The Influence of the Structural State on Wear of Bronze CuAlFe

F.A. Sadykov

An investigation of the influence of the structural state conditioned by different types of deformation-heat treatment (rolling and deformation on Bridgman anvils and following annealing) on wear under conditions of dry friction of bronze on steel was carried out. It was established that after casting, an alloy with a heterogeneous, dendrite structure was most susceptible to wear. A considerable decrease of wear was seen in materials with ultrafine-grained and subfine-grained structural states with equiaxial grains (0.2 to 0.3 µm).

Keywords
bronze, deformation-heat treatment, subfine-grained structure, microhardness, dry sliding, wear intensity

1. Introduction

IT is known that the process of wear in metal materials involves complicated phenomena such as transfer of materials from one contact surface to the other (Ref 1), mechanical alloy-forming processes (Ref 2), phase transformations (Ref 3), dynamic recrystallization (Ref 4), mechanical twinning (Ref 5), and others. A surface film, formed of nanocrystalline (<0.1 µm) fragments of an alloy of the two materials, also has been observed (Ref 6, 7). The mechanism of wear is mainly determined by the mechanisms of formation and destruction of surface films (Ref 8).

At present, materials with ultrafine-grained (0.1 to 1.0 µm) and fine-grained (1 to 10 µm) structures are widely used. These materials have a number of desirable properties, such as high strength and plasticity. Under certain conditions, these materials can be treated as examples of structural superplasticity (Ref 9).

Because the processes of plastic deformation in these materials may be influenced by extensive grain boundaries and the large contribution of grain surface energy (Ref 10), this study investigates the influence of structure grinding to a subfine-grain state on wear processes in the copper alloy, bronze CuAlFe.

2. Experimental Procedure

Casting bronze (Cu-9.0wt%Al-2.5wt%Fe) was chosen for the study. A special preliminary treatment was used to obtain different structural states in the alloy:

- Initial state (as-cast bronze)
- Cold rolling followed by annealing at 600 °C, 0.5 h
- Cold deformation between Bridgman anvils
- Cold deformation followed by vacuum annealing at 150, 250, 400, 600, and 800 °C for 0.5 h

Before cold rolling, the feeds in the as-cast state were annealed at 800 °C for 1 h. The degree of deformation at cold rolling was $e = 0.8$.

The treatment between Bridgman anvils (BA) 8 mm in diameter was performed at constant load of 600 kN at room temperature (20 ± 2 °C). The degree of deformation was high ($e = 7$), and the thickness of the specimens after treatment was 0.1 to 0.2 mm.

The specimens were tested for wear at dry friction using a disk-on-shoe test machine (Fig. 1) at room temperature at 45 to 55% relative humidity. The shoes were made of bronze rough specimens, either as-cast or cold rolled and annealed. The 2 by 5 mm strips were cut from sheet bars made by deformation BA and were glued to the shoes. The disk was made of quench-hardened steel (0.4 wt%C-1.0wt%Cr-1.0wt%Al) with hardness of 52 to 55 HRC. The roughness of the shoe and disk was $R_a = 0.1$ to 0.2 µm. The wear testing was performed under the following conditions: sliding velocity, 0.78 m/c; pressure, 1 to

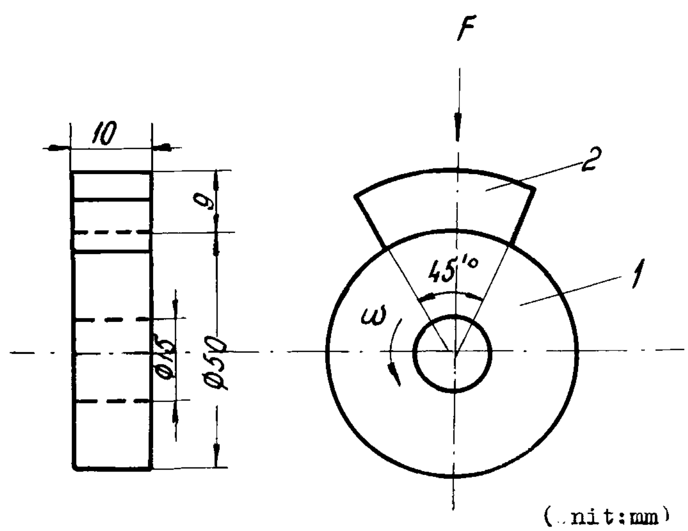


Fig. 1 Experimental set-up for wear testing: (1) disk; (2) shoe

F.A. Sadykov, Institute of Metals Superplasticity Problems, Russian Academy of Sciences, Khalturina, 39, Ufa (450001), Russia.

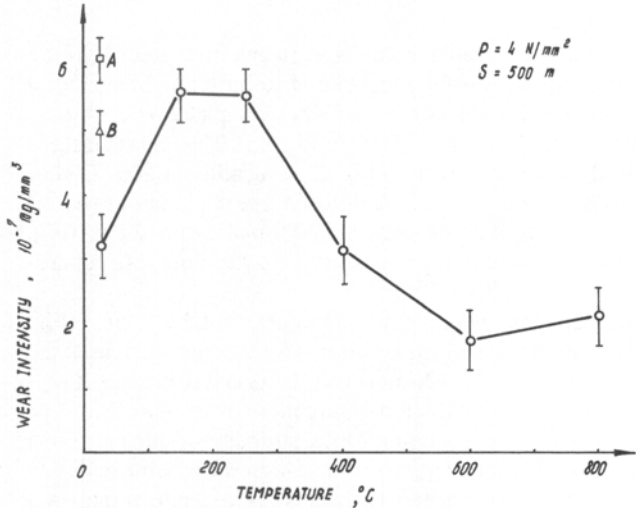


Fig. 2 Dependence of wear intensity on annealing temperature after cold deformation and annealing (curve). A, as-cast state; B, after cold rolling and annealing

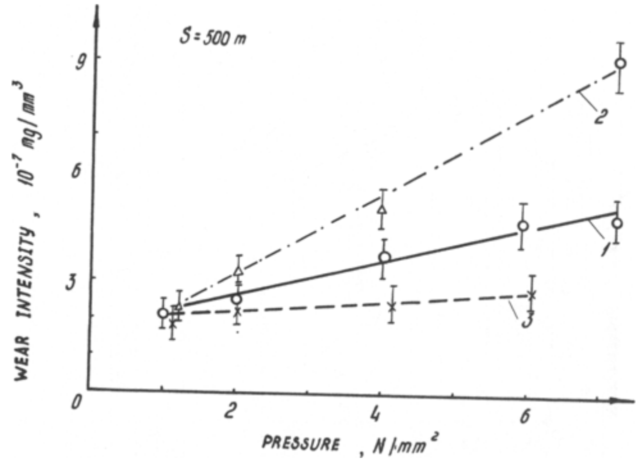
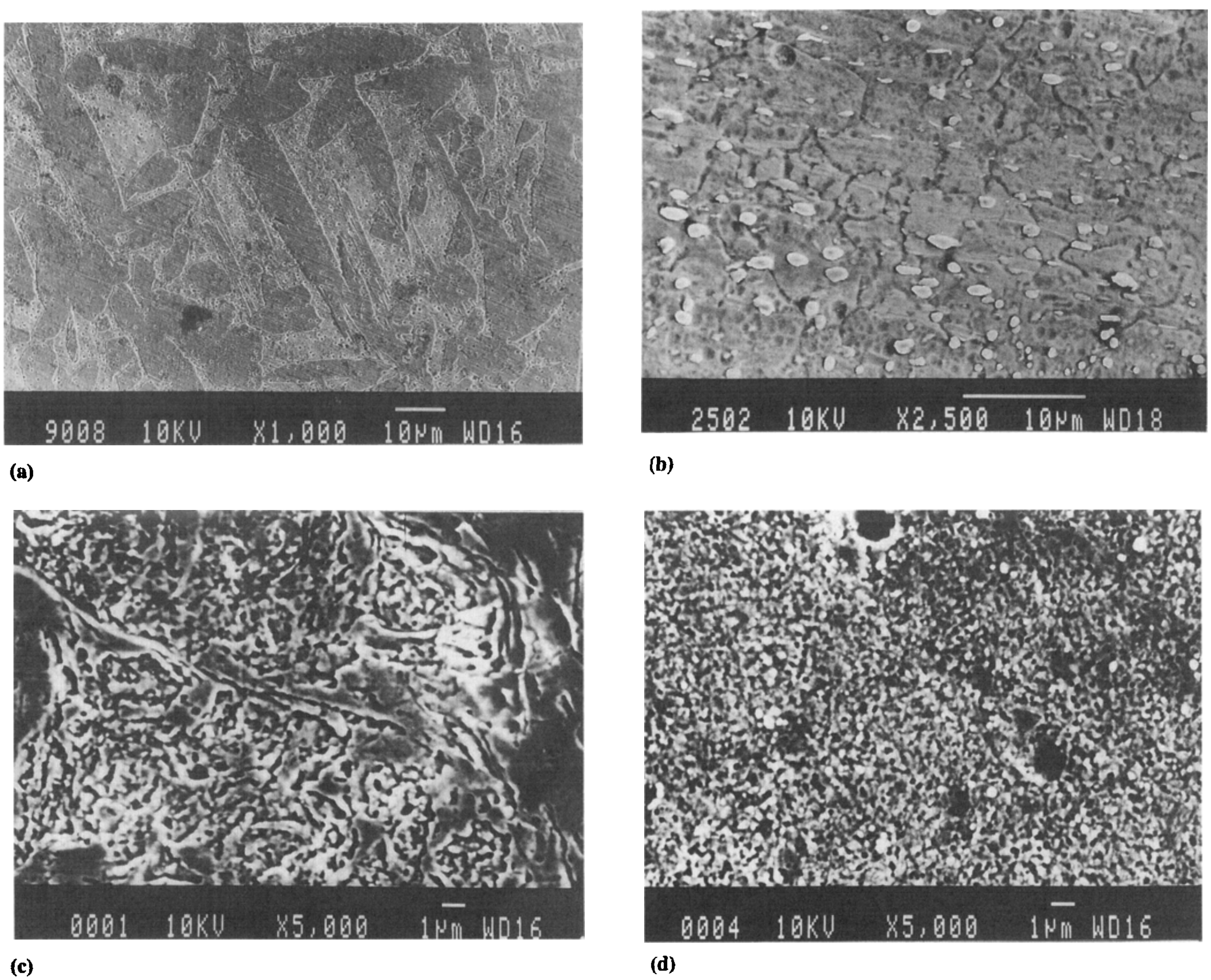


Fig. 3 Dependence of wear intensity on pressure after cold deformation and annealing for annealing temperatures of: (1) 20 °C; (2) 250 °C; (3) 800 °C



(a) (b) (c) (d)

Fig. 4 Microstructure of the specimens after treatment: (a) as-cast ; (b) cold rolled and annealed; (c) cold deformation; and (d) cold deformation followed by annealing (600 °C)

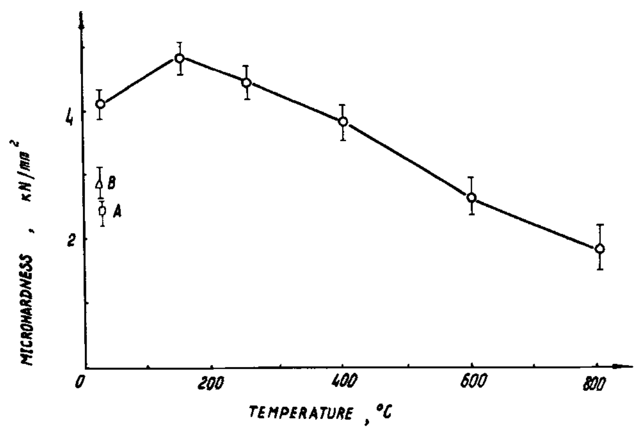


Fig. 5 Dependence of microhardness on annealing temperature after cold deformation and annealing (curve). A, as-cast; B, after cold rolling and annealing

10 N/mm^2; and sliding distance, 50 to 1500 m. Before testing, the disk and shoes were cleaned with acetone and ethyl alcohol. The specimens were weighed before and after the testing to an accuracy of 5×10^{-5} gf to calculate the weight of wear wastage.

The wear intensity, I, was determined by the formula:

$$I = \Delta m / LS \qquad \text{(Eq 1)}$$

where Δm is weight loss, L is sliding distance, and S is contact area.

Scanning electron microscopy (SEM) (JSM-840) was used to study the structure of the worn surfaces.

3. Results and Discussion

The wear results of the specimens after treatment are plotted in Fig. 2. As shown, intensity of wear depends both on treatment and on annealing temperature after the BA deformation. The alloy in the as-cast state showed the greatest wear. After cold rolling and annealing, the wear intensity of the alloy decreased. BA treatment and annealing of the alloy led to a considerable decrease in wear intensity. Specimens that received both the BA treatment and annealing at 600 °C showed the least wear.

The influence of pressure on wear of the specimens is presented in Fig. 3. Wear increases with increasing pressure, as found by many authors (Ref 3, 5, 6). The slope angle:

$$tg\phi = \Delta I / \Delta p \qquad \text{(Eq 2)}$$

is greatest at an annealing temperature of 250 °C and least at 800 °C, where ΔI and Δp are the changes of wear intensity and pressure, respectively.

Typical micrographs of the specimens after treatment are shown in Fig. 4. The alloy has a dendrite structure in the initial state after casting and consists of a basic α-phase, $\alpha + \gamma$-eutectoid, and dispersed phase ($FeAl_3$) (Fig. 4a). The microhardness is 2.4 kN/mm^2, as shown in Fig. 5. Annealing at 600 °C after cold rolling leads to the formation of a fine α-phase (4 to 6 μm) with inclusions of a fine-grained $FeAl_3$ phase (1 to 2 μm) (Fig. 4b). The eutectoid $\alpha + \gamma$ is absent in the structure. Microhardness increases to 2.9 kN/mm^2.

After BA treatment the microhardness is 4.1 kN/mm^2 (Fig. 5). Annealing the specimens after BA treatment increases the microhardness to 4.8 kN/mm^2 at 150 °C and decreases it rapidly (to 1.8 kN/mm^2) if temperature increases to 800 °C.

The analysis of evolution of the structure of one specimen has important features. As a result of high shear deformation ($e = 7$), the casting dendrite structure is divided into small fragments of α-phase (Fig. 4c). After BA deformation and annealing at 600 °C, the formation of subfine-grained (0.2 to 0.3 μm) α-phase structure by recrystallization is obtained (Fig. 4d).

A comparison of the dependence of wear intensity (Fig. 2) and microhardness on temperature (Fig. 5) shows no correlation between wear intensity and hardness, although such a correlation has been observed previously (Ref 6, 11, 12).

SEM micrographs of worn surfaces of specimens are shown in Fig. 6. Analysis of microphotographs of wear surfaces shows that the well-known mechanism for "mild" wear described elsewhere (Ref 9, 13, 14) was observed here.

5. Conclusions

It was established that transformation from a dendrite to a fine- and subfine-grained structure influences the wear processes of CuAlFe bronze.

- As-cast alloy had the greatest wear.
- A fine-grained structure with equiaxial grains (4 to 6 μm) in the alloy showed lower wear intensity than the as-cast state.
- A subfine-grained structure (0.2 to 0.3 μm) showed the least wear.

Acknowledgment

This investigation was supported by the Institute of Metal Superplasticity Problems, Russian Academy of Sciences.

References

1. M. Cocks, Interaction of Sliding Metal Surfaces, *J. Appl. Phys.*, Vol 33, 1962, p 2152-2161
2. D.A. Rigney, L.N. Chen, M.G.S. Neylor, and A.R. Rosenfield, Wear Processes in Sliding Systems, *Wear*, Vol 100, 1984, p 195-219
3. I.M. Liubarskii and L.S. Palatnik, Metal Physics of Friction, *Metallurgy*, Moscow, 1976 (in Russian)
4. R. Heilman, J. Don, T.S. Sun, W.A. Glaeser, and D.A. Rigney, Sliding Wear and Transfer, *Wear*, Vol 91, 1983, p 171-190
5. R. Antoniou and D.W. Borland, Mild Wear of Al-Si Binary Alloys During Unlubricated Sliding, *Mat. Sci. Eng.*, Vol 93, 1987, p 57-72
6. I.V. Kragelskii, Friction and Wear, *Machine-Building*, Moscow, 1968 (in Russian)

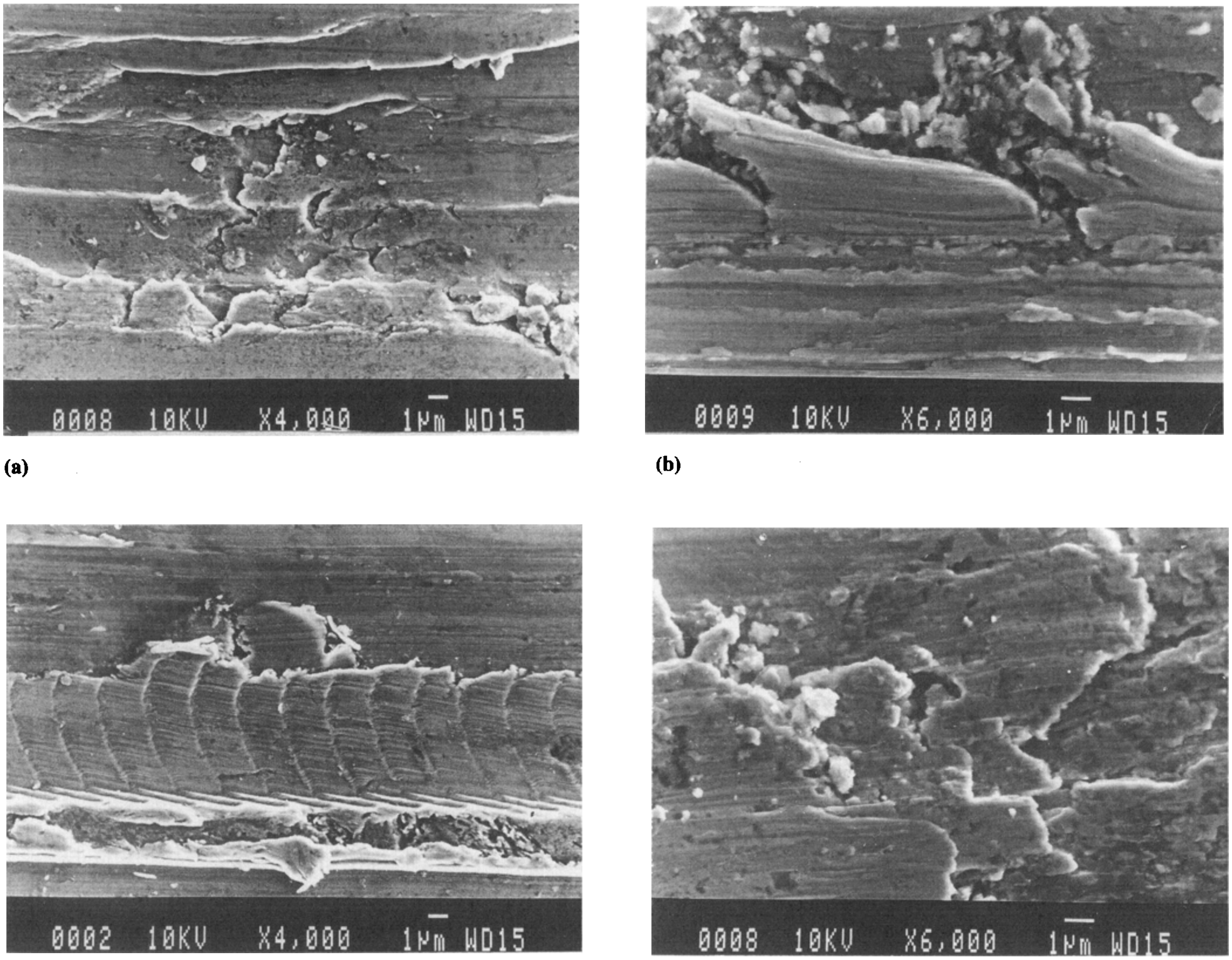


Fig. 6 SEM micrographs of worn surfaces of specimens (a) as-cast; (b) cold rolled and annealed; (c) cold deformation; and (d) cold deformation followed by annealing (600 °C)

7. J.W. Edington, K.N. Melton, and C.P. Cutler, Superplasticity, *Prog. Mat. Sci.*, Vol 21, 1976, p 63-170
8. O.A. Kaibyshev and R.Z. Valiev, Grain Boundaries and Properties of Metals, *Metallurgy*, Moscow, 1987 (in Russian)
9. M. Sundberg, R. Sundberg, S. Hogmark, R. Ottenberg, B. Lehtinen, S.E. Hornstram, et al., Metallographic Aspects on Wear of Special Brass, *Wear*, Vol 115, 1987, p 151-165
10. S.A. Syed Asif, S.K. Bismas, and B.N. Pramila Bai, Transfer and Transitions on Dry Sliding Wear of Copper Against Steel, *Scr. Metall.*, Vol 24, 1990, p 1351-1356
11. M.M. Kruschov and N.A. Babichev, *Wear Study of Metals*, Academy of Science, Moscow, 1960 (in Russian)
12. T. Akagaky and K. Kato, Effects of Hardness on the Wear Mode Diagram in Lubricated Sliding Friction of Carbon Steels, *Wear*, Vol 141, 1990, p 1-15
13. N.P. Suh, The Delamination Theory of Wear, *Wear*, Vol 25, 1973, p 111-124
14. S.C. Lim and M.F. Ashby, Wear-Mechanisms Map, *Acta Metall.*, Vol 35, 1987, p 1-24