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Trans. Nonferrous Met. Soc. China 16(2006) 1159−1162
Transactions of Nonferrous Metals Society of China
www.csu.edu.cn/ysxb/
Science Press

Wear behavior of Al-Si alloy matrix composites reinforced by γ-Al_2O_3 decomposed from AACH

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Received 28 February 2006; accepted 21 September 2006

Abstract: The Al-Si alloy matrix composite reinforced by γ-Al_2O_3 particles was produced by adding $NH_4AlO(OH)HCO_3$(AACH) into molten Al-Si alloy at 850 ℃. During stirring γ-Al_2O_3 particles are formed by the decomposing reaction of AACH. It is found that the γ-Al_2O_3 particles distribute more uniformly in the matrix by adding AACH than by adding γ-Al_2O_3 directly. The wear tests show that the volume loss of the unreinforced Al-Si alloy matrix is about 3 times larger than that of the γ-Al_2O_3 reinforced composites and that of the composites fabricated by adding γ-Al_2O_3 is larger than that by adding AACH.

Key words: Al-Si alloy matrix composite; Al_2O_3 particles; microstructure; wear

1 Introduction

The particles reinforced aluminium alloy matrix composites, which possess high-specific elastic modulus and strength, are being widely used in the aerospace and automobile industries[1−4]. Traditionally, the Al alloy matrix composites are produced by directly adding reinforcements into the matrix. In general, the uniform distribution of reinforcement particles inside the matrix, good wettability between the particle and matrix, and suitable bonding strength of the reinforcement/matrix interface are thought to be the major factors controlling the properties of this kind of materials[5−7]. To overcome these problems, in-situ technique referred to as reaction process has been proposed to fabricate composites by in situ formation of the Al_2O_3 particles as reinforcements within the matrix via chemical reactions [8].

One commonly adopted in situ method involves the reaction between metal oxides, such as CuO, ZnO, SiO_2, Fe_2O_3, MnO_2, and TiO_2[9−13], and Al to produce Al_2O_3 particles or whisker reinforcements. The reaction in the process can be represented as follows: MO+Al → Al_2O_3+M, where Al_2O_3 is a desired reinforcement, but M is also produced in the process. M can enter the Al matrix as alloying elements, hence the alloying strengthening is obvious. It is worthy to notice that the amount of each alloy element in Al alloy has a limit. When higher level of Al_2O_3 is desired in the process, larger amount of M is inevitably presented, thus it is conceivable that the deterioration of materials properties can not be avoided due to the larger amount of M in the matrix than in ordinary Al alloy. In most of the published studies on in-situ Al_2O_3/Al composites, special attention has been given to the effect of Al_2O_3, but less attention to the effect of M on the properties of composites. In order to optimize the properties, the existence of M must be taken into consideration, i.e. besides designing the ceramic reinforcement, the matrix must also be designed.

In order to gain higher level of Al_2O_3, one compound can be introduced into the reaction without M formation. In this paper, the technology of manufacturing Al-Si alloy matrix composites reinforced by γ-Al_2O_3 particles decomposed from $NH_4AlO(OH)HCO_3$ added to the molten Al-Si alloy was described, the microstructure was evaluated by scanning electron microscopy(SEM) and the wear behavior was studied.

2 Experimental

In order to examine the fundamentals of the in situ

Foundation item: Project(105055) supported by Key Project of Ministry of Education of China
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process with respect to supplied AACH powder, differential thermal analysis(DTA) on the AACH powder was firstly carried out at a heating rate of 10 ℃/min in argon atmosphere. In the next experiment, the powders of reinforcement were immersed into molten Al-Si alloy at 850 ℃ to fabricate the Al_2O_3/Al-Si composites.

Al-Si alloy with the composition of 2.6%Cu, 10.4%Si and rest Al (mass fraction, %) was supplied as the matrix metal. The raw material of reinforcement was $NH_4AlO(OH)HCO_3$ (AACH) (99.5% purity) and superfine γ-Al_2O_3 (<100 nm, 99.7% purity) was used as comparing reinforcement. The amount of the powder of AACH used was 8% of the amount of Al_2O_3 (mass fraction). After melting, the molten metal was heated continuously and stirred at a rotating speed of 400 r/min at 850 ℃. The preheated powder of AACH was gradually added to the molten metal surface. As a result, an in situ formation of Al_2O_3 from AACH occurred within the metal matrix, and a molten composite formed. As the reactions were completed, the agitating was kept for a while to let the gas out and the molten was then cast in the form of cylinders with 30 mm in diameter and 50 mm in length. From these cylinders, wear test pieces were machined. Parallel studies of composites prepared by adding superfine γ-Al_2O_3 were performed under the same testing conditions.

Specimens for SEM observations were taken from the as-cast materials. The specimens were polished in a conventional manner and observed on SSX-550 scanning electron microscope(SEM).

Wear tests were carried out using a computer-controlled pin-on-disk tester with the aluminum alloy composites as the pin and GCr15 steel as the disk. The disk specimen was 70 mm in diameter and 5 mm in thickness. The pin test piece had a flat surface with a diameter of 6 mm. The diameter of the wear track was 60 mm. The surfaces of both the disk and the pin were polished with 1500# emery paper. The mass loss was measured after ultrasonic cleaning of the specimen in acetone, using a precision balance having a sensitivity of 0.01 mg. The measured mass loss was converted into volume loss by their corresponding density.

3 Results and discussion

3.1 Microstructure

The typical microstructures of the matrix and the composites are presented in Fig.1. Figs.1(b) and (c) show the microstructures of the composites prepared by adding AACH powder and the traditional composites by adding superfine γ-Al_2O_3 particles respectively.

The unreinforced Al-Si alloy contains many flaky and coarse acicular eutectic Si in the matrix(Fig.1(a)). In the composites, the amount of flaky eutectic Si is lower and the acicular eutectic Si is found to be finer, compared with that in unreinforced Al-Si alloy. The Al_2O_3 particles decomposed from the AACH (Fig.1(b)) distribute uniformly in the matrix and the particle size of γ-Al_2O_3 is measured to be 0.5−1.0 μm in diameter, although some of them are much smaller. Fig.1(c) indicates that the γ-Al_2O_3 particles agglutinate and distribute nonuniformly in the matrix.

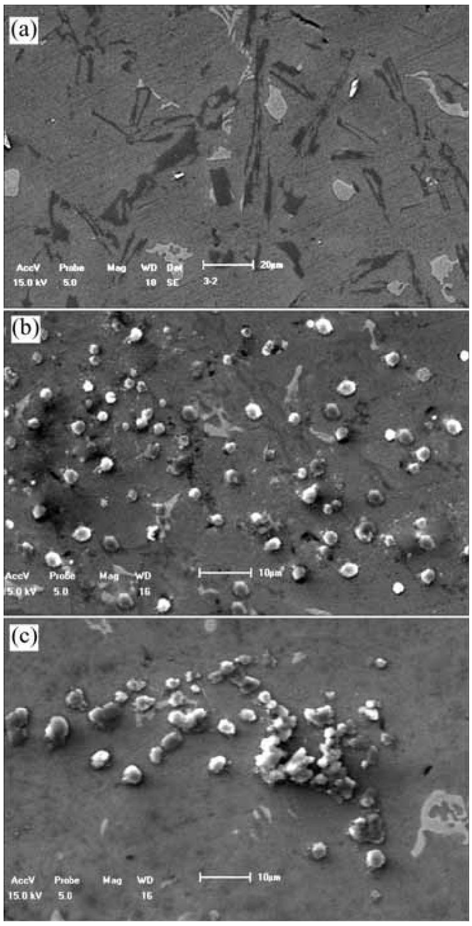

Fig.1 SEM micrographs of matrix and composites: (a) Al-Si alloy matrix; (b) Composite by adding AACH; (c) Composite by adding γ-Al_2O_3

A differential thermal analysis (DTA) was carried out to confirm the onset temperature of the reactions of AACH in molten Al-Si alloy, as typically shown in Fig.2. The endothermic peak occurs at about 183 ℃ due to the following reaction:

$$2NH_4AlO(OH)HCO_3(s) \rightarrow Al_2O_3(s)+2NH_3(g)+2CO_2(g)+3H_2O(g)$$

Fig.3 shows the X-ray diffraction (XRD) pattern of the specimen obtained from the method presented above. The chemical reaction takes place thoroughly, therefore γ-Al_2O_3 particles in the specimen are obtained and residual AACH is not found.

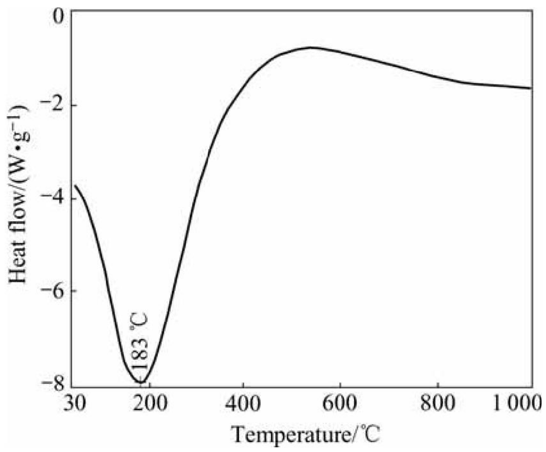

Fig.2 DTA curve of AACH powder heated at 10℃/min in Ar atmosphere

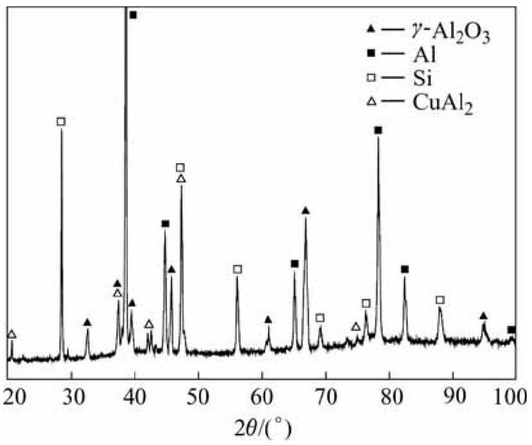

Fig.3 XRD pattern of composite fabricated by adding AACH

The used AACH is known to be one of the raw materials for fabricating commercial superfine high-purity Al_2O_3[14, 15]. The type of Al_2O_3 decomposed from the AACH is γ-Al_2O_3 with a larger specific surface area and a better sorption capacity[16]. At the same time, the Al_2O_3 particles are in spherical like shapes, which have better wettability with the molten aluminum, so they can bond firmly with the aluminum matrix. The microstructure of this kind of composites is able to reduce stress concentration and easy to transmit the load, so it can improve the properties of the composite.

3.2 Wear behavior

The dry sliding wear tests were carried out under a contact load of 20 N at a sliding velocity of 0.2 m/s. The variation in volume loss of unreinforced Al-Si matrix and two composites pin specimens as a function of sliding distance is shown in Fig.4. The volume loss of unreinforced Al-Si alloy is about 3 times larger than that of the two composites and that of the composite fabricated by adding AACH is smaller than that by adding γ-Al_2O_3.

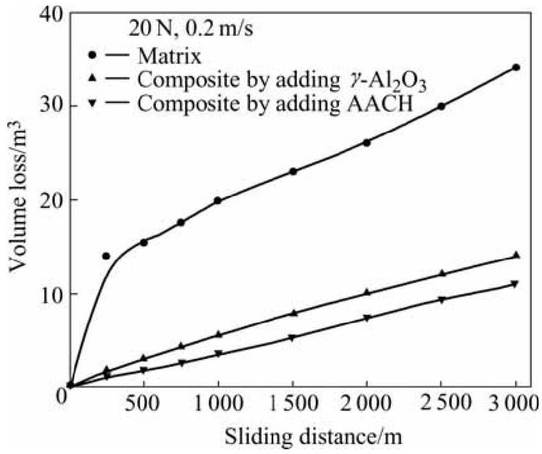

Fig.4 Volume loss of specimens as function of sliding distance (dry sliding)

Fig.5 shows the variation in volume loss of three specimens as a function of load after sliding for 2 000 m under lubricated condition. The volume loss of unreinforced Al-Si alloy is about 3 times larger than that of the two composites. With the increasing of load, the volume loss of the matrix increases rapidly, but slowly for the composites. The wear resistance of the composite is better than that of the corresponding alloy matrix mainly due to the presence of γ-Al_2O_3 particles for taking the external load.

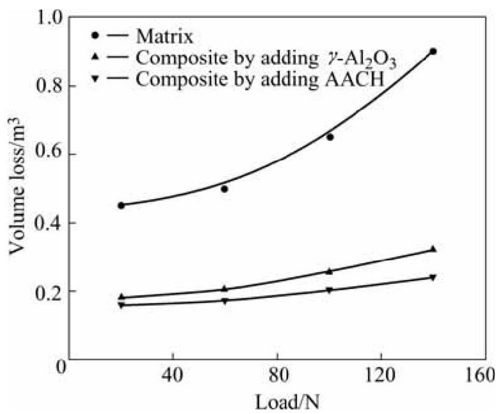

Fig.5 Volume loss of specimens as function of load (lubricated sliding distance 2 000 m)

Based on Fig.4 and Fig.5, the volume loss of the composite prepared by adding AACH is smaller than that of the composite prepared by adding Al_2O_3, so the better wear resistance of the composite prepared by adding AACH is mainly due to the γ-Al_2O_3 particles decomposed from AACH distributed uniformly in the matrix.

4 Conclusions

1) An in situ γ-Al_2O_3 reinforced Al-Si alloy matrix

composite was successfully fabricated by adding AACH, in which γ-Al_2O_3 particles distribute uniformly.

2) In the composites, the amount of flaky eutectic Si is lower and acicular eutectic Si is finer, compared with that in Al-Si alloy matrix.

3) The volume loss of unreinforced Al-Si alloy matrix is about 3 times larger than that of the composites and that of the composite fabricated by adding AACH is smaller than that by adding γ-Al_2O_3.

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(Edited by YUAN Sai-qian)