ABSTRACT AND REFERENCES

MATERIALS SCIENCE

DOI: 10.15587/1729-4061.2018.139219

THE RELATION OF CRACK PROPAGATION BEHAVIOUR AND DELAMINATION ON FIBRE ACRYLIC LAMINATES UNDER VARIOUS CYCLIC CONDITIONS (p. 6-15)

Anindito Purnowidodo
Brawijaya University Malang, Malang, Indonesia

Khairul Anam
Brawijaya University Malang, Malang, Indonesia

Bagus Maulidika
Brawijaya University Malang, Malang, Indonesia

The investigation of the crack propagation behaviour associating with the delamination in the interface of the laminate of the fibre acrylic laminates (FALs) composite is carried out by subjecting the composite to cyclic loads. The cyclic load is controlled by the displacement provided by a fatigue testing machine. The cyclic load was carried out with various displacement ratios, R, values, these are, 0, –1, –3, and –5 in which the displacement amplitude was also varied as high as 0.15, 0.20, 0.30 mm, for every value of R. In the present study, the investigation to the crack propagation behaviour is focused on the negative cyclic of R leading to the composite to be cycled under compressive load. The results obtained in the present study shows that in these cases of the lower value of the displacement ratio of –3 and –5, the fatigue life and the crack length of the FALs increase, and the increasing of the displacement amplitude to 0.30 mm causes both the fatigue life and the crack length to be shorter. The delamination propagation rate is higher in the R=0 case than those in the negative value of R. In addition, the lateral contraction of material to outward over the crack region may contribute to the development of the delamination when the ratio of the displacement cycles is negative, and the lateral contraction is higher when the displacement ratio is more negative. Moreover, the delamination may take place in front of the crack tip when the maximum displacement is 0.20 mm or higher, and it causes the crack propagation to be accelerated.

Keywords: Crack propagation, delamination, cyclic conditions, Fibre Acrylic Laminates.

References

1. Callister, Jr. W. D., Retwisch, D. G. (2008). Introduction in Fundamentals of Materials Science and Engineering, An Integrated Approach. Ch. 1. New Jersey: John Wiley & Sons, Inc., 5–10.
2. Alderliesten, R., Crack, F. (2005). Propagation and Delamination Growth in Glare. Delft, Netherland: DUP Science, 1–4.
3. Jones, R. M. (1999). Introduction to Composite Materials-Mechanics of Composites Materials. Philadelphia, Taylor & Francis, 11–15.
4. Khan, S. U., Alderliesten, R. C., Benedictus, R. (2011). Delamination in Fiber Metal Laminates (GLARE) during fatigue crack growth under variable amplitude loading. International Journal of Fatigue, 33 (9), 1292–1303. doi: https://doi.org/10.1016/j.ijfatigue.2011.04.002
5. Huang, Y., Liu, J., Huang, X., Zhang, J., Yue, G. (2015). Delamination and fatigue crack growth behavior in Fiber Metal Laminates (Glare) under single overloads. International Journal of Fatigue, 78, 53–60. doi: https://doi.org/10.1016/j.ijfatigue.2015.04.002
6. Dadej, K., Bieniaś, J., Surowska, B. (2017). Residual fatigue life of carbon fibre aluminium laminates. International Journal of Fatigue, 100, 94–104. doi: https://doi.org/10.1016/j.ijfatigue.2017.03.026
7. Jones, R., Kinloch, A. J., Hu, W. (2016). Cyclic-fatigue crack growth in composite and adhesively-bonded structures: The FAA slow crack growth approach to certification and the problem of similitude. International Journal of Fatigue, 88, 10–18. doi: https://doi.org/10.1016/j.ijfatigue.2016.03.008
8. Nojavan, S., Schesser, D., Yang, Q. D. (2016). A two-dimensional in situ fatigue cohesive zone model for crack propagation in composites under cyclic loading. International Journal of Fatigue, 82, 449–461. doi: https://doi.org/10.1016/j.ijfatigue.2015.08.029
9. D'Amore, A., Giorgio, M., Grassia, L. (2015). Modeling the residual strength of carbon fiber reinforced composites subjected to cyclic loading. International Journal of Fatigue, 78, 31–37. doi: https://doi.org/10.1016/j.ijfatigue.2015.03.012
10. Zhang, J., Peng, L., Zhao, L., Fei, B. (2012). Fatigue delamination growth rates and thresholds of composite laminates under mixed mode loading. International Journal of Fatigue, 40, 7–15. doi: https://doi.org/10.1016/j.ijfatigue.2012.01.008
11. Bizeul, M., Bouvet, C., Barrau, J. J., Cuenca, R. (2010). Influence of woven ply degradation on fatigue crack growth in thin notched composites under tensile loading. International Journal of Fatigue, 32 (1), 60–65. doi: https://doi.org/10.1016/j.ijfatigue.2009.01.010
12. Bizeul, M., Bouvet, C., Barrau, J. J., Cuenca, R. (2010). Influence of woven ply degradation on fatigue crack growth in thin notched composites under tensile loading. International Journal of Fatigue, 32 (1), 60–65. doi: https://doi.org/10.1007/bf02670759
13. McEvily, A. J., Yang, Z. (1990). The nature of the two opening levels following an overload in fatigue crack growth. Metallurgical Transactions A, 21 (10), 2717–2727. doi: https://doi.org/10.1007/bf02646067
14. Makabe, C., Purnowidodo, A., Miyazaki, T., McEvily Arthur, J. (2005). Deceleration and acceleration of crack propagation after an overloading under negative baseline stress ratio. Journal Testing and Evaluation, 33 (5), 181–187.
15. Makabe, C., Purnowidodo, A., McEvily, A. J. (2004). Effects of surface deformation and crack closure on fatigue crack propagation after overloading and under loading. International Journal of Fatigue, 26 (12), 1341–1348. doi: https://doi.org/10.1016/j.ijfatigue.2004.03.017
16. Pumowidodo, A., Miyazaki, T., Makabe, C., McEvily, A. J. (2004). Transitional Behavior of Residual Fatigue Life After Applying Overload During Fatigue Crack Growth With Constant Stress Amplitude. Pressure Vessel and Piping Codes and Standards, 39–44. doi: https://doi.org/10.1115/pvp2004-2671
17. Barsom, J. M., Rofle, S. T. (1999). Stress Analysis for Members with Crack. Fracture and fatigue control in structure. 3rd ed. Philadelphia: ASTM.
18. Purnowidodo, A., Anam, K., Wahyudi, A., Arief, S. (2014). The Effect of Stop Holes Technique on Crack Growth Behaviours Emanating From a Notch after Overloading. International Journal of Applied Engineering Research, 9 (1), 125–136.
19. Topper, T. H., Lam, T. S. (2003). Derivation of crack closure and effective fatigue crack growth data from smooth specimen fatigue test. Report of Fatigue Branch of The Society of Materials Science Japan, 266, 1–12.
20. Ward-Close, C. M., Blom, A. F., Ritchie, R. O. (1989). Mechanisms associated with transient fatigue crack growth under variable-amplitude loading: An experimental and numerical study. Engineering Fracture Mechanics, 32 (4), 613–638. doi: https://doi.org/10.1016/0013-7944(89)90195-1

21. Sadananda, K. (1999). Analysis of overload effects and related phenomena. International Journal of Fatigue, 21, 233–246. doi: https://doi.org/10.1016/s0142-1123(99)00094-8
22. Purnowidodo, A., Fukuzato, S., Saimoto, A., Makabe, C. (2007). Crack Growth Behavior in Overloaded Specimens with Sharp Notch in Low Carbon Steel. Journal of Testing and Evaluation, 35 (5), 100097. doi: https://doi.org/10.1520/jte100097

DOI: 10.15587/1729-4061.2018.140984

ANALYSIS OF THE PROPERTIES OF ANTIFRICTION COMPOSITES BASED ON ALUMINUM ALLOY'S GRINDING WASTE (p. 16-22)

Tetiana Roik
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-4930-0173

Oleg Gavrysh
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-1961-3267

Volodimir Oliynik
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-3117-2780

Iuliia Vitsiuk
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-8169-4328

We developed antifriction composites based on regenerated grinding waste of AM4.5Kd aluminum alloy with the addition of MoS_2 solid lubricant intended for work in contact pairs of post-printing machines, such as folder-gluing machines and machines for pasting elements into packaging.

Analysis of the structure of the new composite showed that alloying elements of the metal base form strengthening phases, which are evenly distributed in the matrix without segregation clusters. This contributes to an increase in structural strength. Molybdenum disulfide provides the effect of self-lubrication of a contact pair during operation, which causes a reduction in a friction coefficient and a wear rate compared to composite material without solid oil. Structural studies showed uniform distribution of solid oil in the entire volume of the composite, which provides an increase in tribotechnical characteristics due to formation of protective anti-gripping friction films at operation of a part of a complex shape under self-lubricating conditions.

The analysis of functional properties makes possible to recommend antifriction composite made on the basis of industrial grinding waste of AM4.5Kd aluminum alloy with impurities of solid lubricant – MoS_2 molybdenum disulfide for parts of complex compound joints, which operate at increased discrete sliding speeds and loads without lubrication with liquid oil in the air atmosphere.

Tribotechnical tests showed that the new composite wear-resistant material obtained by the developed manufacturing technology gives possibility to force maximum permissible loading modes and sliding operation rates with the consistently high antifriction properties of new composite friction parts of post-printing machines.

Keywords: grinding waste, aluminum alloy, solid oil, structural studies, antifriction properties, post-printing machine.

References

1. Gordon, N. J. (2016). Essentials of Polygraph and Polygraph Testing. CRC Press, 304. doi: https://doi.org/10.1201/9781315438641
2. Kyrychok, P. O., Roik, T. A., Havrysh, A. P., Shevchuk, A. V., Vitsiuk, Yu. Yu. (2015). Novitni kompozytsiini materialy detalei tertia polihrafichnykh mashyn. Kyiv: NTUU KPI, 428.
3. Sviridenok, A. I., Myshkin, N. K., Kovaleva, I. N. (2015). Latest developments in tribology in the journal Friction and Wear. Journal of Friction and Wear, 36 (6), 449–453. doi: https://doi.org/10.3103/s106836661506015x
4. Jeon, C.-H., Jeong, Y.-H., Seo, J.-J., Tien, H. N., Hong, S.-T., Yum, Y.-J. et. al. (2014). Material properties of graphene/aluminum metal matrix composites fabricated by friction stir processing. International Journal of Precision Engineering and Manufacturing, 15 (6), 1235–1239. doi: https://doi.org/10.1007/s12541-014-0462-2
5. Du, Z., Tan, M. J., Guo, J. F., Bi, G., Wei, J. (2016). Fabrication of a new Al-Al 2 O 3 -CNTs composite using friction stir processing (FSP). Materials Science and Engineering: A, 667, 125–131. doi: https://doi.org/10.1016/j.msea.2016.04.094
6. Dixit, S., Kashyap, S., Kailas, S. V., Chattopadhyay, K. (2018). Manufacturing of high strength aluminium composites reinforced with nano tungsten particles for electrical application and investigation on in-situ reaction during processing. Journal of Alloys and Compounds, 767, 1072–1082. doi: https://doi.org/10.1016/j.jallcom.2018.07.110
7. Kostornov, A. G., Fushchich, O. I. (2007). Sintered antifriction materials. Powder Metallurgy and Metal Ceramics, 46 (9-10), 503–512. doi: https://doi.org/10.1007/s11106-007-0078-5
8. Bocian, M., Jamroziak, K., Kulisiewicz, M. (2014). An identification of nonlinear dissipative properties of constructional materials at dynamical impact loads conditions. Meccanica, 49 (8), 1955–1965. doi: https://doi.org/10.1007/s11012-014-9931-z
9. Shevchuk, Y. F., Roik, T. A., Varchenko, V. T. (2007). Antifriction composite materials for friction joints of centrifugal equipment. Powder Metallurgy and Metal Ceramics, 46 (7-8), 404–407. doi: https://doi.org/10.1007/s11106-007-0063-z
10. Pickens, J. W. (2013). Assuring the Benefits of Aluminum Recycling: Engineering Economical Environmental Solutions to the Issues of Black Dross & Saltcake. Recycling of Metals and Engineercd Materials, 1195–1207. doi: https://doi.org/10.1002/9781118788073.ch105
11. Stanzick, H., Wichmann, M., Weise, J., Helfen, L., Baumbach, T., Banhart, J. (2002). Process Control in Aluminum Foam Production Using Real-Time X-ray Radioscopy. Advanced Engineering Materials, 4 (10), 814–823. doi: https://doi.org/10.1002/1527-2648(20021014)4:10<814::aid-adem814>3.0.co;2-5
12. Banhart, J. (2005). Aluminium foams for lighter vehicles. International Journal of Vehicle Design, 37 (2/3), 114. doi: https://doi.org/10.1504/ijvd.2005.006640
13. Muchová, L., Eder, P. (2010). End-of-waste Criteria for Aluminium and Aluminium Alloy Scrap. Technical Proposals, 69.
14. Roik, T. A., Havrish, A. P., Kholiavko, V. V., Havrysh, O. A., Prokhorenko, O. M. (2008). Pat. No. 34407 UA. Kompozytsinyi pidshypnykovyi material na osnovi aliuminiu. MPK (2006) C22C 21/02. No. u200803173; declareted: 12.03.2008; published: 11.08.2008, Bul. No. 15.
15. Jamroziak, K., Roik, T., Gavrish, O., Vitsiuk, I., Lesiuk, G., Correia, J. A. F. O., De Jesus, A. (2018). Improved manufacturing performance of a new antifriction composite parts based on copper. Engineering Failure Analysis, 91, 225–233. doi: https://doi.org/10.1016/j.engfailanal.2018.04.034
16. Konopka, K., Roik, T. A., Gavrish, A. P., Vitsuk, Y. Y., Mazan, T. (2012). Effect of CaF2 surface layers on the friction behavior of copper-based composite. Powder Metallurgy and Metal Ceramics, 51(5-6), 363–367. doi: https://doi.org/10.1007/s11106-012-9441-2
17. Roik, T. A., Gavrish, A. P., Kirichok, P. A., Vitsyuk, Y. Y. (2015). Effect of Secondary Structures on the Functional Properties of

High-Speed Sintered Bearings for Printing Machines. Powder Metallurgy and Metal Ceramics, 54 (1-2), 119–127. doi: https://doi.org/10.1007/s11106-015-9688-5
18. Roik, T. A., Gavrysh, O. A., Vitsiuk, I. I., Khmiliarchuk, O. I. (2018). New Copper-Based Composites for Heavy-Loaded Friction Units. Powder Metallurgy and Metal Ceramics, 56 (9-10), 516–522. doi: https://doi.org/10.1007/s11106-018-9924-x
19. Wejrzanowski, T. (2005). Computer program Micrometer. Material Science, 23, 28–34.
20. Huliaev, A. P. (1986). Metallovedenye. Moscow: Metallurhyia, 544.
21. Kaloshkin, S. D., Tcherdyntsev, V. V., Laptev, A. I., Stepashkin, A. A., Afonina, E. A., Pomadchik, A. L., Bugakov, V. I. (2004). Structure and mechanical properties of mechanically alloyed Al/Al-Cu-Fe composites. Journal of Materials Science, 39 (16/17), 5399–5402. doi: https://doi.org/10.1023/b:jmsc.0000039253.28721.3f
22. Venkata Siva, S. B., Sreenivasa Rao, G., Sahoo, K. L. (2013). Tribological Studies of Al-based Composite. Developed from a Waste Material. 3-rd International Conference on Mechanical, Automotive and Materials Engineering (ICMAME'2013). Singapore, 10.
23. Zhang, J. Z. (2012). Research of Composite Material Properties Based on Waste Glass and Scrap Aluminum. Advanced Materials Research, 468-471, 2868–2871. doi: https://doi.org/10.4028/www.scientific.net/amr.468-471.2868
24. Kumar, S., Mathieux, F., Onwubolu, G., Chandra, V. (2007). A novel powder metallurgy-based method for the recycling of aluminum adapted to a small island developing state in the Pacific. International Journal of Environmentally Conscious Design & Manufacturing, 13 (3 (4)), 1–22.

DOI: 10.15587/1729-4061.2018.140876

RESEARCH INTO PARAMETERS OF MAGNETIC TREATMENT TO MODIFY THE DISPERSEFILLED EPOXY COMPOSITE MATERIALS (p. 23-28)

Vitalii Kartashov
Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine
ORCID: http://orcid.org/0000-0003-0530-3919

Danulo Stukhlyak
Company «NOVO-KOM», Ternopil, Ukraine
ORCID: http://orcid.org/0000-0002-9404-4359

Oleksandr Holotenko
Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine
ORCID: http://orcid.org/0000-0001-9251-8760

Ihor Dobrotvor
Ternopil National Economic University, Ternopil, Ukraine
ORCID: http://orcid.org/0000-0003-2812-1229

Andrii Mykytyshyn
Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine
ORCID: https://orcid.org/0000-0002-2999-3232

Mykola Mytnyk
Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine
ORCID: http://orcid.org/0000-0003-3743-6310

Valerii Marukha
Karpenko physico-mechanical institute of the NAS of Ukraine, Lviv, Ukraine
ORCID: https://orcid.org/0000-0002-4712-8584

Oleksandr Skorokhod
Gomel Branch of the University of Civil Protection of the Ministry of Emergencies of Belarus, Minsk, Republic of Belarus
ORCID: http://orcid.org/0000-0002-6189-287X

Improving the operational properties of epoxy composites makes it possible to extend the scope of their application. One of the techniques to enhance the strength and durability of epoxy composites is the use of magnetic treatment.

In order to modify polymeric compositions under the influence of a magnetic field, it is necessary to maintain the optimal treatment modes and time-temperature conditions, determining which is the aim of this research.

The result of the conducted experimental research is the established influence of parameters of an alternating magnetic field on physical-mechanical properties of the modified epoxy composites. We investigated patterns in the influence of proportionality coefficients, integration and differentiation coefficients in the algorithm to control magnetic treatment on impact viscosity and heat resistance of the modified epoxy composites. The optimum values for the frequency of an alternating magnetic field during treatment of epoxy composites were determined. We examined dependences of the content of a finely-dispersed ferromagnetic filler on residual stresses and temperature in the zone of magnetic treatment. Research into epoxy composites was accompanied by the parallel tests of properties related to the effect of similar temperature at magnetic treatment. The law of change in temperature parameters without magnetic treatment was assigned similarly to that of magnetic treatment. This paper reports results of the mathematical planning of the experiment and correlation dependences of magnetic field induction and the content of a filler on heat resistance of the modified epoxy-composite material. The research identified limiting values for the content of a filler and treatment modes of epoxy-composite materials, which ensure the improved performance properties. Our study is important for improving the technological process to modify epoxy compositions with magnetic treatment.

Keywords: polymer, composite, epoxy oligomer, polyethylene polyamine, residual stresses, impact viscosity, PID-controller.

References

1. Stukhlyak, P. D., Holotenko, O. S., Dobrotvor, I. H., Mytnyk, M. M. (2015). Investigation of the Adhesive Strength and Residual Stresses in Epoxy Composites Modified by Microwave Electromagnetic Treatment. Materials Science, 51 (2), 208–212. doi: https://doi.org/10.1007/s11003-015-9830-z
2. Dosoudil, R., Franek, J., Ušáková, M., Olah, V., Sláma, J. (2008). High-Frequency EMI Noise Suppression by Polymer-Based Composite Magnetic Materials. Advances in Electrical and Electronic Engineering, 406–409.
3. Zhang, W., Choi, H. (2014). Stimuli-Responsive Polymers and Colloids under Electric and Magnetic Fields. Polymers, 6 (11), 2803–2818. doi: https://doi.org/10.3390/polym6112803
4. Peña-Rodríguez, G., Rivera-Suárez, P. A., González-Gómez, C. H., Parra-Vargas, C. A., Garzón-Posada, A. O., Landínez-Téllez, D. A., Roa-Rojas, J. (2018). Efecto de la concentración de magnetita en la estructura, propiedades eléctricas y magnéticas de un material compuesto a base de resina de poliéster. TecnoLógicas, 21 (41), 13–27. doi: https://doi.org/10.22430/22565337.708
5. Dobrotvor, I. H., Stukhlyak, P. D., Buketov, A. V. (2009). Determination of the ranges of the optimal content of a dispersed filler in epoxy composites. Materials Science, 45 (6), 790–797. doi: https://doi.org/10.1007/s11003-010-9244-x
6. Le Roy, D., Dhungana, D., Ourry, L., Faivre, M., Ferrigno, R., Tamion, A. et. al. (2016). Anisotropic ferromagnetic polymer: A first step for their implementation in microfluidic systems. AIP Advances, 6 (5), 056604. doi: https://doi.org/10.1063/1.4943927
7. Nilsén, F., Aaltio, I., Hannula, S.-P. (2018). Comparison of magnetic field controlled damping properties of single crystal Ni-Mn-Ga and

Ni-Mn-Ga polymer hybrid composite structures. Composites Science and Technology, 160, 138–144. doi: https://doi.org/10.1016/j.compscitech.2018.03.026
8. Chung, J.-Y., Lee, J.-G., Baek, Y.-K., Shin, P.-W., Kim, Y.-K. (2018). Magnetic field-induced enhancement of thermal conductivities in polymer composites by linear clustering of spherical particles. Composites Part B: Engineering, 136, 215–221. doi: https://doi.org/10.1016/j.compositesb.2017.10.033
9. Manaila Maximean, D. (2018). New grafted ferrite particles/liquid crystal composite under magnetic field. Journal of Magnetism and Magnetic Materials, 452, 343–348. doi: https://doi.org/10.1016/j.jmmm.2017.12.096
10. Chi, Q. G., Gao, L., Wang, X., Chen, Y., Dong, J. F., Cui, Y., Lei, Q. Q. (2015). Effects of magnetic field treatment on dielectric properties of CCTO@Ni/PVDF composite with low concentration of ceramic fillers. AIP Advances, 5 (11), 117103. doi: https://doi.org/10.1063/1.4935270
11. Dotsenko, O., Suslyaev, V., Frolov, K., Wagner, D. (2016). Effect of magnetic field treatment on the electromagnetic properties of polymer composite based on barium hexaferrite at microwave frequencies. AIP Conference Proceedings, 1772, 040006. doi: https://doi.org/10.1063/1.4964565
12. Shut, M. I., Sichkar, T. H., Malezhyk, P. M. (2012). Doslidzhennia kinetyky tverdnennia epoksydnoho olihomera v mahnitnomu poli. Fizyka i khimiya tverdoho tila, 13 (1), 234–237.
13. Stukhliak, P. D., Kartashov, V. V., Andrievskyi, V. V. (2011). Pat. No. 62717 UA. Prystriy dlia obrobky polimernykh kompozytsiy zminnym mahnitnym polem. MPK V 03 V 13/04. No. u201101904; declareted: 18.02.2011; published: 12.09.2011, Bul. No. 17.
14. Mamunya, Ye. P., Davydenko, V. V., Apekis, L., Zois, H., Snarskii, A. A., Slipchenko, K. V. (2002). Dielectric properties of polymers filled with dispersed metals. Polymers and Polymer Composites, 10 (3), 219–227.
15. Buketov, A. V. (1999). Vplyv mahnitnoi pryrody napovniuvachiv na reolohichni vlastyvosti polimerkompozytsiynykh koroziynostiykykh pokryttiv. Mashynoznavstvo, 4, 61–62.

DOI: 10.15587/1729-4061.2018.140899

SYNTHESIS OF $Ni(OH)_2$ BY TEMPLATE HOMOGENEOUS PRECIPITATION FOR APPLICATION IN THE BINDERFREE ELECTRODE OF SUPERCAPACITOR (p. 29-35)

Vadym Kovalenko
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
Federal State Educational Institution of Higher Education "Vyatka State University", Kirov, Russian Federation
ORCID: http://orcid.org/0000-0002-8012-6732

Valerii Kotok
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
Federal State Educational Institution of Higher Education "Vyatka State University", Kirov, Russian Federation
ORCID: http://orcid.org/0000-0001-8879-7189

Nickel hydroxide is widely used as the active material for hybrid supercapacitors. The most electrochemically active is α-$Ni(OH)_2$, synthesized using template homogeneous precipitation. The disadvantage of template homogeneous synthesis is the inclusion of the template into the composition of nickel hydroxide and the necessity of its removal. In order to reverse this disadvantage, it was proposed to study the possibility of using the remaining template as an inner binder for the preparation of a highly effective pasted supercapacitor electrode, without an external binder. Samples of $Ni(OH)_2$ were prepared by means of template homogeneous precipitation, with polyvinyl alcohol and cellulose ester Culminal C8465 with the concentration of 0.05 % and 0.5 %. Structural properties of the samples were studied by means of X-ray diffraction analysis, particle size and morphology — by means of scanning electron microscopy. Electrochemical properties of nickel hydroxide were evaluated by means of galvanostatic charge-discharge cycling of the pasted electrode prepared without a binder, in the supercapacitor regime. It was discovered; that the use of PVA results in significantly higher crystallinity and lower agglomerate formation. Increasing PVA concentration by 10 times had no effect on these characteristics. For Culminal C8465, the crystallinity is significantly lower, but it increases with template concentration. Higher concentration of Culminal C8465 also leads to significant particle aggregation. Different behavior of PVA and Culminal C8465 has been revealed. PVA behaves like a weak binder and Culminal C8465 shows strong binding properties. Complex analysis of electrochemical characteristics of pasted electrodes prepared without a binder confirmed the possibility of using the remaining template as an inner binder. The highest specific capacity for the electrode without an external binder was 197 F/g when Culminal C8465 was used as a template. It is recommended to conduct the selection of a water-soluble compound that would play the role of a template during the synthesis of nickel hydroxide and would also serve as a binder for the preparation of pasted electrode.

Keywords: nickel hydroxide, template synthesis, homogeneous precipitation, supercapacitor, binder.

References

1. Simon, P., Gogotsi, Y. (2008). Materials for electrochemical capacitors. Nature Materials, 7 (11), 845–854. doi: https://doi.org/10.1038/nmat2297
2. Burke, A. (2007). R&D considerations for the performance and application of electrochemical capacitors. Electrochimica Acta, 53 (3), 1083–1091. doi: https://doi.org/10.1016/j.electacta.2007.01.011
3. Lang, J.-W., Kong, L.-B., Liu, M., Luo, Y.-C., Kang, L. (2009). Asymmetric supercapacitors based on stabilized α-$Ni(OH)_2$ and activated carbon. Journal of Solid State Electrochemistry, 14 (8), 1533–1539. doi: https://doi.org/10.1007/s10008-009-0984-1
4. Lang, J.-W., Kong, L.-B., Wu, W.-J., Liu, M., Luo, Y.-C., Kang, L. (2008). A facile approach to the preparation of loose-packed Ni(OH)2 nanoflake materials for electrochemical capacitors. Journal of Solid State Electrochemistry, 13 (2), 333–340. doi: https://doi.org/10.1007/s10008-008-0560-0
5. Aghazadeh, M., Ghaemi, M., Sabour, B., Dalvand, S. (2014). Electrochemical preparation of α-$Ni(OH)_2$ ultrafine nanoparticles for high-performance supercapacitors. Journal of Solid State Electrochemistry, 18 (6), 1569–1584. doi: https://doi.org/10.1007/s10008-014-2381-7
6. Zheng, C., Liu, X., Chen, Z., Wu, Z., Fang, D. (2014). Excellent supercapacitive performance of a reduced graphene oxide/Ni(OH)2 composite synthesized by a facile hydrothermal route. Journal of Central South University, 21 (7), 2596–2603. doi: https://doi.org/10.1007/s11771-014-2218-7
7. Wang, B., Williams, G. R., Chang, Z., Jiang, M., Liu, J., Lei, X., Sun, X. (2014). Hierarchical NiAl Layered Double Hydroxide/Multiwalled Carbon Nanotube/Nickel Foam Electrodes with Excellent Pseudocapacitive Properties. ACS Applied Materials & Interfaces, 6 (18), 16304–16311. doi: https://doi.org/10.1021/am504530e
8. Hall, D. S., Lockwood, D. J., Bock, C., MacDougall, B. R. (2014). Nickel hydroxides and related materials: a review of their structures, synthesis and properties. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 471 (2174), 20140792–20140792. doi: https://doi.org/10.1098/rspa.2014.0792
9. 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. https://doi.org/10.15587/1729-4061.2017.90873

10. Liu, C., Huang, L., Li, Y., Sun, D. (2010). Synthesis and electrochemical performance of amorphous nickel hydroxide codoped with Fe3+ and CO3. Ionics, 16 (3), 215–219. doi: https://doi.org/10.1007/s11581-009-0383-8
11. Li, J., Luo, F., Tian, X., Lei, Y., Yuan, H., Xiao, D. (2013). A facile approach to synthesis coral-like nanoporous β-$Ni(OH)_2$ and its supercapacitor application. Journal of Power Sources, 243, 721–727. doi: https://doi.org/10.1016/j.jpowsour.2013.05.172
12. Kovalenko, V. L., Kotok, V. A., Sykchin, A. A., Mudryi, I. A., Ananchenko, B. A., Burkov, A. A. et. al. (2017). Nickel hydroxide obtained by high-temperature two-step synthesis as an effective material for supercapacitor applications. Journal of Solid State Electrochemistry, 21 (3), 683–691. doi: https://doi.org/10.1007/s10008-016-3405-2
13. Xiao-yan, G., Jian-cheng, D. (2007). Preparation and electrochemical performance of nano-scale nickel hydroxide with different shapes. Materials Letters, 61 (3), 621–625. doi: https://doi.org/10.1016/j.matlet.2006.05.026
14. Tizfahm, J., Safibonab, B., Aghazadeh, M., Majdabadi, A., Sabour, B., Dalvand, S. (2014). Supercapacitive behavior of β-$Ni(OH)_2$ nanospheres prepared by a facile electrochemical method. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 443, 544–551. doi: https://doi.org/10.1016/j.colsurfa.2013.12.024
15. Aghazadeh, M., Golikand, A. N., Ghaemi, M. (2011). Synthesis, characterization, and electrochemical properties of ultrafine β-$Ni(OH)_2$ nanoparticles. International Journal of Hydrogen Energy, 36 (14), 8674–8679. doi: https://doi.org/10.1016/j.ijhydene.2011.03.144
16. 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
17. 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
18. Hall, D. S., Lockwood, D. J., Poirier, S., Bock, C., MacDougall, B. R. (2012). Raman and Infrared Spectroscopy of α and β Phases of Thin Nickel Hydroxide Films Electrochemically Formed on Nickel. The Journal of Physical Chemistry A, 116 (25), 6771–6784. doi: https://doi.org/10.1021/jp303546r
19. Kovalenko, V., Kotok, V., Bolotin, O. (2016). Definition of factors influencing on $Ni(OH)_2$ electrochemical characteristics for supercapacitors. Eastern-European Journal of Enterprise Technologies, 5 (6 (83)), 17–22. doi: https://doi.org/10.15587/1729-4061.2016.79406
20. Hu, M., Lei, L. (2006). Effects of particle size on the electrochemical performances of a layered double hydroxide, $[Ni_4Al(OH)_{10}]NO_3$. Journal of Solid State Electrochemistry, 11 (6), 847–852. doi: https://doi.org/10.1007/s10008-006-0231-y
21. Vasserman, I. N. (1980). Khimicheskoe osazdenie is rastvorov [Chemical precipitation from solutions]. Leningrad: Khimia, 208.
22. Bora, M. (2013). Homogeneous precipitation of nickel hydroxide powders. Retrospective Theses and Dissertations. Iowa State University, 199. doi: https://doi.org/10.31274/rtd-180813-146
23. Tang, H. W., Wang, J. L., Chang, Z. R. (2008). Preparation and characterization of nanoscale nickel hydroxide using hydrothermal synthesis method. J. Func. Mater, 39 (3), 469–476.
24. Tang, Y., Liu, Y., Yu, S., Zhao, Y., Mu, S., Gao, F. (2014). Hydrothermal synthesis of a flower-like nano-nickel hydroxide for high performance supercapacitors. Electrochimica Acta, 123, 158–166. doi: https://doi.org/10.1016/j.electacta.2013.12.187
25. Yang, L.-X., Zhu, Y.-J., Tong, H., Liang, Z.-H., Li, L., Zhang, L. (2007). Hydrothermal synthesis of nickel hydroxide nanostructures in mixed solvents of water and alcohol. Journal of Solid State Chemistry, 180 (7), 2095–2101. doi: https://doi.org/10.1016/j.jssc.2007.05.009
26. Cui, H. L., Zhang, M. L. (2009). Synthesis of flower-like nickel hydroxide by ionic liquids-assisted. J. Yanan. Univ., 28 (2), 76–83.
27. Xu, L., Ding, Y.-S., Chen, C.-H., Zhao, L., Rimkus, C., Joesten, R., Suib, S. L. (2008). 3D Flowerlike α-Nickel Hydroxide with Enhanced Electrochemical Activity Synthesized by Microwave-Assisted Hydrothermal Method. Chemistry of Materials, 20 (1), 308–316. doi: https://doi.org/10.1021/cm702207w
28. Córdoba de Torresi, S. I., Provazi, K., Malta, M., Torresi, R. M. (2001). Effect of Additives in the Stabilization of the α Phase of $Ni(OH)_2$ Electrodes. Journal of The Electrochemical Society, 148 (10), A1179. doi: https://doi.org/10.1149/1.1403731
29. Kotok, V., Kovalenko, V. (2017). The electrochemical cathodic template synthesis of nickel hydroxide thin films for electrochromic devices: role of temperature. Eastern-European Journal of Enterprise Technologies, 2(11 (86)), 28–34. doi: https://doi.org/10.15587/1729-4061.2017.97371
30. 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
31. 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
32. Oliva, P., Leonardi, J., Laurent, J. F., Delmas, C., Braconnier, J. J., Figlarz, M. et. al. (1982). Review of the structure and the electrochemistry of nickel hydroxides and oxy-hydroxides. Journal of Power Sources, 8 (2), 229–255. doi: https://doi.org/10.1016/0378-7753(82)80057-8
33. Mehdizadeh, R., Sanati, S., Saghatforoush, L. A. (2013). Effect of PEG6000 on the morphology the β-$Ni(OH)_2$ nanostructures: solvothermal synthesis, characterization, and formation mechanism. Research on Chemical Intermediates, 41 (4), 2071–2079. doi: https://doi.org/10.1007/s11164-013-1332-8
34. Kotok, V., Kovalenko, V. (2017). Optimization of nickel hydroxide electrode of the hybrid supercapacitor. Eastern-European Journal of Enterprise Technologies, 1 (6 (85)), 4–9. doi: https://doi.org/10.15587/1729-4061.2017.90810
35. Kotok, V., Kovalenko, V. (2017). Electrochromism of $Ni(OH)_2$ films obtained by cathode template method with addition of Al, Zn, Co ions. Eastern-European Journal of Enterprise Technologies, 3 (12 (87)), 38–43. doi: https://doi.org/10.15587/1729-4061.2017.103010
36. Kotok, V., Kovalenko, V. (2017). The properties investigation of the faradaic supercapacitor electrode formed on foamed nickel substrate with polyvinyl alcohol using. Eastern-European Journal of Enterprise Technologies, 4 (12 (88)), 31–37. doi: https://doi.org/10.15587/1729-4061.2017.108839
37. Kovalenko, V., Kotok, V. (2018). Influence of ultrasound and template on the properties of nickel hydroxide as an active substance of supercapacitors. Eastern-European Journal of Enterprise Technologies, 3 (12 (93)), 32–39. doi: https://doi.org/10.15587/1729-4061.2018.133548
38. 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
39. Ecsedi, Z., Lazău, I., Păcurariu, C. (2007). Synthesis of mesoporous alumina using polyvinyl alcohol template as porosity control additive. Processing and Application of Ceramics, 1 (1-2), 5–9. doi: https://doi.org/10.2298/pac0702005e
40. Pon-On, W., Meejoo, S., Tang, I.-M. (2008). Formation of hydroxyapatite crystallites using organic template of polyvinyl alcohol (PVA) and sodium dodecyl sulfate (SDS). Materials Chemistry and Physics, 112 (2), 453–460. doi: https://doi.org/10.1016/j.matchemphys.2008.05.082
41. Miyake, K., Hirota, Y., Uchida, Y., Nishiyama, N. (2016). Synthesis of mesoporous MFI zeolite using PVA as a secondary template. Journal of Porous Materials, 23 (5), 1395–1399. doi: https://doi.org/10.1007/s10934-016-0199-7
42. Wanchanthu, R., Thapol, A. (2011). The Kinetic Study of Methylene Blue Adsorption over MgO from PVA Template Preparation. Journal of Environmental Science and Technology, 4 (5), 552–559. doi: https://doi.org/10.3923/jest.2011.552.559
43. Kotok, V. A., Kovalenko, V. L., Kovalenko, P. V., Solovov, V. A., Deabate, S., Mehdi, A. et. al. (2017). Advanced electrochromic $Ni(OH)_2$/PVA films formed by electrochemical template synthesis. ARPN Journal of Engineering and Applied Sciences, 12 (13), 3962–3977.
44. Tan, Y., Srinivasan, S., Choi, K.-S. (2005). Electrochemical Deposition of Mesoporous Nickel Hydroxide Films from Dilute Surfactant Solutions. Journal of the American Chemical Society, 127 (10), 3596–3604. doi: https://doi.org/10.1021/ja0434329
45. Kotok, V., Kovalenko, V. (2018). A study of multilayered electrochromic platings based on nickel and cobalt hydroxides. Eastern-European Journal of Enterprise Technologies, 1 (12 (91)), 29–35. doi: https://doi.org/10.15587/1729-4061.2018.121679
46. Parkhomchuk, E. V., Sashkina, K. A., Rudina, N. A., Kulikovskaya, N. A., Parmon, V. N. (2013). Template synthesis of 3D-structured macroporous oxides and hierarchical zeolites. Catalysis in Industry, 5 (1), 80–89. doi: https://doi.org/10.1134/s2070050412040150
47. Gu, W., Liao, L. S., Cai, S. D., Zhou, D. Y., Jin, Z. M., Shi, X. B., Lei, Y. L. (2012). Adhesive modification of indium–tin-oxide surface for template attachment for deposition of highly ordered nanostructure arrays. Applied Surface Science, 258 (20), 8139–8145. doi: https://doi.org/10.1016/j.apsusc.2012.05.009

DOI: 10.15587/1729-4061.2018.140982

INVESTIGATION AND ANALYSIS OF THE POSSIBILITY OF DIFFUSIONLESS PHASE TRANSFORMATIONS IN THE SURFACE LAYER OF A PART UNDER THE ACTION OF GRINDING TEMPERATURES (p. 36-42)

Ala Bezpalova
Odessa State Academy of Civil Engineering and Architecture, Odessa, Ukraine
ORCID: http://orcid.org/0000-0003-3713-0610

Vladimir Lebedev
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0003-2891-9708

Natalia Klimenko
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0003-1841-276X

Tatiana Chumachenko
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0001-6149-4786

Inga Uyadnikova
National University of Physical Education and Sport of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-3750-876X

The possibility of diffusionless phase transformations in the surface layer of the ground part under the influence of instantaneous grinding temperature is investigated and analyzed. This is important because the phase Feα-Feγ transformations that may occur when grinding parts lead to the appearance of so-called grinding burns, which 2-3 times reduce the reliability and durability of the part in the working mechanism. The mechanism of phase transformations, the critical temperature of these transformations and the associated processing modes that provide this temperature are determined. This allows a reasonable approach to the definition of grinding modes and, if necessary, the application of the cooling method. In addition, the problem of optimizing grinding regimes can be solved if the processing performance is taken as a target function, and grinding temperature as a limitation. With rapid surface heating of the hardened steel part by the grinding temperature above the Ac_1 line, there is a reverse martensitic transformation Feα→Feγ. The martensite range during cooling Mn-Mk to a large extent covers negative temperatures. Therefore, austenite is partially fixed in the surface layer, forming a so-called quenching burn. Dependences for determining the formation temperature for steel of any chemical composition, give the possibility to maintain the value of grinding temperature below this level during grinding. The mechanism of diffusionless reverse martensitic transformation in the high-speed surface heating by cutting grains (instantaneous temperature) is considered. The heating rate and the effect of the pressure produced by the abrasive grain on the metal during the chip removal are experimentally determined. Thus, the possibility of diffusionless phase transformation is substantiated and the dependences for the calculation of austenite formation temperatures are given, which in turn provides the opportunity to calculate safe processing regimes.

Keywords: austenite, martensite, γ-iron, α-iron, heating rate, transformation temperature, martensite range, surface layer, critical temperature.

References

1. Chumachenko, T. V. (2011). Tekhnologicheskoe obespechenie kachestva i proizvoditel'nosti obrabotki poverhnostey sheek valov rotorov gazovyh turbin, napylennyh mineralokeramikoy. Odessa, 163.
2. Lebedev, V. G., Klimenko, N. N., Al'-Adzhelat, S. A. (2013). Mekhanizm obrazovaniya prizhogov pri shlifovanii detaley iz zakalennyh staley. Naukovi notatky, 40, 141–144.
3. Lobodyuk, V. A., Estrin, E. I. (2009). Martensitnye prevrashcheniya. Moscow: Fizmalit, 352.
4. Kremen', Z. I., Yur'ev, V. G., Baboshkin, A. F. (2015). Tekhnologiya shlifovaniya v mashinostroenii. Sankt-Peterburg Politekhnika, 424.
5. Biront V. S. Teoriya termicheskoy obrabotki. Krasnoyarsk, 2007. 234 p.
6. Vliyanie teploty, obrazuyushcheysya pri shlifovanii. Biblioteka tekhnicheskoy literatury. Available at: http://delta-grup.ru/bibliot/39/76.htm
7. Lebedev, V., Klimenko, N., Uryadnikova, I., Chumachenko, T., Ovcharenko, A. (2017). Martensite transformations in the surface layer at grinding of parts of hardened steels. Eastern-European Journal of Enterprise Technologies, 3 (12 (87)), 56–63. doi: https://doi.org/10.15587/1729-4061.2017.103149
8. Lebedev, V. G., Klimenko, N. N. (2015). Zakonomernosti obrazovaniya prizhogov otpuska pri shlifovanii podshipnikovyh staley. Perspektyvni tekhnolohiyi ta prylady, 6, 35–40.
9. Fedotov, A. K. (2012). Fizicheskoe materialovedenie. Vol. 2. Fazovye prevrashcheniya v metallah i splavah. Minsk: Vysshaya shkola, 446.

10. Aleksandrova, M. Yu., Dobrynin, S. A., Firsov, G. I. (2008). Modelirovanie temperaturnogo polya na poverhnosti detali pri naruzhnom bescentrovom shlifovanii. Vestnik nauchno-tekhnicheskogo razvitiya. Nacional'naya Tekhnologicheskaya Gruppa, 10 (14), 46–53.
11. Kremen', Z., Yur'ev, V., Baboshkin, A. (2017). Tekhnologiya shlifovaniya v mashinostroenii. Litres, 425.
12. Salov, P. M., Salova, D. P., Vinogradova, T. G., Saikin, S. S. (2016). Thermal phenomena during internal grinding with sliding feed. Vektor Nauki Tol'yattinskogo Gosudarstvennogo Universiteta, 1, 42–47. doi: https://doi.org/10.18323/2073-5073-2016-1-42-47
13. Li, X., Ma, X., Subramanian, S. V., Shang, C., Misra, R. D. K. (2014). Influence of prior austenite grain size on martensite–austenite constituent and toughness in the heat affected zone of 700MPa high strength linepipe steel. Materials Science and Engineering: A, 616, 141–147. doi: https://doi.org/10.1016/j.msea.2014.07.100
14. Rajasekhara, S., Ferreira, P. J. (2011). Martensite→austenite phase transformation kinetics in an ultrafine-grained metastable austenitic stainless steel. Acta Materialia, 59 (2), 738–748. doi: https://doi.org/10.1016/j.actamat.2010.10.012
15. Kaluba, W., Kaluba, T., Zielinska-Lipiec, A. (2007). Morphological Evolutions in Steels during Continuous Rapid Heating. Materials Science Forum, 539-543, 4669–4674. doi: https://doi.org/10.4028/www.scientific.net/msf.539-543.4669
16. Li, C. H., Ding, Y. C., Lu, B. H. (2008). Innovative Technology Investigation into Integrate the Surface Hardening Process with the Grinding Precision Finishing for CBN Grinding Crankshaft. 2008 4th International Conference on Wireless Communications, Networking and Mobile Computing. doi: https://doi.org/10.1109/wicom.2008.3039
17. Xu, Y. (1993). The role of retained austenite and residual stresses in rolling contac. DigitalCommons@University of Nebraska – Lincoln. 1993. Available at: http://digitalcommons.unl.edu/dissertations/AAI9611077/
18. Jin, S., Huang, D., Morris, J. W. Jr., Thomas, G. (2010). Use of the reverse martensitic transformation and precipitation to enhance the strength and stability of austenite. Lawrence Berkeley National Laboratory, 18.
19. Golovin, I. S., Komissarov, A. A., Kustov, S. B., Maikranz-Valentin, M., Siemers, C. (2010). Phase impact of thermal cycling on reversibility and anelastic- transformations ity of martensitic transformation in Fe-22Mn-3Si alloy. Metallofizika i Noveishie Tekhnologii, 32 (2), 191–201.
20. Analyse des évolutions structurales et du comportement mécanique d'un acier au chrome-nickel-molybdène à très bas carbone du type Z1CNDA 12-09-02, en fonction des traitements thermiques. Available at: https://www.theses.fr/1989PA112002
21. Lebedev, V., Klimenko, N., Chumachenko, T., Uryadnikova, I., Ovcharenko, A. (2016). Definition of the amount of heat released during metal cutting by abrasive grain and the contact temperature of the ground surface. Eastern-European Journal of Enterprise Technologies, 5 (7 (83)), 43–50. doi: https://doi.org/10.15587/1729-4061.2016.81207
22. Mirzoev, D. A., Mirzoev, A. A., Chirkov, P. V. (2016). Leave martensite in the input of rapid heating. Bulletin of SUSU. Series: Mathematics. Mechanics. Physics, 8 (1), 61–65.
23. Gulyaev, A. P. (2011). Metallovedenie. Moscow, 643.
24. Blank, V. D., Estrin, E. I. (2011). Fazovye prevrashcheniya v tverdyh telah pri vysokom davlenii. Moscow, 412.
25. Kaufman, L., Cohen, M. (1958). Thermodynamics and kinetics of martensitic transformations. Progress in Metal Physics, 7, 165–246. doi: https://doi.org/10.1016/0502-8205(58)90005-4
26. Tkachenko, I. F. (1997). Raschetnoe opredelenie temperatury ravnovesiya mezhdu austenitom i martensitom. Vestnik Priazovskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Tekhnicheskie nauki, 3, 81–82.
27. Metodika prigotovleniya mikroshlifa. Available at: https://infourok.ru/laboratornaya-rabota-metodika-prigotovleniya-mikroshlifa-852852.html
28. Mikroskop MIM-7. Available at: http://mikroskop-1.ru/?name=Mikroskopy~MIM-7&ref
29. Gorlach, V. V., Egorov, V. L., Ivanov, N. A. (2006). Obrabotka, predstavlenie, interpretaciya rezul'tatov izmereniy. Omsk: Izdatel'stvo SibADI, 85.
30. Maslov, E. N. (1984). Teoriya shlifovaniya materialov. Moscow: Mashinostroenie, 320.
31. Lyubov, B. Ya. (2013). Kineticheskaya teoriya fazovyh prevrashcheniy. Moscow: Metallurgiya, 375.

DOI: 10.15587/1729-4061.2018.140924

STUDYING THE PHYSICALCHEMICAL PROPERTIES OF ALLOYED METALLURGICAL WASTE AS SECONDARY RESOURCESAVING RAW MATERIALS (p. 43-48)

Stanislav Hryhoriev
Zaporizhzhia National University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0002-1170-6856

Artem Petryshchev
Zaporizhzhia National Technical University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0003-2631-1723

Nina Sinyaeva
Zaporizhzhya National University, Zaporizhzhya, Ukraine
ORCID: http://orcid.org/0000-0002-5685-4449

Alina Yurchenko
Zaporizhzhia National University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0002-3549-5723

Olexandr Sklyar
Tavria State Agrotechnological University, Melitopol, Ukraine
ORCID: http://orcid.org/0000-0001-8003-3379

Sergey Kvitka
Tavria State Agrotechnological University, Melitopol, Ukraine
ORCID: http://orcid.org/0000-0001-9234-9274

Viacheslav Borysov
Khortytsia National Academy, Zaponzhzhia, Ukraine
ORCID: http://orcid.org/0000-0002-3117-2118

Valerii Vlasiuk
National Academy of the National Guard of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-2140-3250

Bohdan Tsymbal
National University of Civil Defence of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-2317-3428

Svitlana Borysova
Donbass State Pedagogical University, Sloviansk, Ukraine
ORCID: http://orcid.org/0000-0003-0610-644X

The properties of the phase composition and microstructure of slags from the alumothermic production of ligatures of refractory elements of various grades, as well as scale of the rapid cutting steel R6M5, were examined for the nature of the presence of alloying elements. This is required to ensure a decrease in the losses of Mo, W, as well as other alloying elements, through sublimation with an increase in the temperature when processing technogenic waste. Phase composition was determined by the method of an X-ray phase

analysis. Microstructure was investigated at a scanning electron microscope in a combination with an X-ray microanalysis using the non-reference calculation method for fundamental parameters. It was determined that slags from the alumothermic production of ligatures AHM-50 and AMVT consist of $CaAl_4O_7$ and compounds AlV_2O_4 and CrO_2. That could indicate a certain level of doping the alloy with the refractory elements. The phases of $Al_{75}Mo_{20}W_5$ and $Mo(Si, Al)_3$, which could be represented by metallic inclusions, were identified in the slag from the MFTA ligature smelting. The phases of scale of steel slag R6M5 are mostly represented by Fe_3O_4, Fe_2O_3 and FeO. In addition, $FeWO_4$, MoO_2, WC, Mo_2C were found, which is explained by the elevated degree of W and Mo doping. It is not ruled out that a certain part of atoms in the alloying elements, including Cr and V, could exist in the form of replacement atoms in Fe oxides. The microstructure of the examined slags and scale was characterized by the disordered particles of different size and shape. The presence of particles with a relatively high content of alloying elements was detected in scale. Compounds with an elevated susceptibility to sublimation are absent in the studied materials. That leads to a relatively high degree of using the alloying elements and lowers certain restrictions for adding the examined slags to slag-forming mixtures and for temperature limits of melting modes. The use of slags from the alumothermic production, as well as scale of rapid cutting steels, in the charge for the smelting of a doping alloy ensured the extraction of refractory elements and an additional doping of the resulting product.

Keywords: slag from alumothermic production, alloyed technogenic waste, steel scale, X-ray phase study.

References

1. Pan, J., Zheng, G., Zhu, D., Zhou, X. (2013). Utilization of nickel slag using selective reduction followed by magnetic separation. Transactions of Nonferrous Metals Society of China, 23 (11), 3421–3427. doi: https://doi.org/10.1016/s1003-6326(13)62883-6
2. 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. Eastern-European Journal of Enterprise Technologies, 1 (10 (91)), 44–49. doi: https://doi.org/10.15587/1729-4061.2018.121615
3. 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.
4. Shatokha, V. I., Gogenko, O. O., Kripak, S. M. (2011). Utilising of the oiled rolling mills scale in iron ore sintering process. Resources, Conservation and Recycling, 55 (4), 435–440. doi: https://doi.org/10.1016/j.resconrec.2010.11.006
5. Liu, S., Wu, H.-B., Yu, W., Wang, L.-D., Cai, Z.-X., Tang, D. (2013). Influence of hot-rolling parameters on the microstructure and corrosion-resistance of oxide scales. Cailiao Kexue yu Gongyi/Material Science and Technology, 21 (6), 84–90.
6. Hryhoriev, S., Petryshchev, A., Belokon', K., Krupey, K., Yamshinskij, M., Fedorov, G. et. al. (2018). Determining the physical-chemical characteristics of the carbon-thermal reduction of scale of tungsten high-speed steels. Eastern-European Journal of Enterprise Technologies, 2 (6 (92)), 10–15. doi: https://doi.org/10.15587/1729-4061.2018.125988
7. Zhdanov, A. V., Zhuchkov, V. I., Dashevskiy, V. Ya., Leontyev, L. I. (2015). Wastes generation and use in ferroalloy production. Energy efficiency and environmental friendliness are the future of the global Ferroalloy industry: Proceedings of the Fourteenth International Ferroalloys Congress INFACON XIV, 754–758.
8. Lazarevskiy, P. P., Gizatulin, R. A., Romanenko, Y. E., Valuev, D. V., Valueva, A. V., Serikbol, A. (2015). Extraction of Chromium from Carbon Ferrochromium Residual Wastes. IOP Conference Series: Materials Science and Engineering, 91, 012038. doi: https://doi.org/10.1088/1757-899x/91/1/012038
9. Nokhrina, O. I., Rozhikhina, I. D., Dmitrienko, V. I., Golodova, M. A., Efimenko, Y. A. (2014). Reduction of metals from vanadium converter slag by means of carbon and silicon. Steel in Translation, 44 (2), 99–102. doi: https://doi.org/10.3103/s0967091214020156
10. Lindvall, M., Rutqvist, S., Ye, G. (2010). Recovery of vanadium from V-bearing BOF-slag using an EAF. The Twelfth International Ferroalloys Congress. Sustainable Future. Helsinki, 189–196.
11. Wang, H., Stolyarova, V. L., Lopatin, S. I., Kutuzova, M. E., Seetharaman, S. (2010). High-temperature mass spectrometric study of the vaporization processes of V2O3 and vanadium-containing slags. Rapid Communications in Mass Spectrometry, 24 (16), 2420–2430. doi: https://doi.org/10.1002/rcm.4657
12. Vokhmentsev, S. A., Larionov, A. V., Gulyaeva, R. I., Chumarev, V. M. (2017). Phase composition and thermal properties of ladle smelting slags of AVTU, AKhMK and ATsMO foundry alloys. Tsvetnye Metally, 11, 60–64. doi: https://doi.org/10.17580/tsm.2017.11.11
13. Vohmencev, S. A., Chumarev, V. M., Larionov, A. V., Zhidovinova, S. V., Taranov, D. V. (2017). Fazoviy sostav produktov alyuminotermicheskoy vyplavki ligatury Al-V-Ti-C. Titan, 3 (57), 20–23.
14. Ryabuhin, A. G., Gruba, O. N. (2005). Entropiya kristallicheskih oksidov hroma. Izvestiya Chelyabinskogo nauchnogo centra UrO RAN, 4 (30), 36–40.

DOI: 10.15587/1729-4061.2018.140970

A STUDY OF INITIAL STAGES FOR FORMATION OF CARBON CONDENSATES ON COPPER (p. 49-55)

Yu Dai
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-4879-1289

Igor Kolupaev
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-2125-7118

Oleg Sobol
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-4497-4419

In the CVD method, samples of carbon condensates were obtained under special conditions (low substrate temperature and short growth times). The use of special technological conditions makes it possible to study the initial stages of growth of graphene layers. To analyze the influence of the microinhomogeneities of the copper substrate on growth conditions, various modes of its electrochemical polishing were used in the study. The structural state of the surface was studied using computer processing of digital images of a surface with color segmentation. A metallographic analysis of more than 70 samples was carried out and three main structural elements of the initial stage of growth of graphene layers were identified on the basis of computer image processing during condensation. These are graphene layers, sections of a copper substrate and a cluster of atoms with a structural state different from the graphene (presumably amorphous). It has been established that preparation of the substrate surface should be attributed to the most important technological operations for obtaining a high-quality graphene coating. It has been found that the use of multicomponent electrolytes during the

polishing of the copper substrate makes it possible to increase the uniformity in the dimensions of the structural elements of the surface roughness. This leads to an increase in the surface area of the formation of graphene layers already during the initial stages of growth (at a relatively low process temperature of 700 °C).

The obtained results testify to the prospects of using multistage image analysis (using the clustering method) to optimize the technological regimes for obtaining the "carbon condensate/substrate" systems, taking into account the initial roughness of the latter.

Keywords: carbon condensates, graphene/copper system, CVD process, optical microscopy, computer image processing, phase composition.

References

1. Morton, B. D., Wang, H., Fleming, R. A., Zou, M. (2011). Nanoscale Surface Engineering with Deformation-Resistant Core–Shell Nanostructures. Tribology Letters, 42 (1), 51–58. doi: https://doi.org/10.1007/s11249-011-9747-0
2. Ivashchenko, V. I., Dub, S. N., Scrynskii, P. L., Pogrebnjak, A. D., Sobol', O. V., Tolmacheva, G. N. et. al. (2016). Nb–Al–N thin films: Structural transition from nanocrystalline solid solution nc-(Nb,Al)N into nanocomposite nc-(Nb, Al)N/a–AlN. Journal of Superhard Materials, 38 (2), 103–113. doi: https://doi.org/10.3103/s1063457616020040
3. Grigoriev, S. N., Sobol, O. V., Beresnev, V. M., Serdyuk, I. V., Pogrebnyak, A. D., Kolesnikov, D. A., Nemchenko, U. S. (2014). Tribological characteristics of (TiZrHfVNbTa)N coatings applied using the vacuum arc deposition method. Journal of Friction and Wear, 35 (5), 359–364. doi: https://doi.org/10.3103/s1068366614050067
4. Vasyliev, M. O., Mordyuk, B. M., Sidorenko, S. I., Voloshko, S. M., Burmak, A. P., Kindrachuk, M. V. (2016). Synthesis of Deformation-Induced Nanocomposites on Aluminium D16 Alloy Surface by Ultrasonic Impact Treatment. METALLOFIZIKA I NOVEISHIE TEKHNOLOGII, 38 (4), 545–563. doi: https://doi.org/10.15407/mfint.38.04.0545
5. Sobol', O. V. (2016). The influence of nonstoichiometry on elastic characteristics of metastable β-WC1–x phase in ion plasma condensates. Technical Physics Letters, 42 (9), 909–911. doi: https://doi.org/10.1134/s1063785016090108
6. Sobol', O. V. (2016). Structural Engineering Vacuum-plasma Coatings Interstitial Phases. Journal of Nano- and Electronic Physics, 8 (2), 02024–1–02024–7. doi: https://doi.org/10.21272/jnep.8(2).02024
7. Sobol', O. V. (2007). Nanostructural ordering in W-Ti-B condensates. Physics of the Solid State, 49 (6), 1161–1167. doi: https://doi.org/10.1134/s1063783407060236
8. Song, T., Jiang, X., Shao, Z., Mo, D., Zhu, D., Zhu, M. et. al. (2017). Interfacial microstructure and mechanical properties of diffusion-bonded joints of titanium TC4 (Ti-6Al-4V) and Kovar (Fe-29Ni-17Co) alloys. Journal of Iron and Steel Research, International, 24 (10), 1023–1031. doi: https://doi.org/10.1016/s1006-706x(17)30149-8
9. Krause-Rehberg, R., Pogrebnyak, A. D., Borisyuk, V. N., Kaverin, M. V., Ponomarev, A. G., Bilokur, M. A. et. al. (2013). Analysis of local regions near interfaces in nanostructured multicomponent (Ti-Zr-Hf-V-Nb)N coatings produced by the cathodic-arc-vapor-deposition from an arc of an evaporating cathode. The Physics of Metals and Metallography, 114 (8), 672–680. doi: https://doi.org/10.1134/s0031918x13080061
10. Vacuum-plasma coatings based on the multielement nitrides / Azarenkov N. A., Sobol O. V., Beresnev V. M., Pogrebnyak A. D., Kolesnikov D. A. et. al. // Metallofizika i Noveishie Tekhnologii. 2013. Vol. 35, Issue 8. P. 1061–1084.
11. Pohrelyuk, I. M., Kindrachuk, M. V., Lavrys', S. M. (2016). Wear Resistance of VT22 Titanium Alloy After Nitriding Combined with Heat Treatment. Materials Science, 52 (1), 56–61.doi: https://doi.org/10.1007/s11003-016-9926-0
12. Zubkov, A. I., Zubarev, E. N., Sobol', O. V., Hlushchenko, M. A., Lutsenko, E. V. (2017). Structure of vacuum Cu–Ta condensates. Physics of Metals and Metallography, 118 (2), 158–163. doi: https://doi.org/10.1134/s0031918x17020156
13. Kausar, A. (2016). Adhesion, morphology, and heat resistance properties of polyurethane coated poly(methyl methacrylate)/fullerene-C60 composite films. Composite Interfaces, 24 (7), 649–662. doi: https://doi.org/10.1080/09276440.2017.1257251
14. Hou, C., Zhang, M., Halder, A., Chi, Q. (2017). Graphene directed architecture of fine engineered nanostructures with electrochemical applications. Electrochimica Acta, 242, 202–218. doi: https://doi.org/10.1016/j.electacta.2017.04.117
15. Singh, V., Joung, D., Zhai, L., Das, S., Khondaker, S. I., Seal, S. (2011). Graphene based materials: Past, present and future. Progress in Materials Science, 56 (8), 1178–1271. doi: https://doi.org/10.1016/j.pmatsci.2011.03.003
16. Tsen, A. W., Brown, L., Havener, R. W., Park, J. (2012). Polycrystallinity and Stacking in CVD Graphene. Accounts of Chemical Research, 46 (10), 2286–2296. doi: https://doi.org/10.1021/ar300190z
17. Chu, P. K., Li, L. (2006). Characterization of amorphous and nanocrystalline carbon films. Materials Chemistry and Physics, 96 (2-3), 253–277. doi: https://doi.org/10.1016/j.matchemphys.2005.07.048
18. Meyer, J. C., Geim, A. K., Katsnelson, M. I., Novoselov, K. S., Booth, T. J., Roth, S. (2007). The structure of suspended graphene sheets. Nature, 446 (7131), 60–63. doi: https://doi.org/10.1038/nature05545
19. Lee, C., Wei, X., Kysar, J. W., Hone, J. (2008). Measurement of the Elastic Properties and Intrinsic Strength of Monolayer Graphene. Science, 321 (5887), 385–388. doi: https://doi.org/10.1126/science.1157996
20. Jia, C., Jiang, J., Gan, L., Guo, X. (2012). Direct Optical Characterization of Graphene Growth and Domains on Growth Substrates. Scientific Reports, 2 (1). doi: https://doi.org/10.1038/srep00707
21. Nair, R. R., Blake, P., Grigorenko, A. N., Novoselov, K. S., Booth, T. J., Stauber, T. et. al. (2008). Fine Structure Constant Defines Visual Transparency of Graphene. Science, 320 (5881), 1308–1308. doi: https://doi.org/10.1126/science.1156965
22. Loh, K. P., Bao, Q., Ang, P. K., Yang, J. (2010). The chemistry of graphene. Journal of Materials Chemistry, 20 (12), 2277. doi: https://doi.org/10.1039/b920539j
23. Mouras, S., Hamm, A., Djurado, D., Cousseins, J. C. (1987). Synthesis of first stage graphite intercalation compounds with fluorides. Revue de chimie minerale, 24 (5), 572–582.
24. Yu, Q., Lian, J., Siriponglert, S., Li, H., Chen, Y. P., Pei, S.-S. (2008). Graphene segregated on Ni surfaces and transferred to insulators. Applied Physics Letters, 93 (11), 113103. doi: https://doi.org/10.1063/1.2982585
25. Reina, A., Jia, X., Ho, J., Nezich, D., Son, H., Bulovic, V. et. al. (2009). Large Area, Few-Layer Graphene Films on Arbitrary Substrates by Chemical Vapor Deposition. Nano Letters, 9 (1), 30–35. doi: https://doi.org/10.1021/nl801827v
26. Li, X., Cai, W., Colombo, L., Ruoff, R. S. (2009). Evolution of Graphene Growth on Ni and Cu by Carbon Isotope Labeling. Nano Letters, 9 (12), 4268–4272. doi: https://doi.org/10.1021/nl902515k
27. Li, X., Cai, W., An, J., Kim, S., Nah, J., Yang, D. et. al. (2009). Large-Area Synthesis of High-Quality and Uniform Graphene Films on Copper Foils. Science, 324 (5932), 1312–1314. doi: https://doi.org/10.1126/science.1171245
28. Wood, J. D., Schmucker, S. W., Lyons, A. S., Pop, E., Lyding, J. W. (2011). Effects of Polycrystalline Cu Substrate on Graphene Growth by Chemical Vapor Deposition. Nano Letters, 11 (11), 4547–4554. doi: https://doi.org/10.1021/nl201566c

29. Geng, D., Wu, B., Guo, Y., Huang, L., Xue, Y., Chen, J. et. al. (2012). Uniform hexagonal graphene flakes and films grown on liquid copper surface. Proceedings of the National Academy of Sciences, 109 (21), 7992–7996. doi: https://doi.org/10.1073/pnas.1200339109
30. Regmi, M., Chisholm, M. F., Eres, G. (2012). The effect of growth parameters on the intrinsic properties of large-area single layer graphene grown by chemical vapor deposition on Cu. Carbon, 50 (1), 134–141. doi: https://doi.org/10.1016/j.carbon.2011.07.063
31. Kim, H., Mattevi, C., Calvo, M. R., Oberg, J. C., Artiglia, L., Agnoli, S. et. al. (2012). Activation Energy Paths for Graphene Nucleation and Growth on Cu. ACS Nano, 6 (4), 3614–3623. doi: https://doi.org/10.1021/nn3008965
32. Wang, H., Wang, G., Bao, P., Yang, S., Zhu, W., Xie, X., Zhang, W.-J. (2012). Controllable Synthesis of Submillimeter Single-Crystal Monolayer Graphene Domains on Copper Foils by Suppressing Nucleation. Journal of the American Chemical Society, 134 (8), 3627–3630. doi: https://doi.org/10.1021/ja2105976
33. Li, Z., Wu, P., Wang, C., Fan, X., Zhang, W., Zhai, X. et. al. (2011). Low-Temperature Growth of Graphene by Chemical Vapor Deposition Using Solid and Liquid Carbon Sources. ACS Nano, 5 (4), 3385–3390. doi: https://doi.org/10.1021/nn200854p
34. Kolypaev, I. M., Sobol', O. V., Myrakhovskiy, O. V., Levitsky, V. S., Larinova, T. V., Koltsova, T. S., Sobol, V. O. (2016). Estimation the uniformity of a polygraphene coating on copper (GCC). 2016 International Conference on Nanomaterials: Application & Properties (NAP). doi: https://doi.org/10.1109/nap.2016.7757274
35. Chen, K., Dzhiblin, P., Irving, A. (2001). MATLAB v matematicheskih issledovaniyah. Moscow: Mir, 346.
36. Gonsales, R., Vuds, R., Eddins, S. (2006). Cifrovaya obrabotka izobrazheniy v srede MATLAB. Moscow: Tekhnosfera, 616.
37. Madaan, A., Bhatia, M., Hooda, M. (2018). Implementation of Image Compression and Cryptography on Fractal Images. Lecture Notes in Networks and Systems, 49–61. doi: https://doi.org/10.1007/978-981-10-8360-0_5
38. Kolupaev, I., Sobol, O., Murakhovski, A., Koltsova, T., Kozlova, M., Sobol, V. (2016). Use of computer processing by the method of multi-threshold cross sections for the analysis of optical images of fractal surface microstructure. Eastern-European Journal of Enterprise Technologies, 5 (4 (83)), 29–35. doi: https://doi.org/10.15587/1729-4061.2016.81255
39. Sobol', O. V., Kolupaev, I. N., Murahovskiy, A. V., Levitskiy, V. S. et. al. (2016). Express Method of Analysis Morphological Parameters of Graphene Coatings on a Copper Substrate. Journal of Nano- and Electronic Physics, 8 (4 (1)), 04013-1–04013-5. doi: https://doi.org/10.21272/jnep.8(4(1)).04013

DOI: 10.15587/1729-4061.2018.140912

STUDYING AND DESIGNING IMPROVED COATINGS FOR LABYRINTH SEALS OF GASTURBINE ENGINE TURBINES (p. 56-63)

Viktor Greshta
Zaporizhzhia National Technical University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0002-4589-6811

Daria Tkach
Zaporizhzhia National Technical University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0003-0851-1481

Ievgenii Sotnikov
Motor Sich JSC, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0003-3549-2765

Dmytro Pavlenko
Zaporizhzhia National Technical University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0001-6376-2879

Olexandr Klymov
Zaporizhzhia National Technical University, Zaporizhzhia, Ukraine
ORCID: http://orcid.org/0000-0003-1248-6645

An analysis of improving efficiency of aircraft engine turbines by means of improvement of composition of sealing coatings used in labyrinth seals was made. It was established that a number of contradictory requirements to properties of such coatings are imposed at the initial stage of engine running-in and during further operation. Main types of damage of above coatings used in the design of labyrinth seals during operation of gas turbine engines were shown. In connection with the necessity of raising temperature of gases in turbines of aircraft engines, it was proposed to additionally dope the serial nickel-based coatings with yttrium-containing master alloys. The results of study of influence of doping of the wearing-in sealing coatings on operating properties in conditions of action of a high-temperature gas flow were presented. It was found that doping of the KNA-82 serial coating with a multicomponent Co-Ni-Cr-Al-Y master alloy is the most rational solution.

It was established that the use of the developed coating in a temperature range of 1,100...1,200 °C makes it possible to reduce specific consumption of fuel by aircraft engines by improving turbine efficiency and prevent wear of the end faces of ridges of the rotor labyrinth seal. Based on simulation of flow in the labyrinth seal clearance by numerical method, it was shown that the use of the developed coating materials in seals of the compressor turbine and the free turbine makes it possible to reduce amount of cooling air leakage into the turbine air-gas channel by reducing wear of tops of the labyrinth rotor seal ridge.

Keywords: gas turbine engine, efficiency, radial clearance, labyrinth seal, alloying, gas flow rate.

References

1. Kofman, V. M. (2012). Opredelenie koefficienta poleznogo deystviya turbiny GTD po parametram neravnomernyh gazovyh potokov. Vestnik Ufimskogo gosudarstvennogo aviacionnogo tekhnicheskogo universiteta, 16 (5 (50)), 39–40.
2. Sporer, D., Wilson, S., Dorfman, M. (2010). Ceramics for Abradable Shroud Seal Applications. Ceramic Engineering and Science Proceedings, 39–54. doi: https://doi.org/10.1002/9780470584293.ch5
3. Chupp, R. E., Hendricks, R. C., Lattime, S. B., Steinetz, B. M. (2006). Sealing in turbomachinery. NASA/TM-2006-214341, 62.
4. Bondarchuk, P. V., Tisarev, A. Yu., Lavrushin, M. V. (2012). Razrabotka metodiki rascheta sistemy upravleniya radial'nymi zazorami v turbine GTD. Vestnik Samarskogo gosudarstvennogo aerokosmicheskogo universiteta, 3 (34), 272–278.
5. Inozemcev, A. A., Bazhin, S. V., Snitko, M. A. (2012). Voprosy optimizacii radial'nyh zazorov TVD aviacionnogo GTD. Vestnik dvigatelestroeniya, 2, 149–154.
6. Inozemcev, A. A., Sandrackiy, V. L. (2006). Gazoturbinnye dvigateli. Moscow, 1204.
7. Komarov, O. A., Dmitriev, S. Yu., Dautov, D. R., Ossiala, V. B. A. (2017). Poteri KPD v turbine vysokogo davleniya s bandazhirovannoy rabochey lopatkoy. Vestnik Ufimskogo gosudarstvennogo aviacionnogo tekhnicheskogo universiteta, 21 (2 (76)), 70–75.
8. Ma, X., Matthews, A. (2009). Evaluation of abradable seal coating mechanical properties. Wear, 267 (9-10), 1501–1510. doi: https://doi.org/10.1016/j.wear.2009.03.044
9. Gao, S., Xue, W., Duan, D., Li, S. (2016). Tribological behaviors of turbofan seal couples from friction heat perspective under high-speed rubbing condition. Friction, 4 (2), 176–190. doi: https://doi.org/10.1007/s40544-016-0114-x
10. Karpinos, B. S., Korovin, A. V., Lobun'ko, A. P., Vedishcheva, M. Yu. (2014). Ekspluatacionnye povrezhdeniya turboreaktivnyh dvuh-

konturnyh aviacionnyh dvigateley s forsazhnoy kameroy sgoraniya. Vestnik dvigatelestroeniya, 1.

11. Fois, N., Watson, M., Marshall, M. (2016). The influence of material properties on the wear of abradable materials. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 231 (2), 240–253. doi: https://doi.org/10.1177/1350650116649528
12. Hardwicke, C. U., Lau, Y.-C. (2013). Advances in Thermal Spray Coatings for Gas Turbines and Energy Generation: A Review. Journal of Thermal Spray Technology, 22 (5), 564–576. doi: https://doi.org/10.1007/s11666-013-9904-0
13. Faraoun, H. I., Seichepine, J. L., Coddet, C., Aourag, H., Zwick, J., Hopkins, N. et. al. (2006). Modelling route for abradable coatings. Surface and Coatings Technology, 200 (22-23), 6578–6582. doi: https://doi.org/10.1016/j.surfcoat.2005.11.105
14. Voevodin, A. A., Erohin, A. L., Spasskiy, S. E. (1991). Model' vybora skhemy mnogosloynogo ionno-plazmennogo pokrytiya na osnove rascheta napryazheniy v ego sloyah. Poverhnost'. Fizika, himiya, mekhanika, 9, 78–84.
15. Dvirnik, Ya. V., Pavlenko, D. V. (2014). Metodika modelirovaniya techeniya potoka v osevom kompressore GTD chislennym metodom. Vestnik dvigatelestroeniya, 1, 34–40.
16. Koval', V. A., Anurov, Yu. M., Belyaeva, S. O., Kovaleva, E. A., Yaroslavcev, S. V. (2009). Chislenniy analiz vozmozhnostey 2-D i 3-D metodov proektirovaniya osevyh turbomashin. Eastern-European Journal of Enterprise Technologies, 4 (5 (40)), 12–18. Available at: http://journals.uran.ua/eejet/article/view/21063/19508
17. Bielikov, S. B., Hreshta, V. L., Tkach, D. V. et. al. (2017). Otsinka ekspluatatsiynoi nadiinosti teplozakhysnykh ushchilniuvalnykh pokryttiv detalei hazoturbinnykh dvyhuniv. Novi materialy i tekhnolohiyi v metalurhii ta mashynobuduvanni, 2, 14–17.
18. Greshta, V. L., Tkach, D. V., Klimov, A. V., Sotnikov, E. G., Lekhovicer, Z. V., Stepanova, L. P. (2016). Issledovanie fazovogo sostava zharostoykih uplotnitel'nyh pokrytiy, primenyaemyh v GTD. Aviacionno-kosmicheskaya tekhnika i tekhnologiya, 8, 113–121.
19. Umanskiy, A. P., Polyarus, E. N., Kostenko, A. D., Terent'ev, A. E. (2012). Vliyanie sostava pokrytiy na osnove intermetallidov nikelya na mekhanizmy ih iznashivaniya v usloviyah vysokotemperaturnyh triboispytaniy. Problemy trybolohiyi, 3, 123–127.
20. Makarov, A., Zaytsev, N. (2015). Engineering and theoretical problems of labyrinth seals application in high-speed rotor machines. Perm National Research Polytechnic University Aerospace Engineering Bulletin, 42, 61–81. doi: https://doi.org/10.15593/2224-9982/2015.42.05
21. Reznik, S. B., Bandurko, E. A. (2013). Raschetno-eksperimental'naya ocenka effektivnosti razlichnyh tipov labirintnyh uplotneniy. Vestnik dvigatelestroeniya, 10 (107), 189–193.