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Microstructural Characterization and Mechanical Property of Fly Ash/Al-25Mg Composites

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Abstract: Fly ash/A1-Mg composites are fabricated by powder metallurgical method. The morphology and structure of fly ash/A1-Mg composites are characterized by scanning electron microscope (SEM) and X-ray diffraction, respectively. The influences of different fly ash content on the friction and wear behavior of the composites are investigated at a constant sliding velocity of 400 r/min and the worn mechanism of composites is discussed. The results indicate that the friction coefficient is steadily lower than that of Al alloy matrix at the lower fly ash content and loads. For the fly ash/A1-Mg composites, the wear mechanism is characterized as abrasive wear and adhesive wear under small normal load and at low fly ash content, and it is characterized as delamination wear and abrasive wear transferred onto the counterpart under high normal load and at high fly ash content.

Key words: fly ash; microstructure; friction and wear; wear mechanism

1 Introduction

Aluminum alloys[1,2] are used in many engineering applications due to their light weight and high strength characteristics. However, low hardness and consequently low wear resistance limit their use in some applications. Aluminum metal matrix composites (Al-MMCs) containing particulate reinforcements are considered as the promising solution for imparting better wear resistance to aluminum alloys. The addition of silicon carbide[3-9] and alumina[5] to aluminum alloys was reported to improve their wear resistance. Various other types of reinforcements such as nickel aluminide[10,11], glass[12], boron carbide[13] and aluminum diboride[14] have also been reported as effective reinforcements for improving tribological properties of aluminum based alloys. It was reported that wear resistance increases with increasing reinforcement content due to high hardness and strength of the reinforcement phase.

Recently, there are some researches about fly ash on aluminum matrix composite. Rohatgi P K and his colleagues used pressure casting method to prepare aluminum-fly ash composite[15,16]. G Laplanchea, M K Surappa, R Suraj and others did a lot of interrelated research work about the fly ash comprehensive utilization and its utilization on aluminum alloy[17-19]. They used the disused byproducts such as fly ash as the filling material to put into light metal and its alloy and then made use of traditional casting technology to prepare fly ash/aluminum alloy composite material. They detected the property of this material, assessed its property and studied its probable prospects of application in components of machine. For example, piston, the shell of engine and all the components which link lever were all made by fly ash-aluminum alloy composite[20,21]. Using the powder metallurgical method can prepare the composite in which the filling material distributed well and it also contains different mass percent fly ash. Based on the preparing work, the author focuses on the friction and wear of fly ash/Al-25 wt%Mg composite, and probes the abrasion mechanism tentatively.

2 Experimental

2.1 Materials preparation

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Table 1 Chemical compositions of fly ash/wt%

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O+Na_2O	TiO_2	P_2O_5	SO_3
Content	51.49	27.62	9.25	3.19	0.58	1.31	0.8	0.14	0.42

Aluminum alloy powder (Al-25Mg) was chosen as the matrix alloy with sieved fly ash particles (5-50 um) as the reinforcement. The chemical composition of fly ash particles is shown in Table 1. The particles were surface treated in an acidic solution under ultrasonic vibration, and then washed by distilled water until the pH value became 7 and dried in an oven. Then they were mixed with Al-25Mg alloy powder for 6 hours in the mixer until the aluminum alloy powder and the fly ash were mixed together completely. Pressed the mixture under the pressure of 500 MPa and then kept the pressure for 10 minutes until it shaped. Then sintered it in the tubular furnace by heating at a rate of 10 ℃/min up to the test temperature (650 ℃) in contact with the Al-25Mg alloy in ultra-high purity argon (99.999%, O_2<0.1 vppm), with the chamber held isothermically for 60 min. Afterwards, the system was cooled down at a rate of 4 ℃/min to 500 ℃ and then air cooled to room temperature. The size of the composite was 31 mm×6 mm×7 mm, and the mass fraction of the fly ash was 5%, 10%, 15% and 20%, respectively.

2.2 Characterization

Friction and wear tests were conducted with MM-200 friction-abrasion testing machine, grinding ring 45£ steel, hardness was 45-50 HRC, inside diameter was 16mm, outside diameter was 40 mm, load with 78, 98, 118, 137 and 157 N, time for abrasion was 4, 6, 10, 15, 20 minutes, respectively. Experiments were carried out under dry conditions, at room temperature (20 ℃, relative humidity 65±1%). The sliding speed in the experiments was 400 r/min and the loads varied from 78 to 157 N. Each experiment was repeated thrice and the averages of closely repeatable test values were taken. The wear rate was calculated using the weight loss and graphical methods. The microstructure and worn surface were examined by SEM (Hitachi, S-3000N). XRD pattern was recorded on a D/max-r B X-ray diffractometer (Rigaku).

3 Results and discussion

3.1 Microstructure and composition

Fig.1(a) shows the morphology of 10 wt% fly ash/A1-Mg composite fabricated by powder metallurgical method at the temperature of 650 ℃. It is found that the fly ash/A1-Mg composite is uniform and compact and has no obvious defects on the surface, with the content of fly ash (mass fraction) to be about 10%. Fig.1(b) presents the XRD pattern of the 10 wt% fly ash/A1-Mg composite. It reveals that Al and $MgAl_2O_4$ were the major phases with a minor amount of MgO and Mg_2Si during the sintering process. Fly ash not only has Al_2O_3, but also provides SiO_2 as a good initial interface for the reactions listed as follows[9]: $3SiO_2$+4A1 (l)→$2Al_2O_3$(s)+3Si(l); $2SiO_2$+2Al(l)+Mg(l)→$MgAl_2O_4$(s)+2Si(l); 2MgO(s)+4Al(l)+$3SiO_2$(s)→$2MgAl_2O_4$(s)+3Si(l); 2Mg(l)+Si(l) → Mg_2Si(s).

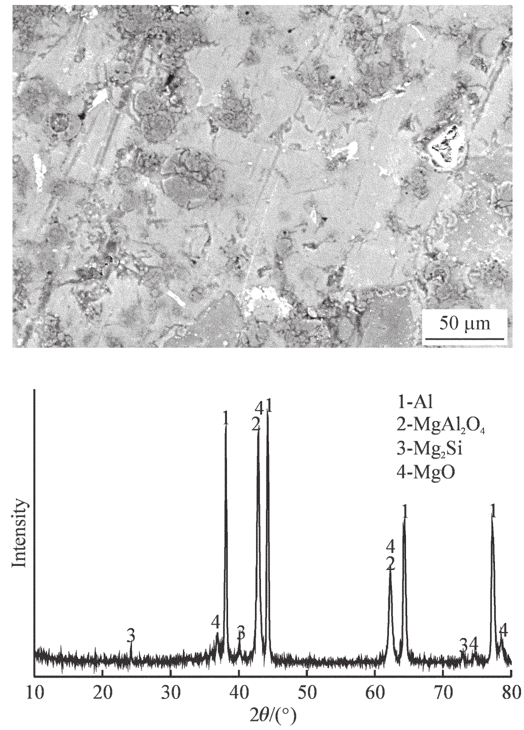

Fig.1 X-ray diffraction pattern of 10 wt% fly ash/A1-Mg composite

3.2 Friction and wear mechanism

In Fig.2, the curved lines show the wear rate of matrix alloy and composites with different test loads when the rotary speed is 400 r/min. The curved lines show that the wear rate of the matrix alloy sample is larger than the composites sample and both the wear rate of matrix alloy and composite will increase as the contacting pressure increases. When the load is low, the wearing quality of composite is better than aluminum matrix and if the load is heavier, the improvement of the wearing quality of composites will decrease. When the load is between 78 and 117 N, the relation between loads and wear rate will be linear. When the load is above 117 N, the wear rate of the matrix alloy and composite will change rapidly. From the picture, there are turning points on the wear rate curved lines of matrix alloy and composites, which indicates that the abrasion mechanism of these two materials changes with the increasing of load. The turning point of the abrasion mechanism for aluminum matrix alloy is when the load is between 98 and 117 N and the turning point of the abrasion mechanism for composites is when the load is 117 to 137 N, and furthermore with the increasing of fly ash, the turning point of composites abrasion mechanism will move towards the heavier load[22-25].

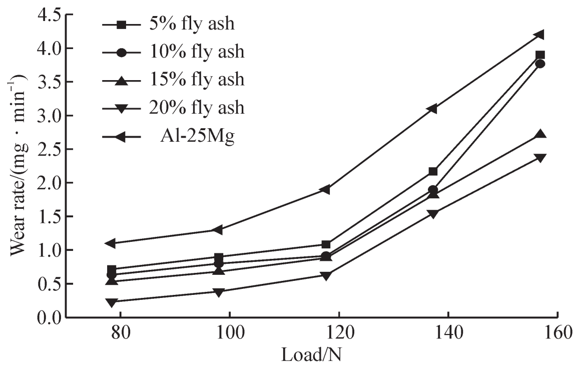

Fig.2 The effect of test loads on wear rate of the composites

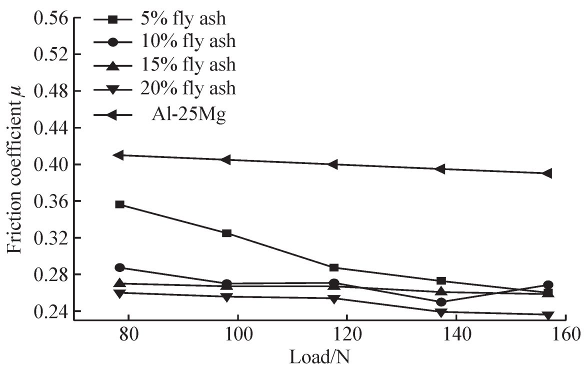

Fig.3 The effect of test loads on friction coefficient of the composites

In Fig.3, the curved lines show the effect of test loads on the friction coefficient of the composites. The friction coefficient of the composites and aluminum matrix trends to decrease with increasing test load and then keep steady. Besides, the friction coefficient of composites is less than aluminum matrix and with increasing fly ash, the friction coefficient of the composites will decrease slightly. Test load influences the property of friction and wear by the size of contact area and the degree of distortion. With increasing load, the contact area increases, and the degree of distortion also increases, and wear particles will appear and increase and it is very difficult to discharge them from the contact area. So, the load increases and wear raises. In the process of sliding friction, the metal surface will be in elastic stage and the non-linear relationship between contact surface and the load exists, which makes friction coefficient decrease with increasing load[26,27].

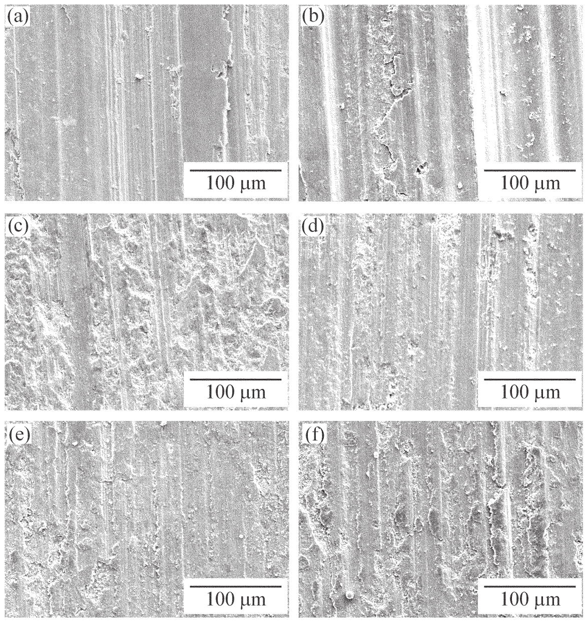

Fig.4 The wear surface of the composites under two test loads (a) (b)10%fly ash 78 and 118 N; (c) (d)15%fly ash 78 and 118 N; (e) (f)20%fly ash 78 and 118 N

Fig.4 is the SEM pictures of the wear surface of the composites sliding for 6 minutes under 78 and 118 N. From Figs.4(a), (b), we can see that the wear surface of the composites with low fly ash has obvious ploughs and micro cracks. When the intensity of the sticky point is higher than the intensity of the matrix shear strength, additive wear will appear. From Figs.4(e), (f), we can find that the wear surface of the composites with 20% fly ash is scaly and there are also superficial drop pits in it, which belongs to the characteristic of peeling wear and fatigue wear. Besides, from Fig.4, we can find that with increasing fly ash, the abrasion mechanism will change from abrasive wear and additive wear into peeling wear and fatigue wear. Because the hardness and abrasive resistance of the fly ash are much stronger than aluminum alloy matrix, so when sliding friction begins, the aluminum matrix on the surface of the composites will be ground off first, thus, the fly ash particles will be exposed on the surface of the material and contact directly with the dual faces, which can play a part of bearing load and restricting the direct contact between the disc and matrix alloy. As shown in Fig.4(e), under low load, the main abrasion mechanism of composite is additive abrasion and particle abrasion. When the load becomes heavy, if the restricting power of aluminum matrix towards fly ash can not resist the power of friction force towards it, fly ash particles will drop off and lose their carrying capacity, the wear of the composites will become worse. At this time, the composite abrasion mechanism changes into peeling abrasion, fatigue abrasion and particle abrasion, just as in Fig.4(f). Of course, the detached fly ash particles can play the role of ball bearing on the friction surface, three-body wear is present[8-10], thereby, it can reduce the wear of the composites. With increasing fly ash, load bearing area of fly ash will increase, thus, the pressure on individual fly ash particle will reduce. So, the more fly ash it has, the heavier the load for changing from micro abrasion to serious abrasion will be[28-31].

In addition, the more fly ash on the grilling surface,the more obvious the effect of 'ball bearing' on the grilling surface will become, thus, the effect of reducing friction will be clearer. So, the wearing property of fly ash particle/Al-25% composite will increase with increasing fly ash.

4 Conclusions

The microstructure, friction and wear property and abrasion mechanism of fly ash/Al-25Mg composites were investigated. The following results can be obtained:

a) Interfacial reaction was accelerated by high temperature and long exposure time. Severe chemical reaction occurred at the interface of metal and fly ash. Several phases ($MgAl_2O_4$, Mg_2Si, Al, and MgO) were detected in the composites.

b) The friction and wear property of fly ash/Al-25Mg composite is better than matrix alloy, besides, friction coefficient is lower than matrix alloy steadily. And with increasing fly ash, the wearing quality of the composite will improve.

c) Under the situation of lower fly ash and at low load, the main abrasion mechanism of fly ash/Al-25 Mg composite is adhesive wear and abrasion wear.If the fly ash is more and the load is higher, the abrasion mechanism of the fly ash/Al-25 Mg composite will mainly change into delamination wear and abrasion wear.

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