SINTERED METALS AND ALLOYS

EFFECT OF FACTORS GOVERNING DRY FRICTION ON STRUCTURE FORMATION FOR THE TRIBOLOGICAL SYNTHESIS ZONE IN COMPOSITES BASED ON COPPER

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Features and peculiarities of structure formation for the friction zone in highly effective composite materials based on copper for prescribed experimental conditions (high contact loads and sliding rates, absence of a lubricant, operation in a high vacuum or in air) are considered. It is shown that reliable efficiency for a tribological system under friction conditions with action of high compressive forces and sliding rates is provided by material adaptation that is achieved via the tribological synthesis at the contact surfaces of a lubricating layer different in composition and structure from the original composite.

***Keywords**: self-lubricating composite antifriction material, solid lubricant, structure, composition, friction coefficient, wear resistance wear, friction surface, spectrum, tribological system, friction mechanism.*

The efficiency of tribological systems for different purposes is mainly governed by processes that occur with friction: oxidation, that is a result of reaction of the friction surface with the surroundings; diffusion redistribution of elements in the surface layer; selected mass transfer; phase and structural transformations; absorption reduction of the strength of the surface working layer; distribution of stresses in contact surfaces or their amorphization [1-5].

Friction in a vacuum, with insufficient oxygen and moisture typical for it, has a complex character caused by absence of convection cooling and traditional lubrication. Here contact reaction is accomplished at high temperatures, under conditions of plastic deformation, breaking of oxides, and the rapidly increasing activity of friction surfaces adhesion that leads to occurrence of a seizure zone and increased wear.

Taking account of the specific nature of friction in a vacuum a new class of self-lubricating composite antifriction materials has been developed based on copper grade IPM (SKAM IPM) intended for operation with different loads, rates, and temperatures in the absence of a lubricating medium.

Materials with a microheterogeneous structure have been created based on underlying principles [6-11]. The composition and structure of the material base carrying the main load in a friction assembly has been developed taking account of the loading-rate and temperature operating regimes [12] and of the set of physicomechanical and tribological properties of the composite corresponding to them. Selection of an antifriction structural component and the technique for introducing it into a composite is due to the requirement for providing the effect of self-lubrication that is achieved by forming at the working surfaces a protective separating film operating as a solid lubricant [7].

Thus, SKAM IPM is a composite of the composition and structure that on operating in a vacuum has a capacity under the action of high compressive forces, sliding rates and absence of a liquid lubricant to adapt to a prescribed friction

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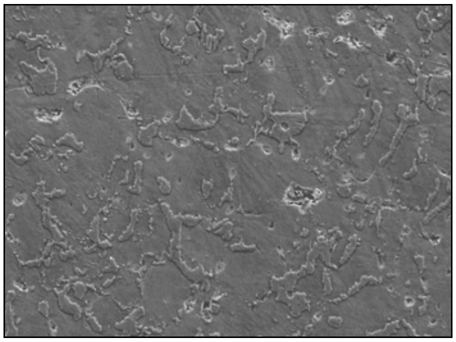

Fig. 1. Microstructure of composite material SKAM IPM-304 (×400)

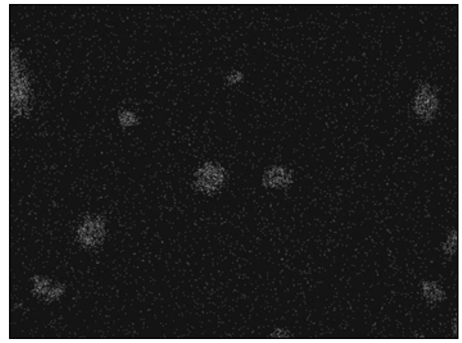

Fig. 2. Distribution of lead in the original structure of the composite SKAM IPM-304 (×1000)

condition due to tribological synthesis at the contact surface layers of the material that in composition and structure are different from the base but provide efficiency of the tribological system as a whole.

Given below are the results of structural studies of the tribological synthesis zone in a composite SKAM IPM-304 in combination with data for their tribological tests in a vacuum and in air with different loads and sliding rates.

The alloying elements strengthening the copper base were tin and phosphorus. Tin forms a solid solution with copper and phosphorus forms copper phosphide Cu_3P. During alloy solidification apart from copper phosphide there is formation of a new excess phase, i.e. eutectic, that consists of α-solid solution of tin in copper and Cu_3P phosphide crystals. Molten eutectic wets the solid solution of tin in copper and by distribution along grain boundaries in the form of a broken network (Fig. 1) it not only strengthens the composite, but it also retains its ductility that promotes uniform distribution of the energy load that arises in a friction assembly during operation in a vacuum [13-15]. The antifriction structural component of the materials in all cases was lead (Fig. 2) that with dry friction in a vacuum plays the role of a solid lubricant.

Comprehensive studies of SKAM IPM materials was carried out in the Institute for Problems of Materials Science, National Academy of Sciences of Ukraine, in the Institute of Space Research of the Academy of Sciences of Bulgaria, and in the Laboratory of Technology Test for Aerospace and Space Materials (Austria). The object of study was specimens of SKAM IPM-304 distinguished by the different amounts of alloying elements (Sn, P) and solid lubricant (Pb) introduced.

Tribological characteristics of the composite were studied in air with a relative humidity of 53-55% and in a vacuum of 10^{-3} Pa by the “European Round Robin Test” procedure in a vacuum tribometer. Studies were carried out at 20-22°C, with loads of 2 and 10 N, sliding rates of 0.2 and 1 m/sec by the following schemes: pin (test specimen) – disk (chromium steel AISI 52100) and ball (steel AISI 52100) – disk (test specimen).

The structural and morphological features of the friction surfaces were studied by means of a scanning electron microscope, and the composition of the surface layer after friction in a vacuum and in air was studied by x-ray microanalysis.

It was established that with minimum loads (2 N) and sliding rates (0.2 m/sec) the process of lead redistribution commences over the friction surface as the initial stage of forming a protective separating film promoting a change-over to self-lubrication. The moving forces of the transformation process for initially isolated globular inclusions of lead into a continuous film are an increase in temperature and plastic deformation under load, and also the difference in thermal expansion coefficients of the components of the material.

With relatively low compressive loads and sliding rates the friction surface is a system of parallel friction tracks (Fig. 3) that form mainly in relation to the content of solid lubricant in the contact zone of the specimen with the counterbody. In areas with an increased lead concentration (Fig. 3, area 1) there is almost no transfer of elements of the base material into the contact zone. In the friction zone, impoverished in lead (Fig. 3, area 2), inclusions of the components of the base, i.e. tin and copper, are detected.

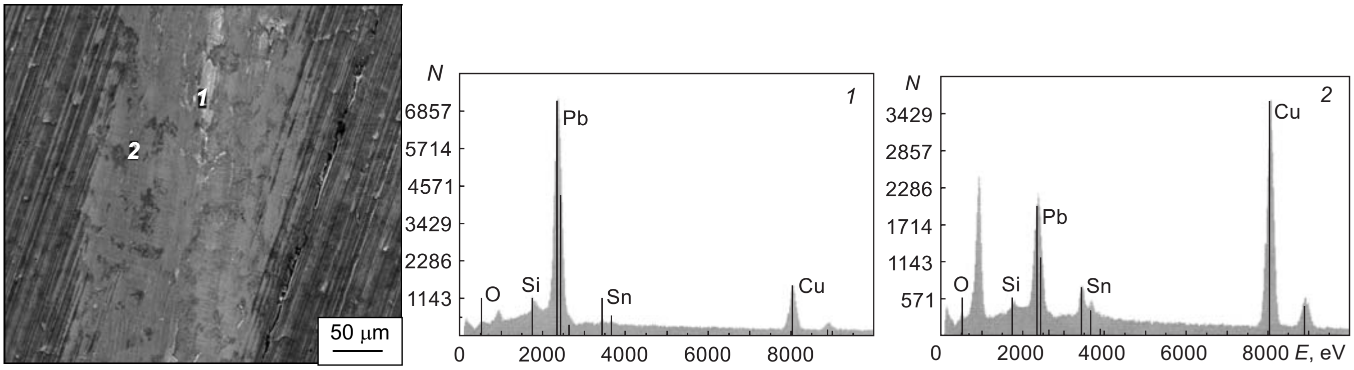

Fig. 3. Microstructure and spectra of areas of a friction surface for SKAM IPM-304 specimens after testing in a pair with steel AISI 52100 in a vacuum with a load of 2 N and a sliding rate of 0.2 m/sec: 1) area enriched in lead, 2) impoverished in lead, *N* is the number of γ-quanta; here and subsequently in diagrams the data provided were obtained in the Austrian research laboratory (Zaibersdorf)

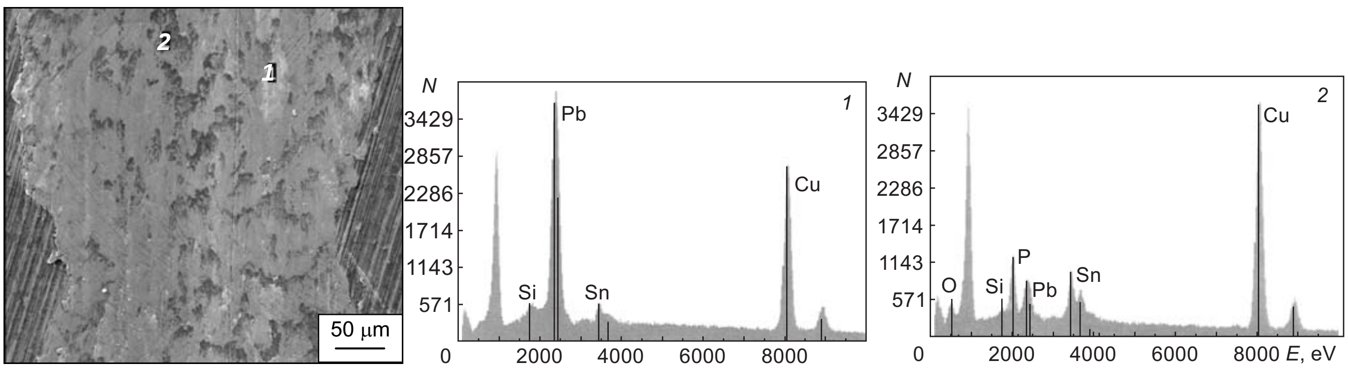

Fig. 4. Microstructure and spectra of areas of a friction surface for SKAM IPM-304 specimens after testing in a vacuum with a load of 10 N and a sliding rate of 0.2 m/sec: 1) area enriched in lead, 2) impoverished in lead

With an increase in load to 10 N and the same sliding rate the banded structure of the material in the friction zone is retained and often there are areas that have the elemental composition of the base (Fig. 4, area 2). However, with the optimum lead content within the composite material (Fig. 4, area 1) there is stimulated enrichment of the friction surface with solid lubricant that reduces the sliding resistance and effectively prevents the surfaces in contact in a vacuum from seizure. Confirmation of this is the constancy of the tribological characteristics, i.e. friction coefficient and wear, that equal respectively: $f = 0.21$-0.24; $I = (2\text{-}4) \cdot 10^{-5}$ mm^3/N · m for specimens in the form of pins; $f = 0.15$; $I = 6 \cdot 10^{-6}$ mm^3/N · m for specimens in the form of disks (Figs. 3 and 4).

With an increase in sliding rate from 0.2 to 1 m/sec with the minimum load (2 N) the structure of the friction zone changes markedly. Individual friction tracks disappear and the whole contact surface is covered by a thin layer of solid lubricant. Due to its uniform distribution in the friction zone (Fig. 5) stable values of friction coefficient and wear ($f = 0.12$ for specimens in the form of pins; $f = 0.18$ for specimens in the form of disks; $I = 8 \cdot 10^{-6}$ mm^3/N · m) are established and maintained for a long time.

Thus, due to the effective self-lubrication during friction in a vacuum SKAM IPM composite materials of the optimum composition provide stable operation of a tribological system even with a fivefold increase in load or sliding rate. A marked increase in friction coefficient and wear was only recorded with a compression pressure of more than 15 MPa.

Concerning the low friction coefficient and high wear resistance of self-lubricating materials, and also their stability they adapt functionally to operating conditions, as confirmed by the results of tribological tests, not only in a vacuum but also in air.

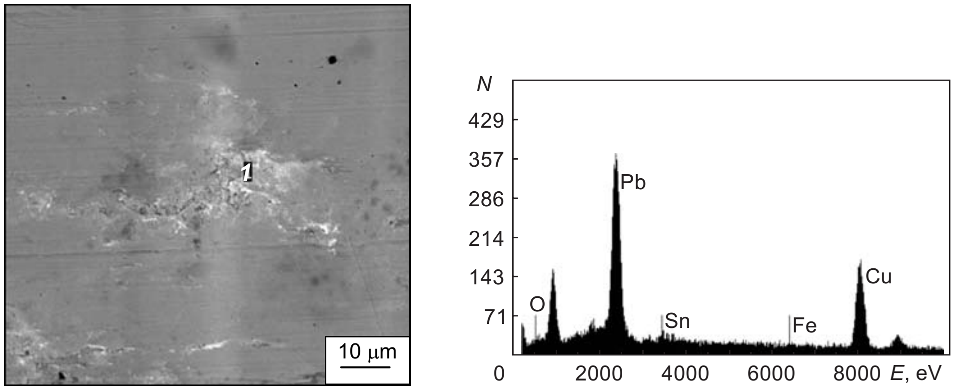

Fig. 5. Microstructure and spectra of area 1 enriched with lead of the friction surface for a SKAM IPM-304 specimen after testing in a vacuum with a load of 2 N and a sliding rate of 1 m/sec

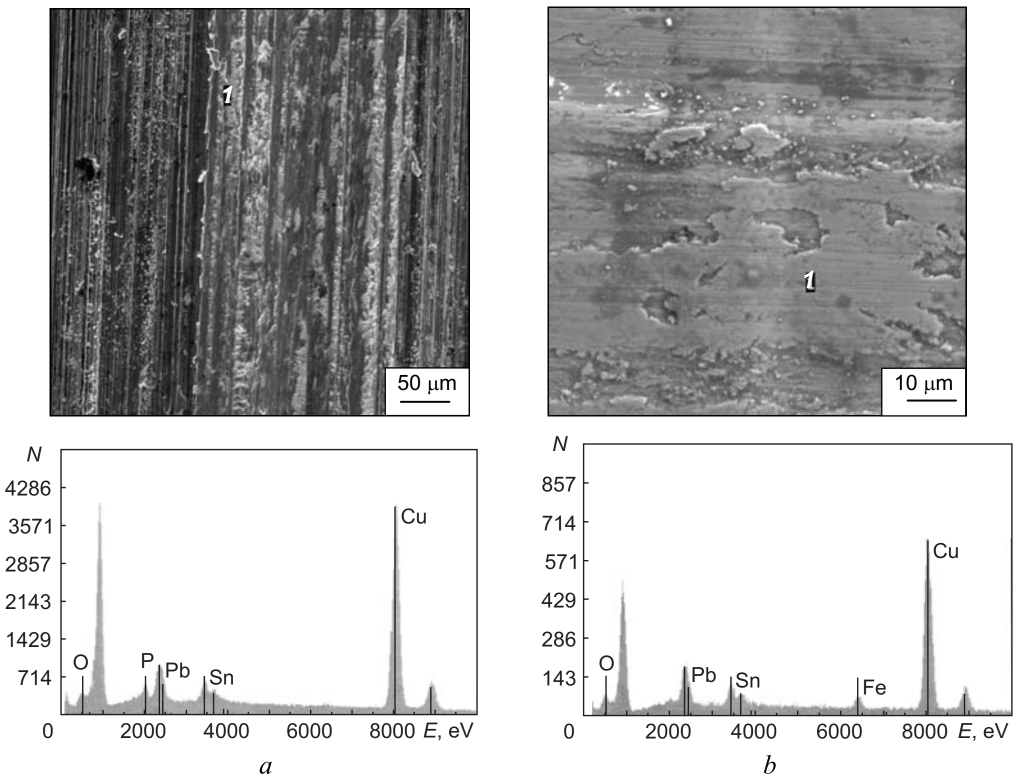

Fig. 6. Microstructure and spectra of area 1 enriched with lead of the friction surface for a SKAM IPM-304 specimen after testing in air in a pair with steel AISI 52100: a) P = 10 N; V = 0.2 m/sec; b) P = 2 N; V = 1 m/sec

The features established for tribological synthesis in the friction zone and its effect on the process characteristics during friction in air may be described as follows. A change in load and sliding rate affects the morphology of the friction zone the same as with friction in a vacuum: an increase in pressure does not overcome formation of banded structure at the contact surface (Fig. 6a), and an increase in rate promotes its change in appearance (Fig. 6b). In all cases at the contact surface there are traces of transfer of components of the base. With friction in air lead oxidizes; the amount of pure lead at the friction surface decreases sharply (Fig. 6), and therefore the characteristics of the friction process in air are markedly worsened compared with that in a vacuum. As a result of lead oxidation self-lubrication is weakened: the oxide formed, inferior to pure metal with respect to lubricating properties and adhesion,

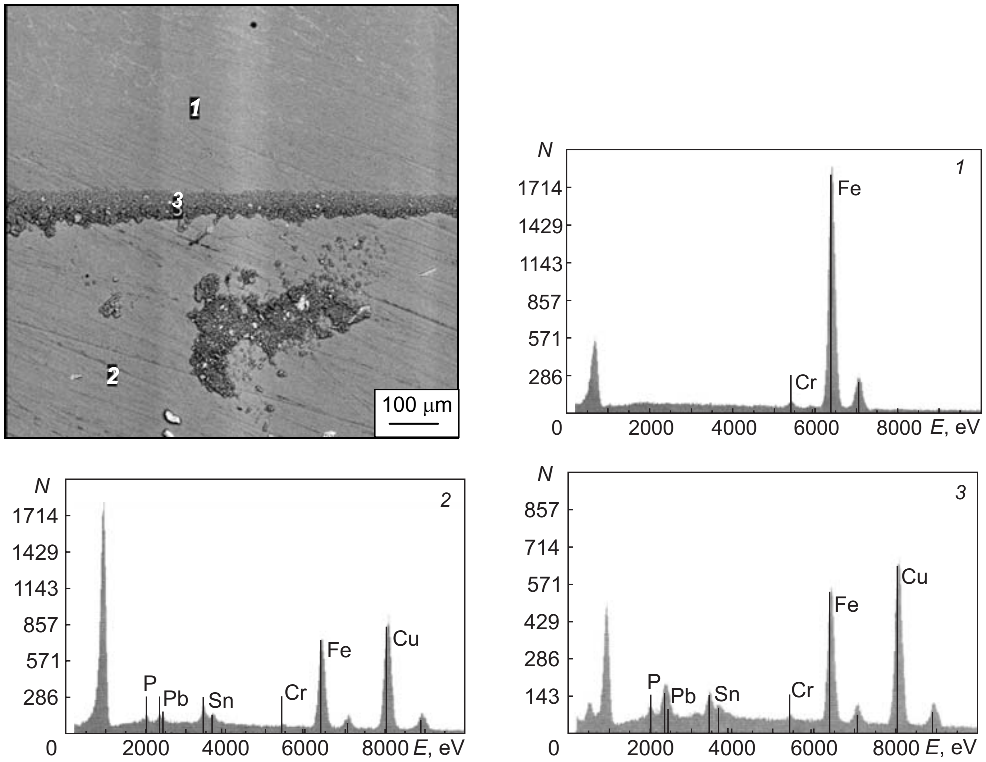

Fig. 7. Microstructure and spectra of areas of the counterbody made of steel AISI 52100 in friction in air in a pair with SKAM IPM-304 specimen with a load of 2 N and a sliding rate of 0.2 m/sec: 1) surface not participating in friction; 2) surface of the friction zone; 3) layer of wear products

passes into the wear product. With a load of 10 N and a sliding rate of 0.2 m/sec the friction coefficient of test specimens in the form of disks is 0.60 with wear of $1 \cdot 10^{-5}$ mm^3/N · m. With a reduction in load to 2 N and an increase in rate to 1 m/sec the following characteristics were recorded: $f = 0.67$ and $I = 1 \cdot 10^{-5}$ mm^3/N · m for specimens in the form of disks, $f = 0.77$ and $I = 7 \cdot 10^{-5}$ mm^3/N · m for specimens in the form of pins. It is noted that with a pressure above 5 MPa the wear resistance of SKAM IPM materials with friction in air is markedly reduced, and the friction coefficient increases an becomes unstable.

Results of spectral analysis of the friction surface of the steel counterbody and wear products are demonstrative. In the contact zone of the counterbody, apart from the main elements of the composite, i.e. iron and chromium, there are components transferred from the material of the composite base (copper, tin, and phosphorus) and also solid lubricant, i.e. lead (Fig. 7). We note that the composition of the wear products for SKAM IPM specimens with friction in air, according the spectral analysis, are absolutely identical in composition to the rubbing surface of the counterbody.

Thus, the dynamics of forming the zones of tribological synthesis during friction in a vacuum for antifriction composites SKAM IPM based on copper are characterized by the activating effect of self-lubrication. An increase in sliding rate with friction in a vacuum markedly intensifies self-lubrication that is expressed in forming in the contact zone a thin continuous layer of solid lubricant. This promotes stabilization of the process with the minimum values of friction coefficient and wear.

With friction of SKAM IPM materials in air release of a solid lubricant, i.e. lead, within the tribological synthesis zone oxidizes that is accompanied by transfer of lead oxide and components of the composite material base to the surface of the counterbody made from chromium steel and into the wear products. Due to the effect of self-lubrication SKAM IPM composites demonstrate reliable and stable efficiency with friction in a vacuum with high loads and rates changing over broad limits.

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