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THE MECHANICAL PROPERTIES OF AL-Cu ALLOY REINFORCED WITH CONTINUOUS FIBERS AND AL_2O_3 PARTICLES

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ABSTRACT

In the present work, an Al –Cu alloy matrix composites reinforced with continuous AL_2O_3 fibers and AL_2O_3 particles were produced by the squeeze casting technique. The influence of the fibers and the particles on the mechanical properties of the composites, particulars on the tensile strength of the composites in the transverse direction of the fibers, was investigated. Tensile strength, elongation, and hardness of the composites were examined in the longitudinal and the transverse directions of the fibers. The fracture surfaces of the composites in the transverse direction were examined using SEM. The obtained results showed that, the tensile strength of the composites with fibers in the longitudinal and the transverse directions of the fibers were both improved by the introduction of particles. Tensile fracture when stretched in the transverse direction tended to propagate along the interface between the fibers and the matrix in composites without particles, but propagate in the matrix in the hybrid composites with particles.

KEY WORDS

Hybrid composite, AL_2O_3 fiber, AL_2O_3 particle and Mechanical properties.

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1. INTRODUCTION

Metal matrix composite (MMC) materials exhibit quite a good combination of strength and stiffness of the reinforcing phase with ductility and toughness of the matrix. Aluminum alloys are most useful candidate matrix materials for weight reduction. The introduction of continuous fibers in Aluminum alloy is expected to improve the mechanical properties, such as strength and elastic modulus, and the results of several research studies have been published [1-10]. However, in continuous fiber-reinforced alloys, prepared by the squeeze casting process, the mechanical properties of the alloys in the transverse direction of the fiber are not satisfactory because the fibers come into contact with each other due to the compression deformation of the preform under high pressure. It has been suggested that the fibers be separated from one another by adhering fine particles to the fiber surface as a technique for preventing contact between fibers. In this way, the problem of low strength in the transverse direction, which is a defect of unidirectionally reinforced alloy, may be solved. There have been some reports of hybrid composites prepared by introducing particles between the fibers of the preform [11-13]. The fibers used were SiC, Carbon and Tyranno fibers and the reinforcements adhered to the surface of the fibers were SiC particles and SiC whiskers. However, there have been no reports of hybrid composites made using AL_2O_3 continuous fibers and AL_2O_3 particles as the reinforcements, despite the fact that they are resistant to wear, and have high stiffness and strength. In this study, Aluminum alloy AL-4.5%Cu was used as the matrix, and the hybrid preform was made of continuous AL_2O_3 fibers with fine AL_2O_3 particles adhered to their surfaces. The hybrid composites were prepared by the squeeze casting process. The distribution of the reinforcements, the fiber fractions, and the particle fractions were examined in order to discover their effects on the mechanical properties of the composites, particularly their tensile strength in the transverse direction.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 Fabrication of the Composites

The materials used for the composites were Aluminum alloy AL-4.5%Cu as the matrix, and AL_2O_3 continuous fibers and AL_2O_3 particles as the reinforcements. The chemical composition of the matrix alloy is shown inTable 1, and the properties of the reinforcements are shown in Table 2.

Table 1 Chemical composition of the matrix alloy %

Cu	Mg	Fe	Ti	Al
4.51	0.30	0.15	0.14	Bal

Table 2 Properties of the reinforcements from supplier's data sheet

Reinforcement	Composition	Diameter (μm)	Density (g/cm³)
AL_2O_3 fiber	85 % AL_2O_3 15 % SiO_2	15	3.3
AL_2O_3 particle	99.9 AL_2O_3	1	4.0

Preforms were produced by first dispersing AL_2O_3 particles in an aqueous solution containing a binder of polyvinyl alcohol, and then adhering the particles to the surfaces of AL_2O_3 fibers by transferring the fibers to the solution. The preform was produced by positioning the fibers in a steel case with open ends unidirectionally, and it was dried at 100°C for one hour in air. This heating bumed out the organic binder. A scanning electron micrograph of the preform structure is shown in Fig.1, where the adhesion of the particles to the surface of the fibers can be seen. This particles separate the fibers from each other and promote melt infiltration between the fibers. A schematic drawing of the preform in the steel case is shown in Fig.2, the infiltration direction is parallel to the fibers and from both ends simultaneously. In this way, preform compression and fiber damage are limited.

Fig.3, shows a schematic drawing of the squeeze casting process. The preform in a steel case was preheated to 700°C and introduced into the mold, which was preheated to 300°C. The liquid Aluminum alloy at 800°C was rapidly squeezed into the preform at a pressure of 40MP_a with a plunger to form the composite, and maintained for 60 seconds. After infiltration, the prepared composite was cooled in the mold. The fiber volume fractions of the composites, V_f, were 40% , 50% and 70%, and particle volume fractions, V_p, were 0%, 5% and 10%. As the comparison, binary alloy was produced by the same process (hereinafter referred to as the matrix alloy).

2.2 Mechanical Tests

2.2.1 Tensile testing

Tensile tests were conducted on composites and matrix material. Tensile specimens with a diameter of 5mm and a gauge length of 15mm were machined from the cast composites, and the specimens were solution treated at 515°C for 10 hours, water quenched, then aged at 160°C for 4 hours (T6 treatment). Tensile testing at room temperature in air was performed on universal testing machine. A constant cross-head speed of 0.5mm/min, was used.

2.2.2 Hardness tests

The Vickers hardness, Hv, of the materials was established using a Vickers hardness tester. A minimum of six hardness readings were taken for each specimen.

2.3 Metallographic Examination and SEM Fractography

The initial microstructure of the composites and matrix material was characterized by optical microscopy after standard metallographic preparation technique. A scanning electron microscopy, SEM, (Jeol-Ts-20 Japan) was used to examine the tensile failed specimens.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Microstructure

Optical micrographs of the matrix alloy and transverse sections of composites are shown in Fig.4. The microstructure of the matrix, the composite without particles (V_f = 50%), and the composite with particles (V_f = 50%, V_p = 10%) can be seen in Fig.(4a,b and c). From this figure, it is clear that, the matrix alloy infiltrated the cavities among the fibers, and there were no cracked fibers in the composites without particles and with particles. In the composites without particles, many fibers were in direct contact with adjacent fibers and the distribution of the fibers was not uniform (Fig. 4b). In contrast, in the composites with particles, particles were observed in the matrix and near the fiber surface (Fig. 4c), propably as a result of the particles adhered to the surfaces of the fibers being partly dispersed during infiltration. In the composites with particles, the particles in the matrix and near the fiber surfaces prevented the fibers from contacting each other, so the fibers were separated uniformly.

3.2 Mechanical Properties

Fig. 5, shows the tensile strength of composites with various fiber and particle volume fractions. As shown, the tensile strength of composites in the longitudinal direction of the fiber increased as fiber volume fraction increased in all the composites. This may be due to dominant fiber strength in the longitudinal direction. In the longitudinal direction, the tensile strength of composites with particles was slightly higher than that of composites without particles. In contrast, the tensile strengths of composites in the transverse direction decreased as the fiber volume fractions increased, but the decrease in composites with particles was slight. These results indicate that the introduction of particles between the fibers improves the tensile strength of composites in the transverse direction of the fiber.

Fig. 6, shows the elongation of composites with various fiber and particle volume fractions in the longitudinal and transverse directions of the fibers. The elongation in the longitudinal direction decreased as fiber volume fraction increased in all the composites (Fig. 6a). The elongation of composites in the transverse direction also decreased as fiber volume fraction increased, but the decrease in composites with particles was slight (Fig. 6b).
Fig.7, shows the hardness of composites with various fiber and particle volume fractions. The hardness of the composites in the longitudinal and the transverse directions of the fiber increased as fiber and particle volume fractions increased by a similar degree.

3.3 Fractographic Examination

Fig.8, shows examples of fracture surfaces when stretched in the transverse direction of the fibers, after heat treatment of a composite reinforced with 50% fibers only and a composite reinforced with 50% fibers and with 10% particles. In the composite without particles, the area of exposed fiber surface on the fracture surface was larger than that of the fractured matrix (Fig. 8a). In contrast, in the composite with particles, the area of the particles and fractured matrix on the fracture surface was large (Fig. 8b).

The low strength and elongation of the composites without particles in the transverse direction of the fibers may be attributed to the propagation of fractures along the interface where the contact point between fibers acts as a failure point. In contrast, the superior of strength and elongation of the composites with particles in the transverse direction may be attributed to the propagation of fractures inside the matrix due to the uniform distribution of the fibers in the matrix without direct fiber to fiber contact.

Finally, this study indicates that the problem of low strength in the transverse direction is a defect in unidirectionally reinforced alloy and can be solved by introducing fibers with particles adhered to their surfaces.

4 CONCLUSIONS

From this study, the following conclusions may be drawn :

1. In composites without particles, many fibers were in direct contact with adjacent fibers and the distribution of the fibers was not uniform. However, in composites with particles, the particles in the matrix and on the surfaces of the fiber prevented the fiber from contacting each other, so the fibers were separated uniformly.
2. The tensile strength of composites in the longitudinal and the transverse directions of the fibers increased as the particle fractions increased. In particular,

the tensile strength in the transverse direction were noticeably improved by the introduction of the particles.

3. The elongation of the composites in the longitudinal direction of the fibers decreased as the fiber volume fractions increased, but that in the transverse direction was increased by the introduction of fibers with particles adhered to their surfaces.
4. The hardness of the composites increased as the fiber and the particle volume fractions increased.
5. In composites without particles, fractures tended to propagate along the interface, but in composites with particles, fractures tended to propagate inside the matrix.

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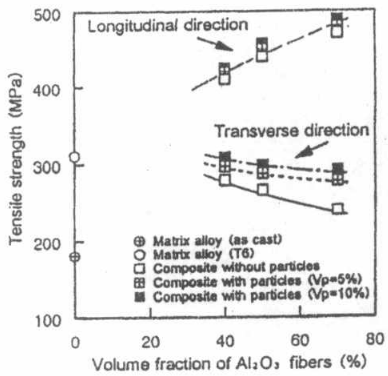
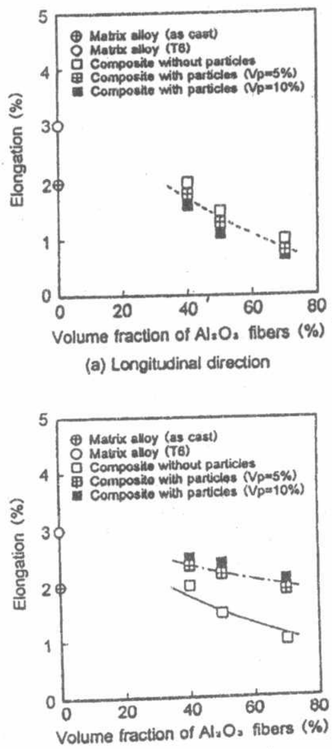


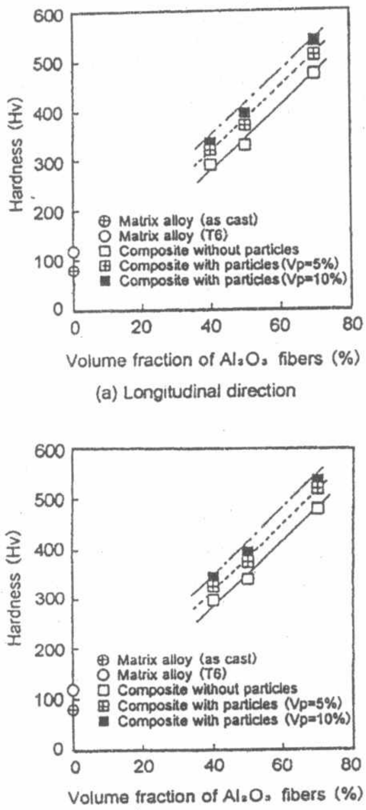
Fig . 5 Effect of volume fraction of fibers and particles on tensile strength of composites.



(a) Longitudinal direction

(b) Transverse direction

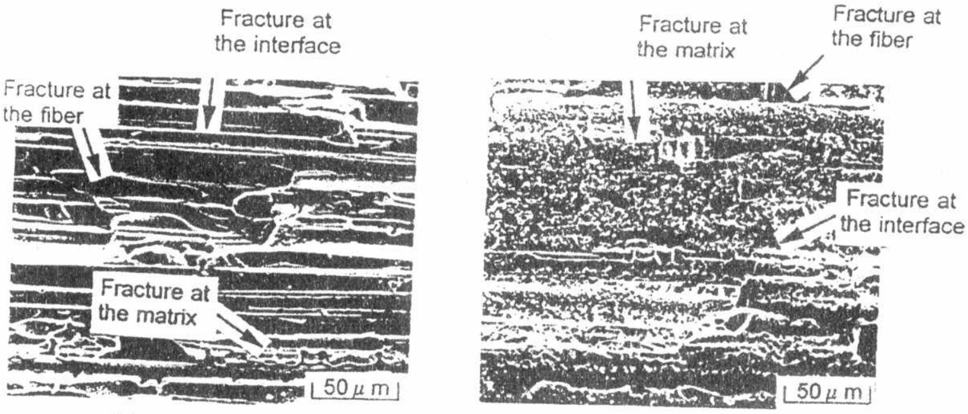
Fig . 6 Effect of volume fraction of fibers and particles on elongation of composites in the longitudinal and transverse directions of the fibers .



(a) Longitudinal direction

(b)Transverse direction

Fig . 7 Effect of volume fraction of fibers and particles on hardness of composites .



(a) Composite without particles (Vf=50%, Vp=0%)

(b) Composite with particles (Vf=50%, Vp=10%)

Fig . 8 Fracture surfaces of the composites with and without particles .

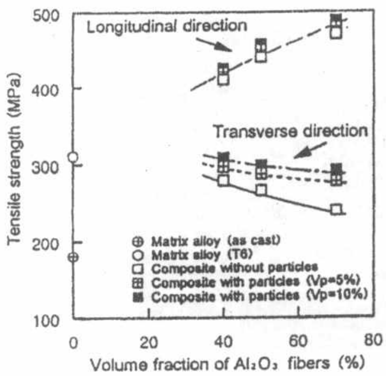
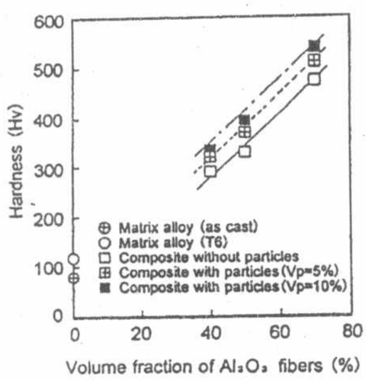
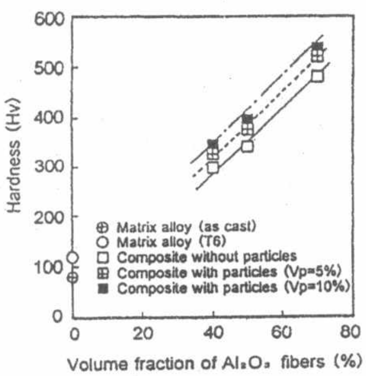


Fig . 5 Effect of volume fraction of fibers and particles on tensile strength of composites.

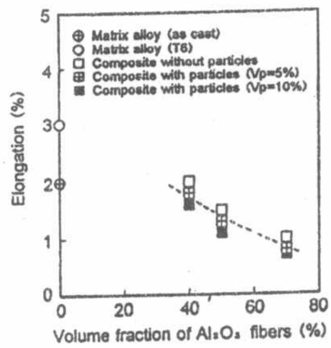


(a) Longitudinal direction

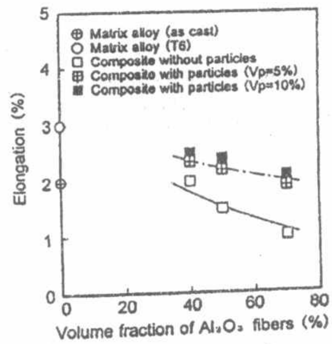


(b)Transverse direction

Fig . 7 Effect of volume fraction of fibers and particles on hardness of composites .

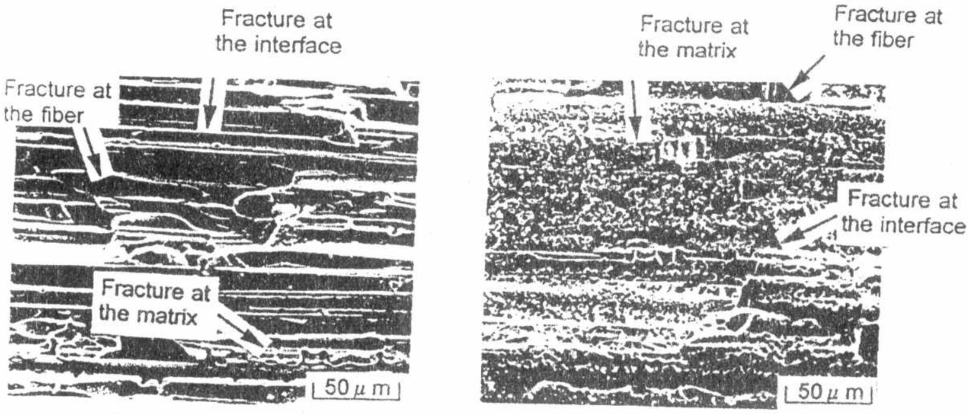


(a) Longitudinal direction



(b) Transverse direction

Fig . 6 Effect of volume fraction of fibers and particles on elongation of composites in the longitudinal and transverse directions of the fibers .



(a) Composite without particles (Vf=50%, Vp=0%)

(b) Composite with particles (Vf=50%, Vp=10%)

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