The influence of volumetric electromechanical mandreling on the lead yield from the matrix material on the bronze bearing bushing surface

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Abstract. The data on the effect of electromechanical mandreling (EM) modes of rolled bushings made of Bronze-Tin-Zinc-Lead (BTZL) 4-4-2.5 on the lead yield from the matrix material to the work surface are given. As a result of an X-ray analysis, it was found that up to 13.3% of lead is eliminated from the matrix material to the bushing’s surface, filling all irregularities after machining, bringing the actual contact area to the contour one and significantly reducing contact stresses under loading, which serves as a reserve for increasing the movable joint’s durability, along with decreasing the friction torque in the joint when operating under ‘film’ starvation conditions.

1. Introduction

An extremely important task of material engineering is development of fundamentally new ways of improving the wear resistance and durability (bearing capacity) of structural materials. A distinctive feature of these methods is to combine plastic deformation and phase transformations during heat treatment and formation of structures with a higher dislocation density and even distribution of them both over the cross section and the surface of work pieces in a single technological process.

A significant part of the smooth cylindrical movable joints in modern machine engineering constitute joint bearings. During operation of sleeve bearings, the gap, size and curvature of the contact land, the pressure and its distribution along the contact arc constantly change, vibrations and dynamic loads increase. This changes the temperature operation mode of the friction pair. These factors cause not only fluctuations in the wear rate of the bearing and the shaft at the beginning and the end of operation, but also transition from one prevailing type of wear to another. The highest values of wear of the mating parts are observed during their breaking-in period, after exceeding the allowable clearance (above 0.001 - 0.01 of the shaft diameter), as well as during start and stop periods. Average values of the wear rate depend on the modes and conditions of loading, materials of the mating bodies, as well as the type of lubricant.

In joint bearings, rolled thin-walled bushings are widely used, the use of which allows to spare expensive copper alloys significantly. Rolled bushings of joint bearings are made mainly of tin - zinc - lead bronze. These bronzes have higher mechanical properties, including hardness, than babbits.

They work mainly in the conditions of boundary lubrication. Even joint bearings, designed to work in the fluid friction mode, during the start and stop of the machine work in limited lubrication
conditions. In this regard, the wear of joint bearings, operating under external friction conditions, depends also on the adhesion of the contacting materials. However, the surfaces of all real bearing materials are coated with films of complex composition and interaction between the shaft and the liner occurs through the films covering their surfaces. By changing the films’ composition, applying additional technological operations, it is possible to control the friction and wear process.

The presence of soft components on the friction surface reduces significantly the breaking-in time and the formation of an equilibrium roughness, which determines the durability of the friction unit, despite the changing characteristics of the friction process, operational reliability and durability.

The main advantage of soft materials in comparison with other anti-friction materials is a possibility of their use at high loads, as well as at cryogenic (-200 °C) and high temperatures (up to 1000 °C), weak dependence of the friction coefficient on the loading conditions, and absence of gas release. In addition, as a rule, soft metal coatings have good adhesion to the matrix metal, high wear resistance, as well as heat and electrical conductivity. They provide the possibility of obtaining coatings with a smooth increase in shearing resistance.

The aim of work is to study the effect of EM modes [1 - 4] on the quantitative release of lead from a matrix material to the friction surface of a rolled bushing made of BTZL 4-4-2.5.

2 Methodology of Experiment
In order to study the effect of EM modes on formation of elemental composition on the work surface of bushings of joint bearings, the surfaces of thin-walled rolled bushings made of BTZL 4-4-2.5 were processed before and after treating them with EM in various modes. The bushings were pre-installed in the cages with H/k transitional fit. EM was performed according to the compression scheme, with an end stop of the bushing’s lower end.

To determine the final elemental composition of the surfaces of bronze bushings treated with EM, as well as to obtain distribution maps (topography), fragments 10×10 mm in size were made from the processed bushings.

Electron microscopic images were obtained using XL30 ESEM-TMP scanning electron microscope.

X-ray microscopic analysis was performed using a wave dispersion spectrometer (INCA Wave 700) mounted on the scanning electron microscope.

The studies were carried out at an accelerating voltage of 30 kV. Under such conditions, the penetration depth of electrons into bronze is ~ 3 microns. The elements were registered by using the following characteristic X-ray lines: copper - Kβ, zinc - Kα, lead and tin - Lα. As reference standards for quantitative microanalysis (determining the mass fraction of elements in a point) we used respectively for: Cu - pure copper, Zn - pure zinc, Sn - pure tin, Pb - PbS with a lead content of 88%. The probe current did not exceed 60 µA. The results of all quantitative measurements were adjusted using ZAF correction and averaged over several measurement points.

3. Research Results and Discussion
As a result of the research, electron microscopic images of lead distribution on the inner surfaces of bushings were obtained.

On the maps (Figure 1), a lighter color corresponds to a larger mass fraction of lead.

In the electron microscopic image in the reflected electrons there are visible areas of chemical elements with a large atomic number (lighter ones are presumably lead-containing areas).

In order to identify the predicted result, the surface of an untreated bushing was compared with the surface of the bushings treated with EM (Figure 1).

With an increase in the current (Figure 1 b, c), and, as a result, an increase in temperature in the contact zone of the tool and the bushing surface, an increase in the amount of released lead is observed. This phenomenon is explained by the fact that lead is practically insoluble in tin bronzes in the solid state [5]. The structure of tin-zinc-lead bronzes BTZL 4-4-2.5 consists of crystals of α-solid
solution and inclusions of lead. Under the influence of high temperatures and pressure in EM process, some of the lead is squeezed to the surface from surface layers (Figure 2).

The data on the content of chemical elements on the surface of folded bushings made of BTZL 4-4-2.5, treated with EM were taken at three points (Figure 3), and the results were summarized in Table 1.

It can be seen from the table that the proportion of lead in the studied areas (points) on the surface of a rolled bushing made of BTZL 4-4-2.5 after EM exceeds significantly its content in the base.

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**Figure 1.** Electron-microscopic images of the surface of a rolled bushing made of BTZL 4-4-2.5 with a mandrel diameter of 30 mm: a - not treated; b - after EM (current $I = 4000$ A; tension $i = 0.3$ mm; speed of tool movement relative to the surface being treated $V = 66$ mm/min); c - after EM ($I = 5000$ A; $i = 0.5$; $V = 66$ mm/min)

**Figure 2.** The transverse section of a rolled bushing made of BTZL 4-4-2.5, treated with EM at $I = 5000$ A; $i = 0.4$; $V = 66$ mm/min: 1 - matrix material; 2 - lead release on the surface

**Figure 3.** The points of quantitative analysis of lead on the surface of a rolled bushing made of BTZL 4-4-2.5 after EM for modes: $I = 5000$ A; $i = 0.5$; $V = 66$ mm/min
Table 1. The content of chemical elements on the surface of rolled bushings made of BTZL 4-4-2.5

| Place of analysis | Mass fraction of elements, % |
|-------------------|-----------------------------|
|                   | Cu  | Zn  | Sn  | Pb  |
| Base              | 89.0±0.4 | 3.78±0.08 | 3.56±0.06 | 1.8±0.3 |
| Point 1           | 35.2±0.2 | 1.61±0.07 | 0.61±0.06 | 60.5±0.3 |
| Point 2           | 8.53±0.09 | 0.61±0.06 | <0.06 | 91.2±0.5 |
| Point 3           | 28.8±0.3 | 2.3±0.07 | 1.22±0.06 | 60.6±0.2 |

The greatest influence on the percentage of lead release to the surface of a rolled bushing is exerted by the force of the current (Figure 4), and as it increases, the temperature in the contact zone of the tool and a processed surface of the bushing increases, which leads to the intensive formation of a liquid phase of lead in the surface layers and extrusion most of it to the work surface of the bushing.

Figure 4 shows the effect of combination of the studied factors of EM process on the lead release.

From the graphs (Figure 4), it can be concluded that the largest amount of lead, ~13.6% to the surface of a rolled bushing, is released under the following modes of non-free EM: I = 5200 A; i = 0.5; V = 33 mm / min. Reducing the processing speed and increasing the current contributes to a greater heating of the surface layer of the bushing, and an increase in processing tension contributes to the extrusion of molten lead to the surface of the rolled bushing.

It was established that hardness over the section of a rolled bushing after EM is even and with tension of i = 0.5 mm, I = 5000 A is 1221 MPa, which is 28 MPa less than the original.

4. Conclusions
Lead from 6.9 to 13.3%, which is a solid lubricant for a joint bearing, is released onto the working surface of a rolled bushing made of BTZL 4-4-2.5. The strength of current has a predominant influence on its release.

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