

Fabrication and Characterization of 5 vol.% (Al₂O₃)_p + 8 vol.% (Al₂O₃)_f /A336 Hybrid Micron and Nano-Composites

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Abstract. Hybrid composites are fabricated by adding two reinforcements into matrix materials so that the expected excellent properties can be achieved through the combined advantages of short fibres, and different size particles (micron or nano), which provide a high degree of design freedom. In this paper, hybrid preforms were produced with the different size reinforcement of the Al₂O₃ particles and short fibres. The Al-Si alloy-based hybrid composites reinforced by 5 vol. % Al₂O₃ particles and 8 vol. % Al₂O₃ fibres were fabricated by preform-squeezing casting route. The structure and performance of composite materials were studied with Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM). The results show that the reinforcements, both particles and fibres, distribute homogeneously in the matrix materials, and the properties of composites are found to improve in comparison with the matrix Al-Si alloy.

1 Introduction

Metal matrix composites (MMCs) have widely been recognized to possess superior mechanical properties, such as enhanced wear resistance, high elastic modulus and yield strength, low coefficients of thermal expansion, as compared to the unreinforced monolithic metals [1-8]. With further development of metal matrix composites, their great potential has been demonstrated to be broadly used in the automobile and aerospace industries, and to fabricate various civil products as advanced materials as well. Recently, among the various types of metal matrix composites, researchers pay extra attention to aluminum or magnesium matrix composites reinforced with hybrid reinforcement in which both of particles and short fibres are employed. This is because they provide large opportunities to optimize the engineering performance of the MMCs for potential applications in the automobile industry, where a relatively low volume of reinforcement is required [9-10]. In this study, the hybrid preform with a cellular structure made by ceramic Al₂O₃ particles and fibres was fabricated. Then, the squeeze casting process was adopted to infiltrate the liquid aluminum into preform under an applied pressure. The results of preliminary microstructure analyses with both optical and Scanning Electron microscopy (SEM) show that the ceramic reinforcement including both the particles and fibres are dispersed uniformly in the matrix alloy without agglomeration and cave. The property evaluation indicates that the hybrid reinforced composite has improved elastic modulus, tensile strengths and hardness, relatively low

thermal expansion coefficient in comparison to the matrix alloy.

2 Experimental Procedures

2.1 Materials

Al₂O₃ ceramic particles and Al₂O₃ short fibres were employed as the raw materials for preparation of the hybrid reinforcements. Two different sizes of the particles, 5.0 μm (named micron) and 600nm (named nano), respectively, were used for the hybrid preforms for the purpose of a comparative study. The matrix alloy was A336 with the chemical composition (wt.%) of Al-12.0 Si-1.0Ni-1.0 Cu-1.0 Mg.

2.2 Hybrid Preform Preparation

Figure 1 presents the flow chart of the process for fabricating the hybrid preforms. The fabrication steps involve mixing of ceramic short fibres and particles, the introduction of binding compounds, shape formation of preforms under pressure, drying and sintering. In the hybrid preform, the fibres serve as the cellular structure skeleton, and the content level of the fibre was pre-determined based on the desired amount of porosity levels of the cellular solid. Meanwhile, the particles were dispersed in the pores present in the cellular solid. The contents, sizes, and types of the ceramic reinforcement would be adjusted with the definite quantity and the shape of preforms.

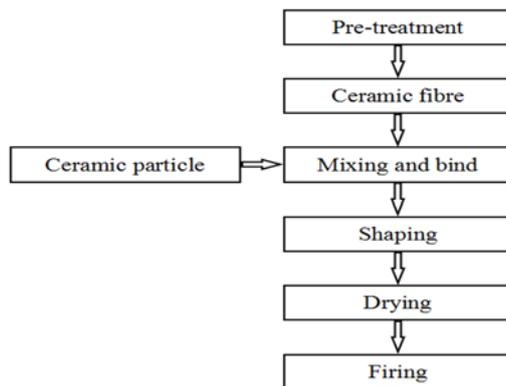


Figure 1 Flowchart Showing the Procedure for Fabricating Hybrid Perform

2.3 Composite Fabrication

Figure 2 shows the fabrication process of the composites in which a squeeze casting process was adopted. During fabrication, a hybrid perform was first preheated to 300°C. Then, molten matrix alloy at 730°C infiltrated into the preheated preform under an applied pressure of 100MPa.

The pressure was maintained at the desired level for 20 seconds. After squeezing casting, a cylindrical disk of the dual-phase reinforced composite was obtained. The geometry of the disk is 0.010 m in diameter and 0.025 in thickness. In the hybrid composite, the main reinforcement phase was particles, and short fibres serve as the second reinforcement phase.

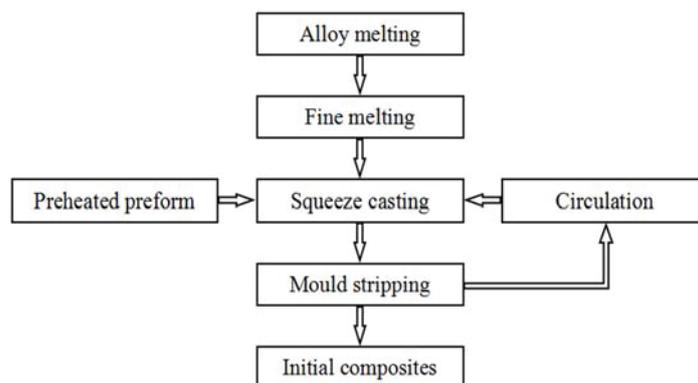


Figure 2 Flowchart Showing the Procedure for Fabricating Hybrid Composites

2.4 Microstructure

The microstructure of the new material was examined by optical microscopy and scanning electron microscopy (SEM). The alumina composites samples for optical microscopy and SEM were cut, mounted, mechanically grounded, and polished following the standard metallographic procedure. The SEM was conducted in a JEOL-200CX machine, and accelerating voltage is 200kV.

Following ASTM B557, subsize flat tensile specimens (25mm) in gage length, 6mm in width, and 6 mm in thickness) were machined from the center of the squeeze cast disc. The tensile properties, including 0.2% yield strength (YS), ultimate tensile strength (UTS), and elastic modulus, were obtained based on the average of three tests.

2.5 Property Evaluation

The mechanical properties of the hybrid composite were evaluated by tensile testing, which were performed at ambient temperature 300 °C, on an Instron machine equipped with computer data acquisition system.

3. Results and Discussion

3.1 Microstructure

Figure 3 shows the hybrid preform made from the Al₂O₃ particles and fibres. Figure 4 shows the cylindrical disk of the squeeze cast hybrid reinforced Al-Si alloy-based composites.



Figure 3 A Hybrid Preform



Figure 4 Squeeze Cast Hybrid Composite

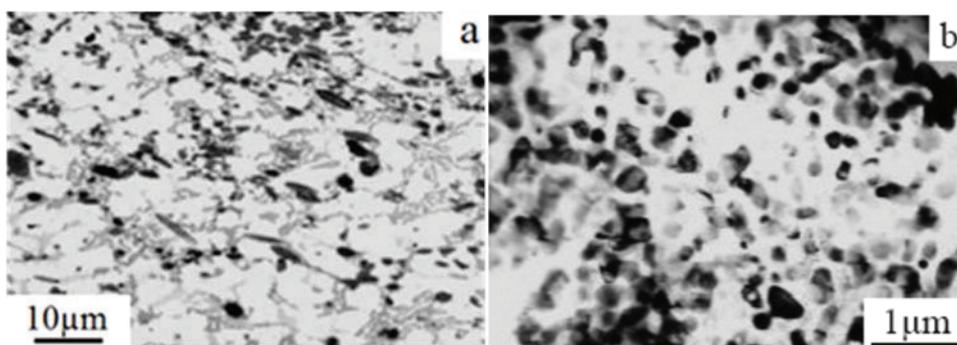


Figure 5 Microstructure of Al-Si/(8% vol. Al₂O₃ Fibres+ 5 vol. % Al₂O₃ Particles: (a) micron and (b) nano

The microstructure of aluminum composite materials reinforced by Al₂O₃ particles and fibres is shown in Figure.5 (a, b). As shown in Figure 5 (a), the black dots are Al₂O₃ particles, and the gray areas are the matrix Al-Si alloy. Despite a large difference in the particle size, evidently, the reinforcement of the particles and fibres are dispersed uniformly without agglomeration and cavities in the matrix alloy. However, it can be seen from Figure 5 (a) and (b) that, with the same particle volume, a difference in the dispersion distance of the particle reinforcement is present in the composites. When the particle size is large (5 µm), the dispersion distance between the particles is around 1~5 µm. As the particle size decreases to the nano level (600 nm), the distance between the particles is also reduced to 80~200 nm. This observation should be attributed to the fact that, as the volume of reinforcement is constant, the number of particles are reduced with increasing the size of particles. The fewer the particles, the

larger the dispersion distance which is present between the particles. It has been documented [9] that, the strength of preforms and the process parameters such as the preheated temperature of the pre-form, the pouring temperature of the matrix alloy, and the applied pressure level in the perform plus squeeze casting process, could influence the quality and performance of the composites significantly. It appears that the applied pressure during casting and infiltration enables molten matrix alloy with relatively high superheat in the preheated die to flow into the perform and wet reinforcement even with sub-micron particles involved although no wetting agents was employed. Also, because the contacting time between the molten alloy and reinforcement at relatively casting high temperature is shortened with the help of the applied pressure, no observation on severe chemical reactions between the matrix alloy and reinforcement occurred during fabrication. As a result, the microstructure of the composites is homogeneous without the porosity and reactants.

Table 1. Properties of composites and aluminum alloy and iron cast

Material		Composite	Al-Si alloy	Gray Iron 250
Density [kg·m ³]		2.78	2.75	7.25~7.35
Tension strength [MPa]	RT	275	265	250
	300°C	158	131	
Hardness [HB]		138	130	215
Elasticity modulus [GPa]		96	80	311
Linear expansibility [10 ⁻⁶ /°C]	25~250°C	20.1	24.6	11.8
	25~400°C	21.4	25.7	

3.2 Mechanical property of the composites

Table 1 shows the tensile and physical properties of the hybrid composite with the reinforcement of micron (5 µm) sized 5 vol. % Al₂O₃ particles + 8 vol. % Al₂O₃ fibres

in comparison with the base Al-Si alloy and cast iron. The hybrid composite exhibits improved tensile strengths over those of the matrix alloy and gray iron 250. In particular, high temperature tensile strength (158 MPa) of the composite is 20% higher than that of the matrix alloy. With almost no increase in material density, the elastic modulus

of the hybrid composite shows 20% improvement over the matrix alloy despite that it is still lower than that of gray iron 250. Also, the thermal expansion of coefficient of the hybrid composite is lower than that of the matrix alloy.

4. Conclusions

1. Hybrid preforms with Al₂O₃ particles in micron or nano sizes and fibres were prepared by blending and shaping. The hybrid composites were fabricated by a squeeze casting process after the preform was infiltrated by molten Al-Si alloy under an applied pressure.

2. The results of the microstructure analyses of the hybrid composites show that the reinforcement of the particles and fibres are dispersed uniformly in the matrix alloy without agglomeration and Al₂O₃ fibres orientate random in the matrix. This observation indicates that the adopted squeeze casting process is capable of manufacturing the hybrid composites with reinforcements of different sizes and physical geometries.

3. The hybrid composite exhibits improved tensile strengths over those of the matrix alloy and gray iron 250. In particular, high temperature tensile strength (158 MPa) of the composite is 21% higher than that of the matrix alloy. With almost no increase in material density, the elastic modulus of the hybrid composite shows 20% improvement over the matrix alloy.

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References

1. Zhu H., and Li Z., Wear behavior of SiC_p reinforced Al matrix composite, *Mat. Mech. Eng.*, 20(3), 1996, 40-45.
2. Finot M., Micromechanical model of reinforcement fracture in particle-reinforced metal composites, *Metall Trans*, 25A (11), 1994, 2403-2406.
3. Tohgo K., and Weng G. J., A progressive damage mechanics in particle-reinforced metal-matrix composites under high triaxial tension, *Trans ASME*, 116(7), 1994, 414-420.
4. Yue C., Zhang Y., and Bao S., Investigations of Tribological Properties of Particle-Reinforced Aluminum Matrix Composites under Dry Sliding, *Mechanical Engineering (China)*, 12(8), 2001, 963-962.
5. Qi H., Ding Z., Fan Y., and Jiang Z., Research on automotive brake discs of SiC_p/Al composite, *Acta material composite sinica*, 18(1), 2001, 62-66.
6. Wang H., and Li W., Research on wear properties of aluminum matrix composites-brake materials, *J. Chin. Electr. Microsc. Soc.*, 19(4), 2000, 551-552.
7. Bai Y., Yun H., Han E., Tan R., and Bi J., Research on properties of aluminum matrix composites, *Materials protection*, 36(9), 2003, 5-9.
8. Fan J., Sang J., and Zhang Y., The spatial distribution of reinforcements in aluminum matrix composites, *Acta Metallurgica Sinica*, 34(11), 1998, 1198-1204.
9. Hu H., Squeeze casting of Magnesium alloys and their composites. *Journal of Mat. Sci.*, 33, 1998, 1579-1589.
10. Ye H., and Liu X., Review of recent studies in magnesium matrix composites. *Journal of Mat. Sci.*, (39), 2004, 6153-6171.