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REGULAR ARTICLE

# Study on fatigue strength of SnSb11Cu6 babbitt-steel bimetal sliding bearing material prepared by MIG brazing

Xinbo Wang[1], Zhongwei Yin[1,*], and Yonghong Chen[2]

[1] School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China
[2] Chongqing Hongjiang Machinery Co., LTD., Chongqing 402162, PR China

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**Abstract.** The babbitt-steel bimetal sliding bearing material prepared by the MIG brazing has been applied in many fields. In the application, usually only the bonding force is tested, and the fatigue strength is not evaluated. For this reason, this study referred to the test method for the fatigue strength of bearing materials of internal combustion engines, used the sapphire test machine (Dana Glacier Vandervell Bearings, UK) to inspect the SnSb11Cu6 babbitt-steel bimetal material prepared by MIG brazing, and analyzed the test results in depth. The test results show that, the fatigue strength of the bimetal material is more than 40 MPa. In comparison, according to the same test method and conditions on the same sapphire test machine, the fatigue strength of the SnSb11Cu6 babbitt-steel bimetal bearing material obtained by the centrifugal casting method after optimizing process was usually around 35 MPa. Therefore, the MIG brazing could produce higher fatigue strength for SnSb11Cu6 babbitt-steel bimetal bearing material. In addition, in this study, the process of fatigue failure was usually that after the microcracks were generated on the surface, they expanded to the inside of the lining, thereby resulting in spalling. This study has guiding significance for engineering practice and scientific research.

**Keywords:** Babbitt / fatigue / MIG / bearing / microcrack

## 1 Introduction

Babbitt alloy is the most widely known sliding bearing material, which has good antifriction ability, embedability, frictional conformability and anti-seizure property. It is widely used in internal combustion engines, construction machinery, turbo-machinery and generators [1–4]. Preparation methods of babbitt-steel bimetal materials include centrifugal casting [5,6], arc spraying [7], plasma-arc powder deposition [8], laser cladding deposition [9], TIG arc brazing [10], MIG arc brazing [11], etc., and each preparation method has its advantages. Different characteristics, such as the contact-impact [1], the mechanical and tribological properties [12], the fracture and wear [13] and the creep characteristics [14] have been studied by many researchers. Moreover, babbitt alloys have a variety of failure modes. Branagan made a survey of damage investigation of babbitted industrial bearings and discussed the major individual damage types [15]. For the babbitt-steel bimetal material prepared by the MIG method, most applications only consider the bonding strength, such as rolling mill, compressor, gear box, etc., and there are currently few literatures on fatigue strength. However, for the main bearings and connecting rod bearings used in internal combustion engines, the fatigue strength of the bearing materials must be tested before application. One of the methods for measuring fatigue strength is to test the bearing material using the sapphire fatigue test machine, which has been widely used in the detection of fatigue strength for sliding bearing materials of internal combustion engines.

In this study, the test bearing material was prepared by MIG brazing, and then manufactured into test bearings. During manufacturing process, the test bearings needed to be subjected to ultrasonic flaw detection and coloring flaw detection. Besides, the test bearings should pass the inspection according to the drawing. After that, a sliding bearing was randomly taken out to observe the metallographic structure under a metallographic microscope and the bonding status of the joint interface under a scanning electron microscope (SEM). Next, three test bearings were mounted on the sapphire fatigue test machine [16–19] in sequence and subjected to fatigue tests in accordance with the test procedure. Finally, the test results were analyzed in depth.

* e-mail: yinzw1972@163.com

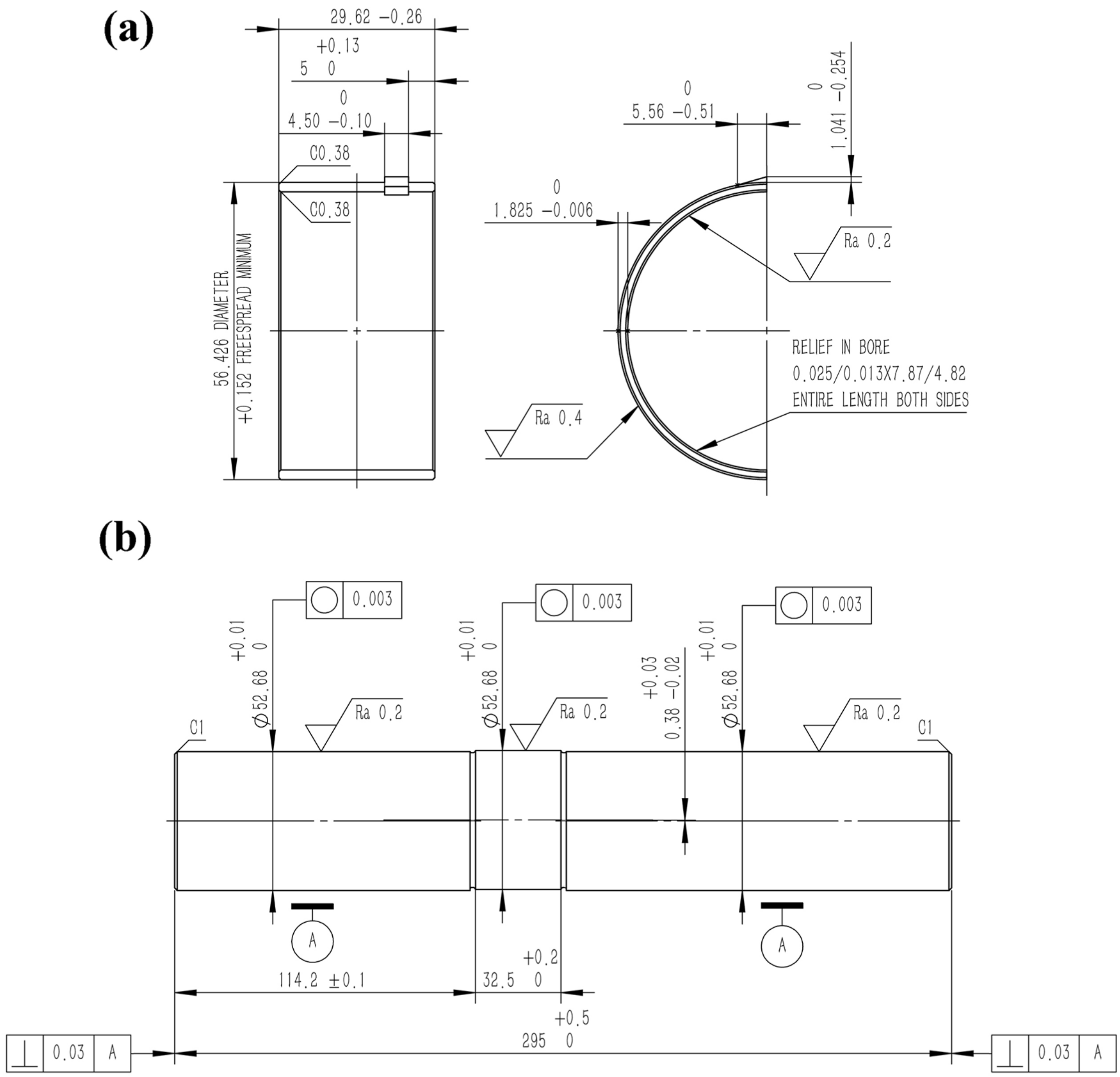


**Fig. 1.** Drawings of (a) test journals and (b) test shafts.

**Table 1.** Chemical composition of babbitt alloy SnSb11Cu6 (wt.%).

| Chemical composition | Sn | Sb | Pb | Cu | Fe | As | Bi | Cd | Others |
|---|---|---|---|---|---|---|---|---|---|
| SnSb11Cu6 | Remainder | 10.0–12.0 | 0.35 | 5.5–6.5 | 0.08 | 0.10 | 0.08 | 0.05 | ≤0.2 |

## 2 Experimental details

### 2.1 Test bearings and shafts

The drawings of test bearings and test shafts are shown in Figure 1. For test bearings, the material of steel substrates was ASTM 1010, and the material of linings was babbitt alloy SnSb11Cu6. The chemical composition of babbitt alloy SnSb11Cu6 is shown in Table 1. The maximum thickness of lining for each test bearing was $0.3 \pm 0.05$ mm. The test shafts were made of steel ASTM 4140, the test parts of which were eccentric, and the hardness of the test parts was 48-52 HRC. In this study, except that one bearing was not involved in the test, but was used for observation of metallographic structure and taking SEM photo, three test bearings and three shafts were needed for fatigue tests. They were named test bearing 1, 2, 3, and shaft 1, 2, 3.

### 2.2 Preparation of test bearings

For MIG brazing between babbitt alloy and steel, the inert gas for protecting welding was pure argon, and the diameter of the babbitt alloy wire for welding was 1.6 mm. The ASTM 1010 steel pipe was cut into two semicircles along the central axis by wire-electrode cutting,

**Table 2.** Parameters of MIG brazing.

| Current (A) | Voltage (V) | Inert gas flow rate (L/min) |
|---|---|---|
| 125 | 21 | 15 |

**Table 3.** Properties of Shell Rimula R3 Multi 10W-30.

| Parameters | Values |
|---|---|
| SAE viscosity grade | 10W-30 |
| Density at 15 °C (kg/m$^3$) | 881 |
| Kinematic viscosity at 40 °C (cSt) | 75.1 |
| Kinematic viscosity at 100 °C (cSt) | 11.5 |
| Dynamic viscosity at −25 °C (mPa·s) | 6700 |
| Viscosity index | 147 |

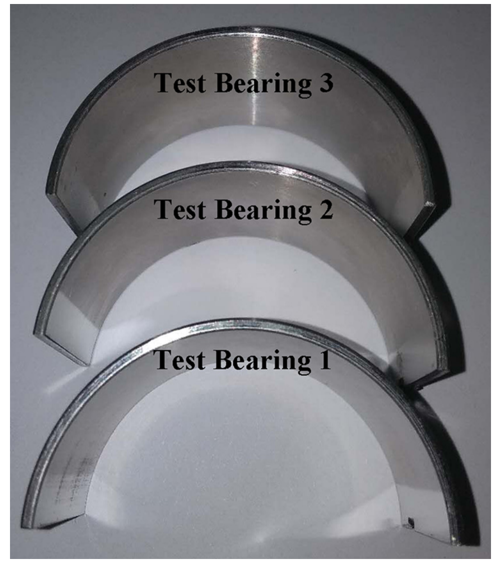


**Fig. 2.** Test bearings.

and then was manufactured for the following welding. Before welding, the substrate surface for welding and babbitt alloy wire should be cleaned up. Different welding parameters can cause different mechanical properties of babbitt-steel bimetal bearing material [11]. Based on our research experiences in babbitt wires for welding and welding processes, the welding parameters in this study are shown in Table 2. After welding, the welded babbitt-steel blanks were rough machined and then inspected by ultrasonic testing. The ultrasonic testing of the babbitt-steel bimetallic test bearing was carried out according to the standard ISO4386-1. The results showed that no defects such as shelling and looseness were found at the joint interface between the babbitt and the steel back, and the bonding state was good. After ultrasonic testing, the blanks were manufactured into test bearings according to drawings. The test bearings are shown in Figure 2. After finishing manufacture, the surfaces of test bearings were subjected to coloring inspection according to ISO4386-3, and no red line or spot defects were found.

### 2.2.1 Experimental methods

The schematic diagram and physical map of sapphire test machine are shown in Figure 3. The test bearing is held in the rod-half of a connecting rod/piston assembly. Reciprocating motion of this assembly is induced by the eccentric portion of the rotating shaft, and the shaft itself is supported rigidly in slave bearings. The downward motion of the piston is resisted by the build-up of oil pressure in the cylinder chamber. A relief valve controls the maximum pressure in the chamber, and hence the load on the test bearing. The rod-half test bearing is subjected to a sinusoidal load for a prescribed test bearing. If the load is high enough, this will cause fatigue of the bearing lining material. During the upstroke, oil is supplied to the cylinder via inlet valves. The cap-half connecting rod bearing is only subjected to low load.

The load applied to the test bearing is measured by strain gauges fixed to the connecting rod. The signal from the strain gauges is collected and outputs to a computer. The connecting rod is calibrated prior to assembly, so that a continuous measurement of bearing load is possible. The temperature at the back of the test bearing is measured by a thermocouple, recorded and displayed on the computer. The lubricating oil temperature at the lubricating oil inlet is controlled at 70 °C. In this study, the lubricant for tests was Shell Rimula R3 Multi 10W-30 oil. The main properties of the lubricating oil are listed in Table 3.

The procedure involves a sequence of 20 h test runs, each subsequent test being carried out at a higher load. The load increment is 3 MPa and the starting load is selected 5 to 6 increments below the expected mean rating of the material according to the empirical value of babbitt-steel bimetal bearing material. Each test of 20 h is equivalent to $3.6 \times 10^6$ load cycles. Firstly, the test bearing experiences a run-in for 30 min under no-load conditions. Then the load is increased to the starting load selected. After tested for 20 h, the test bearing is removed and examined closely for cracks by naked eye or with low magnification. If cracks exist, the test is terminated and the result is noted. If the bearing is undamaged, then the bearing is refitted and the test continues at a higher load.

## 3 Results and discussions

The load and temperature curves under maximum load, i.e., fatigue strength are shown in Figure 4, which illustrates the fatigue strength of the three test bearings is 40 MPa, 40 MPa and 43 MPa, respectively. The temperature at the back of test bearings fluctuated around a stable value, and the temperature value under a larger load was higher than that under a lower load.

After tests, the test bearings are shown in Figure 5. For test bearing 1 and 2, there were many cracks on the inner surfaces, and for test bearing 3, sheet-like peeling occurred on the inner surface. In engineering practice, cracking and spalling are common modes of fatigue failure for babbitt-

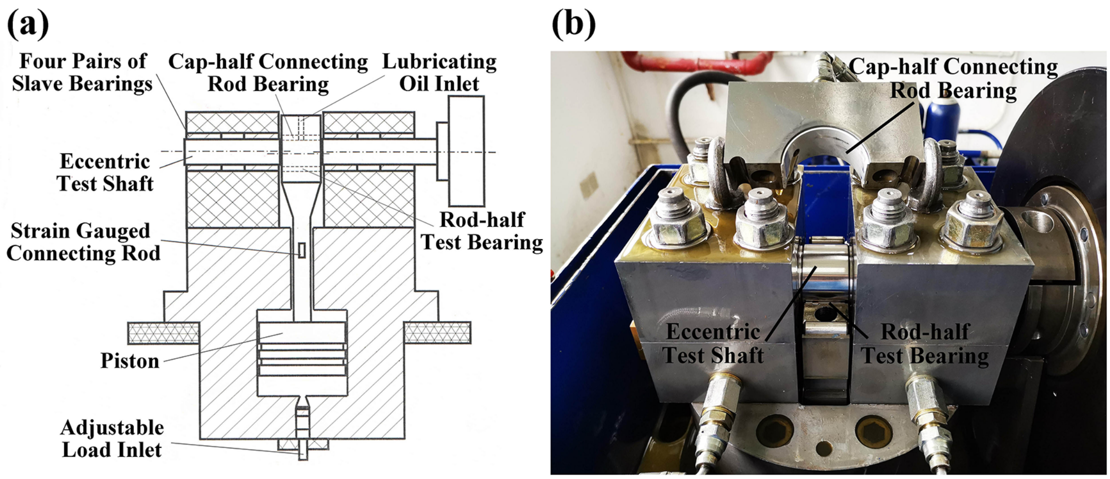


**Fig. 3.** (a) Schematic diagram of sapphire test machine. (b) Physical map of sapphire test machine.

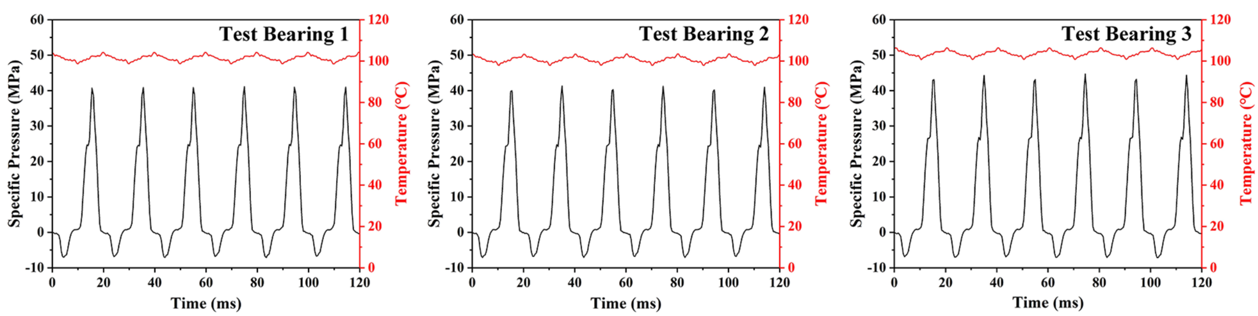


**Fig. 4.** Load and temperature curves under maximum load (fatigue strength).

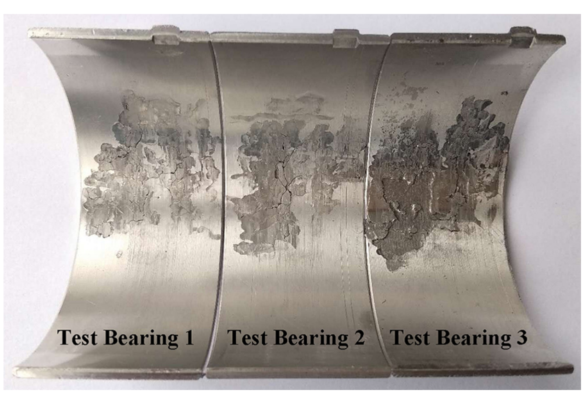


**Fig. 5.** Fatigue damaged test bearings.

steel bimetal sliding bearings, which are the same with the test study above. As the test progressed, the temperature gradually increased, and the strength and hardness of the babbitt alloy decreased greatly with the increase of temperature [20]. Under the action of periodic impact load, once the impact load exceeded the fatigue strength of the babbitt alloy, micro-cracks usually appeared on the surface of test bearing, and simultaneously, the lubricating oil entered the gaps of micro-cracks and accelerated the propagation of cracks under the impact load. In addition, the temperature rose, thermal stress occurred inside and on the surface of the babbitt alloy material, which was also one of the factors that caused micro-cracks on the surface of the test bearing. Under the action of the pulsating oil film pressure, the cracks propagated along the normal direction of the surface of test bearing. When the cracks extended close to the joint interface, they continued to extend in a direction parallel to the joint interface. After the cracks met each other, sheet-peeling occurred.

The SnSb11Cu6 babbitt alloy consists of the hard phase and the soft phase, and the $\beta$ phase (SnSb) and ε phase (Cu6Sn5) which are both the hard phases and are dispersed in the soft phase $\alpha$ solid solution. The $\beta$ phase is cuboidal, and the size of $\beta$-phase grains in the babbitt layer is different due to the difference in the content of trace elements or the preparation processes. The ε phase is needle-like or star-shaped, forming a hard phase skeleton of the babbitt alloy, which prevents segregation of the $\beta$ phase during crystallization. After the SnSb11Cu6 babbitt alloy is welded on the steel back, an intermetallic compound layer with Fe and Sn as the main elements is formed at the joint interface to form a transition layer from babbitt lining to steel back. This transition layer can enhance the bonding strength of babbitt-steel bimetal material. When babbitt SnSb11Cu6 acts as the lining and ε phase is concentrated on the babbitt side of the transition layer, the crack

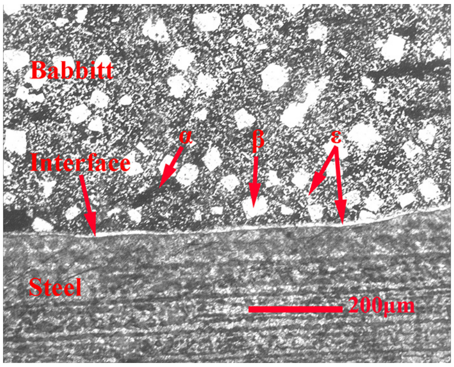


**Fig. 6.** Metallographic structure of the babbitt-steel bimetal bearing material prepared by MIG brazing (100X).

**Table 4.** EDS data of marked points in SEM image (at. %).

| Point | Sn | Sb | Fe | Cu |
|---|---|---|---|---|
| 1 | 62.05 | 13.65 | 3.79 | 20.51 |
| 2 | 66.49 | 15.22 | 14.19 | 4.1 |
| 3 | 43.44 | 9.92 | 43.32 | 3.32 |
| 4 | 2.37 | 0.94 | 94.18 | 2.51 |

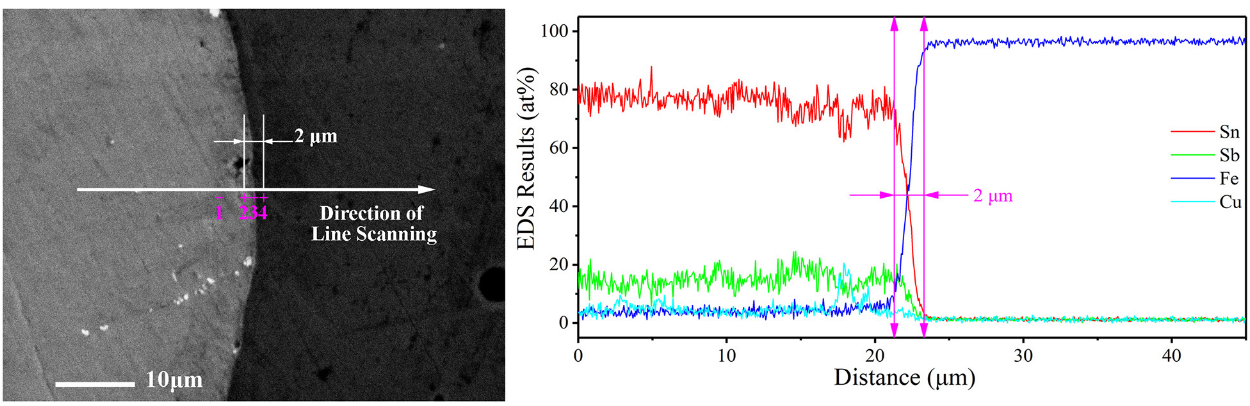


**Fig. 7.** SEM image and EDS analysis around interface of babbitt-steel bimetal bearing material.

propagation is inhibited and the bonding strength is improved [2]. If the hard and brittle $\beta$-phase grains are coarse and the segregation is serious, the stress concentration is likely to occur and the crack is likely to be generated and expanded. If the $\beta$-phase grains are fine and uniform in distribution, in addition to expanding in the $\beta$ phase or along the grain boundary of the $\beta$ phase, the cracks will propagate by tearing the $\alpha$ solid solution and breaking the $\varepsilon$ phase, which will have a greater resistance. Therefore, the finer the crystal grains are and the more uniform the grain distribution is, the higher the fatigue strength is. By observing Figure 6 which shows the metallographic structure of the SnSb11Cu6 babbitt-steel bimetal bearing material prepared by MIG brazing, it could be seen that around the joint interface there was a segregation layer of acicular $\varepsilon$ phase, which increased the resistance of crack propagation in the vicinity of the interface and improved the bonding force of babbitt-steel bimetal material. Figure 6 also shows that the $\beta$-phase grains were fine and uniformly distributed in $\alpha$ solid solution. Therefore, when the cracks propagated, the expansion resistance was inevitably large, and so the material had strong fatigue strength. The elemental composition near the interface was analyzed by SEM image and EDS line scanning, as shown in Figure 7, and it was found that there was an intermetallic transition layer mainly composed of Fe and Sn elements in the vicinity of the interface, and the thickness thereof was about 1.5 $\mu$m to 2 $\mu$m. There was a clear accumulation of copper element on the babbitt side of the transition layer, indicating the presence of $\varepsilon$ phase. The element contents of the four points marked in Figure 7 were showed in Table 4. The results of EDS line scanning confirmed the analysis of the metallographic structure in Figure 6. The test proved that the babbitt alloy prepared by MIG brazing had high fatigue strength, which was in agreement with the above analysis results.

## 4 Conclusions

This study referred to the test method for the fatigue strength of bearing materials of internal combustion engines, used the sapphire test machine to inspect the SnSb11Cu6 babbitt-steel bimetal material prepared by MIG brazing. The test results illustrated that by MIG brazing preparation method, SnSb11Cu6 babbitt-steel bimetal bearing material could obtain good fatigue strengths, which were 40 MPa, 40 MPa and 43 MPa, while according to the same test method and conditions on the same sapphire test machine the centrifugal casting method usually gains the fatigue strength of around 35 MPa. The modes of fatigue failure were consistent with those in engineering practice, which were cracking and spalling. By observing the metallographic structure, the $\beta$-phase grains were fine and uniformly distributed, and no segregation occurred, which would increase the resistance to crack propagation and thus improving the fatigue strength. The results of EDS line scanning showed that there was an intermetallic transition layer mainly composed of Fe and Sn elements in the vicinity of the interface. On the babbitt alloy side of the transition layer, there was a segregation layer in which the $\varepsilon$-phase crystal grains were aggregated, and the segregation layer could prevent the crack propagation, improve the bonding strength, and thereby improving the fatigue strength. The test results are consistent with the analysis results.

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