

Original article

Boundary conditions analysis of the possible use of bushings made from copper composite materials for a towing vehicle's chassis

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ABSTRACT

The paper analyzes the possible boundary conditions for the application of new type of bushings in the vehicle's chassis. The bushings have been manufactured from the copper-based antifriction composite material alloyed by nickel and molybdenum, with the addition of CaF₂ as a solid lubricant (DN5M3KF9). The structure and tribotechnical properties at heavy loaded reversing friction (the temperature of 400-6000C and pressure up to 6.0 MPa in air) have been examined.

The study focuses on the distribution of CaF₂ in the composite with a Cu-Ni-Mo matrix, its role in self-lubrication of the material, and the behavior of CaF₂ in the friction area under extreme operating conditions.

It was shown that the solid lubricant is evenly distributed over the contact surfaces as it piles up over the entire friction area during heavy loaded reversing friction. It is established that the tribofilms formed in the presence of the CaF₂ solid lubricant provide high wear resistance. Tribological properties allow for extending the application boundaries of the new bushings based on copper in the vehicle chassis for towing artillery guns.

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KEYWORDS

bearing bushing, copper, composite, solid lubricant, technology, friction films, wear resistance, towing vehicle's chassis



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1. Introduction

The stable operation of heavy loaded units at reversing friction depends not only on the design features, but also on the effective materials of sliding bearings. This fully applies to the friction units of the automobile chassis in vehicles for towing artillery guns. Currently, the bearing bushings of cast brass are used in such units [1, 2].

During the towing of artillery guns on roads with different surface (asphalt, concrete, dirt, gravel) dynamic loadings act on the running objects of the automobile chassis, causing cracks, breakage and wear. The range of loads is up to 3 MPa, depending on the road profile and the type of surface [2].

Long-time towing of artillery guns on a road leads to exorbitantly high temperatures under high specific pressures in friction units of a vehicle's chassis. Such conditions result in the destruction of the plastic lubricant, beading of brass bearing bush and loss of functional properties.

Among antifriction composite materials intended for severe operating conditions and incorporating solid lubricants, materials based on brasses, polymers and ceramics ($\text{Al}_2\text{O}_3/\text{TiC}/\text{CaF}_2$, $\text{Al}_2\text{O}_3/\text{CaF}_2/\text{AgO}/\text{CaF}_2$) are well known [3, 4].

The known cast and powder alloys based on copper demonstrate the unsatisfactory tribotechnical properties, such as the high friction coefficient and wear in heavy conditions of the reversing friction in a towing vehicle's chassis [1, 2]. It relates to cast brass bushings, which are used today in friction junctions of a towing vehicle's chassis.

In various countries, bearing bushes for such friction units are made of simple L63-type brass (Ukrainian manufacture), which corresponds to the European brass CuZn36 or CuZn37 or American brass C27200.

Nevertheless, the use of cast brass bushings is ineffective. Moreover, the temperature can reach 400-600⁰C on friction surfaces in contact places between a bearing bush and a vehicle's axis. In this case, the grease starts to burn in the friction block with brass bushing. Spots of scorching are formed, the friction coefficient is increased and wear is intensified.

The use of self-lubricating materials in friction units is becoming increasingly important in civil and military engineering. Using slide bearings and other friction elements operating without additional lubrication determines the improvement of technological maintenance of machinery.

In this case, bearing bushes made of composite materials are very promising.

The main task in the framework of development of new composite bearing materials for heavy loaded units is to increase durability of the friction pair by, for example, applying solid lubricants to operate at conditions of high loads and temperatures.

High antifriction properties, the ability to operate at dry reversing friction and high physical properties contribute to the increase in the life of heavy loaded bearings

made of self-lubricant composite materials for an automobile chassis in vehicles designed for towing artillery guns [1, 5, 6].

Therefore, powder copper has been selected as a basis for new self-lubricant materials for bearing bushes. This choice was dictated by, above all, high thermal conductivity of materials based on pure copper, as distinct from brass. This is a very important factor to remove heat from the friction zone at the contact surfaces in the chassis of a towing vehicle.

Any liquid lubricant is not able to operate in severe operating conditions (high temperatures and loads) in friction units of the chassis in vehicles for towing artillery guns. This is due to high temperatures (400-600°C) that occur during the operation of a friction unit. This is particularly important to protect friction surfaces from the increased wear and frictional adhesion. Numerous studies have shown that using solid lubricants as a component of materials improves the tribotechnical characteristics of plain bearings [1–5]. For instance, calcium fluoride CaF_2 as a thermally and chemically stable substance is widely used as a solid lubricant to improve frictional contact, especially in severe operating conditions [4–6].

These arguments were a reason for complex research, which were directed for studying tribotechnical properties of new bearings for loadings of up to 6.0 MPa and temperatures 400-600°C that arise in friction units of a vehicle's chassis.

The authors have applied the scientifically grounded material science-based approach with the purpose to get the possibility of prognostics and control new materials' functional properties.

This is a theoretical and practical importance to determine a structure and properties, distribution of CaF_2 in the metal matrix, and its effect on the friction behavior of alloy composite materials based on copper in extreme operating conditions of a vehicle's chassis.

The objective of the present paper is to study boundary conditions of the possible use of bearing bushings made from self-lubricant copper composite materials for friction units of a chassis in vehicles for towing artillery guns by analyzing the features of the structure formation, its properties and formed wear-resistant films.

2. Experimental results and discussion

1.1. Examination Techniques

The subject of the study is the new composite copper-based material DN5M3KF9 doped with nickel and molybdenum, with CaF_2 additions, mass.%: 83 Cu–5Ni–3Mo–9 CaF_2 [5]. The samples were prepared by means of powder metallurgy methods. The starting materials were the following powders: copper (60–63 μm), nickel (10 μm), CaF_2 after drying at the temperature of 120°C for 1 h (100 μm), and molybdenum (60–63 μm).

Preparation of Powder Charge. After sifting the powders, the starting mixture was prepared in three stages: (1) mixing of Cu, Ni and Mo metal powders for 1.5 h, (2) “dry” mixing of metal powders and CaF₂ for 1.5 h, and (3) “wet” mixing of the mixture and a spirit of glycerin for 1 h. The three-stage mixing allows avoiding the segregation of powders.

Compaction and Consolidation. In the studies the authors used the technology of cold pressing followed by hot pressing to minimize porosity. Cold pressing was performed at the room temperature and the specific pressure of 350 - 400 MPa. The porosity of samples was 12-15% after cold pressing. Next, the hot pressing operation was performed at the temperature $t = 820 - 870$ °C and the specific pressure of 500 MPa in the atmosphere of a shielding gas (H₂). The relative density of the samples was 0.98-0.99 after hot pressing.

Examination Techniques. The structure was examined using a metallographic microscope and using raster electron microscope, calcium fluoride in the matrix was identified using a scanning electron microscopy (SEM) and analyzed using the energy-dispersive X-ray spectroscopy (EDS). Moreover, the SEM images were used for the quantitative description of CaF₂ in the composite. The amount of CaF₂ was preliminarily assessed using the Micrometer software [7]. Tribological tests were performed on the VMT-1 friction-testing machine. The parameters for tribotechnical tests were the following: $V = 1.0$ m/sec; $P = 2.0 - 6.0$ MPa; temperature $t = 400-600$ °C, the counterface is made of 40 Kh steel (C = 0.4%, Cr = 1.0) with HRC = 53–55; the shaft–pin friction pair; the lubricant for cast brass materials (liquid lubricant GOI-54p). These parameters correspond to the operation of bearings in real conditions.

1.2. Results and discussion

The use of hot pressing operation ensures completeness of the diffusion homogenizing. It minimizes porosity, and thus increases the structural strength of the copper-based material and allows bringing closer the composite material’s properties to the properties of the cast one.

The new composite copper-based material Cu–5%Ni–3%Mo–9%CaF₂ (DN5M3KF9) has the complex heterogeneous structure after manufacture using the developed technological modes (Fig. 1).

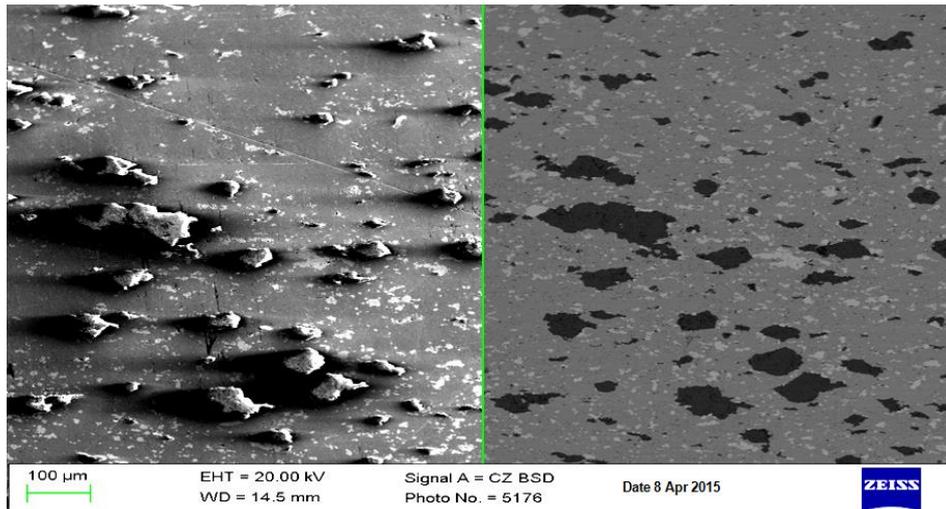


Fig. 1. Microstructure of the composite material Cu–5%Ni–3%Mo–9%CaF₂ (raster electron microscope): a) image in secondary electrons; b) phase-contrast image

Source: own elaboration

The metallographic examination of the material structure has shown that its structure is α -solid solution based on copper alloyed by nickel and molybdenum with solid lubricant CaF₂ added. Moreover, in the metal matrix there are a large number of fine-grained hardening intermetallic phases Ni₃Mo (Fig. 2).

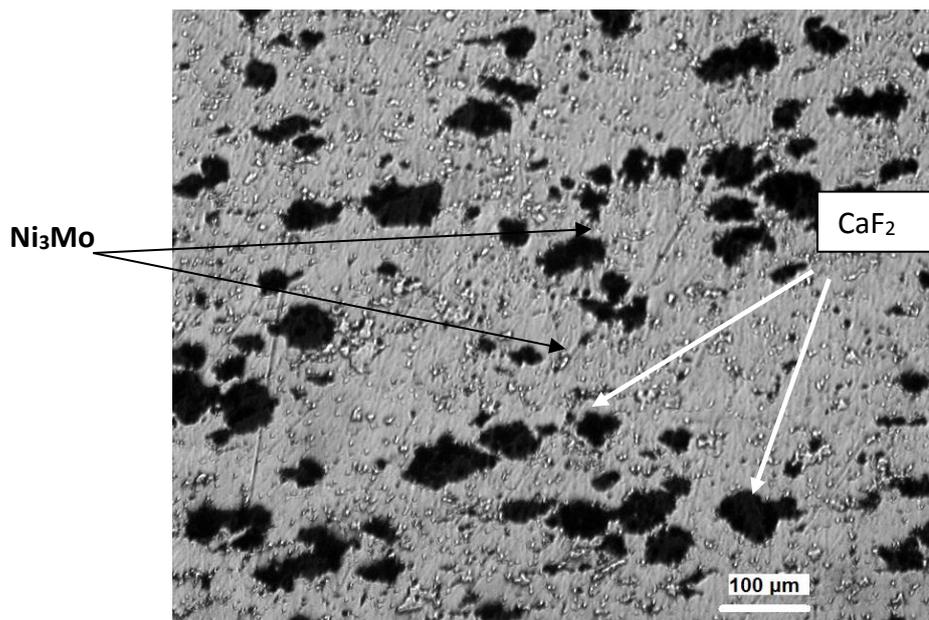


Fig. 2. Microstructure of composite material Cu–5%Ni–3%Mo–9%CaF₂ (DN5M3KF9), unetched slice

Source: own elaboration

The solid lubricant CaF₂ particles have been uniformly arranged (Fig. 3).

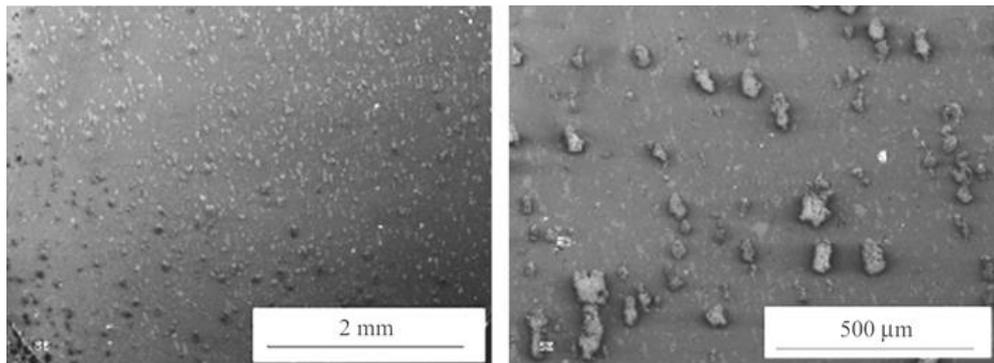


Fig. 3. SEM images of CaF₂ areas: a) distribution of CaF₂ areas in metal matrix of material;
b) elongation in one direction of CaF₂ areas

Source: own elaboration

Table 1. Properties of composite and cast materials

| Material | Thermal conductivity, λ , Wt/m \times K, | Pressure, P , MPa | Coefficient of friction, f | Linear wear of sample, $\mu\text{m}/\text{km}$ | Mass loss of counterface mg/km | Comment |
|------------------|--|---------------------|-------------------------------------|--|--------------------------------|--|
| DN5M3KF9 | 226.0-278.0 | 1.5-2.5 | 0.15-0.16 | 30.0-38.0 | -0.8* | No liquid lubricant; there are tribofilms on surface |
| Same | Same | 3.0-4.0 | 0.18-0.20 | 46.0-52.0 | -1.4* | |
| Same | Same | 5.0-6.0 | 0.21-0.26 | 75.0-94.0 | -2.8* | |
| Brass L63 (cast) | 97.0-111.0 | 1.5-2.5 | 0.13-0.14 | 90-120 | +3.3 | Friction with liquid lubricant, |
| Same | Same | 3.0-4.0 | 0.42-0.57 | 1240-1430 | +5.1 | liquid lubricant smoking |
| Brass L63 (cast) | Same | 5.0-6.0 | Intensive wear, plastic deformation | | | Liquid lubricant smoking and burning |
| Same | | | | | | |

* Minus sign means an increase in the mass of the counterface because of the transfer of a solid lubricant onto its surface.

Source: own elaboration

The areas of CaF₂ occurrence are somewhat elongated in the direction of compaction (figure 3b). The particle sizes of CaF₂ and the dimensions of these areas (average diam-

eter $D = 23.7 \mu\text{m}$, average minimum diameter $d_{\text{min}} = 19.3 \mu\text{m}$, maximum diameter $d_{\text{max}} = 39.6 \mu\text{m}$) confirm their elongation under uniaxial compression [6].

The presence of the alloying elements Ni, Mo, the Ni_3Mo hardening phases and the uniform distribution of the solid lubricant (CaF_2) provide high physical and tribotechnical properties of the composite material (Table 1).

Analyzing the Table 1 data it is seen that the composite copper-based bearing material with the solid lubricant CaF_2 has higher tribological properties compared to the cast brass. The new material also has higher thermal conductivity. This factor is very important for removing heat from the friction zone. The composite self-lubricant material is able to function at extremely heavy loaded conditions of up to 6.0 MPa in a vehicles' chassis.

During the tribological tests the dense friction films were formed on the contact surfaces; both on the surfaces of the new material and the counterface. The scanning electron microscopy of the friction surfaces after the tribological tests confirms the presence of a thin dense layer (tribofilm) (Fig. 4).

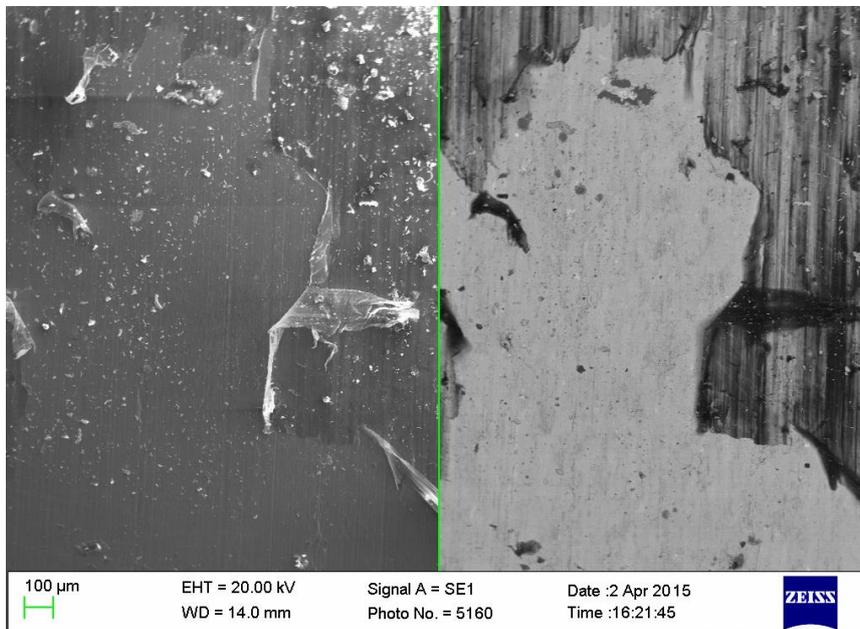


Fig. 4. Images of the material Cu–5%Ni–3%Mo–9%CaF₂ friction surface: a) image in secondary electrons; b) phase-contrast image

Source: own elaboration

As is shown on Fig. 4, dense antiscoring films (tribofilm), the so-called secondary structures, cover all friction surfaces. They probably consist of the chemical elements of bearing and counterface and the solid lubricant CaF_2 . During the friction process different chemical reactions take place between O_2 from the air and elements of the examined material and the counterface of 40 Kh steel at high loads. Besides, calcium fluoride first emerges in the friction area (Figure 3) and then spreads over the entire contact surface. Such physical and chemical processes result in the friction films formation.

They protect a contact pair against intensive wear and stabilize the work of a friction unit in a vehicle's chassis (Fig. 5).

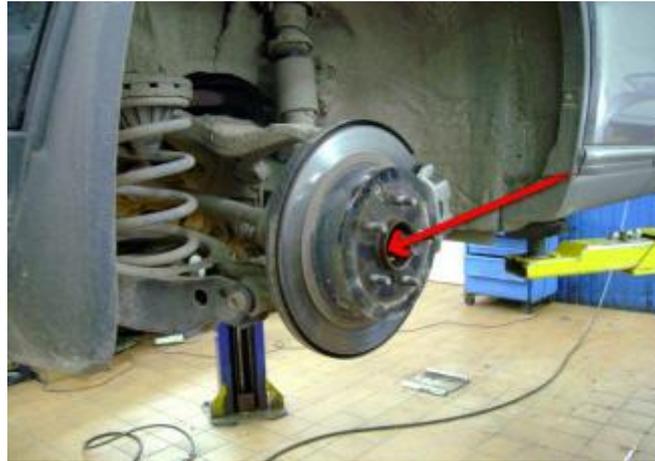


Fig. 5. Images of the vehicle's chassis with the bearing bushing from the material $\text{Cu-5\%Ni-3\%Mo-9\%CaF}_2$

Source: own elaboration

Conclusions

The authors have examined the new effective composite material $\text{Cu-5\%Ni-3\%Mo-9\%CaF}_2$ (DN5M3KF9) with high antifriction properties that performs well in more severe conditions than the L63 cast brass. This material has the much lower coefficient of friction and wear rate than materials made of the L63 cast brass used in similar operating conditions, especially under loads of up to 6.0 MPa in a vehicle's chassis. Brass bushings of a chassis are unable to work in heavy operating conditions. This is attributed to the ineffectiveness of the lubricant oil - it is squeezed out from the contact zone under high loads and burns upon the heating of the contact surfaces. In such conditions, the bearings have dry friction contact with the shaft because the surfaces remain unprotected, juvenile.

The friction of the new material DN5M3KF9 is accompanied by the formation of the continuous homogeneous friction film (tribofilm), which is clearly seen on the friction surfaces. It serves as a lubricant layer between the bushing and the shaft, and improves antifriction properties. The results of tribotechnical testing and the contact surfaces analysis demonstrate that the rate of wear corresponds to the rate of the friction films formation. It results in the consistently high antifriction characteristics under such conditions. The composite self-lubricant material is able to function at extremely heavy loaded conditions of up to 6.0 MPa without any liquid lubricant, unlike the cast brass. Its high thermal conductivity allows removing heat from the friction area that stabilizes the work of a friction unit in chassises of vehicles for towing artillery guns.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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