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THE EFFECT OF MICROALLOYING ON MECHANICAL PROPERTIES OF LOW-CARBON CHROMIUM-NICKEL-MOLYBDENUM STEEL

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Abstract—The research covers the effect of niobium, as well as niobium and vanadium together, on mechanical properties of high-strength chromium-nickel-molybdenum steel after thermal improvement (heat treatment). The mechanical properties of steels are determined after applying various tempering temperatures (from 580 to 660°C), durations of tempering (from 1 to 16 hours), and also after quenching from rolling heat and furnace heat with subsequent tempering. It is shown that after quenching and tempering in the temperature range 580–660°C, simultaneous microalloying by niobium and vanadium, compared to microalloying by niobium alone, increases the yield strength but in significantly decreases toughness and ductility. Quenching from rolling heat increases strength while maintaining high toughness and the increase in strength is most noticeable for steel microalloyed only by niobium.

Keywords: microalloying, chromium-nickel-molybdenum steel, quenching, subsequent tempering.

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REFERENCES

1. Gorynin, I.V., Rybin, V.V., Malyshevsky, V.A., Semicheva, T.G., *Teoriticheskie i eksperimentalnye osnovy sozdaniya vtorichnotverdeyushchikh svarivaemykh konstruktsionnykh stalei* [Theoretical and experimental basics of secondary hardening welded construction steels creating], *Metallovedenie i Termicheskaya Obrabotka Metallov*, 1999, No 3, pp. 8–13.

2. Gorynin, I.V., Rybin, V.V., Malyshevsky, V.A., Semicheva, T.G., Sherohina, L.G., *Prevrashchenie dislokatsionnogo martensita pri otpuske vtorichnotverdeyushchei stali* [Transmutation of dislocation martensite at leaving of secondary hardening steel], *Metallovedenie i Termicheskaya Obrabotka Metallov*, 1999, No 3, pp. 13–19.

3. Gorynin, I.V., Rybin, V.V., Malyshevsky, V.A., Legostaev, Yu.L., Semicheva, T.G., *Osnovnye aspekty sozdaniya i primeneniya vysokoprochnoi konstuktsionnoi stali* [Basic aspects of creation and application of high-strength construction steel], *Voprosy Materialovedenia*, 1999, No 3, pp. 7–20.

4. Haisterkamp, F., Hulka, K., Matrosov, Yu.I., Morozov, Yu.D., Efron, L.I., Stolyarov, V.I., Chevskaya, O.N., *Niobiisoderzhashchie nizkolegirovannye stali* [Niobium-containing low-alloyed steels], Moscow: SP Intermet Inzhiniring, 1999, p. 94.

5. Pyshmintsev, I.Yu., Pumpyansky, D.A., Farber, V.M., *Plastichnost stali i ee kharakteristiki* [Plasticity of steel and its characteristics], *Metallovedenie i Termicheskaya Obrabotka Metallov*, 2007, No 11, pp. 20–27.

6. Goldshtein, M.I., Farber, V.M., *Dispersionnoe uprochnenie stali* [Dispersive hardening of steel], Moscow: Metallurgiya, 1979, p. 208.

7. Shchastlivtsev, V.M., Tabatchikova, T.I., Yakovleva, I.L., Egorova L. Yu., Watutin K. A., Kruglova A. A., Orlov V. V., Khlusova E. I. *Issledovanie struktury i svoistv nizkolegirovannoi khladostoikoi stali 10 GNB, proizvedennoi po razlichnym tekhnologicheskim skhemam* [Study of structure and properties of 10 GNB low-alloyed cold-resistant steel, made by different technologic schemes], *Voprosy Materialovedeniya*, 2008, No 1, pp. 7–20.

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RESEARCH OF RECRYSTALLIZATION PROCESSES IN LOW-CARBON LOW-ALLOYED STEEL DURING HIGH-TEMPERATURE ROLLING MODELING

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Abstract—Processes of dynamic and static recrystallization occurring at different conditions of plastic deformation (reduction modes, deformation temperature) of low-carbon low-alloyed steel are under consideration. Modeling of thermomechanical processing is carried out at Gleeble 3800, followed by complex microstructural analysis. Temperature-deformation conditions leading to formation of uniform dispersed structure are revealed during the investigations. In conclusion the results of implementation in industry of worked out hot rollingmodes are given.

Keywords: thermomechanical treatment, low-carbon steel, recrystallization, hot rolling, ferrite-bainite structure, Gleeble 3800

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REFERENCES

1. Bernshtein, M.L., Zaimovsky, V.A., Kaputkina, L.M., *Termomekhanicheskaya obrabotka stali* [Thermal and mechanical treatment of steel], Moscow: Metallurgy, 1983, p. 480.

2. Efron, L.I., Litvinenko, D.A., *Poluchenie vysokoprochnykh svarivaemykh stalei s beinitnoi strukturoi s primeneniem termodeformatsionnoi obrabotki* [Obtaining of high-strength welded steels with bainite structure using thermal and deformational treatment], MiTOM, 1994, No 10, pp. 28–32.

3. From, A., Standstrom, R., Influence of mixed grain side distribution on the toughness in high and extra high strength steels, *Mater. Characterization*, 1999, No 42, pp. 111–122.

4. Kantor, M.M., Voronin, V.N., Bozhenov, V.A., Antonov, V.G., Sharygin, Yu.M., *Materialovedcheskie usloviya sokhraneniya nesushchei sposobnosti metalla magistralnykh gazoprovodov pri ikh dlitelnoi ekspluatatsii* [Material science conditions of saving of trunk gas pipeline metal carrying ability at long exploitation], *Metally*, No 4, 2009, pp. 46–56.

5. Orlov, V.V., *Printsipy upravlyaemogo sozdaniya strukturnykh elementov nanorazmernogo mashtaba v trubnykh stalyakh pri znachitelnykh plasticheskikh deformatsiyakh* [Principles of controlled creation of nano-sized structure elements in tube steels at significant plastic deformation], *Voprosy Materialovedeniya*, 2011, No 2 (66), pp. 5–17.

6. Shchastlivtsev, V.M., Tabatchikova, T.I., Yakovleva, I.L., *Issledovanie struktury i svoistv nizkolegirovannoi khladostoikoi stali 10 GNB, proizvedennoi po razlichnym tekhnologicheskim skhemam* [Study of structure and properties of 10 GNB low-alloyed cold-resistant steel, made by different technologic schemes], *Voprosy Materialovedeniya*, 2008, No 1 (53), pp. 7–19.

7. Fernandez, A.I., Uranga, P., Lopez, B., Rodrigues-Ibabe, J.M., Dynamic recrystallization behavior covering a wide austenite grain size range in Nb and Nb-Ti microalloyed steels, *Materials Science and Engineering*, 2003, A 361, pp. 367–376.

8. Perttula, J.S., Karjalainen, L.P., Recrystallization in austenite measured by double compression and stress relaxation methods, *Materials Science Technologies*, 1998, No 14, pp. 626 – 630.

9. Zisman, A.A., Soshina, T.V., Khlusova, E.I., *Postroenie i ispolzovanie kart strukturnykh izmenenii pri goryachei deformatsii austenita nizkouglerodistoi stali 09HN2MDF dlya optimizatsii promyshlennykh tekhnologii* [Construction and use of maps of structure changes at hot deformation of low-carbon 09HN2MDF steel austenite for optimization of industrial technologies], *Voprosy Materialovedeniya*, 2013, No 1 (73), pp. 37–48.

10. Medina, S.F., Hernandez, C.A., Modeling of the Dynamic Recrystallization of Austenite in Low Alloy and Micro-alloyed Steels, *Acta Materialia*, 1996, V. 44, No 1, pp. 155–163.

11. Majid Abbasi, et al., EBSD and reconstruction of pretransformation microstructures, examples and complexities in steels, M*aterials Characterization*, 2014, No 95, pp. 219–231.

12. Medina, S.F., Quispe, Valles, P., Banos, J.L., Recrystallization-Precipitation Interaction Study of Two Medium Carbon Niobium Micro-alloyed Steels, *ISIJ International*, 1999, V. 39, No 9.

13. Sun, W.P., Militzer, M., Bai, D.Q., Jonas, J.J., Measurement and Modelling of the Effects of Precipitation on Recrystallization Under Multipass Deformation Conditions, *Acta Materialia*, 1993, V. 41, No 12.

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VIABILITY OF TURBINE BLADE MATERIAL WITH A LONG SERVICE LIFE

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Abstract—This article deals with structural features and characteristic changes that affect the mechanical characteristics after different service life in real conditions using the example of the blades of the 4th stage of turbine GTE-45-3 with an operating time of 13,000 to 100,000 hours. To study the change in the state of the material under different operating conditions, determine the degree of influence of heat treatment on the regeneration of the microstructure, and restore the mechanical characteristics of the alloy after different periods of operation, non-standard methods were used: relaxation tests on miniature samples to determine the physical yield strength and microplasticity limit and quantitative evaluation of the plasticity coefficient of the material from experimental values of hardness, which allow us to identify the changes occurring in the microvolumes of the material and predict the performance of the product as a whole.

Keywords: turbine blades, heat-resistant nickel alloy, heat treatment, microstructure, carbide phase, mechanical characteristics, physical yield strength, microplasticity limit, hardness, plasticity coefficient.

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REFERENCES

1. Tsareva, I.N., Berdnik, O.B., Krivina, L.A., Tarasenko, Yu.P., Development of a modern comprehensive technology for extending the life of turbine blades of SGT Siemens power plants and alike, *MATEC Web of Conferences 224, 01023 (2018) ICMTMTE*, 2018.

2. Tarasenko, Yu.P., Berdnik, O.B., Tsareva, I.N., Kazansky, D.A., The analysis of the main structural and mechanical characteristics of EP800 and EI893 alloys to optimize production of the first stage of a GTE-45-3 gas-turbine power plant, *Journal of Machinery Manufacture and Relability*, 2016, V. 45, pp. 83–89.

3. Skudnov, V.A., Chegurov, M.K., *Relaksatsiya napryazhenii v metallakh i splavakh* [Relaxation of tensions in metals and alloys], Nizhny Novgorod: NGTU, 2010, p. 30.

4. Milman, Yu.V., Golovanov, B.A., Chugunova, S.I., *Kharakteristiki plastichnosti, poluchaemye pri izmerenii tverdosti* [Specifications of plasticity obtained at strength measurement], Kiev, 1992, p. 25.

5. Zubchenko, A.S., Koloskov, M.M., Kashirsky, Yu.V., et al., *Marochnik stalei i splavov* [Markbook of steels and alloys], Moscow: Mashinostroenie, 2003, 2nd edition, p. 784.

6. Patent No 2204817, Russian Federation: Chuvildeev, V.N., Madyanov, S.A., Kraev, A.P., Nokhrin, A.V., Melnikov, G.Yu., Gruntenko, G.S., Nikityuk, V.M., Sposob opredelenija technisheskogo sostojanija materialov elementov konstrukzii [Way of determination of construction elements materials technical state], Published 27.04.2006.

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RESEARCHING STRUCTURE HETEROGENEITY OF VT41 TITANIUM ALLOY BILLET AFTER THERMOMECHANICAL TREATMENT

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Abstract—The heterogeneity of the titanium VT41 structural state after hot upset test was investigated by analytical methods of optical and scanning microscopy. Vickers microhardness measurements were performed to estimate the mechanical properties. The analysis of the distribution of deformation and the features of the formation of the structural components of the specimen. Globular grains were deformed by the mechanism of intergranular slipping. β-grains and α-plates made the greatest contribution to plastic deformation. Lamellar grains of α-phase in the zone of localization of deformation undergo recrystallization. The dimensions of the zone in which the recrystallization occurred, coincide with the zone of localization of the deformation, estimated by macrostructure. When tempering the billet, the β-phase in the center of the sample breaks down into α-plates, and in the near-surface areas into smaller grains, probably representing needle-like β-titanium martensite. A decrease in microhardness in the central regions may be due both to recrystallization and to the fact that martensite has been quenched in the surface layers.

Keywords: titanium alloys, deformation, recrystallization, metallography, SEM

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REFERENCES

1. Aleksandrov, V.K., Anoshkin, N.F., Bochvar, G.A., et al., *Polufabrikaty iz titanovykh splavov* [Semi-finished products made of titanium alloys], Moscow: Metallurgiya, 1979.

2. Solonina, O.P., Glazunov, S.G., *Zharoprochnye titanovye splavy* [Heat-resistant titanium alloys], Moscow: Metallurgiya, 1976.

3. Anoshkin, N.F., Brun, M.Ya., Shakhanova, G.V., Trebovaniya k bimodalnoi strukture s optimalnym kompleksom mekhanicheskikh svoistv i rezhimy ee polucheniya [Requirements to bimodal structure with optimal complex of mechanical properties and regimes of its obtaining], *Titan*, 1998, No 1 (10), pp. 35–41.

4. Kashapov, O. S., Pavlova, T. V., Kalashnikov, V. S., Zavodov, A. V., Vliyanie usloviy okhlazhdeniya krupnykh promyshlennykh pokovok iz zharoprochnogo titanovogo splava VT41 na fazovyy sostav i mekhanicheskiye svoistva [Influence of cooling conditions of large industrial forgings from heat-resistant titanium alloy VT41 on the phase composition and mechanical properties], *Tsvetnye metally*, 2018, No 2, pp. 76–82. DOI: 10.17580 / tsm.2018.02.10.

5. Moiseyev, V.N., *Titanium alloys: Russian Aircraft and Aerospace applications*, Series: Advances in metallic alloys, Fridlyander, J.N., Eskin, D.G., (Eds), Taylor & Francis Group, 2006.

6. Suwas S., Singh A.K. Textural changes during β→α and α→β→α transformations in a Near- α Titanium Alloy, *Metallurgical and materials transactions*, 2004, V. 35A, pp. 925–938. DOI: 10.1007/ s11661-004-0017-8.

7. Jing, R. Liang, S.X., Liu, C.Y., et al. Structure and mechanical properties of Ti–6Al–4V alloy after zirconium addition, *Materials Science and Engineering: A*, 2012, V. 552, pp. 295–300. DOI: 10.1016/j.msea.2012.05.043.

8. Fu, B., Wang, H., Zou, C., Wei, Z., The influence of Zr content on microstructure and precipitation of silicide in as-cast near α titanium alloys, *Materials Characterization*, 2015, V. 99, pp. 17–24. DOI: 10.1016/j.matchar.2014.09.015.

9. Ahmed, T., Rack, H.J., Phase transformations during cooling in (α+β) titanium alloys, *Materials Science and Engineering A*, 1998, V. 243, pp. 206–211, DOI: 10.1016/j.matchar.2016.05.020.

10. Zhang, X. D., Evans, D. J., Baeslack, W.A., Fraser, H.L., Effect of long term aging on the microstructural stability and mechanical properties of Ti-6Al-2Cr-2Mo-2Sn-2Zr alloy, *Materials Science and Engineering*, 2003, A344, pp. 300–311.

11. Da Costa Teixeira, J., Appolaire, B., Aeby-Gautier, E., et al., Transformation kinetics and microstructures of Ti17 titanium alloy during continuous cooling, *Materials Science and Engineering A*. 2007, V. 448, pp. 135–145. DOI: 10.1016/j.msea.2006.10.024.

12. Lutjering, G., Williams, J.C., *Titanium*. Berlin; Heidelberg: Springer-Verlag, 2nd ed., 2007.

13. Sauer, C., Lutjering, G., Influence of layers at grain boundaries on mechanical properties of Ti-alloys, *Materials Science and Engineering*, 2001, A319–321, pp. 393–397.

14. Es-Souni, M., Creep behaviour and creep microstructures of a high-temperature titanium alloy Ti–5.8Al–4.0Sn–3.5Zr–0.7Nb–0.35Si–0.06C (Timetal 834). Part I. Primary and steady-state creep, *Materials Characterization*, 2001, No 46, pp. 365–379.

15. Davies, P., Pederson, R., Coleman, M., Birosca, S., The hierarchy of microstructure parameters affecting the tensile ductility in centrifugally cast and forged Ti-834 alloy during high temperature exposure in air, *Acta Materialia*, 2016, No 117, pp. 51–67.

16. Kashapov, O.S., Pavlova, T.V., Kalashnikov, V.S., Kondratev, A.R., *Issledovanie vliyaniya rezhimov termicheskoi obrabotki na strukturu i svoistva opytnykh pokovok iz splava VT41 s melkozernistoi strukturoi* [Researching of influence of thermal treatment regimes on structure and properties of test forgings made of VT41 alloy with fine-grained structure], *Aviatsionnye materialy i tekhnologii*, 2017, No 3 (48), pp. 3–9, DOI: 10/18577/2071-9140-2017-0-3-3-7.

17. Russo, P.A., Yu, K.O., Effect of Ni, Fe, and primary alpha on the creep of alpha-beta processed and annealed Ti-6Al-2Sn-4Zr-2Mo-0.09Si, *Titanium-99. Science and technology*, 1999, pp. 596–603.

18. Welk, B.A., Microstructural and Property Relationships in Titanium Alloy Ti-5553, *Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University*, The Ohio State University, 2010, p. 88.

19. Zeng, W.D., Zhou, Y.G., The influence of microstructure on dwell sensitive fatigue in Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy, *Materials Science and Engineering*, 2000, No A290, pp. 33–38.

20. Gorbovets, M.A., Nochovnaya, N.A., *Vliyanie mikrostruktury i fazovogo sostava zharoprochnykh titanovykh splavov na skorost rosta treshchiny ustalosti* [Influence of microstructure and phase composition of heat-resistant titanium alloys on fatigue crack growth speed], Trudy VIAM, 2016, No 4, Art. 3, URL: http://www.viam-works.ru (date of reference 03/12/2018), DOI: 10/18577/2307-6046-2016-0-9-11-11.

21. Zakharova, L.V., *Vliyanie khimicheskogo sostava, termicheskoi obrabotki i struktury na stoikost titanovykh splavov k rastreskivaniyu ot goryachesolevoi korrozii* [Influence of chemical composition, thermal treatment and structure on durability of titanium alloys to cracking by hot salty corrosion], Trudy VIAM, 2016, No 9, article 11, URL: http://www.viam-works.ru, (accessed December 3, 2018), DOI: 10/18577/2307-6046-2016-0-9-11-11.

22. Orlov, M.R., Naprienko, S.A., Razrushenie dvukhfaznykh titanovykh splavov v morskoi vode [Destruction of double phased titanium alloys in marine water], *Trudy VIAM*, 2017, No 1, Art. 10, URL: http://www.viam-works.ru (date of reference 03/12/2018), DOI: 10/18577/2307-6046-2017-0-1-10-10.

23. Kablov, E.N., Kovalev, I.E., Zhemanyuk, P.D., Tkachenko, V.V., Voitenko, S.A., Pirogov, L.A., Banas, F.P., Kovalev, A.E. Efficiency of surface cold-work hardening of titanium alloys having different phase composition, *Computational and Experimental Methods, Fifth International Conference on Computer Methods and Experimental Measurements for Surface Treatment Effects*, Seville, 2001, pp. 23–32.

24. Kablov, E.N., Kashapov, O.S., Pavlova, T.V., Nochovnaya, N.A., *Razrabotka opytno-promyshlennoi tekhnologii izgotovleniya polufabrikatov iz psevdo-α-titanovogo splava VT41* [Development of test-industrial technology of manufacturing of semi-finished products made of pseudo-α-VT41 titanium alloy], *Titan*, 2016, No 2 (52), pp. 33–42.

25 Sun, Z., Li, X., Wu, H., Yang, H., Morphology evolution and growth mechanism of the secondary Widmanstatten в-phase in the TA15 Ti-alloy, *Materials Characterization*, 2016, V. 118, pp. 167–174.

26. Kablov, E.N., Strategicheskie napravleniya razvitiya materialov i tekhnologii ikh pererabotki na period do 2030 goda [Strategic development of materials and technologies of their recycling until 2030], *Aviatsionnye Materialy i Tekhnologii*, 2012, No S, pp. 7–17.

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ANALYSIS OF THE STRESS-STRAIN STATE OF COPPER M0B UNDER DIFFERENT SCHEMES OF EQUAL CHANNEL ANGULAR PRESSING AND ITS EFFECT ON THE STRUCTURE AND PHYSICAL AND MECHANICAL PROPERTIES

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Abstract—The results of studies of the stress-strain state of copper M0b after deformation under different schemes of equal channel angular pressing (ECAP) are presented. The level of macro and micro stresses in copper has been determined in various ECAP modes. It is shown that the strength properties, deformation porosity and parameters of the fine copper structure differ depending on the loading pattern.

Keywords: M0b copper, equal channel angular pressing, stress-strain state, fine structure parameters

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REFERENCES

1. Valiev, V.Z., Aleksandrov, I.V., *Nanostrukturnye materialy, poluchennye intensivnoi plasticheskoi deformatsiei* [Nanostructured materials obtained using intensive plastic deformation], Moscow: Logos, 2000, p. 272.

2. Rybin, V.V., *Bolshie plasticheskie deformatsii i razrushenie metallov* [Big plastic deformation and destruction of metals], Moscow: Metallurgiya, 1986, p. 223.

3. Cheremskoy, P.G., Slezov, V.V., Betekhin, V.I., *Pory v tverdom tele* [Pores in solid body], Moscow: Energoatomizdat, 1990, p. 376.

4. Umansky, Ya.S., Skakov, Yu.A., Ivanov, A.N., Rastorguev, L.N., *Kristallografiya, rentgenografiya i elektronnaya mikroskopiya* [Crystalography, roentgenography and electronic microscopy], Moscow: Metallurgiya, 1982, p. 631.

5. Rusakov, A.A., *Rentgenografiya metallov* [Roentgenography of metals], Moscow: Atomizdat, 1977, p. 479.

6. Sennikova, L.F., Davidenko, A.A., Tkachenko, V.M., Metlov, L.S., *Vliyanie bolshikh plasticheskikh deformatsii na strukturu i svoistva medi M0b* [Influence of large plastic deformations on structure and properties of M0b copper], *Voprosy Materialovedeniya*, 2017, No 1 (89), pp. 92–98.

7. Chen, C., Beygelzimer, Y., Toth, L.S., Estrin, Yu., Kulagin, R., Tensile yield strength of a material pre-processed by simple shear, *J. Eng. Mater. Technol*, 2016, No 138 (3), p. 031010.

8. Vasiliev, D.M., *Difraktsionnye metody issledovaniya struktur* [Diffraction methods of structure researching], St Petersburg, 1998, p. 502.

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STRUCTURE AND CURRENT MELTING DENSITIES OF MICROWIRES IN GLASS INSULATION MADE OF COPPER AND RESISTIVE ALLOY BASED ON NICKEL

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Abstract—The paper studies the structure of cast microwires in glass insulation, obtained at the current density, which leads to melting of the metal core. High melting currents values allow us to recommend cast microwires as low-base fuses against current overloads in electric circuits.

Keywords: cast microwire in glass insulation, current density, electrical resistance.

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REFERENCES

1. Badinter, E.Ya., et al., *Litoi mikroprovod i ego svoistva* [Alloyed microwire and its properties], Kishinev: Shtiintsa, 1973.

2. Alferov, Zh.I., Bely, O.V., Dvas, G.V., Ivanova, E.A., *Perspektivnye napravleniya razvitiya nauki v Peterburge* [Promising areas of science development in St Petersburg], St Petersburg: Permyakov, 2015, pp. 137–163.

3. Masailo, D.V., Smelov, A.I., Peskov, T.V., Farmakovsky, B.V., Razrabotka tenzo- i termorezistivnykh splavov dlya litya mikroprovodov [Development of tenzor- and thermal-resistive alloys for microwires casting], *Voprosy Materialovedeniya*, 2014, No 3 (79), pp. 73–78.

4. Patent 2424349, Russian Federation: *Amorphous nickel-based alloy for microwire alloying*. Publ. 16.11.2009.

5. Vasilchuk, V.K., et al., Izmerenie parametrov termopreobrazovatelei s pomoshchyu ustanovki U362M11. Tochnye izmereniya energeticheskikih velichin: peremennogo toka, napryazheniya, moshchnosti, energii i ugla sdviga faz [Measurement of options of thermal converter using U362M11 settings. Accurate measurements of energetic values: alternating current, voltage, power, energy and angle of phase shift], *Proceedings of the Conference*, Leningrad, 1982, pp. 67–70.

6. Solntsev, Yu.P., Pirainen, V.Yu., Vologzhanina, S.A., *Materialovedenie spetsialnykh otraslei mashinostroeniya* [Material science of special machine building industries], St Petersburg: KhIMIZDAT, 2007.

7. Gorynin, I.V., Farmakovsky, B.V., Dlinnomernye litye mikroprovoda v steklyannoi izolyatsii s zhilkoi iz intermetallicheskikh soedineny [Lengthy casted microwires in glass isolation with intermetal bindings vein], *Voprosy Materialovedeniya*, 2015, No 4 (84), pp. 58–61.

8. Miasoedov, B.F., Umnye materialy i perspektivy ikh razvitiya [Smart materials and perspectives of its development], *Materials of 7th All-Russian scientific conference Technologies and materials for experimental conditions*, Tuapse, 2012, pp. 2–4.

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COMPOSITE CLADDED POWDERS FOR SPRAYING OF PROTECTIVE COATINGS

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Abstract—The paper presents results of the development of technology for producing cladded and surface-alloyed powder materials. High-speed mechanosynthesis of matrix powders of FeCrAl and solid nanosized particles of tungsten carbide occurs in a disintegrator in the presence of an active gas phase (nitrogen).

Keywords: cladded, surface-alloyed powders, high-speed mechanosynthesis, nanosized particles.

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REFERENCES

1. Alferov, Zh.I., Bely, O.V., Dvas, G.V., Ivanova, E.A., *Perspektivnye napravleniya razvitiya nauki v Peterburge* [Promising areas of science development in St Petersburg], St Petersburg: Permyakov, 2015, pp. 137–163.

2. Korkina, M.A., Samodelkin, E.A., Farmakovsky B.V., Kuznetsov, P.A., Burkanova, E.Yu. Patent RU(11) 2 460 815(13) C2: *Method for obtaining composite powder material of metal-ceramics system of wear-resistant class*. Publ. 10.09.2012. Bull. 25.

3. Kuznetsov, P.A., Farmakovsky, B.V., *Metody polucheniya nanomaterialov* [Methods of obtaining of nanomaterials], *Materialy dlya morskoi tekhniki*, St Petersburg: Professional, 2010, V. 2, pp. 301–306.

4. Eshmemetieva, E.N., Samodelkin, E.A., Gerashchenkova, E.Yu., Farmakovsky, B.V., Yurkov, M.A., Klimov, V.N., Nizkaya, A.V. Patent RU (11) 2 561 615(13) C1: *Production of composite clad powder for application of coatings.* Publ 27.08.2015. Bull. 24.

5. Bobkova, T.I., *Razrabotka materialov i tekhnologii polucheniya iznosostoikikh gradientnykh pokrytii na baze nanostrukturirovannykh kompozitsionnykh poroshkov* [Development of materials and technology of wear-resistant gradient coatings obtaining based on nanoconstructional composite powders],
Abstract of the Cand. Sc. (Eng) Dissertation, St Petersburg, 2017.

6. Bobkova, T.I., Prudnikov, I.S., Farmakovskaya, A.Ja., Farmakovsky, B.V., Vasiliev, A.F. Patent RU (11) 2 551 037(13) C2: *Method for obtaining wear and corrosion resistant gradient coatings*. Publ. 20.05.2015.

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NANOSTRUCTURED POWDERS BASED ON ALUMINUM REINFORCED BY SILICON NITRIDE DESIGNED FOR SPRAYING OF MULTIFUNCTIONAL STRENGTHENED COATINGS

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Abstract—The work deals with topical issues such as development of composite nanostructured powder materials. The results of creating powders based on the system "aluminum–nitride of silicon" are presented. Complex investigations of the composition, structure and properties of powder materials, as well as coatings formed on their basis by supersonic cold gas dynamic spraying, were carried out.

It has been found that the high-energy treatment of a powder mixture of aluminum with nanofibers of silicon nitride provides the formation of a composite powder in which a new phase of the $Si_{(1-x)}Al_xO_{(1-x)}N_x$ type is formed, which additionally increases the hardness in the coatings to be sprayed.

Keywords: composite materials, nanostructured powders, supersonic cold gas-dynamic spraying, composite coatings, aluminum coatings.

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REFERENCES

1. Rogov, V.A., Solovev, V.V., Kopylov, V.V., *Novye materialy v mashinostroenii* [New materials in machine building], Moscow: RUDN, 2008, p. 324.

2 Gerashchenkov, D.A., Farmakovsky, B.V., Samodelkin, E.A., Gerashchenkova, E.Yu., Issledovanie adgezionnoi prochnosti kompozitsionnykh armirovannykh pokrytii sistemy metall – nemetall, poluchennykh metodom kholodnogo gazodinamicheskogo napyleniya [Research of adhesive strength of composite reinforced coatings of metal – nonmetal system obtained by cold gas dynamic spraying], *Voprosy Materialovedeniya*, 2014, No 2 (78), pp. 103–117.

3. Alferov, Zh.I., Belyi, O.V., Dvas, G.V., Ivanova, E.A*., Perspektivnye napravleniya razvitiya nauki v Peterburge* [Promising areas of science development in St Petersburg], St Petersburg: Permyakov, 2015, pp. 137–163.

4. Bobkova, T.I., Deev, A.A., Bystrov, R.Yu., Farmakovsky, B.V., Nanesenie iznosostoikikh pokrytii s reguliruemoi tverdostyu s pomoshchyu sverkhzvukovogo kholodnogo gazodinamicheskogo napyleniya [Wear-resistant coatings with adjustable hardness made by supersonic cold gas dusting], *Metalloobrabotka*, 2012, No 5, pp.45–49.

5. Bobkova, T.I., Farmakovsky, B.V., Bogdanov, S.P., Sozdanie kompozitsionnykh nanostrukturirovannykh poverkhnostno-armirovannykh poroshkovykh materialov na osnove sistem Ti/WC i Ti/TiCN dlia napyleniya pokrytii povyshennoi tverdosti [Creation of composite nanostructured surfacing-reinforced powdered materials based on Ti/WC and Ti/TiCN systems for spraying high-strength coatings], *Voprosy Materialovedeniya*, 2015, No 3 (83), pp. 80–90.

6. Saalieva, N.J., Engelsht, V.S., Makarov, V.P., Termicheskoe razlozhenie nitrida kremniya v atmosfere azota [Thermal decay of silicon nitride in nitrogen atmosphere], *Vestnik KRSU*, 2003, No 5, Art. 06. URL: https://www.krsu.edu.kg/vestnik/2003/v5/a06.html

7. Gorynin, I.V., Rybin, V.V., Farmakovsky, B.V., Kuznetsov, P.A., Bakhareva, V.A., Nanomaterialy konstruktsionnogo i funktsionalnogo klassa [Nanomaterials of constructional and functional class], *Voprosy Materialovedeniya*, 2006, No 1 (45), pp. 169–178.

8. Skvortsova, A.N., Tolochko, O.V., Bobkova, T.I., Vasileva, E.A., Staritsyn, M.V., Issledovanie vliyaniya tekhnologicheskikh parametrov metoda kholodnogo gazodinamicheskogo napyleniya na iznosostoikost pokrytiya alyuminii-uglerodnye nanovolokna [Research of influence of technological settings of cold gas-dynamic spraying on wear-resistance of aluminum – carbon nano-fibres coatings], *Voprosy Materialovedeniya*, 2018, No 1 (93), pp. 126–136.

9. Gogolinsky, K.V., Lvova, N.A., Useinov, A.S., Primenenie skaniruyushchikh zondovykh mikroskopov i nanotverdomerov dlia izucheniya mekhanicheskikh svoistv tverdykh materialov na nanourovne (obobshchayushchaya statya) [Applying of scanning probe microscopes and hardness nanotesters for discovering of mechanical properties of solid materials on nano-level (generalizing article)], *Zavodskaya laboratoriya. Diagnostika materialov*, 2007, No 6, V. 73, pp. 28–36.

10. Klimov, V.N., Kovaleva, A.A., Bobkova, T.I., Deev, A.A., Chernysh, A.A., Yurkov, M.A., Struktura i svoistva bronzovogo pokrytiya, poluchennogo gazodinamicheskim i mikroplazmennym napyleniem [Structure and properties of bronze coating obtained using gas-dynamic and microplasma spraying], *Voprosy Materialovedeniya*, 2016, No 2 (86), pp. 57–68.

11. Bobkova, T.I., Razrabotka materialov i tekhnologii polucheniya iznosostoikikh gradientnykh pokrytii na baze nanostrukturirovannykh kompozitsionnykh poroshkov [Development of materials and technology of wear-resistant gradient coatings obtaining based on nano-constructional composite powders], *Abstract of the Cand. Sc. (Eng) Dissertation*, St Petersburg, 2017, p. 28.

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FUNCTIONAL GRADIENT COATINGS OBTAINED BY SUPERSONIC COLD GAS DYNAMIC SPRAYING

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Abstract—The paper studies the development of a technology for obtaining a wear-resistant functional gradient coating during supersonic cold gas dynamic spraying. The process goes due to the variation of the composition of the gas phase in a heterophase flow. The coating has a high microhardness (up to 12 GPa) on the peripheral layers and wear resistance is 3 times higher than that of coatings obtained by traditional technology.

Keywords: protective coating, functional gradient coating, microhardness, wear resistance

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REFERENCES

1. Kuznetsov, P.A., Farmakovsky, B.V., Metody polucheniya nanomaterialov [Methods of obtaining of nanomaterials], *Materialy dlia morskoi tekhniki*, St Petersburg: Professional, 2010, V. 2, pp. 301–306.

2. Bobkova, T.I., Deev, A.A., Bystrov, R.Yu., Farmakovsky, B.V., Nanesenie iznosostoikikh pokrytii s reguliruemoi tverdostyu s pomoshchyu sverkhzvukovogo kholodnogo gazodinamicheskogo napyleniya [Wear-resistant coatings with adjustable hardness using supersonic cold gas spraying], *Metalloobrabotka*, 2012, No 5–6, pp. 45–49.

3. Farmakovsky B.V., Dzhurinsky D.V., Vasiliev A.F. Patent RU(11) 2 285 746(13) C2: *Method of application of functional coatings at high adhesive properties.* Publ. 20.10.2006. Bull. 29.

4. Gerashchenkov, D.A., Vasiliev, A.F., Farmakovsky, B.V., Mashek, A.Ch., Issledovanie temperatury potoka v protsesse kholodnogo gazodinamicheskogo napyleniya funktsionalnykh pokrytii [Researching of flow temperature in cold gas dynamic spraying of functional coatings], *Voprosy Materialovedeniya*, 2014, No 1 (77), pp. 87–96.

5. Gerashchenkov, D.A., Farmakovsky, B.V., Samodelkin, E.A., Gerashchenkova, E.Yu., Issledovanie adgezionnoi prochnosti kompozitsionnykh armirovannykh pokrytii sistemy metall – nemetall, poluchennykh metodom kholodnogo gazodinamicheskogo napyleniya [Researches of adhesive strength of composite reinforced coatings of metal – nonmetal system obtained by cold gas-dynamic spraying method], *Voprosy Materialovedeniya*, 2014, No 2 (78), pp. 103–117.

6. Gerashchenkov, D.A., Razrabotka tekhnologicheskogo protsessa naneseniya pokrytii metodom kholodnogo gazodinamicheskogo napyleniya na osnove armirovannykh poroshkov sistemy Al – Sn + Al_2O_3 [Development of technological process of drawing of coatings by cold gas dynamic spraying method based on reinforced powders of Al – Sn + Al_2O_3 system], *Abstract of the Cand. Sc. (Eng) dissertation*, St Petersburg, 2015.

7. Burkanova, E.Yu., Farmakovsky, B.V., Vysokoskorostnoi mekhanosintez s ispolzovaniem dezintegratornykh ustanovok dlia polucheniya nanostrukturirovannykh materialov sistemy metal–keramika [High speed mechanosynthesis using disintegrating installations for the preparation of nanostructured materials of metal-ceramic], *Voprosy Materialovedeniya*, 2012, No 1 (69), pp. 80–85.

8. Bobkova, T.I., Razrabotka materialov i tekhnologii polucheniya iznosostoikikh gradientnykh pokrytii na baze nanostrukturirovannykh kompozitsionnykh poroshkov [Development of materials and technology of wear-resistant gradient coatings obtaining based on nano-constructional composite powders], *Abstract of the Cand. Sc. (Eng) Dissertation*, St Petersburg: 2017, p. 28.

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POWDERED COMPOSITES OF Al–Zn–Sn ALLOYS FOR FUNCTIONAL COATINGS

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Abstract—The features of the process of obtaining a powder composition from an alloy based on the Al–Zn–Sn system are studied. A technology has been developed for obtaining powders of optimal composition, including Al; 6–11% Zn; 6–11% Sn; 2–4% Si; 0.6–0.8% Ce. Functional wear-resistant coatings recommended for practical use in products of precision and power engineering were made by supersonic cold gas dynamic spraying.

Keywords: functional coatings, powder composition, Al–Zn–Sn system, supersonic cold gas dynamic spraying, wear resistance, microhardness, porosity.

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REFERENCES

1. Antsiferov, V.N., Bobrov, G.V., Druzhinin, L.K., *Poroshkovaya metallurgiya i napylennye pokrytiya* [Powdered metallurgy and dusted coatings], Moscow: Metallurgiya, 1987.

2. Valitova, V.M., Afonichev, D.D., Khairetdinov, E.F., Patent RU (11) 2 039 125 (13) C1: *Composition powder for plasma spraying coatings*. Publ. 09.07.1995.

3. Volkov, V.A., Elkin, I.A., Zagainov, A.V., Protasov, A.V., Elsukov, E.P., Dinamicheskoe ravnovesie faz v protsessakh mekhanosinteza splava sostava $Fe_{72.6}C_{24.5}O_{1.1}N_{1.8}$ [Dynamic phase balance in processes of $Fe_{72.6}C_{24.5}O_{1.1}N_{1.8}$ alloy mechanical synthesis], *Fizika metallov i metallovedenie*, 2014, V. 115, No 6, pp. 596–601.

4. Gerashchenkov, D.A., Farmakovsky, B.V., Vasiliev, A.F., Somkova, E.A., Bystrov, R.Yu., Patent RU (11) 2 413 024 (13) C1: *Wear-corrosion-resistant alloy on base of aluminium for nano-structured coating.* Publ. 27.02.2011. Bull. 6.

5. Gerashchenkov, D.A., Farmakovsky, B.V., Samodelkin, E.A., Gerashchenkova, E.Yu., Issledovanie adgezionnoi prochnosti kompozitsionnykh armirovannykh pokrytii sistemy metall – nemetall, poluchennykh metodom kholodnogo gazodinamicheskogo napyleniya [Research of adhesive strength of composite reinforced coatings of metal – nonmetal system obtained by cold gas dynamic spraying], *Voprosy Materialovedeniya*, 2014, No 2 (78), pp. 103–117.

6. *Dospekhi dlia Burana: Materialy i tekhnologii VIAM dlia MKS Energiya-Buran* [Armor for Buran: Materials and technologies VIAM for the Energy-Buran Space Station], Kablov, E.N., (Ed.), Moscow: Nauka i zhizn, 2013.

7. Gerashchenkov, D.A., Razrabotka tekhnologicheskogo protsessa naneseniya pokrytii metodom kholodnogo gazodinamicheskogo napyleniya na osnove armirovannykh poroshkov sistemy Al–Sn+Al_2O_3 [Development of technological process of drawing of coatings by cold gas dynamic spraying based on reinforced powders of Al–Sn+Al_2O_3 system], *Abstract of the Cand. Sc. (Eng) dissertation*, St Petersburg, 2015.

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RESEARCH AND DEVELOPMENT OF TECHNOLOGY FOR LASER CONFIGURATION OF SENSITIVE ELEMENT OF FLUXGATE INCLINOMETER

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Abstract—The paper presents the results of thermodynamic analysis of oxidation processes occurring during laser treatment of amorphous magnetically sensitive ribbon (71KNSR) in air and in the atmosphere of argon. Kinetic assessment of the rate of chemical reactions is based on the Arrhenius equation. The results of analytical calculations show that the decrease of magnetic properties of the alloy after laser treatment in the air is mostly determined by the formation of iron oxides Fe_2O_3 and Fe_2O_4. Chemical elemental analysis of the composition of the samples after laser configuration in argon shows a significant decrease in their composition of oxygen compared to samples configured in the air. Analysis of samples using scanning electron and magnetic force microscopy confirms the preservation of the magnetic properties after treatment in argon. The developed technology is used for the manufacture of a sensitive element of a fluxgate inclinometer.

Keywords: laser cutting, amorphous magnetically sensitive ribbon, inclinometer, thermodynamic analysis and kinetic evaluation of chemical interactions.

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REFERENCES

1. Patent 2291294, Russian Federation. Ferrum-probe borehole inclinometer. Publ. 10.01.2007, Bull. No 1.

2. Patent 2330303, Russian Federation. Ferrum-probe magnetometer. Publ. 27.07.2008, Bull. No 21.

3. Vlaskin, K.I., Razrabotka elektromagnitnykh sistem malogabaritnykh pervichnykh preobrazovatelei ferrozondovogo tipa [Development of electromagnetic systems of small-sized primary ferrum-probe type converters], *Abstract of the Cand. Sc. (Eng) Dissertation*, Ufa, 2016.

4. Rodrigues, G.C., Vorkov, V., Duflou, J. R., Optimal laser beam configurations for laser cutting of metal sheets, *Procedia CIRP*, 2018, V. 74, pp. 714–718.

5. Wang, Y.C., Luo, X.M., Chen, L.J., Yang, H.W., Zhang, G.P., Enhancement of shear stability of a Fe-based amorphous alloy using electrodeposited Ni layers, *Journal of Materials Science & Technology*, 2018, V. 34, No 12, pp. 2283–2289.

6. Guo, L.Y., Geng, S.N., Pang, J., Hu, Y.H., Lan S., Wang, C.M., Wang, W.M., Structural transformation and property improvement of Fe78Si9B13 amorphous ribbon by pulsed laser processing, *Materials & Design*, 2018, V. 160, pp. 538–548.

7. Yulmetova, O.S., Scherbak, A.G., Composition analysis of thin films formed on beryllium surfaces under pulsed laser action by the method of chemical thermodynamics, *International Journal of Advanced Manufacturing Technology*, 2018, V. 97, pp. 3231–3236.

8. Scherbak, A.G., Yulmetova, O.S., Contrast image formation based on thermodynamics approach and surface laser oxidation for optoelectronic read-out system, *Optics and laser technology*, 2018, V. 101, pp. 242–247.

9. Gibbs, J.W., Bumstead, H.A., Van Name, R.G., Longley, W.R., The Collected Works of J. Willard Gibbs: Longmans, Green and Co., 1928.

10. Laidler, K.J., The development of the Arrhenius equation, *Journal of Chemical Education*, 1984, No 61 (6), p. 494.

11. Glushko, V.P., *Termicheskie konstanty veshchestv* [Thermal constants of substances], Moscow: AN USSR, VINITI, 1974, 7th ed., V. 2.

12. Kogan, Ya.D., Kolachev, B.A., Levinsky, Yu.V., Nazimov, O.P., Fishgoit, A.V., *Konstanty vzaimodeistviya metallov s gazami: Spravochnoe izdanie* [Constants of interactions of metals and gases: Reference book], Moscow: Metallurgiya, 1987.

13. Nechaev, V.V., Osnovy prikladnoi termodinamiki. Fazovye ravnovesiya. Uchebnoe posobie [Basics of applied thermodynamic. Phase equilibriums], Moscow: MIFI, 2002, p. 128.

14. Martin, Y., Wickramasinghe, H.K., Magnetic imaging by “force microscopy” with 1000-A resolution, *Appl. Phys*. Lett., 1987, V. 50 (20), pp. 1455–1457.

15. Sader, J.E., Larson, I., Mulvaney, P., White, L.R., Method for calibration of atomic force microscope cantilevers, *Rev. Sci. Instrum*, 1995, V. 66, pp. 3789–3498.

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EVOLUTION OF THE STRUCTURE AND PHASE STATE OF THE HEAT-RESISTANT INTERMETALLIC COATING OF OPERATING TURBINE BLADES

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Abstract—The paper treats important problems of domestic engineering, namely, the urgent necessity to increase service life of large-sized turbine blades of the power gas-turbine stations operated on thermal power plants. The heat-resistant coating of the Ni–Co–Cr–Al–Y system with intermetallic phase structure

β-(Ni, Me)Al + γ′-(Ni, Me)$_3$Al has been developed. It was made by high-energy plasma powder spraying and intended for protection of blade surface against high-temperature and erosive gas flow. The article studies microstructure, phase structure and physicomechanical properties of a coating given in an initial state, and after laboratory research of heat resistance and a post-operational state at ~29 000 hours (time of real operation of the gas-turbine engine of the GTE-45-3 power station on thermal power plant). After long-term operation, a decrease in the content of the intermetallic phase of β-(Ni, Me)Al in the phase composition, an increase in the pore size and a decrease in the hardness of the coating have been established. At the same time, erosion resistance and heat-resistant properties of the coating remain, and, consequently, there is a sufficient resource.

Keywords: gas-turbine power station, turbine blades, high-energy plasma spraying, heat-resistant coating, intermetallic phases, microstructure, porosity, density, hardness, heat resistance, operating time, resource.

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REFERENCES

1. Baldaev, L.Kh., *Renovatsiya i uprochnenie detalei mashin metodami gazotermicheskogo napyleniya* [Renovation and hardening of machine details by gas-thermal spraying methods], Moscow: KKhT, 2004.

2. Kuzmin, V.I., Kartaev, E.V., Vashchenko, S.P., Sergachev, D.V., Kornienko, E.E., Povyshenie effektivnosti plazmennogo napyleniya poroshkovykh pokrytii [Improving of efficiency of plasma spraying of powdered coatings], *Vestnik Yugorskogo gosudarstvennogo universiteta*, 2014, No 2, pp. 7–14.

3. Tarasenko, Yu.P., Tsareva, I.N., Berdnik, O.B., Fel, Ya.A., Kuzmin, V.I., Mikhalchenko, A.A., Kartaev, E.V., Struktura i fiziko-mekhanicheskie svoistva zharostoikogo intermetallidnogo pokrytiya Ni–Co–Cr–Al–Y, poluchennogo na modernizirovannom plazmennom oborudovanii [Structure and physical and mechanical properties of heat-resistant intermetallic coating Ni–Co–Cr–Al–Y obtained on modernized plasma equipment], *Teplofizika i aeromechanika*, 2014, V. 21, No 5, pp. 671–680.

4. Kolobov, Yu.R., Kablov, E.N., Kozlov, E.V., Koneva, N.A., Povarova, K.B., Grabovetskaya, G.P., Buntushkin, V.P., Bazyleva, O.A., Muboyadzhyan, S.F., Budinovsky, S.A., *Struktura i svoistva intermetallidnykh materialov s nanofaznym uprochneniem* [Structure and properties of intermetallic materials with nano-phase hardening], Moscow, 2008.

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INTERACTION OF TUNGSTEN IN DRY SLIDING AGAINST STEEL UNDER HIGH DENSITY ELECTRIC CURREN

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Abstract—The possibility of creating a wear-resistant dry sliding electrical contact tungsten/steel was studied. It was shown that tungsten caused severe wear of the quenched steel counterbody due to unlimited plastic flow of its surface layer at a current density up to 150 A/cm^2. This indicated the impossibility of achieving satisfactory characteristics of such a contact. Low electrical conductivity and wear resistance of the contact tungsten/steel were presented in comparison with the known high copper/steel contact char-

acteristics under the same conditions. X-ray phase analysis data of the steel sliding surfaces made it possible to state that the cause of the unsatisfactory sliding of tungsten was the absence of the necessary concentration of FeO oxide on the sliding surface of the steel.

Keywords: dry sliding, surface layer, wear-resistant, concentration of FeO oxide

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REFERENCES

1. Kostetsky, B.I., Nosovsky, N.G., Karaulov, A.K., *Poverkhnostnaya prochnost metallov pri trenii* [Surfacing strength of metals at friction], Kiev, Tekhnika, 1976.

2. Tushinsky, L.I., Optimizatsiya struktury dlia povysheniya iznosostoikosti splavov [Structure optimization for increasing of wear-resistance of alloys], *Fizika iznosostoikosti poverkhnosti metallov, Compilation of science works*, Leningrad: LFTI AN USSR, 1988, pp. 42–55.

3. Aleutdinova, M.I., Fadin, V.V., Iznosostoikost uglerodistykh stalei pod vozdeistviem trenia i elektricheskogo toka vysokoi plotnosti [Wear-resistance of carbonaceous steels under impact of friction and high-density electricity], *Voprosy Materialovedeniya*, 2015, No 3 (83), pp. 47–53.

4. Aleutdinova M.I., Fadin V.V., Kolubaev A.V., Aleutdinova V.A. Contact Characteristics of Metallic Materials in Conditions of Heavy Loading by Friction or by Electric Current, *Friction and Wear Research (FWR)*, 2014, No 2, pp. 22–28.

5. Holm, R., Electric Contacts Handbook, Berlin; Göttingen; Heidelberg : Springer, 1958.

6. Umansky, Ya.S., Skakov, Yu.A., Ivanov, A.N., Rastorguev, L.N., *Kristallografiya, rentgenografiya i elektronnaya mikroskopiya* [Crystalography, roentgenography and electronic microscopy], Moscow: Metallurgiya, 1982.

7. Senouci, A., Zaidi, H., Frene, J., Bouchoucha, A., Paulmier, D., Damage of surfaces in sliding electrical contact copper/steel, *Applied Surface Science*, 1999, V. 144–145, pp. 287–291.

8. Bouchoucha, A., Zaidi, H., Kadiri, E.K., Paulmier, D., Influence of electric fields on the tribological behaviour of electrodynamical copper/steel contacts, *Wear*, 1997, V. 203–204, pp. 434–441.

9. Fadin, V.V., Changes in the structure of the surface layer of metal materials upon friction and electric current loading, *Russian Physics Journal*, 2013, V. 56, No 4, pp. 378–383.

10. Fadin, V.V., Aleutdinova, M.I., Kolubaev, A.V., O roli medi v formirovanii parametrov zony kontakta metallicheskikh kompozitov pri nagruzhenii treniem i elektricheskim tokom [About role of copper in forming of settings of metallic composites contact at loading by friction and electric current], *Izvestiya vuzov. Fizika*, 2013, V. 56, No 12/2, pp. 208–212.

11. Wang, P., Zhang, H., Yin, J., et al., Wear and friction behaviours of copper mesh and flaky graphite-modified carbon/carbon composite for sliding contact material under electric current, *Wear*, 2017, V. 380–381, pp. 59–65.

12. Hase, A., Mishina, H., Identification and evaluation of wear phenomena under electric current by using an acoustic emission technique, *Tribology International*, 2018, V. 127, pp. 372–378.

13. Liu, Xi., Shi, X., Lu, G., Deng, X., et al., The synergistic lubricating mechanism of Sn-Ag-Cu and C60 on the worn surface of M50 self-lubricating material at elevated loads, *Journal of Alloys and Compounds*, 2019, V. 777, pp. 271–284.

14. Savchenko, N.L., *Transformatsionno-uprochnennye keramicheskie i metallokermicheskie kompozitsii dlya ekspluatatsii v usloviyakh vysokoskorostnogo treniya* [Transformational-hardened ceramic and metal-ceramic composites for using in high-speed friction conditions], Abstract of the Dr. Sc. (Eng) Dissertation, Tomsk, 2015, p. 34.

15. Lia, X., Gao, Y., Yang, Q. Sliding tribological performance of B_4C-hBN composite ceramics against AISI 321 steel under distilled water condition, *Ceramics International*, 2017, V. 43, pp. 14932–14937.

16. Kovalchenko, A.M., Blau, P.J., Qu, J., Danyluk, S., Scuffing tendencies of different metals against copper under non-lubricated conditions, *Wear*, 2011, V. 271, pp. 2998–3006.

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BIOTECHNOLOGICAL METHOD OF OBTAINING NANOPARTICLES OF SILVER, CADMIUM AND ZINC SULFIDES. PHYSICO-CHEMICAL CHARACTERISTICS. CREATION OF POLYMERIC NANOCOMPOSITES

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Abstract—A simple and environmentally safe method for obtaining stable nanoparticles of metal sulfides nanoparticles – NpAg_2S, NpCdS and NpZnS was developed using different strains of microorganisms in an aqueous solution of metal salts and sulfur sources at the Research Center "Kurchatov Institute" – GosNIIgenetika. The concentration of nanoparticles is 1–4 mg/ml in aqueous suspensions. Using of the methods of electron microscopy, spectrofluorimetry, dynamic light scattering determined the main characteristics of biogenic nanoparticles: shape, size distribution, crystal structure, effective diameter, luminescent spectrum, zeta potential. According to its characteristics, these nanoparticles are referred to quantum dots. It is established that the stability of nanoparticles in aqueous suspensions is due to protein molecules adsorbed on the surface of nanoparticles, which are supplied by cells of microorganisms. Effective immobilization of biogenic nanoparticles on the surface of various polymer supports has been carried out. Biogenic nanoparticles along with nanoparticles obtained by physico-chemical methods can be used as fluorophores for imaging of biological processes, also as photocatalysts, solar cells and for new nanocomposite materials.

Keywords: biogenic nanoparticles (Np), biosynthesis of NpAg_2S, NpCdS и NpZnS, bacterial strains, biotechnological method, polymeric materials, bionanocomposites.

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REFERENCES

1. Ali, S.M., Ramay, S.M., Aziz, M.M., Ur-Rehman, N., Al Garow, M.S., Al Ghamad, S.S., Machmood, A., Al Khuraiji, T.S., Atig, S., Efficiency enhancement of perovskite solar cells by incorporation of CdS quantum dot through fast electron injection, *Organic Electronics*, 2018, V. 62, pp. 21– 25.

2. Jabeen, U., Mujtaba, S., Khan, S.U., Photocatalytic degradation of Alizarin CdS using ZnS and cadmium dosed ZnS nanoparticles under unfiltered sunlight, *Surface and Interfaces*, 2017, V. 6, pp. 40–49.

3. Ye, Z., Kong, L., Chen, F., Chen, Z., Li, Y., Lin, C., A comparative study of photocatalytic activity of ZnS photocatalyst for degradation of various dyes, *Optik*, 2018, V. 164, pp. 345–354.

4. Li, J., Zhu, J.J., Quantum dots for fluorescent biosensing and bio-imaging applications, *Analyst*, 2013, V. 138, pp. 2506–2515.

5. Mal, Y., Nanchariah, Y.N., Van Hullenbusch, E.D., Lens, P.N.L., Metal chalcogenide quantum dots. Biotechnological synthesis and application, *Royal Society of Chemistry*, 2016, V. 6, pp. 41477–41495.

6. Voeikova, T.A., Shebanova, A.S., Ivanov, Yu.D., Kaisheva, A.L., Novikova, L.M., Zhuravleva, O.A., Shumyantseva, V.V., Shaitan, K.V., Kirpichnikov, M.P., Debabov, V.G., *Rol belkov vneshnei membrany bakterii Shewanella oneidensis MR-1 v obrazovanii I stabilizatsii nanochastits sulfide serebra* [Outside membrane proteins Shewanella oneidensis MR-1 bacteria role in formation and stabilization of silver sulfide nano-particles], *Biotekhnologiya*, 2015, No 5, pp. 41–48.

7. Voeikova, T.A., Zhuravleva, O.A., Bulushova, N.V., Veiko, V.P., Ismagulova, T.T., Lupanova, T.N., Shaitan, K.V., Debabov, V.G., *«Belkovaya korona» nanochastits sulfida serebra, poluchennykh v prisutstvii gramotritsatelnykh I grampolozhitelnykh bakterii* [«Protein crown» of silver sulfide nanoparticles, obtained with gram-negative and gram-positive bacteria], *Molekularnaya genetika, mikrobiologiya, virusologiya*, 2017, No 4, pp. 151–156.

8. Lu, Y.X., Li, L., Ding, Y., Zhang, F., Wang, Y., Yu, W., Hydrothermal synthesis of functionalized CdS nanoparticles and their application as fluorescence probes in the determination of uracil and thymine, *Journal of Luminescence*, 2012, V. 132, pp. 244–249.

9. Xiao, X., Ma, X.-Bo, Yuan, H., Liu, P.-C., Lei, Y.-B., Xu, H., Du, D.-L., Sun, J.-F., Feng, Y.-J., Photocatalytic properties of zinc sulfide nanocrystals biofabricated by metal-reducing bacterium Shewanella oneidensis MR-1, *Journal of Hazardous Materials*, 2015, V. 288, pp. 134–139.

10. Yu, X., Yu, J., Cheng, B., Huang, B., One-pot template-free synthesis of monodisperse zinc sulfide hollow spheres and their photocatalytic properties, *Chemistry a European Journal*, 2009, V. 15, pp. 6731–6739.

11. Yue, L., Qi, S., Wang, J., Cai, J., Xin, B., Controllable biosynthesis and characterization of α-ZnS and β-ZnS quantum dots: Comparing their optical properties, *Materials Science in Semiconductor Processing*, 2016, V. 56, pp. 115–118.

12. Qi, P., Zhang, D., Zeng, Y., Wan, Y., Biosynthesis of CdS nanoparticles: A fluorescent sensor for sulfate-reducing bacteria detection, *Talanta*, 2016, V. 147, pp. 142–146.

13. Zhou, N.-Q., Tian, Li-J., Wang, Yu-Cai, Li, Dao-Bo, Li, Pan-Pan, Zhang, X., Yu, Han-Qing, Extracellular biosynthesis of copper sulfide nanoparticles by Shewanella oneidensis MR-1 as a photothermal agent, *Enzyme and Microbial Technology*, 2016, V. 95, pp. 230–235.

14. Dong, B., Li, C., Chen, G., Zhang, Y., Deng, M., Wang, Q., Facile synthesis of highly photolumenescent Ag2Se quantum dotes as a new fluorescent probe in the second near-infrared window for in vivo imaging, *Chemistry of Materials*, 2013, V. 25, pp. 2503–2509.

15. Levshenko, E.N., Gritskova, I.A., Gusev, S.A., Gusev, A.A., Volkova, E.V., *Polimernye mikrosfery v kachestve nositelei fluorestsentnoi metki pri postroenii trekhmernoi modeli sosudistogo rusla eksperimentalnykh zhivotnykh* (Polymeric microspheres as carrier of fluorescent mark at construction of three-dimensional model of vascular channels of experimental animals), *Biotekhnologiya*, 2013, V. 6, pp. 65–70.

16. Volkova, E.V., Lukashevich, A.D., Levacheva, I.S., Levachev, S.M., Gusev, S.A., Gritskova, I.A., *Vybor polimernykh mikrosfer dlya provedeniya reaktsii lateksnoi agglyutinatsii v plashechnom formate* [Choise of polymeric microspheres for carriage of latex agglutination reaction in spot format], Vestnik MITHT, 2013, V. 8, No 6, pp. 68–72.

17. Brazhnik, K.I., Baryshnikova, M.A., Sokolova, Z.A., Nabiev, I.R., Sukhanova, A.V., *Novye napravleniya v issledovanii i rannei diagnostike raka s primeneniem detektsionnykh sistem na osnove fluorestsentnykh nanokristallov* [New directions of research and diagnostics of cancer using detection systems based on fluorescent nano-crystals], *Rossijskii bioterapevticheskii zhurnal*, 2013, V. 12, No 3, pp. 11–24.

18. Gao, X., Cui, Y., Levenson, R.M., Chung, L.W., Nie, S., In vivo cancer targeting and imaging with semiconductor quantum dots, *Nature Biotechnology*, 2004, V. 22, pp. 969–976.

19. Voeikova, T.A., Zhuravleva, O.A., Gracheva, T.S., Bulushova, N.V., Ismagulova, T.T., Shaitan, K.V., Debabov, V.G., *Optimizatsiya mikrobnogo sinteza nanochastitz sulfida serebra* [Optimization of microbial synthesis of silver sulfide nanoparticles], *Biotekhnologiya*, 2017, V. 33, No 3, pp. 38–46.

20. Bahtina, A.V., Sivaev, A.A., Levachev, S.M., Gusev, S.A., Lobanova, N.A., Lazov, M.A., *Sintez aminosoderzhashchikh polimernykh mikrosfer zatravochnoi sopolimerizatsiei dlya primeneniya*

v biotekhnologii [Synthesis of amine-containing polymeric inoculating copolymerization microspheres for applying in biological technology], *Tonkie khimicheskie tekhnologii*, 2017, V. 12, No 4, pp. 75–84.

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EXPERIMENTAL STUDY OF VIBROINSULATING PROPERTIES OF MODERN STRUCTURAL POLYURETHANE

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Abstract—Modern mechanical engineering often uses polyurethane elastomers as vibroinsulating material. It is difficult to choose the most perfect structural polyurethane among a large number of proposed materials for manufacturing shock absorbers. The article presents experimental research of vibroinsulating properties using two parameters out of five. Based on preliminary tests, an implicit preference is given to one of the three proposed materials. The energy absorption coefficient and the creep of the elastomer are chosen as criteria for evaluating the vibroinsulation properties of polyurethane elastomers. Final choice of polyurethane elastomer for shock absorbers manufacturing could be made if additional tests are carried out for studying three criteria.

Keywords: polyurethane, vibroinsulation properties, shock absorber, energy absorption coefficient, polyurethane creep.

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REFERENCES

1. Manuel Valero, F., Preparation and Properties of Polyurethanes based on Castor Oil Chemically Modified with Yucca Starch Glycoside, *Journal of Elastomers and Plastics*, 2009, No 41, pp. 223–244.

2. Maity, M., Polyblend Systems of Polyurethane Rubber and Silicone Rubber in the Presence of Silane Grafting Agent, *Journal of Elastomers and Plastics*, 2001, No 33, pp. 211–224.

3. Kahraman, H., Haberstroh, E., Einfluss von aktiven Fullstoffen in Elastomeren auf den anisotropen Mullins-Effekt, *Gummi. Fasern. Kunststoffe*, 2014, No 5, pp. 296–298.

4. Gonella, L.B., New Reclaiming Process of Thermoset Polyurethane Foam and Blending with Polyamide-12 and Thermoplastic Polyurethane. *Journal of Elastomers and Plastics*, 2009, No 41, pp. 303–322.

5. Neise, E., Zepp, C., Optische Deformationsanalyse von Fahrzeugreifen. Dynamische Reifenanalyse. *Gummi. Fasern. Kunststoffe*, 2013, No 1, pp. 23–30.

6. Yokoyama, N., Properties of Polyurethane Containing New Phenolic Additives, *Journal of Elastomers and Plastics*, 2007, No 39, pp. 347–369.

7. Yakovlev, S.N., *Proektirovanie i osnovy tekhnologii detalei mashin iz poliuretana* [Designing and basics of polyurethane machines details], St Petersburg: Renome, 2013, p. 176.

8. Lepetov, V.A., Yurtsev, L.N., *Raschety i proektirovanie rezinovykh izdelii* [Calculating and designing of rubber products], Leningrad: Khimiya, 1977, p. 304.

9. Right, P., *Poliuretanovye elastomery* [Polyurethane elastomers], Moscow: Khimiya, 1973, p. 304.

10. Marcos Pacheco, F.M., Thermal, Chemical, and Morphological Characterization of Microcellular Polyurethane Elastomers, *Journal of Elastomers and Plastics*, 2009, No 41, pp. 323–338.

11. Janusz, D., Synthesis and Investigation of Glycolysates and Obtained Polyurethane Elastomers, *Journal of Elastomers and Plastics*, 2010, No 42, pp. 117–127.

12. Yakovlev, S.N., Self-Oscillation of an Elastic Polyurethane Coating in Polishing, *Russian Engineering Research*, 2014, No 5, pp. 295–298.

13. Kryzhanovsky, V.K., Burlov, V.V., *Plastmassovye detali tekhnicheskikh ustroistv* [Plastic details of technical devices], St Petersburg: NOT, 2014, p. 456.

14. Demidovich, B.P., Maron, I.A., *Chislennye metody analiza* [Numerical methods of analysis], Moscow: Lan, 2008, p. 357.

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STUDYING CHANGES IN THE ELECTRICAL RESISTANCE OF CARBON-NANOTUBES-MODIFIED ELASTOMERS DURING THEIR COMPRESSION, STRETCHING AND TORSION

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Abstract—Developing "smart" materials with improved both structural and functional characteristics is one of the promising areas of materials science. Measuring the electrical resistance of CNTs-modified (various mass contents) polymers and in particular, elastomers during performing several tests (compression, stretching, and torsion) at a constant current is relevant in electrical engineering, mechanical engineering, aviation, and space industry. Changes in the elastomer shape under different types of testing lead to the destruction of macromolecules and the structuring of the material as a whole. Therefore, it is important to study the effect of CNTs-based modifying fillers on the elastomer. When compressing, stretching or twisting the nano-modified elastomer, along with the mutual movement of its macromolecular fragments and aggregates, the modifier particles also move, which generally determines the transport of electrons in the resulting structure and affects the physical and mechanical parameters of the composite material. To conduct studies, elastomers containing different amounts of a CNTs-based modifying filler were prepared. To investigate and elucidate relevant dependencies, a measuring system (MS) was constructed, which makes it possible to determine electrical resistance values of the composite material with different CNTs contents in the polymer matrix composition exposed to various mechanical loads.

Basing the research results, it was established that the electrical resistance of the elastomer composites modified with 1.0–2.5 wt.% CNTs decreases when compressing from 0 to 100 N, whereas when the compression force ranges from 100 to 350 N, the electrical resistance remains unchanged. When the elastomer composites modified with 2–2.5 wt.% CNTs were stretched by 30–40 %, the electrical resistance was found to increase from $5 \cdot 10^3$ to $1.9 \cdot 10^7$ Ω.

Keywords: composite, elastomer, CNTs, electrical resistance, compression, tension, torsion

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REFERENCES

1. Makhsidov, V.V., Reznikov, V.A., Mukhametov, R.R., Doriomedov, M.S., Intellektualnye polimernye materialy i ikh primenenie v aerokosmicheskoy otrasli [Smart polymer materials and their application in aerospace], Voprosy Materialovedeniya, 2017, No 3 (91), pp. 110–120.

2. Farafonova, O.V., Shukshina, E.I., Ermolaeva, T.N., Primenenie mnogostennykh uglerodnykh nanotrubok dlia uvelicheniya chuvstvitelnosti opredeleniya farmatsevticheskikh preparatov s pomoshchyu pezoelektricheskikh immunosensorov [Applying of multi-walled carbon nanotubes for increasing of sensitivity of pharmaceutical preparation using piezoelectric immunity sensors], Biotekhnologiya: sostoyanie i perspektivy razvitiya, 2017, pp. 353–354.

3. Panteleev, K.V., et al., Analiz raspredeleniya elektrofizicheskikh i fotoelektricheskikh svoistv nanokompozitnykh polimerov modifitsirovannym zondom Kelvina [Analysis of distribution of photoelectric and physical properties of nanocomposite polymers by modified Kelvin probe], Pribory i metody izmerenii, 2017, V. 8, No 4.

4. Vertuccio, L., Guadango, L., et al., Effect of carbon nanotube and functionalized liquid rubber on mechanical and electrical properties of epoxy adhesives for aircraft structures, Composites Part B, 2017, V. 129, pp. 1–10.

5. Kim, Y.J., Shin, T.S., et al., Electrical conductivity of chemically modified multiwalled carbon nanotube/epoxy composites, Carbon, 2005, V. 43, pp. 23–30.

6. Luo, J., Cheng, Z., et al., Electrically conductive adhesives based on thermoplastic polyurethane filled with silver flake and carbon nanotubes, Composites science and technology, 2016, V. 129, pp. 191–197.

7. Sethi, J., Sarlin, E., et al., The effect of multi-wall carbon nanotube morphology on electrical and mechanical properties of polyurethane nanocomposites, Composites: Part A, 2017; V. 102, pp. 305–313.

8. Li, Q., Siddaramaiah, H., et al., Positive temperature coefficient characteristic and structure of graphite nanofibers reinforced high density polyethylene/carbon black nanocomposites, Composites part B, 2009, April; V. 40, pp. 218–224.

9. Billias, M.G., Borders, M.E., Electrically conductive structural adhesive, Google Patents, 1984. URL: https://patents.google.com/patent/US4428867

10. Kymakis, E., Amaratunga, G.A., Electrical properties of single-wall carbon nanotube-polymer composite films, Journal of Applied Physics, 2006, No 99(8), pp. 084302.

11. Ascione, F., Lamberti, M., et al., Strength and stiffness of adhesively bonded GFRP beam-column moment resisting connections, Compos Struct, 2017, V. 160, pp. 1248–1257.

12. Barra, G., Vertuccio, L., et al., Toughening of Epoxy Adhesives by Combined Interaction of Carbon Nanotubes and Silsesquioxanes, Materials, 2017, No 10, pp. 1–18.

13. Hsieh, T.H., Kinloch, A.J., et al., The Effect of Carbon Nanotubes on the Fracture Toughness and Fatigue Performance of a Thermosetting Epoxy Polymer, Journal of Materials Science, 2011, V. 46, pp. 7525–7535.

14. Bezryadin, A., Verschueren, A., Tans, S., Dekker, C., Multiprobe transport experiments on individual single-wall carbon nanotubes, Physical Review Letters, 1998, V. 80, pp. 4036–4039.

15. Nardelli, M.B., Bernholc, J., Mechanical deformations and coherent transport in carbon nanotubes, Physical review. B, Condensed matter, 1999, December, No 60(24), pp. 16338–16341.

16. Peng, S., Cho, K., Chemical control of nanotube electronics, Nanotechnology, 2000, V. 11, pp. 57–60.

17. Tombler, T.W., Zhou, C., et al., Reversible electromechanical characteristics of carbon nanotubes under local-probe manipulation, Nature, 2000, V. 405, pp. 769–772.

18. Shchegolkov, A., et al., The influence of graphene-like structures on the effect of temperature self-regulation in an electroconducting polymer material, AIP Conference Proceedings, AIP Publishing, 2018, V. 2041, No 1, p. 020025.

19. Yagubov, V.S., Shchegolkov, A.V., Samoreguliruemy elektronagrevatel na osnove elastomera, modfitsirovannyi mnogosloinymi uglerodnymi nanotrubkami [Self-regulating electric heater based on elastomer and modified by multilayer carbon nanotubes], Vestnik VGUIT, 2018, V. 80, No 3, pp. 341–345, DOI: 10.20914/2310-1202-2018-3-341-345.

20. Karim, N., et al. Graphene-based surface heater for de-icing applications, RSC Advances, 2018, V. 8, No 30, pp. 16815–16823.

21. UNT series “Taunit”, LLC “NanoTechCentr” URL: http://nanotc.ru/producrions/87-cnm-taunit (дата обращения: 12.12.2018).

22. Raza, M.A., Westwood, A., et al. Characterisation of graphite nanoplatelets and the physical properties of graphite nanoplatelet/silicone composites for thermal interface applications, Carbon, 2011, V. 49, pp. 4269–4279.

23. Shang, S., Gan, L., et al., Carbon nanotubes based high temperature vulcanized silicone rubber nanocomposite with excellent elasticity and electrical properties, Composites: Part A, 2014, V. 66, pp. 135–141.

24. Yagubov, V., Stoliarov, R., Memetov, N., Blokhin, A., Tkachev, A., Gorshkova, A., Moskova, M., Nanomodified electroconducting glue compositions based on polychloroprene rubber, 2D Systems of the

Strong Correlated Electrons: From Fundamental Research to Practical Applications AIP Conf. Proc. 2041, 2018, p. 020026. URL: https://doi.org/10.1063/1.5079357.

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THEORETICAL AND EXPERIMENTAL RESEARCH OF COMPOSITE MATERIALS REINFORCED BY CARBON FABRICS. Part 4: Mechanical and analytical model of structure deformation of the carbon fabric

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Abstract—Theoretical studies of the deformation of the carbon fabric structure have been performed. The paper describes investigations that made it possible to obtain functional relationships between the mechanical characteristics of the fabric and the parameters of the structure of carbon fibers, their mechanical characteristics, the parameters of the structure and the technological parameters of the fabric. Based on theoretical studies, mechanical and analytical models of structure deformation of carbon fabric were built.

Keywords: carbon fabrics, structure, reinforcing component, deformation, mechanical-analytical model, mechanical properties

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GLOBAL TRENDS IN CARBON FIBER RESEARCH

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Abstract—The review provides an analysis of global trends in current research in the field of carbon fiber composite materials. The paper considers studies conducted in 2018 and identifies four priority areas by assessing the amount of their funding. The mentioned areas include the utilization of carbon composites, optimization of their production process, the use of carbon composites in the aviation and shipbuilding industries. The review may contribute to the determination of high-priority and relevant research that will be conducted in the near future.

Keywords: carbon plastics, carbon fibers, composites, financing, priority areas, research funding priorities.

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REFERENCES

1. Vaganov, G.V., Myagkova, L.A., Svetlichny, V.M., Ivankova, E.M., Yudin, V.E., *Ugleplastiki na osnove poroshkovykh poliimidnykh svyazuyushchikh modifitsirovannykh uglerodnymi nanokonusami* [Carbon fibers based on powdered polyimide binders, modified by carbon nanocones], *Polimernye materialy i tekhnologii*, 2015, V. 1, No 1, pp. 38–44.

2. Dao, T.D., Ha, N.S., Goo, N.S., Yu, W.R., Design, fabrication, and bending test of shape memory polymer composite hinges for space deployable structures, *J. Intell. Mater. Syst. Struct.*, 2017, V. 29, No 8, pp. 1560–1574.

3. Wang, X., Jiang, M., Zhou, Z., Gou, J., Hui, D., 3D printing of polymer matrix composites: A review and prospective, *Compos. Part B Eng*, 2017, V. 110, pp. 442–458.

4. Sun, H., Zhang, Y., Zhang, J., Sun, X., Peng, H., Energy harvesting and storage in 1D devices, *Nat. Rev. Mater*, 2017, V. 2, p. 17023.

5. Goh, G.D., Agarwala, S., Goh, G.L., Dikshit, V., Sing, S.L., Yeong W.Y., Additive manufacturing in unmanned aerial vehicles (UAVs): Challenges and potential, *Aerosp. Sci. Technol.*, 2017, V. 63, pp. 140–151.

6. Yin, X.W., Cheng, L.F., Zhang, L.T., Travitzky, N., Greil, P., Fiber-reinforced multifunctional SiC matrix composite materials, *Int. Mater. Rev*., 2017, V. 62, No 3, pp. 117–172.

7. Huang, X., Fabrication and Properties of Carbon Fibers*, Materials*, 2009, V. 2, No 4, pp. 2369–2403.

8. Roudsari S., et al., Analytical Study of Reinforced Concrete Beams Strengthened by FRP Bars Subjected to Impact Loading Conditions, *Am. J. Eng. Appl. Sci.*, 2018, V. 11, No 2, pp. 407–425.

9. Shirvanimoghaddam K., et al., Carbon fiber reinforced metal matrix composites: Fabrication processes and properties, *Compos. Part Appl. Sci. Manuf.*, 2017, V. 92, pp. 70–96.

10. Reznik, S.V., Aktualnye problemy proektirovaniya, proizvodstva i ispytaniya raketno-kosmicheskikh kompozitnykh konstruktsii [Topical problems of design, production and testing of space rocket composite constructions], *Inzhenernyi zhurnal nauka i innovatsii*, 2013, V. 3, No 15, p. 25.

11. Stolyankov, Yu.V., Iskhodzhanova, I.V., Antyufeeva, N.V., K voprosu o defektakh obraztsov ispytanii ugleplastikov [To the issues of defects of carbon-fibers samples tests], *Trudy VIAM*, 2014, V. 10, pp. 1–10.

12. Kulikova, Yu.V., Tukacheva, K.O., Analiz tekhnologii utilizatsii polimernykh kompozitsionnykh materialov [Analysis of technologies of polymeric composite materials recycling], *Transport, transportnye sooruzheniya, ekologiya*, 2017, No 4, pp. 103–122.

13. Zerrahn A., Wind Power and Externalities, *Ecol. Econ*., 2017, V. 141, pp. 245–260.

14. Griffin, D.A., Zuteck, M.D., Scaling of Composite Wind Turbine Blades for Rotors of 80 to 120. Meter Diameter, *J. Sol. Energy Eng.*, 2001, V. 123, No 4, pp. 310–318.

15. Kondo, T., Nanba, H., Takezawa, T., Okumura, M., Technical Trend Analysis by Analyzing Research Papers' Titles, *Human Language Technology. Challenges for Computer Science and Linguistics*, 2011, pp. 512–521.

16. Grimpe, C., Extramural research grants and scientists' funding strategies: Beggars cannot be choosers, *Res. Policy*, 2012, V. 41, No 8, pp. 1448–1460.

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ELECTRON-BEAM WELDING OF LARGE THICKNESS STEELS OF OIL PRODUCING PLATFORM IONTS

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Abstract–The paper treats problems of reducing the cost of welding and improving the quality and productivity of welding parts of cold-resistant steel of great thickness during the construction of oil platforms. The design of tooling structure, and devices for electron-beam welding have been developed such as welding wire feeder, video observation system, software for controlling the workpiece moving and the electron beam gun travel.

Keywords: electron beam gun, large thickness steels, welding wire feeder.

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REFERENCES

1. Paton, B.E., Tekhnologiya svarki, paiki, rezki [Technology of welding, soldering, and cutting], *Mashinostroenie*: Encyclopedia, Moscow: Mashinostroenie, 2006, V. III-4.

2. Paton, B.E., *Tekhnologiya elektricheskoi svarki metallov i splavov plavleniem* [Technology of electric welding of metals and alloys by melting], Moscow: Mashinostroenie, 1974.

3. Kaidalov, A.A., *Elektronno-luchevaya svarka i smezhnye tekhnologii* [Electron beam welding and similar technologies], Kiev: Ekotekhnologiya, 2004.

4. Tekhnologii i oborudovanie elektronno-luchevoi svarki [Technologies and equipment of electron beam welding], *Materials of the first St Petersburg international scientific and technical conference*, St Petersburg, 2008.

5. Tekhnologii i oborudovanie ELS [Technologies and equipment of ELS], *Proceedings of St Petersburg international scientific and technical conference*, St Petersburg, 2011.

6. Nazarenko, O.K., Kaidalov, A.A., Kovbasenko, S.N., *Elektronno-luchevaya svarka* [Electro-ray welding], Kiev: Nauk. dumka, 1987, p. 255.

7. Sharonov N. I., Sharapov M. G. Modernisazija ustroistva dlja raswertki elertrjnnogo lucha pri elertronno-luchevoy swarke traektorii “szhataja skoba” [Modernization of digital beam welding scanning], *Voprosy Materialovedenia*, 2018, No 2 (94), pp. 161–166.

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INVESTIGATION OF CORROSION DAMAGE OF WROUGHT ALUMINIUM ALLOYS AT FULL-SCALE ACCELERATED TESTS. Part 2. PITTING CORROSION

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Abstract—The paper presents the results of a study of pitting corrosion of aluminum alloys of seven doping systems after testing by the full-scale accelerated method. The advantages of the method of laser scanning microscopy in the analysis of pitting corrosion are shown, which makes it possible to improve significantly the accuracy of measurements in comparison with the metallographic method. Peculiarities of the kinetics of pitting growth under long-term, accelerated tests were studied, the role of pitting corrosion in the part of characterizing the alloy’s susceptibility to local corrosion failure was shown.

Keywords: pitting corrosion, aluminum alloys, full-scale accelerated tests.

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REFERENCES

1. Kablov, E.N., Innovatsionnye razrabotki VIAM po realizatsii “Strategicheskikh napravlenii razvitiya materialov i tekhnologii ikh pererabotki na period do 2030 goda” [Innovate developments of the All-Russian Scientific Research Institute of Aviation Materials within the project “Strategic development of materials and technologies of their recycling until 2030”], *Aviatsionnye Materialy i Tekhnologii*, 2015, No 1, pp. 3–33, DOI: 10.18577/2071-9140-2015-0-1-3-33

2. Kablov, E.N., Startsev, O.V., Medvedev, I.M., Obzor zarubezhnogo opyta issledovanii korrozii i sredstv zashchity ot korrozii [Review of foreign experience of corrosion study and facilities for corrosion-protection], *Aviatsionnye Materialy i Tekhnologii*, 2015, No 2, pp. 76–87.

3. Kablov, E.N., Startsev, O.V., Medvedev, I.M., Panin, S.V., Korrozionnaya agressivnost primorskoi atmosfery. Ch. 1: Faktory vliyaniya (obzor) [Corrosion aggressive of Primorye atmosphere. Part 1: Factors of influence (review)], *Korroziya: materialy, zashchita*, 2013, No 12, pp. 6–18.

4. Antipov, V.V., *Strategiya razvitiya titanovykh, magnievykh, berillievykh i alyuminievykh splavov* [Strategy of development of titanium, magnesium, beryllium, and aluminum alloys], *Aviatsionnye Materialy i Tekhnologii*, 2012, No 5, pp. 157–167.

5. Kablov, E.N., Iz chego sdelat budushchee? Materialy novogo pokoleniya, tekhnologii ikh sozdaniya i pererabotki – osnova innovatsii [What is future made of? Materials of the new generation, technologies of its creation and processing as the basis of innovations], *Krylya Rodiny*, 2016, No 5, pp. 8–18.

6. Soltis, J., Passivity breakdown, pit initiation and propagation of pits in metallic materials, *Corrosion Science*, 2015, No 90, pp. 5–22.

7. Vinogradova, S.S., Tazieva, R.F., Parametry matematicheskikh modelei pittingovoi korrozii [Options of mathematically models of pitting corrosion], *Vestnik Kazanskogo tekhnologicheskogo universiteta*, 2012, V. 15, No 20, pp. 66–68.

8. Vinogradova, S.S., Tazieva, R.F., Kaidrikov, R.A., *Obzor stokhasticheskikh modelei pittingovoi korrozii* [Review of stochastic models of pitting corrosion], *Vestnik Kazanskogo tekhnologicheskogo universiteta*, 2012, V. 15, No 8, pp. 313–318.

9. Szklarska-Smialowska, Z., Pitting corrosion of aluminum, *Corrosion Science*, 1999, No 41, pp. 1743–1767.

10. Zhilikov, V.P., Karimova, S.A., Leshko, S.S., Chesnokov, D.V., Issledovanie dinamiki korrozii aliuminievykh splavov pri ispytanii v kamere solevogo tumana [Research of aluminum alloys corrosion dynamic at tests in salt fog chamber], *Aviatsionnye Materialy i Tekhnologii*, 2012, No 4, pp. 18–22.

11. Knight, S.P., Salsgaras, M., Trueman, A.R., The study of intergranular corrosion in aircraft aluminum alloys using X-ray tomography, *Corrosion science*, 2011, No 53, pp. 727–734.

12. Kolobnev, N.I., Makhsidov, V.V., Samokhvalov, S.V., Sbitneva, S.V., Popov, V.I., Kurs, M.G., Vliyanie deformatsii posle zakalki I rezhimov stareniya na mekhanicheskie I korrozionnye svoistva splava sistemy Al–Mg–Si–Cu–Zn [Influence of deformation after quenching and aging modes on mechanical and corrosion properties of Al–Mg–Si–Cu–Zn system alloy], *Aviatsionnye Materialy i Tekhnologii*, 2011, No 1, pp. 12–15.

13. Kurs, M.G., Laptev, A.B., Kutyrev, A.E., Morozova, L.V., Issledovanie korrozionnogo razrusheniya deformiruemykh alyuminievykh splavov pri naturno-uskorennykh ispytaniyakh. Chast 1 [Study of corrosion destruction of deformable aluminum alloys at natured accelerated tests. Part 1], *Voprosy Materialovedeniya*, 2016, No 1 (85), pp. 116–126.

14. Skripchenko, Yu.S., Sherokhovatost obrabotannoi poverkhnosti [Roughness of treated surface], *Vestnik Voronezhskogo gosudarstvennogo tekhnicheskogo universiteta*, 2011, V. 7, No 12–2, pp. 99–100.

15. Aliev, A.A., Bulgakov, V.P., Prikhodko, B.S., Kachestvo poverkhnosti i svoistva detalei mashin [Quality of surface and properties of machine details], *Vestnik Astrakhanskogo gosudarstvennogo universiteta*, 2004, No 1, pp. 8–12.

16. Vilner, A.Yu., *Fiziko-khimicheskaya obrabotka krupnogabaritnykh detalei letatelnykh apparatov* [Physical and chemical treatment of large-sized details of aircraft], *Nauka i sovremennost*, 2010, No 2–2, pp. 309–314.

17. State Standard GOST 2789-73: *Sherokhovatost poverkhnosti. Parametry i kharakteristiki* [Roughness of surface. Options and specifications].

18. State Standard GOST 9.908-85: *Edinaya sistema zashchity ot korrozii I stareniya. Metally I splavy. Metody opredeleniya pokazatelei korrozii i korrozionnoi stoikosti* [Uniform corrosion and aging protection system. Metals and alloys. Methods of definitions of corrosion and corrosion durability indicators].

19. ASTM G46-94 (2013). *Standard Guide for Examination and Evaluation of Pitting Corrosion*.

20. Iskhodzhanova, I.V., Orlov, M.R., Grigorenko, V.B., Lapteva, M.A., Primenenie metoda konfokalnoi lazernoi skaniruyushchei mikroskopii dlya issledovaniya korrozionnykh povrezhdenii [Applying of confocal laser scanning microscopy method for researches of corrosion damage], *Trudy VIAM*, 2015, No 4, article 11, URL: http://www.viam-works.ru (reference date 18/01/2016). DOI: 10.18577/2307-6046-2015-0-4-11-11.

21. Sinyavsky, V.S., Valkov, V.D., Kalinin, V.D., *Korroziya i zashchita alyuminievykh splavov* [Corrosion and protection of aluminum alloys], Moscow: Metallurgy, 1986, 2nd ed.

22. Kurs, M.G., Antipov, V.V., Lutsenko, A.N., Kutyrev, A.E., *Integralnyi koeffitsent korrozionnogo razrusheniya deformiruemykh alyuminievykh splavov* [Integral coefficient of corrosion destruction of deformable aluminum alloys], *Aviatsionnye Materialy i Tekhnologii*, 2016, No 3, pp. 24–32, DOI: 10.18577/2071-9140-2016-0-3-24-32.

23. Kurs, M.G., Kutyrev, A.E., Primenenie integralnogo koeffitsenta korrozionnogo razrusheniya dlya prognozirovaniya izmeneniya prochnostnykh svoistv deformiruemykh alyuminievykh splavov (Application of integral coefficient of corrosion destruction for forecasting of strength properties changes in deformable aluminum alloys), *Modern material science: traditions of native schools and innovation approach*, Moscow: VIAM, 2017, pp. 132–142.