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Worn surface characteristics of Cu-based powder metallurgy bake materials for aircraft

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Abstract: Cu-based powder metallurgy brake materials are used for aircraft widely and successfully. The characteristics of worn surface of Cu-based powder metallurgy brake materials for aircraft after working under service condition were studied, and two main wear mechanisms were discussed. The results show that the main components of worn surface are graphite, SiO_2, Fe, Cu and oxide of Fe (Fe_3O_4 and FeO); the worn surface can be divided into three zones: severe wear zone, mild wear zone, and low wear zone; fatigue wear and grain wear are the main wear mechanisms of Cu-based materials. Some debris kept between brake discs reduce the wear rate to a certain extent by taking part in the regeneration of friction film.

Key words: powder metallurgy brake materials; wear; copper matrix; aircraft; worn surface

1 Introduction

Powder metallurgy(P/M) brake materials are made of metal matrix, friction components and solid lubricants. They are normally classified into three types according to the matrixes, i.e. Cu-based, Fe-based and Cu-Fe-based brake materials[1−2]. Compared with Fe-based and Cu-Fe-based materials, Cu-based materials have many advantages, such as better heat conductivity, higher anti-wear property. As a result, Cu-based brake materials are successfully and widely used for aircraft brake materials[3].

The information of friction surface as brake materials working under service condition is very important for the wear mechanisms[4−5], for the characteristics of worn surface after braking can reveal the wear mechanisms, and even more, help to evaluate the performances of brake composites[6−9]. However, systematic research on friction mechanisms and wear theory on copper based powder metallurgy brake material are scare.

The main aim of this research is to investigate the characteristics of worn surface and the main wear mechanisms of Cu-based aircraft brake materials.

2 Experimental

2.1 Sample preparation

Specimens were prepared from commercial powders of electrolytic Cu powder (<75 μm), Sn powder (<90 μm), flake graphite powder (180 μm), sponge Fe powder (<74 μm) and natural SiO_2 powder (74−590 μm). The powders listed in Table 1 were weighed and blended in a V-cone mixer for 8 h. The blended powder was compacted in a die (50 mm in diameter) under 400 MPa. The height of the compact was approximately 6 mm.

Subsequently, the specimens were sintered in a bell furnace full with dry H_2 at temperature of 1 000 ℃ for 3 h. The pressure was controlled at 3.5 MPa by using a lever arm placed on the top of an upper punch. The

Table 1 Chemical compositions of Cu-based materials (mass fraction, %)

Matrix elements		Abrasion elements (SiO_2)	Lubrication elements (graphite, MoS_2)	Alloy elements (Sn, Mn)
Cu	Fe			
50−60	15−20	5−10	15−20	5

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sintered specimens were cooled by water till lower than 100 ℃ and then machined into rings with sizes of 75 mm in outer diameter and 53 mm in inner diameter.

2.2 Testing and analysis

The friction and wear properties tests with 30CrMoSiVA structural steel (HRC40) as counterpart were carried out on a ring-on-ring tester with the load of 0.5 MPa, moment of inertia of 2.5 kg·cm^2 and rotating rate of 6 500 r/min.

X-ray diffraction(XRD) analysis for the worn surface was carried out on a Rigaku-3014 type X-ray diffractometer. Morphologies of the worn surface were investigated by KYKY-2800 scanning electron microscope(SEM).

3 Results and discussion

3.1 XRD analysis of worn surface

The XRD pattern of the worn surface is shown in Fig.1. It can be seen from the pattern that the main components of worn surface are graphite, SiO_2, Fe, Cu and oxides of Fe (Fe_3O_4 and FeO).

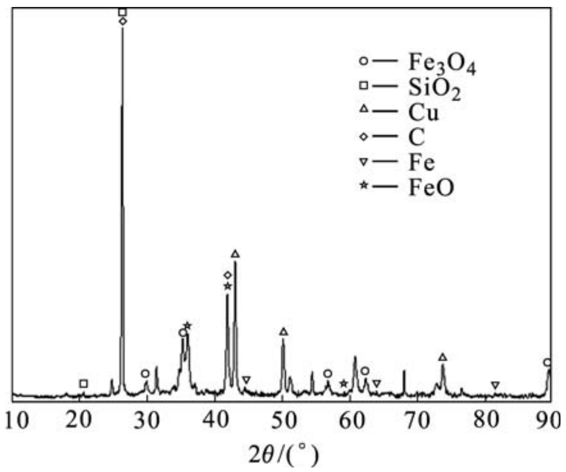

Fig.1 XRD pattern of worn surface

Graphite has layer structure with wider interlayer spacing, which tends to cleave along the layers. So it is widely used as lubricant to eliminate seizure and make the brake process stable. Consequently, the tribological properties of brake materials are improved. The resistance and hardness of SiO_2 particles are much higher than those of the Cu and Fe matrix. Therefore, the friction of SiO_2 against counterpart is intense during sliding, which hinders the relative movement of friction pairs and enhances friction coefficient remarkably. Proper quantities of metallic phase existing in friction film can be used as bond and favor the deformability of the friction film. Fe_3O_4 and FeO are oxides of Fe elements. Because spinal structure Fe_3O_4 can act as lubricant to a certain extent, its existence on the worn surface can improve the abrasive properties of composites. Moreover, the concurrence of Fe_3O_4 and FeO indicates that the worn surface is at a temperature around 600 ℃ during sliding [10]. Under this condition, no oxides of Cu are detected due to the sacrificing oxidation of Fe and graphite.

3.2 Characteristics of worn surface

The investigation of worn surface shows that the worn surface can be divided into three zones, named zone A, zone B and zone C according to the degree of destruction of friction film, as shown in Fig.2. Zone A is rough, which indicates severe wear happened during sliding. Zone B is relatively smooth, which indicates mild wear occurred during sliding. Zone C has mirror surface, glassy luster and integrated friction film, which shows this zone has better wear resistance property. In addition, it can be seen from Fig.2 that zone B and zone C spaced distribute and zone A block distributes among zone B and zone C.

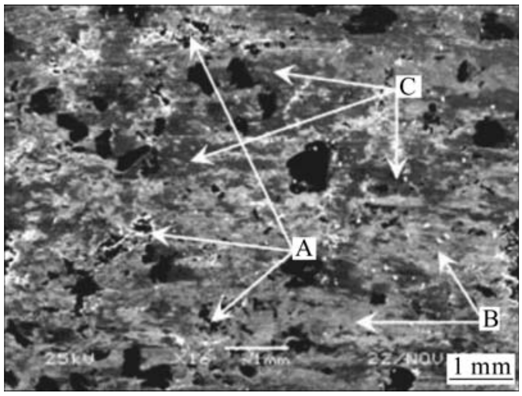

Fig.2 Low-magnification morphology of worn surface

The morphologies of zone A were observed by SEM. Three types of microstructures are found in zone A, which correspond various abrasion mechanisms, namely fatigue wear and grain wear, respectively.

3.2.1 Zone A

1) Fatigue abrasion

The typical microstructure of Cu-based aircraft brake material is shown in Fig.3, in which the arrow shows the direction of compaction. It is noted that graphite distributes over the composite in tiers, following the vertical direction of compaction in the main. The reason is related with the movement direction of pressure and compressive displacement of the graphite. During compaction, the graphite strips generate displacement and rotary motion, which results in tiering up of graphite

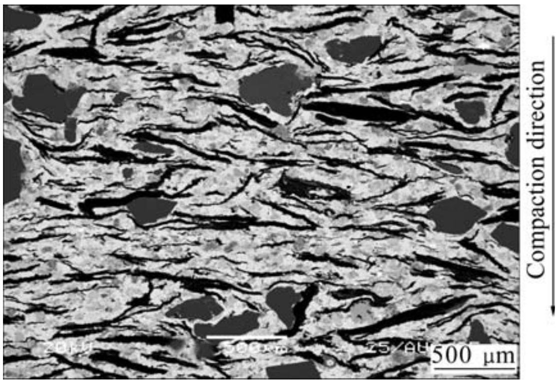

Fig.3 Micrograph of composites

strips. According to fatigue wear theory[11−13], when hard surface (the counterpart) slips on soft surface (the Cu-based composites), dislocation stuffs in a certain depth below the soft surface, which results in the initiation of micro-cracks extending parallel to the direction of sliding. It is evident that uniform distribution of graphite strips aggravates the proliferation of the micro cracks, as shown in Figs.4(a) and (b). When the size of micro cracks gets above certain critical dimension, materials between surface and cracks break off in thin sheets, leaving pits on worn surface, as shown in Figs.4(c) and (d).

2) Grain abrasion

The morphologies of worn surface and subsurface of composites are shown in Figs.5(a) and (b). The groove (in Fig.5(a)) reveals plowing happened during sliding. The composites are composed of several elements, but the wear resistance property of each element is different. The hard particles have much better wear resistance than the soft elements. After the other components abrade, the hard particles project on the friction surface, whereby the relative motion between composite and counterpart is prevented, and coefficient of friction is also raised. At the same time, the hard particles projecting on the friction surface are easy to break and crush. The broken and crushed particles roll between friction pairs, plough the worn surface and bring about grain abrasion[14]. Shear marks can be seen from Fig.5(c) that shows the debris of grain-abrasion.

From the data mentioned above, the involved wear mechanisms of Cu-based aircraft brake composites can be classified into two main mechanisms, namely, fatigue induced wear and grain induced wear and any one of them can lead to severe destruction of worn surface and result in over wear, rough brake and even failure in brake.

3.2.2 Zone B and zone C

From the SEM image shown in Fig.6(a), it can be seen that the worn surface is covered with scales; there is evident interface between the matrix and the scales, as shown in Fig.6(b). It has been mentioned that grooves or

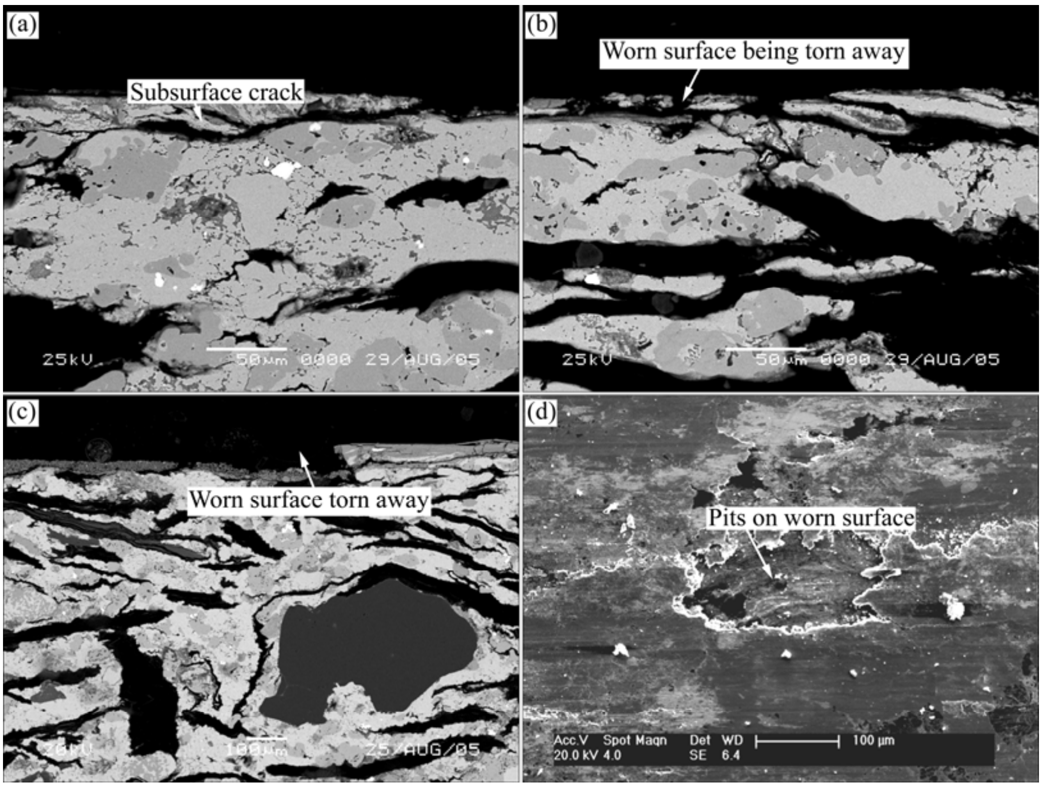

Fig.4 Views of fatigue wear: (a) Subsurface crack; (b) Worn surface being torn away; (c) Worn surface torn away; (d) Pits on worn surface

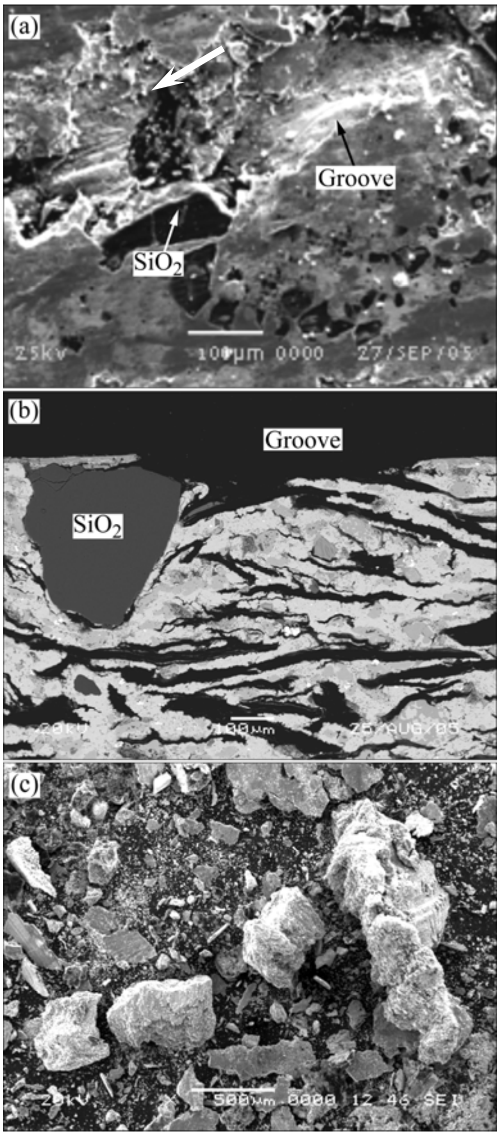

Fig.5 Views of abrasion: (a) Worn surface; (b) Subsurface; (c) Worn debris

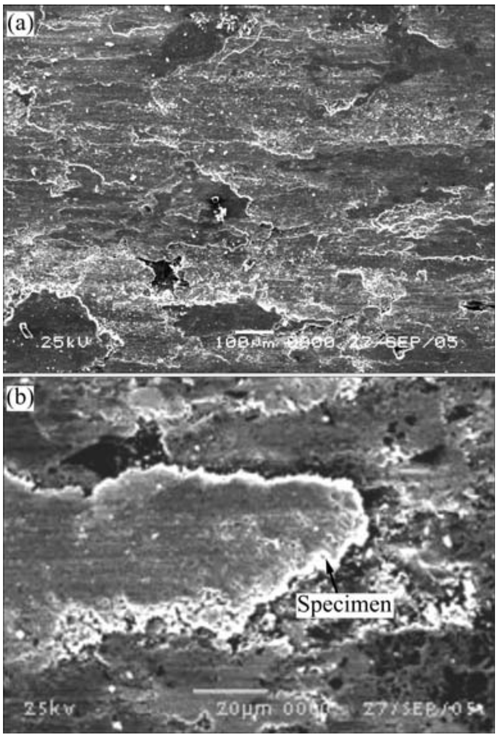

Fig.6 SEM micrographs of mild wear section: (a) Worn surface; (b) Enlarged micrograph of worn surface showing smear

pits generate during wear processes accompanied with wear debris. Part of debris break away from worn surface, while the rest accumulate in grooves or pits transform into friction film under the action of multiaxial stress. This reveals that Zone B is regenerative section of worn surface, during which small extent wear happens, the roughness of the worn surface decreases, and a combination of scales and worn surface forms. Accordingly, mild wear transforms into low wear. The schematic view of regeneration of worn surface is shown in Fig.7.

Fig.8(a) shows the SEM micrograph of low wear zone. Though a few of micro cracks can be seen, the worn surface is quite smooth. It is also found that the friction film is integrated and bonds with matrix tightly, as shown in Fig.8(b). Taking Fig.8 into account, it can be

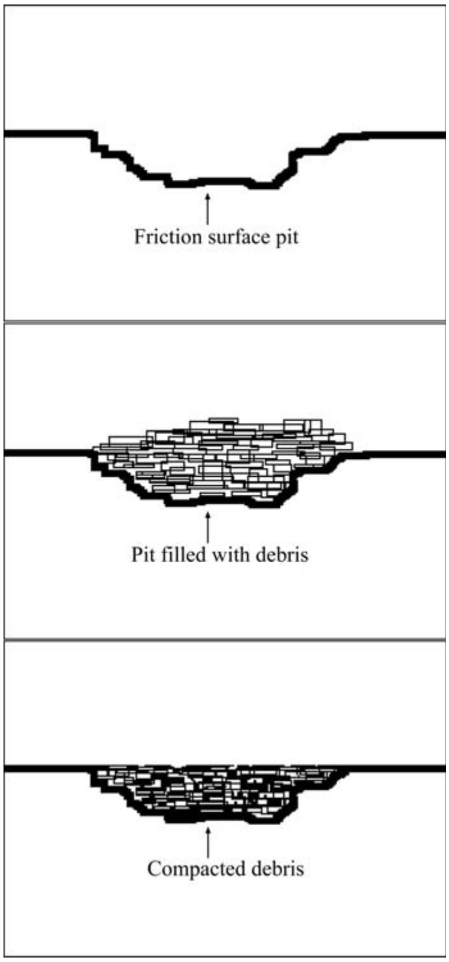

Fig.7 Schematic view of regeneration of worn surface

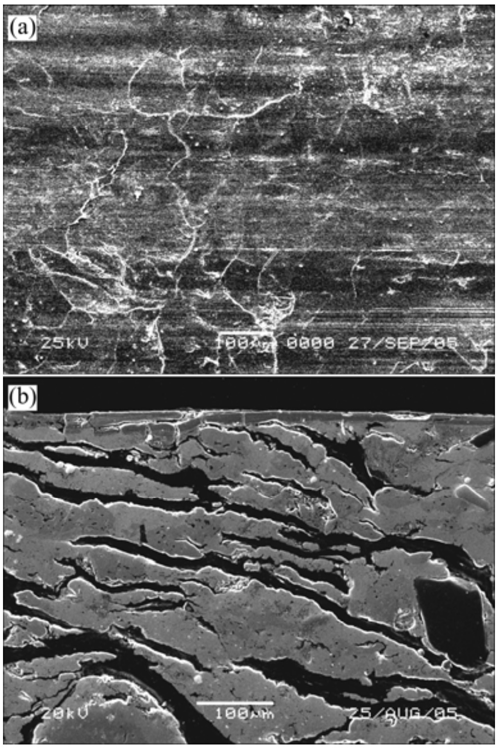

Fig.8 SEM micrographs of low wear zone: (a) Worn surface; (b) Cross-section

concluded that low wear zone results from the regeneration of wear film on mild wear zone.

4 Conclusions

1) The main components of worn surface are graphite, SiO_2, Fe, Cu and oxide of Fe (Fe_3O_4 and FeO).

2) The worn surface can be divided into three zones: severe wear zone, mild wear zone and low wear zone according to degree of destruction of friction film. Grain wear and fatigue wear are the main mechanisms of severe wear. Smear is the main characteristic of mild wear zone, meanwhile the friction film regenerates on it. Low wear zone results from the regeneration of wear film on mild wear zone.

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