Simulation of Microstructure on Tribological Properties of Babbitt Alloy

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Abstract

In order to research the mechanism of influence of SnSb grain on the tribological properties of Babbitt alloy, simplified models of coarse grain, refined grain and refined grain with passivated shape among Babbitt microstructure were established according to the SnSb phase grain size and shape was measured in the experiment. The strain, stress, contact stress and friction stress during the contact of ball and disk friction pairs were simulated by Workbench software. The simulation result that strain, stress, friction stress and contact stress of Babbitt alloy was gradually decrease with the change of grain size and shape during the sliding process. Moreover, the refined and round shape SnSb grian effect of Babbitt alloy tribological peoperties was the most obvious.

Keywords

Grain Size; Grain Shape; Simulation; Babbitt Alloy.

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1. Introduction

Babbitt alloy is characterized by the distribution of hard phases SnSb (β) and Cu6Sn5 (η) on a soft matrix, which possess excellent properties including the embedding of wear debris, easy of compatibility with shaft, good wear resistance, and impact resistance due to the soft matrix[1]. Therefore, they are widely used in various engineering fields, such as in the support shaft neck part of steam turbine, hydroelectric power plant and radial forging machine[2,3].

However, Babbitt alloy is prone to adhesive wear, abrasive wear, and even melting under dry friction or insufficient lubrication condition, leading to the failure of sliding bearings. It results from the coarse grain size and the sharp-angled rhombic shape of SnSb grain, distribution uniformity. To improve the mechanical and tribological properties of Babbitt alloy, refined grain size and modified shape of SnSb was achieved through techniques such as liquid die forging, laser melting, and the addition of other modifying elements, which refiney the grain or passivation the sharp angle of SnSb grain[4-6]. Thus, compared to those with coarse grain of Babbitt alloy, the tribological performances of Babbitt alloy (with refined SnSb grain) was enhanced. To simulating the distribution of polycrystalline phase shape, the representative volume element model with Voronoi diagrams, Monte Carlo methods and cellular automata are used[7-10]. Currently, grains are often represented by polyhedra or polygons of uniform size to represent various shape and size. Dong found that the content of Cu6Sn5 phase significantly impacted the stress-strain behavior of Babbitt alloy, and controlling the content and refining the SnSb phase is beneficial for improving the performance of the alloy by using images of the actual microstructure of Babbitt alloy and combining them with the RVE model in ABAQUS software[11]. Guo established a relationship between the wear rate of Babbitt alloy and the content of hard phases, contact pressure and sliding speed, to analyze the effect of the hard phase content on the wear resistance of Babbitt alloy by ABAQUS software[12]. Most of the literatures mentioned based on image processing and analyzes the impact of such microstructure on the mechanical properties of materials. However, they do not consider the effect of individual grain (size, shape, and distribution) on material performance and their tribological properties, therefore, establishing a relationship between grain characteristics and tribological performance.

The tribological performance of Babbitt alloy bush is related to the stress on the surface of the friction pair. This study focus on the effect of the grain size, shape and distribution of the SnSb phase in Babbitt alloy on the mechanical and tribological performance. According to Archard's wear theory, wear is proportional to the load and the stress on the contact surface, thus finite element analysis can be used to analyze the frictional stress. The effect of SnSb grain size, shape, and distribution on the strain, stress and frictional stress in Babbitt alloy were investigated by Workbench. Its provide guidance on how changes in microstructure affect the tribological performance of Babbitt alloy.

2. Simulation Process

Distribution of grain in the microstructure of Babbitt alloy and the non-uniform size of the grain was unordered, as shown in Figure 1. It is appropriate to simplify the microstructure of the Babbitt alloy to establish model. The rhombic SnSb hard phase is harder compared to the matrix of Babbitt alloy. Thus the white hard phase in Figure 2a can be considered as a protrusion as shown in Figure 2b and 2c to examine the effect of the hard SnSb phase on the wear resistance of the Babbitt alloy. The composition of Babbitt alloy is as follow: 11% Sb,6% Cu, 0.1% As, 0.1% Fe, and the rest of them is Sn. The average size of the untreated SnSb phase of Babbitt alloy at 100x magnification is 0.088 mm, the average size of refined grain is 0.045 mm, and the size of refined and rounded grain is 0.055 mm by using metallographic microscopy[5,13]. For ease of simulation and comparison, the size of the SnSb phase in Babbitt alloy is set as shown in Table 1. The diameter of the Babbitt alloy sample is φ4 mm, and the height is 0.5 mm. Initially, the steel ball and the Babbitt alloy disc are in point contact. During the friction process, due to minor wear of the ball, a small face contact occurs, thus the contact surface between the ball and the disc is a small circular face. The size of this small circular face is magnified 10 times without affecting the calculation results, with a contact diameter of φ2 mm. To facilitate the calculation, the thickness of the small circular face is set to 0.5 mm. The ball is simplified as a small cylindrical body. The model is established by SolidWorks software, as shown in Figure 3.

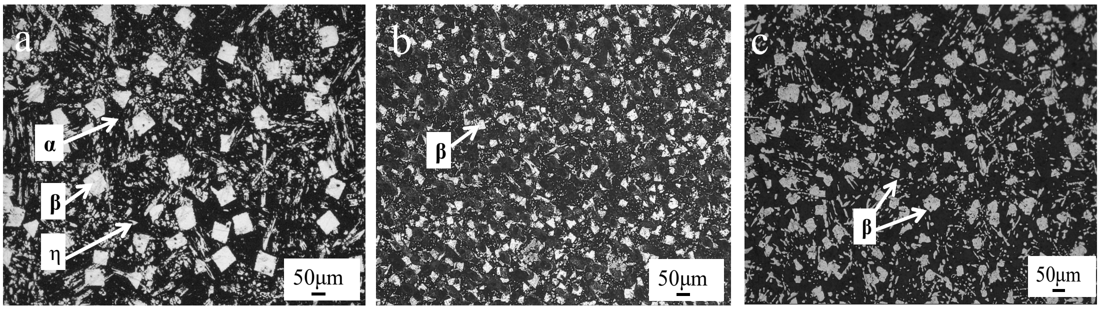
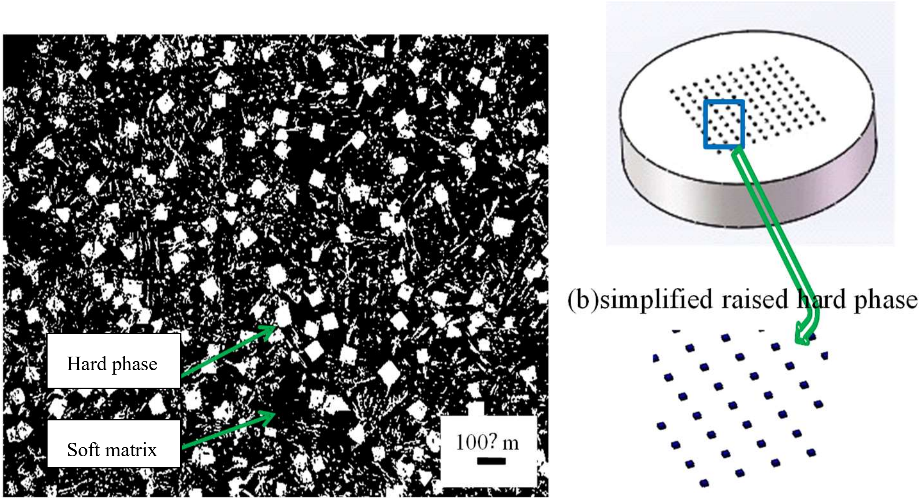


Figure 1. (a) coarse SnSb grain,(b) refined SnSb grain; (c) refined and round SnSb grain

The established model were imported into Workbench software, the relevant parameters were set as shown in Table 2. Before performing the analysis, it was necessary to divide the part into mesh, as shown in Figure 4. The following assumptions were made for the simulation: (i) surface roughness was not considered; (ii) the impact of frictional heat was ignored; (iii) distribution of Cu_6Sn_5 was ignored. Due to the significant difference in hardness between the ball and the Babbitt alloy, the wear on the ball was negligible. In Workbench, the statics structural and transient analysis module were used, setting the contact type to frictional, meaning that before relative sliding, a certain amount of shear stress was transmitted through the contact area. The experimental dry friction coefficient was determined to be 0.4, with the target surface being the disc and the contact surface being the small cylindrical body, similar to a static analysis. Boundary conditions applied a downward force of 5 N on the upper surface of the small cylindrical body, used a fixed constraint on the lower surface of the disc, and applied a displacement of 0.5 mm in the X direction to the ball. The load step end time in the transient analysis settings was set to 0.24 seconds. The model after loading is shown in Figure 5.



(b)simplified raised hard phase

(a) microstructure of babbitt alloy (c) close up view

Figure 2. Microstructure of Babbitt alloy

Table 1. Different grain size and distribution mode of Babbitt

	SnSb grain size/mm	Granular height/mm	quantity	volume	distribution mode
Coarse grain	0.4×0.4	0.02	3	0.0096 mm^3	regular triangle
Refined grain	0.34×0.34	0.02	4	0.0096 mm^3	square
Refined and round grain	φ34	0.02	5	0.0096 mm^3	square

Table 2. Property of Babitt alloy and GCr15

	Young's modulus /MPa	Poisson's coefficient	Density g/cm^3
Babbitt	47930	0.28	7.38
GCr15 ball	208000	0.3	7.85

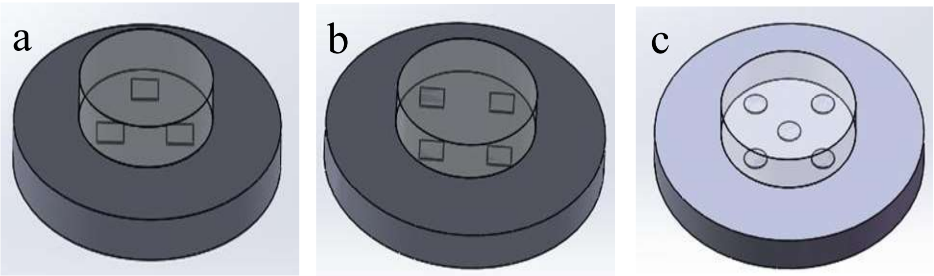


Figure 3. Different SnSb phase Babbitt model: (a) coarse grain, (b) refined grain, (c) refined and round grain

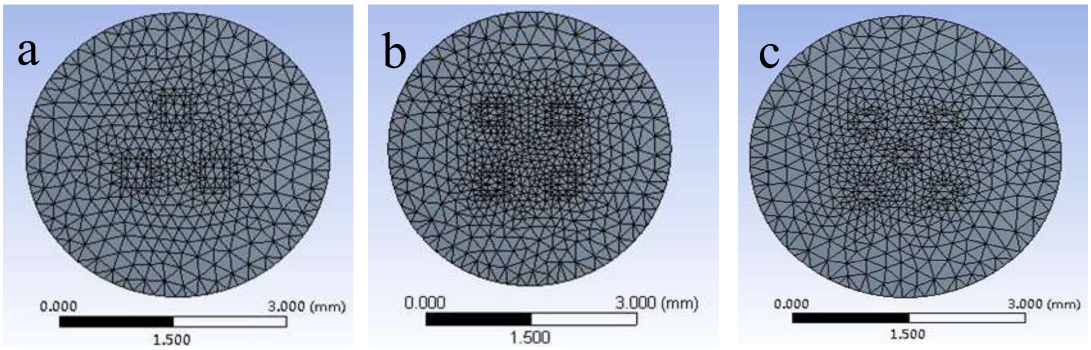


Figure 4. Meshing contact model: (a) coarse grain, (b) refined grain, (c) refined and round grain

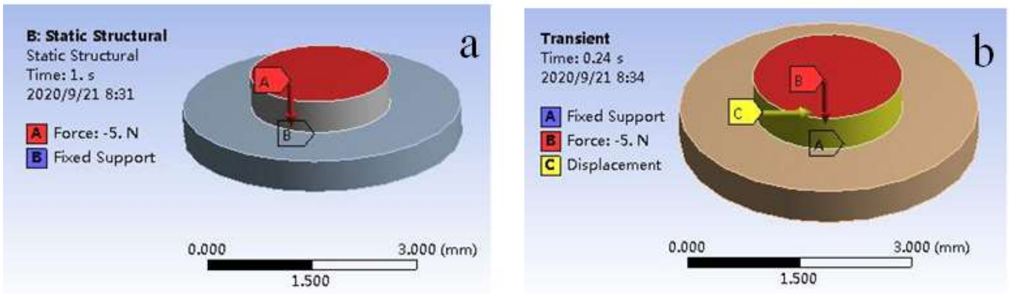


Figure 5. constraints condition of ball and disc:(a) static structural, (b) transient analysis

3. Result and Discussion

3.1 Effect of Grain on Strain and Stress of Babbitt Alloy

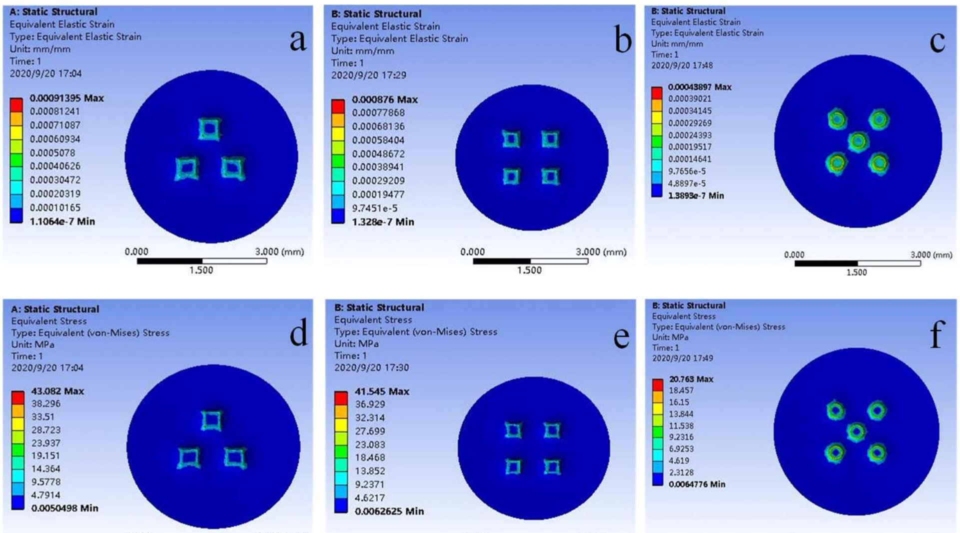


Figure 6. Equivalent elastic strain, at 5 N: (a) coarse grain, (b) refined grain, (c) refined and round grain; equivalent stress: (d) coarse grain, (e) refined grain, (f) refined and round grain

When the load is applied before friction, the different strain and stress of Babbitt alloy reflect the effect of the size, shape and distribution of grain in the microstructure on its mechanical properties. Strain and stress reflect the deformation resistance of Babbitt alloy in the friction process. The stronger strain resistance, the higher wear resistance of Babbitt alloy.

As for grain size, As presented in Figure 6a, b, d and e, the maximum strain and equivalent stress of coarse grain and refined grain was 9.1×10-4 mm, 8.8×10-4 mm, 43.08 MPa and 41.55 MPa, respectively. It can be seen that the strain and stress of refined grain is smaller than that of coarse grain. The load uniformity of refined grain is good, which result from the number of refined grain is more than the number of coarse grain. Combined with the hardness test in the experiment, the Vickers hardness of refiney grain Babbitt alloy was higher than that of coarse grain. It can be inferred that the stress change of refined grain under the same load was small, and the small stress was conducive to preventing the formation and expansion of crack. Therefore, the wear resistance of babbitt alloy(with refined grain) was better.

As for grain shape, Figure 6a, c, d and f reveal that the maximum strain and equivalent stress of refined grain with sharp corner and rounded corner grain was 8.8× 10^{-4}mm, 4.4× 10^{-4}mm, 41.55MPa and 20.77MPa, respectively. It can be observed that the strain and stress of the round grain are smaller than those of the grain with sharp angle. It can be also seen that the stress distribution around the round grain is uniform, which means that the round grain shape is not easy to produce stress concentration. Therefore, Babbitt alloy is not easy to deformation and cracks are not easy to spread after wear.

3.2 Effect of Grain on Babbitt Wear During Dry Friction

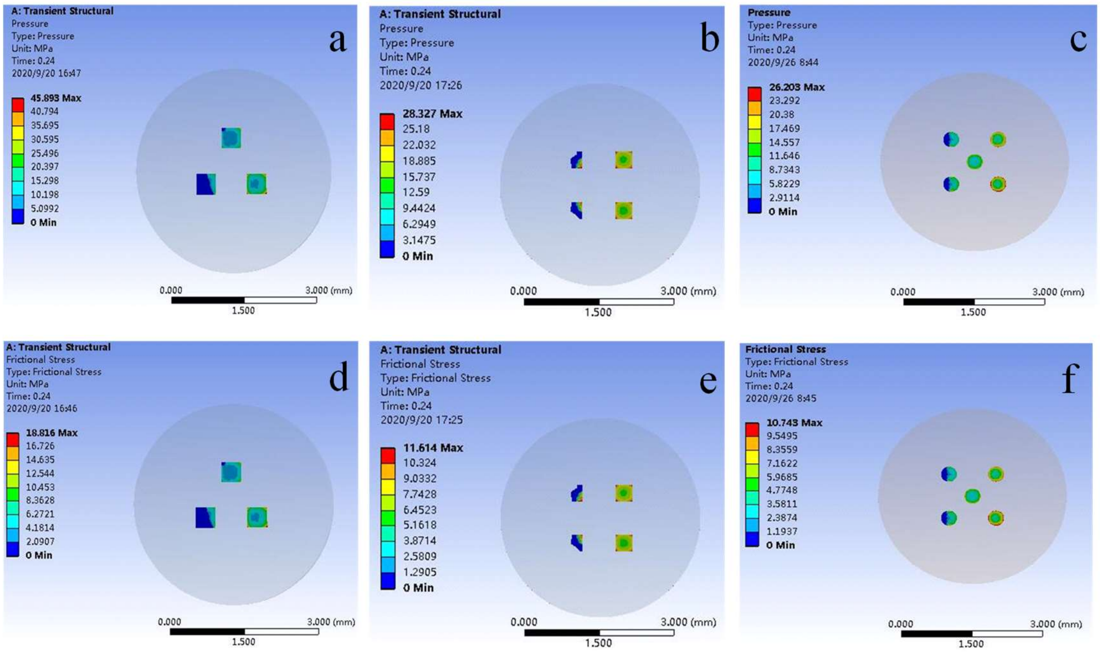


Figure 7. Contact stress: (a) coarse grain, (b) refined grain, (c) refined and round grain; friction stress: (d) coarse grain, (e) refined grain, (f) refined and round grain

The maximum contact stress and friction stress of Babbitt alloy (with coarse grain, refined grain) was 45.89 MPa, 28.33 MPa, and 18.82 MPa, 11.61 MPa, respectively, as shown in Figure 7 a, b, d and e. It is evident that grain refinement effectively reduces both the contact and friction stresses of Babbitt alloy. This reduction is attributed to the increase in the number of grains, which enhances the load-bearing capacity due to the grain refinement.

Regarding the Babbitt alloy with different SnSb grain shape, it revealed from Figure 7a, c, d and f that the contact stresses and friction stresses of Babbitt (sharp corner and round shape) was 28.33 MPa, 26.2 MPa, and 11.61 MPa, 10.74 MPa, respectively. From a morphological perspective, sharp corner significantly affectt Babbitt alloy, where the stress is higher at these points. It demonstrates that the stresses around the rounded grain are distributed rather than concentrated at a single point. This indicates that rounded the sharp corner of SnSb grain can effectively mitigate their impact on Babbitt alloy. During the friction process, Babbitt alloy with rounded grain corner do not exhibit significant stress concentration under 5 N, which reduces the likelihood of crack initiation and thus prevents deformation of the matrix, enhancing the wear resistance of the Babbitt alloy.

4. Conclusion

Simulation the microstructure of Babbitt alloy was conducted. Under the same load, the contact stress and friction stress of Babbitt alloy during simulated sliding were analyzed. During reciprocating motion, both the friction stress and contact stress of the Babbitt alloy decreased as the grain size and shape changed. The trend showed that the greatest reduction occurred with coarse grain, while the smallest reduction was observed with rounding of the grain. This alteration in grain size and shape significantly enhances the wear resistance of Babbitt alloy.

Acknowledgments

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