

CONTENTS

**METALS SCIENCE. METALLURGY**

- Tsukanov V. V., Ziza A. I. Improving of heat treatment modes for 35KhN3MFA and 38KhN3MFA steel grades to increase resistance to brittle fracture. 2. Double tempering..... 7
- Sagaradze V. V., Kataeva N. V., Mushnikova S. Yu., Kalinin G. Yu, Kharkov O. A., Kostin S. K., Parmenova O. N. Structure and properties of two-layer steel used for Arctic vessels' hulls building. .... 14
- Grinberg E. M., Alekseev A. A. X-ray studies on low-temperature martensite decomposition in hardened medium-carbon steel. .... 26
- Gromov V. E., Peregudov O. A., Ivanov Yu. F., Morozov K. V., Alsaraeva K. V. Evolution of rails surface structure and properties over a long-running operation ..... 30
- Kudryavtsev A. S., Okhapkin K. A., Trapeznikov Yu. M., Artemyeva D. A., Kovalev P. V. Improving the 08Kh16N11M3 steel characteristics by optimizing its alloying system ..... 38
- Aleutdinova M. I., Fadin V. V. Wear resistance of carbon steels under impact of friction and electric current of high density ..... 47
- Pustovalov D. A., Mokritskii B. J., Konnova G. V., Grigorieva A. S., Konovalova N. S. Comparative evaluation of the properties of cutting tool materials by the area of indentation for oscillation scribing .. 54
- Shaboldo O. P., Vitorsky Ya. M., Mazurov S. A., Tikhonova A. M., Filippova N. A. Thermomechanical modes for thin tapes manufacturing of TS6 titanium  $\beta$ -alloy..... 63
- Ospennikova O. G., Petrushin N. V, Trenienkov I. A., Timofeeva O. B. Phase and structural transformations in heat resistant intermetallide nickel-based alloy..... 69

**FUNCTIONAL MATERIALS**

- Bobkova T. I., Farmakovskiy B. V., Bogdanov S. P. Composite nanostructured surface-reinforced powder materials based on systems Ti/WC and Ti/TiCN used for coatings with enhanced hardness.... 80
- Tarasenko Yu. P., Tsareva I. N., Levanov Yu. K., Krivina L. A., Berdnik O. B., Ilyichev V. A. On obtaining intermetallide coatings by gas dynamic powder spraying ..... 91
- Gerashchenkov D. A., Oryshchenko A. S. Aluminium matrix functional coatings with high microhardness prepared from composite powders of Al-Sn + Al<sub>2</sub>O<sub>3</sub> systems by cold gas dynamic spraying ..... 100
- Masaylo D. V., Kovalev A. A. Increasing of cast microwires strength after production ..... 108
- Urkanova L. A., Lkhasaranov S. A., Minyaeva A. A., Semenov A. P., Smirnyagina N. N. Influence of carbon nanomodifier on changing phase composition, structure and properties of cement composites ..... 114
- Kameneva A. L. Evolution of the film structure formed by magnetron sputtering and arc evaporation in the low temperature zone 1 ..... 122

**POLYMERIC COMPOSITE MATERIALS**

- Sedletsky R. V. Service-life assessment of spheroplasts as materials for deepwater submersibles .... 133
- Deev I. S., Startsev O. V., Nikishin E. F. Fractographic analysis of KMU-4I carbon fiber reinforced plastic after 12 years of exposure to space environment of the International Space Station and the subsequent bending tests ..... 140

Dushin M. I., Platonov A. A., Karavaev R. Y., Merkulova Y. I. Parameters defining modes of impregnation of reinforcing fillers of composites binding ..... 150

#### **WELDING AND RELATED PROCESSES. WELDING MATERIALS AND TECHNOLOGIES**

Belyaev S. N., Scherbak A. G. Influence of solid-phase interactions on joints forming by diffusion welding for precision instrument making units ..... 160

#### **CORROSION AND PROTECTION OF METALS**

Kuzmin L. Yu., Lashevsky V. O., Kalinin G. Yu. Effect of cathodic polarization on the mechanical characteristics of high-strength nitrogen-containing steels in sea water..... 167

Kuzmin Yu. L., Medyanik T. E., Mushnikova S. Yu., Parmenova O. N. Electrochemical protection of shipbuilding stainless steels and welding joints against pitting and crevice corrosion in sea water, fouling conditions included. .... 173

#### **RADIATION MATERIALS SCIENCE**

Margolin B. Z., Varovin A. Ya., Minkin A. J., Sorokin A. A., Piminov V. A., Evdokimenko V. V., Fedosovsky M. E., Sherstobitov A. E., Ovchinnikov A. G., Erak D. Yu., Bobkov A. V., Timofeev A. M., Timokhin V. I., Yakushev S. V., Vasiliev V. G. Determination of in-service change in the geometry of WWER-1000 core baffle: calculations and measurements..... 182

#### **STRUCTURAL-WORKING STRENGTH AND SERVICEABILITY OF MATERIALS**

Sadkin K. E., Ilyin A. V., Lavrentyev A. A. Cyclic crack resistance of high-strength steels for estimating service life of constructions for deepwater equipment ..... 197

#### **TESTS, DIAGNOSTIC AND QUALITY CONTROL OF MATERIALS**

Mokritsky B. Ya., Pustovalov D. A., Altukhova V. V., Kvasha V. Yu. Assessment of carbide cutters operational properties..... 209

**Abstracts of published articles** ..... 215

**Index of authors**..... 229

**Instructions for authors of the scientific and technical journal "Voprosy Materialovedeniya". Manuscript requirements** ..... 231

## ABSTRACTS OF PUBLISHED ARTICLES

UDC 669.15–194.55:621.785:539.422.22

**Improving of heat treatment modes for 35KhN3MFA and 38KhN3MFA steel grades to increase resistance to brittle fracture. 2. Double tempering.** Tsukanov V. V., Ziza A. I. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 7–13.

The paper compares 35KhN3MFA and 38KhN3MFA steel grades resistance to brittle fracture. It has been found that the double tempering significantly increases resistance to brittle fracture. Also, the metal produced by different technologies after such treatment doesn't tend to stress corrosion cracking. The conclusion about the necessity of double tempering for all steel products operating in low temperatures has been made.

*Keywords:* stress corrosion cracking, secondary martensite, double tempering, impact toughness, resistance to brittle fracture.

UDC 669.15–194.55:621.8:629.561.5

**Structure and properties of two-layer steel used for Arctic vessels' hulls building.** Sagaradze V. V., Kataeva N. V., Mushnikova S. Yu., Kalinin G. Yu, Kharkov O. A., Kostin S. K., Parmenova O. N. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 14–25.

A Kh20N6G11AM2BF austenitic steel containing 0.4 wt.% of nitrogen tempered after rolling heating and after 1150°C hardening and 15% cold deformation, has high mechanical properties, good wear characteristics and stress corrosion cracking (SCC) resistance. So it could be used as a cladding material to hulls steels for Arctic class ships. Strong bonding of Kh20N6G11M2AFB austenitic steel cladding containing 0.4 wt.% N with 10N3KhDMBF hull steel has been described. The shear resistance has been registered equal to 437–520 MPa. Redistribution of the alloying elements forming martensitic layer observed at the boundary of the cladding layer and the base material must be taken into account in the final heat treatment considering different processing conditions (cladding packet, longitudinal welding, explosive bonding).

*Keywords:* nitrogen-containing steel, corrosion cracking, structure, electron microscopy, cladding material.

UDC 669.14.018.298.3:669.017.3

**X-ray studies on low-temperature martensite decomposition in hardened medium-carbon steel.** Grinberg E. M., Alekseev A. A. – Voprosy Materialovedeniya, 2015, N 3(83), p. 26–29.

Changes in the degree of tetragonality in the low-temperature martensite decomposition in hardened medium-carbon steel have been studied. The heat treatment of the steel included hardening at room temperature in mineral oil, water, 10% aqueous solution of NaCl and ageing at room temperature or low-temperature tempering at 155°C. The controlling factor leading to changes in the microhardness of the low-temperature martensite decomposition in medium carbon-steel is carbon depletion of the supersaturated solid solution. The concentration of carbon and, accordingly, the degree of martensite lattice tetragonality under aging and low tempering decreases to a certain limit, regardless of the cooling rate and hardening temperature. Dispersed carbides formed in the decomposition of martensite have a composition Fe<sub>2</sub>C.

*Keywords:* martensitic transformation, hardening, kinetics, low-temperature martensite decomposition, carbon contents, tetragonality degree.

UDC 669.14.018.294.2:539.22

**Evolution of rails surface structure and properties over a long-running operation.** Gromov V. E., Peregudov O. A., Ivanov Yu. F., Morozov K. V., Alsaraeva K. V. – Voprosy Materialovedeniya, 2015, N 3(83), p. 30–37.

The investigations of properties, structure, and phase composition of 10 mm depth surface layer of P65 rails over a long-running operation (passing tonnage equals to 1000 million gross ton-km) have been carried out by methods of scanning and transmission electron diffraction microscopy and microhardness measurement. It has been shown that rails operation leads to multilayer structure formation. The surface hardness increase caused by the formation of nanosized grain structure, containing carbide phase inclusions. The paper presents possible reasons and mechanisms of carbide phase dissolution under the long operation.

*Keywords:* rails, structure, phase composition, defect substructure, carbides, operation.

UDC 669.15–194:621.039.53

**Improving the 08Kh16N11M3 steel characteristics by optimizing its alloying system.** Kudryavtsev A. S., Okhapkin K. A., Trapeznikov Yu. M., Artemyeva D. A., Kovalev P. V. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 38–46.

The paper studies reducing of carbon content in the 08Kh16N11M3 steel used for sodium coolant equipment, while maintaining the original level of the mechanical properties by nitrogen alloying.

*Keywords:* steel, fast neutron reactors, carbon contents, nitrogen alloying, mechanical properties.

UDC 621.891

**Wear resistance of carbon steels under impact of friction and electric current of high density.** Aleutdinova M. I., Fadin V. V. – Voprosy Materialovedeniya, 2015, N 3(83), p. 47–53.

Current dependences of both wear intensity and specific surface electric conductance of sliding electric contact carbon steel/quenched steel are represented. It is shown that structural steels containing up to 0.2% of carbon demonstrate higher wear intensity than tool steels containing carbon concentration of 0.7% C and 1.2% C which are normally harder. The catastrophic wear of steel containing 1.2% C begins at lower current density than that of the other steels. Reducing of the steel wear resistance while increasing carbon contents is presented as a consequence of material plasticity decreasing that inhibits the stress relaxation in surface layer due to plastic deformation.

*Keywords:* surface layer plasticity, fatigue deterioration, low-cycle fatigue, contact spots, friction, wear resistance, electric conductance of sliding contact.

UDC 621.91.02:620.178.152.5

**Comparative evaluation of the properties of cutting tool materials by the area of indentation for oscillation scribing.** Pustovalov D. A., Mokritskii B. J., Konnova G. V., Grigorieva A. S., Konovalova N. S. – Voprosy Materialovedeniya, 2015, N 3(83), p. 54–62.

A simple express technique of comparative evaluation of materials necessary for cutting tools manufacture is relevant, since the laboratory methods are labor-consuming and expensive. The paper considers the possibility of connection between parameters of pendulum scribing and physical and mechanical properties of the materials in question. The experiments were performed on the original installation, measurement and analysis of trace parameters made by optical digital microscopes. Scribing pendulum is a hard pendulum with indenter moving along a circular arc interacting with the sample. The material is deformed and indentation trace is being formed having variable parameters, precisely length, depth and width. Indentation area has been taken as a parameter of trace scribing, and the area of the track scribing has been calculated.

The results of experiments allow us to conclude that the connection area of the track with physical and mechanical properties of materials has been installed. Studying carbide tool materials we've found a tendency that with increasing of material hardness and resistance, the area of the track scribing decreases. Thus it is possible to rank materials according its physical and mechanical properties, as well as to predict its performance characteristics.

*Keywords:* tool materials, metal cutting tools, pendulum scribing, indentation trace, physical and mechanical properties.

UDC 669.295:621.771.23

**Thermomechanical modes for thin tapes manufacturing of TS6 titanium  $\beta$ -alloy.** Shaboldo O. P., Vitorsky Ya. M., Mazurov S. A., Tikhonova A. M., Filippova N. A. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 63–68.

The paper studies thermomechanical rolling effects on the structure and properties of TS6 titanium alloy for tapes production up to 0.2 mm thick with a level of strength of 1300–1400 MPa and longation of 3–6%.

*Keywords:* titanium alloy, thermomechanical rolling schedules, thin tapes production, strength, ductility.

UDC 669.017.165:669.018.44

**Phase and structural transformations in heat resistant intermetallide nickel-based alloy.** Ospennikova O. G., Petrushin N. V., Trenienkov I. A., Timofeeva O. B. – Voprosy Materialovedeniya, 2015, N 3(83), p. 69–79.

The paper studies monocrystals of heat resistant intermetallide nickel-based alloy, microsegregation alloying elements within dendritic cells. The parameters of the lattices  $\gamma'$ - and  $\gamma$ -phases have been determined at room temperature by X-ray structural analysis. Alloying elements W, Cr, Mo and Co concentrate in the dendritic branches. It is shown that the long-term (up to 690 h) creep tests in the temperature range 1000–1200°C do not practically change the phase composition of VIN3 alloy.

*Keywords:* heat resistant intermetallide alloy, microstructure, segregation of alloying elements, phase stability.

UDC 621.762.2:621.763:621.793.7

**Composite nanostructured surface-reinforced powder materials based on systems Ti/WC and Ti/TiCN used for coatings with enhanced hardness.** Bobkova T. I., Farmakovskiy B. V., Bogdanov S. P. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 80–90.

The paper presents a new method of creating composite powder materials for protective coatings, investigates the dependence of the coatings properties on the ratio of matrix and reinforcement components in the powder compositions. Properties of the coatings and its practical applications as innovative reinforcing materials have been studied as well as unique compositions based on systems Ti/WC and Ti/TiCN.

*Keywords:* composite powder materials, surface reinforcement, corrosion resistance, hardness.

UDC 621.793.7:669.017.165:620.197

**On obtaining intermetallide coatings by gas dynamic powder spraying.** Tarasenko Yu. P., Tsareva I. N., Levanov Yu. K., Krivina L. A., Berdnik O. B., Ilyichev V. A. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 91–99.

Intermetallide coating designed against gas corrosion in the internal cavities of the blades for gas turbine engines has been obtained by gas dynamic spraying. The phase composition of the coating after deposition and heat treatment is a face-centered cubic nickel with 30% content of intermetallide phase  $\beta$ -NiAl and 10% of alumina  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. Microhardness of the coating equals to 4250 N/mm<sup>2</sup>.

*Keywords:* protection against gas corrosion, intermetallide coating, method of gas-dynamic spraying.

UDC 621.793:621.762:620.178.162

**Aluminium matrix functional coatings with high microhardness prepared from composite powders of Al-Sn + Al<sub>2</sub>O<sub>3</sub> systems by cold gas dynamic spraying.** Gerashchenkov D. A., Oryshchenko A. S. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 100–107.

The limits of operational capabilities for antifriction composite coatings prepared from composite powders of Al-Sn + Al<sub>2</sub>O<sub>3</sub> systems by cold gas dynamic spraying have been determined. The tests for friction pairs with 20X13 steel sample have been carried out at extreme conditions.

*Keywords:* functional antifriction coatings, cold gas dynamic spraying, tribological tests, operational capabilities.

UDC 621.315.3:539.4

**Increasing of cast microwires strength after production.** Masaylo D. V., Kovalev A. A., Farmakovskiy B. V. – *Voprosy Materialovedeniya*, 2015, N 3 (83), p. 108–113.

Modifying methods for glass insulation surface of cast microwires have been developed to improve its mechanical strength and elasticity. The paper presents the possibility of increasing the tensile strength with a substantial increase of bending elasticity.

*Keywords:* cast microwires, glass insulation, surface modification, tensile strength, bending elasticity.

UDC 661.66

**Influence of carbon nanomodifier on changing phase composition, structure and properties of cement composites.** Urkhanova L. A., Lkhasaranov S. A., Minyaeva A. A., Semenov A. P., Smirnyagina N. N. – *Voprosy Materialovedeniya*, 2015, N 3(83), p. 114–121.

Carbon nanomaterials are perspective additives for modifying cement composites. In this work the influence of carbon nanomodifier (CNM) formed in plasma chemical reactor on phase composition, structure and properties of cement stone was investigated. Method of dispersion of nanoparticles has been used, which consists in ultrasonic mixing with carbon nanomodifier and superplasticizers.

*Keywords:* carbon nanomodifier, cement composites, ultrasonic method, phase composition.

UDC 621.793:559.23

**Evolution of the film structure formed by magnetron sputtering and arc evaporation in the low temperature zone 1.** Kameneva A. L. – *Voprosy Materialovedeniya*, 2015, N 3(83), p. 122–132.

One of the basic ways of stabilizing of the film structure and performance properties of the polycrystalline films is to establish the dependence of the evolution of the film structure during the deposition according to the temperature and process conditions of the deposition, and ultimately building of the model structural zone (MSZ). MSZs of the films formed by spraying and evaporation in vacuum in the low temperature zone 1 have been investigated in the article. Structure evolution in the MSZ films is studied depending on the temperature, process and physical parameters of the deposition process of DC magnetron sputtering in an inert or reactive environment, RF magnetron sputtering and arc evaporation. The author of the article developed a model of structural zones of polycrystalline films formed in the low temperature zone 1 by arc evaporation. Value of heating speed of the film during its deposition was set. The value of film heating rate during its deposition  $V_{\text{heat}} = 3.7\text{--}4.1 \text{ K / min}$ , allowing to increase the rate of the stages and to stabilize the formation of two-component polycrystalline films, have been established.

*Keywords:* model of structural zones, low temperature zone, polycrystalline films, structure evolution, temperature and process conditions of deposition, magnetron sputtering, arc evaporation.

UDC 678.067:544.723

**Service-life assessment of spheroplasts as materials for deepwater submersibles.** Sedletsky R. V. – *Voprosy Materialovedeniya*, 2015, N 3 (83), p. 133–139.

The paper proposes experimental method of resource assessment based on the physicochemical theory of reversible water mass transfer and wave-like changes in spheroplasts strength under hydrostatic pressure at any level. The author marks the illegality of spheroplast service life assessment (as elements for deepwater submersible materials) based on the phenomenological concept of time and pressure analogues, combined with a misguided interpretation of Fick diffusion laws concerning the filled polymer composites.

*Keywords:* spheroplast, buoyancy elements, meniscus modeling, water absorption, reversible water mass transfer, service life assessment.

UDC 678.067:620.174

**Fractographic analysis of KMU-4I carbon fiber reinforced plastic after 12 years of exposure to space environment of the International Space Station and the subsequent bending tests.** Deev I. S., Startsev O. V., Nikishin E. F. – Voprosy Materialovedeniya, 2015, N 3(83), p. 140–149.

The paper presents results of comparative fractographic research of nature of fracture at static bending tests and microphase matrix structure of the control and exhibited samples of KMU-4I carbon fiber reinforced plastic within 12 years of exposure to space environment as a part of Komplast 10-1 panels on the exterior surface of the modulus of the International Space Station.

*Keywords:* carbon fiber reinforced plastic, microstructure, fractography, Komplast panels, long-term exposure, International Space Station.

UDC 678.7–405.8

**Parameters defining modes of impregnation of reinforcing fillers of composites binding.** Dushin M. I., Platonov A. A., Karavaev R. Y., Merkulova Y. I. – Voprosy Materialovedeniya, 2015, N 3(83), p. 150–159.

The paper considers parameters defining conditions of binding injection at impregnation of dry fillers under excess pressure or vacuum and influence of injection speed on formation of plastics porosity.

*Keywords:* polymeric composite materials, non-autoclave methods, porosity, binding, viscosity.

UDC 621.791.4

**Influence of solid-phase interactions on joints forming by diffusion welding for precision instrument making units.** Belyaev S. N., Scherbak A. G. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 160–166.

Possible solid-state interactions determining formation of the welding connection have been considered in its totality and sequence. Calculation methods of thermodynamic analysis to assess the likelihood of occurrence of specific interactions and technological welding schemes have been presented. The paper shows X-ray analysis data determining the structural and phase changes in the connection zone and practical welding results of the gyroscopic instruments units.

*Keywords:* diffusion welding, solid-phase reactions, double oxides, intermetallides, solid solutions, ceramic-metal units.

UDC 669.14.018:620.197.5

**Effect of cathodic polarization on the mechanical characteristics of high-strength nitrogen-containing steels in sea water.** Kuzmin L. Yu., Lashevsky V. O., Kalinin G. Yu. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 167–172.

The influence of cathodic polarization on the mechanical properties of high-strength nitrogen-containing steel 04Kh20N6G11M2AFB in sea water has been analyzed.

*Keywords:* nitrogen-containing steel, cathodic polarization, hydrogen absorption, mechanical properties, electrochemical protection.

UDC 621.039.531:539.434

**Electrochemical protection of shipbuilding stainless steels and welding joints against pitting and crevice corrosion in sea water, fouling conditions included.** Kuzmin Yu. L., Medyanik T. E., Mushnikova S. Yu., Parmenova O. N. – Voprosy Materialovedeniya, 2015, N 3 (83), p. 173–181.

The results of corrosion resistance testing of high-strength non-magnetic nitrogen-containing 04Kh20N6G11M2AFB steel under sea water conditions, fouling included, have been considered. It is shown that the electrochemical method by AP4N aluminum alloy protectors provides corrosion resistance of these steels in seawater, with severe fouling problems.

*Keywords:* high strength nitrogen-containing non-magnetic steel, pitting and crevice corrosion, electrochemical protection, protectors, corrosion resistance, bench testing.

UDC621.039.531:539.434

**Determination of in-service change in the geometry of WWER-1000 core baffle: calculations and measurements.** Margolin B. Z., Varovin A. Ya., Minkin A. J., Sorokin A. A., Piminov V. A., Evdokimenko V. V., Fedosovsky M. E., Sherstobitov A. E., Ovchinnikov A. G., Erak D. Yu., Bobkov A. V., Timofeev A. M., Timokhin V. I., Yakushev S. V., Vasiliev V. G. – *Voprosy Materialovedeniya*, 2015, N 3(83), p. 182–196.

The paper gives the basic constitutive equations describing a radiation swelling and a creep depending on neutron dose, irradiation temperature and triaxial stress state, and justifies these equations experimentally. The WWER-1000 core baffle change in geometry was calculated by different models describing the effect of stresses on radiation swelling. The calculated results are compared with the measured ones for the operating WWER-1000 core baffle at the Balakovo NPP, Unit 1. A method of individual prediction of core baffle geometry change on the basis of the measurement results has been proposed.

*Keywords:* neutron dose, irradiation, swelling, core baffle, geometry change.

UDC 669.14.018:295.421

**Cyclic crack resistance of high-strength steels for estimating service life of constructions for deepwater equipment.** Sadkin K. E., Ilyin A. V., Lavrentyev A. A. – *Voprosy Materialovedeniya*, 2015, N 3 (83), p. 197–208.

More than a decade the cyclic crack resistance (dependence of fatigue crack growth on the scope of the stress intensity factor) is being determined, but the number of problems related to these data defining deepwater equipment resource, remains a blank spot. For example, crack kinetics under alternating cycles and predominantly compressive loads and possible impact of differences in the frequency of loading on the specimen and on the construction in a corrosive environment. Investigation of these effects is performed by revision control of compliance, allowing to register loads and complete crack opening and closure during testing with frequency reduction to 0.01 Hz.

*Keywords:* high-strength steel, cyclic crack resistance, constructions service life, deep sea equipment.

UDC621.914.2:620.178.152.5

**Assessment of carbide cutters operational properties.** Mokritsky B. Ya., Pustovalov D. A., Altukhova V. V., Kvasha V. Yu. – *Voprosy Materialovedeniya*, 2015, N 3 (83), p. 209–214.

Performance tests for choosing an effective tool material are economically irrational given the high cost of the machine-hour. Express tests are needed. The paper shows a possibility of using a pendulum scribing to select the tool material under given operation conditions for end mills.

*Keywords:* end mills, operating properties, forecasting, express met.