SPECIAL FEATURE

On the structure, thermal and tribotechnical properties of the antifriction infiltrated materials based on iron and copper

Larisa Dyachkova[1,*], Andrey Leonov[2] and Eugene Feldshtein[3]

[1] Institute of Powder Metallurgy, Belarusian National Academy of Sciences, Platonova 41, Minsk 220005, Belarus
[2] Belarusian Agrarian Technical University, Nezavisimosty 99, Minsk 220023, Belarus
[3] Department of Mechanical Engineering, University of Zielona Góra, Prof. Z. Szafrana 4, 65-516 Zielona Góra, Poland

This paper describes some properties of the Fe-based materials infiltrated with tin bronze and Cu-based materials infiltrated with tin. It was shown that due to the increased thermal conductivity infiltrated materials based on iron and copper have high tribotechnical properties. With an increase the thermal conductivity the coefficient of friction is reduced, and the seizure pressure increases in infiltrated iron-based materials as a result of the increase in the copper phase and certainty of its morphology, and in copper materials through the creation of a gradient structure in content of tin.

Introduction

There are mechanical, electrical, thermal, vibratory and chemical processes in the friction of machinery. Under the influence of these processes changes occur in the structure of anti-friction material, associated with metal hardening or relaxation, carburization and decarburization, hydrogen saturation or depriving, metal oxidation [1–3]. This can lead to a premature wear of the machine parts. The wear rate depends on many factors, one of which is the material antifriction properties.

According to the molecular–mechanical theory of friction and wear [4] the temperature that develops in the process of friction has the great influence on the performance of the antifriction material. Very high temperatures can arise in the local areas and then in the entire areas of the working surface, which can cause phase transformations in the surface layer and even melting of the material. The high temperature and plastic deformation lead to diffusion processes. As a result of that the coagulation of the individual structural components and the mutual diffusion dissolution of materials of friction pairs are possible [5,6]. To prevent the development of high temperatures in the area of friction, antifriction materials should have high thermal properties, particularly conductivity, a heat capacity and a stable coefficient of the linear thermal expansion. High thermal properties provide a removal and a dissipation of heat generated in the friction zone, protecting the friction units from the excessive heat that can cause decreasing of the mechanical and tribotechnical properties of materials. In addition, the layer of a lubricant can be destroyed that accelerates wear surface oxidation processes, both due to an atmospheric oxygen and oxygen formed due to the decomposition of lubricant decomposition at high temperatures.

Thus, to improve the operability of the antifriction material it should have a high thermal conductivity and a low coefficient of friction. However, with increasing a thermal conductivity, the friction coefficient increases whereas the thermal conductivity of the clean metal is higher than the thermal conductivity of its alloys [7]. However, the alloys have a less ductility, a higher hardness and a strength, thus a high wear resistance and a low friction coefficient.

In our opinion, it can be possible to achieve simultaneous improvements in both parameters through the creation of a composite state. The iron-based materials should include a phase having a significantly higher thermal conductivity, such as copper. The copper materials can create a gradient structure that combines an alloying antifriction layer and a low alloying layer with a high thermal conductivity.

The most effective method for introducing copper into a porous iron skeleton and for the creation of a gradient structure in the copper-based material is the infiltration. This process allows

*Corresponding author:. Dyachkova, L. (dyachkova@tut.by)

0026-0657/© 2016 Elsevier Ltd. All rights reserved. http://dx.doi.org/10.1016/j.mprp.2016.05.003

Please cite this article in press as: L. Dyachkova, et al., Met. Powder Rep. (2016), http://dx.doi.org/10.1016/j.mprp.2016.05.003

practically eliminating the residual porosity and significant increasing of the strength of the material [8–10].

The driving force of the spontaneous infiltration is a capillary force. Different metal compositions may be infiltrated, such as tungsten–cobalt and tungsten–nickel mixtures [11], alumina–steel composites [12], low alloy steels [13]. Copper [11,14] and copper alloys [15,16] are most widely used as infiltrating materials due to their good wetting properties.

The process of the spontaneous infiltration depends on many factors. The study of these factors is the subject of many investigations. In [17] the influence of the shape of the solid phase particles on the infiltration process was studied, in [18] – the impact of the contact angle on the capillary forces, in [19] – the influence of viscosity and capillary forces, in [20–22] – the possibility of the infiltration when components interact. The results of studying infiltration of fusible metals in copper are presented in [23]. It is known that alloying of copper with tin enhances the operational properties by improving the embedability, conformability and resistance to seizure [24,25].

This paper describes the manufacturing process of materials based on iron and copper with a high thermal conductivity and tribotechnical properties that have been produced using the infiltration method.

Experimental procedure

The method for the thermal conductivity testing

The thermal conductivity was measured with the calorimeter using a method of monotonic bilayer plate heating samples 15 mm in diameter and 30 mm in height.

The thermal conductivity was calculated by the equation

$$\lambda(t) = \frac{C_{Ceffect}(t) + 0.5C_O(t)\times h}{(\tau_{HB}-\tau_0)\times S}(1-\sigma_\alpha-\sigma_k-\sigma_c-\sigma_\lambda), \quad (1)$$

where C_O – sample heat capacity, $C_{Ceffect}$ – effective heat capacity of standard material (AISI 316 steel with thermal conductivity of 13.45 W/(m K)), τ_{HB}, τ_0, σ_α, σ_k, σ_c, σ_λ – coefficients accounted not identical thermocouples, the difference of the standard and sample heating rates and so on.

The heat capacity was calculated by the equation

$$C_x = C_O m_O \times \frac{Q_1}{Q_2}, \quad (2)$$

where m_O – the sample mass, Q_1 and Q_2 – the heat flow measured using heat flux sensors.

The thermal conductivity of the copper material infiltrated with tin was calculated according the equation [26]:

$$\lambda = \frac{\lambda_1 \times \lambda_2 \times H}{H_1 \times \lambda_2 + H_2 \times \lambda_1}, \quad (3)$$

where λ – the thermal conductivity of copper infiltrated material, W/(m K); H – the height of the sample, m; λ_1, λ_2 – the thermal conductivities of the copper layer and the infiltrated with tin layer accordingly, W/(m K); H_1, H_2 – the heights of the copper layer and the infiltrated with tin layer accordingly, m.

Base powders for P/M materials processing

Ready-made powders of iron, copper, graphite and tin were used. The particulates of the atomized iron powder were of the size less than 200 μm. Graphite with particulates of the size less than 20 μm was used as carbon. The particulates of the copper powder were of the size less than 50 μm, and of tin powder less than 30 μm.

Preparation of composite samples

Two composite materials based of iron and copper obtained by infiltration were studied.

The FeGr1Cu17Sn0.7 iron-based composites based of iron were obtained by infiltrating CuSn5 alloy into a skeleton of FeGr1 composition. The mixture of components was prepared in a mixer of a 'drunken barrel' type for 0.5 h. Then the samples of 82–83% density were pressed using a hydraulic press. The samples were sintered or infiltrated in an electric belt furnace in the atmosphere of an endothermic gas at temperatures of 1100 °C for 1 h.

The copper-based composites were obtained by infiltrating Sn into a skeleton of copper that was pressed at a pressure of 400 MPa and sintering in the atmosphere of an endothermic gas at temperatures of 700 °C for 1 h. To obtain the different copper skeleton densities the porogen of 0.3 and 0.5 wt.% were added into the copper. The samples were infiltrated in the atmosphere of an endothermic gas at temperatures of 400–700 °C for 0.5 h.

The samples of the infiltrate (CuSn5 for the iron-based skeleton or Sn for the copper skeleton) were pressed using a hydraulic press to obtain a density of 65–70%.

The contact infiltration process was used to prepare the composite samples. To ensure a right heating of green preforms of both Fe-based and Cu-based materials they were placed above the pellets of the infiltrate in crucibles on the conveyer of the furnace.

Microstructure and SEM examinations

The microstructure of cross sections of the specimens was examined using an MEF-3 optical microscope. Cross sections of iron-based materials were etched in a 4% solution of a picric acid in an ethyl alcohol and cross sections of copper-based materials were etched in a 3% solution of ferric chloride in ethanol.

Surface textures were analyzed using MIRA scanning electron microscope.

Hardness testing

Hardness was determined by the Brinell hardness tester using the ball of 2.5 mm in diameter and the load of 1839 N. Microhardness was measured using a 'Micromet-II' tester with a load of 0.2 N.

Tribotechnical testing

Tribotechnical tests were carried out in conditions of a distributed contact using a MT-2 tester of a 'pin-on-disc' type. Rotating counter-bodies were made of AISI 1045 steel and had a disc form and hardness of 42–45 HRC. They were in contact with the flat surfaces of the three pin samples 10 mm in diameter. Tests were carried out at the sliding speed of 7 m/s in two stages. In the first stage, average coefficients of friction were determined under the load increasing from 10 N until seizure occurred. In the other stage, the wear rates were determined under a stable load equal to 50 N and the test time of 1 h. I-20 industrial oil was used as the lubricant with the flow rate of 8–10 drops per minute. The magnitude of the linear wear was registered using an optimeter with the accuracy of 0.001 mm.

Please cite this article in press as: L. Dyachkova, et al., Met. Powder Rep. (2016), http://dx.doi.org/10.1016/j.mprp.2016.05.003