# Abstracts

*Lepikhin P. P., Romashchenko V. A., Beiner O. S., and Tarasovskaya S. A.* **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 1. Effect of the Discretization Spacings of the Computational Domain on the Accuracy of Determination of Stress-Strain State and Strength** // Problems of Strength. – 2018. – No. 6. – P. 5–14.

The effect of two-dimensional regular finite-difference mesh spacings on the accuracy of calculation of the dynamic axisymmetric stress-strain state and strength of hollow composite cylinders of finite length, fixed overall dimensions and thickness has been numerically determined by the Wilkins method modified for helical orthotropy and implemented in an application package, created earlier by the authors. The cylinders were made by a ribbon consisting of VMPS glass fibers, impregnated with an EDT-10 epoxy binder, on a technological mandrel. Loading is done by exploding a spherical explosive charge in the center of symmetry of a cylinder in an air atmosphere. The obtained results allow one to choose mesh spacings along the radial and axial coordinates, which ensure an acceptable accuracy of determination of the maximum values of hoop stresses and strains, as well as strength functions by maximum stress and strain criteria and by the generalized von Mises criterion.

*Larin A. A., Vyazovichenko Yu. A., Barkanov E., and Itskov M.* **Experimental Investigation of Viscoelastic Characteristics of Rubber-Cord Composites Considering the Process of Their Self-Heating** // Problems of Strength. – 2018. – No. 6. – P. 15–28.

The dissipative characteristics of rubber-cord composites under the action of cy-clic load considering the features of their self-heating have been experimentally investigated. Full-scale uniaxial tension experiments are performed on the plane specimens along the reinforcement fibers of the unidirectional rubber-cord composites. In compliance with the test results, stress-strain state curves for the specimens are determined, which form the hysteresis loops under cyclic loading. The tensile testing of the specimens is performed under long-term cyclic loading using the experimental setup INSTRON ElectroPuls E3000 Test System. The process of significant self-heating of the specimens under their long-term cyclic deformation has been experimentally established and studied. Using the non-contact methods, the variation in the specimen temperature in time is measured. The mechanisms of their non-stationary heating are obtained, as well as the dependences of the stabilization temperature of the thermal state on the loading conditions. It has been determined that the area of hysteresis loops, which is formed when specimens undergo deformation in the temperature-stabilized state, depends nonlinearly on the amplitude of strains. The qualitative and quantitative dependences of the loss modulus, as well as the dissipation coefficients and relaxation times on the loading frequency, strain amplitude and temperature due to the material self-heating, are determined. The approximation dependences of the loss modulus of the composite on the loading frequency and self-heating temperature are constructed on the basis of the generalized three-parameter linear (Zener) model and the exponential temperature-dependent initial elastic modulus.

*Hart E. L. and Hudramovich V. S.* **Application of the Projection-Iterative Scheme of the Method of Local Variations to Solving Stability Problems for Thin-Walled Shell Structures under Localized Actions** // Problems of Strength. – 2018. – No. 6. – P. 29–37.

The tasks of the stability of reinforced spherical shells that are part of the extended inhomogeneous structures are investigated under localized actions based on the developed new projection-iterative version of the method of local variations. Stability under local loading implies the performance of thin-walled shell structures in rocket and space equipment, antenna and waveguide technology, as well as power engineering. Under localized actions, there is a significant concentration of stresses and strains. The methods for solving relevant tasks are rather complex, multiple-mesh variational-difference schemes are within the area of focus. For the tasks of stress-strain state and stability under considerably inhomogeneous stress states, the local variation method is effective, but it requires more computation time as compared with the Ritz-type finite difference and variation methods. Noteworthy is that this leads to the need to develop more adequate schemes for its implementation based on the concept of projection-iterative methods. This scheme of the method of local variations is analyzed, its convergence is investigated, and the practical efficiency associated with a significant decrease in computation time for numerical implementation is shown. The tasks of the stability of complex shell structures with spherical shells reinforced by support rings under the exposure of local loads are considered. The experimental investigation data are given. The calculated data of the critical forces and the configuration of the waveforms are corroborated experimentally.

*Kruts V. A.* **The Influence of Stiffness of Elastic Restraint in a Damaged Regular System on Its Resonant Vibration** // Problems of Strength. – 2018. – No. 6. – P. 38–48.

The paper summarizes the findings of a study of the influence of stiffness parameters of an elastic restraint in a damaged regular system consisting of two duplicate elements and modeling a two-blade assembly, on the generation of vibration of the system under fundamental resonance. A discrete dual-mass model whose vibration is described by a nonlinear set of differential equations of second order has been chosen as a design model of the structurally regular system under consideration. Numerical investigations have been performed using the Runge-Kutta method to solve a nonlinear set of differential equations and the fast Fourier transform method to process the solutions obtained. The dependences of the resonant frequency ratios and resonant amplitude ratios of the first-harmonic vibration on the damage parameter have been derived for the discrete model of the regular system in in-phase and anti-phase modes, with different parameters of the elastic restraint for the damaged subsystem and for the intact one. It is demonstrated that with a preset value of the damage parameter the frequencies of the in-phase and anti-phase modes grow with increasing coefficient of the elastic restraint of the subsystems. This influence is the most significant in the case of the anti-phase mode of vibration of the subsystems. The elastic restraint coefficient has also a substantial effect on the level of resonant amplitudes of the first-harmonic vibration for the regular-system model under study. It has been found out that as the elastic restraint coefficient grows the resonant amplitude of the intact subsystem increases under the in-phase-mode vibration and decreases under the anti-phase one. The values of the resonant amplitudes of vibration of the damaged subsystem are influenced by the coefficient to a lesser extent. The maximum value of the resonant amplitudes of vibration of the damaged subsystem is almost independent of the elastic restraint coefficient.

*Rodichev Yu. M., Smetankina N. V., Shupikov O. M., and Ugrimov S. V.* **Stress-Strain Assessment for Laminated Aircraft Cockpit Windows at Static and Dynamic Loads** // Problems of Strength. – 2018. – No. 6. – P. 49–56.

The method of strength calculations for laminated aircraft cockpit windows influenced by different operating factors (bird strike, pressurization) is devised. The method is based on embedding the initial un canonical shell in the auxiliary one of canonical form in plan with the boundary conditions, which permit of a simple analytical problem solution as a trigonometric series. For satisfying the initial boundary conditions, the auxiliary shell is supplemented with compensating loads, which are continuously distributed over the contour of the initial shell. The compensating loads enter in the equations of motion for the auxiliary shell as integral relations. The system of motion equations is rearranged in the system of ordinary differential equations of second order, which is integrated by the solution expansion in the Taylor series. The windows are treated as a lominated open-ended cylindrical shell consisting of isotropic layers of constant thickness. The laminated window model is based on the modified theory of first order that accounts for transverse shear strains, thickness reduction, rotary inertia, and compression of the normal element in each layer. For the composition, the hypothesis of broken line is valid. The model of pressure pulse that apparently represents the effect of the bird impact on the windows was constructed on the basis of experimental studies. The stress-strain state of the window element in AN aircrafts was evaluated set on the bird strike and cockpit pressurization. Five window alternatives are examined. Calculation results are in good agreement with experimental data. The results become theoretical and practical bock-grounds for engineering calculations and optimum design of laminated aircraft window elements influenced by different operating factors. Thus, the advanced method can be applied to estimation of the lifetime of existing window elements and development of the new ones.

*Savvova O. V., Topchyi V. L., Babich O. V., and Belyakov R. O.* **Influence of Lithium-Silicate Glass Structure on the Mechanical Properties of High-Strength Transparent Glass-Crystalline Materials** // Problems of Strength. – 2018. – No. 6. – P. 57–63.

The development prospects of high-strength transparent glass-crystalline materials on the basis of lithium disilicate for protection of optical systems are found to be closely related to their structural features. We formulate the main criteria for the synthesis of transparent pyroceramics, develop model glasses of the $R_2O$–RO–$RO_2$–$R_2O_3$–$P_2O_5$–$SiO_2$ system with the ratio $SiO_2/Li_2O$ = 4.0 and produce glass-crystalline materials on their basis under conditions of two-stage low-temperature short-term heat treatment under production conditions. The mechanism of formation of the structure and phase composition of glass-crystalline materials on the basis of model glasses under thermal processing is investigated. The essence of the mechanism consists in the formation of lithium metasilicate nuclei-forming agents in the form of spherulites whose growth is limited by the glass phase distribution, the subsequent growth of needle-like crystals of lithium metasilicates, and their recrystallization into lithium disilicate crystals with a pronounced pseudocubic habitus pattern in the form of crossed needles and proportion of 50 vol.%, which form a layered structure in the form of dendritic needles. It is shown that a certain crystallographic orientation of lithium disilicate crystals ensures the scatter reduction of the material elastic characteristics and provides the elastic modulus as high as 307 GPa, the compressive strength of 650 MPa, and impact strength as high as 5.5 kJ/$m^2$. It was established that the formation of a closed-form mesh block structure on the basis of 0.4 $\mu$m lithium disilicate lamellar crystals provides high-strength properties of the developed material, with a transparency in the visible part of the light spectrum, which makes it possible to use this material as the basis for obtaining transparent bullet-proof pyroceramic for the protection of optical devices of military equipment. Investigation of the ballistic stability of the developed pyroceramic and comparison of its physical and chemical properties with other known transparent ceramic high-strength materials proves the expediency of creating high-strength glass-crystalline materials on the basis of lithium disilicate to obtain transparent high-strength components for the purpose of the local protection against high-speed impact action.

*Balyts'kyi O. I. and Ivas'kevych L. M.* **Assessment of Hydrogen Embrittlement in High-Alloy Chromium-Nickel Steels and Alloys in Hydrogen at High Pressures and Temperatures** // Problems of Strength. – 2018. – No. 6. – P. 64–72.

The existence of two (low- and high-temperature) extremes of hydrogen embrittlement in heat-resistant austenitic steels and alloys with intermetallic hardening in the range of 293–1073 K has been reviewed. The low-temperature minimum of their properties in hydrogen is 250–300 degrees higher than that of martensitic homogeneous austenitic steels. The high-temperature maximum of hydrogen embrittlement manifests itself at 1073 K in steels and alloys with intermetallic hardening and a small percentage of refractory elements (Mo, Nb, W), which retard phase transformations during tests. At 293 K, the action of the external hydrogen atmosphere and pre-absorbed internal hydrogen is determined by the structural class and the Ni content of the material. The degree of brittleness of Ni-based alloys (56 and more wt.% Ni) and heat-resistant martensitic steels is determined by the gaseous hydrogen pressure, and the additional action of internal hydrogen is perceptible only at low pressures. The ductility and low-cycle life characteristics of austenitic steels (23–28 wt.% Ni) deteriorate only after hydrogen pre-saturation and change only slightly with increasing hydrogen atmosphere pressure, and iron-nickel alloy (43 wt.% Ni) is sensitive to the action of external and internal hydrogen. The existence of a hydrogen degradation limit, the limiting minimum values of the performance characteristics of steels and alloys (specific elongation and lateral contraction ratio, number of cycles to fracture), which do not decrease with increasing adsorbed hydrogen pressure and absorbed hydrogen content and with decreasing loading rate and frequency, has been established. Such values of the mechanical characteristics of martensitic steels and Ni-based alloys are achieved at hydrogen pressures of over 10 and 30 MPa and of dispersion-hardening austenitic steels alloys of a hydrogen content of 15 and 30 ppm, respectively.

*Rudnitskii N. P.* **High-Temperature Strength of Copper-Based Condensed Materials** // Problems of Strength. – 2018. – No. 6. – P. 73–79.

The temperature dependences of Vickers microhardness, ultimate strength, and offset yield point in the temperature range between 290 and 1070 K have been determined for the transversal direction in copper-based composites Cu–Zr–Y–Mo, Cu–Cr, Cu–C, and Cu–W. The materials produced by electron-beam evaporation/condensation are used for the manufacture of current collectors which, when in operation, are subjected to intensive wear and electrical erosion as well as to mechanical

loading at elevated temperatures. This production method provides composite materials with a special layered structure, where copper layers are interspersed with dispersed-particle layers of other metals. The paper describes the procedures of Vickers microhardness and tensile testing at high temperatures. A general thermodynamic activation analysis of the derived relationships of hardness and strength has been performed for various copper-based composite systems in the range of (0.2–0.8)$T_{melt}$ of copper. A comparative analysis of the obtained values of the activation energy of plastic deformation of copper and copper-based composites as well as the theoretical and experimental data on deformation, internal friction, creep, and self-diffusion processes in copper has revealed that in a wide range of temperatures the activation energy of plastic deformation undergoes a significant change during a transition from one temperature region to another. This is indicative of a successive changeover of effective (governing) thermally activated mechanisms of plastic deformation. It has been proved that a heat-induced change in the strength characteristics (hardness, ultimate strength, offset yield point) of the composites studied is controlled by the same plastic deformation mechanisms whose temperature regions coincide.

*Muzyka M. R.* **On the Material Damage Evaluation by the Elastic Modulus Deterioration Parameter** // Problems of Strength. – 2018. – No. 6. – P. 80–88.

The assessment methods of the normal elastic modulus of plastically deformed materials according to their hardness values and the material damage evaluation via the deteriorated elastic module are described. The normal elastic modulus was found to be very sensitive to the structural state changes. The deformed material state differs from the undeformed one by the accumulation of scattered damages of different nature. It was established that when assessing the material damage degree in the operation process, the most informative indicator of the elastic modulus deterioration is the so-called “aftereffect deteriorated module” (i.e., taken after some operation period), which is used as a measure of material deterioration and defined as the ratio between the deteriorated elastic modulus and its current value. The results on derived relations between the elastic modulus and the material damageability parameter are presented. A stable correlation between the elastic modulus and the Weibull homogeneity parameter is found. The latter describes the scatter degree of hardness characteristics, correlates with the change in the physical and mechanical properties of the material, and is calculated by the scatter degree of hardness values via the known Humbel formula. The metal hardness values determined at the loading/operation stage are found to more accurately characterize the actual level of accumulated damage in the metal than those in the unloaded state, but exhibit a higher scatter than the latter. Dependences, which control respective current value of the material elastic modulus in structural elements at a certain operation stage, are derived, and the aftereffect deteriorated modulus is used to assess the material damage. It is shown that for all investigated materials, the plastic deformation leads to the elastic modulus reduction. This reduction with the rise in deformation was also observed after the preliminary plastic deformation of the material, which was realized in the current study by the material unloading after achieving various degrees of plastic deformation.

*Degtyarev V. A.* **Effect of Dynamic Loads an the Limit Stresses and Second Critical Brittle Temperatures of Butt Weld Joints** // Problems of Strength. – 2018. – No. 6. – P. 89–98.

Experimental results for cracked butt weld joints of 09G2 and 12GN2MFAYu steels are evaluated at different ratios of static and dynamic stresses over a wide range of climatic temperatures. The test were performed on a unit built upon the impact-testing machine. The opening of crack edges was measured with a displacement gauge. The crack propagation was followed with a TV camera and microscope. In low-temperature tests of specimens over the range of 20...−100°C, cooling and automatic temperature control systems were used. Experimental studies resulted in the diagrams of limit stresses, the assessment demonstrated that static and breaking dynamic loads were linearly related. At a preset temperature, the dynamic component of limit stress is shown to decrease with the static one. The weld joint of 09G2 steel was established to exhibit higher sensitivity to dynamic loads over the whole temperature range. It was demonstrated that limit stresses and second critical brittle temperatures should be evaluated with due regard to both static and dynamic stresses. The limit stress and second critical brittle temperature under combined loading of weld joints are dependent on the ratio of static and dynamic stresses. Without regard for dynamic stresses, underestimation of limit stresses and overestimation of second critical brittle temperatures are taking place. With an increase in dynamic over loading coefficients and dynamic ratios the limit stress decreases, while the second critical brittle temperature increases. Second critical brittle temperatures of weld joints in steel with higher mechanical properties are found to be much lower.

*Devin L. N.* **Peculiarities of Determining the Physico-Mechanical Characteristics of Brittle Materials on Small-Sized Specimens** // Problems of Strength. – 2018. – No. 6. – P. 99–109.

The paper presents methods for determining the elastic modulus, sound speed, logarithmic decrement of vibrations (internal friction), tensile, compressive and bending strength, crack resistance, specific work of fracture of small-sized specimens. The specimens of polycrystals of superhard materials, which are prepared in high-pressure apparatuses, or of other expensive sintered materials (boron carbide, silicon nitride, hard alloys), which have a high hardness and elastic modulus, have typically a small size. Most of such materials experience significant dynamic loads during operation in products (metal-cutting tools, armor protection elements). It has been shown that disk specimens of brittle materials 3–15 mm in size can be used to determine strength characteristics under dynamic loading. The use of such specimens makes it possible to avoid oscillations in the loading diagram and to reduce the measurement error of breaking load. Moreover, it is possible to determine on such specimens the specific work of fracture of brittle materials from energy balance in measuring bars. Methods for determining mechanical characteristics under dynamic loading using Hopkinson–Kolsky bars are described, and examples of using procedures for the investigation of hard alloys, polycrystals of superhard materials based on diamond and cubic boron nitride, boron carbide and silicon nitride, obtained by the Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine, are given.

*Ismail Ali A. and Al-Harbi M. M.* **On Estimating a Constant Stress Life Test Model Using Time-Censored Data from the Linear Failure Rate Distribution** // Problems of Strength. – 2018. – No. 6. – P. 110–117.

In this paper, a constant stress partially accelerated life test model is considered and investigated using type-I censored data from the linear failure rate distribution. The maximum likelihood estimates (point and interval) of the distribution parameters and the acceleration factor are obtained. For accuracy reasons, the mean squared errors are calculated using different sizes of samples. For illustration, Monte Carlo simulation studies are presented.

*Mirmohammad S. H., Safarabadi M., Karimpour M., Aliha M. R. M., and Berto F.* **Study of Composite Fiber Reinforcement of Cracked Thin-Walled Pressure Vessels Utilizing Multi-Scaling Technique Based on Extended Finite Element Method** // Problems of Strength. – 2018. – No. 6. – P. 118–130.

One of the most important challenges of storing fluids in thin walled pressure vessels under internal pressure is preventing crack propagation. In low temperature, steel shows brittle crack propagation characteristic which is highly dangerous. In this paper, a new numerical model is presented in order to investigate the reinforcement of a cracked thin walled pressure vessel by composite patch. The extended finite element method (XFEM) technique is used to model brittle crack propagation in the thickness of a thin-walled pressure vessel utilizing multi-scaling technique. Crack propagation in the thickness of a pressure vessel was studied utilizing the combination of XFEM approach in fracture mechanics and multi-scaling technique. Then, the critical energy which is the maximum strain energy that the pressure vessel can absorb before the brittle crack starts to propagate was calculated using numerical techniques of XFEM. In order to increase the critical energy, cohesive elements and composite patches with different stacking sequence which were extracted from previous experimental and analytical studies were used and the best stacking sequence was indicated using the current XFEM code. Moreover, optimization was carried out using traditional optimization technique for reinforcing with composite patches which is based on the optimum ratio of the increased critical energy to the thickness of the reinforcement. Results show that in constant reinforcing thickness and by changing the stacking angle, the maximum energy capacity is increased by 7–11%. Also, by increasing the thickness of the reinforcement a significant growth in strain energy capacity is observed up to 40%. Last but not least, Hashin damage criteria was used in order to make sure that none of the laminas experience damage when the crack is propagating.

*Rafi M. M.* **Study of Bond Properties of Steel Rebars with Recycled Aggregate Concrete. Experimental Testing** // Problems of Strength. – 2018. – No. 6. – P. 131–145.

Recycling of concrete can provide an effective solution for waste management. This study investigates the interfacial bond stress versus slip response of steel bars embedded in recycled aggregate concrete. The bond tests were conducted using concentric pullout specimens. The specimens made from natural aggregate concrete were used as control specimens. Three rebar diameters, two rebar types (hot-rolled deformed and cold-twisted ribbed), and three levels of replacement of recycled aggregates (RA) were considered. The bar embedment length was taken as 5 times the bar diameter. The 12 mm-diameter bar exhibited the highest interfacial bond strength, which decreased with the bar diameter. The bond behavior of bars was nearly unaffected by the concrete type for the levels of RA replacement considered. The cold-twisted ribbed bars demonstrated a stiffer post-peak interfacial bond stress-slip response, as compared to hot-rolled deformed bars.