FRICTION-WEAR PROPERTY OF HIGH SILICON ZA27 ALLOY PREPARED BY SPRAY DEPOSITION①

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ABSTRACT The friction-wear properties of spray deposited 6% silicon ZA27 alloy have been investigated, and compared with those of conventional casting ZA27 alloys containing silicon or not. The experimental results indicate that wear resistance and antifriction abilities of the material prepared by spray deposition are about 3.4~ 8.1 times and 1.6~ 2.4 times higher than those of conventional casting alloys respectively. The reasons for the improvements of friction-wear performance were also investigated from the view of microstructures.

Key words spray deposition zinc-based alloy tribology microstructures

1 INTRODUCTION

Conventional casting high silicon aluminum zinc-based alloys (ZA) have superior ambient mechanical properties and excellent tribological properties. Much study has been carried out on the influence of the new forming process on the mechanical properties of ZA alloys. Some former research results showed that the composites manufactured by extrusion casting, rheocasting and vacuum infiltration had very outstanding friction-wear properties[1-3]. Therefore, adopting novel processes would be an effective way to improve the properties and widen application range of the ZA alloys. For example, much attention has been given to spray deposition, which is a new rapid solidification technique[4]. We will discuss the friction-wear properties of 6% silicon ZA27 alloy manufactured by the spray deposition, comparing with those of the conventional casting ZA27 alloys whether containing silicon or not.

2 EXPERIMENTAL DETAILS

2.1 Sample preparation

The procedures preparing deposits were carried out as follows. First, the master ZA27 alloy was melted in an electric resistance furnace. Then 6% silicon and 0.3% rare earth were added into the melt and they were superheated to 780 ℃ holding for 15 ~ 20 min. At last the molten metal was transferred into the middle package of the spray deposition apparatus to get the deposits. The conventional casting samples of ZA27 alloy were also made for comparison. The sample number, composition and process are shown in Table 1.

Table 1 Composition and process of material investigated

No.	Composition	Processing
1	ZA27	conventional casting
2	ZA27+ 6% Si + 0.3% RE	conventional casting
3	ZA27+ 6% Si + 0.3% RE	spray deposition

2.2 Wear tests

The wear experiment was carried out on an MM-200 wear and abrasive testing machine. The schematic diagram is shown in Fig. 1. During the experiment, the upper sample was kept

① Supported by the Aeronautical Science Foundation and the National Doctorate Program Fund of State Education Committee of China
Received Nov. 20, 1995; accepted Jan. 10, 1995

on static while the lower one revolving around the shaft. In all testing, sliding speed was kept at 0.418 m/s and 30~ 40 lubricating oil droplets were dripped onto the surface of samples at 2 s intervals. The experimental loads were 300, 500 and 700 N respectively. Each experiment was finished in 3 h.

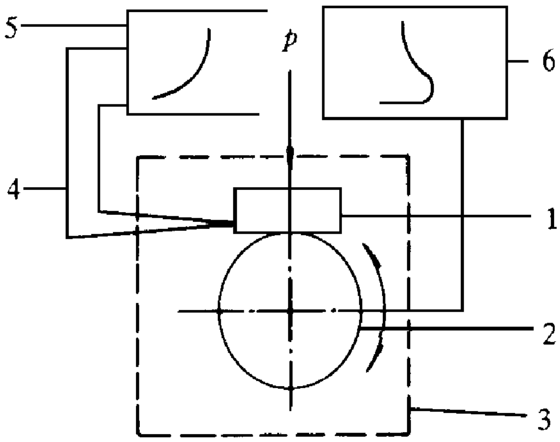

Fig. 1 Schematic diagram of wear and abrasive testing installation

1 —Upper sample; 2 —Lower sample;
3 —MM-200 wear and abrasive testing machine;
4 —Thermocouples; 5 —Temperature Recorder;
6 —Friction moment recorder

The upper samples of 18 mm × 8 mm × 8 mm were machined from the materials investigated. Lower samples were made of 45 steel, heat treated to give a hardness of HRC 50 ±2.

3 EXPERIMENTAL RESULTS

3.1 Wear-resistant property

The wear-resistant property was measured by the amount of upper sample's weight loss during the testing. Table 2 shows the relationship between the wear-resistant property and the load. The heavier the load, the larger the weight loss. The conventional casting ZA27 alloy (No. 1) had the poorest wear-resistant property. After adding silicon to ZA27 alloy (No. 2), the wear resisting property was greatly improved. The wear resistance of the spray deposited material (No. 3) was approximately equal to that of No. 2 material.

3.2 Antifriction property

Table 2 Weight loss of upper samples/ mg

Materials	Applied load/ N		
	300	500	700
1	16.2	28.5	39.8
2	1.5	6.8	9.3
3	2.0	8.4	11.7

As an excellent bearing material, it should have superior antifriction ability and good wear resistance. In this paper both the weight loss of the lower samples and friction coefficient were used to evaluate the antifriction ability.

The friction coefficient during wear testing changes with the friction moment (Table 3) and can be expressed as follows:

$$\mu = \frac{M}{R \times p} \cdot \frac{\alpha + \sin\alpha\cos\alpha}{2\sin\alpha} \qquad (1)$$

Table 3 Friction coefficient($\overline{\mu}$) of the samples under different load

Materials	Applied load/ N		
	300	500	700
1	0.07	0.09	0.09
2	0.05	0.05	0.08
3	0.04	0.04	0.06

where R is the radius of the upper sample; p is the load; α is the contact angle between the upper and lower samples. When the load was fixed, the change of friction moment reflected the change of the wear coefficient because there was little change of the contact angle. Neither the friction moment nor the wear coefficient was a constant.

Therefore, we could use the mean wear coefficient $\overline{\mu}$ to evaluate the material's antifriction ability:

$$\overline{\mu} = \frac{W}{2\pi RNp} \qquad (2)$$

where W is the total friction work in each testing, N is the total rounds of the lower sample. The relationships between the mean friction coefficient of the materials and the load are shown in Fig. 2, and the mean friction coefficient of spray deposits has the least value.

The relationship of the shaft-wear amount and load is shown in Table 4. The amount of weight loss of the shaft in contact with spray deposited material had the least value. Although adding silicon to the ZA27 alloy improved the wear-resistant property, it still cannot be used to manufacture bearing, because it intensively wears the shaft.

Table 4 Shaft-wear amount of the samples/ mg

Materials	Applied load/ N		
	300	500	700
1	0.7	4.3	5.4
2	1.9	5.5	6.3
3	0.7	2.3	3.4

3.3 Microstructures

The improvement of the friction-wear property is related to the difference of the microstructures. The microstructure of the conventional casting ZA27 alloy is composed of α(Al), copper-rich phases and interdendritic eutectic phases (Fig. 3(a)). The microhardness (HV) of the α(Al) phases is 110, which is higher than that of the copper-rich phases (HV 60~ 80) and the interdendrite eutectic phases (HV 37 ~ 50). Therefore this material belongs to the bearing alloy of soft-particle and hard-matrix. When 6% silicon is added to the ZA27 alloy, the bulky polygon silicon-rich phases appear and their volume fraction is about 5% ~ 10%. The other microstructure is the same as the above material except that the volume fraction of interdentrite eutectic phases increases a little (Fig. 3(b)). The microhardness (HV) of silicon-rich phases is 1 300 and its compressive strength is much greater than that of the α(Al) phases.

The microstructure of the spray deposit materials varies greatly (Fig. 3(c)). Its unetched optical image is made up of the dispersed circular silicon-rich phase (approximately 20% ~ 25% (in volume)) and the matrix. The matrix seen from the SEM image is the lamellar eutectoid, in which the black and white lamellar phases are the solid solutions based on aluminum and zinc respectively. So it belongs to the hard-particle and soft-matrix bearing material.

4 ANALYSIS AND DISCUSSION

4.1 Wear-resistant property and shaft-wear property

As we know metals will deform elastically or plastically when they are loaded. If the value of the load is over one third of that of the hardness(HV), soft materials shall deform plastically. At this time, as the load increases the average stress keeps at a constant and the contact area will increase to support the load. Therefore we may suppose that the soft material is in the condition of elastic deformation when the value of the average stress is under one third of the value of the hardness. According to the Hertz's contact stress theory, we can work out the maximum load only producing elastic deformation.

Supposing that the samples contact smoothly, the average stress can be expressed as follows:

$$\sigma = p/(2bL) \tag{3}$$

and

$$b = \sqrt{8pR'/(\pi LE')} \tag{4}$$

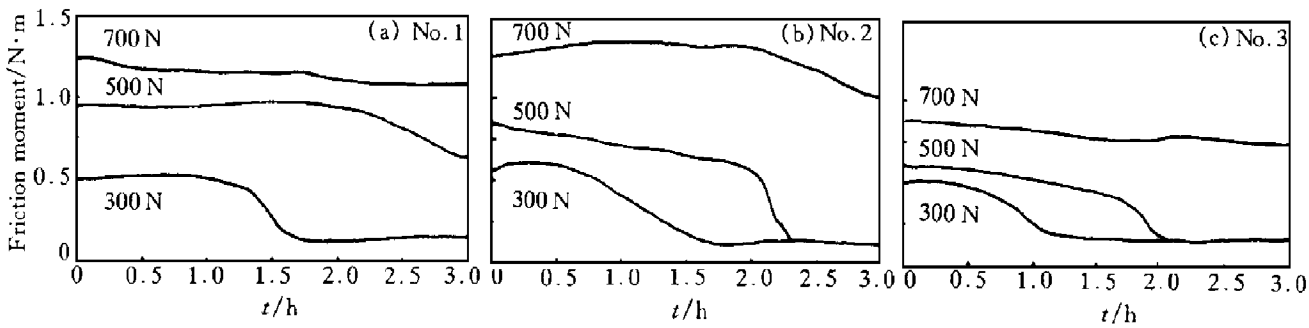

Fig. 2 Relationships between moment and time under different loads

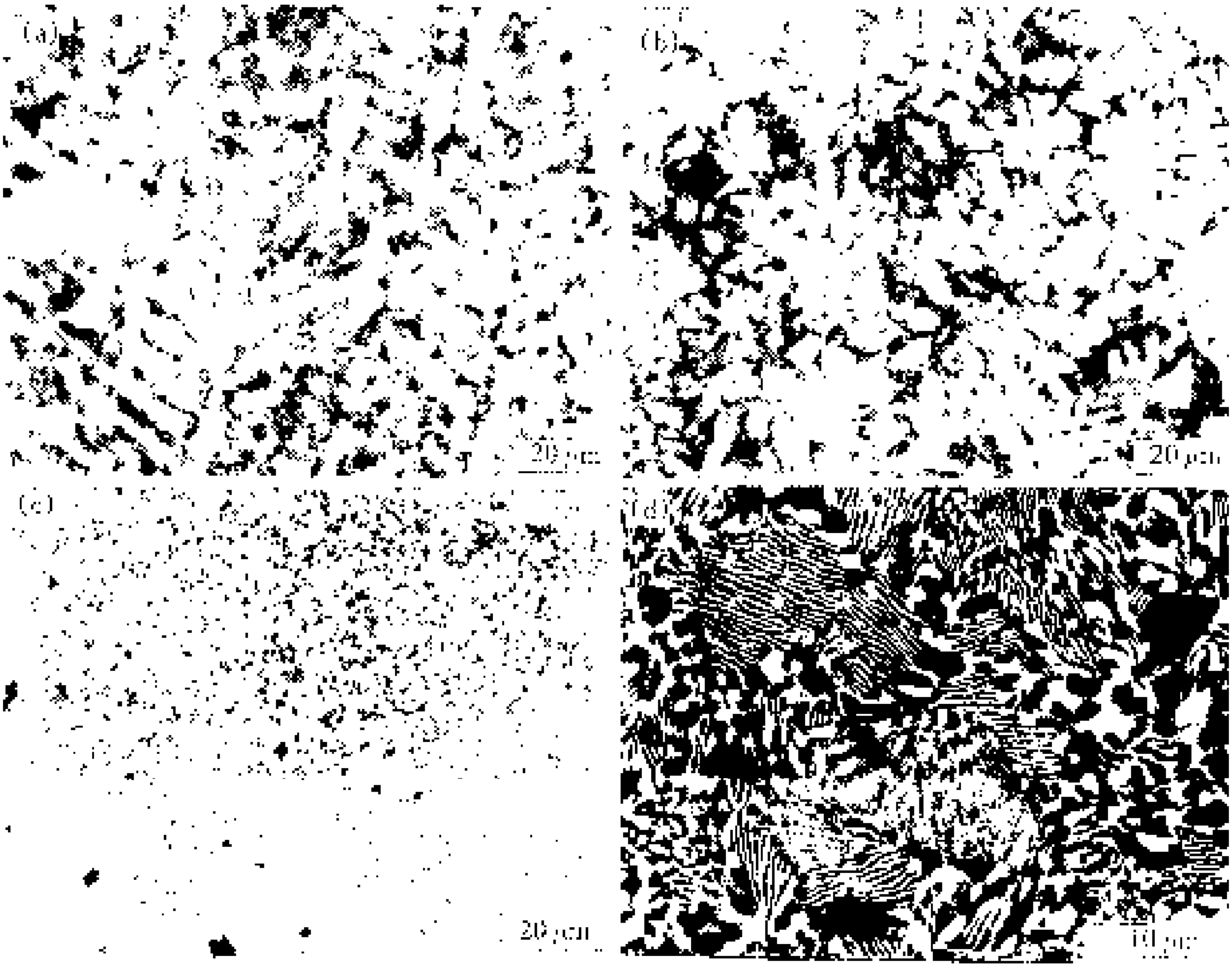

Fig. 3 Microstructures of materials

(a) —1# material; (b) —2# material;
(c) —optical image(unetched) of 3# material; (d) —SEM image of 3# material

where L is the length of contact line; R' is the equivalent radius and E' is the equivalent elastic module.

According to the above assumption and eq. (3), the maximum load for producing elastic deformation only can be deduced as follows:

$$p_{\max} < \frac{32}{9\pi} \cdot L \cdot B^2 \cdot \frac{R'}{E'} \quad (5)$$

where B is hardness HB; $p_{\max}$ is shown in Table 5.

Table 5 Maximum load to produce elastic deformation only

Sample number	HB	$p_{\max}$ / 10^{-3} N
1	112	2.12
2	106	1.90
3	102	1.76

$1/E' \approx (1/2)(1/E_1 + 1/E_2)$; the elastic module E_1 of the materials investigated is 7.35 TPa, the elastic module E_2 of the lower sample is 1.96 TPa.

The calculated results showed that all of the testing loads are greater than the maximum value of elastic deformation. Therefore, plastic flow would happen in the upper sample even on the condition of static load and adhesion phenomenon would happen in some regions.

In the conventional casting ZA27 alloy, the primary α phases are the hard matrix while the interdentric eutectic phases play the role of the soft phases. After machined and a pre-wearing, lots of contact points were formed between the α phases and the lower samples(Fig. 4(a)). However the first α phase is face-centered cubic structure, and it will soften and deform plastically in the wear testing. After adding silicon to the alloy, the bulky polygon silicon-rich phases had excellent high-temperature properties. They damaged the shaft seriously but wore a little themselves(Fig. 4(b)). A large amount of silicon-rich phases in the spray deposits increased wear resistance of the samples but did not damage the shaft seriously (Fig. 4(c)). So it has excellent wear performance.

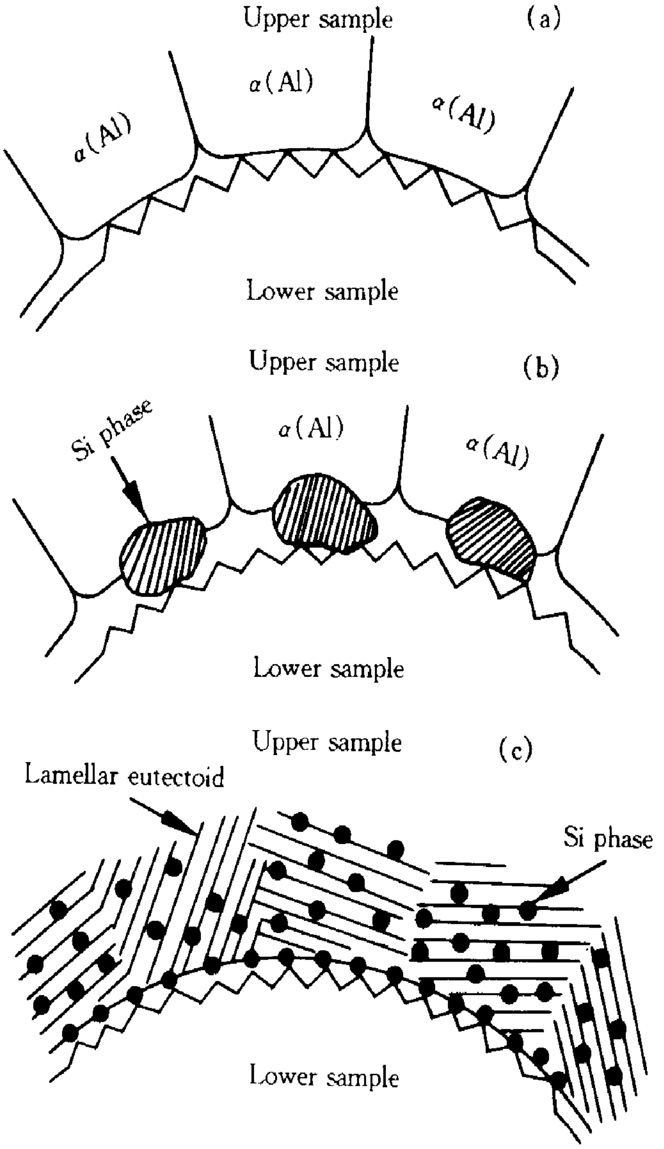

Fig. 4 Microstructure models of wear surface

4.2 Friction coefficient

According to the classic friction law, the friction force F varies directly as the normal load p changes, i.e. $F = \mu p$. When the load is kept at constant, the wear coefficient mainly changes with the friction force. The wear force comes from the shearing force of the contacting points and the furrow force between the soft surface and hard particles. Different microstructures are the main reasons for the various wear forces. In the conventional casting ZA27 alloy, the wear force mainly comes from the shearing force of the particles, but after adding silicon, the wear force mainly comes from the furrow force. The adhesion tendency of the close-packed hexagonal structure zinc-rich phases in the spray deposits is less than that of the α (Al) phases (*fcc*) of the conventional casting alloys, and the furrow force of dispersed silicon-rich phases is less than that of bulky polygon silicon-rich phases. Therefore the spray deposits have the least friction coefficient.

5 CONCLUSIONS

(1) After adding 6% silicon to the conventional casting ZA27 alloy, a large amount of bulky polygon silicon-rich phases are formed in the alloy, which greatly improve the wear-resistant property of the sample but make its mating component (the shaft) wear seriously.

(2) Wear amounts of the three materials have a positively linear relationship with the load, which is fit to the Archard law. Friction coefficient changes a little as the load increases.

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(Edited by Huang Jinsong)