MICROSTRUCTURE AND PROPERTIES OF $Al_2O_3sf/Al-1.5Mg$ COMPOSTITE MANUFACTURED BY EXTRUSION DIRECTLY FOLLOWING LIQUID INFILTRATION[①]

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ABSTRACT The microstructure and properties of short alumina fiber reinforced Al-1.5Mg composite ($Al_2O_3sf/Al-1.5Mg$) manufactured by extrusion directly following liquid infiltration (EDFLI) were experimentally investigated. It was found that the microstructure of $Al_2O_3sf/Al-1.5Mg$ composite is characterized by a well-densified matrix, with fine recrystallized grains and free from microvoids and non-wetting defects, and quite uniformly and quasi unidirectionally distributed fibers maintaining adequate aspect ratios, which leads to a better strengthening effect. It was also found that the mechanical properties E, $\sigma_{0.2}$, σ_b and the thermal expansion resistance of the composite simultaneously increase with the enhancement of the fiber volume fraction while the elongation δ is still maintained at a relative high level. Besides, the $Al_2O_3sf/Al-1.5Mg$ composite possesses corrosion resistance equivalent to that of the Al-1.5Mg alloy.

Key words $Al_2O_3sf/Al-1.5Mg$ composite microstructure properties extrusion infiltration

1 INTRODUCTION

Among the industrial aluminium alloys Al-Mg alloy possesses the best corrosion resistance. For this reason, it is widely used in corrosive surroundings. However, the corrosion resistance of the alloy is significantly influenced by its Mg content. When the Mg content is low ($\leqslant$2.5%), the alloy presents excellent corrosion resistance but rather poor mechanical strength. Although increasing Mg content can enhance the mechanical strength of the alloy, yet it at the same time increases the tendency of grain boundary corrosion and thus incurs the deterioration of the corrosion resistance of the alloy. Due to this contradiction between the corrosion resistance and the mechanical strength of the alloy, its application is to some extent limited. Therefore, reinforcing the Al-Mg alloy with ceramic particulates or fibers which contains less than 2.5% Mg becomes one effective way to solve the problem, that is, to promote the mechanical strength while maintaining the corrosion resistance of the alloy. In this paper, the microstructure and properties of $Al_2O_3sf/Al-1.5Mg$ composite manufactured by the technique EDFLI are experimentally investigated.

2 EXPERIMENTAL

The reinforcing material is Al_2O_3sf, with its chemical composition and physical properties listed in Table 1. The matrix alloy is Al -

Table 1 Chemical composition and physical properties of Al_2O_3sf

Chemical composition		Physical properties			
Al_2O_3 /%	SiO_2 /%	diameter /μm	density /g·cm^{-3}	σ_b /MPa	E /GPa
72.3	27.7	5~10	3.4	~600	~240

① Supported by the National Natural Science Foundation of China; Received Mar. 20, 1995

1. 5%Mg binary alloy prepared by ingot metallurgy. The investigated composite products are rods 15 mm in diameter. They were manufactured by the technique EDFLI and the details of the technical process have been reported in reference[1].

The specimens for microstructure and property investigation were all prepared from as-manufactured Al_2O_3sf/Al-1. 5Mg composite rods. The experimental investigation includes: examining the microstructure with optical microscope; determining the mechanical properties E, $\sigma_{0.2}$, δ by tensile test and carrying out corresponding fractography observation with SEM; testing the linear expansion coefficient with optical differential expansion measuring appliance; investigating the corrosion resisting property by grain boundary corrosion proof test.

The specimens for tensile test and linear expansion coefficient measuring were standard cylindrical tensile specimens 5 mm in diameter and cylindrical rod specimens with the size 5 mm in diameter by 50 mm in length respectively. Tensile tests were carried out on a standard Instron material test machine, with a tensile velocity of 0. 5 mm/min. Besides, all tensile specimens were strain-gauged during testing, with the span being 12 mm. The grain boundary corrosion proof test was carried out by the method suggested by reference [2]. The solution of 3%+NaCl+0. 45%HCl was used as corrodent and the corrosion proof test lasted for 24 h, with the corrodent kept at a relative constant temperature of 35±1 ℃.

3 RESULTS AND DISCUSSION

3. 1 *Matrix Microstructure, Fiber Distribution and Dimension Features*

Fig. 1 shows the microstructure of the Al_2O_3sf/Al-1. 5 Mg composite manufactured by the technique EDFLI. The matrix of the composite, being well-densified and free from microvoids, is obviously characterized by a uniform and very fine deformation-recrystallization microstructure. The reinforcing fibers are uniformly distributed in the matrix and there exists no tangling up or bunching of the fibers. Besides, the fibers are well-aligned along the extrusion direction. That is to say, the fibers have been oriented by the extrusion process. Fig. 2 is a statistic plot obtained by stochastically measuring under microscope, the aspect ratios of the random fibers extracted with sodium hydroxide solution from the Al_2O_3sf/Al-1. 5 Mg composite. It clearly shows that the fibers in the Al_2O_3sf/Al-1. 5 Mg composite manufacured by the technique

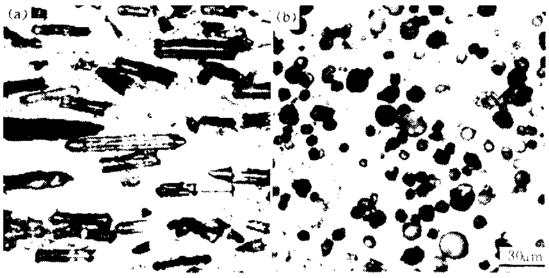

Fig. 1 Microstructure of Al_2O_3f/Al-1. 5Mg composite
(a)—longitudinal; (b) transverse

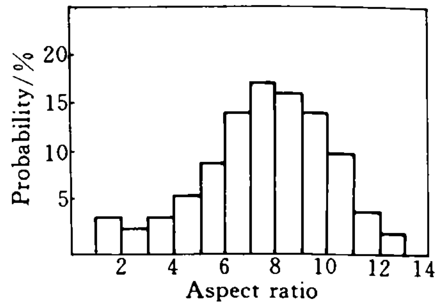

Fig. 2 Statistic survey of fiber aspect ratio of Al_2O_3sf/Al-1. 5Mg composite

EDFLI have maintained a high aspect ratios, with the average aspect ratio being within the range of 8～10. It is more than once higher than the average level of the similar composite formed by hot extrusion reported in reference [3].

The above structural characteristics of the Al_2O_3sf/Al-1. 5 Mg composite are attributed to the manufactruing process. In recent research[4], it has been made clear that during extrusion which directly follows liquid infiltration, the extruded composite billet undergoes deformation in such condition that the matrix alloy is kept in the solid-liquid or just solidified state. Therefore, the obtainment of the fine densified recrystallized matrix microstructure is considered to be the joint effect of the following aspects: the fining of the primary grains by crystallization under pressure and flow solidification[5]; the further breaking down of the primary grains by extrusion deformation; the consequent recrystallization which follows the extrusion deformation. The uniform and oriented distribution and the maintaining of high aspect ratios of the reinforcing fibers are due to: during extrusion, the liquid matrix alloy within the container above the deforming zone always bears high isostatic pressure and there exists relative motion between the liquid matrix alloy and the reinforcing fibers, which effectively helps to improve the wetting between the liquid matrix alloy and reinforcing fibers and avoid the gathering together of the fibers themselves; the matrix alloy presents very low flow stress when in the solid-liquid or just solidified state[6]. During extrusion under such condition, both the shear stress of the matrix acts on the reinforcing fibers and the resistance of the matrix to fiber deflection are quite low, which enables the reinforcing fibers to well orient themselves to the direction of plastic flow without being severely fractured or damaged.

3. 2 *Mechanical Properties and Fracture Characteristics*

The room-temperature mechanical properties of the Al_2O_3sf/Al-1. 5Mg composite are listed in Table 2. Despite the fact that the tensile strength of the Al_2O_3sf is only about 600 MPa, the Al_2O_3sf/Al-1. 5Mg composite manufactured by the technique EDFLI presents satisfactory mechanical properties. The elastic modulus E , the yield stress $\sigma_{0.2}$, and the tensile strength σ_b all rise significantly with the increase of the fiber content, indicating that good reinforcing effect is obtained. Besides, the elongation of the composite is still maintained at a relative high level, being much higher than that of the similar composites manufactured by other techniques[7,8] and good enough for practical application.

Table 2 Room-temperature mechanical properties of Al_2O_3sf/Al-1. 5Mg composite

V_f	E /GPa	$\sigma_{0.2}$ /MPa	σ_b /MPa	δ_5/%
0	70. 8	97. 5	187. 0	19. 8
0. 1	83. 2	118. 6	203. 4	7. 6
0. 2	94. 0	136. 4	226. 3	5. 9

Fig. 3 shows the SEM fractographs of tensile fracture of the Al_2O_3sf/Al-1. 5Mg composite. It again confirms that the distribution of the reinforcing fibers is quite uniform and that there exist no non-wetting defects and tangling up or bunching of the reinforcing fibers. Further, lots of dimples, with the reinforcing fibers inside them, are observed over the whole fracture surface, indicating that fiber failure under tension stress and microvoid coalescence are jointly responsible for the tensile fracture. Besides, the fact that no pullout of the reinforcing fibers are observed and that lots of deformed matrix remains are found adhering to the exposed fiber (Fig. 3 (b)) implies that good interfacial bond between the matrix and the reinforcing fibers has been obtained.

The reason that the technique EDFLI can assure good reinforcing effect lies in that it is able not only to eliminate such defects as microvoids, to improve fiber distribution and to increase the interfacial bond by crystallization under pressure and consequent large plastic deformation, but also to reduce to the greatest extent fiber damage and fracture during extrusion, assuring the maintenance of high aspect ratios. Accorrding to the mechanics of fiber reinforced composite, the fiber can provide good reinforcing effect only when its aspect ratio is greater than a critical value, that is, the critical aspect ratio. The critical aspect ratio is generally calculated by the formula $S_c = \sigma_{fb}/\sigma_{my}$ with S_c representing the critical aspect ratio while σ_{fb} and σ_{my} being the tensile strength of the fiber and the yield stress of the matrix respectively[9]. As far as the Al_2O_3sf/Al-1. 5 Mg composite investigated in this research is concerned, the critical aspect ratio is estimated at about 6 owing to the fact that the tensile strength of Al_2O_3sf and the yield stress of Al-1. 5Mg alloy are about 600 MPa and 100 MPa respectively. On the other hand, it has been mentioned earlier in this paper that the actural average aspect ratio of the fibers in the Al_2O_3sf/Al-1. 5 Mg composite is within the range of 8～10. Therefore, most of the fibers in the Al_2O_3sf/Al-1. 5 Mg composite can provide good reinforcing effect because their actual aspect ratios are greater than the critical aspect ratio. Besides, it has been reported in references [8, 10] that fiber tangling up or bunching and other non-wetting defects are sources which lead to stress concentration and preferential void nucleation or crack initiation and that they are responsible for low-strain fracture of composites. Since the technique EDFLI can eliminate the above defects, the elongation of the composite manufactured by it is maintained at a higher level.

3. 3 *Linear Expansion Coefficient and Corrosion Resisting Property*

The linear expansion coefficient is one important physical property which determines the thermal expansivity of material. Listed in Table 3 are the linear expansion coefficients of the Al_2O_3sf/Al-1. 5 Mg composite with different fiber volume contents. It is clear that the higher the fiber volume content, the lower the linear expansion coefficient of the composite. The reason for this is that the linear expansion coefficient of the Al_2O_3sf is much lower than that of the Al-1. 5 Mg alloy.

Al - 1. 5 Mg is an alloy with excellent cor -

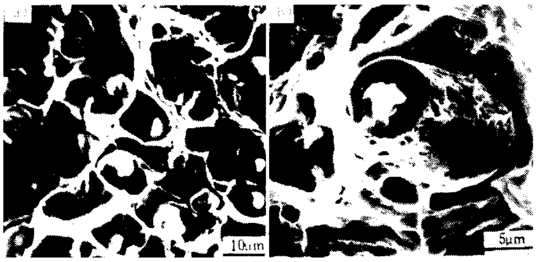

Fig. 3 SEM fractographs of Al_2O_3sf/Al-1. 5Mg composite

Table 3 Linear expansion coefficient of Al_2O_3sf/Al-1.5Mg composite

V_f	α_l /10^{-6}·℃$^{-1}$		
	20～100 ℃	20～200 ℃	20～300 ℃
0	24.3	25.2	26.0
0.1	21.4	22.3	23.1
0.2	18.7	19.3	19.8

rosion resistance. It is worth investigating whether the introduction of the reinforcing Al_2O_3sf will affect the corrosion resistance of the alloy. Fig. 4 gives a comparision between

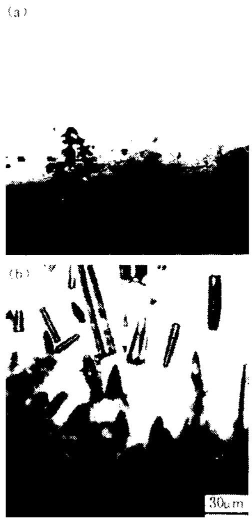

Fig. 4 Optical micrographs of Al-1.5Mg alloy and Al_2O_3sf/Al-1.5Mg composite after grain boundary corrosion proof test
(a)—Al-1.5Mg alloy;
(b)—Al_2O_3sf/Al-1.5Mg composite

the microstructures of the Al-1.5Mg alloy and the Al_2O_3sf/Al-1.5Mg composite, with both having experienced the grain boundary corrosion proof test. It shows that neither of the two materials possesses the tendency of grain boundary corrosion. Besides, no corrosion trace exists in the vicinity of the matrix/fiber interface, indicating that no corrosion develops along the matrix/fiber interface. The reason for this lies in that Al_2O_3sf itself consists of oxide ceramic phases which are very stable and corrosion-resistance. When mixed with the matrix alloy, it will not influence the corrsion resistance of the alloy. The only possibility is that the interfacial reaction may deteriorate the corrosion ressistance of the composite in the vicinity of the matrix fiber interface. Recent investigation[6] has revealed that the resultant of the interfacial reaction of the Al_2O_3sf/Al-1.5Mg composite is the stable and corrosion-resistant $MgAl_2O_4$. It will not affect the corrosion resistance of the composite.

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(Edited by Zhu Zhongguo)