Abstracts

A. P. Zinkovskii, S. N. Kabannik, and A. L. Stel'makh, "Rapid Method of Predicting the Subsonic Flutter Stability of AGTE Axial-Flow Compressor Blade Cascades. Part 2. Mathematical Implementation of Method and Its Potential Application," *Problems of Strength*, No. 5, 5–15 (2019).

The paper considers the implementation of the rapid method of predicting the dynamic stability of the compressor blade assemblies against subsonic flutter. The first flexural mode of blade vibrations is analyzed at the design stage for a wide range of the angle of attack based on the developed database of the critical values of the reduced vibration frequency in straight cascades of blade airfoils. The multiple regression equation is developed that depends on the relative blade spacing and stagger angle of the straight cascade of blade airfoils, coefficient of the flexural-torsional coupling of the blade, and angle of attack with the correlation factor of the studied parameters in the range of 0.92–0.98. Using the obtained equation, the numerical program has been developed for the determination of the dynamic stability limit against subsonic flutter for the first flexural mode of the blade vibrations. The program allows one to find the numerical values of critical reduced frequencies as the characteristics of its dynamic stability and determine their dependence on the angle of attack. The results of practical application of the developed program are presented using the assessment of the dynamic stability of the flexural mode of axial compressors in four modern aircraft gas-turbine engines. It is shown that at the design engine stage it is possible to select the reduced vibration frequencies of the blade assembly for the specified geometry of its peripheral sections and angle of attack of the inflow upon the condition of the occurrence of subsonic flutter.

P. P. Lepikhin, V. A. Romashchenko, O. S. Beiner, and S. A. Tarasovskaya, "Computational Investigation of the Effect of Reinforcement Schemes and Angles on the Stress-Strain State and Strength of Composite Cylinders under Axisymmetric Internal Explosion. Part 3. Results of Calculations for Two-Layer Cylinders with Orthogonal and Combined Reinforcement of the Layers," *Problems of Strength*, No. 5, 16–25 (2019).

The effect of reinforcement patterns and angles on the stress-strain state and strength of two-layer wound composite cylinders of finite length with orthogonal reinforcement and two types of combined reinforcement of the layers under axisymmetric internal explosion has been numerically investigated. Using the data presented in Part 2, a comparative analysis of the effect of winding angles on strength for five different reinforcement patterns has been performed according to three failure criteria for an anisotropic material. The obtained results allow one to choose reinforcement patterns and angles, which ensure the highest and lowest initial strengths of the cylinder, according to the maximum stress and strain criteria and the generalized von Mises criterion, as well as circumferential stiffness.

M. A. Degtyarev and K. V. Avramov, "Numerical Simulation of the Stress-Strain State of the Rocket Retention Module," *Problems of Strength*, No. 5, 26–34 (2019).

The paper considers the thermal stress state of the module for retaining the rocket during firing. The high-temperature gas flow leaves the cruise propulsion system and flows around the retention module. As a result, it heats up. The temperature field, which is nonstationary with large gradients, causes the elastoplastic deformation of the structure. A procedure is proposed to determine the stress-strain state, which consists of two stages. In the first stage, the temperature field of the retention module is calculated. To this end, the high-temperature supersonic flow leaving the cruise propulsion system is numerically investigated. The flow parameters are used in a semiempirical procedure, by which the temperature field in the retention module is determined. At the second stage, the stress-strain state caused by the temperature field is calculated. The elastoplastic deformation of the material is described by a bilinear deformation curve and is calculated by the finite element method, which is implemented in the ANSYS software. As a result of a numerical simulation, it has been found that the most dangerous stress state is observed in the lower part of longitudinal reinforcement, where plastic strains occur.

A. F. Bulat, V. I. Dyrda, S. N. Grebenyuk, and G. N. Agal'tsov, "Methods for Evaluating the Characteristics of the Stress-Strain State of Seismic Blocks under Operating Conditions," *Problems of Strength*, No. 5, 35–42 (2019).

The concept of the vibration and seismic isolation of heavy mining machines, buildings, and structures with rubber seismic blocks is considered. The concept of the seismic isolation of structures is very topical. In Japan, New Zealand, France, Greece, England, USA, and in a number of other countries, it is successfully used for the earthquake protection of such important structures as nuclear power stations, schools, bridges, museums, office and residential buildings. Seismic isolation systems including rubber blocks are most commonly used. The known publications in these countries do not present analytical calculations and technological peculiarities of manufacturing elements. In Ukraine, this concept was extended by developing seismic isolation blocks for the earthquake protection of residential buildings and vibration isolation blocks for the vibration protection of heavy equipment (weight of up to 300 t, used in Russia, Ukraine) and residential buildings. Results of static and dynamic tests of a parametric series of rubber seismic blocks for the vibration protection of residential buildings are presented. A pile design with anti-vibration rubber mounts is considered. Developed and tested rubber seismic block designs were used to protect against subway and motor vehicle induced vibrations two dwelling houses in Kiev (a ten-section ten-storey and a three-section 27-storey dwelling house) and three houses in Lviv. Vibration and seismic isolation with rubber seismic blocks provides a natural vibration frequency of building in the horizontal plane of under 1 Hz, which complies with the requirements of the state building codes and Eurocode 8 for the design of seismic isolation systems for buildings.

I. B. Chepkov, A. V. Hurnovych, S. V. Lapyts'kyi, V. G. Trofymenko, O. B. Kuchyns'ka, and A. V. Kuchyns'kyi, "Method of Measuring the Ballistic Coefficient of Bullets," *Problems of Strength*, No. 5, 43–49 (2019).

The method, employing universal expressions, was examined to determine the ballistic coefficient of a bullet by the G7 standard (air drag law for the flight of a long boat tail tangent ogive G7 bullet in view of its initial velocity and flight trajectory descent within a 100–200-m range). The method permits of measuring the ballistic coefficient of a bullet without a specialized measuring laboratory, i.e., under unequipped shooting-ground conditions. The only metrological equipment is a mobile unit for evaluating the initial bullet velocity. The relation is derived based on the experimental design by the central alternate that describes the range of point values for an examined process since the range of nonexistent ones does not permit of employing the uniform alternate. The range of initial bullet velocities is divided into the three subranges to include all points of the central alternate into the range of existent values. The above ballistic coefficient-based approach can be used to compute the bullet velocity at an arbitrary distance in the tests of armored targets under field conditions without bulky equipment. The reliability of describing the examined process is provided by the approved mathematical model of bullet flight in air as a motion of a solid body based on the system of four differential equations of first order. Adequacy of empirical description of the relation between the ballistic coefficient and initial bullet velocity and flight trajectory descent within 100–200 m is verified by determining the standard deviation for the values based on the mathematical model of bullet flight and the polynomial and their comparison with the accuracy of the ballistic coefficient measurement (no more than 10^{-3}).

O. V. Byakova, G. V. Stepanov, A. O. Vlasov, V. E. Danylyuk, N. V. Semenov, O. M. Berezovs'kyi, and S. V. Gnyloskurenko, "Characterization of Aluminum Foam Impact Response," *Problems of Strength*, No. 5, 50–60 (2019).

The paper addresses the investigation of high-strain rate compressive behavior of Al foams subjected to impact at the intermediate striking velocity ranged from 40 to roughly about 80 m/s. Relatively ductile AlSiMg foam and high-strength AlZnMg foam, whose cell walls contain numerous brittle eutectic domains, are used in the experiments. Strain-rate sensitivity for different structural kinds of Al foams is determined by comparison of the plateau stress achieved at the dynamical and quasi-static compression. Difference in the dynamical response of these Al foams is revealed and clarified based on the strain rate and inertia effects under conditions of plastic cell collapse or brittle damage of the cell wall material induced by cracking of eutectic domains.

S. R. Ignatovich and N. I. Bouraou, "Power Law of Crack Length Distribution in the Multiple Damage Process," *Problems of Strength*, No. 5, 61–73 (2019).

Multiple fatigue damage, which is characterized by crack initiation and propagation processes, is considered. We proposed two models of multiple damage, which imply random crack initiation and further propagation, with the exponential dependence between their length on the number of loading cycles. Crack initiation is modeled by the stationary Poisson flow with a constant intensity, while crack propagation is characterized by the rate parameter controlling the dependence of crack propagation rate and its length. The first model describes the deterministic case of multiple crack propagation at a fixed value of the above rate parameter, while the second one predicts their propagation by random trajectories according to distribution of the rate parameter. In the former case, crack length distribution is shown to be the Pareto power law with the exponent, which is defined by the ratio of kinetic parameters of initiation and propagation of defects. In the latter case, the rate parameter is uniformly distributed, in accordance with experimental data, so that the power-law distribution of crack length is close to the Pareto distribution. The respective distribution exponent also depends on the ratio of kinetic parameters of multiple damages and tends to drop during damage accumulation to the threshold level (namely, reaches the value of 2). This finding complies with experimental data on multiple damages of various classes of materials, including metals and rock masses. We also substantiated the range of ratios of kinetic parameters of defect initiation and propagation, which ensure the Pareto law of cracks length distribution and can be used to estimate the critical state of cracked bodies.

P. A. Fomichev, A. V. Zarutskii, "Fatigue Life Prediction for Specimens with an Open Hole with a Pre-Compressed Boundary via the Nominal Stresses under Regular Cyclic Loading," *Problems of Strength*, No. 5, 74–81 (2019).

The method of predicting the fatigue life of structural elements containing open holes with a preliminary compressed material in the hole vicinity under cyclic loading is proposed. The method is based on the commonly accepted approach of the life prediction via nominal stresses. The presence of residual stresses caused by plastic deformation of the material in the hole zone is taken into account by adjusting the cyclic load ratio in calculations. The concept of "fictitious compression stresses" is introduced for this purpose; its value is determined by solving the contact problem in an elastoplastic formulation in a finite element package. A functional relation between the value of residual stresses and the fatigue life of specimens with pre-compressed hole surface is established. The calculation results via the proposed method are compared with fatigue test results for specimens with pre-compressed hole surface. Satisfactory correlation between calculated and experimental data is obtained. The advantage of the proposed method is the reduction of required input data to construction of the fatigue curve for standard specimens with a stress-free hole. Considering that for the same alloy with identical heat treatment such curves may differ for different material batches, testing of standard specimens under regular loading is mandatory. Despite a usual scatter in fatigue life experimental values, the proposed method allows one to obtain a reliable and conservative assessment of the effect of hole boundary zone pre-compression on the fatigue life at the design stage.

D. V. Breslavs'kyi, V. O. Metelyov, O. K. Morachkovs'kyi, and O. A. Tatarinova, "Short-Term Creep of Steel St3 under Low-Frequency Cyclic Loading," *Problems of Strength*, No. 5, 82–91 (2019).

Creep constitutive equations have been derived for the materials that exhibit the properties of orthotropy (transversal isotropy) and transient creep under cyclic loading. A low-frequency case is considered. The paper provides results of experimental studies of the short-term creep of St3 steel under static and stepwise cyclic loading at room temperature. The results of calculations by the proposed constitutive equations are compared with the experimental data. A good agreement has been found for the number of cycles above 4 or 5, which demonstrates the applicability of the proposed constitutive equation to the low-frequency creep calculations for sheet materials.

A. G. Trapezon, "Residual Stress Effect on the Strength Estimate of Base–Coating Systems," *Problems of Strength*, No. 5, 92–102 (2019).

The effect of manufacturing-induced residual stresses in layered isotropic composites of base-coating type on the latter strength is studied. The conventional method, based on the principle of additivity of the initial properties of layers of a symmetric composite, is applicable to uniaxial tension or compression, but not to bending, where the latter principle is not valid. Therefore, in the latter case, stress calculation has to be based on the method of equivalent bending stiffness linking the derived strength characteristic with operating stresses in the composite layers. Residual stresses in strength assessment are taken into account by substituting their analytical expressions into respective calculation models. The reliability of mostly used relationships for determining residual stresses is analyzed. To this purpose, an independent derivation of engineering formulas for axial residual stresses was carried out, varying elastic parameters, thickness, and number of layers of the composite. The substitution of the above formulas into the additivity relation for an isotropic symmetric system under uniaxial loading does not change the latter form, due to self-balancing of residual stresses and, therefore, residual stresses do not affect the strength estimate. As an example, the axial tensile strength of an aluminum alloy clad with corrosion-resistant steel was calculated for various ratios of cladding layer-to-steel layer thickness. The results on the composite hardening are presented. It is shown that, in contrast to the uniaxial tension of a composite, residual stresses in bending loading, significantly affect the strength assessment results. Numerical results on such an assessment are presented for a case study. A scheme for determining the endurance limit under cyclic bending was elaborated based on the Goodman hypothesis and experimentally verified. All analytical derivations implied the assumptions of homogeneity and isotropy of the physicomechanical properties of the composite constituents, their ideal adhesion, and elastic stress-strain state described by Hooke's law.

A. R. Torabi, S. M. J. Razavi, F. Berto, and M. R. Ayatollahi, "On Suitability of the Averaged Strain Energy Density Criterion in Predicting Mixed Mode I/II Brittle Fracture of Blunt V-Notches with Negative Mode I Contributions," *Problems of Strength*, No. 5, 103–121 (2019).

The main goal of the present research is to check the suitability of the well-known brittle fracture criterion, namely the averaged strain energy density (ASED), in predicting mixed mode I/II brittle fracture of round V-notches under negative mode I conditions. For this purpose, it is attempted for the first time to theoretically predict the fracture loads of numerous round-tip V-notched Brazilian disk (RV-BD) specimens made of PMMA and subjected to mixed mode I/II loading with negative mode I contributions that have been most recently reported in the open literature. It is revealed that ASED criterion is suitable for brittle fracture prediction not only under conventional mixed mode I/II loading conditions, but also under mixed mode I/II loading with negative mode I contributions.

Ali A. Ismail and M. M. Al-Harbi, "Statistical Inference of Constant-Stress Partially Accelerated Life Test Model Using Failure-Censored Data from the Linear Failure Rate Distribution," *Problems of Strength*, No. 5, 122–129 (2019).

In this article, the case of failure-censored constant-stress partially accelerated life test for highly reliable materials or devices assuming the linear failure rate distribution is considered. The maximum likelihood estimates of the distribution parameters and the acceleration factor are obtained. In order to evaluate the performance, the mean squared errors are calculated using different sizes of samples. In addition, the approximate confidence intervals of model parameters are constructed. For illustrative purposes, Monte Carlo simulation studies are offered.

R. Kumar Gupta, S. A. R. Hashmi, S. Verma, and A. Naik, "Development of Graphene Nanoplatelets-Reinforced Thermo-Responsive Shape Memory Nanocomposites for High Recovery Force Applications," *Problems of Strength*, No. 5, 130–143 (2019).

The development and large-scale implementation of multifunctional advanced materials with smart and intelligent properties like shape memory are very topical. In the present work, we report the development of multifunctional graphene nanoplatelets (GNPs)-reinforced thermo-responsive shape memory composites, in ether type shape memory polyurethane (SMPU) matrix. A unique twin screw co-rotating microcompounder with a back flow channel was operated to ensure proper dispersion of GNPs in the SMPU matrix for developing different compositions of nanocomposites, namely SMC0, SMC1, SMC2, and SMC3, respectively. The detailed characterizations and properties of the above developed nanocomposites were studied using various complementary techniques for spectroscopy, morphology, mechanical, thermal, shape memory, DMA, etc. The dynamic thermomechanical properties of all the developed nanocomposites were studied at 0.1 and 10 Hz, respectively. Structure of SMP and developed composite were also analyzed using various spectroscopic methods. The addition of GNPs to the SMP matrix improved the mechanical and shape memory properties, although a noticeable impact on thermal property is also reported. The fractured microphotographs reveal the uniform dispersion of GNP in SMPU. Addition of 1 phr GNPs increased storage modulus of SMPU from 3.14 to 4.11 GPa and the value of $\tan\delta$ peak was decreased from 0.81 to 0.53, respectively. The GNPs in SMPU matrix influences the shape recovery, which is improved with the addition of GNPs in the experimental range.

M. Gáspár, R. P. S. Sisodia, and A. Dobosy, "Physical Simulation-Based Characterization of HAZ Properties in Steels. Part 2. Dual-Phase Steels," *Problems of Strength*, No. 5, 144–155 (2019).

The development of high-strength weldable steels has diversified the range of design alternatives subjected to more and more severe operation conditions. An excellent combination of high work-hardening rate and ductility improves the ultimate tensile strength of dual-phase (DP) steels and made them lucrative for application in automotive industry. The paper focuses on HAZ hardening and softening of three automotive DP steels, which affect their mechanical properties and their crack susceptibility, respectively. A Gleeble 3500 thermomechanical simulator was used to simulate the welding thermal cycles for all HAZ subzones that correspond to TIG welding of three DP steels. Steel samples were heated to different peak temperatures (650, 775, 950, and 1350°C) and cooled at two cooling times of 5 and 30 s. The Rykalin 2D model was used for the numerical simulation of this process. The hardness and microstructure of the specimens were then tested and analyzed using Vicker's hardness test and optical microscope, respectively. In the investigated cooling time range, the HAZ of the examined cold-rolled DP steels was more susceptible to softening than to hardening. The softening occurred in almost all HAZ sub-regions but was the most pronounced in the fine-grained and intercritical HAZ, where we recorded the highest decrease in hardness for all DP steels. With an increase in heat input and longer cooling time, softening occurred in CGHAZ of all three DP steels under study, which can be attributed to the formation of upper bainite.