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STRUCTURE AND MECHANICAL PROPERTIES OF HIGH STRENGTH AUSTENITIC Mn–N–Cu–V–C DISPERSIONALLY HARDENED STEEL

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Abstract—The paper presents the results of a study of the structure and mechanical properties of high-strength austenitic dispersionally hardened Mn–Ni–V–C steel with a yield strength of at least 700 MPa. Its composition and the hardening method were selected so that the steel meets the requirements for high strength and non-magnetic properties. It is shown that the introduction of 1–2% Cu into Mn–Ni–V–C steel expands the region of existence of the γ-phase in the Fe–Ni–Mn phase diagram, narrows the two-phase γ+α-region and shifts it towards lower Mn contents, increasing stability of austenite to martensitic transformation during cold deformation. A numerical assessment of the influence of alloying austenite-forming elements Ni, Mn, Cu on the critical degree of cold plastic deformation, leading to the formation of deformation martensite in steel, is proposed. The temperature range of the reverse transformation of this martensite into austenite during annealing is established, depending on the nickel content in the steel. For precipitation hardened steel with a composition of 10%Mn; 10%Ni; 2%Cu; 0.3–0.4%C; ~1.4%V the regularities of dissolution upon heating for quenching and precipitation during aging of particles of the strengthening carbide phase VC were studied. It has been shown that the maximum strength is achieved after quenching from 1150°C and aging at 650°C for 15 hours. Taking into account the studies carried out on the stability of austenite, static and cyclic strength and durability, the optimal alloying range of steel with nickel, manganese and copper was substantiated, and the optimal mode of heat treatment was revealed, which provides a combination of high strength with good ductility and toughness of steel.

Keywords: steel, austenite, stability, deformation martensite, ferromagnetic, precipitation hardening, carbides, strength, fracture toughness, durability

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ON THE FORMATION OF RECRYSTALLIZATION NUCLEI IN AUSTENITIC NITROGEN-CONTAINING STEEL UNDER HOT DEFORMATION

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Abstract—This article presents the results of studying the structure of high-strength corrosion-resistant austenitic nitrogen-containing steel formed as a result of hot deformation. It was found that, depending on the temperature, degree and rate of deformation, the mechanism of formation of nuclei of dynamic recrystallization changes. At temperatures above 1100°C, nuclei are formed due to bending and subsequent migration of grain boundaries; however, with a decrease in temperature and an increase in the degree and rate of deformation, subgrains become centers of recrystallization near the initial boundaries.

Keywords: nitrogen-containing austenitic steel, EBSD analysis, structure, dynamic recrystallization, hot deformation, recrystallization nuclei

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FORMATION OF AUSTENITE IN FERRITE-BEINITE, BEINITE-MARTENSITE AND MARTENSITIC SHIPBUILDING STEELS AND ITS INFLUENCE ON THE TRANSFORMED STRUCTURE

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Abstract—This article investigates the kinetics of austenite grain growth during heating and the features of phase transformations depending on the austenite grain size in ferrite-bainitic, bainite-martensitic and martensitic shipbuilding steels. The kinetics of dynamic and static recrystallization is studied depending on the holding time at a given temperature. The studies carried out made it possible to determine the effect of the austenite grain size in shipbuilding steels of manganese, manganese-nickel and nickel alloying composition on the transformed structure.

Keywords: shipbuilding steel, austenite grain size, dynamic recrystallization, static recrystallization, phase transformations, structure, properties

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METHODOLOGY OF SCIENTIFIC SELECTION OF ACCUMULATION MODES AND PRELIMINARY HEAT TREATMENT OF FORGINGS MADE OF MEDIUM CARBON MEDIUM ALLOY STEELS

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Abstract—This article considers issues related to the forgings from medium-carbon medium-alloyed steel grades. It is necessary to take into account the processes of phase and structural transformations when assigning modes of accumulation of ingots after forging and preliminary heat treatment (PHT). The main provisions of the appointment of PHT modes were analyzed. The paper formulates their limited application when using diagrams of isothermal transformation of austenite, built according to standard techniques.

Keywords: diffusion transformation, accumulation, isothermal exposure, structural heredity, grain size variation, incubation period of austenite decomposition, thermokinetic diagram

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ESTIMATION OF THE INFLUENCE OF THE STRUCTURAL STATE ON THE MECHANICAL PROPERTIES OF STEEL 14Kh17N2

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Abstract—The issues of ensuring the stability of the structural state and mechanical properties are very relevant for production in the manufacture of products, as well as for assessing their quality and extending the resource. The article presents the results of a study of the influence of heat treatment parameters on the structural characteristics of steel-martensitic-ferritic class 14X17H2, the impact of structural parameters on mechanical properties is assessed.

*Keywords***:** steel, heat treatment, hardening, tempering, structure, carbides, delta ferrite, hardness, relaxation, mechanical properties

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STRUCTURAL-PHASE STATE AND DEFECTIVE SUB-STRUCTURE OF LOW-CARBON STEEL WELDS

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Abstract–The structural-phase state, defective substructure and fracture surface of welds made of low-carbon alloy steel obtained with and without a carbon-containing additive have been investigated by scanning and transmission electron microscopy. A quantitative analysis of the parameters of the structure and dislocation substructure of the weld metal is carried out, and the contributions of the scalar and excess dislocation density to the strength of welds are estimated. It is shown that high values of scalar and excess dislocation density in a weld formed without a carbon-containing additive in the flux can lead to material embrittlement.

Keywords: weld, fractography, structure, phase composition, fracture surface, dislocations

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SOME ASPECTS OF IMPROVING THE QUALITY OF GTE CAST TURBINE BLADES OF NICKEL SUPERALLOYS

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Abstract—The results of the development of casting technology for single-crystal high-pressure turbine blades from nickel superalloys with a crystallographic orientation (CGO) [001] were obtained on an automated casting unit for directional crystallization UVNK-9A, at machine-building enterprise. The construction of the casting blades blocks, technologies for the manufacture of molds, rods and casting of GTE working blades of heat-resistant nickel alloys with a single-crystal structure and set-up CGO have been developed under real production conditions on UVNK-9A units substituting through-type furnaces. It is shown that preproduction series of single-crystal castings of working blades with shroud shelf were obtained, with a yield of suitable structure ≥ 75%. The structural-phase characteristics of the alloy of single-crystal blades castings were investigated by scanning electron microscopy in as cast state and after subsequent heat treatment. A comparative quantitative analysis of the microstructure and strength characteristics of supernickel alloy castings with CGO [001], obtained on a high-gradient directional crystallization unit and in a through-type furnace.

Keywords: heat-resistant nickel alloys; directional crystallization; single-crystal blades; microstructure

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PLASMA PROTECTIVE CERAMIC COATING OF THE Al_2O_3–Ni SYSTEM FROM CLADDED POWDER MIXTURE

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Abstract—To solve the problem of increasing the adhesive-cohesive strength of multifunctional plasma coatings used to protect parts of power and machine building equipment from wear and corrosion, a ceramic coating of the Al_2O_3–Ni system, obtained from a powder mixture based on corundum clad nickel. The coating was applied by the method of high-energy plasma powder spraying (on the "Thermoplasma" installation) on the intermetallic sublayer of the Ni–Co–Cr–Al–Y system. The aim of this work was to study the microstructure, phase composition, mechanical, tribological and adhesion properties of a plasma ceramic coating formed from a powder material based on aluminum oxide clad with a refractory metal component (nickel). According to the research results, it was found that the initial powder material has a multiphase composition (Ni + α-Al_2O_3 + γ-Al_2O_3) and a spherical morphology of particles. From it, during high-energy plasma spraying, a coating is formed with a phase composition (Ni + γ-Al_2O_3 + γ'-Ni_3Al), a layered microstructure with nickel interlayers and a columnar structure of oxide grains. The coating has high values of hardness and adhesive-cohesive strength, low coefficient of friction and is recommended for wear protection of parts of power engineering and mechanical engineering.

Keywords: cladded powder material, high-energy plasma spraying, oxide phases, layered microstructure, columnar grains, hardness, coefficient of friction, adhesive-cohesive strength

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OBTAINING PROTECTIVE COATINGS BASED ON $NbCo_2$–Zr–WC COMPOSITION

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Abstract—The results of complex studies on the production of protective coatings based on the composition $NbCo_2$–Zr–WC are presented. Coatings obtained by microplasma spraying have high microhardness (~15.0 GPa) and wear resistance (~1.0·10–8).

Keywords: intermetallic compound, protective coatings, microplasma spraying, microhardness, wear resistance

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STUDY OF HIGH-TEMPERATURE BEHAVIOR OF A HEAT-PROTECTIVE COATING OF ZIRCONIUM DIOXIDE BY LASER HEATING

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Abstract—When studying the high-temperature behavior of the heat-protective coating of zirconium dioxide, the method of laser heating has been tested. The coating was applied by the method of high-energy plasma spraying on the intermetallic sublayer of the Ni–Co–Cr–Al–Y system made of a powder material of the composition (ZrO_2 + 7% Y_2O_3) of spherical morphology.

The aim of this work was to study the processes of structural-phase transformations, melting and crystallization occurring in a ceramic coating material under the action of a single laser pulse with a duration of 14 ms with different energies (5, 10, 15, and 20 J). It was found that after spraying, the coating in the initial state has a two-phase composition (T-ZrO_2 + K-ZrO_2), and a layered microstructure with a columnar structure of zirconium dioxide grains. Laser heating with a pulse energy of 5 J stimulates the phase transformation T-ZrO_2 → K-ZrO_2, the appearance of porosity and microcracks. With an increase in the pulse energy to 10 and 15 J, the processes of melting and ultrafast crystallization, accompanied by grain refinement, intensively occur on the coating surface. According to the theoretical estimates, the reflow processes affect surface layers with a thickness of 2.2 to 6.6 μm, and phase transformations take place at a depth of ~11 μm. With an increase in the laser pulse energy to E = 20 J, the process of destruction of the coating was initiated by the mechanism of cracking with delamination of fragments of the surface layer 5–10 μm thick.

The laser heating method is recommended as an express diagnostics for comparative tests of the heat resistance of ceramic coatings obtained by different methods and from different starting materials.

Keywords: high-energy plasma spraying, powder material, zirconium dioxide, layered microstructure, columnar grains, pulsed laser heating, structural phase transformations, melting, recrystallization, express method

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EFFECT OF SURFACE TENSION OF INTERSTITIAL FLUID ON THE PHYSICOCHEMICAL PROPERTIES OF LAYERED DOUBLE MAGNESIUM AND ALUMINUM HYDROXIDES OBTAINED BY SOLID-PHASE SYNTHESIS

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Abstract—The paper presents the results of studies of the effect of the surface tension of the interstitial fluid on the structural and surface properties (specific surface area and pore volume, pore diameter distribution) of layered magnesium and aluminum double hydroxides (Mg-Al LDH) obtained by the interaction of $AlCl_3 \cdot 6H_2O$, $MgCl_2 \cdot 6H_2O$ and ammonium carbonate. The equations connecting the specific surface area and the specific pore volume of the synthesized Mg-Al LDH samples with the surface tension of the interstitial medium are obtained. It is shown that the substitution of the aqueous medium in the pore space for acetone before drying the synthesized Mg-Al LDH allows to significantly increase the capacity of the adsorption monolayer of products and does not significantly affect the mechanism of the sorption process.

Keywords: layered double magnesium and aluminum hydroxide, liquid surface tension, specific surface area, specific pore volume, sorption

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OBTAINING A HIGH-NICKEL-ALLOYED LAYER ON THE SURFACE OF LOW-CARBON STEEL USING MONOMETALLIC POWDERS AND LASER PROCESSING

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Abstract—The paper studies deposition of a highly nickel-alloyed corrosion-resistant layer on the surface of a low-carbon economically alloyed steel. The formation of the layer is carried out in two stages – at the first stage, a precursor coating is applied by cold spraying, and at the second, an alloyed layer is formed on the surface by laser. A layer with a nickel content of up to 70% is formed on the surface of the steel. The results of X-ray diffraction phase analysis indicate that a face-centered cubic lattice of a solid solution and Ni_3Fe intermetallic compound has been formed in the studied layer.

Keywords: laser cladding, laser alloying, cold gas-dynamic spraying, intermetallic compounds, microhardness, fiber-optic laser, nickel alloys

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PREDICTION OF HYDROSTATIC STRENGTH OF SPHEROPLASTICS

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Abstract—In this work, calculations of the hydrostatic strength of a spheroplastic are carried out using the previously described empirical formula. The calculations were based on the physical and mechanical characteristics of the polymer binder and hollow glass microspheres. Measurements of the physical and mechanical characteristics of the polymer binder, hollow glass microspheres and spheroplastics were performed with standard methods: dynamic mechanical analysis (DMA), gas and hydrostatic pycnometers. The results of tensometric tests of Poisson's ratios of binders were also used. The hydrostatic strength measurements were carried out in a high pressure hydrochamber. Comparison of the calculations and experimental data for a number of spheroplastic compositions based on multicomponent epoxy binders is carried out. The degree of influence of the properties of microspheres and binders on the hydrostatic strength of a spheroplastic is shown. The correlation of the calculated values with experimental knowledge is assessed.

Keywords: spheroplastics, multicomponent epoxy binder, glass microspheres, physical and mechanical characteristics, prediction of hydrostatic strength

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SOLUTION-FREE TECHNOLOGY OF PREPREG PRODUCTION BASED ON HIGH-TEMPERATURE POWDER PHTHALONITRILE BINDING

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Abstract—The article presents the results of studies of the properties of samples of powder phthalonitrile binding with different particle-size distribution. Microstructural studies of the phthalonitrile binder have been carried out. The main technologies for combining polymer binding with reinforcing fillers are described. Examples of calculating the ranges of values of the weight characteristics of prepregs are given, taking into account the possible spread of the surface density of the reinforcing filler and the selected

range of the mass content of the binder. The fundamental possibility of using a powder phthalonitrile binding to obtain PCMs using prepreg technology is shown.

Keywords: polymeric composite materials, prepreg, fibreglass, phthalonitrile, matrix, autohesion, powder binding

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FEM ASSESSMENT OF THE PROCEDURES PROVIDING FOR A UNIFORM CRACK SHAPE IN SPECIMENS FOR FRACTURE TOUGHNESS TESTED IN FULL THICKNESS

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Abstract—Acceptance tests of base metal and welded joints include the evaluation of critical CTOD values as required in product specifications. Tests have to be done in natural (full) thickness. For blanks made of pipes, quantitative criteria of satisfactory straightening and the fixture dimensions are developed. Satisfactory fatigue precrack front linearity can be attained with additional treatment. Local side compression appears efficient for the examined materials. Sequential FEM calculations of welding, side compression and specimen notching allow constructing the residual stress curves to predict fatigue crack extension. The optimum compression displacement is found. The above sequence of operations is proved to be preferable in comparison with side compression performed after notching.

Keywords: fracture toughness, welded joints, pipes, fatigue crack front linearity, local side compression

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HIGH-TEMPERATURE LOW-CYCLE FATIGUE OF A HEAT-RESISTANT ALLOY OF THE Co–Cr–Ni–W–Ta SYSTEM OBTAINED BY ADDITIVE MANUFACTURING

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Abstract—The results of fatigue tests of smooth cylindrical specimens with total deformation control under conditions of a symmetric cycle and elevated temperature are presented. The relationship between the values of the fatigue characteristics of the material with allowance for stresses, plastic deformation and the number of cycles to failure is considered. Comparison of deformation curves plotted from experimental data with deformation curves plotted by evaluative methods is presented.

Keywords: mechanical properties, fatigue, high-temperature alloys based on cobalt, selective laser melting (SLM), deformation approach, Ramberg-Osgood equation, Basquin-Manson-Coffin equation.

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STUDY OF THE METAL OF THE IRRADIATED WELD OF THE WWER-440 REACTOR BODY AFTER 45 YEARS OF OPERATION

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Abstract—This work presents the results of a study of the mechanical characteristics and chemical composition of metal samples cut from a non-irradiated weld seam of a WWER-440 reactor vessel after 45 years of operation. The calculated distribution of the critical temperature of brittleness over the thickness of the irradiated weld seam of the WWER-440 reactor vessel (140 mm) is obtained taking into account the distribution of the initial properties, the content of phosphorus and copper, and the density of the fast neutron flux over the thickness of the seam. Since all the circumferential welds connecting the shells in the WWER-440 reactor vessel are manufactured using the same technology, the results of the study of the non-irradiated weld can be used to assess the distribution of properties in the irradiated weld. At the same time, it is assumed that the effect of thermal aging at a temperature of 270°C (operating temperature of a non-irradiated weld) is small and can be neglected.

Keywords: weld, critical brittleness temperature, WWER-440 reactor vessel, fast neutron fluence, radiation embrittlement, phosphorus content, copper content.

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A STUDY OF PRIMARY DAMAGE FORMATION IN COLLISION CASCADES IN TITANIUM

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Abstract—Molecular dynamics (MD) simulations were applied to study radiation damage formation in collision cascades initiated by primary knock-on atoms (PKA) with energy E_{PKA} = 5, 10, 15 and 20 keV in α-Ti at T = 100, 300, 600 and 900 K ambient temperatures. A series of 24 collision cascades was simulated for each (E_{PKA}, T) pair. The necessary sampling set size was justified by a simple *a posteriori* procedure. The number of Frenkel pairs and the fraction of vacancies, ε_v, and self-interstitial atoms (SIAs), ε_i, in point defect clusters were evaluated as functions of (E_{PKA}, T). It was established that collision cascades in α-Ti are extended along PKA trajectories and tend to split into subcascades. In contrast to other elemental metals with close-packed crystal structure, $\varepsilon_v \geq \varepsilon_i$ in collision cascades in α-Ti. Moreover, both ε_v and ε_i demonstrate weak temperature dependence. This is anindirect indication that both vacancy and SIA clusters created in collision cascades in α-Ti are stable in the considered temperature range.

Keywords: α-titanium, radiation damage, Frenkel pairs, point defect clusters, collision cascades, molecular dynamics simulations

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INVESTIGATION OF THE MICROSTRUCTURE OF THE BASE AND WELD METAL OF STEEL Fe–0.08C–18Cr–10Ni–Ti AFTER LOW-TEMPERATURE IRRADIATION IN THE BOR-60 REACTOR IN THE RANGE OF DAMAGE DOSES FROM 40 TO 101 DISPLACEMENTS PER ATOM

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Abstract—The microstructures of irradiated samples of Fe–0.08C–18Cr–10Ni–Ti steel were studied by transmission electron microscopy (TEM). Specimens of the base metal (BM) and the weld metal (WM) were irradiated in the BOR-60 reactor at temperatures from 330 to 350°C to doses of 43 dpa (BM) and 40 dpa (WM), 96 dpa (BM) and 101 dpa (WM). New data on the quantitative microstructural characteristics of dislocation loops, titanium carbonitrides, fine G-phase, and voids in irradiated specimens in the range of damage doses from 40 to 101 dpa were obtained during the studies of specimens of the base metal and the weld metal.

Keywords: Fe–0.08C–18Cr–10Ni–Ti steel, neutron irradiation, BOR-60, damage dose, microstructure, dislocation loops, secondary phases, G-phase particles

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