Wear Resistance of Friction Pair of Metal Composite/Copper under Electric Current

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Abstract. Sliding of metal composites against copper counterbody under severe conditions (i.e. at the contact current density higher 50 A/cm^2 and at high roughness of counterbody) is carried out. It is shown that the composite of composition of Cu-30% of graphite shows low wear resistance in these conditions. Higher wear resistance is inherent in the composites containing lead and bearing steel. Impregnation of these composites by industrial oil hasn't led to noticeable increase in wear resistance.

1. Introduction

It is known that sliding with current collection is carried out against copper counterbody as a rule. Satisfactory wear resistance is reached in this case due to application of metal composites, low sliding surface roughness (R_a<0.8 μm), low contact current density (j<50 A/cm^2), low pressure (0,02 MPa), boundary lubrication, i.e. in the conditions of absence of high mechanical stresses in a surface layer [1-3]. Increase in these parameters has to cause decrease in wear resistance. The possibility of obtaining satisfactory contact characteristics under severe sliding is both of scientific and practical interest. One can assume that increase in wear resistance will increase the contact pressure. Wear resistance can also increase at change of metal initial structure. Studying such structures is always topical. Now composites of structures of Cu-30% Gr and 43% Cu-42% Fe-10% Pb-2% Zn-Gr (where Gr is graphite) are widely applied. These composites have structure of the pressed powder but show good characteristics at sliding with current density up to 50 A/cm^2.

The current collection materials containing a large amount of copper have rather high cost. Therefore, it is of interest to study a possibility of application of steel based composites with low copper content. One can suppose that the steel processed from grinding wastes of ball bearing production can serve as a basis of such composite. Determination of operability of this composite under sliding current collection can give an idea of prospect of application of this steel for creation of current collection materials. It is advisable to carry out the current collection sliding under severe conditions, i.e. at a high initial roughness of sliding surface of copper counterbody, at current density higher 50 A/cm^2.

The purpose of the present work is determination of operability of a composite based on recycled bearing steel in the conditions of current collection sliding against copper counterbody.

2. Experimental details

Model composites CM1 – CM3 had compositions of powder mixture as shown in the table 1 where BBS is recycled ball bearing steel. Commercial composites CM1 and CM2 had structures of the pressed powder product. Metallographic studying of a worn surface was carried out on an optical microscope Neophot-21. Hardness *HB* was determined on Brinell's hardness tester. Porosity *P* was obtained by Archimedes method. Bending strength was received by testing machine Instron-1185. Specific electric resistance ρ was determined by ammeter-voltmeter method. Initial parameters of a roughness (R_a=5 μm, R_z=31 μm) of a counterbody sliding surface were measured on the non-contact MICRO MEASURE 3D station profile-device. Copper (*HB*=0.7 GPa) served as counterbody.

Table 1. Mechanical and physical properties of metal composites.

Composition (vol.%) /properties	Hardness *HB* (MPa)	Bending strength σ (MPa)	Porosity *P* (%)	Specific electric resistance ρ (μΩ·m)
1. Cu-30% Gr (CM1)	94	14	28	0.12
2. Cu-42% Fe-7% Pb-2% Zn-11% Gr (CM2)	610	142	15	0.16
3. Cu-4% Gr-89% BBS (CM3)	1650	694	19	0.38

Wear tests of composites were carried out under the dry sliding electric contact and with lubricant at alternating current (50 Hz) under pressure of 0.02 MPa and 0.13 MPa, sliding velocity of 5 m/s using tribometer CMT-1. Tests were performed according to the scheme "pin-on-ring" similar to that represented elsewhere [4]. The sliding distance for each test was 9 km. Linear intensity of wear was found as $I_h=h/L$ where *h* is specimen height change for sliding distance *L*. The contact current density *j* is determined as $j=i/A_a$ where *i* is the current passing through the nominal contact area A_a=20 mm^2.

3. Results and discussion

Contact current density *j* is the main factor deteriorating a contact layer and limiting wear resistance. It is visible that increase of *j* causes increase in specific surface contact electric conductivity $r_s^{-1}=j/U$ (*U* is contact voltage drop) and also I_h (figure 1). But the surface layer of commercial composite CM1 quickly wears out under pressure of 0.02 MPa and catastrophically deteriorates under contact pressure 0.13 MPa at *j*=0 A/cm^2. One can see also that increasing of pressure leads to rise of conductivity r_s^{-1} and wear intensity I_h of composites CM2 and CM3. The composite CM2 shows the lowest I_h.

Distinction in tribotechnical behavior of composites is shown also in morphological details of a sliding surface. The composite CM1 does not form a transfer layer on a counterbody surface and thus isn’t capable to create wear resistant contact at high roughness of counterbody. Therefore, it is not of interest for further studying. The composite of CM2 forms big sectors of copper on a working surface that is well shown on the optical image (figure 2, a-b). Besides, signs of formation of viscous liquid and absence of traces of adhesive interaction are observed in an explicit form. It should be noted that the composite CM2 forms a transfer layer on sliding surface of counterbody. The image of this transfer layer is visually close to the image of the layer presented in figure 2, a-b. Structural changes of surface layer of composite CM2 are not observed after sliding under pressure of 0.02 - 0.13 MPa and the cross section of surface layer has the image as in figure 2, e.

The sliding surface of composite CM3 contains traces of a plastic pushing off of surface layer by asperities of the interfaced counterbody surface and plastic shifts of big surface sectors are visible as a result of adhesive interaction with a counterbody (figure 2, c-d). Copper is not observed visually on a worn surface. The composite of CM3 forms a transfer layer on a counterbody only at sliding with current collection. This layer is a result of penetration of wear particles of a composite CM3 in copper surface. Structural changes in the CM3 surface layer are absent under pressure of 0.02 - 0.13 MPa and its cross section has an image as in figure 2,e.

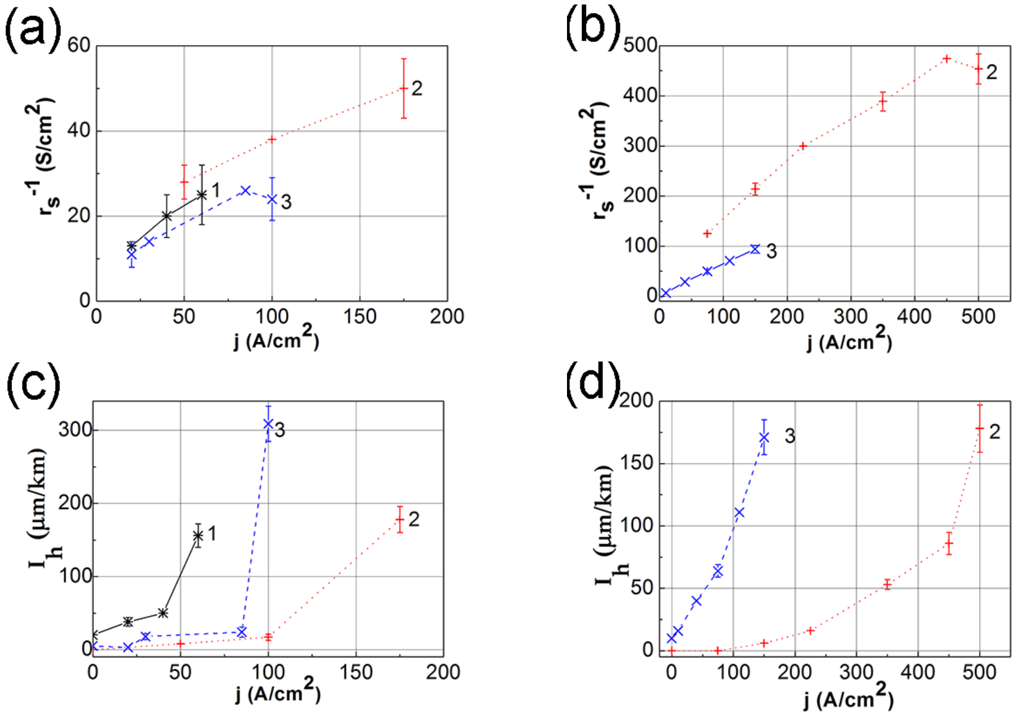

Figure 1. Current dependence of specific surface electric conductivity r_s^{-1} of contact and wear intensity I_h of composites CM1 (1), CM2 (2), CM3 (3) at contact pressures 0.02 MPa *(a,c)* and 0.13 MPa *(b,d)*

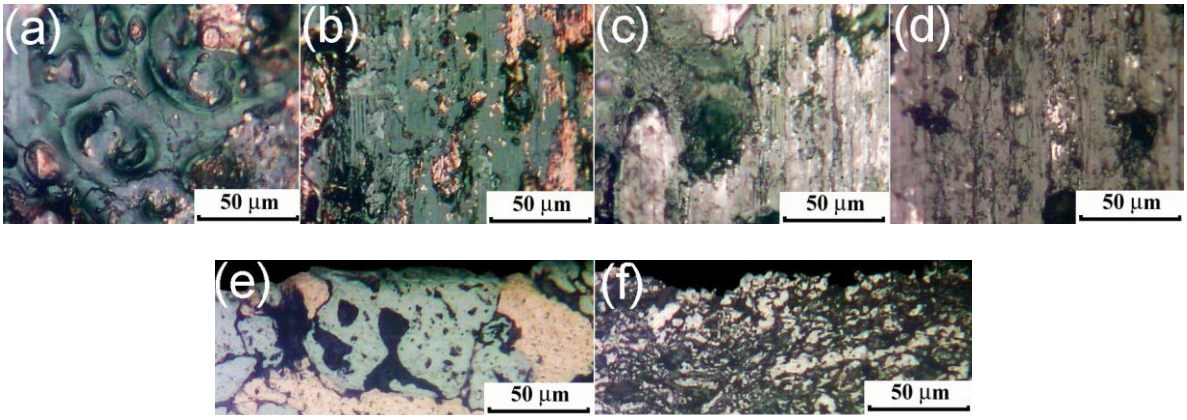

Figure 2. Worn surfaces of composite CM2 at pressures of 0.02 MPa *(a)*, 0.13 MPa *(b)*; worn surfaces of composite CM3 at pressures of 0.02 MPa *(c)*, 0.13 MPa *(d)*; cross section of worn surfaces of composite CM2 *(e)* and composite CM3 *(f)* at contact pressure of 0.02 MPa

Composites CM2 and CM3 have been impregnated with industrial oil at temperature of 100 °C for 1 hour and tested in similar conditions. Conductivity r_s^{-1} and wear intensity I_h of the impregnated composites don't differ considerably from the same contact characteristics of the composites presented in figure 1. One can note that wear of copper counterbody is not observed at presented sliding regimes.

The composite CM2 contains lead and carbon in the structure, forms a transfer layer on a counterbody and carries out sliding on this layer. It reduces adhesive interaction. Such type of self-organization of a sliding surface means that the initial roughness of a counterbody does not influence considerably on contact characteristics. Besides, the surface of a counterbody is not deformed plastically at sliding under pressure of 0.13 MPa. Therefore, the plastic flow can be realized only in transfer layer and in the surface layer of composite CM2. High plasticity of lead and copper on the interface of two bodies allows easily relax stresses due to plastic deformation. High concentration of copper in the structure of composite CM2 provides the good heat outflow from friction zone that leads to small increase of contact temperature and the plastic flow does not occur on a large scale. It expands possibilities of increasing of wear resistance of a composite CM2 at sliding against copper.

It should be noted that the working surface of a copper counterbody usually quickly deteriorates in the dry sliding contact with metals [5]. Low content of copper in structure of composite CM3 and low heat conductivity of its porous steel framework are the factors promoting increase of local surface temperature. Besides, strong adhesion in contact spots causes the high mechanical stresses which can not be relax due to local plastic micro-shears in surface layer owing to low plasticity of composite CM3. As a result, the pulling out of surface layer macro-fragments of a composite CM3 is performed and their following fixing on the counterbody sliding surface occurs. Thus the sliding surface of copper counterbody becomes protected from micro-cutting by asperities of a contact surface of a composite CM3 having higher hardness. Therefore, wear of a copper counterbody is absent but the CM3 composite surface layer deteriorates quickly without noticeable signs of self-organization (figure 2, f) that is observed as high wear.

Lubrication of a contact zone due to impregnation of a porous framework with industrial oil hasn't reduced adhesion in the sliding contact that was visible as absence of noticeable reduction of I_h. It is caused by impossibility to create a dividing film on contact spots owing to low viscosity of oil or its fast evaporation in a contact zone or its low ability to impregnation, etc. Probably the creation of the wear resistant sliding electric contact with use of recycled ball bearing steel can be carried out by a correcting of primary structure of composite or by increase in oil viscosity, i.e. due to use of greasing.

4. Summary

Dry sliding of metal composites against copper surface with high roughness under electric current can be accompanied by formation of a transfer layer on the interfaced surface. Absence of such layer leads to fast wear of Cu-30%Gr composite. The transfer layer in the form of wear particles penetrated in a sliding surface of a copper counterbody, prohibits from its wear, but does not prohibit from wear of the composite containing the recycled bearing steel. In this case catastrophic wear begins at the contact current density lower 100 A/cm^2. The composite containing lead demonstrates rather high wear resistance because it forms a plastic transfer layer on a counterbody surface that allows to relax the stress in a friction zone due to plastic micro-shears at the contact current density higher 100 A/cm^2. Impregnation of these composites with industrial oil (low viscosity) doesn't lead to significant changes of contact characteristics. It indicates expediency of use of grease. It should be noted that sliding against copper counterbody does not cause structural changes of surface layer of composites.

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