ABSTRACT AND REFERENCES

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ANALYSIS OF TRIBOLOGICAL EFFICIENCY OF MOVABLE JUNCTIONS "POLYMERICCOMPOSITE MATERIALS – STEEL" (p. 6-15)

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The paper reports an analysis into tribological efficiency of mating parts "polymeric-composite materials – steel" is carried out. Improperly selected materials produce significant operating costs in terms of tribology. Therefore, selecting the type of polymeric-composite materials to be used in the structures of nodes and machine parts is a task related to substantial improvement of their technical level.

The testing of samples made from polymeric-composite materials for relative abrasive resistance when mated with samples made from steel 45 has made it possible to establish that the lowest value for weight wear was demonstrated by material Nylon 66. Among the examined materials, the closest to Nylon 66 in terms of the values for relative abrasive resistance is the material PA-6-210KS that demonstrated the values that are 1.65 times less. During operation of machines, in the presence of abrasive wear, it is advisable to mate the materials "Nylon 66 – steel 45" and "PA-6-210KS – steel 45". The results from a tribotechnical study without lubrication at the friction machine SMC-2 for the mating parts "polymeric-composite material – steel 45" make it possible to establish that the least wear was demonstrated by sample made from the material UPA-6-30, that is 0.00083 g. In terms of wear resistance, the closest to it is a sample from the material PAG/6.6 R196-GF30, which is 6.1 times greater for weight wear. The sample made from steel 45 mated with a sample from the material UPA-6-30 has the lowest value of weight wear, 0.00005 g. At the same time, the lowest value for the friction coefficient is demonstrated by the mated materials "steel 45 – UPA-6-30", 0.163. The progress of the mating process is achieved fastest, after 20 minutes, when using the material UPA-6-30 at a temperature in the friction zone of 348±2 K.

Our research is necessary to substantiate further utilization and selection of polymeric-composite materials for mating parts working under difficult conditions. The current study is of interest to manufacturers of agricultural and quarry machinery and various transport machines.

Keywords: polymeric-composite material, weight wear, steel 45, mating of samples, friction coefficient, relative abrasive resistance.

References

1. Bulgakov, V., Adamchuk, V., Ivanovs, S., Kaletnik, H. (2019). Experimental investigation of technical and operational indices of asymmetric swath reaper machine-and-tractor aggregate. Engineering for Rural Development, 256–263. doi: https://doi.org/10.22616/erdev2019.18.n387
2. Vigneshwaran, S., Uthayakumar, M., Arumugaprabu, V. (2019). Prediction and Analysis of Abrasive Water Jet Machining Performance on Hybrid Composite. Journal of Testing and Evaluation, 48 (2), 20180593. doi: https://doi.org/10.1520/jte20180593
3. Derkach, O. D., Kabat, O. S., Bezus, R. M., Kovalenko, V. L., Kotok, V. A. (2018). Investigation of the influence of fullerene-containing oils on tribotechnical characteristics of metal conjunction. ARPN Journal of Engineering and Applied Sciences, 13 (14), 4331–4336.
4. Garg, N., Chandrashekar, G., Alisafaei, F., Han, C.-S. (2019). Fiber Diameter-Dependent Elastic Deformation in Polymer Composites – A Numerical Study. Journal of Engineering Materials and Technology, 142 (1), 011002. doi: https://doi.org/10.1115/1.4043766
5. Santo, L., Quadrini, F., Bellisario, D., Iorio, L. (2019). Applications of Shape-Memory Polymers, and Their Blends and Composites. Shape Memory Polymers, Blends and Composites, 311–329. doi: https://doi.org/10.1007/978-981-13-8574-2_13
6. Aulin, V., Lysenko, S., Lyashuk, O., Hrinkiv, A., Velykodnyi, D., Vovk, Y. et. al. (2019). Wear Resistance Increase of Samples Tribomating in Oil Composite with Geo Modifier KGMF-1. Tribology in Industry, 41 (2), 156–165. doi: https://doi.org/10.24874/ti.2019.41.02.02
7. Aulin, V., Hrynkiv, A., Lysenko, S., Rohovskii, I., Chernovol, M., Lyashuk, O., Zamota, T. (2019). Studying truck transmission oils using the method of thermal-oxidative stability during vehicle operation. Eastern-European Journal of Enterprise Technologies, 1 (6 (97)), 6–12. doi: https://doi.org/10.15587/1729-4061.2019.156150
8. Qi, X., Wang, Y. (2019). Novel Techniques for the Preparation of Shape-Memory Polymers, Polymer Blends and Composites at Micro and Nanoscales. Shape Memory Polymers, Blends and Composites, 53–83. doi: https://doi.org/10.1007/978-981-13-8574-2_3
9. Prysyazhnyuk, P., Lutsak, D., Shlapak, L., Aulin, V., Lutsak, L., Borushchak, L., Shihab, T. A. (2018). Development of the composite material and coatings based on niobium carbide. Eastern-European Journal of Enterprise Technologies, 6 (12 (96)), 43–49. doi: https://doi.org/10.15587/1729-4061.2018.150807
10. Tiptipakorn, S., Rimdusit, S. (2019). Thermal Stability of Shape Memory Polymers, Polymer Blends, and Composites. Shape Memory Polymers, Blends and Composites, 167–197. doi: https://doi.org/10.1007/978-981-13-8574-2_8
11. Srinivasababu, N. (2019). Comparison in Performance of Hybrid and Marvel NoKH Okra/Abelmoschus esculentus Fibre Reinforced

Polymer Composites Under Tensile Load. Engineering Design Applications II, 243–255. doi: https://doi.org/10.1007/978-3-030-20801-1_18

12. Lutsak, D., Prysyazhnyuk, P., Burda, M., Aulin, V. (2016). Development of a method and an apparatus for tribotechnical tests of materials under loose abrasive friction. Eastern-European Journal of Enterprise Technologies, 5 (7 (83)), 19–26. doi: https://doi.org/10.15587/1729-4061.2016.79913
13. Bakanin, D., Bychkovsky, V., Filippenko, N., Butorin, D., Kuraitis, A. (2019). Development and Automation of the Device for Determination of Thermophysical Properties of Polymers and Composites. Advances in Intelligent Systems and Computing, 731–740. doi: https://doi.org/10.1007/978-3-030-19756-8_69
14. Aulin, V., Hrynkiv, A., Lysenko, S., Dykha, A., Zamota, T., Dzyura, V. (2019). Exploring a possibility to control the stressedstrained state of cylinder liners in diesel engines by the tribotechnology of alignment. Eastern-European Journal of Enterprise Technologies, 3 (12 (99)), 6–16. doi: https://doi.org/10.15587/1729-4061.2019.171619
15. Marszałek, J., Stadnicki, J. (2019). Mesoscopic Modelling of Unidirectional Polymer Laminate Reinforced with Glass Roving Fabric. Mechanisms and Machine Science, 51–60. doi: https://doi.org/10.1007/978-3-030-13321-4_5
16. Wu, S., Kondo, Y., Kakimoto, M., Yang, B., Yamada, H., Kuwajima, I. et. al. (2019). Machine-learning-assisted discovery of polymers with high thermal conductivity using a molecular design algorithm. Npj Computational Materials, 5 (1). doi: https://doi.org/10.1038/s41524-019-0203-2
17. Aulin, V. V., Chernovol, M. I., Pankov, A. O., Zamota, T. M., Panayotov, K. K. (2017). Sowing machines and systems based on the elements of fluidics. INMATEH - Agricultural Engineering, 53 (3), 21–28. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85039172369&partnerID=40&md5=2468069fc8914b34091c229527a0cc3e
18. Sokolowski, K., Zambrzycki, M., Fraczek-Szczypta, A., Blazewicz, S. (2019). Ceramic coating formation during carbothermic reaction of polysiloxanes with carbon and graphite materials. Materials Chemistry and Physics, 238, 121908. doi: https://doi.org/10.1016/j.matchemphys.2019.121908
19. Sankaranarayanan, S., Likozar, B., Navia, R. (2019). Real-time Particle Size Analysis Using the Focused Beam Reflectance Measurement Probe for In Situ Fabrication of Polyacrylamide–Filler Composite Materials. Scientific Reports, 9 (1). doi: https://doi.org/10.1038/s41598-019-46451-x
20. Feyzullahoğlu, E. (2017). Effect of Different Fillers on Adhesive Wear Properties of Glass Fiber Reinforced Polyester Composites. Tribology in Industry, 39 (4), 482–486. doi: https://doi.org/10.24874/ti.2017.39.04.07
21. Aulin, V., Lyashuk, O., Tykhyi, A., Karpushyn, S., Denysiuk, N. (2018). Influence of Rheological Properties of a Soil Layer Adjacent to the Working Body Cutting Element on the Mechanism of Soil Cultivation. Acta Technologica Agriculturae, 21 (4), 153–159. doi: https://doi.org/10.2478/ata-2018-0028
22. Botan, M., Musteata, A. E., Ionescu, T. F., Georgescu, C., Deleanu, L. (2017). Adding Aramid Fibers to Improve Tribological Characteristics of two Polymers. Tribology in Industry, 39 (3), 283–293. doi: https://doi.org/10.24874/ti.2017.39.03.02
23. Panneerselvam, T., Kandavel, T. K., Raghuraman, S. (2016). Experimental investigations on tribological behaviour of alumina added Acrylonitrile butadiene styrene (ABS) composites. Tribology in Industry, 38 (3), 338–346.
24. Ashmarin, G. M., Aulin, V. V., Golobev, M. Yu., Zvonkov, S. D., Malyuchkov, O. T. (1986). Electrical conductivity of copper after laser treatment. Russian metallurgy. Metally, 5, 185–189. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0022959597&partnerID=40&md5=a27075bbaeb23b2bea5c5f9b2cc75f68
25. Oladele, I. O., Olajide, J. L., Amujede, M. (2016). Wear resistance and mechanical behaviour of epoxy/mollusk shell biocomposites developed for structural applications. Tribology in Industry, 38 (3), 347–360. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84989248998&partnerID=40&md5=5d6a9d6decb8de737ce0b400121e0195
26. Ashmarin, G. M., Aulin, V. V., Golubev, M. Yu., Zvonkov, S. D. (1986). Grain boundary internal friction of unalloyed copper subjected to continuous laser radiation. Physics and chemistry of materials treatment, 20 (5), 476–478. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0022781198&partnerID=40&md5=12a45ba637bf291f2ffb4fe3a9da90e0
27. Bîrsan, I.-G., Cîrciumaru, A., Bria, V., Ungureanu, V. (2009). Tribological and electrical properties of filled epoxy reinforced composites. Tribology in Industry, 31 (1-2), 33–36. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-74049115422&partnerID=40&md5=09c05046e2a613645fc79c11fe8bb25e
28. Căpitanu, L., Onişoru, J., Iarovici, A. (2004). Tribological aspects for injection processing of thermoplastic composite materials with glass fiber. Tribology in Industry, 26 (1-2), 32–41. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-47149103073&partnerID=40&md5=d9ea7df25effc0e25979b2af100dc5cc
29. Aulin, V., Lyashuk, O., Pavlenko, O., Velykodnyi, D., Hrynkiv, A., Lysenko, S. et. al. (2019). Realization of the logistic approach in the international cargo delivery system. Communications - Scientific Letters of the University of Zilina, 21 (2), 3–12. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85066994460&partnerID=40&md5=105d35bd46f8ab7b6de0b6688948d0e3
30. Myshkin, N. K., Pesetskii, S. S., Grigoriev, A. Y. (2015). Polymer tribology: Current state and applications. Tribology in Industry, 37 (3), 284–290. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84941957788&partnerID=40&md5=898d9e4440a69f9f7237f020888370ff
31. Cerit, A. A., Karamiş, M. B., Fehmi, N., Kemal, Y. (2008). Effect of reinforcement particle size and volume fraction on wear behaviour of metal matrix composites. Tribology in Industry, 30 (3-4), 31–36. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-76649086674&partnerID=40&md5=80413e399317cac297443c6121bdf2ca
32. Riecky, D., Zmindak, M., Pelagic, Z. (2014). Numerical finite element method homogenization of composite materials reinforced with fibers. Communications - Scientific Letters of the University of Zilina, 16 (3 a), 142–147. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84919961587&partnerID=40&md5=5268bd99b57539e4058c0f0e255c3e0e
33. Bria, V., Dima, D., Andrei, G., Birsan, I.-G., Circiumaru, A. (2011). Tribological and wear properties of multi-layered materials. Tribology in Industry, 33 (3), 104–109. Available at: http://www.tribology.fink.rs/journals/2011/2011-3/2.pdf
34. Aulin, V., Hrinkiv, A., Dykha, A., Chernovol, M., Lyashuk, O., Lysenko, S. (2018). Substantiation of diagnostic parameters for deter-

mining the technical condition of transmission assemblies in trucks. Eastern-European Journal of Enterprise Technologies, 2 (1 (92)), 4–13. doi: https://doi.org/10.15587/1729-4061.2018.125349
35. Hassan, S. B., Aigbodion, V. S., Patrick, S. N. (2012). Development of polyester/eggshell particulate composites. Tribology in Industry, 34 (4), 217–225. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84871914470&partnerID=40&md5=827dcc75092ac0ae9c025ce1e4b2923a
36. Todić, A., Čikara, D., Lazić, V., Todić, T., Čamagić, I., Skulić, A., Čikara, D. (2013). Examination of wear resistance of polymer - Basalt composites. Tribology in Industry, 35 (1), 36–41. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84875410103&partnerID=40&md5=ac878f662a36868beeeadc2426f6d16a
37. Danchenko, Y., Andronov, V., Barabash, E., Obigenko, T., Rybka, E., Meleshchenko, R., Romin, A. (2017). Research of the intramolecular interactions and structure in epoxyamine composites with dispersed oxides. Eastern-European Journal of Enterprise Technologies, 6 (12 (90)), 4–12. doi: https://doi.org/10.15587/1729-4061.2017.118565
38. Petru, M., Broncek, J., Lepsik, P., Novak, O. (2014). Experimental and numerical analysis of crack propagation in light composite materials under dynamic fracturing. Communications - Scientific Letters of the University of Zilina, 16 (3 a), 82–89. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84920052758&partnerID=40&md5=993ab820ab09a50372ff085635383742
39. Bastiurea, M., Rodeanu Bastiurea, M. S., Andrei, G., Dima, D., Murarescu, M., Ripa, M., Circiumaru, A. (2014). Determination of specific heat of polyester composite with graphene and graphite by differential scanning calorimetry (2014) Tribology in Industry, 36 (4), 419–427. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84919829774&partnerID=40&md5=c0b5cdd104d2180cbd622a242fa15829
40. Besnea, M. A. C., Trufasu, D. C., Andrei, G., Bastiurea, M., Rodeanu, M. S. (2015). Estimation of wear behavior of polyphenylene sulphide composites reinforced with glass/carbon fibers, graphite and polytetrafluoroethylene, by pin-on-disc test. Tribology in Industry, 37 (1), 88–96.
41. Kondratiev, A., Gaidachuk, V. (2019). Weight-based optimization of sandwich shelled composite structures with a honeycomb filler. Eastern-European Journal of Enterprise Technologies, 1 (1 (97)), 24–33. doi: https://doi.org/10.15587/1729-4061.2019.154928

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DESIGNING THE ORGANOPLASTICS BASED ON AROMATIC POLYAMIDE, STUDY OF THEIR OPERATIONAL PROPERTIES AND APPLICABILITY (p. 16-22)

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Polymeric composite materials that are reinforced with organic fibers are characterized by great possibilities in terms of improving the durability of friction nodes in machines and mechanisms. These composites successfully compete with non-ferrous metals and their alloys and, in some cases, outperform polymeric and metallic analogs by their properties. In this regard, we have studied the influence of the organic fiber lola on operational characteristics of the aromatic polyamide phenylone, brand C-1, and on possibilities to apply the developed polymeric composite materials.

Experimental studies have confirmed that the reinforcement of phenylone with the organic fiber lola in the amount of 5–15 % by weight improves its operational characteristics. This is predetermined by the arrangement of the supramolecular structure of the basic polymer due to the introduction of organic fiber. Thus, at the interface " phenylone-filler" one clearly observes the transformation of the binder's globular structure into fibrillar one. That leads to a positive effect: there is an increase in destruction energy (by 1.5 times) and chemical resistance (by 1.1–1.36 at aging in 5 % HCl, and by 1.27–1.6 – in 10 % HCl). It should be noted that the developed organoplastics are stable at a temperature of 673 K, while the starting polymer begins to destroy intensively at 400 K. Specifically, it was determined that at a further increase in the mass fraction of the filler these indicators deteriorate, due to insufficient adhesion between the filler and the binder.

Using the organic fiber lola (in the amount of 5–15 % by weight) makes it possible to obtain composites with improved operational characteristics: enhanced thermal and chemical parameters, high resistance to impact loads. Thus, there is reason to argue about the prospects of using the fiber lola as a filler for composites. Organoplastic with an optimum fiber content (15 % by weight) is recommended for manufacturing the components of tribological nodes for modern equipment instead of non-ferrous metals and their alloys due to sufficiently high operational properties.

Keywords: phenylone, polyamide, organic fiber, lola, organoplastics, heat resistance, chemical resistance, structuring, tribological nodes.

Referense

1. Solomentseva, A. V., Fadeeva, V. M., Zhelezina, G. F. (2016). Antifriction organoplastics for heavy loaded sliding friction units of aircraft structures. Aviation Materials and Technologies, 2, 30–34. doi: https://doi.org/10.18577/2071-9140-2016-0-2-30-34
2. Burya, A. I., Yeriomina, Y. A. (2016). The effect of various metallic filling materials on the wear resistance of aromatic-polyamide-based composite materials. Journal of Friction and Wear, 37 (2), 151–154. doi: https://doi.org/10.3103/s1068366616020033
3. Kulagina, G. S., Zhelezina, G. F., Levakova, N. M. (2019). Antifriction organoplastics for high-loaded friction knots. Proceedings of VIAM, 2, 89–96. doi: https://doi.org/10.18577/2307-6046-2019-0-2-89-96
4. Buria, O. I., Yeromina, K. A., Lysenko, O. B., Konchyts, A. A., Morozov, O. F. (2019). Polimerni kompozyty na osnovi termoplastychnykh viazhuchykh. Dnipro: Seredniak T.K., 239.
5. Baurova, N. I., Makarov, K. A. (2017). Machining of Machine Elements Made of Polymer Composite Materials. Russian Metallurgy (Metally), 2017 (13), 1141–1144. doi: https://doi.org/10.1134/s0036029517130043
6. Scaffaro, R., Maio, A. (2019). Influence of Oxidation Level of Graphene Oxide on the Mechanical Performance and Photo-Oxidation

Resistance of a Polyamide 6. Polymers, 11 (5), 857. doi: https://doi.org/10.3390/polym11050857

7. Matyas, A. (2018). Influence of Graphite Additives on Mechanical, Tribological, Fire Resistance and Electrical Properties in Polyamide 6. Tehnički Vjesnik, 25 (4), 1014–1019. doi: https://doi.org/10.17559/tv-20160702212234
8. Silva, M. R., Pereira, A. M., Alves, N., Mateus, G., Mateus, A., Malça, C. (2019). Development of an Additive Manufacturing System for the Deposition of Thermoplastics Impregnated with Carbon Fibers. Journal of Manufacturing and Materials Processing, 3 (2), 35. doi: https://doi.org/10.3390/jmmp3020035
9. Wang, Z., Ni, J., Gao, D. (2017). Combined effect of the use of carbon fiber and seawater and the molecular structure on the tribological behavior of polymer materials. Friction, 6 (2), 183–194. doi: https://doi.org/10.1007/s40544-017-0164-8
10. Gao, X., Yu, W., Zhang, X., Zhang, J., Liu, H., Zhang, X. (2019). Facile Fabrication of PA66/GO/MWNTs-COOH Nanocomposites and Their Fibers. Fibers, 7 (8), 69. doi: https://doi.org/10.3390/fib7080069
11. Volpe, V., Lanzillo, S., Affinita, G., Villacci, B., Macchiarolo, I., Pantani, R. (2019). Lightweight High-Performance Polymer Composite for Automotive Applications. Polymers, 11 (2), 326. doi: https://doi.org/10.3390/polym11020326
12. Burya, A. I., Tomina, A.-M. V., Volnyanko, E. N., Terenin, V. I. (2018). Investigation of the thermophysical properties of organoplastics based on phenylon reinforced by lola fiber. Polymer Materials and Technologies, 4 (4), 72–77. doi: https://doi.org/10.32864/polymmattech-2018-4-4-72-77
13. Burya, O. I., Naberezhnaya, O. A., Terenin, V. I., Tomina, A. M. V. (2015). Tribological characteristics of organic plastics based on phenylone. Problems of friction and wear, 3, 51–55.
14. Shul'deshova, P. M., Zhelezina, G. F. (2014). An influence of atmospheric conditions and dust loading on properties of structural organic plastics. Aviatsionnye materialy i tehnologi, 1, 64–68.
15. Kolesnikov, I. V., Byeli, A. V., Myasnikova, N. A., Myasnikov, Ph. V., Kravchenko, Y. V., Novikov, E. S. (2012). The multilayered antifriction nanostructured covering for lubrication in thehigh-gravity loaded friction units. Ehkologicheskiy vestnik nauchnyh tsentrov Chernomorskogo ehkonomicheskogo sotrudnichestva, 2, 34–41.
16. Boccardi, S., Boffa, N. D., Carlomagno, G. M., Del Core, G., Meola, C., Monaco, E. et. al. (2019). Lock-In Thermography and Ultrasonic Testing of Impacted Basalt Fibers Reinforced Thermoplastic Matrix Composites. Applied Sciences, 9 (15), 3025. doi: https://doi.org/10.3390/app9153025
17. Raskatov, V. M. (1980). Mashinostroitel'nye materialy. Moscow, 512.
18. Kataeva, V. M., Popova, V. A., Sazhina, B. I. (Eds.) (1975). Spravochnik po plasticheskim massam. Vol. 2. Moscow: Himiya, 568.
19. Cherkasova, N. G., Burya, A. I. (2011). Reaktoplasty, haoticheski armirovannye himicheskimi voloknami. Dnepropetrovsk, 234.
20. Buria, O. I., Naberezhna, O. O., Tomina A.-M. V., Terenin V. I. (2015). Pat. No. 105957 UA. Heatproof composition. MPK F16C 19/00. No. u201510084; declareted: 15.10.2015; published: 11.04.2016, Bul. No. 7.
21. Lipatov, Yu. S. (1980). Mezhfaznye yavleniya v polimerah. Kyiv: Naukova Dumka, 260.
22. Kargin, V. A. Slonimskiy, G. L., Sogolova, T. I. (1966). Svyaz' nadmolekulyarnoy struktury s mehanicheskimi svoystvami polimerov. 22nd Annual Technical Conference: Technical papers SPE. Montreal, 12, 43.
23. Karpinos, D. M., Oleynik, V. I. (1981). Polimery i kompozitsionnye materialy na ih osnove v tehnike. Kyiv: Naukova Dumka, 180.
24. Shitova, I. Yu., Samoshina, E. N., Kislitsyna, S. N., Boltyshev, S. A. (2015). Sovremennye kompozitsionnye stroitel'nye materialy. Penza: PGUAS, 136.
25. Zuev, Yu. S. (1972). Razrushenie polimerov pod deystviem agressivnyh sred. Moscow: Himiya, 229.
26. Bazhenov, S. L. (2014). Mehanika i tehnologiya kompozitsionnyh materialov. Dolgoprudniy: Intellekt, 328.
27. Danilova, S. N., Okhlopkova, A. A., Gavrilieva, A. A., Okhlopkova, T. A., Borisova, R. V., Dyakonov, A. A. (2016). Wear resistant polymer composite materials with improved interfacial interaction in the system "polymer – fiber". Vestnik Severo-Vostochnogo federal'nogo universiteta im. M. K. Ammosova, 55 (5), 80–92.

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"SMART" ANTICORROSION PIGMENT BASED ON LAYERED DOUBLE HYDROXIDE: CONSTRUCTION AND CHARACTERIZATION (p. 23-30)

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Paint coatings are widely used for decorative purposes and to prevent corrosion of metal surfaces. However, regular paint coating only provides passive protection of the metal. To create an active type of corrosion protection, various anti-corrosion additives are added to paint formulations. As a result of analyzing available data, a bi-functional (colored and anti-corrosion) pigment was theoretically constructed as monophase Zn-Al-tripolyphosphate LDH with the generalized formula $Zn_{0.8}Al_{0.2}(P_3O_{10})_{0.04}$. In this LDH, Zn^{2+} as "host" cation and Al^{3+} as "guest" cation govern white color of the pigment, and intercalated tripolyphosphate-anions – corrosion inhibitor. A continuous constant pH synthesis at a temperature of 70 °C was selected as a preparation method. This method was used to prepare theoretically constructed pigment. The crystal structure of the pigment sample was studied by means of X-ray diffraction, morphology and particle size were determined by means of scanning electron microscopy, thermal properties were evaluated by means of thermogravimetry. Color characteristics were recorded using the color comparator, anti-corrosion properties were evaluated by recording anodic polarization curves of 08KP steel in 5 % (wt.) Na_2SO_4 solution with and without the pigment extract. By means of X-ray diffraction analysis, it was found that bi-phase precipitate, containing the constructed LDH (with $Zn(OH)_2$ structure) and Zn-Al LDO (ZnO structure) was formed. This indicated partial decomposition of LDH during synthesis, but the reason for it is unknown. By means of SEM, the formation of agglomerates of the same particles with high surface area was found. The study of color characteristics revealed that the prepared pigment has high whiteness value (diffuse reflection coefficient above 90 %, color purity below 1 %, lightness

above 96 %). This is due to the color of both LDH and LDO phases. By recording anodic polarization curves, it was found that corrosion rate in the presence of water extract of the pigment is lower by 5.36 times (corrosion current density decreased from 5.63 mA/cm^2 to 1.03 mA/cm^2. All of this shows that a bi-functional pigment was prepared, which has great pigment properties, high whiteness, and high anti-corrosion properties.

Keywords: paint coats, Zn-Al LDH, "smart" bi-functional pigment, tripolyphosphate, inhibitor.

References

1. Deyá, C. (2016). Silane as adhesion promoter in damaged areas. Progress in Organic Coatings, 90, 28–33. doi: https://doi.org/10.1016/j.porgcoat.2015.09.001
2. Burmistr, M. V., Boiko, V. S., Lipko, E. O., Gerasimenko, K. O., Gomza, Y. P., Vesnin, R. L. et. al. (2014). Antifriction and Construction Materials Based on Modified Phenol-Formaldehyde Resins Reinforced with Mineral and Synthetic Fibrous Fillers. Mechanics of Composite Materials, 50 (2), 213–222. doi: https://doi.org/10.1007/s11029-014-9408-0
3. Brooman, E. W. (2002). Modifying organic coatings to provide corrosion resistance: Part II–Inorganic additives and inhibitors. Metal Finishing, 100 (5), 42–53. doi: https://doi.org/10.1016/s0026-0576(02)80382-8
4. Deyá, M. C., del Amo, B., Spinelli, E., Romagnoli, R. (2013). The assessment of a smart anticorrosive coating by the electrochemical noise technique. Progress in Organic Coatings, 76 (4), 525–532. doi: https://doi.org/10.1016/j.porgcoat.2012.09.014
5. Blustein, G., Deyá, M. C., Romagnoli, R., Di Sarli, A. R., del Amo, B. (2010). Improvement of anticorrosive performance of phosphate-based alkyd paints with suitable additives. Journal of Coatings Technology and Research, 8 (2), 171–181. doi: https://doi.org/10.1007/s11998-010-9289-7
6. Silva, R. S., Aleman, C., Ferreira, C. A., Armelin, E., Ferreira, J. Z., Meneguzzi, A. (2015). Smart Paint for anodic protection of steel. Progress in Organic Coatings, 78, 116–123. doi: https://doi.org/10.1016/j.porgcoat.2014.10.002
7. Abd El-Ghaffar, M. A., Youssef, E. A. M., Ahmed, N. M. (2004). High performance anticorrosive paint formulations based on phosphate pigments. Pigment & Resin Technology, 33 (4), 226–237. doi: https://doi.org/10.1108/03699420410546917
8. Yan, H., Wang, J., Zhang, Y., Hu, W. (2016). Preparation and inhibition properties of molybdate intercalated ZnAlCe layered double hydroxide. Journal of Alloys and Compounds, 678, 171–178. doi: https://doi.org/10.1016/j.jallcom.2016.03.281
9. Guo, Y., Wang, J., Li, D., Tang, P., Leroux, F., Feng, Y. (2018). Micrometer-sized dihydrogenphosphate-intercalated layered double hydroxides: synthesis, selective infrared absorption properties, and applications as agricultural films. Dalton Transactions, 47 (9), 3144–3154. doi: https://doi.org/10.1039/c7dt03483k
10. Deyá, M. C., Blustein, G., Romagnoli, R., del Amo, B. (2008). Zinc hypophosphite: a suitable additive for anticorrosive paints to promote pigments synergism. Journal of Coatings Technology and Research, 6 (3), 369–376. doi: https://doi.org/10.1007/s11998-008-9147-z
11. Blustein, G., del Amo, B., Romagnoli, R. (2000). The influence of the solubility of zinc phosphate pigments on their anticorrosive behaviour. Pigment & Resin Technology, 29 (2), 100–107. doi: https://doi.org/10.1108/03699420010319148
12. Blustein, G., Deyá, C., Romagnoli, R. (2016). Synergism in anticorrosive paints. Bulletin of Materials Science, 39 (3), 749–757. doi: https://doi.org/10.1007/s12034-016-1217-8
13. Kalendova´, A. (2003). Comparison of the anticorrosion efficiencies of pigments based on condensed phosphates and polyphosphosilicates. Anti-Corrosion Methods and Materials, 50 (2), 82–90. doi: https://doi.org/10.1108/00035590310463957
14. Alibakhshi, E., Naeimi, A., Ramezanzadeh, M., Ramezanzadeh, B., Mahdavian, M. (2018). A facile synthesis method of an effective anti-corrosion nanopigment based on zinc polyphosphate through microwaves assisted combustion method; comparing the influence of nanopigment and conventional zinc phosphate on the anti-corrosion properties of an epoxy coating. Journal of Alloys and Compounds, 762, 730–744. doi: https://doi.org/10.1016/j.jallcom.2018.05.172
15. Deyá, M., Vetere, V., Romagnoli, R., del Amo, B. (2003). Zinc tripolyphosphate: An anticorrosive pigment for paints. Surface Coatings International Part B: Coatings Transactions, 86 (1), 79–85. doi: https://doi.org/10.1007/bf02699598
16. Deyá, M., Vetere, V. F., Romagnoli, R., del Amo, B. (2001). Aluminium tripolyphosphate pigments for anticorrosive paints. Pigment & Resin Technology, 30 (1), 13–24. doi: https://doi.org/10.1108/03699420110364129
17. Song, D., Gao, J., Shen, L., Wan, H., Li, X. (2015). The Influence of Aluminum Tripolyphosphate on the Protective Behavior of an Acrylic Water-Based Paint Applied to Rusty Steels. Journal of Chemistry, 2015, 1–10. doi: https://doi.org/10.1155/2015/618971
18. Vetere, V. F., Deyá, M. C., Romagnoli, R., Amo, B. (2001). Calcium tripolyphosphate: An anticorrosive pigment for paint. Journal of Coatings Technology, 73 (6), 57–63. doi: https://doi.org/10.1007/bf02698398
19. Deyá, M., Di Sarli, A. R., del Amo, B., Romagnoli, R. (2008). Performance of Anticorrosive Coatings Containing Tripolyphosphates in Aggressive Environments. Industrial & Engineering Chemistry Research, 47 (18), 7038–7047. doi: https://doi.org/10.1021/ie071544d
20. Khan, A. I., Ragavan, A., Fong, B., Markland, C., O'Brien, M., Dunbar, T. G. et. al. (2009). Recent Developments in the Use of Layered Double Hydroxides as Host Materials for the Storage and Triggered Release of Functional Anions. Industrial & Engineering Chemistry Research, 48 (23), 10196–10205. doi: https://doi.org/10.1021/ie9012612
21. Mandal, S., Tichit, D., Lerner, D. A., Marcotte, N. (2009). Azoic Dye Hosted in Layered Double Hydroxide: Physicochemical Characterization of the Intercalated Materials. Langmuir, 25 (18), 10980–10986. doi: https://doi.org/10.1021/la901201s
22. Mandal, S., Lerner, D. A., Marcotte, N., Tichit, D. (2009). Structural characterization of azoic dye hosted layered double hydroxides. Zeitschrift Für Kristallographie, 224 (5-6). doi: https://doi.org/10.1524/zkri.2009.1150
23. Alibakhshi, E., Ghasemi, E., Mahdavian, M., Ramezanzadeh, B. (2017). A comparative study on corrosion inhibitive effect of nitrate and phosphate intercalated Zn-Al- layered double hydroxides (LDHs) nanocontainers incorporated into a hybrid silane layer and their effect on cathodic delamination of epoxy topcoat. Corrosion Science, 115, 159–174. doi: https://doi.org/10.1016/j.corsci.2016.12.001
24. Alibakhshi, E., Ghasemi, E., Mahdavian, M., Ramezanzadeh, B. (2017). Fabrication and characterization of layered double hydroxide/silane nanocomposite coatings for protection of mild steel.

Journal of the Taiwan Institute of Chemical Engineers, 80, 924–934. doi: https://doi.org/10.1016/j.jtice.2017.08.015

25. Kotok, V., Kovalenko, V., Vlasov, S. (2018). Investigation of NiAl hydroxide with silver addition as an active substance of alkaline batteries. Eastern-European Journal of Enterprise Technologies, 3 (6 (93)), 6–11. doi: https://doi.org/10.15587/1729-4061.2018.133465
26. Solovov, V. A., Nikolenko, N. V., Kovalenko, V. L., Kotok, V. A., Burkov, A. A., Kondrat'ev, D. A. et. al. (2018). Synthesis of Ni(II)-Ti(IV) Layered Double Hydroxides Using Coprecipitation at High Supersaturation Method. ARPN Journal of Engineering and Applied Sciences, 13 (24), 9652–9656.
27. Marangoni, R., Bouhent, M., Taviot-Guého, C., Wypych, F., Leroux, F. (2009). Zn2Al layered double hydroxides intercalated and adsorbed with anionic blue dyes: A physico-chemical characterization. Journal of Colloid and Interface Science, 333 (1), 120–127. doi: https://doi.org/10.1016/j.jcis.2009.02.001
28. Kovalenko, V., Kotok, V. (2019). Influence of the carbonate ion on characteristics of electrochemically synthesized layered (α+β) nickel hydroxide. Eastern-European Journal of Enterprise Technologies, 1 (6 (97)), 40–46. doi: https://doi.org/10.15587/1729-4061.2019.155738
29. Kotok, V., Kovalenko, V. (2018). A study of the effect of tungstate ions on the electrochromic properties of Ni(OH)2 films. Eastern-European Journal of Enterprise Technologies, 5 (12 (95)), 18–24. doi: https://doi.org/10.15587/1729-4061.2018.145223
30. Kovalenko, V., Kotok, V. (2019). Anionic carbonate activation of layered (α+β) nickel hydroxide. Eastern-European Journal of Enterprise Technologies, 3 (6 (99)), 44–52. doi: https://doi.org/10.15587/1729-4061.2019.169461
31. Arizaga, G. G. C., Gardolinski, J. E. F. da C., Schreiner, W. H., Wypych, F. (2009). Intercalation of an oxalatooxoniobate complex into layered double hydroxide and layered zinc hydroxide nitrate. Journal of Colloid and Interface Science, 330 (2), 352–358. doi: https://doi.org/10.1016/j.jcis.2008.10.025
32. Andrade, K. N., Pérez, A. M. P., Arízaga, G. G. C. (2019). Passive and active targeting strategies in hybrid layered double hydroxides nanoparticles for tumor bioimaging and therapy. Applied Clay Science, 181, 105214. doi: https://doi.org/10.1016/j.clay.2019.105214
33. Kovalenko, V., Kotok, V., Yeroshkina, A., Zaychuk, A. (2017). Synthesis and characterisation of dyeintercalated nickelaluminium layereddouble hydroxide as a cosmetic pigment. Eastern-European Journal of Enterprise Technologies, 5 (12 (89)), 27–33. doi: https://doi.org/10.15587/1729-4061.2017.109814
34. Cursino, A. C. T., Rives, V., Arizaga, G. G. C., Trujillano, R., Wypych, F. (2015). Rare earth and zinc layered hydroxide salts intercalated with the 2-aminobenzoate anion as organic luminescent sensitizer. Materials Research Bulletin, 70, 336–342. doi: https://doi.org/10.1016/j.materresbull.2015.04.055
35. Wang, Q., Feng, Y., Feng, J., Li, D. (2011). Enhanced thermal- and photo-stability of acid yellow 17 by incorporation into layered double hydroxides. Journal of Solid State Chemistry, 184 (6), 1551–1555. doi: https://doi.org/10.1016/j.jssc.2011.04.020
36. Liu, J. Q., Zhang, X. C., Hou, W. G., Dai, Y. Y., Xiao, H., Yan, S. S. (2009). Synthesis and Characterization of Methyl-Red/Layered Double Hydroxide (LDH) Nanocomposite. Advanced Materials Research, 79-82, 493–496. doi: https://doi.org/10.4028/www.scientific.net/amr.79-82.493
37. Tian, Y., Wang, G., Li, F., Evans, D. G. (2007). Synthesis and thermo-optical stability of o-methyl red-intercalated Ni–Fe layered double hydroxide material. Materials Letters, 61 (8-9), 1662–1666. doi: https://doi.org/10.1016/j.matlet.2006.07.094
38. Hwang, S.-H., Jung, S.-C., Yoon, S.-M., Kim, D.-K. (2008). Preparation and characterization of dye-intercalated Zn–Al-layered double hydroxide and its surface modification by silica coating. Journal of Physics and Chemistry of Solids, 69 (5-6), 1061–1065. doi: https://doi.org/10.1016/j.jpcs.2007.11.002
39. Tang, P., Deng, F., Feng, Y., Li, D. (2012). Mordant Yellow 3 Anions Intercalated Layered Double Hydroxides: Preparation, Thermo- and Photostability. Industrial & Engineering Chemistry Research, 51 (32), 10542–10545. doi: https://doi.org/10.1021/ie300645b
40. Tang, P., Feng, Y., Li, D. (2011). Fabrication and properties of Acid Yellow 49 dye-intercalated layered double hydroxides film on an alumina-coated aluminum substrate. Dyes and Pigments, 91 (2), 120–125. doi: https://doi.org/10.1016/j.dyepig.2011.03.012
41. Tang, P., Feng, Y., Li, D. (2011). Improved thermal and photostability of an anthraquinone dye by intercalation in a zinc–aluminum layered double hydroxides host. Dyes and Pigments, 90 (3), 253–258. doi: https://doi.org/10.1016/j.dyepig.2011.01.007
42. Kotok, V., Kovalenko, V. (2019). Definition of the influence of obtaining method on physical and chemical characteristics of $Ni(OH)_2$ powders. Eastern-European Journal of Enterprise Technologies, 1 (12 (97)), 21–27. doi: https://doi.org/10.15587/1729-4061.2019.156093
43. Mahjoubi, F. Z., Khalidi, A., Abdennouri, M., Barka, N. (2017). Zn–Al layered double hydroxides intercalated with carbonate, nitrate, chloride and sulphate ions: Synthesis, characterisation and dye removal properties. Journal of Taibah University for Science, 11 (1), 90–100. doi: https://doi.org/10.1016/j.jtusci.2015.10.007
44. Kovalenko, V., Kotok, V. (2018). Comparative investigation of electrochemically synthesized (α+β) layered nickel hydroxide with mixture of α-$Ni(OH)_2$ and β-$Ni(OH)_2$. Eastern-European Journal of Enterprise Technologies, 2 (6 (92)), 16–22. doi: https://doi.org/10.15587/1729-4061.2018.125886
45. Kovalenko, V., Kotok, V. (2017). Obtaining of Ni–Al layered double hydroxide by slit diaphragm electrolyzer. Eastern-European Journal of Enterprise Technologies, 2 (6 (86)), 11–17. doi: https://doi.org/10.15587/1729-4061.2017.95699
46. Kovalenko, V., Kotok, V. (2017). Study of the influence of the template concentration under homogeneous precepitation on the properties of $Ni(OH)_2$ for supercapacitors. Eastern-European Journal of Enterprise Technologies, 4 (6 (88)), 17–22. doi: https://doi.org/10.15587/1729-4061.2017.106813
47. Solovov, V., Kovalenko, V., Nikolenko, N., Kotok, V., Vlasova, E. (2017). Influence of temperature on the characteristics of Ni(II), Ti(IV) layered double hydroxides synthesised by different methods. Eastern-European Journal of Enterprise Technologies, 1 (6 (85)), 16–22. doi: https://doi.org/10.15587/1729-4061.2017.90873
48. Kovalenko, V., Kotok, V. (2019). Investigation of characteristics of double Ni–Co and ternary Ni–Co–Al layered hydroxides for supercapacitor application. Eastern-European Journal of Enterprise Technologies, 2 (6 (98)), 58–66. doi: https://doi.org/10.15587/1729-4061.2019.164792
49. Vlasova, E., Kovalenko, V., Kotok, V., Vlasov, S., Sukhyy, K. (2017). A study of the influence of additives on the process of formation and corrosive properties of tripolyphosphate coatings on steel. Eastern-

European Journal of Enterprise Technologies, 5 (12 (89)), 45–51. doi: https://doi.org/10.15587/1729-4061.2017.111977
50. Deyá, M. C., Blustein, G., Romagnoli, R., del Amo, B. (2002). The influence of the anion type on the anticorrosive behaviour of inorganic phosphates. Surface and Coatings Technology, 150 (2-3), 133–142. doi: https://doi.org/10.1016/s0257-8972(01)01522-5
51. Vlasova, E., Kovalenko, V., Kotok, V., Vlasov, S. (2016). Research of the mechanism of formation and properties of tripolyphosphate coating on the steel basis. Eastern-European Journal of Enterprise Technologies, 5 (5 (83)), 33–39. doi: https://doi.org/10.15587/1729-4061.2016.79559
52. Vlasova, E., Kovalenko, V., Kotok, V., Vlasov, S., Sknar, I., Cheremysinova, A. (2017). Investigation of composition and structure of tripoliphosphate coating on low carbon steel. Eastern-European Journal of Enterprise Technologies, 2 (6 (86)), 4–10. doi: https://doi.org/10.15587/1729-4061.2017.96572
53. Vlasova, O., Kovalenko, V., Kotok, V., Vlasov, S., Cheremysinova, A. (2017). Investigation of physical and chemical properties and structure of tripolyphosphate coatings on zinc plated steel. Eastern-European Journal of Enterprise Technologies, 3 (12 (87)), 4–8. doi: https://doi.org/10.15587/1729-4061.2017.103151
54. Deyá, M. C., Romagnoli, R., del Amo, B. (2004). The influence of zinc oxide on the anticorrosive behaviour of eco - friendly paints. Corrosion Reviews, 22 (1), 1–18. doi: https://doi.org/10.1515/corrrev.2004.22.1.1

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INTENSIFICATION OF THE PROCESS OF METALLIZING TUNGSTENCONTAINING ORE RAW MATERIALS BY THE POWDER METALLURGY METHOD (p. 31-36)

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X-ray diffraction phase analysis of samples performed on a DRON-6 diffractometer has shown that the processes of $CaWO_4$ transition to WC and W_2C had the highest probability in the temperature range of 1,173–1,473 K. The end-product $CaWO_4$, thermally treated with carbon, was represented by carbon in oxycarbide and carbide phases. The processes of tungsten reduction from its oxides through the phases of formation of tungsten carbide and oxygen compounds (higher and lower) and finally tungsten metal were shown. Basic chemical and phase transformations occurred within the temperature range of 300–1,800 K. This opens the prospect of producing tungsten as an alloying material without formation of liquid phases in a heterogeneous system and enables production of tungsten based alloying material at relatively low temperatures which significantly reduces power consumption. Qualitative and quantitative composition of charge materials for laboratory studies and industrial tests in a form of briquettes for metallization of tungsten-containing compounds in a furnace with induction heating was presented. The mechanism of phase and structural transformations occurring in reduction of tungsten from scheelite concentrates in the temperature range of 1,273–1,473 K and microanalysis of samples of chemical transformations were studied. A furnace unit with induction heating in which industrial tests were performed in stages was schematically shown.

The tests have shown that a 1.3 times sample weight reduction and a 23 % specific density reduction occurred in the process of heat treatment of the samples based on scheelite concentrate.

Several batches of spongy tungsten instead of standard ferrotungsten were produced and tested in smelting high speed steels. Advantages of the new technology of tungsten metallization from a scheelite concentrate and positive efficiency of using the new material in special metallurgy were shown.

Keywords: tungsten concentrate, carbothermic reduction, induction heating, metallization, phase analysis, microstructure, resource conservation.

References

1. Dang, J., Zhang, G.-H., Chou, K.-C., Reddy, R. G., He, Y., Sun, Y. (2013). Kinetics and mechanism of hydrogen reduction of MoO_3 to MoO_2. International Journal of Refractory Metals and Hard Materials, 41, 216–223. doi: https://doi.org/10.1016/j.ijrmhm.2013.04.002
2. Wang, L., Zhang, G.-H., Chou, K.-C. (2016). Synthesis of nanocrystalline molybdenum powder by hydrogen reduction of industrial grade MoO_3. International Journal of Refractory Metals and Hard Materials, 59, 100–104. doi: https://doi.org/10.1016/j.ijrmhm.2016.06.001
3. Zhu, H., Li, Z., Yang, H., Luo, L. (2013). Carbothermic Reduction of MoO3 for Direct Alloying Process. Journal of Iron and Steel Research International, 20 (10), 51–56. doi: https://doi.org/10.1016/s1006-706x(13)60176-4
4. Jung, W.-G. (2014). Recovery of tungsten carbide from hard material sludge by oxidation and carbothermal reduction process. Journal of Industrial and Engineering Chemistry, 20 (4), 2384–2388. doi: https://doi.org/10.1016/j.jiec.2013.10.017
5. Torabi, O., Golabgir, M. H., Tajizadegan, H., Torabi, H. (2014). A study on mechanochemical behavior of MoO3–Mg–C to synthesize molybdenum carbide. International Journal of Refractory Metals and Hard Materials, 47, 18–24. doi: https://doi.org/10.1016/j.ijrmhm.2014.06.001
6. Leont'ev, L. I., Grigorovich, K. V., Kostina, M. V. (2016). The development of new metallurgical materials and technologies. Part 1. Steel in Translation, 46 (1), 6–15. doi: https://doi.org/10.3103/s096709121601006x
7. Kozyrev, N. A., Bendre, Yu. V., Goryushkin, V. F., Shurupov, V. M., Kozyreva, O. E. (2016). Termodinamika reaktsiy vosstanovleniya WO_3 uglerodom. Vestnik Sibirskogo gosudarstvennogo industrial'nogo universiteta, 2 (16), 15–17.
8. Ryabchikov, I. V., Belov, B. F., Mizin, V. G. (2014). Reactions of metal oxides with carbon. Steel in Translation, 44 (5), 368–373. doi: https://doi.org/10.3103/s0967091214050118

9. Shveikin, G. P., Kedin, N. A. (2014). Products of carbothermal reduction of tungsten oxides in argon flow. Russian Journal of Inorganic Chemistry, 59 (3), 153–158. doi: https://doi.org/10.1134/s0036023614030206
10. Smirnyagina, N. N., Khaltanova, V. M., Kim, T. B., Milonov, A. S. (2012). Thermodynamic modeling of the formation of borides and carbides of tungsten, synthesis, structure and phase composition of the coatings based on them, formed by electron-beam treatment in vacuum. Izvestiya vysshih uchebnyh zavedeniy. Fizika, 55 (12 (3)), 159–163.
11. Kuz'michev, E. N., Nikolenko, S. V., Balahonov, D. I. (2017). Poluchenie karbida vol'frama iz sheelitovogo kontsentrata kontsentrirovannymi potokami energii. Himicheskaya tehnologiya, 3, 113–118.
12. Belskii, S. S. (2015). Scheelite concentrate treatment with the recovery of tungsten trioxide. Vestnik Irkutskogo gosudarstvennogo tehnicheskogo universiteta, 12 (107), 204–208.
13. Grigoriev, D. (2010). Some kinetic laws carbon-thermic restoration mixes of scale of a fastcutting steel with scheelite concentrate additives. Metally i lit'e Ukrainy, 9-10, 57–61.
14. Tsivirko, E. I., Grigor'ev, D. S. (2010). Nekotorye fazovye i strukturnye prevrashcheniya pri uglerodotermicheskom vosstanovlenii smesi okaliny bystrorezhushchih staley s dobavkami sheelitovogo kontsentrata. Novi materialy i tekhnolohiyi v metalurhiyi ta mashynobuduvanni, 2, 90–94.
15. Grigor'ev, D. S. (2011). Nekotorye fazovye i veshchestvennye prevrashcheniya pri uglerodotermicheskom vosstanovlenii sheelitovogo kontsentrata. Stal', 60–63.
16. Grigoriev, D. S. (2010). Tungsten concentrate restoration degree definition method improvement. Novi materialy i tekhnolohiyi v metalurhiyi ta mashynobuduvanni, 2, 72–75.
17. Ostrik, P. N., Popov, A. N., Grigor'ev, S. M. (1982). A. S. 977510 SSSR, MKI3V 34/34, 36/36. Sposob polucheniya metallizovannyh molibden – ili vol'framsoderzhashchih kontsentratov. Otkrytiya. Izobreteniya, 49, 102.
18. Grigor'ev, S. M., Revun, M. P., Kovalev, A. M. (2006). Shahtnaya pech' s induktsionnym nagrevom i vedushchie parametry teplovoy obrabotki briketirovannoy shihty. Metallurgicheskaya i gornorudnaya promyshlennost', 5, 23–25.
19. Piven', A. N., Grigor'ev, S. M. (1988). Sovershenstvovanie ehkonomicheskih metodov upravleniya material'nym resursosnabzheniem ehlektrostaleplavil'nyh tsehov. Izv. Vuzov. Chernaya metallurgiya, 12, 123–127.

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STUDY INTO THE STRUCTURALPHASE TRANSFORMATIONS ACCOMPANYING THE RESOURCESAVING TECHNOLOGY OF METALLURGICAL WASTE PROCESSING (p. 37-42)

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The paper reports a study into the physical-chemical properties of a doped alloy obtained from reduction smelting. That was necessary to identify the parameters that reduce the loss of Ni and Cr when processing oxide alloyed raw materials and utilizing the doping additive received. It was determined that the alloy at Si:C in the charge 0.14–0.50 (O:C=1.78) contains the following phases: a solid solution of C and the alloying elements in γ-Fe and Fe_3Si. At Si:C=0.14, it is dominated by a solid solution of C and the alloying elements in γ-Fe with a weakly manifested Fe_3Si. A stepwise change of Si:C in the charge to 0.26, 0.38, and 0.50 led to the increased manifestation of Fe_3Si. The alloy's microstructure at different Si:C in the charge clearly manifested several phases, with a different content of the basic alloying elements. The content of Ni is 2.97–14.10 % by weight, that of Cr is 0.91–17.91 % by weight. An increase in Si:C in the charge from 0.14 to 0.50 led to an increase in the content of Si from 0.04 % by weight to 0.55 % by weight. Values for carbon in the examined local areas at the surface of the alloy exposed to X-ray microanalysis ranged from 0.51 to 1.48 % by weight. Local areas of the microstructure with increased Mo (to 9.10 % by weight), Si, and C indicate a possibility of the presence of Mo in the form of silicides or carbosilicides. It follows from the results obtained in the course of our study that the most acceptable Si:C in the charge is 0.26 (at O:C=1.78). In this case, reduction is ensured with a predominance in the phase composition of the solid solution of C and alloying elements in γ-Fe and the manifestation of residual Si in the form of silicides. In other words, we have determined indicators for obtaining an alloy with a relatively low content of Si and C, which is sufficient to provide the required reducing and oxidizing capability of the alloy. This expands the possibilities for resource saving when using the resulting alloy with the replacement of certain part of standard alloying materials when smelting steel brands limited for carbon and silicon.

Keywords: corrosion-resistant steel scale, alloyed technogenic waste, reduction smelting, X-ray phase studies.

References

1. Grigor'ev, S. M., Petrishchev, A. S. (2015). Refining metallized molybdenum concentrate by means of a lowtemperature plasma-forming mixture. Steel in Translation, 45 (12), 954–958. doi: https://doi.org/10.3103/s0967091215120049
2. Mechachti, S., Benchiheub, O., Serrai, S., Shalabi, M. (2013). Preparation of iron Powders by Reduction of Rolling Mill Scale. International Journal of Scientific & Engineering Research, 4 (5), 1467–1472.
3. Hryhoriev, S., Petryshchev, A., Shyshkanova, G., Zaytseva, T., Frydman, O., Krupey, K. et. al. (2018). A study of environmentally friendly recycling of technogenic chromium and nickel containing waste by the method of solid phase extraction. EasternEuropean Journal of Enterprise Technologies, 1 (10 (91)), 44–49. doi: https://doi.org/10.15587/17294061.2018.121615
4. Zhang, Y., Wei, W., Yang, X., Wei, F. (2013). Reduction of Fe and Ni in FeNiO systems. Journal of Mining and Metallurgy, Section B: Metallurgy, 49 (1), 13–20. doi: https://doi.org/10.2298/jmmb120208038z
5. Zhao, L., Wang, L., Chen, D., Zhao, H., Liu, Y., Qi, T. (2015). Behaviors of vanadium and chromium in coalbased direct reduction of highchromium vanadiumbearing titanomagnetite concentrates followed by magnetic separation. Transactions of Nonferrous Metals Society of China, 25 (4), 1325–1333. doi: https://doi.org/10.1016/s10036326(15)637311
6. Ryabchikov, I. V., Belov, B. F., Mizin, V. G. (2014). Reactions of metal oxides with carbon. Steel in Translation, 44 (5), 368–373. doi: https://doi.org/10.3103/s0967091214050118
7. Hryhoriev, S., Petryshchev, A., Shyshkanova, G., Yakimtsov, Y., Zhuravel, S., Yamshinskij, M. et. al. (2017). Study into properties of the resourcesaving chromiumcontaining briquetted alloying additive from ore raw materials. EasternEuropean Journal of Enterprise Technologies, 4 (12 (88)), 38–43. doi: https://doi.org/10.15587/172 94061.2017.108191
8. Simonov, V. K., Grishin, A. M. (2013). Thermodynamic analysis and the mechanism of the solidphase reduction of Cr2O3 with carbon: Part 1. Russian Metallurgy (Metally), 2013 (6), 425–429. doi: https://doi.org/10.1134/s0036029513060153
9. Simonov, V. K., Grishin, A. M. (2013). Thermodynamic analysis and the mechanism of the solidphase reduction of Cr_2O_3 with carbon: Part 2. Russian Metallurgy (Metally), 2013 (6), 430–434. doi: https://doi.org/10.1134/s0036029513060165
10. Petryshchev, A., Milko, D., Borysov, V., Tsymbal, B., Hevko, I., Borysova, S., Semenchuk, A. (2019). Studying the physicalchemical transformations at resourcesaving reduction melting of chrome–nickelcontaining metallurgical waste. EasternEuropean Journal of Enterprise Technologies, 2 (12 (98)), 59–64. doi: https://doi.org/10 .15587/17294061.2019.160755
11. Ackerbauer, S., Krendelsberger, N., Weitzer, F., Hiebl, K., Schuster, J. C. (2009). The constitution of the ternary system Fe–Ni–Si. Intermetallics, 17 (6), 414–420. doi: https://doi.org/10.1016/j.intermet.2008.11.016
12. Azimi, G., Shamanian, M. (2010). Effects of silicon content on the microstructure and corrosion behavior of Fe–Cr–C hardfacing alloys. Journal of Alloys and Compounds, 505 (2), 598–603. doi: https://doi.org/10.1016/j.jallcom.2010.06.084
13. Liu, X., Lin, M., Yang, S., Ruan, J., Wang, C. (2014). Experimental Investigation of Phase Equilibria in the NiCrSi Ternary System. Journal of Phase Equilibria and Diffusion, 35 (3), 334–342. doi: https://doi.org/10.1007/s1166901402799
14. Jung, W. G., Back, G. S., Johra, F. T., Kim, J. H., Chang, Y. C., Yoo, S. J. (2018). Preliminary reduction of chromium ore using Si sludge generated in silicon wafer manufacturing process. Journal of Mining and Metallurgy, Section B: Metallurgy, 54 (1), 29–37. doi: https://doi.org/10.2298/jmmb170520054j

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WELDING METHOD FOR HIGH CRACK SENSITIVITY OF Q&T STEEL (p. 43-51)

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Components for combat vehicles need (such as body panzers, main battle tank, armored personnel carrier) to be made of high strength and hardness steel. However, during and after the welding process is complete, this steel often leaves cracks. Quenched and Tempered Steel is made of Hot Rolled Plate Steel (thickness 8 mm), which is heat-treated with quench and temper to increase strength and hardness. The novelty of this research is the welding method to create a welded joint consisting of fine structure, high strength, and high hardness produced. This joint is produced by manual gas metal arc welding. The scheme of investigation:

a) The first step. Preparation of welded specimen 120×100×8 mm in size (Fig. 3). The specimen is divided into five parts, each is given code SS (without heat treatment), S750 (heating at 750 °C), S800 (heating at 800 °C), S850 (heating at 850 °C) and S900 (heating at 900 °C). Heating rate used=10 °C/minutes.

b) The second step. Heating specimen S750 at 750 °C and holding for 30 minutes, then quenching in the water medium. The same way applied to specimens S800, S850, and S900.

c) The third step. The observation of metallography, hardness, and impact energy was done for SS, S750, S800, S850, and S900.

d) The fourth step. Removing the first layer of the weld in half-plate thickness using a hand grinding machine of each specimen, and continue to the second layer welding.

e) The fifth step. The second layer of the welds is ground in half and proceed to the final welding.

The results of the tests carried out on KSTA 500 Steel include the chemical composition of base metal; microstructure and hardness for standard and water quenched weld joint. Medium carbon steel is equivalent to Quenched and Tempered Steel used in this study and has a high cracking susceptibility.

The microstructure for the standard welded joint is dominated by martensite when quenched and tempered steel made, and martensite produced when water quenched heat treatment is conducted on the welded joint.

Water quenched weld joint shows the finer microstructure of the heat-affected zone, but weld metal tends to be coarse and brittle. The highest hardness is achieved after 850 °C water quenching, i. e., base metal=578 VHN, heat affected zone=555 VHN, fusion line=457 VHN, and weld metal=252 VHN.

Keywords: austenite, brittling, coarsening, crack, cracking, hardening, martensite, quenching, refining, weldability.

References

1. Demir, T., Übeyli, M., Yıldırım, R. O. (2008). Effect of Hardness on the Ballistic Impact Behavior of High-Strength Steels Against 7.62-mm Armor Piercing Projectiles. Journal of Materials Engineering and Performance, 18 (2), 145–153. doi: https://doi.org/10.1007/s11665-008-9288-3
2. Bailey, N., Coe, F. R., Googh, T. G., Hart, P. H. M., Jenkins, N., Pargetter, R. J. (1973). Welding steels without hydrogen cracking. Abington Publishing and ASM International.
3. Datta, R., Mukerjee, D., Jha, S., Narasimhan, K., Veeraraghavan, R. (2002). Weldability Characteristics of Shielded Metal Arc Welded High Strength Quenched and Tempered Plates. Journal of Materials Engineering and Performance, 11 (1), 5–10. doi: https://doi.org/10.1361/105994902770344321
4. ASM Handbook. Properties and Selection: Irons, Steels, and High Performance Alloys. Vol. 6. Copyright ASM International, 1996, 246–247.
5. Jefferson, T. B.; O'brien, R. L. (Ed.) (1997). Jefferson's Welding Encyclopedia. American Welding Society, 758.
6. Yue, X., Lippold, J. C., Alexandrov, B. T., Babu, S. S. (2012). Continuous Cooling Transformation Behavior in the CGHAZ of Naval Steels. Welding Journal, 91 (3), 67S–75S.
7. Mani, E., Udhayakumar, T. (2018). Effect of prior austenitic grain size and tempering temperature on the energy absorption characteristics of low alloy quenched and tempered steels. Materials Science and Engineering: A, 716, 92–98. doi: https://doi.org/10.1016/j.msea.2018.01.020
8. Yang, J., Song, Y., Lu, Y., Gu, J., Guo, Z. (2018). Effect of ferrite on the hydrogen embrittlement in quenched-partitioned-tempered low carbon steel. Materials Science and Engineering: A, 712, 630–636. doi: https://doi.org/10.1016/j.msea.2017.12.032
9. Chen, G., Luo, H., Yang, H., Han, Z., Lin, Z., Zhang, Z., Su, Y. (2019). Effects of the welding inclusion and notch on the fracture behaviors of low-alloy steel. Journal of Materials Research and Technology, 8 (1), 447–456. doi: https://doi.org/10.1016/j.jmrt.2018.04.005
10. Qasim, B. M., Khidir, T. C., F. Hameed, A., Abduljabbar, A. A. (2018). Influence of heat treatment on the absorbed energy of carbon steel alloys using oil quenching and water quenching. Journal of Mechanical Engineering Research and Developments, 41 (3), 43–46. doi: https://doi.org/10.26480/jmerd.03.2018.43.46
11. Schumacher, J., Clausen, B., Zoch, H.-W. (2018). Influence of inclusion type and size on the fatigue strength of high strength steels. MATEC Web of Conferences, 165, 14003. doi: https://doi.org/10.1051/matecconf/201816514003
12. Leister, B. M., Dupont, J. N. (2012). Fracture Toughness of Simulated Heat-Affected Zones in NUCu-140 Steel. Welding Journal, 91, 53-s–58-s.
13. Shen, S., Oguocha, I. N. A., Yannacopoulos, S. (2012). Effect of heat input on weld bead geometry of submerged arc welded ASTM A709 Grade 50 steel joints. Journal of Materials Processing Technology, 212 (1), 286–294. doi: https://doi.org/10.1016/j.jmatprotec.2011.09.013
14. Madhusudhan Reddy, G., Mohandas, T., Papukutty, K. . (1998). Effect of welding process on the ballistic performance of high-strength low-alloy steel weldments. Journal of Materials Processing Technology, 74 (1-3), 27–35. doi: https://doi.org/10.1016/s0924-0136(97)00245-8
15. Yanet, M., Mónica, Z. (2015). Microstructure Characterization of Heat Affected Zone in Single Pass Welding in 9Cr-1Mo Steels. Procedia Materials Science, 8, 904–913. doi: https://doi.org/10.1016/j.mspro.2015.04.151
16. ASTM E23 - 07a. Standard Test Methods for Notched Bar Impact Testing of Metallic Materials (2007). ASTM International, West Conshohocken, PA. doi: https://doi.org/10.1520/e0023-07a

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INCREASING EFFICIENCY OF PLASMA HARDENING BY LOCAL COOLING OF SURFACE BY AIR WITH NEGATIVE TEMPERATURE (p. 52-57)

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The martensitic transformation interval of some hypoeutectoid, all eutectoid and all hypereutectoid steels covers to a large extent the region of negative temperatures. Due to the fact that the plasma hardening operation is carried out in workshops where the minimum temperature is +20 °C, the surface temperature of the part after plasma heating cannot reach negative values. Because of this, the temperature range of the martensitic transformation is not fully used and in the hardened structure there is a certain amount of austenite, which has not undergone martensitic transformation. This circumstance reduces the hardness of the hardened layer and often low tempering is required to convert residual austenite to tempered martensite, which lengthens and makes the heat treatment more expensive. Complete or almost complete martensitic transformation is possible if the surface heated by the plasma beam is immediately cooled to a negative temperature.

It is shown that local cooling of the hardened surface to a temperature of –40 °C can be carried out by air using the Ranque-Hilsch tube, which significantly expands the possibilities of full hardening for eutectoid and hypereutectoid steels. The studies consisted in heating the surface with a plasma stream to a temperature of 750 °C and 900 °C. The temperature was changed by the plasma torch current and by changing the velocity of the plasma flow spot moving along the sample surface. The experiments were carried out on steels 45 (0.45 % C), U8 (0.8 % C) and U10 (1 % C). The study of the structures was carried out on a MIM-7 microscope with a video camera and with the image displayed on the screen. The approximate quantitative composition of austenite, martensite, and associated structures was determined by the areas on the screen.

During plasma hardening of steel 45 from a temperature of 900 °C using the Ranque-Hilsch tube, there is practically no residual austenite in the structure. When hardening U8 steel, residual austenite is detected in a small amount. When hardening U10 steel, the amount of residual austenite is approximately 15 %. Local surface cooling allows high-quality hardening of steels of most grades, regardless of the carbon content.

Keywords: carbon content, martensitic interval, cooling temperature, hypoeutectoid steel, eutectoid steel, hypereutectoid steel.

References

1. Lashchenko, G. I. (2003). Plazmennoe uprochnenie i napylenie. Kyiv: Ekotehnologiya, 64.
2. Gulyaev, A. P. (2010). Materialovedenie. Moscow: Avangard.
3. Yan, M. F., Chen, B. F., Li, B. (2018). Microstructure and mechanical properties from an attractive combination of plasma nitriding and secondary hardening of M50 steel. Applied Surface Science, 455, 1–7. doi: https://doi.org/10.1016/j.apsusc.2018.04.213
4. Xiang, Y., Yu, D., Li, Q., Peng, H., Cao, X., Yao, J. (2015). Effects of thermal plasma jet heat flux characteristics on surface hardening. Journal of Materials Processing Technology, 226, 238–246. doi: https://doi.org/10.1016/j.jmatprotec.2015.07.022
5. Martynov, V., Brzhozovsky, B., Zinina, E., Yankin, I., Susskiy, A. (2017). Fluctuations in the Process Plant as a Quality Assessment Criterion of Low-temperature Plasma Hardening Process. Procedia Engineering, 176, 451–460. doi: https://doi.org/10.1016/j.proeng.2017.02.344
6. Semboshi, S., Iwase, A., Takasugi, T. (2015). Surface hardening of age-hardenable Cu–Ti alloy by plasma carburization. Surface and Coatings Technology, 283, 262–267. doi: https://doi.org/10.1016/j.surfcoat.2015.11.003
7. Lebrun, J. P. (2015). Plasma-assisted processes for surface hardening of stainless steel. Thermochemical Surface Engineering of Steels, 615–632. doi: https://doi.org/10.1533/9780857096524.4.615
8. Esfandiari, M., Dong, H. (2006). Plasma surface engineering of precipitation hardening stainless steels. Surface Engineering, 22 (2), 86–92. doi: https://doi.org/10.1179/174329406x98368
9. Xiang, Y., Yu, D., Cao, X., Liu, Y., Yao, J. (2017). Effects of thermal plasma surface hardening on wear and damage properties of rail steel. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 232 (7), 787–796. doi: https://doi.org/10.1177/1350650117729073
10. Safonov, E. N., Mironova, M. V. (2018). Plasma hardening hypereutectoid steel. IOP Conference Series: Materials Science and Engineering, 411, 012069. doi: https://doi.org/10.1088/1757-899x/411/1/012069
11. Petrov, S. V., Saakov, A. G. (2002). Technology and equipment for plasma surface hardening of heavy-duty parts. Materials and Manufacturing Processes, 17 (3), 363–378. doi: https://doi.org/10.1081/amp-120005382
12. Nechaev, V. P., Ryazantsev, A. A. (2012). Issledovanie, razrabotka, obosnovanie vozmozhnostey povysheniya nadezhnosti raboty krupnomodul'nyh shesteren putem plazmennogo uprochneniya ih poverhnostey. Prohresyvni tekhnolohiyi i systemy mashynobuduvannia, 43, 227–232.
13. Horobryh, M. A., Klement'ev, V. A. (2012). Vihrevoy ehffekt Ranka-Hilsha. Vihrevaya truba. Molodoy ucheniy, 6, 54–55.
14. Korkodinov, I. A., Khurmatullin, O. G. (2012). The Application of Ranque – Hilsh Effect. Vestnik permskogo natsional'nogo issledovatel'skogo politehnicheskogo universiteta. Mashinostroenie, materialovedenie, 14 (4), 42–54.
15. Metodika prigotovleniya mikroshlifa. Available at: https://infourok.ru/laboratornaya-rabota-metodika-prigotovleniya-mikroshlifa-852852.html
16. Mikroskop MIM-7 metallograficheskiy. Available at: https://svetlovodsk.flagma.ua/mikroskop-mim-7-metallograficheskiy-o4107365.html
17. Pribor dlya izmereniya tverdosti po metodu Rokvella TR 5006M. Available at: http://ukrsk.com.ua/pribor_tr_5006m.html