AlSi11/ Si_3N_4 interpenetrating composites Tribology properties of aluminum matris composites

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Abstract— In present work, the metal-ceramic interpenetrating composites (IPCs) as AlSi11/ Si_3N_4 are fabricated by infiltrating technique. IPCs exhibit special characterization of brittle ceramic reinforced phase introduced by ductile metal matrix phase. During the sliding wear processes, IPCs exhibit four wear mechanism such as initial adhesive wear, mixed adhesive and abrasive wear, adhesive wear and final abrasive wear. Reinforcements inhibit plastic flow and restrict propagation of wear cracks. Increase in the volume fraction of reinforcement leads to improvement in the wear resistance. Under higher load and lower round speed conditions, the friction coefficients are lower than that of relative conditions.

Keywords-interpenetrating composites; Si3N4; aluminum; network structure;tribology

1. Introduction

It is well known that metal–ceramic interpenetrating composites (IPCs) exhibit superior performance, mechanical stability and failure tolerance such as excellent wear resistance, high fracture toughness and high hardness [1-3]. IPCs have attracted considerable attention as result of their unique mechanical properties, which can be widely used in aerospace and automotive industries and other structural applications [4]. Especially, aluminum matrix composites reinforced by Si_3N_4 have the potential for use in aerospace applications owing to Si_3N_4 ceramics processing higher Young's modulus, combined with lower density, higher melting point and excellent oxidation resistance. Moreover, metal-ceramic interpenetrating composites have a large use in the occlusal contact area accompanying with high forces, such as mechanical production of oil pump, piston, die and bearing [5].

Tribology properties of IPCs can generally be enhanced by introducing a secondary phase (s) as three dimensional network structure into the metal matrix materials. There is a plethora of papers by experimentalists who have studied the wear behavior of metal composites reinforced by ceramics secondary phases [6]. However, there has little work to study the abrasive behavior of Si_3N_4/AlSi11 interpenetrating composites. The abrasive wear resistance of Si_3N_4/AlSi11 interpenetrating composites has been found to be significantly lower than that of AlSi11 metal owing to the changes of microstructure, the morphology, the volume fraction and mechanical properties of three-dimensional network reinforcing phase, and interface between matrix and reinforcement.

So, in present paper, an attempt has been made to evaluate the dry sliding wear behavior of Si_3N_4/AlSi11 interpenetrating composites over a range of loads and sliding speeds. The microstructures of them are discussed. And, the sliding wear mechanisms of them are studied.

2. Experimental Procedure

A reticulated polyurethane (PU) was chosen as a template to prepare the porous perform (skeleton as the reinforcement of IPCs) by the replica technology. The pore size of the PU was about to 5-10 ppi (pores per inch). Si_3N_4 powder ($Si_3N_4 \geqslant$ 97%, diameter $\leqslant$100 μm) was used as starting material. The sintering temperature is 1400°C at 200°C/h.

The composition of the alloys used in this study was Al-11wt.%Si which chemical composition is shown in Table 1. In order to eliminate the influence of impurities, the melt need to be refined. Alloy was melted in a clay–graphite crucible under Ar atmosphere. The liquid metal was infiltrated into the preform skeleton by pressure infiltration technology. Si_3N_4/AlSi11 interpenetrating metal-ceramic composites reinforced by different volume fraction as 12, 20%, respectively, were fabricated. The micro-structural characterization of IPCs and porous perform were performed on a scanning electron microscope (SEM. Hitachi, S-2500) which was shown in Figure 1. Samples for making micrographs were mounted in a holder and polished using SiC papers (up to 2000 grit). The microstructures of matrix were characterized using SEM equipped with an energy dispersive spectroscopy (EDS) which was shown in Figure 2.

The specimens were subjected to wear test under dry sliding condition. The tests were conducted on 6mm diameter, 35 mm long cylindrical specimens against a rotating steel disc which is covered by corundum sand paper. A pin-on-disc wear test machine was used for carrying out wear tests (Figure 3). The tangential friction force and wear depth were monitored with the help of electronic sensors. These two parameters were measured as a function of load and sliding distance. For each type of material, tests were conducted at four different nominal loads (100, 150, 200 and 250 N) at different sliding speed as

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100, 200, 300 and 400 rpm. Wear tests were carried out at temperature of 200°C without lubrication for 20 min.

Table 1 Chemical composites of metal matrix

Cu	Mg	Si	Fe	Mn	Zn	Ti	Al
4.7600	0.5900	17.0600	0.1890	0.0160	0.0060	0.0016	Bal.

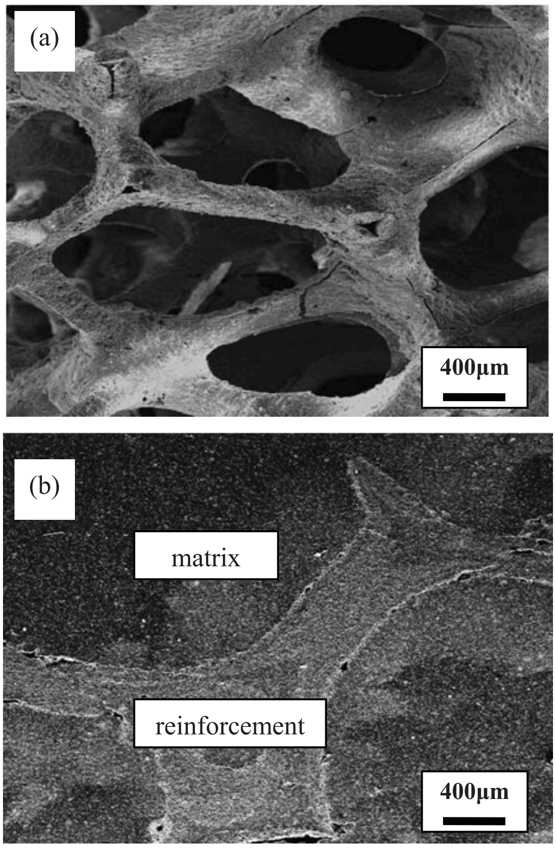
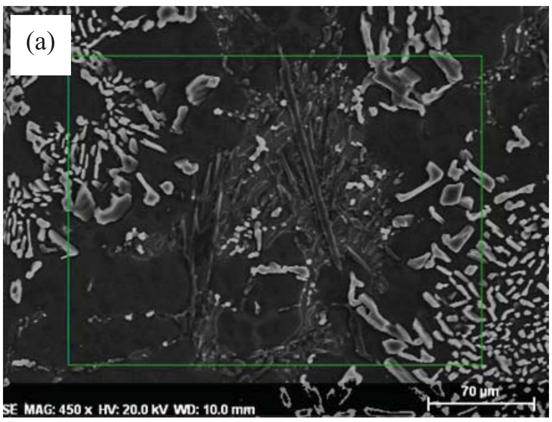


Figure 1. 3-D network structure and interpenetrating composites: (a)skeleton and (b) IPCs



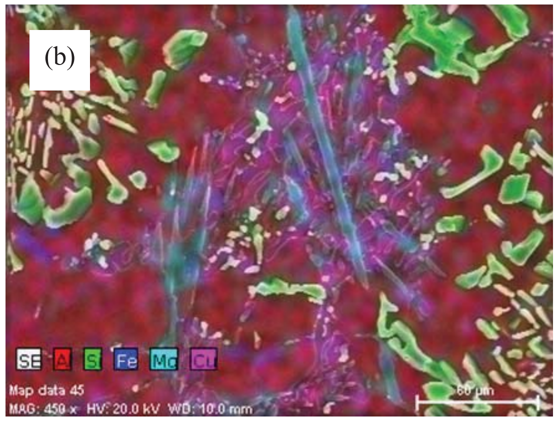


Figure 2. Al matrix alloy and its EDS analysis: (a) SEM micrograph of Al matrix alloy and (b) EDS analysis

Figure 3. Pin-on-disc wear test machine

3. Results and Discussion

Due to IPCs possessing a continuous metal network with $V_{AlSi11} \geq V_{Si3N4}$, it has a high toughness. Due to IPCs possessing interpenetrating ceramic phase, it has a higher Young's modulus, hardness and load bearing capacity than MMCs. Wear resistance properties research for IPCs is interesting. There are many factors influencing on wear behavior, which make it difficult to compare results from different laboratories or different testing methods [7]. The friction coefficients were tested with different time under different load which were shown in Figure 4 (a). It is shown that under lower load, the friction coefficient curve is not steady, while under higher load, it is steady. Under higher load conditions, the friction coefficients are lower than lower load conditions. Figure 4 (b) shows the friction coefficients- time relations under different round speed. It is shown that under lower round speeds, the friction coefficients are higher than higher round speeds. The reason is that higher load and round speeds causes soft matrix metal covering with the wear surface. This effect would require more testing to confirm and explain it. It is well known that the wear resistance of the IPCs increases with increasing Si_3N_4 content. The width and depth of the wear grooves of the Si_3N_4 12wt.% composites are narrower and shallower than those of Si_3N_4 20wt.% composites. The grooves become even more indistinct with the increasing Si_3N_4 content.

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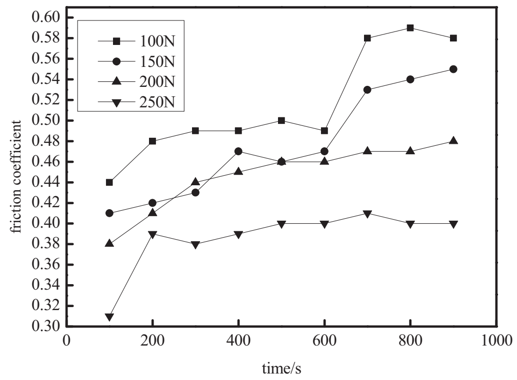
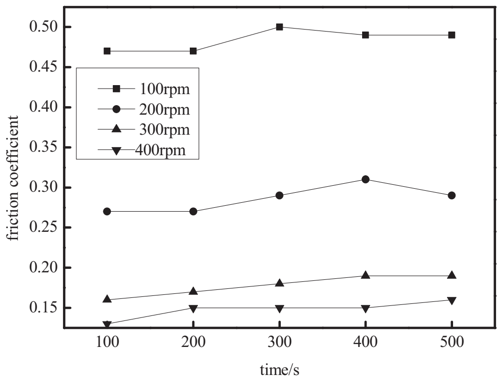


(a) Friction coefficient-time curve under different load



(b) Friction coefficient-time curve under different speed

Figure 4. Friction coefficient-time curve under different wear conditions

Figure 5 shows the worn surface of IPCs and its metal matrix. It is shown that with an increase in test time, the morphology of the worn surface changes from fine scratches to distinct grooves. The worn surfaces of the metal matrix and the ceramic skeleton are different significantly. There is light and shallow scratch on the surface of ceramic reinforcement which is shown in Figure 5 (a). The surface exhibits a fractured and broken characterization. It is shown that ceramic skeleton is undergone abrasive wear. There are smooth and rough areas to be seen. The smooth areas are due to the polishing effect at the start of the wear test. The damaged layer formed during this polishing stage is fatigued with further sliding distance. The revealing angular ceramic grains cause microcracks forming and result in the damaged spall. There is a severe surface damage on the surface of metal matrix which is shown in Figure 5 (b). Some deep and symmetrical furrows on the worn surface of metal matrix are observed which are described as local damage and even fractured flakes. The metal matrix showed adhesive wear with extensive plastic deformation, evidenced by smearing at the edge of the wear track.

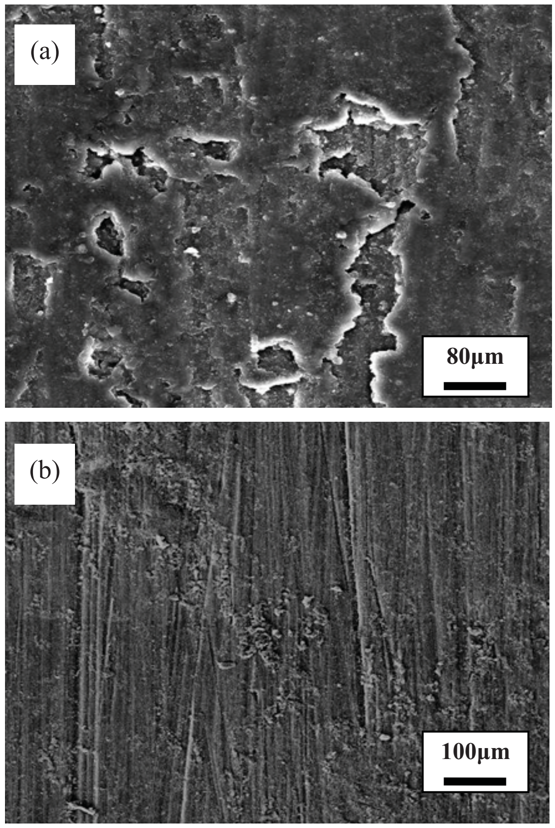


Figure 5. The worn surface of : (a) ceramic reinforcement and (b) metal matrix

This cyclic wear process is illustrated schematically in Figure 6. The overall wear processes divided into four stage as initial stage (I), continual stage (II), middle stage (III) and final stage (IV). Each individual stage is not steady state process. In initial abrasive wear process (Figure 6a), the wear surface is surrounded by matrix material that is subjected to compressive loading. Owing to relatively soft and ductile performance of the matrix, this stage is relatively short and considered as the conventional wear mechanism. On the other words, metal matrix alloy was cut by the counter as plates, which was either removed out of the cells or smeared along the sliding direction. With the continuing abrasive wear, the reinforcement phase is gradually exposed and the compressive load is carried by matrix and reinforcement together (Figure 6b). Owing to the high modulus of ceramic reinforcement relative to the matrix, however, this stage is hold for long time. With the wear processes going on, the soft and ductile matrix gradually recedes away and the compressive load is carried primarily by reinforcement phase (Figure 6c). In the finial stage, the exposed reinforcement phase finally failed by fracture due to its brittleness (Figure 6d). Then the wear surface turn flat and the first stage repeat again. This cyclic processes result in the removal of materials and occurrence of abrasive wear. The four stage wear behavior has also been observed by other researchers [8-10]. The AlSi11/Si_3N_4 interpenetrating composites showed a similar transition processing as initial adhesive wear (I), mixed adhesive and abrasive wear (II), adhesive wear (III) and final abrasive wear (IV).

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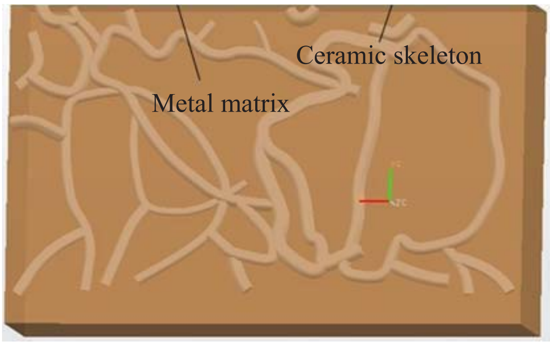
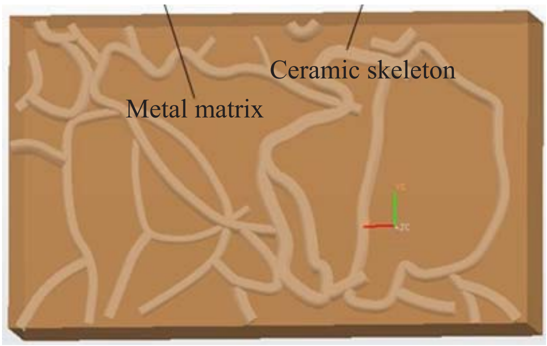
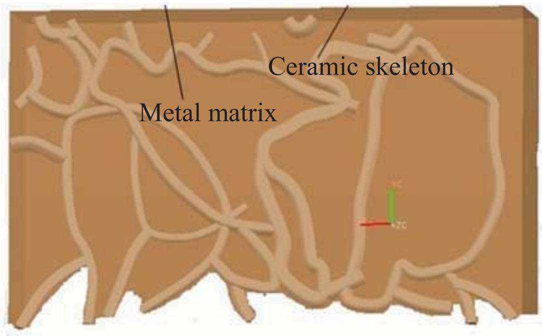


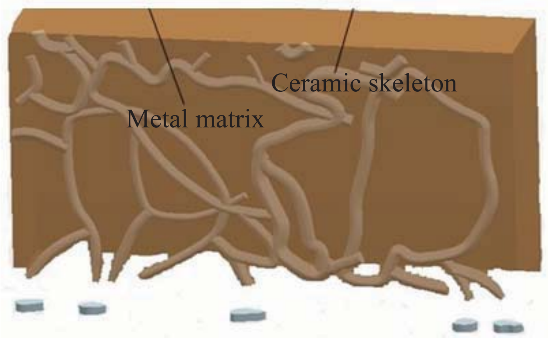
(a) initial stage



(b) continual stage



(c) middle stage



(d) final stage

Figure 6. Wear processing of interpenetrating composites

4. Conclusions

A AlSi11/Si_3N_4 interpenetrating composites (IPCs) were fabricated by infiltrating technique. The friction coefficient related to wear load, wear speed and wear time were discussed. The worn surface damage of IPCs is studied based on the lower and upper extreme cyclic wear behavior. Owing to the special topology structure characteristic, aluminum alloy reinforced with ceramic network structure can improve dry sliding wear resistance. Reinforcements inhibit plastic flow and restrict propagation of wear cracks. Increase in the volume fraction of reinforcement leads to improvement in the wear resistance. Reinforcements are crushed into small pieces regardless of the morphology of original reinforcement present in the composite, hence wear resistance of composite is marginally affected by the reinforcement volume fraction. The wear mechanisms in IPCs could be classified into four modes as initial adhesive wear (I), mixed adhesive and abrasive wear (II), adhesive wear (III) and final abrasive wear (IV).

5. Acknowledgment

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