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Wearing resistance of in-situ Al-based composites with different SiO_2/C/Al molar ratios fabricated by reaction hot pressing

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Abstract: The in-situ Al-based composites with different SiO_2/C/Al molar ratios were fabricated by reaction hot pressing. The dry sliding wear characteristics of the composites were investigated using a pin-on-disc wear tester. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) were used to investigate the surface composition and its morphology. The results show that when the SiO_2/C/Al molar ratio is 3:6:9, more in-situ synthesized Al_2O_3 and SiC along with Si particles are produced, and Al_4C_3 is prevented completely from the Al−SiO_2−C system. Thereby, a significant improvement of wear resistance is obtained. When the sliding velocity increases from 0.4 to 1.6 m/s, the wear loss decreases gradually. With increasing the normal load, the wear loss increases as well. Ploughing, craters and micro-grooving are observed as dominant abrasive wear mechanisms. Whereas, when a high velocity is employed, only the oxidation mechanism controls the wear behavior of the composites.

Key words: metal matrix composite; wear mechanism; friction; hardness

1 Introduction

Recently, the in-situ aluminum matrix composites (AMCs) have been applied widely as potential materials in automobile, aerospace and military applications due to their excellent properties such as specific strength, stiffness, wear resistance and elastic modulus [1−4]. Since AMCs have been used widely for tribological applications [1]. It is necessary to study the wear behavior of AMCs and further the improvement of wear properties. Indeed, many factors including the normal load, sliding velocity, type, orientation, size, shape and volume fraction of reinforcement should be pointed out to determine a unique information and many unexpected parameters can be produced [5]. Many ceramics such as Al_2O_3, SiC, Si and Al_4C_3 have been extensively employed as good wearing reinforcements [6−10]. These particles show excellent properties such as high melting temperature, high elastic modulus and high strength. However, the presence of hard Si and Al_4C_3 as brittle phases might also play a key role in determining the wear properties under specific conditions [11,12]. In our previous work [13], we investigated the reaction mechanisms in Al−SiO_2−C system, and we studied the effect of varying the SiO_2/C/Al molar ratio on the mechanical properties of the fabricated composites. It was found that when the SiO_2/C/Al molar ratio was 3:6:9, more in-situ Al_2O_3 and SiC along with Si particles formed, and Al_4C_3 was prevented completely from the SiO_2−C−Al system. In addition, a significant improvement of tensile properties was obtained. For further consideration, the wear properties have not yet been investigated. In this research, the influence of varying the SiO_2/C/Al molar ratio on the wear properties was investigated. Reactive sintering was used to produce three composites with different SiO_2/C/Al molar ratios of 3:0:9, 3:3:9 and 3:6:9. The influence of both the sliding velocity and normal load on the wear properties was studied as well.

2 Experimental

Pure aluminum powder (99.6% purity), silica powder (99.2% purity) and flaky carbon (99.8% purity) with average sizes of 30, 2 and 5 μm, respectively, were used as starting materials. The powder mixtures were ball-milled using low energy at 160 r/min for 4 h in a

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planetary ball mill under an argon atmosphere with a mass ratio of milled media to material of 4:1. The mixture powders were transferred into the graphic mold pre-coated with boron nitride to avoid the reaction between the mold and the reactants. Reaction hot pressing (RHP) was used to produce the composites namely S1, S2 and S3 with different SiO_2/C/Al molar ratios of 3:0:9, 3:3:9 and 6:3:9, respectively. In one step as shown in Fig. 1(a), the mixture of powders was heated from 25 to 600 °C and compacted with 25 MPa for 1 h. Then, the compact was heated to the synthesis temperature (1050 °C) and held for 1 h. Following which, the compact was cooled down to 580 °C and re-compacted with 25 MPa for 1 h to produce dense composites. The stoichiometric starting materials were weighed according to the hypothetical reactions shown in Table 1. The heating and cooling rates in all experiments were 10 °C/min. To prepare the wear samples, the tested wear surfaces of samples were polished to remove their oxidation surfaces. The dry sliding wear tests were conducted on a pin-on-disc wear testing machine at room temperature in the air atmosphere under a relative humidity of 30%−40%. The test pins are 9 mm in diameter and 15 mm in length. The counterpart discs were made of CGR15 steel with hardness of around HRC 62 and surface roughness (R_a) of 0.2 μm. The track radius was fixed to be 30 mm, as shown in Fig. 1(b).

The counterpart disc was 70 mm in diameter and 10 mm in thickness. The normal loads were 10, 20, 30 and 40 N separately for sliding velocities of 0.4, 0.8 and 1.6 m/s. An electronic balance with the precision of 0.001 mg was used to detect the mass loss. A scanning electron microscope (SEM, Quanta 200FEG) along with energy dispersive X-ray spectroscopy (EDX) was used to investigate the microstructures, morphologies and wear surfaces of the composites.

3 Results and discussion

3.1 Microstructures and mechanical properties

The SEM images of composites S1, S2 and S3 fabricated with different SiO_2/C/Al molar ratios of 3:0:9, 3:3:9 and 3:6:9 are shown in Figs. 2(a)−(c), respectively, which further confirm the presence of fine particles as reinforcements and their sizes are in order of micrometers.

Coupled with the XRD pattern of each composite (Fig. 3), in composite S1, only Al_2O_3 and Si are detected as new phases. Adding the carbon to the Al−SiO_2 system for composite S2, the XRD pattern confirms the presence of Al_2O_3, Si, Al_4C_3 and SiC. Additionally, when the SiO_2/C/Al molar ratio is 6:3:9, more Al_2O_3 and Si besides SiC form and Al_4C_3 is prevented completely from Al−SiO_2−C system.

Additionally, as shown in Figs. 4(a)−(c), TEM and EDX images show the presence of the rod-like Al_4C_3 (comprising of Al and C)), polygonal SiC (comprising of Si and C), polygonal Al_2O_3 (comprising of Al and O) and Si particles with sizes of around 0.4, 0.6, 1.8 and 0.3 μm, respectively. Also, it can be seen that there is no impurity existing at the interfaces between the reinforcements and aluminum matrix, indicating that the formed interface is

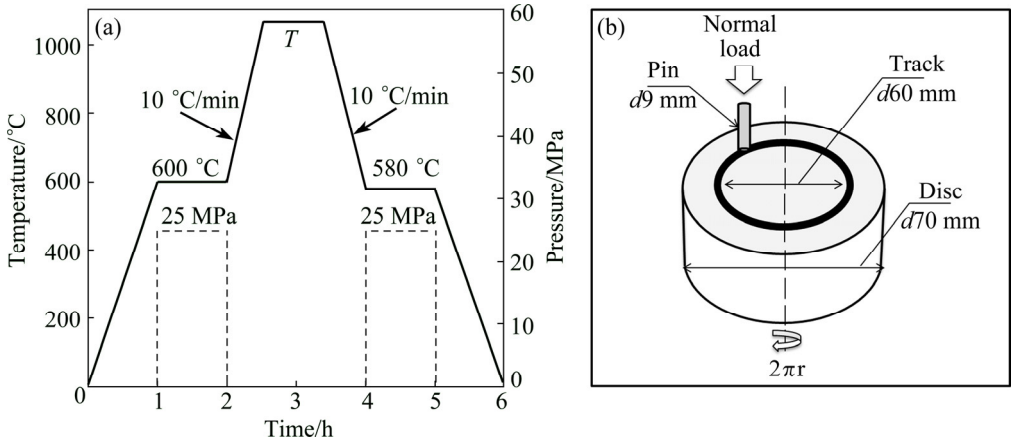

Fig. 1 RHP whole process (a) and pin-on-disc configuration (b)

Table 1 Composites nomenclature, hypothetical reactions, raw materials and produced phases

Composite	Hypothetical reaction	Mass of raw material/g			Produced phase
		Al	SiO_2	C	
S1	$3SiO_2+9Al→2Al_2O_3+3Si+5Al$	92.54	7.46	0.0	Al_2O_3, Si, Al
S2	$3SiO_2+9Al+3C→2Al_2O_3+3SiC+5Al$	91.29	7.25	1.46	Al_2O_3, SiC, Al
S3	$6SiO_2+9Al+3C→4Al_2O_3+3SiC+3Si+Al$	91.29	14.5	1.46	Al_2O_3, SiC, Si, Al