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OPERATIONAL CHARACTERISTICS OF THE COMPOSITE ALUMINUM - CARBON NANOFIBERS

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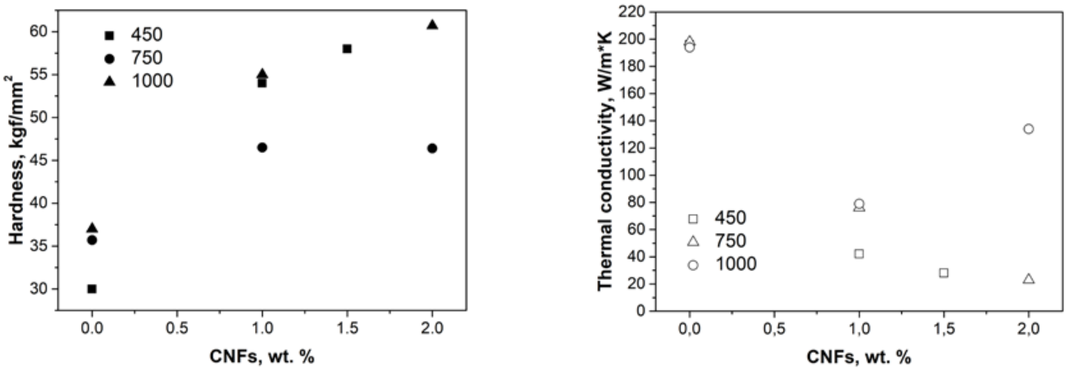
Abstract. The operational properties of aluminum-based composites reinforced by carbon nanostructures were considered. It was determined that increasing of carbon content in the sample leads to reduction of the coefficient of friction. The determining factor affecting the wear resistance is the thermal conductivity of the material.

Keywords: metal matrix composite; aluminum; carbon nanofibers; thermal conductivity; wear.

1. Introduction

Carbon nanotubes (CNTs) and nanofibers (CNFs) are introduced into the metal matrix to increase its strength. [1]. Besides, carbon nanotubes hinder dislocation motion in the matrix material during plastic deformation and cause strain hardening [1-3]. The increase in strength is generally accompanied by an increase in wear resistance. Carbon layers of CNTs lubricate the surface of the wear crater and reduce the coefficient of friction. In [4], the tribological properties of Al-CNTs composites were studied depending on the method of preparation, and it was noted by the authors noted that the key to achieving antifriction and antiwear properties is the good dispersion of carbon nanostructures in the matrix.

Earlier we published articles on preparation of composite powder materials with carbon nanofibres, obtained by CVD synthesis of carbon nanostructures directly on the surface of aluminum particles [5, 6].



(a) (b)

Fig. 1. Change of hardness (a) and thermal conductivity (b) of the material depending on the CNFs content.

In the present article, the composite powder material based on aluminum with 1, 1.5 and 2 wt. % of CNFs is compacted by hot pressing at a pressure of 2 GPa and at temperatures of

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450, 750 and 1000°C. According to the Clapeyron-Clausius equation the melting point of aluminum rises by 50°C per 1 GPa [7] with increasing the pressure. As a result, for the presented samples melting took place near the mark of 760°C. Fig. 1 shows the graphs of the hardness and thermal conductivity of the material, depending on the CNFs content.

Figure 1 shows that an increase in the carbon content leads to an increase in hardness. The samples obtained at the melting temperature have a hardness dip, which can be explained by the interaction of CNFs with the aluminum matrix and the destruction of the structure of CNFs, which are graphitized at higher temperatures [5]. The thermal conductivity of the samples with the increase of carbon content decreases due to the formation of a thermal barrier at the aluminum-carbon interface. However, as the pressing temperature increases, the thermal conductivity increases slightly due to the increase in the number of aluminum-aluminum contacts formed upon melting the matrix.

2. Experimental details

Experimental studies of the coefficient of friction and wear rate were carried out in accordance with the document P 50-54-62-88 "Provision of wear resistance of products. Method of accelerated assessment of rubbing surfaces wear resistance ". Accepted for friction testing, the assembly of the friction unit includes a roller fixed to a lifting carriage in a special holder, fixed perpendicularly to a plate and movement direction. In each experiment, one pass of the roller along the plane was realized. The length of the friction path in one pass was 70 mm. The average sliding speed of the roller along the plane was ≈5 mm/s. The roller was pressed against the plane with a force of 45H. The material of the counterbody is 12X1 steel. Wear studies were carried out in the friction mode of turning the steel grade ШХ15 on a flat surface of the composite material. The investigations were carried out using an end face friction machine. The ball-on-plane (ball diameter is 8 mm) type wear tester was used. The load was 6.5 N, while the rotational speed of the spindle with the ball fixed to it was 620 rpm; the time of one test was 5 minutes.

3. Results and discussion

The graphs of the frictional force against time for the samples of pure aluminum and aluminum with the addition of 1 to 2 wt.% of CNFs obtained in the same conditions are shown in Fig. 2. From the dependences obtained, it can be seen that the force of limit of static friction for friction of pure aluminum are ≈14 N under the selected conditions of frictional interaction (load, speed). Further, a decrease in the friction force after force of limit of static friction is observed, but starting from ~ 5 s friction force sharply increases, which is associated with the destruction of the oxide film and the appearance of an adhesive interaction of friction surfaces.

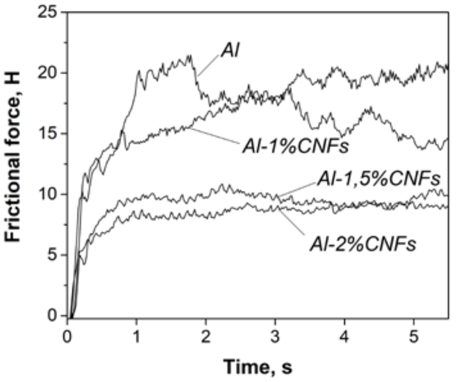


Fig.2. Dependence of sliding frictional force on the time when testing samples Al and Al-CNFs composites.

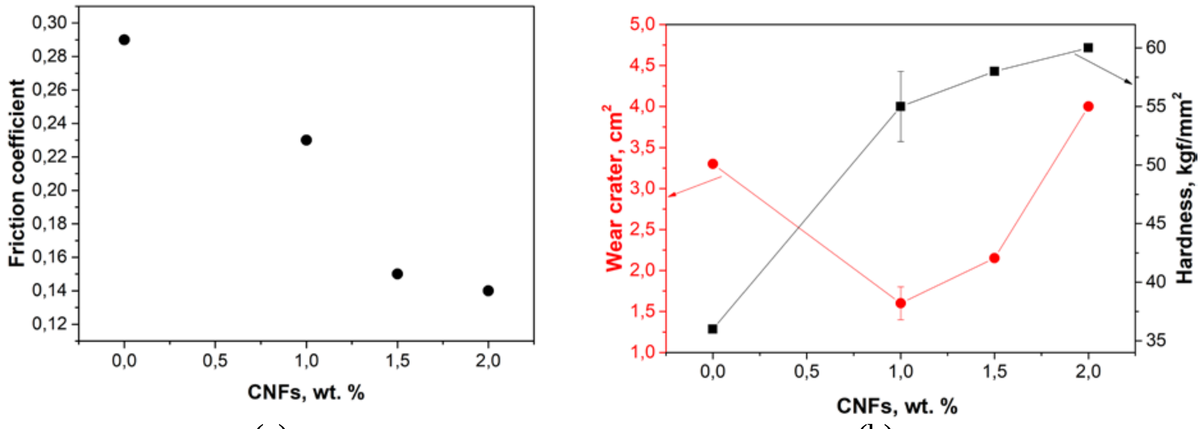
The graph of friction against time shows that the force of limit of static friction is 35% less for a sample with carbon nanofibers than for the aluminum sample, which is due to the presence of CNFs. Further, after force of limit of static friction the force of friction continues to increase slightly and is set at a value of ≈11N. The absence of a sharp intermediate increase in the frictional force indicates the stability of the destruction and recovery of the oxide film. The friction force of a sample material containing 1.5% of nanofibers is ≈31% less than that of pure aluminum, as well as the anti-friction action of carbon nanofibers. For a sample with 1.5% CNFs, it is seen that its force of limit of static friction is 53.6% (2 times) less than for aluminum samples (≈6N), which is due to the presence of CNFs. Samples of Al-1.5% CNFs have higher hardness and 62.5% (2.7 times) less frictional force compared to pure aluminum. This indicates the anti-friction action of carbon nanofibers with increasing their concentration in the matrix. For a sample with 2% CNFs, it can be seen that its force of limit of static friction (≈5H) is 64.3% (2.8 times) less than of the aluminum samples, which is due to the presence of CNFs. Further, after overcoming the limit of static friction, the frictional force increases slightly and is set at a value of ≈7N. Just like in the previous case, the absence of a sharp intermediate increase in the frictional force indicates the stability of the destruction and recovery of the oxide film. Material with 2% CNFs has a hardness higher and a friction force of about 56% (2.3 times) less than that of pure aluminum, which also indicates the anti-friction action of carbon nanofibers. Fig. 3 shows the dependence of the change in friction coefficient on the content of CNF. The coefficient of friction was determined according to the equation:

$$f= F\,f/F\,n, \qquad (1)$$

where f is the coefficient of sliding friction; $F\,n$ is the normal load in the contact, $F\,f$ is the sliding friction force.

From the summary graph (Fig. 3(a)), it can be seen that an increase in the carbon content in the sample leads to a decrease in the coefficient of friction. The coefficient of sliding friction is minimal at 1.5-2% CNFs, and is 0.14-0.15.

For the quantitative evaluation of wear, the diameter of the wear crater was used as an indicator. Dependences of the diameter of wear crater on the concentration of CNFs are shown in Fig. 3(b) as well as the hardness values for the samples. As it can be seen from the graph, with increasing in carbon content, the hardness of the samples also increases, and the wear dependence has a minimum near 1% CNFs.



(a) (b)

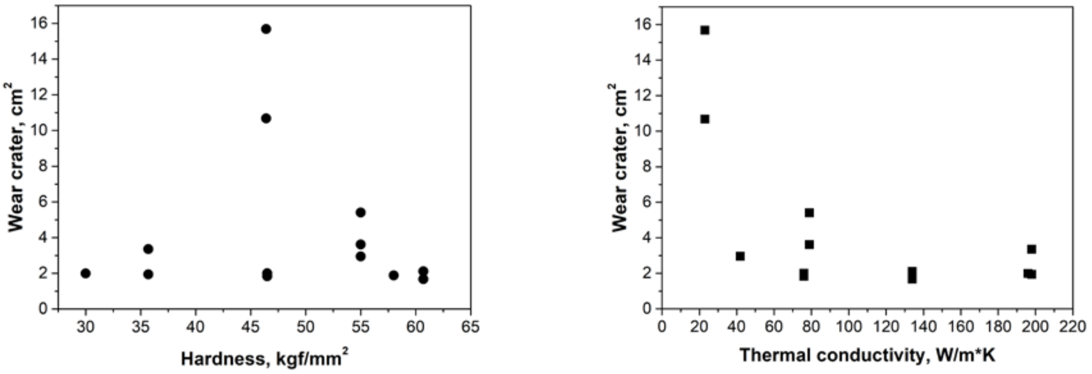
Fig. 3. Dependences of the change in friction coefficient (a), wear crater and hardness (b) on the content of CNFs.

The wear crater in the sample with 1% CNFs decreased by 50% compared to pure aluminum, and further increase in the carbon content did not lead to a significant increase in wear resistance, despite the higher hardness of the composites. At the same time, the wear of a material containing 2% CNFs is not much higher in comparison with pure aluminum.

One of the problems in carrying out the wear tests was the spreading of the aluminum matrix of the sample onto the counterbody, especially in case of pure aluminum sample. In this connection, additional tests were carried out according to the conical body-plane scheme. In this case, the counterbody was a cone made of high-speed steel (P6M5) with an angle of 114.2 degrees, the plane was an aluminum composite. The load was 36 N, shaft rotational speed was 620 rpm, test time was 2 min.

Carrying out a series of tests according to two schemes showed a direct dependence of the wear of the material on hardness (Fig. 4(a)). A wide spread of values in the region of 45 HB is observed for the samples with low density.

A comparison of wear with the thermal conductivity of the material showed an interesting trend (Fig. 4(b)). Increasing the thermal conductivity leads to a decrease in wear of the material. When carbon nanofibers were introduced into the samples, the thermal conductivity of the material was reduced due to the occurrence of a thermal barrier at the interface, especially with increase in the content of CNF (samples with hardness of in the region of 55 HB, Fig. 1(b)). Also, low thermal conductivity is observed in materials with high porosity (samples with hardness in the region of 45 HB, Fig. 1(b)).



(a) (b)

Fig. 4. Dependence of the change in the wear crater of the material on the hardness of the material (a) and of the wear crater on the thermal conductivity (b).

When subjected to friction in the spin friction, the material undergoes local heating in the contact zone, which leads to its more softening in case of its overheating. In this regard, materials reinforced with CNFs, despite the high hardness, show increased wear due to low thermal conductivity.

4. Conclusion

As a result, the paper shows that the introduction of carbon nanofibers into an aluminum matrix leads to an increase in the hardness of the composite. As the carbon content increases, the thermal conductivity of the samples decreases due to the formation of a thermal barrier at the aluminum-carbon interface.

Investigations of tribotechnical properties of composite materials showed the antifriction effect of carbon nanofibers, which manifests itself both at the time of friction and during the movement of friction surfaces relative to each other. An increase in the carbon content to 1.5-2% of CNFs in the sample leads to a decrease in the coefficient of sliding friction to 0.14-0.15. For anti-wear properties, a sample with 1% CNFs has the best properties. It can be assumed that the thermal conductivity of the material is the determining factor influencing the anti-wear properties, since local heating in the contact zone leads to its softening.

Reference

[1] X.H. Chen, J.C. Peng, X.Q. Li, F.M. Deng, J.X. Wang, W.Z. Li // *J. Mater. Sci. Lett.* **20** (2001) 2057.

[2] F.M. Deng, X.H. Chen, W.X. Chen, W.Z. Li // *Trans. Nonferrous Met. Soc. China* **14** (2004) 681.

[3] T. Larionova, T. Koltsova, Y. Fadin, O. Tolochko // *Wear* **319** (2014) 118.

[4] I.Y. Kim, J.H. Lee, G.S. Lee, S.H. Baik, Y.Z. Lee // *Wear* **267** (2009) 593.

[5] A.I. Rudskoy, O.V. Tolochko, T.S. Kol'tsova, A.G. Nasibulin // *Metal Science and Heat Treatment* **55** (2014) 564.

[6] T.S. Kol'tsova, F.M. Shakhov, A.A. Voznyakovskii, A.I. Lyashkov, O.V. Tolochko, A.G. Nasibulin, A.I. Rudskoi, V.G. Mikhailov // *Technical Physics* **59** (2014) 1626.

[7] A.P. Babichev, N.A. Babushkina, A.M. Bratkovsky, *Physical quantities* (Energoatomizdat, M., 1991).