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Wear modes in testing the antifriction layer of babbitt B83

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In this work, study of wear modes of antifriction layers of B83 babbitt during tribological tests was carried out. The assumed conditions for changing wear modes were determined during testing with a continuous increase in load by analyzing data of changes in the coefficient of friction and temperature near the contact zone. The data obtained made it possible to conduct experiments for a deeper study of the processes occurring in the friction zone. The results of friction experiments and studies by electron microscopy confirmed the correctness of the assumption about the conditions for change of wear modes. Changes in wear modes and wear mechanisms were judged by the behavior of the friction coefficient, the difference in friction surfaces, wear products, and wear intensity. The results obtained will make it possible to determine and recommend the modes of "wear-free" operation of the babbitt alloy.

Keywords: wear modes, wear mechanism, dry sliding friction, debris, babbitt.

1. Introduction

Soft tribological alloys based on tin, lead and aluminum are used for the production of anti-friction layers for almost a billion bearing shells every year. The use of such materials ensures that the conflicting requirements for the wearable working surface of the bearing: combination of hardness for wear resistance and softness for friction coefficient reduction [1]. Babbitts are anti-friction tin-based alloys, due to their tribological characteristics; such alloys are the best choice for bearing materials [2]. These materials provide excellent compatibility with steel shafts, are also capable of absorbing outsider particles, and have the unique ability to adapt to misalignment by gently lapping during initial bedding in due to their low melting points [3, 4]. The main disadvantage of babbitts is low wear resistance, which limits the scope of the material.

Improving the properties of babbitts is possible in several ways, which can be divided into two main groups: changing the structure due to the manufacturing method and creating a composite material based on babbitt by introducing various particles of micron and submicron sizes into the composition. Of particular interest is the development of methods of coating based on babbitt and a comprehensive study of their characteristics. Babbitt-based coating technologies are used to create and restore anti-friction layers on the surfaces of triboassembly parts. These layers can be obtained by casting, forming, arc welding, flame and plasma spraying or powder laser welding [5, 6]. The choice of method depends on many parameters and production conditions (for example, complex product geometry). The application of babbitt coatings using thermal spraying methods does not require extensive preparation to improve the mechanical adhesion of the applied layer to the substrate. In this case, it is possible to eliminate machining and control of preheating, in contrast to conventional and centrifugal casting. The advantages of thermal spraying include a high deposition rate [3].

Among all the methods of applying antifriction layers, arc surfacing technologies are the most common. The use of these technologies preserves the hardening phase, excluding its segregation, and makes it possible to form coatings of the required thickness. The coatings obtained by this method practically do not require subsequent mechanical processing [7]. In addition, high (compared to casting methods) cooling rates ensure the formation of a finely dispersed structure, that increases fatigue strength and resistance to brittle fracture of the contact surfaces of materials during operation and increases the service life of plain bearings [8]. Technological conditions of arc surfacing assume minimal melting of the steel substrate surface and the formation of layers of specified sizes, and the conditions for solidification of the molten metal ensure the formation of the required structure and properties. For surfacing, special additives are used in the form of wire, rods and tapes [9].

The structure of babbitt metal alloys (Sn-Sb-Cu) mainly consists of two intermetallic compounds (SnSb, Cu_xSn_y) in a soft Sn solid solution matrix. During the operation of the bearings, the Sn matrix acts as an anti-friction lubricant, while the intermetallic compounds, bearing loads, provide strength and hardness. In the composition of tin babbitt alloys, the amount of Cu and Sb is 0.5 – 8 wt.% and 8 – 12 wt.%, respectively. Increasing the content of Sb above the specified range can lead to a decrease in wear resistance, mechanical properties and fatigue failure [10]. The reason for this is the acute-angled geometric shape of the intermetallic phases of the Sn-Sb system, the vertices and edges of which are stress concentrators [11,12]. Among babbitts, one of the best antifriction alloys due to its structural components is high-tin babbitt B83. It does not contain lead, which makes this babbitt safer for the environment. Babbitt B83 is used as a matrix for the production of composite materials using various technologies [13,14,15]. Although the B83 alloy is a well-known material for a long time, modern technologies for the production and creation of composite materials leave topical issues of using and further comprehensive study of this material.

The study and description of the friction process is a non-trivial task, which becomes more complicated when studying materials with an inhomogeneous structure, such as babbitt. Data on the coefficient of friction and wear resistance may not be sufficient to predict the behavior of materials in a triboassembly. For example, it is impossible to establish a simple relationship between wear resistance and hardness. This can be explained by the fact that wear mechanisms are influenced by many variables of the friction process. Depending on the conditions, various wear mechanisms arise in the process of friction, which include adhesion, oxidation, plastic deformation, material delamination, strain hardening, the formation of surface and subsurface cracks and related structural changes, etc. [16]. The transition from soft to hard wear occurs when a certain level of load and/or speed is exceeded. Each wear mode corresponds to certain wear mechanisms and their combinations, which, among other things, depend on the composition of the friction pair materials.

In the process of friction of babbitts, the soft matrix wears out first, since intermetallic phases are immersed in the matrix under the action of loads [17,18]. With the gradual removal of the matrix, the sufficiently brittle intermetallics begin to take loads. These phases are crushed under the action of shear stresses and fill the friction surface, creating a working friction layer. [19,20].

Understanding the wear mechanisms in the process of friction makes it possible to determine the conditions for changing wear modes and the range of acceptable triboloading conditions. Knowledge of both the wear pattern and wear mechanisms of the material is also necessary to understand the mechanisms of material failure and chemical effects upon contact [21].

The main attention of this article is focused on the wear modes of the deposited coating from B83 babbitt, used as an antifriction layer of plain bearing liners. The experimental work was aimed at studying the influence of the specific load on the change of wear modes, which are characterized by the behavior of the friction coefficient and the wear intensity value. The study of the friction surfaces and wear products was carried out to determine the wear mechanisms of each of the modes.

2. Materials and methods of research

To form anti-friction coatings on substrates made of high-quality low-carbon steel, the process of argon-arc surfacing with a non-consumable electrode was used. As a filler material, surfacing rods from B83 alloy developed and manufactured by hot extrusion were used.

Tribological testing of samples was carried out under conditions of dry sliding friction on a CETR UMT Multi-SpecimenTestSystem according to the schemes of a fixed bushing (counterbody, steel HRC > 63) against a rotating disk (sample). The samples were discs made of St20 steel 8 mm thick coated with B83 babbitt 3 mm thick, sample diameter 20 mm. Steel bushing dimensions: inner diameter 12 mm, outer diameter 16 mm.

The structure of the obtained samples was examined on a Leica DMILM microscope using the Qwin software for image analysis. The Qwin program allows to determine the dimensions of the structural components of the samples. For the reliability of the statistical analysis, the analysis was carried out in five separate fields.

To determine the hypothetical conditions for changing regimes, a disk with a B83 babbitt coating was tested at a load of 40 N (0.45 MPa) with a constant increase of 0.1 N/s. The sliding speed was 0.5 m/s. Since the test scheme did not allow installing a thermocouple in close proximity to the test zone, temperature changes were measured on the counterbody, which indirectly served to describe the friction process.

The tribotechnical characteristics of the samples were evaluated in a wide range of specific loads of 0.5, 1, 1.5, 2, and 2.5 MPa. The sliding speed was 0.5 m/s, the duration of the test at each load was 10 min. The mass loss D_m of the samples was recorded after testing at each of the series of loads by weighing the sample on an analytical weighing-machine. The degree of wear of the samples during dry sliding friction was estimated from the wear intensity $I_m = D_m/L$, where L is the friction path. Wear intensity was determined for each load.

The friction surface and wear products (debris) were analyzed on a LEO 1420 VP scanning electron microscope (Carl Zeiss) equipped with an attachment for EDS analysis.

3. Results

Figure 1 shows the initial sample with the anti-friction layer of B83 babbitt obtained by argon-arc surfacing. After surfacing, the deposited layer was subjected to mechanical treatment to level the surface. The samples for friction test were cut from the initial specimen. The microstructure of the anti-friction babbitt layer is shown in Fig. 2.

Figure 3 shows graphs of changes in the parameters of the friction process with a constant increase in load during the test of the disk with the babbitt layer against the steel bushing. Attention should be paid to changes in temperature and coefficient of friction. An abrupt change in temperature behavior may be due to a change in wear mode [22,23]. Also,

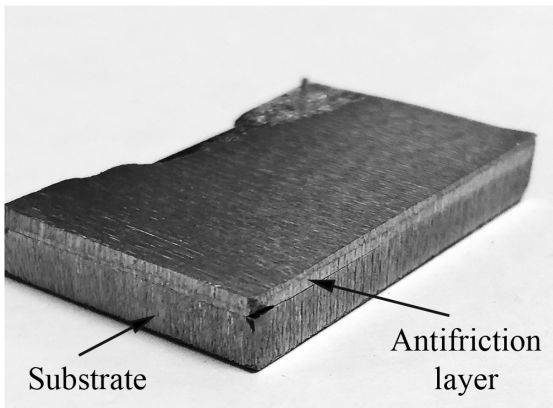

Fig. 1. The initial sample with the anti-friction layer of B83 babbitt.

a change in the regime is evidenced by a change in the curve of the coefficient of friction. Judging by the graphs, such changes in the friction process occurred at a point with a load of approximately 130 N, which corresponds to a specific load of 1.5 MPa.

More detailed information about changes in wear patterns was obtained after testing samples under a number of loads, which hit the expected transition point (0.5, 1, 1.5, 2, 2.5 MPa).

Figure 4 shows the change in the coefficient of friction when testing the disc with the babbitt layer under various loads. The resulting curve can be divided into two sections with specific loads from 0.5 to 1.5 MPa and from 1.5 to 2.5 MPa. The different character and slope of the friction coefficient curve in these areas indicates different processes occurring in the friction zone.

Additionally, the previous (specific load 1 MPa) and subsequent (specific load 2 MPa) points relative to the transition point were analyzed to determine differences in wear mechanisms. The friction coefficient curves for specific loads of 1 and 2 MPa is shown in Fig. 5.

Figure 6 shows electronic photographs of the friction surface at various specific loads. Differences in surfaces indicate a change in the processes occurring during friction.

Figure 7 shows electronic photographs of wear products after testing. Debris differs in size and shape under different loads.

4. Discussion

In the manufacture of the samples by argon-arc surfacing, the structural composition of the deposited layer of babbitt did not change compared to the original alloy B83. Inclusions of compounds of the Cu-Sn and Sn-Sb systems are clearly visible.

Changes in the sizes of structural components are noticeable. In addition to a general decrease in all intermetallic phases, the Cu_3Sn compounds changed shape from acicular to more rounded (Fig. 2). Changes in dimensions and geometry give reason to expect an improvement in tribological characteristics: wear reduction and increase of resistance to fatigue failure.

The load curve (Fig. 3) shows the continuity of the loading process. Peaks and bursts on this curve may indicate the phenomena of jamming and seizing of materials during friction. When analyzing a curve showing changes in the coefficient of friction, two sections with different behavior and a clear boundary between them can be observed. The coefficient of friction in the left section (Fig. 3) is unstable, that can be explained by a continuous increase in the load, which forces the material to constantly be in the running-in mode and resist wear. After passing a certain point, the value of the friction coefficient stabilizes, that is shown in the right section (Fig. 3), and nothing prevents the wear process.

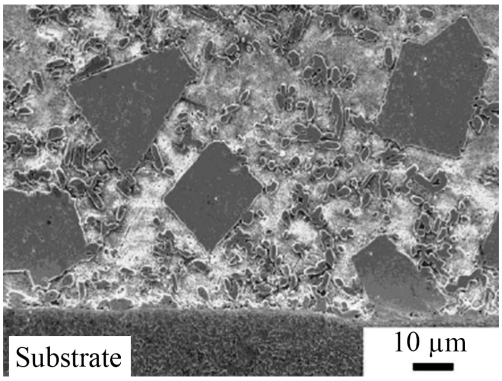

Fig. 2. The microstructure of the anti-friction babbitt layer.

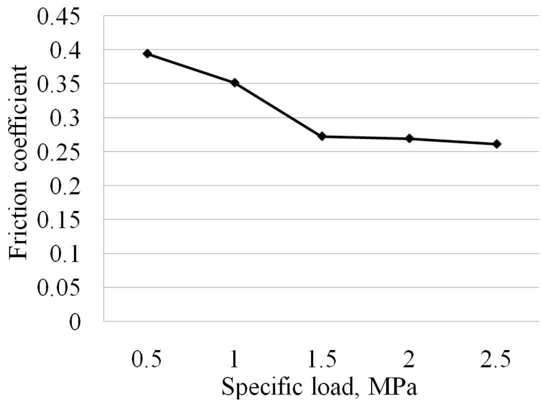

Fig. 4. Friction coefficient of the babbitt layer under various loads.

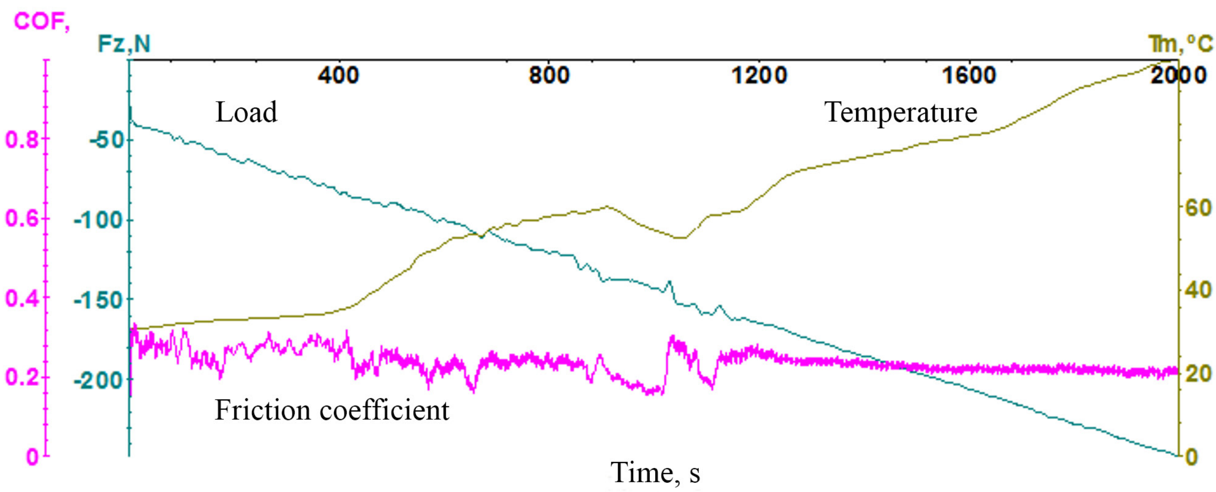

Fig. 3. (Color online) Load, coefficient of friction and temperature during test of the disc with a layer of babbitt B83.

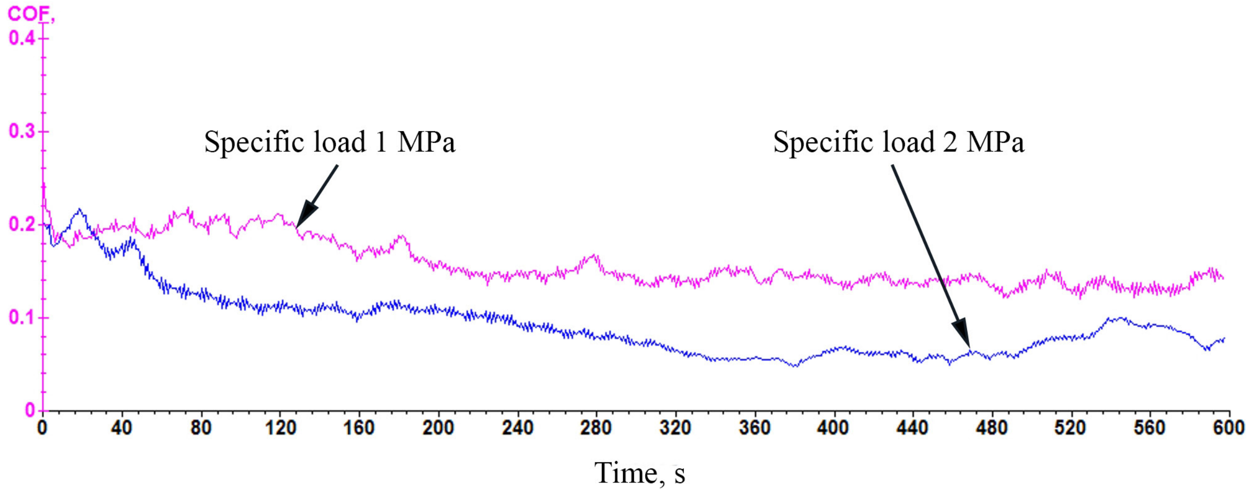

Fig. 5. (Color online) The friction coefficient curves for various specific loads.

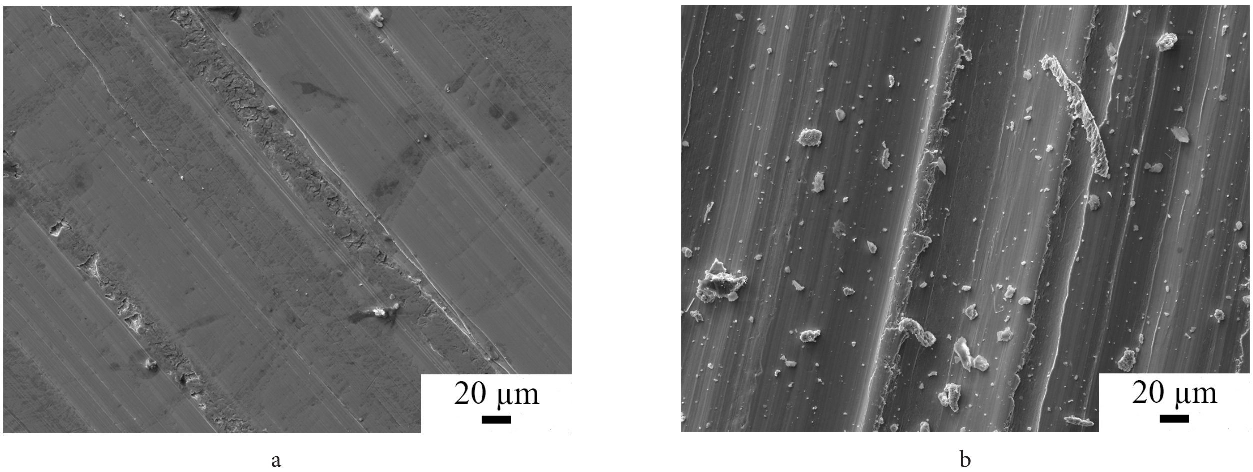

Fig. 6. Friction tracks on the sample surface: specific load 1 MPa (a), specific load 2 MPa (b).

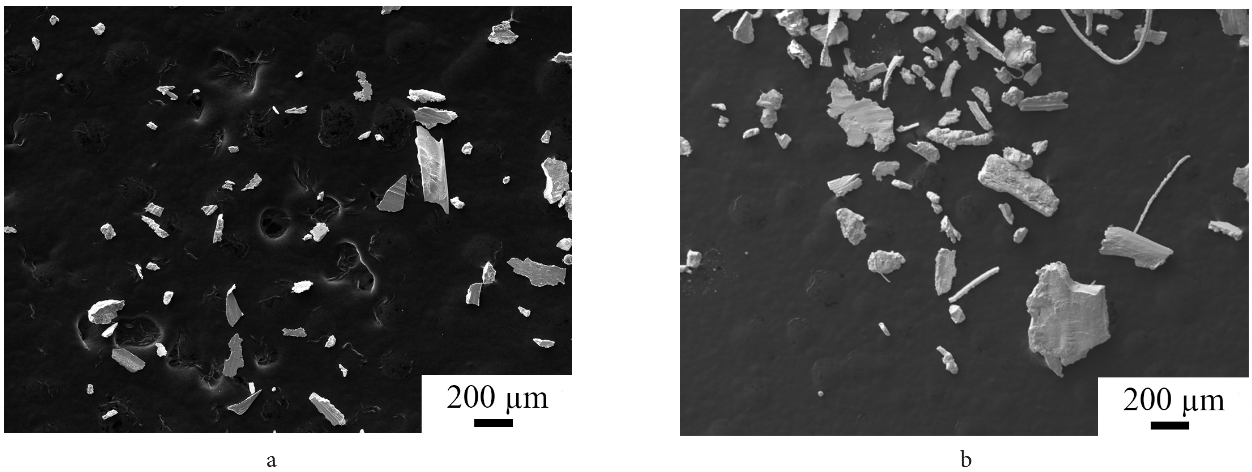

Fig. 7. Wear products during testing of the babbitt layer: specific load 1 MPa (a), specific load 2 MPa (b).

The curves of the load and the temperature values of the friction process also indicate an event that occurred when the behavior of the coefficient of friction changed. It can be assumed that the moment of change in the behavior of the friction coefficient is the moment of change of wear modes from soft to hard, at which the babbitt softens and the fatigue wear mechanism begins to operate [24].

The analysis of the friction coefficient data during testing with specific loads from 0.5 to 2.5 MPa confirms the assumption of a change in modes. It can be seen (Fig. 4) that at initial specific loads, the coefficient of friction noticeably decreases with increasing load. In this area, the friction process corresponds to the abrasive and adhesive wear mechanisms. After a specific load of 1.5 MPa, the slope of the friction coefficient graph changes significantly, that can be explained by changes in the friction process and wear mechanisms. A further increase in the load leads to a slight decrease in the coefficient of friction. The mechanism of fatigue wear begins to participate in the process of friction, which is accompanied by softening of the material [25]. These phenomena correspond to the dependence of the friction coefficient on the load specified in the source [26].

Figure 5 allows seeing the difference in material behavior under loads related to different wear modes. At a load of 1 MPa, the running-in process lasts longer; small fluctuations may indicate the involvement of fresh intermetallic phases in the process of friction. At a load of 2 MPa, the running-in process is approximately 5 times faster; the coefficient of friction is reduced and more stable, that may indicate softening of the material.

Invaluable information in the study of friction processes is provided by analysis using electron microscopy of wear products and friction surfaces [27,28]. Such studies show a clear difference between wear modes (Fig. 6). With a load of 1 MPa, the friction surface is relatively smooth and clean; traces of abrasive wear and flaking of small particles are noticeable, that indicates a soft wear mode.

While at a load of 2 MPa, the friction surface has rough grooves and traces of plastic deformation, and also large number of various particles of debris, that indicates a hard wear mode [29]. In addition, fatigue cracks were found on the friction surface under a load of 2 MPa [30]. Differences in the size and shape of the debris are clearly visible. Wear products during soft wear (Fig. 7a) are debris in the form of fragments and peeling flakes [31,32]. Debris size is related to the intensity of adhesive wear. An increase in frictional heating leads to plasticity of coatings, that leads to a change in wear mechanisms. At a load of 2 MPa, the size of the fragments noticeably increases and a belt debris appears (Fig. 7b), the occurrence of which is characterized by the formation of fatigue grooves on the friction surface [27].

The difference in the wear modes of the sample coated with babbitt under loads of 1 and 2 MPa becomes apparent. The difference of about 10 times of the wear intensity values confirms this assumption: for specific load 1 MPa $I_m = 0.046 \cdot 10^{-3}$ g/m, for 2 MPa $I_m = 0.4395 \cdot 10^{-3}$ g/m.

5. Conclusion

The article investigates the tribological characteristics of the anti-friction layer of B83 babbitt applied by argon-arc surfacing. The behavior of this material during friction tests was studied and wear modes were determined. At a test speed of 0.5 m/s and continuous loading, the moment of change of friction modes from soft to hard was determined, which occurred at a specific load of 1.5 MPa. Experiments carried out at the same speed and a range of loads from 0.5 to 2.5 MPa made it possible to obtain data for further analysis. The results of friction experiments and studies using electron microscopy confirmed the correctness of the assumption about the moment of transition of wear modes. The change in wear modes and wear mechanisms was judged by differences in the behavior of the friction coefficient, the difference in friction surfaces and wear products. Differences in wear intensity for soft and hard friction reach 10 times. The data obtained will allow to determine and recommend the modes of "wear-free" operation of the B83 babbitt. As shown, this babbitt alloy can be used both for the manufacture of bulk bushings and plain bearings and for the creation of new functionally organized layered compositions with improved tribotechnical properties based on structural steels. In addition, the working surface layers of such compositions can be made not only from B83 babbitt, but also from composite materials based on the alloy.

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References

1. P.A. Bykov, I.E. Kalashnikov, L.I. Kobeleva, I.V. Katin, R.S. Mikheev. Letters on Materials. 11 (2), 181 (2021). Crossref
2. A. Zeren. Materials&Design. 28 (8), 2344 (2007). Crossref
3. P.R. Campos Alcover Junior, A.G. Marenda Pukasiewicz. Tribology International. 131, 148 (2019). Crossref
4. A. Zeren, E. Feyzullahoglu, M. Zeren. Materials&Design. 28 (1), 318 (2007). Crossref
5. L.K. Bolotova, I.E. Kalashnikov, L.I. Kobeleva, I.V. Katin, A.G. Kolmakov, R.S. Mikheev, N.V. Kobernik, N.B. Podymova. Russian Metallurgy (Metally). 2018 (1), 63 (2018). Crossref
6. P.A. Nikiforov, E.A. Gridasova, N.S. Ryndin. FEFU: School of engineering bulletin. 4 (25), 80 (2015). (in Russian)
7. P.P. Gvozdev, N.V. Kobernik, R.S. Mikheev. Svarka Diagnost. 6, 36 (2013). (in Russian)
8. M. Moazami Goudarzi, S.A. Jenabali Jahromi, A. Nazarboland. Mater. Design. 30, 2283 (2009). Crossref
9. N.V. Kobernik, G.G. Chernyshov, R.S. Mikheev, T.A. Chernyshova, L.I. Kobeleva. Fiz. Khim. Obrab. Mater. 1, 51 (2009). (in Russian)
10. T.E. Abioye, H. Zuhailawati, M.A.I. Azlan, A.S. Anasyida. Journal of Materials Research and Technology. 9 (6), 13196 (2020). Crossref
11. N.P. Barykin, R.F. Fazlyakhmetov, A.K. Valeeva. Met Sci Heat Treat. 48 (1-2), 88 (2006). Crossref
12. B.A. Potekhin, V.V. Il'yushin, A.S. Khristolyubov. Met Sci Heat Treat. 51, 378 (2009). Crossref
13. A.G. Kolmakov, I.E. Kalashnikov, L.K. Bolotova, N.B. Podymova, P.A. Bykov, I.V. Katin, L.I. Kobeleva. Inorganic Materials. 56 (15), 1499 (2020). Crossref
14. L.I. Kobeleva, L.K. Bolotova, I.E. Kalashnikov, R.S. Mikheev, A.G. Kolmakov. Inorganic Materials: Applied Research. 11 (1), 1 (2020). Crossref
15. I.E. Kalashnikov, A.G. Kolmakov, L.K. Bolotova, P.A. Bykov, L.I. Kobeleva, R.S. Mikheev, M.L. Kheifets. Inorganic Materials: Applied Research. 10 (3), 635 (2019). Crossref
16. G. Rasool, M.M. Stack. Tribology International. 74, 93 (2014). Crossref
17. D. Zhang, J.K.L. Ho, G. Dong, H. Zhang, M. Hua. Tribology International. 90, 22 (2015). Crossref

18. Y. He, Z. Zhao, T. Luo, X. Lu, J. Luo. Materials & Design. 52, 923 (2013). Crossref
19. A.Kh. Valeeva, I.Sh. Valeev, R.F. Fazlyakhmetov, A.I. Pshenichnyuk. Letters on materials. 5 (2), 147 (2015). (in Russian) Crossref
20. D. Zhang, F. Zhao, Y. Li, P. Li, Q. Zeng, G. Dong. Applied Surface Science. 390, 540 (2016). Crossref
21. D. Du, W. Zhang, J.An. Materials. 15 (4), 1416 (2022). Crossref
22. P.A. Bykov, L.I. Kobeleva, I.E. Kalashnikov, T.A. Chernyshova. Materials Science. 3, 27 (2011). (in Russian)
23. Y. Wang, W. Zhao, L. Li, J. An. Transactions of Nonferrous Metals Society of China. 31 (10), 2986 (2021). Crossref
24. N.B. Dhokey, R.K. Paretkar. Wear. 265 (1–2), 117 (2008). Crossref
25. H. Singh, K. Singh, S. Vardhan, S. Mohan, G. Singh. Materials Today: Proceedings. 58, 886 (2022). Crossref
26. I.G. Fuks, I.A. Buyanovski. Introduction to tribology. Study Guide. Moscow, Neft' i gaz (1995) 278 p. (in Russian)
27. Y.T. Zhao, S.Q. Wang, Z.R. Yang, M.X. Wei. Journal of Materials Science. 45 (1), 227 (2010). Crossref
28. S.Q. Wang, M.X. Wei, F. Wang, Y.T. Zhao. Tribology International. 43, 577 (2010). Crossref
29. H. Cao, Y. Tian, Y. Meng. Facta Universitatis, Series: Mechanical Engineering. 19 (1), 23 (2021). Crossref
30. D. Liang, J. Ma, Y. Cai, X. Liu, S. Xie, X. Wei, G. Xu, J. Shen. Surface and Coatings Technology. 387, 125535 (2020). Crossref
31. G.W. Stachowiak, P. Podsiadlo. Wear. 249 (1-2), 194 (2001). Crossref
32. A. Raj J, S.V. Kailas. Wear. 456–457, 203378 (2020). Crossref