Wear and Failure of Babbit Bushes in Steam Turbine Sliding Bearings

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An investigation of wear and failure of babbit bushes was completed in this study. The results showed that wear at dry sliding of babbit obtained by plasma spraying was less than that of babbit in the as-cast state and after a deformation heat treatment. The failure of babbit bushes was caused by a simultaneous and interrelated exhibition of fatigue and wear processes that depend considerably on cohesion strength between the bush and the bearing base and accumulation of defects on the contact surface between the bush and the shaft.

Keywords babbit bushes of steam turbine, cohesion of babbit bushes, deformation heat treatment, failure of babbit, plasma spraying, wear tests

1. Introduction

The reliable operation of sliding bearings determines to a considerable extent the life and reliable operation of the steam turbine as a whole.[1,2] The cases of sliding bearing bush failure in the process of operation have set the urgent tasks of finding the causes of failure and of increasing wear resistance and resistance to fatigue failure of a sliding bearing babbit bush. For this reason, the investigation described in this article was completed to determine the causes of babbit bush failure in the process of steam turbine operation for the effect of grain size of babbit constitutive phases on bush wear resistance. In addition, the work was completed to select a technology of forming an intermediate layer between the babbit bush and the bearing base that would provide a high cohesive strength running in the bush.

2. Experimental Details

The babbit of chemical composition (4.9 wt.% Cu, 11.3 wt.% Sb, remainder Sn) was selected as an object for the investigation (Table 1). To study the destroyed specimens of sliding bearing bushes, optical and scanning electron microscopy methods were used (Neofot 32 (Carl Zeiss Jena Gmbh, Germany) and JSM 840, (JEOL Corp., Tokyo, Japan) respectively). Mechanical tests, of the specimens were performed using the Instron universal dynamometer (Instron Corp., Canton, MA). Brinell hardness was determined with a hardness gauge at a load of 610 N and a ball diameter of 5 mm. Microhardness was determined with a microhardness gauge at a load of 0.2 N. The density of the destroyed babbit was determined by a hydrostatic weighing method on an analytical balance. The chemical composition of the alloy was determined by a method of local x-ray spectrum analysis using the JSM 840 scanning electron microscope and the link analyzer.

Tribology tests were performed with the help of a friction machine according to a friction pattern disk shoe both at dry friction and in a liquid lubricant medium under the following conditions: sliding speed of 0.79 m/s, pressure from 0.5 to 3.5 MPa, and sliding distance up to 25 km. Wear intensity I was determined by the formula

$$I = \Delta m / L \cdot S \quad \text{(Eq 1)}$$

where $\Delta \boldsymbol{m}$ is weight loss, $\boldsymbol{L}$ is sliding distance, and $\boldsymbol{S}$ is contact area.

To perform a test for determining the quality of babbit cohesion with the base (steel, babbit), laminated specimens were manufactured: babbit plus steel and babbit plus babbit with the intermediate tin sublayer applied according to different technologies in conformity with Table 2. The quality of cohesion

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Table 1 Data on babbit's structure parameters and mechanical and tribological properties

Type of babbit treatment	Cast state	Plasma spraying	Deformation heat treatment: Annealing, at 200°C	Deformation heat treatment: Annealing at 100°C + compression to 53%
Chemical composition, wt.%	Sb-11.9; Cu-4.5; Sn-remainder	Sb-13.5; Cu-6.0; Sn-remainder	Sb-11.9; Cu-4.5; Sn-remainder	
Brinell hardness	26.9	20.3	26.8	22.8
Density, g/cm^3	7.45	6.74	7.45	
Porosity, %	0	7.7	0	
Grain size of β-phase, μm	100	10 to 20	150	50
Grain size of α-phase, μm	0.5	0.5 to 1.0	0.5 to 1.0	
Wear intensity at dry sliding, mg/mm^3	11.5×10^{-8}	8.6×10^{-8}	9.7×10^{-8}	
Wear intensity with lubricant, mg/mm^3	6.1×10^{-10}	6.1×10^{-10}	6.0×10^{-10}	

Table 2 Data of shearing and tearing-off tests of laminated specimens

Sublayer obtaining method	Shearing stress, MPa	Tearing-off stress, MPa
Tin sublayer applied by rubbing	34.9	70.0
Tin sublayer obtained chemically	29.3	72.0
Sublayer is absent; babbit obtained by plasma spraying	20.3	41.0

was determined by shearing and tearing-off tests. The tests were performed with the help of the Instron testing machine at a traverse speed of 1 mm/min and at room temperature.

3. Results and Discussion

3.1 Babbit Bush Failure

To investigate the cause of the bush failure, the parts of steam turbine babbit bushes destroyed during operation were used as well as a part of a bush that had been cast according to the serial technology and had not been operated. The studies were performed to determine chemical composition, structure, fracture morphology, and density of the destroyed babbit.

Figure 1 presents the microstructure of the specimens. Figure 1 (a) shows that the structure corresponds to the babbit of the selected composition and consists of α phase (solid solution of antimony and copper in tin), β phase (SbSn cubic crystals), and η phase (Cu_6Sn_5 compound). The babbit structure revealed at a great magnification (5000×) shows that the main α phase is a fine-dispersed phase (Fig. 1b) with components of size 0.5 to 1 μm. At some areas of the specimen, crack formations can be seen on a β-phase crystal (Fig. 1a). Pores are also locally observed, which are probably gas bubbles (Fig. 1c).

The fracture surfaces of the destroyed babbit pieces were also studied with the help of a scanning electron microscope. Figure 2 presents a typical photograph of the fracture surface. The analysis shows that fragile failure of β and η phases (Fig. 2a) and elastic failure of the α phase (Fig. 2b) occur. Figure 2(c) presents a fracture surface area with a pore, which is probably a gas bubble. Figure 2(d) shows the fracture area where a crack was formed.

Scanning electron microscopy was also used to study the surface of friction of the destroyed babbit bush after it had been operated. Figure 3(a) presents a representative area of the surface of friction. It can be seen that the surface of friction consists of a number of parallel wear furrows, which are characteristic of metal wear.[1,2] The presence of large reoriented areas that can in the process of friction form cracks and crumble is remarkable. Individual cracks were observed to be located across the friction furrows of a worn-out surface (Fig. 3b).

The nature of bearing loading as it occurs in the process is cyclic. For this reason, damages from mechanical fatigue occur in the bush (Fig. 3b). The emergence of fatigue cracks with the cyclic loading being present is characteristic of a babbit.[3,4]

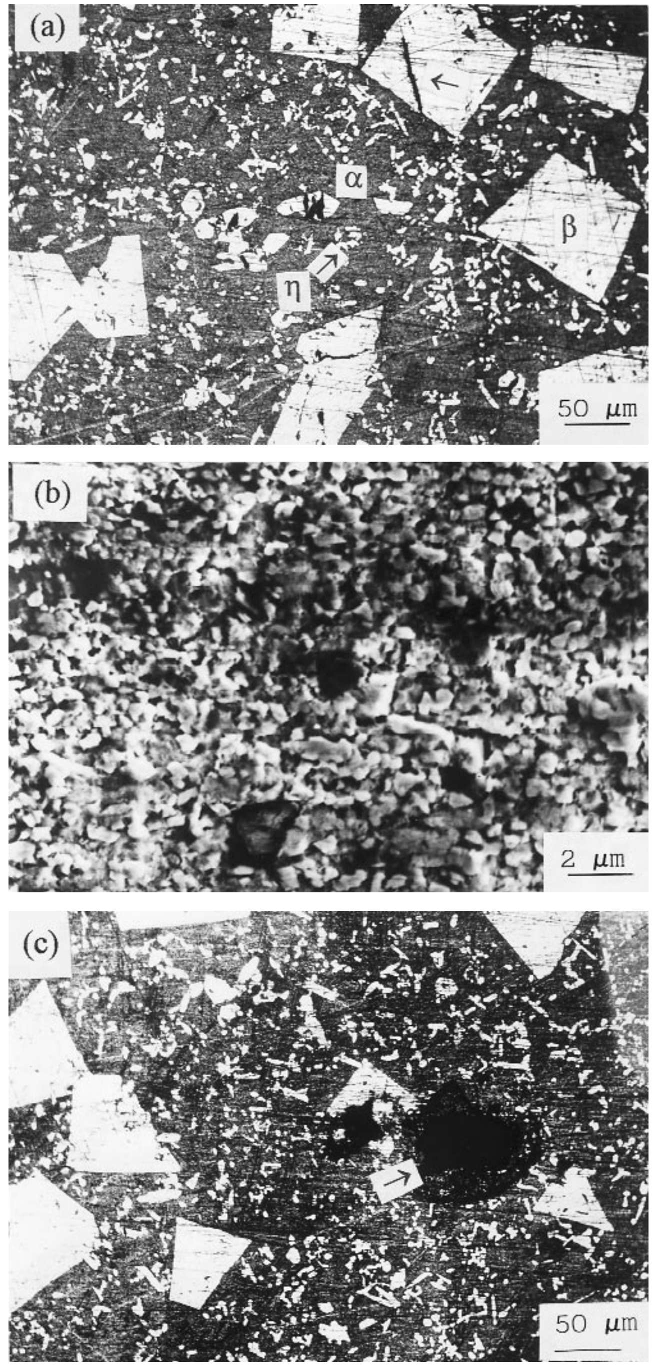

Fig. 1 Babbit microstructure. **(a)** The presence of α (gray matrix), β (cubic crystals), and η (arrow) phases (optical microscopy). **(b)** View of α phase (scanning electron microscopy). **(c)** Gas bubble (arrow) (optical microscopy)

In addition, abrasive wear occurs due to the effect of solid particles in a lubricant (wear products and admixtures in a lubricant) and that of a direct contact between the shaft and the babbit bush.

In general, the type of failure is characteristic of sliding bearings and is a simultaneous and interrelated display of fatigue and wear processes.[5]

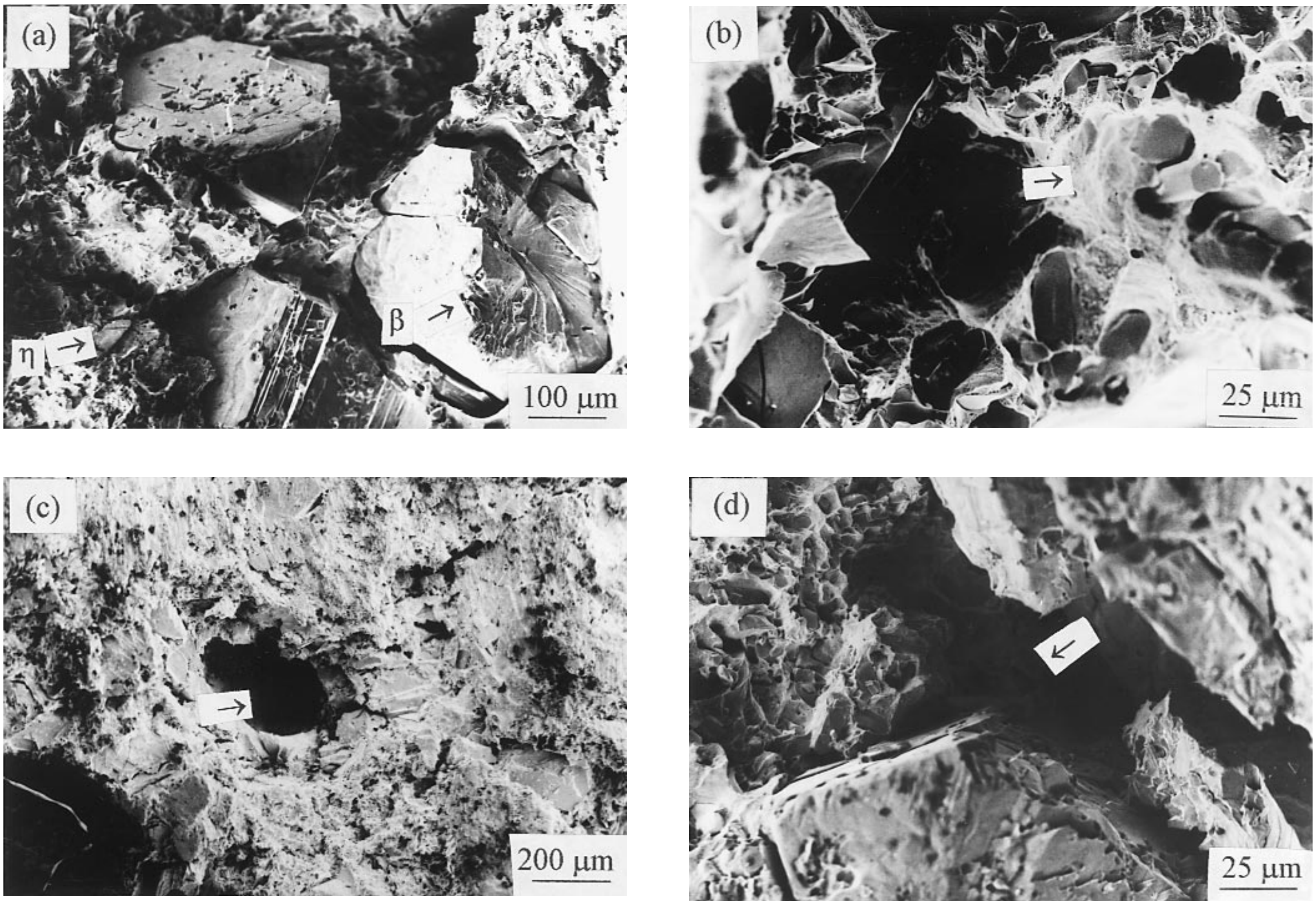

Fig. 2 Scanning electron micrographs of destroyed babbit surface fracture. **(a)** Fragile failure of β and η phases (arrows). **(b)** Elastic failure of α phase (arrow). **(c)** Fracture area with a pore (arrow). **(d)** Fracture area with a crack (arrow)

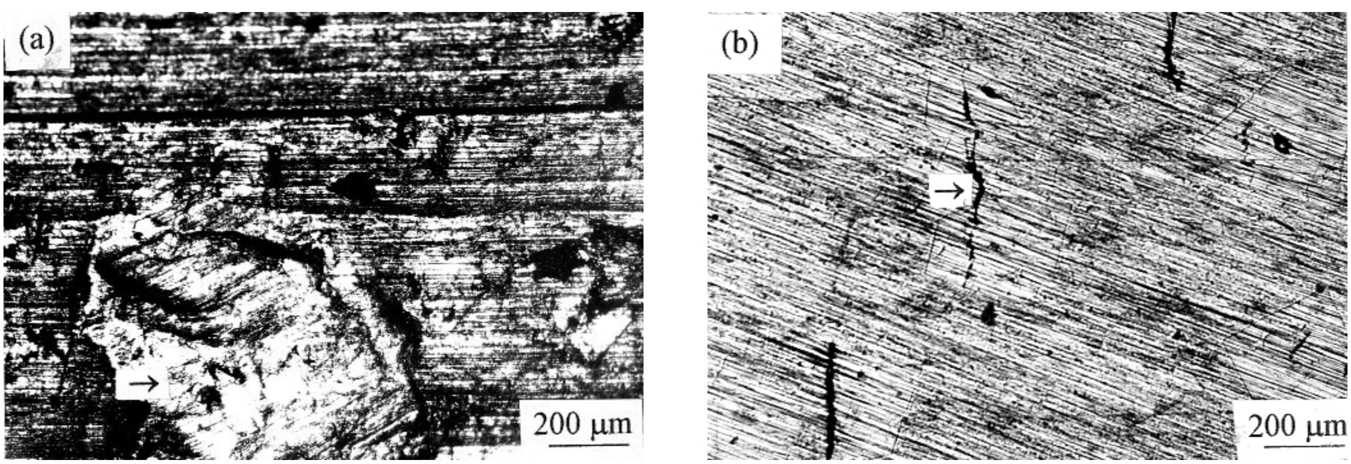

Fig. 3 View of babbit surface of friction. **(a)** A large reoriented area (arrow). **(b)** Cracks (arrow)

3.2 Structure, Mechanical Properties, and Wear Resistance

At present, there are data in the literature illustrating the fact that both fatigue strength [6] and wear resistance[7,8] depend considerably on the material structural state.

Deformation heat treatment is one of widespread methods of forming the regulated material structures.[9] For this purpose, the influence of different deformation treatment conditions on the babbit structure, plasticity, and wear resistance indices was estimated. The deformation heat treatment included the following.

- The first part of the specimens was annealed at temperatures of 100, 150, and 200°C for 2 h.
- The second part was given the previous treatment plus compression for a deformation degree of 50%.
- The third part was compression at 20°C for a deformation degree of 20 to 60%.
- The fourth part was given the previous treatment plus annealing at 100 to 200°C.
- The fifth part was forging at 20°C for a deformation degree of 70%.
- The sixth part was given the previous treatment plus annealing at 100 to 200°C.

The investigation results related to the structural and physical-mechanical properties of the babbit show the following. The data on the babbit hardness, depending on the annealing temperature, show that with this condition there is no change in the hardness as compared with as-cast state, which is obviously conditioned by the process occurring at room temperature corresponding to 0.47 to 0.57 of melting temperature for the selected alloy.

The curves' "stress deformation" were built on the basis of the results of specimen compression presented in Fig. 4. It can be seen that there is a difference in the deformation behavior of the specimen without porosity (curve 1) and that with gas bubbles (curve 2).

During the babbit compression, the hardness decreases from 27 in the initial state down to 20.5 with the increase of the deformation degree to 65%. This is probably caused by the crack formation in β phase that occurs during the compression.

The crack formation in β phase during the compression begins to show at the deformation degree of 35% and higher (Fig. 5a). At higher deformation degrees, 60% and more, the crack formation and the failure of β and η phases are more considerable and cover a large area of the deformed volume (Fig. 5b). At forging, these phases go to smaller pieces (Fig. 5c).

The main α phase after the compression is subfine-grained equiaxial and does not undergo considerable changes. The annealing at 200°C after the compression did not result in a marked increase of the eutectic grain sizes of the main α phase.

The plasma babbit structure is most fine grained for the β and η phases (Fig. 6a) as compared with the cast babbit structure. The main α phase is highly fine grained (Fig. 6b). It should be noted that a considerable porosity confirms the previously mentioned results on density and hardness of plasma babbit.

The influence of the treatment and the structural state of the babbit on its wear resistance is of interest. The babbit wear resistance was studied in the cast state, after the deformation heat treatment, as well as in the plasma-sprayed form both at dry friction sliding and using a lubricant (turbine oil).

Table 1 presents the results of wear intensity estimation. The analysis shows that the deformation heat treatment reduces wear intensity by 25%, which agrees well with the data of Ref 10 and 11, where the possibility to increase wear resistance by deformation heat treatment is shown. The plasma babbit wear intensity at dry friction is 40% lower than for the babbit in the cast state. However, when using a lubricant (turbine oil), the difference does not show. The dependence of wear intensity on grain size of babbit β phase presented in Fig. 7 shows that babbit wear resistance increases when grain size decreases. It should be noted that Ref 12 also shows the possibility of the bush durability increasing by using a babbit of less grain size of β phase than that of a cast babbit.

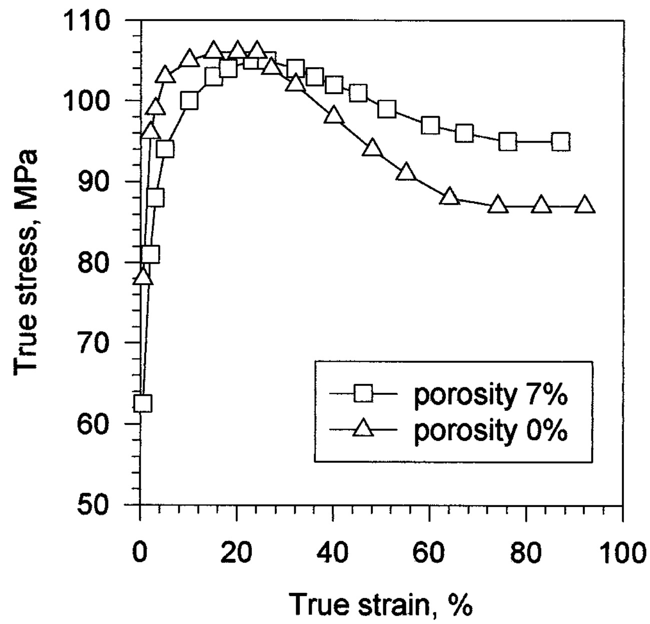

Fig. 4 Flow stress dependence on deformation at specimen compression

4. Cohesion of Babbit Bushes

The data in Ref 12 are indicative of the fact that the cohesive strength between the bush and the base, changing the bearing flexural rigidity, considerably affects the babbit bush fatigue resistance. For this reason, the investigation was completed to determine the cohesive strength between the bush and the base under various technological regimes of applying the intermediate layer.

Table 2 presents the results of shearing and tearing-off tests of laminated specimens. The analysis of test results shows that the cohesive strength between the babbit and the base through the tin sublayer applied chemically is not worse than that of the specimens with the tin sublayer applied by rubbing. A marked decrease in the cohesive strength values occurs for the specimens with the babbit applied directly to the base by plasma spraying without the tin sublayer.

The data presented allow for a recommendation of a chemical method of applying the tin coating as an intermediate layer because, as compared with the basic variant, the following is provided in this case: uniform coating application, decrease of tin consumption, productivity increase, and the possibility of running in the bearings that have a complex shape of the surface conjugated with the bush.

5. Conclusions

The complex investigation of the babbit bush by methods of optical and electron microscopy, x-ray-spectrum analysis, and mechanical and tribological tests established the following.

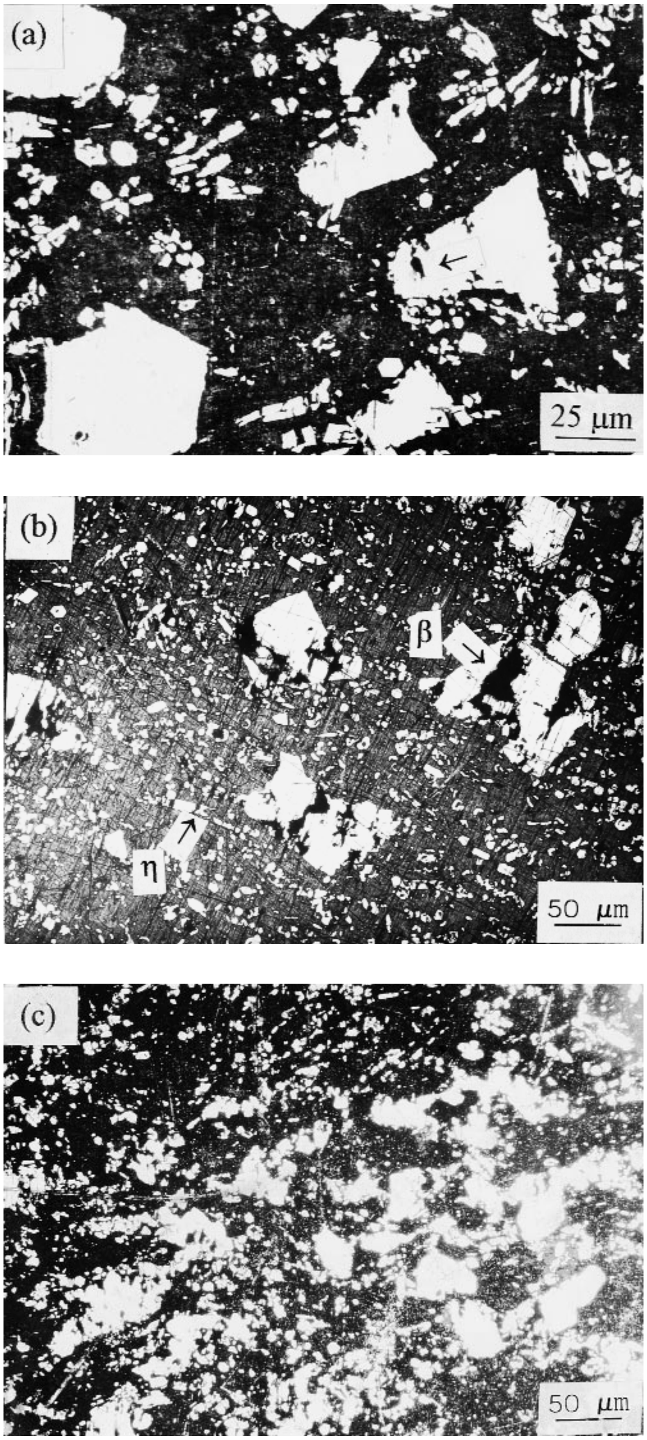

Fig. 5 Babbit microstructure after compression and forging. **(a)** and **(b)** Crack formation and failure of β and η phases (arrows) after compression for a deformation degree of 35 and 60%, respectively. **(c)** After forging

- The operation failure of the babbit bush is caused by a joint display of wear and fatigue processes.
- The initiating effect of an insufficient cohesion of the bush with the bearing base and that of the damage of the contact

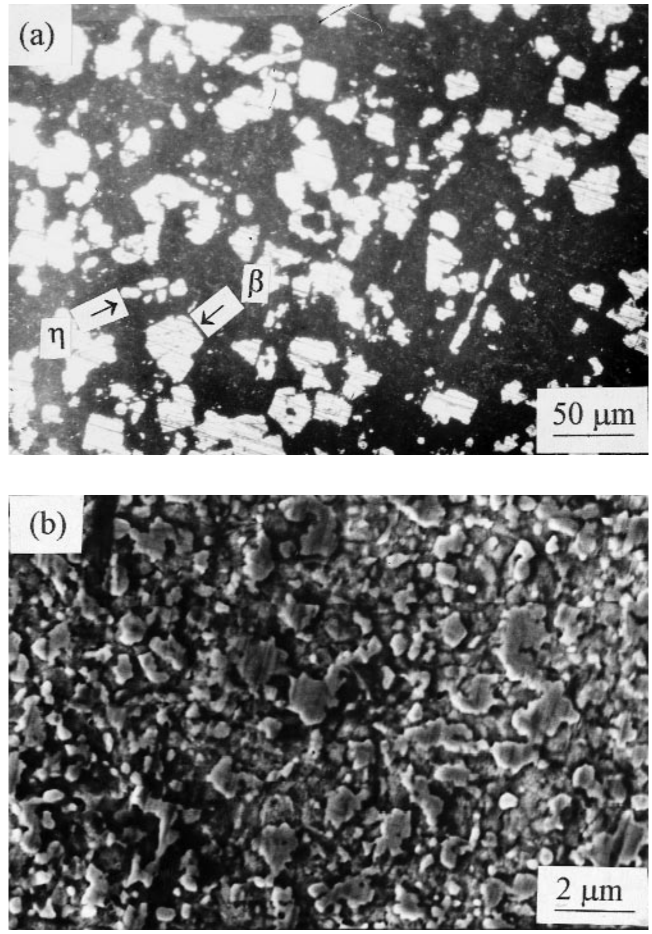

Fig. 6 Plasma-spray-coated babbit microstructure. **(a)** Optical micrograph. **(b)** Scanning electron micrograph of α phase

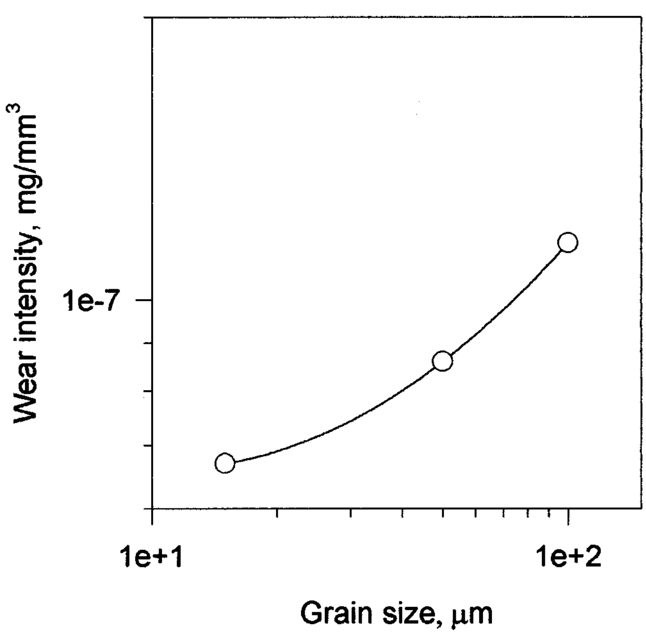

Fig. 7 Dependence of babbit wear intensity on β-phase grain size at dry sliding

surface of the bush with the shaft on the process of the babbit bush failure has been shown.

- The deformation heat treatment reduces wear intensity by 25% at dry friction as compared with the babbit in the cast state.
- The babbit obtained by plasma spraying has the least wear intensity at dry friction, which is probably connected with the β-phase grain size.

Acknowledgments

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