Interfacial Structure and Mechanical Properties of MgLiAl/SiC_w Composites

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ABSTRACT: Study on interfacial structure and tensile properties of MgLiAl/SiC_w composites were carried out. The results showed that there is a clear interface between the Mg-Li-Al matrix and SiC whiskers and there are not any compounds formation on the interface. Calculation of thermodynamics confirmed that the clear interface between the matrix and SiC whiskers may contribute to the low reactionary potential or the low reactionary dynamics. However, some SiC whiskers were attacked. As a result, SiC whiskers connect with matrix in {111} and formed 70.5° or 109.5° stages on the surface of the whiskers. The reason for that is the lower interfacial energy of {111}. Tensile test confirmed that the MgLiAl/SiC_w composites showed higher tensile strength and higher modulus compared with Mg-Li-Al matrix. Moreover, the specific strength and specific modulus were also increased obviously.

KEYWORDS: MgLiAl/SiC_w composites, Interfacial structure, Mechanical property

INTRODUCTION

Magnesium matrix composites with high specific strength and high specific modulus have a good potential of application in aerospace and automobile industry. However, owing to the poor ductility of hcp magnesium and hard particles in the composites, it is difficult to make magnesium matrix composites into products. In order to improve the ductility, magnesium-lithium matrix composites were implored recently[1-4]. Contributing to the bcc structure of Mg-Li alloys, the ductility of Mg-Li matrix composites is improved greatly[5]. Another advantage of adding lithium to magnesium is the low density of lithium(0.53g/cm^3) which can decrease the density of magnesium matrix composites apparently. Nevertheless, the compatibility of reinforcements with molten Mg-Li alloys presents a serious problem because of the high diffusive mobility and reactive of lithium[6,7]. Some transition metals(Fe, Ti) are stable in contact with molten Mg-Li alloys[8,9]. However, Fe or Ti increase the densities of the Mg-Li matrix apparently. Carbon fibre and some ceramic reinforcements possesses low density and high strength and therefore seem to be attractive, maintaining the low densities of Mg-Li based composites. According to the results reported by J.F.Mason et al[7], Mg-Li-C system is thermodynamically unstable and all efforts to manufacture composites of such a type have so for failed. Attempt to strengthen Mg-Li matrix with Saffil Al_2O_3 fibres is frustrated by the infiltration of lithium down the grain boundaries of the fibres, leading to the severe brittleness of the fibre. The most promising reinforcement may be the SiC whiskers. The purpose of this paper is to investigate the compatibility and interfacial structure of MgLiAl/SiC composites, with the aid of TEM and HREM.

2 Experimental procedures

2.1 Preparation of Mg-Li-Al alloys

Three kinds of Mg-Li-Al alloys were prepared by heating solid pieces of magnesium, lithium and aluminum in a steel crucible. In order to keep the melt from oxidation, the melt was continuously flushed with pure argon gas. The composition of Mg-Li-Al alloys fabricated are presented in table1.

Table1 Composition of Mg-Li-Al alloys

	Li(%Wt)	Al(%Wt)	Mg
Mg4Li1Al	4.0	1.58	surplus
Mg8Li1Al	8.6	1.36	surplus
Mg11Li3Al	11.0	2.84	surplus

2.2 Fabrication of composites

All of the composites were manufactured by liquid pressure infiltration technique in a vacuum furnace. The reinforcements adopted were β-SiC whiskers supplied by Toyo company of Japan. After over heating the Mg-Li-Al alloy and preform of 13vol% SiC whiskers to 740~760°C in a vacuum furnace, a pressure of 8MPa is applied to the melt and make it infiltrate into the SiC preform, until the melt solidification.

2.3 Microstructure observation and mechanical testing

The microstructure of specimen were examined by JSM-6400 SEM and H-800 TEM. In order to investigate the interface of MgLiAl/SiC composites, H-9000 HREM and SAD techniques were employed. The specimen used for observation by TEM and HREM were prepared via ion thinning method. Tensile test were carried out using an instron machine with a strain rate of 8.3×10^{-3}/sec. Tensile specimen were machined with a gauge length of 15mm and a cross-section size of $1.5\times4mm^2$.

3 Results and discussion

3.1 Interfacial structure

Fig.1 is a typical TEM photograph of Mg8Li1Al/SiC_w composites which shows a clear interface and there are not any compounds between SiC whisker and the matrix alloy. According to the report of J.F.Mason[7], the following reactions between Mg-Li-Al alloy and SiC whiskers below seem to be the most likely.

$$2Mg+SiC=Mg_2Si+C \quad (1)$$

$$2Mg+Li+SiC=Mg_2Si+1/2Li_2C_2 \quad (2)$$

According to the Gibbs free energy of reactants in the two side of the equation above[10], the reactionary Gibbs free energy changes are calculated and presented in Fig.2. The result showed that the reactionary free energy changes of equation(1) and equation(2) varied between -5.9~-1.5KJ/mol, and -34~-23.4KJ/mol respectively in the range of 300~1100K. On the basis of ΔG_T, it appears that the interaction can happen automatically. However, the thermodynamic potential seem to be low. Therefore, it can be conclude that the clear interface may contribute to the low thermodynamic potential or the slow reactionary speed between the matrix and the SiC whiskers. Another interfacial character of Mg8Li1Al/SiC_w composites is the disordered distribution of matrix atoms near the interface, as shown in Fig.3. The reason may be the difference of thermal expansion coefficient between matrix and SiC whiskers. The expansive coefficient of Mg8Li1Al is tested to be 3.03×10^{-5} in the range of 20°C to 200°C temperature. But the expansive coefficient of SiC is only 4.18×10^{-6}. Apparent difference in expansive coefficient for the matrix and SiC whiskers caused the tensile stress in the matrix near the interface of the composites. Therefore some adjustment of matrix atoms presented. Appearance of disordered arrangement of matrix atoms near the interface of the composites confirmed the fact that the interface between the matrix and SiC whiskers connect tightly.

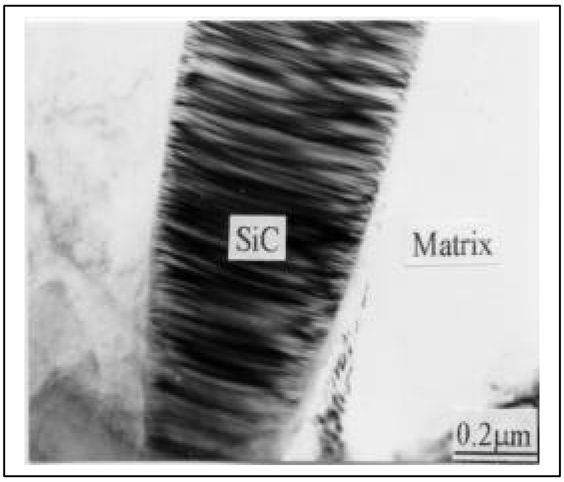

Fig.1 TEM image of Mg8Li1Al/SiC_w composites

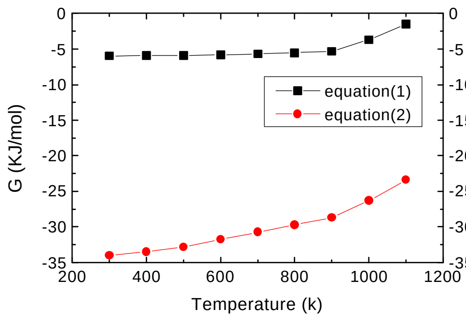

Fig.2 Variation of ΔG_T with temperature for the reaction of (1) and (2)

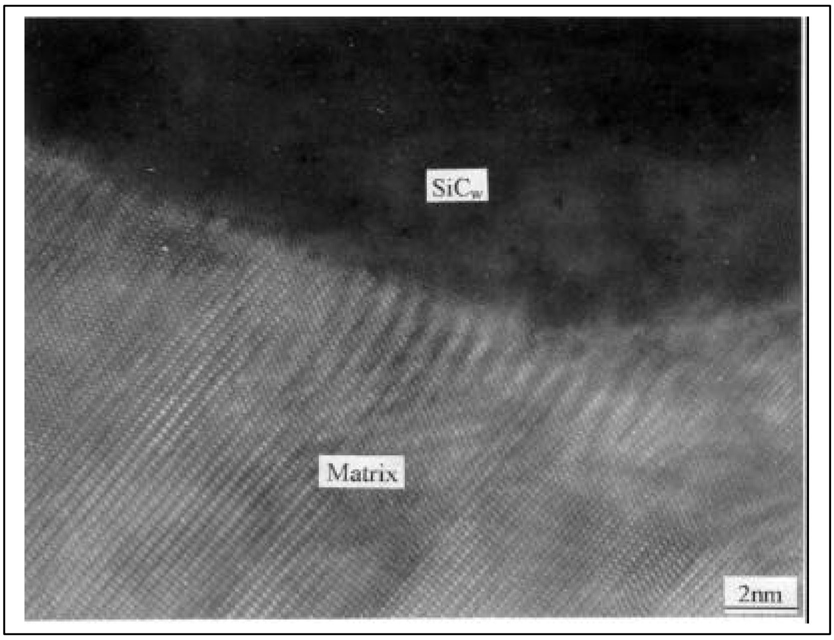

Fig.3 HREM image of Mg8Li1Al/SiC composites

Although most of SiC whiskers presented clear interface with Mg-Li-Al matrix, morphology changes were identified for some SiC whiskers. Fig.4(a)and(b) are TEM images of Mg8Li1Al/SiC$_w$ composites, which shows stages on the surface of SiC whisker. Adjacent stages formed 70.5°C or 109.5° angles. Such kinds of SiC morphology are found both in Mg8Li1Al/SiC$_w$ and Mg11Li3Al/SiC$_w$ composites. Moreover, with the increasement of lithium in the matrix, SiC whiskers with stages morphology are found increased

According to the analysis on SiC whiskers by HREM and SAD(Fig.5), it is found that the surface of stages are parallel to (111) of β-SiC. The angles between {111} are calculated according to the formula of $\cos\phi = (h_1h_2 + k_1k_2 + L_1L_2)/\sqrt{(h_1^2 + k_1^2 + L_1^2)(h_2^2 + k_2^2 + L_2^2)}$ to be 70.5° or 109.5°, which is just the angles of stages described above in Fig.4. The reason for β-SiC whiskers to connect with matrix in {111} may contribute to the fcc structure of β-SiC whiskers, in which {111}possesses the lowest surface energy. As a result, in order to decease the interfacial energy of Mg8Li1Al/SiC composites, SiC whiskers were invaded by the Mg8Li1Al melt and connect in {111} with matrix and formed 70.5° or 109.5° angles on the surface of SiC whiskers during the fabrication of the composites.

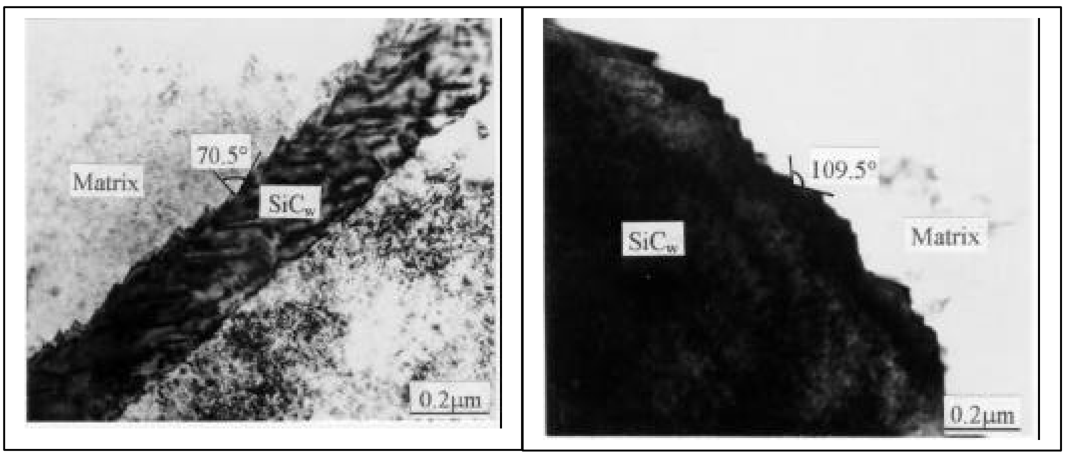

Fig.4 TEM photographs of Mg8Li1Al/SiC$_w$ composites which show (a)70.5° and (b)109.5° stages

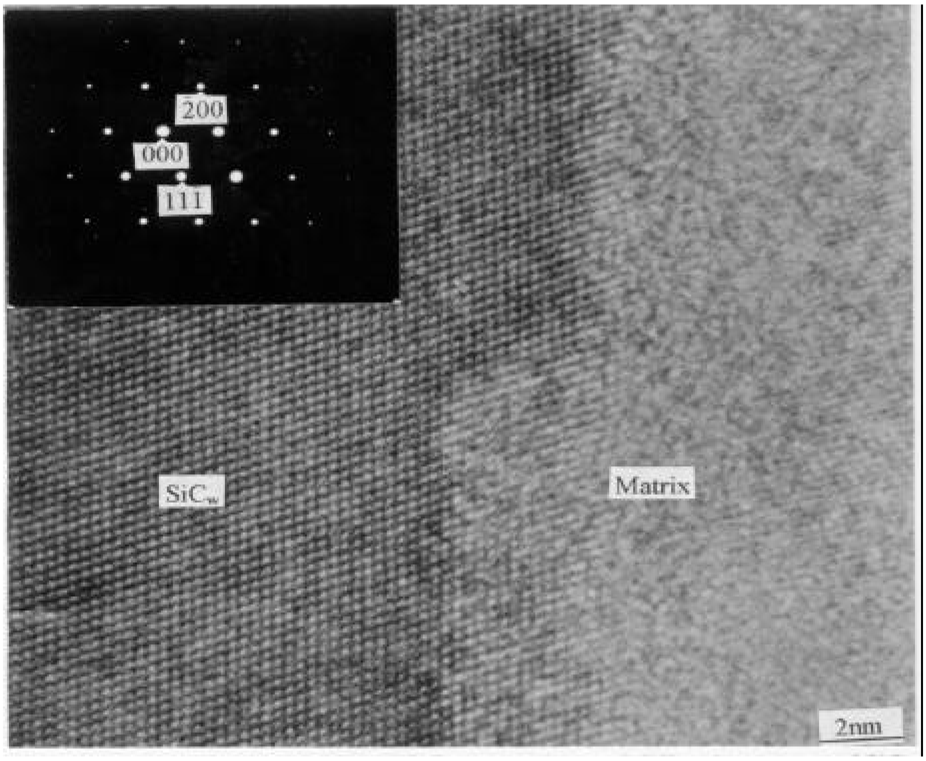

Fig.5 HREM image of interface in Mg8Li1Al/SiC$_w$ composites and diffraction pattern of SiC whisker

3.4 Tensile properties

Table2 are properties of both MgLiAl/SiCw composites and the matrix alloys. The results revealed that the ultimate strength and elastic modulus of MgLiAl/SiCw composites increased greatly compared with the matrix alloys. For example, the ultimate strength of Mg11Li3Al/SiC composites is 196.6MPa which is 41.6% higher than the matrix strength(138.8MPa). The elastic modulus of Mg11Li3Al/SiC composites is 60.5GPa which is 31.8% higher than the value of matrix modulus(45.9GPa). Apparently, SiC whiskers have obvious strengthening effect on Mg-Li-Al alloy. Moreover, MgLiAl/SiCw composites showed higher specific modulus and higher specific strength than matrix alloys, as shown in Fig.6 and Fig.7 respectively. The elongation of the composites decreased obviously compared with the matrix alloys. However, owing to the good plasticity of the matrix alloys, the elongation of MgLiAl/SiC$_w$ composites remain 4.5%~5.8%.

Table2 Properties of MgLiAl/SiC$_w$ composites and the matrix alloys

	Density g/cm^3	Elastic modulus GPa	Ultimate Strength MPa	specific modulus $GPa.cm^{-3}/g$	specific strength $MPa.cm^{-3}/g$	Elongation %
Mg4Li1Al	1.64	43.7	157.2	26.6	95.8	17
Mg8Li1Al	1.52	44.7	131.5	29.4	86.5	35
Mg11Li3Al	1.51	45.9	138.8	30.4	91.9	45
Mg4Li1Al/SiC$_w$	1.84	58.7	190	31.9	103.2	4.5
Mg8Li1Al/SiC$_w$	1.72	59.4	182.8	34.5	106.2	5.2
Mg11Li3Al/SiC$_w$	1.67	60.5	196.6	36.2	117.7	5.8

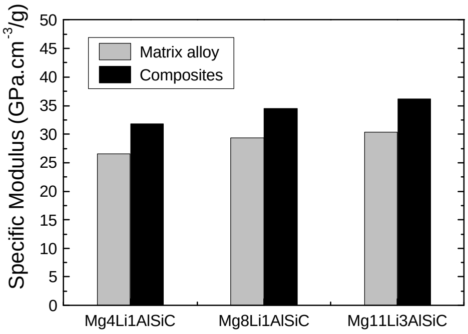

Fig.6 Comparing of Specific modulus for MgLiAl/SiC_w composites and Mg-Li-Al alloys

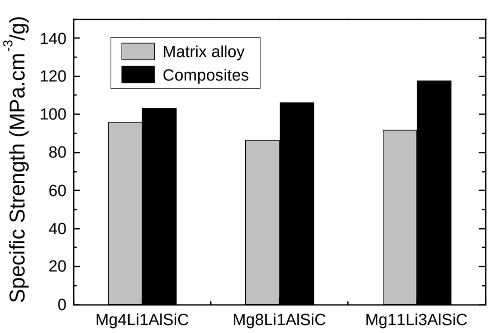

Fig.7 Comparing of specific strength for MgLiAl/SiC composites and Mg-Li-Al alloys

4 Conclusions

MgLiAl/SiC_w system is stable in thermodynamics. There is a clear interface between the Mg-Li-Al matrix and SiC whiskers. The atoms of Mg-Li-Al alloy and SiC whiskers connect closely. A few SiC whiskers were found to connected in {111} with matrix and formed 70.5° or 109.5° stages on the surface of SiC whiskers. SiC whiskers has obvious strengthening effect on Mg-Li-Al alloys. The tensile strength and elastic modulus of Mg11Li3Al/SiC composites are 196.7MPa and 60.5GPa respectively, which are 41.6% and 31.8% higher than it′s matrix alloy. MgLiAl/SiC_w composites also showed higher specific strength and higher specific modulus compared with matrix alloys.

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