittle Transition and Impact Fracture Behavior of 3Mn–Si–Ni Low Carbon Martensitic Steel," *Problems of Strength*, No. 2, 142–152 (2019).

Impact behavior related to crack initiation and growth of low carbon martensitic 3Mn–Si–Ni steel was investigated by instrumented impact Charpy V-notch tests. Load–displacement curves were acquired, so significant characteristic load parameters and impact absorbed energies in different fracture phases from 20~−70℃ were determined. The ductile-brittle transition temperature (DBTT) was also investigated and the corresponding fractograph was obtained. The DBTT of the 3Mn–Si–Ni steel is −50℃. With the temperature decreased from 20 to −70℃, the maximum force F_m increases and the difference between the F_m and the crack stable propagation initial force F_{iu} decreases. Higher force was used to trigger the crack and tended to be brittle fracture at lower temperature, such as −50 and −70℃. Also once the crack initiated, it will extend rapidly until fracture when the tested steel serves at very low temperature, especially below −20℃. With the impact temperature decreasing to −70℃, the crack unstable growth final force Fa decreased to nearly zero and there isn't distinct secondary fiber area.

K. K. Ramachandran and N. Murugan, "Influence of Axial Force on Tensile Strength and Microstructural Characteristics of Friction Stir Buttwelded Aluminum Alloy/Steel Joints," *Problems of Strength*, No. 2, 153–170 (2019).

In this work, the effect of axial force on the tensile strength, microhardness, joint interface microstructure and fracture surface morphology of friction stir welded (FSW) dissimilar butt joints of 3 mm thick aluminum (Al) alloy AA5052-H32 and HSLA steel IRS-M42-97 were investigated. The FSW trials were carried out by varying the axial force from 5–9 kN while keeping the other parameters constant. The highest joint strength of about 90% of the ultimate tensile strength (UTS) of the base Al alloy is obtained at 7 kN axial force. It is found that axial force in the range, 6–8 kN could produce joints with joint strength above 75% of the UTS of the base Al alloy. EDS and XRD analysis suggests that the intermetallic compound (IMC) layer formed at the joint interface is consistent with $FeAl_3$ and FeAl at lower and higher axial forces, respectively. Joint interface analysis shows that the thickness of IMC layer formed at the interface is critical in the performance of the joint and the joint with an average IMC layer thickness of about 1 μm at the joint interface has exhibited the highest joint strength.

O. A. Katok, R. V. Kravchuk, V. V. Kharchenko, and M. P. Rudnits'kyi, "A Setup for Complex Investigation of Mechanical Characteristics of Structural Materials for NPP Equipment," *Problems of Strength*, No. 2, 171–181 (2019).

The complex experimental equipment has been developed and manufactured in compliance with the existing standards for measuring hardness and strength characteristics via the method of instrumented indentation, as well as for short-term static uniaxial tensile tests of structural materials and small punch testing of miniature disk specimens in the macro-range of loads of 2–10,000 N. This allows one to obtain the necessary characteristics of hardness and strength in relation to the current state of materials of the main equipment at NPP and thereby minimize the volume of material used for the production of specimens on the same setup employing various normative techniques of both destructive and non-destructive inspections. The equipment is designed in the form of replaceable units: indentation, tension, and punching of miniature disk specimens, which are installed depending on the test method. As a result, there is a unified assembly that makes it possible to reduce the effect of instrument errors in the validity of the data obtained using different test methods and facilitate its modification according to the other tests. The developed experimental equipment has been tested using the segment of metal of the double ball pipe wall ∅990× 70 mm (the basic metal is 10GN2MFA steel and the deposited material is 08Kh19N10G2V steel) of the Du850 main circulation pipeline of NPP from WWER-1000 reactor pressure vessel. The mechanical characteristics obtained by the methods of indirect control were compared with those obtained from standard tensile tests. At the same time, the deviation of the values of yield strength and ultimate strength obtained employing the indirect control methods from the values obtained in the standard tensile testing is within the limits recommended by the normative documents.