THERMAL CONDUCTIVITY AND EXPANSION OF MAGNESIUM ALLOY MATRIX COMPOSITES BY LIQUID PRESSING PROCESS

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1 Introduction

Magnesium alloy matrix composites are offering several advantages over other MMCs, including lightweight, better specific strength and modulus. [1-5] Despite the practical significance, relatively little research has been conducted on thermal property of magnesium alloy matrix composites. [6-8] Coefficient of thermal expansion (CTE) and thermal conductivity (TC) of liquid pressed AZ91 magnesium alloy matrix composites could be affected by reinforcement shape.

The squeeze casting process, one of the conventional fabrication methods for the metal matrix composites, has merits such as high productivity and easiness for near-net-shape fabrication, but has shortcomings of poor reliability, the requirement of high-pressure loading of 50 MPa or more in order to enhance the wettability between reinforcements and matrix, and easy collapse of preform patterns. The liquid pressing process is new-concept process using low pressure near to the theoretically required minimum loading pressure to infiltrate the metallic melt in reinforcement preform.

The objective of this study is to examine the thermal properties of liquid pressed AZ91 magnesium alloy matrix composites. The change in thermal properties with two different shapes of reinforcement is discussed based on thermal property prediction models and micrographic observations.

2 Experimental

The AZ91 magnesium alloy was used as a matrix of composites. Table 1 shows the chemical composition of AZ91 magnesium alloy. Unidirectional carbon fiber (UD C_f, Mitsubishi Rayon TR-50S) and approximately 10 μm sized silicon carbide particle (SiC_p, Saint-Gobain SIKA F-600) were used as reinforcements of the composites. Figure 1 shows the schematic illustration of liquid pressing process. A reinforcement preform and AZ91 magnesium alloy were inserted into the mold, degassed, and vacuumed. The mold was heated to 695°C, held for 5 minutes, and then pressed under a pressure of about 10 MPa. The fabricated composites were sectioned three different directions (x, y and z) to observe microstructure using scanning electron microscope (SEM). For the quantitative CTE and TC measurements, dilatometer and laser flash method were used. The effects of reinforcement shape on thermal properties were analyzed by several prediction models.

Table 1. Chemical compositions of AZ91 magnesium alloy.

Ele.	Mg	Al	Zn	Si	Cu	Mn	Ni
Wt.%	Bal.	9.0	1.0	0.30	0.10	0.13	0.010

Pressing

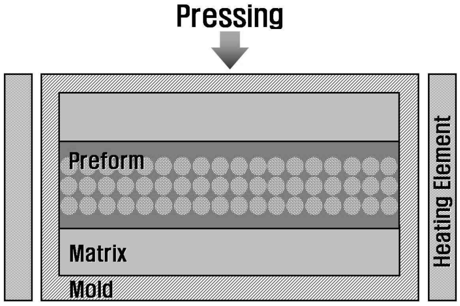

Fig. 1. Schematic illustration of liquid pressing process.

3 Results and Discussion

3.1 Microstructures

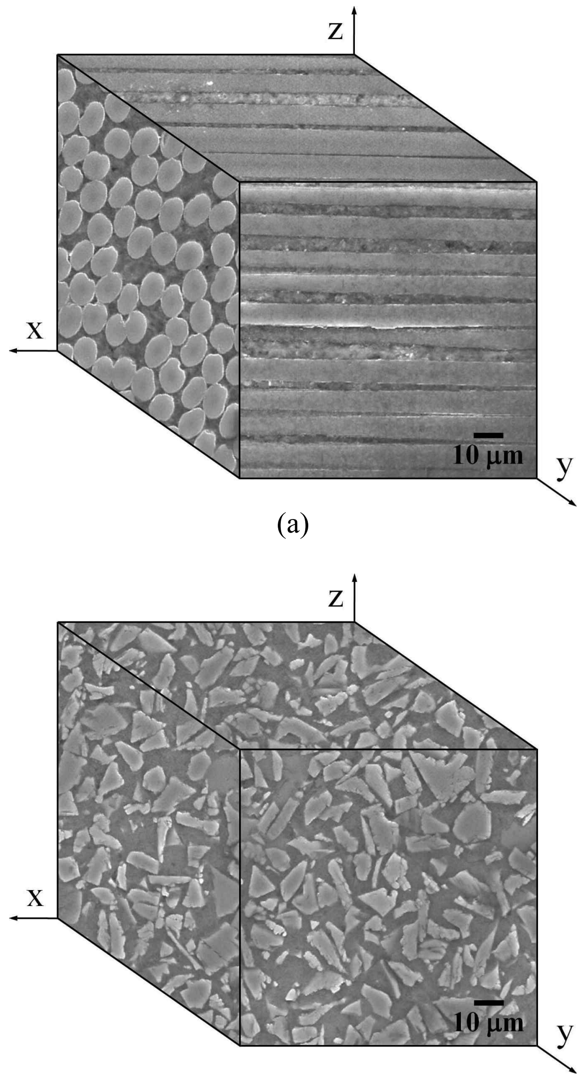

Fig. 2. SEM micrographs of liquid pressed (a) UD C_f/AZ91 and (b) SiC_p/AZ91 composites, respectively.

Figure 2 shows the SEM micrographs of AZ91 magnesium alloy matrix composites fabricated with different reinforcement shapes of UD C_f and SiC_p, respectively. The reinforcements of UD C_f and SiC_p are uniformly distributed through the composites and there is no evidence of pores or separated interface. Figure 2(a) showing that the UD C_f/AZ91 composite has anisotropic microstructures due to continuous carbon fiber. On the other hand, the SiC_p/AZ91 composite (Figure 2(b)) has isotropic microstructures due to discontinuous SiC_p.

3.2 Thermal Properties

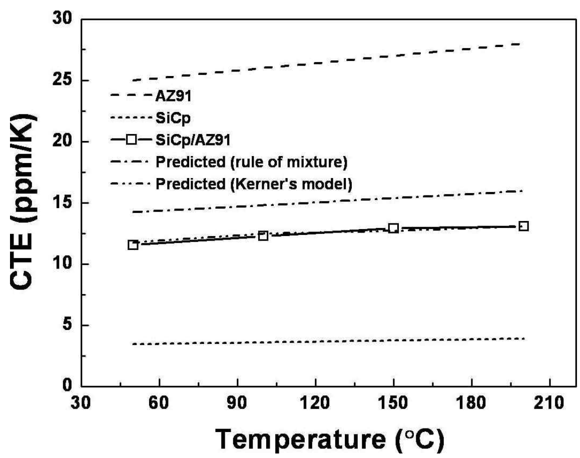

Fig. 3. Experimental and predicted CTE of liquid pressed SiC_p/AZ91 composite as a function of temperature.

Figure 3 shows the experimental and predicted CTE of liquid pressed SiC_p/AZ91 composite with the raw materials of SiC_p and AZ91. The CTE of SiC_p/AZ91 increased from 11.55 to 13.08 ppm/K with increment of temperature. In order to understand the effects of reinforcement shape on CTE, thermal property predictions were conducted. There are several models to predict the CTE of the metal matrix composites. In this study, the thermal expansion of SiC_p reinforced AZ91 composite was calculated using two different models as follows.

Rule of mixture

$$\alpha_c = (1 - V_f)\alpha_m + V_f \alpha_f \tag{1}$$

Kerner's model [9]

$$\alpha_c = (1 - V_f)\alpha_m + V_f \alpha_f + \frac{V_f (1 - V_f)(\alpha_f - \alpha_m)(K_f - K_m)}{(1 - V_f)K_m + V_f K_f + 3K_f K_m / 4G_m} \tag{2}$$

with

$$K = \frac{E}{3(3 - E/G)} \tag{3}$$

where: α = CTE, V = volume fraction, K = bulk modulus, and subscript c = composite, f = reinforcement, m = matrix

As shown in Figure 3, the predicted Kerner's model, completely matches the experimental result of the SiC_p/AZ91 composite.

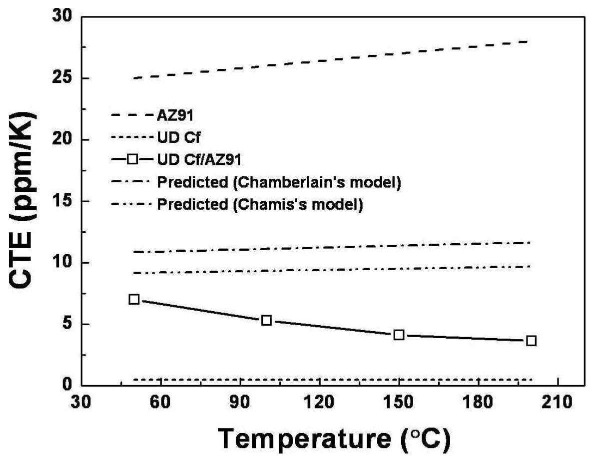

Fig. 4. Experimental and predicted CTE of liquid pressed UD C_f/AZ91 composite as a function of temperature.

Figure 4 shows the experimental and predicted CTE of the UD C_f/AZ91 composites. The predicted models do not match the experimental result. The discrepancy between the experimental result and the calculated results of UD C_f/AZ91 composite was considered due to increase in constrain effect of the rigid continuous UD C_f as a softening of magnesium alloy matrix. The stiffness of magnesium alloy matrix decreases with increasing temperature, but there is little change in that of continuous UD C_f at the experimental temperature range. Therefore, the effect of continuous UD C_f on the resistance of thermal expansion increases and the CTE of UD C_f/AZ91 composite decreases.
The thermal expansion of UD C_f reinforced AZ91 composite was also calculated using two different models as follows.

Chamberlain's model [10]

$$\alpha_2 = \alpha^m + \frac{2\left(\alpha_2^f - \alpha^m\right)V_f}{\nu^m\left(F - V_f\right) + \left(F + V_f\right) + \left(E^m / E_1^f\right)\left(1 - \nu_{12}^f\right)\left(F - V_f\right)} \tag{4}$$

Chamis's model [10]

$$\alpha_2 = \alpha_2^f \sqrt{V_f} + \left(1 - \sqrt{V_f}\right)\left(1 + V_f \nu^m E_1^f / E_1\right)\alpha^m \tag{5}$$

where: α = CTE, V = volume fraction, F = packing factor, E = young's modulus, and subscript 1 = 1-direction, 2 = 2-direction, f = reinforcement, m = matrix

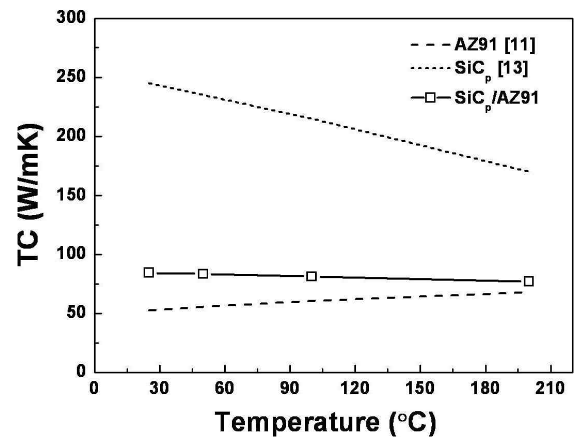

Fig. 5. TC of liquid pressed SiC_p/AZ91 as a function of temperature.

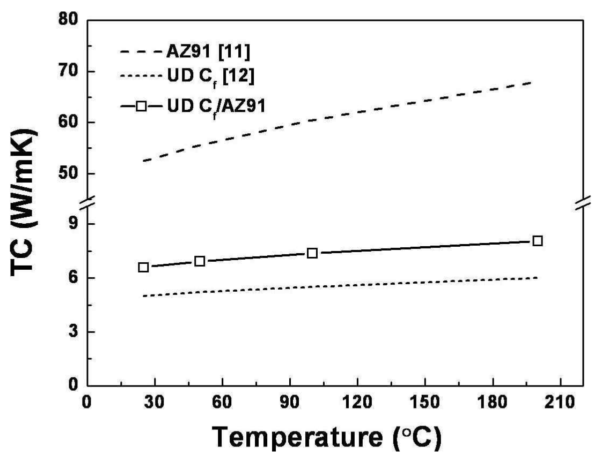

Fig. 6. TC of liquid pressed UD C_f/AZ91 as a function of temperature.

Figure 5 and Figure 6 show the TC of SiC_p/AZ91 and UD C_f/AZ91 composites with the raw materials of SiC_p, UD C_f, and AZ91. The TC of SiC_p/AZ91 composite decreased from 84.80 at room temperature to 77.05 W/mK at 200℃. On the contrary, the TC of UD C_f/AZ91 composite increased from 6.58 to 8.05 W/mK with increasing temperature. The TC of AZ91 magnesium alloy [11] and carbon fiber [12] increase with increasing temperature and that of SiC decreases with increasing temperature. [13] So the trends of experimental TC of both composites were in good agreement with estimated results from the data of the raw materials. The relatively low TC of both composites comparing with calculated results are considered due to the interfacial defects and reaction layers between matrix and reinforcements. Generally, the interfacial defects and reaction layers disturb the heat flow, which results in the decrease of TC of composite.

4 Conclusions

In this study, the CTE and TC of liquid pressed AZ91 magnesium alloy matrix composites were examined with different reinforcement shape, and the following conclusions are drawn.

1. The prediction of CTE shows that the predicted model of SiC_p/AZ91 composite is in good agreement with experimental result. UD C_f/AZ91 composite, on the other hand, the predicted results exhibited different trends compared to the experimental results. The present study suggests that the discrepancy between the experimental result and the calculated results of UD C_f/AZ91 composite was considered due to increase in constrain effect of the rigid continuous UD C_f as a softening of magnesium alloy matrix.

2. The TC of UD C_f/AZ91 increased with increasing temperature. SiC_p/AZ91 composite, on the contrary, shows different trend in TC. It means that the trends of experimental TC of both composites were in good agreement with estimated results from the data of the raw materials. The relatively low TC of both composites comparing with calculated results are considered due to the interfacial defects and reaction layers between matrix and reinforcements.

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