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Investigation of friction and wear behaviours of CuSn10 alloy in vacuum

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Methodology of research

ABSTRACT

Purpose: Friction and wear always occur at machine parts which run together. This affects the efficiency of machines negatively. Today, many industrial applications use vacuum conditions. Therefore, it became essential to determine the tribological behaviour of the machine components running under these conditions. In this paper, friction and wear behaviour of CuSn10 alloy which is used commonly in the industry as a bearing material is investigated at vacuum conditions.
Design/methodology/approach: A couple formed between commercial CuSn10 alloy and Fe 70 (general construct steel) to simulate widely used bearing applications in the industry is investigated. The results obtained at various bearing surface pressures and different vacuum stages are compared to those obtained at atmospheric conditions.
Findings: The test results clearly showed that the coefficient of friction increased in vacuum comparing to the results obtained in atmospheric conditions. However, the wear resistance of the alloy increased in vacuum conditions and the samples showed lower wear rate.
Research limitations/implications: The results showed that there are some important differences in friction and wear behaviors of CuSn10 alloy in vacuum and atmospheric conditions.
Originality/value: Investigation of friction and wear behaviours of CuSn10 alloy in vacuum were made.
Keywords: Wear; Wear mechanisms; Dry Friction; Pin-on-disk; Vacuum

1. Introduction

Friction and wear occur at machinery components which run together. The researchers investigate friction and wear behaviour of materials because of the adverse effect observed in the performance and life of machinery components [1]. Much of the research reported in the literature were carried out under the atmospheric conditions. However, some tribological behaviours have been recently investigated under the vacuum conditions. Especially, as a result of some new developments in aeronautic, space, electronic, material, metallurgy, chemistry, coating and manufacturing industrial areas necessitate the machinery components to be investigated under the vacuum conditions. Therefore there are great interest among the scientists related to the effect of the vacuum environment on the material's friction and wear behavior [2-6].

For practical purposes, however, and in accordance with the definition proposed by the American Vacuum Society, the term vacuum is generally used to denote a space filled with a gas at a pressure less than atmospheric pressure [7]. However a perfect or absolute vacuum, which implies a space that is entirely devoid of matter, is practically unrealizable [8].

The literature contains some published data about wear experiments for some materials carried out under the vacuum conditions at some certain levels. It has been observed that the friction and wear properties of the materials showed some differences in vacuum environment in comparison to that for normal atmospheric environment. For example, K. Lepper et al. [9] observed that friction and wear behaviour were affected more by environment (vacuum, air) than by differences in compositon and microstructure in selected aluminum alloys during dry sliding conditions. In an another work, G. B. Rudrakshi et al. [10] examined the wear behaviour of Al-Cu-Si-Pb alloy in different environments, and observed that the wear rate and coefficient of friction decreased significantly in vacuum environment compared with those in atmospheric environment. Although they observed some increase in the wear with the increase in the sliding speed in both environments, the coefficient of friction remained relatively constant. Emge et al[11] observed that the coefficient of friction for unlubricated sliding of copper in vacuum environment increased with the increase in the sliding speed. However, it has not been encountered enough information in the literature on the friction and wear behaviour of conventional bearing alloys in vacuum environment.

In this study, the wear and friction behaviour of CuSn10 alloy will be examined in both atmospheric and vacuum conditions and the results will be compared. Also, the main wear mechanisms operated in atmospheric and vacuum conditions will be studied.

2. Experimental procedure

In this study, the bearing material CuSn10 widely used in industry is investigated in order to see the possible effects of vacuum condition on wear and friction behaviour. The alloy was purchased from the market to be a sample representing the commonly used material in the industrial applications. The diameter and the length of the pins were 5 mm and 30 mm respectively. Before the experiments, the top surfaces of each pin were finished with CC-1500 abrasive paper so that they had the same surface conditions with the abrasive disk surface (surface roughness 0,35µm).

The experiments were conducted with a pin-on-disk type test machine (ASTM G-99) shown in Figure 1. This system can run in atmosphere, controlled environment and vacuum conditions. The system consists of a horizontal abrasive disk, sample holder, loading rig, wear amount sensor, and measuring equipments for friction force and temperature. The vacuum system is a combination of an oil rotary pump and diffusion pump with a capacity to reach pressures down to 10^{-6} mbar. Abrasive disk used in the experiments was manufactured from the Fe 70 general purpose construction steel with the intend for representing the bearing applications. The disk hardness was 595VSD30/20 ±5 (55RSD-C) after the tempering process. Before the tests, disk surface were grinded down to the surface roughness of about 0.35µm.

Friction and wear experiments were performed at three different ambient pressures. These are; (i) the normal atmospheric condition (1013 mbar pressure and 45 % relative humidity), (ii) 10^{-3}mbar, and (iii) 10^{-6}mbar vacuum conditions. The normal load was applied using dead-weights. The experiments were carried out at different surface pressures of 0.3 MPa, 0.5 MPa, 1MPa, and 2MPa. During the experiments, the ambient temperature was stabilized as (20 ± 2)˚C.

The experiments were conducted for 40 minutes corresponding to a sliding distance of 2400m (this is the length of road approximately 2.5 times the “rodaj” distance which was determined prior to experiments) and the sliding speed of the disk was kept constant at 1 m/s.

The wear behaviour of pin specimens were measured by the volume lost technique. For this, the weight lost of the alloys were measured prior and after each experiments by using a balance with an accuracy of 10^{-5} g. The volume lost values were obtained by means of the measured weight values divided by the alloy density.

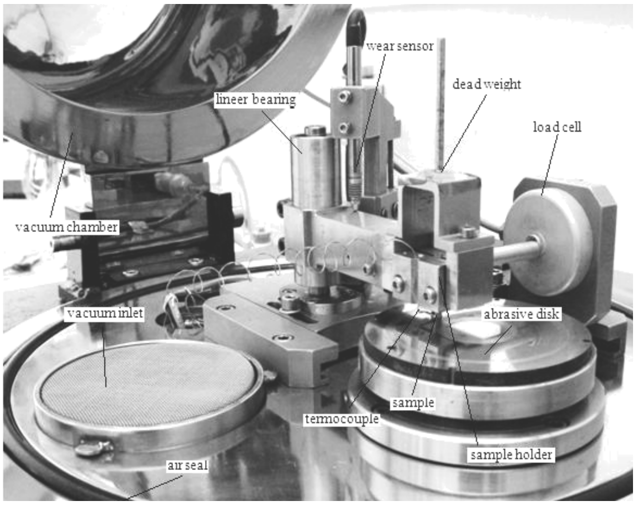

Fig. 1. Pin-on-disk type friction and wear test machine including vacuum system

The frictional forces of the samples were measured and recorded continuously by using a load-cell with a capacity of 250.00 ± 0.01 N. The surface temperature of the samples was measured by a T-type termocouple. Prior to testing, each of the samples in the shape of pin and the disk were cleaned in an ultrasonic bath using acetone for 10 minutes.

The microstructure of the alloy was investigated using optical microscope after preparing standard metallographic technique. Worn surfaces of the alloy samples were examined using scanning electron microscopy (SEM) in the secondary imaging mode.

3. Results and discussion

The chemical composition of the alloy CuSn10 bronze (DIN 1705, 2.1050) used in this study is given in Table 1. The optical microstructure of the alloy is shown in Figure 2. The hardness of the bronze material used was measured to be “139BSD62,5/2,5/30”. The experimental results on the coefficient of friction and the amount of wear are given in Figs. 3 and 4, respectively. Figure 3 show that the coefficient of friction is increased with decreasing the pressure of the chamber. However, in contrast to this, Figure 4 shows the significant decrease in the amount of wear as the pressure decreases, the other experimental parameters being the same. This is also noted that the obtained wear amounts increase with the increasing in the applied surface pressure in atmospheric conditions. On the other hand, the obtained wear amounts decrease with the increase in the applied surface pressure in vacuum conditions.

Table 1.
Chemical composition of the alloy (pin)

Alloy	Chemical compositions, % weight								
	Cu	Sn	Pb	Ni	Fe	Zn	Si	P	Mn
CuSn10	87.951	10.450	0.360	0.673	0.025	0.45	0.053	0.012	0.026

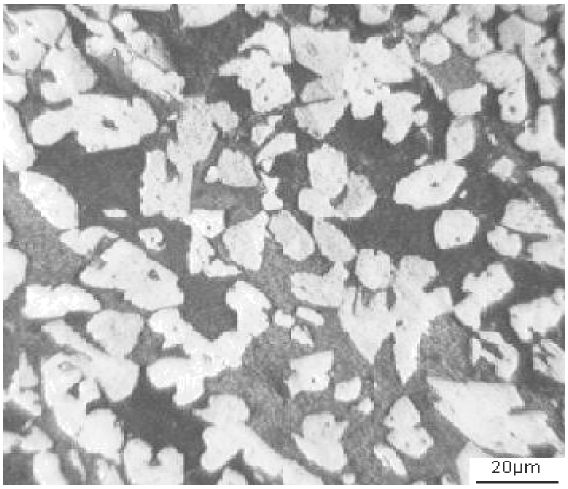

Fig. 2. Optical micrograph showing the microstructure of CuSn10 bronze alloy

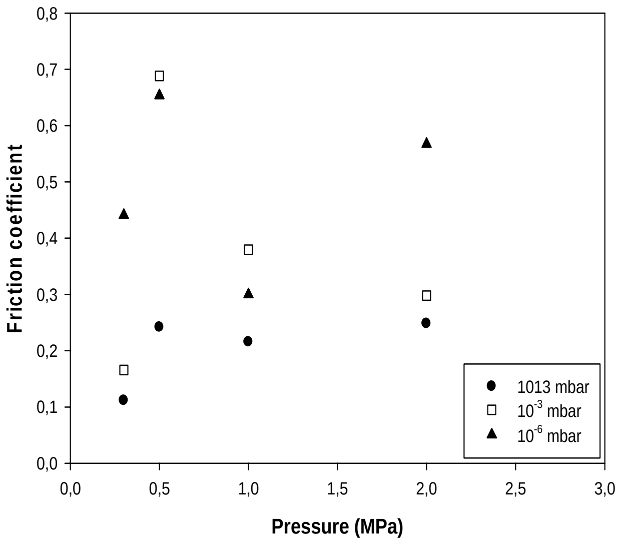

Fig. 3. The variation in friction coefficient of CuSn10 as a function of surface pressures in different environmental conditions

It was observed that the monitored temperature of the samples was increased as the surface pressure increased during the experiment performed both in atmospheric pressure and vacuum conditions. In addition, the measured temperature values increased with the decreasing ambient pressure (vacuum). It is known that the increase in temperature with the increased surface pressure is due to the frictional force [1]. In the vacuum environment, the decreasing heat transfer contributes on the temperature increase [1,4].

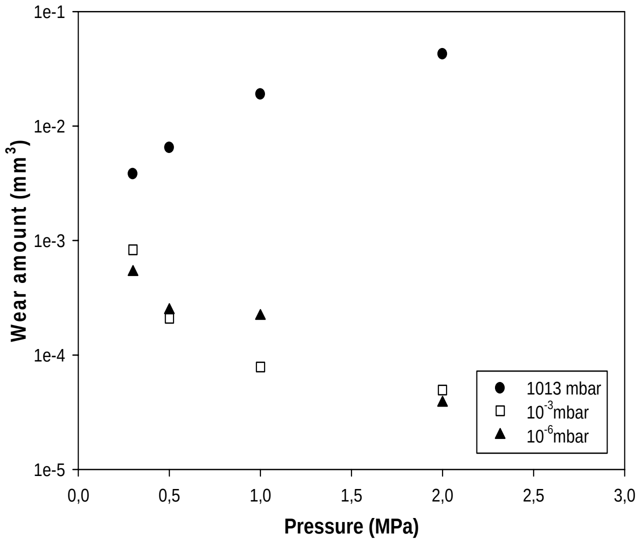

Fig. 4. Volume loss of CuSn10 alloy with applied pressure in different environmental conditions

SEM images of the worn surfaces of the samples are shown in Figures 5-7. It was observed that the worn surfaces of the samples tested under atmospheric pressure condition exhibited mostly abrasive wear (Figure 5). However, the worn surfaces of the samples tested under vacuum environment exhibited mainly adhesive wear (Figures 6 and 7). In the experiments performed under atmospheric conditions, the oxide layer covered the on the sample surface is removed during the sliding by means of frictional effect (relative motion). It is expected that the removed layer can be easily regenerated by means of the increasing surface temperature as well as oxygen content. This oxide layers are naturally hard and brittle. Therefore, the observed wear amount is increased by the existence of these layers. This effect can be confirmed from the SEM image (Figure 4). Since the newly formed oxide layer's bonding ability is relatively weak, it is deduced from the existence of this oxide layer makes the sliding of the surfaces more easily.

a)

b)

c)

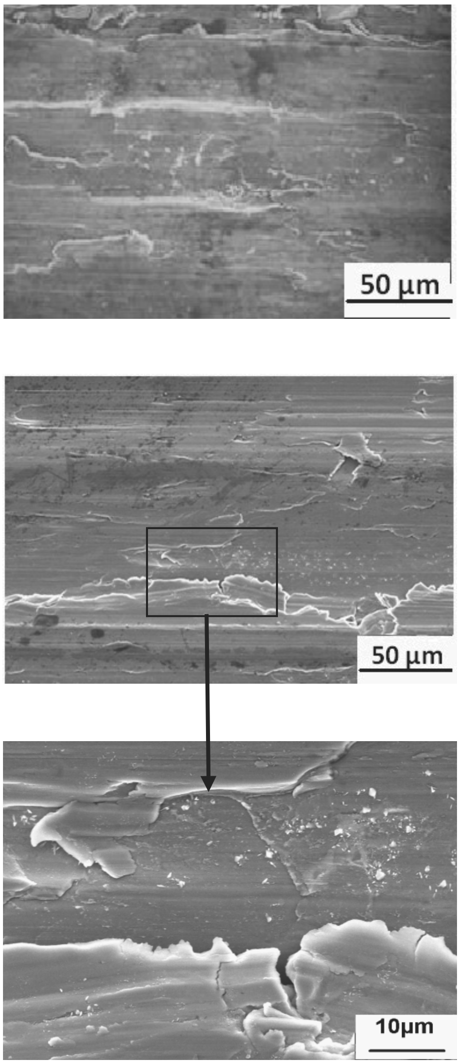

Fig. 5. SEM micrographs showing the worn surfaces of CuSn10 alloy samples tested under the atmospheric conditions: a) 0.3 MPa surface pressure, b) 2MPa surface pressure, c) 2MPa surface pressure

In a vacuum environment, due to the decreased amount of oxygen, the possibility of forming some oxide layers is small and therefore the effect of metal-metal contact will increase. As a result of this effect, the friction coefficient increases with adhesive influence resulting in cold welding. This result agrees well with the literature [4, 12-14]. The decrease of the wear amount under the vacuum conditions may be related to the partial melting of constituent phases in the sample. The partial melting arises from the increase in temperature during the sliding resulting in plastering wear [15]. Therefore, the partially melted phases covering the surfaces of the samples may cause some decrease in the wear [4].

a)

b)

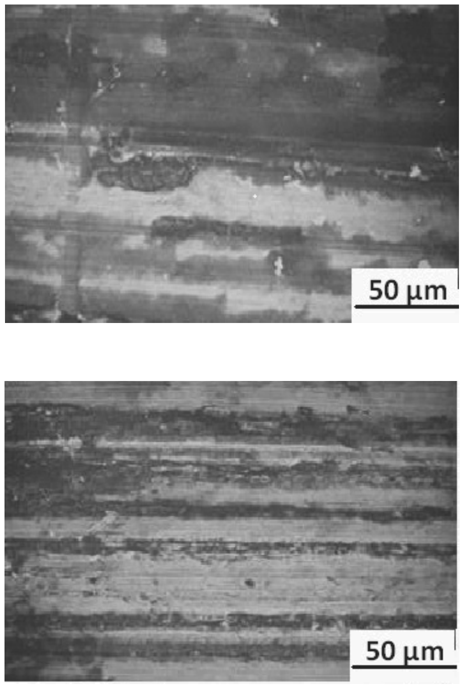

Fig. 6. SEM micrographs showing the worn surfaces of CuSn10 samples tested under 10^{-3}mbar vacuum condition: a) 0.3 MPa surface pressure, b) 2MPa surface pressure

This effect can be seen from Figures 6 and 7. Due to the lack of oxygen in the vacuum condition, the possibility of oxide forming decreases leading to prevent a film in-between the mating surfaces [4, 14]. Thus a contradicting result is obtained in vacuum compared with the one in atmospheric conditions.

4. Conclusions

- The friction coefficient of CuSn10 alloy was found to be higher under vacuum condition as compared to the atmospheric condition.
- Although the friction coefficient is relatively higher under vacuum conditions compared to the values obtained under the atmospheric conditions, lower volume loss was obtained under vacuum conditions.
- In the atmospheric conditions, the volume loss of the CuSn10 bronze sample increased with increasing the surface pressure.
- The volume loss decreased depending on the vacuum level.

Acknowledgements

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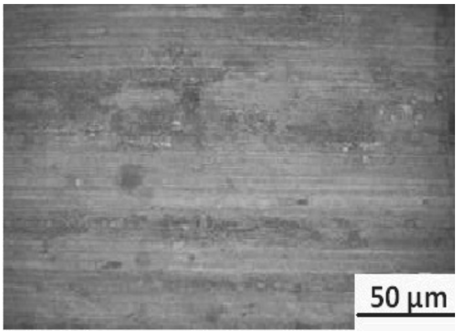
a)



b)

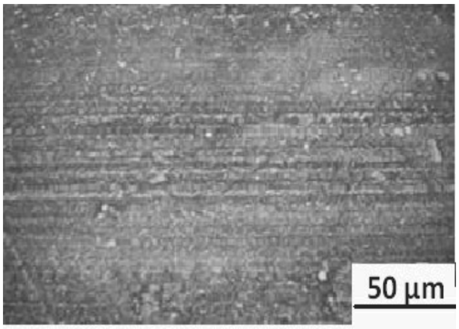


Fig. 7. SEM micrographs showing the worn surfaces of CuSn10 alloy samples tested under 10^{-6}mbar vacuum condition: a) 0.3 MPa surface pressure, b) 2MPa surface pressure

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