Identification of Mg_2Si phase in AZ91/SiC composites

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ABSTRACT: The aim of this work was to identify the Mg_2Si intermetallic phase that appears during crystallization of AZ91/SiC composite. Authors performed several examinations that lead to that goal: SEM examination, XRD analysis and thermoanalysis. Results of those examinations show presence of Mg_2Si phase.

Keywords: AZ91/SiC composite, Mg_2Si intermetallic phase, microstructure analysis, Mg-Al alloys

1 INTRODUCTION

The world industry is facing increasing challenges to reduce transportation impact on environment and to achieve low fuel consumption without sacrificing vehicles or other devices performance. In addition to a wide range of novel vehicle propulsion and power-saving technologies under development, light-weighting of elements is required to face these challenges. Magnesium alloys and their composites have been attracting attention as an important lightweight material and are being utilized in the automobile and aerospace industries [1-4].
In terms of the reinforcement in magnesium-based composites, the SiC particles are extensively used because magnesium cannot form any stable carbide.
The alloy chosen for this examination was the AZ91 alloy. The equilibrium phase for these alloy is the solid α-Mg solution, but during solidification a nonequilibrium eutectic (α-Mg - β-$Mg_{17}(Al, Zn)_{12}$) is also created and present. When it is a base for composite the AZ91 crystallize with the same phases. However because of impurities and ceramic particles addition into composite, it is possible that different phases can be created. Like Mg_2Si or Al-Mn or others.

2 MATERIALS AND PROCESSING

The AZ91 alloy was selected as the matrix for the composites. The chemical composition is shown in Table 1. The castings were performed to prepare specimens, which contain 5wt% of SiC particles. There were used about 6000 g of AZ91 (Table 1). The reinforcement particles are silicon carbide with an average diameter of 45 μm.
The SiC particles were pre-heated up to 320°C before they were put into the liquid alloy. The composite was stirred mechanically for 180 – 240 s. The samples were casted in standard thermoanalysis croning sand cups with K type thermocouple, Figure 1. Thermoanalysis data was gathered to analyze the heat release rate connected with phase transformation.

Table 1. Chemical composition of AZ91 alloy

Chemical composition %wt.							
Al	Zn	Mn	Fe	Be	Si	Cu	Ni
9.03	0.6	0.2	0.0026	0.0011	0.0023	0.0016	0.00062

The as-cast plates were sectioned and polished before microstructural analysis using transmission electron microscopy (SEM) and X-ray diffraction (XRD) method.

Figure 1. Standard thermoanalysis croning sand cup with K type thermocouple

3 RESULTS OF COMPOSITE MICROSTRUCTURE ANALYSIS

SEM examinations of the composite based on AZ91 5 wt.% SiC, Figure 2 and 3, confirmed presence Mg_2Si phase in the microstructure

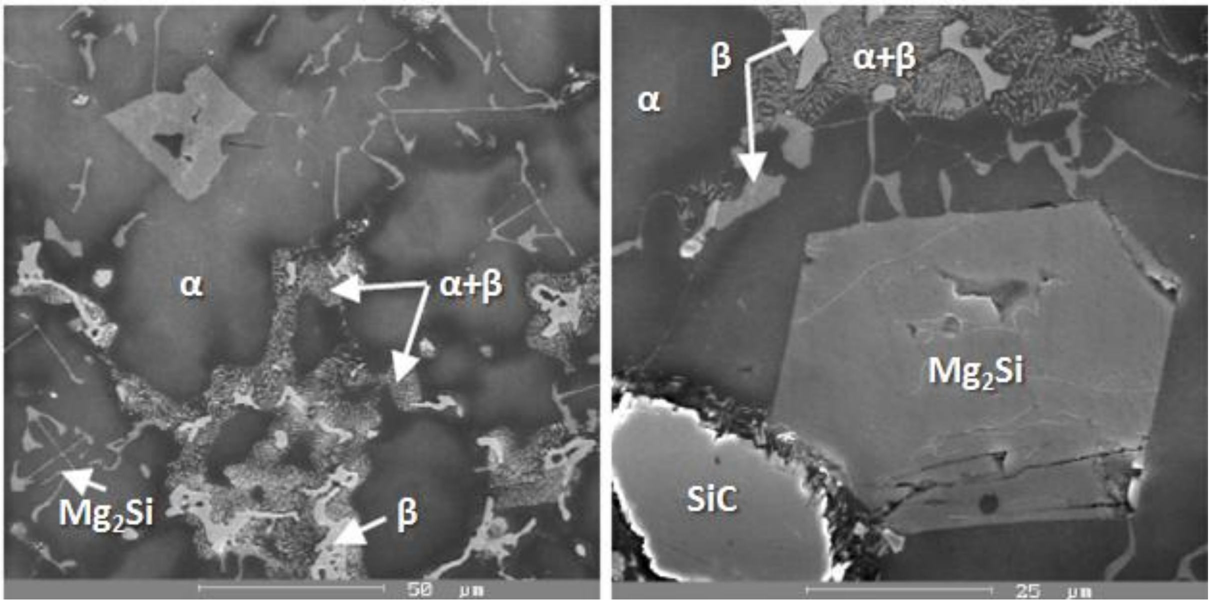

Figure 2. AZ91/SiC composite microstructure [5].

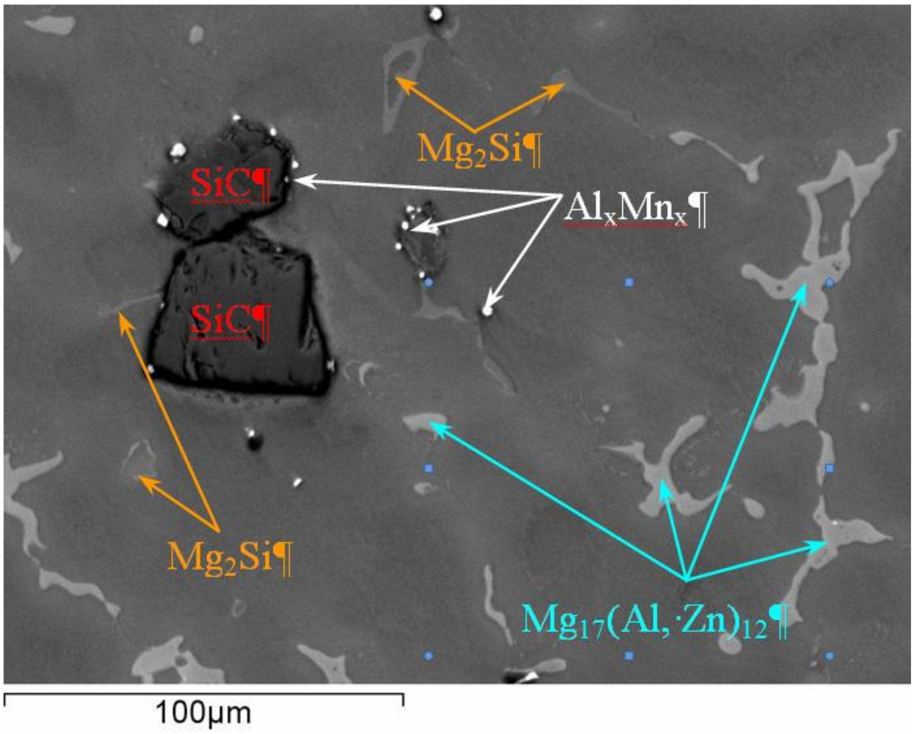

Figure 3. SEM micrograph of AZ91/SiC composite shows formation of Mg_2Si phase.

The X-ray diffraction examination graph of the AZ91 alloy - red line and the AZ91/SiC composite - black line is shown in Figure 4. Presence of different phases can be observed. The XRD graph of the composite contains a peak about 24° which shows the formation of intermetallic phase Mg_2Si.

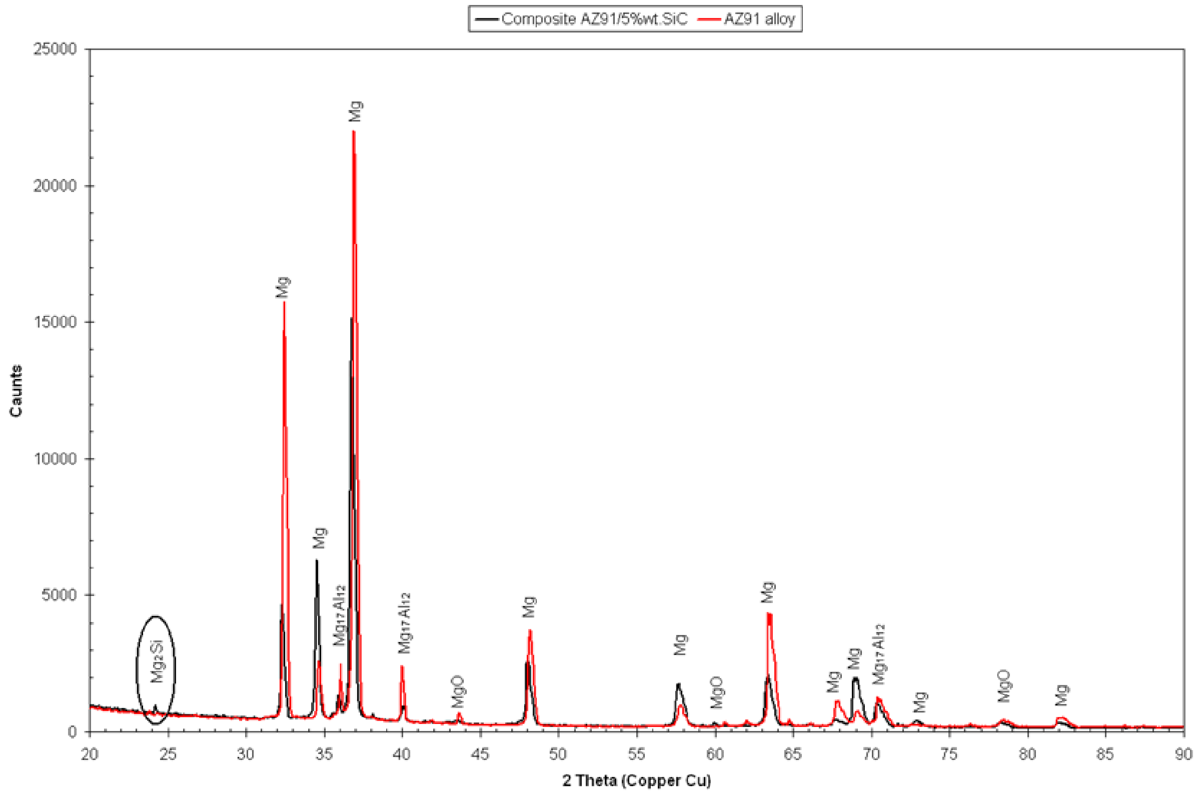

Figure 4. The XRD graph of AZ91 alloy and AZ91/SiC (5wt% of ceramic particles) composite: red line shows examination run for alloy and composite examination run is marked in black

Cooling curve for AZ91/SiC composite is shown in Figure 5. This figure shows changes in cooling rate caused by phase transformations. Not only primary phase and eutectic forming regions are visible. Presented graph shows a third region (M) in which an exothermic reaction occurred. It can be the region where Mg_2Si forms.

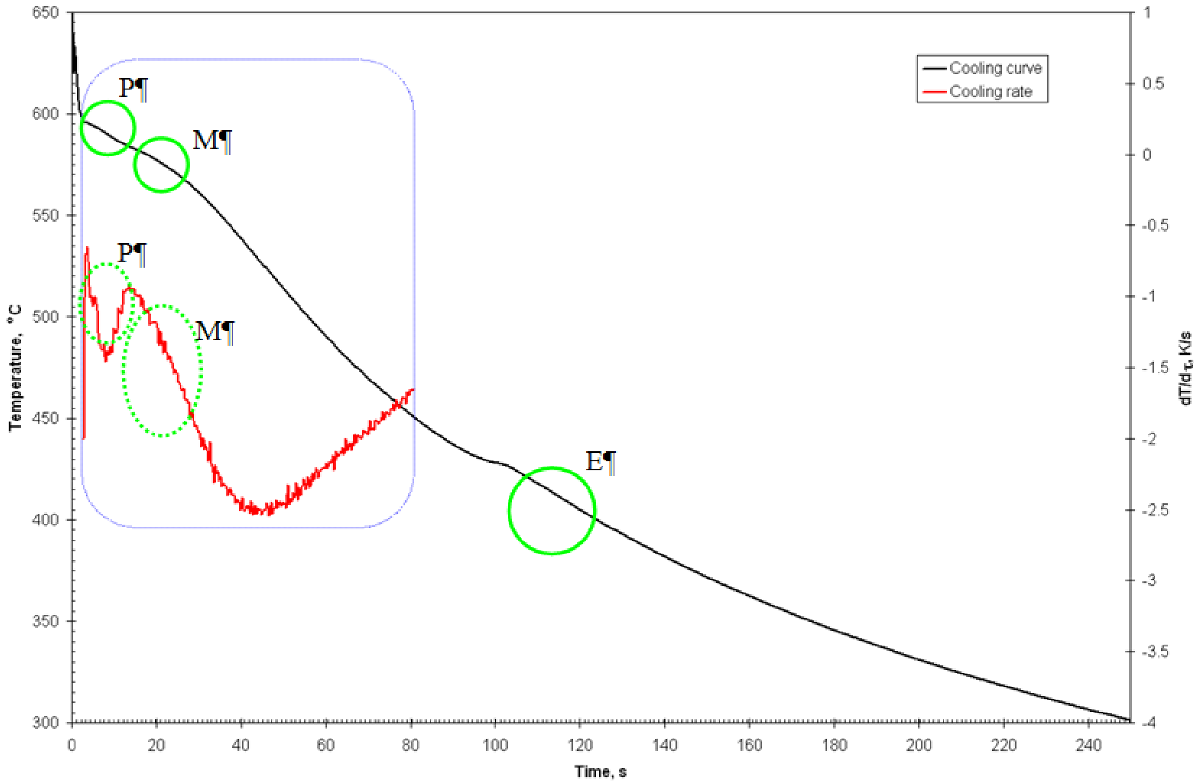

Figure 5. Cooling curve for AZ91/SiC composite. Green circles point starts of phase transformations. P – stands for primary phase; M – Mg_2Si, E – eutectic reaction.

4 DISCUSSION

During the solidification of the composite based on AZ91 alloy reinforced SiC particles there forms the intermetalic Mg_2Si phase formation. This phase exhibits a high melting temperature of 1085 °C, low density of $1.99x10^3$ kg m^{-3}, high hardness of $4.5x10^9$ Nm^{-2}, a low thermal expansion coefficient of $7.5x10^{-6}$ K^{-1}, a reasonably high elastic modulus of 120 GPa [6] and binding energy between Mg and Si is very high (the enthalpy of formation is - 26.8 kJ per g-atom. Thus when small amounts of Si (for example 0.5 at.%) are added to the alloy with 2 at.% Mg, the 1 at.% excess Mg would cause Mg_2Si [7].

Reactions between SiC, SiO_2 and Mg and Al might happen as follows:

$$\frac{1}{2}SiO_2 + Mg \rightarrow MgO + \frac{1}{2}Si \qquad (1)$$

$$Mg + \frac{1}{2}Si \rightarrow \frac{1}{2}Mg_2Si \qquad (2)$$

$$\frac{1}{2}SiC + Mg \rightarrow \frac{1}{2}Mg_2Si + \frac{1}{2}C \qquad (3)$$

$$\frac{3}{4}SiC + Al \rightarrow \frac{1}{4}Al_4C_3 + \frac{3}{4}Si \qquad (4)$$

These reactions depend on the processing parameters, especially on temperature and chemical composition of both the matrix and the reinforcement SiC particles. Authors [8] calculated the Gibbs free energies of reaction Eq. (1) – (4) within the temperature range of 650–900 °C using thermodynamic data. The results indicate that there is no chemical reaction between SiC and magnesium, Eq. (3), and between SiC and aluminium, Eq. (4), at the temperatures 650 to 900 °C because the Gibbs free energies of reaction changes from 941 J to 4900 J for Eq. (3) and from 5154 J to 9678 J for Eq. (4). The Gibbs free energy of reaction (1) changes from −130333 J to −122247 J and for reaction (2) from −32045 J to −27127 J for Eq. (2) [8]. It indicates that reactions described with Eq. (1) and (2) are possible.

5 CONCLUSIONS

During crystallization of AZ91/SiC composite there forms the Mg_2Si phase.

Presence of Mg_2Si phase is probably effect of chemical reaction of SiO_2 with Mg that provides Si for creating Mg_2Si. The SiO_2 may be connected with fabrication of SiC particles as well as fact that specimens were casted into sand mould.

Acknowledgements

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6 BIBLIOGRAPHIES

[1] Lu, L., Dahle, A.K., StJohn, D.H., 2006, Heterogeneous nucleation of Mg-Al alloys. Scripta Materiala 54, 2197-2201.

[2] Luo, A., 1996, Heterogeneous nucleation and grain refinenent in cast Mg(AZ91)/SiC metal matrix composites. Canadian Metallurgical Quaretly 35, 375-383.

[3] Asthana, R., 1998, Solidification processing of reinforced metals. *Key Engineering materials.* 151-152.

[4] Beausir B., Biswas S., Kim D. I., Toth L. S., Suwas S.: Analysis of microstructure and texture evolution in pure magnesium during symmetric and asymmetric rolling. Acta Materialia xxx (2009) xxx–xxx.

[5] Palcek P., Namesny A., Chalupova M., Hadzima B.: Failure mechanism in magnesium alloys matrix composites. 22nd DANUBIA-ADARIA Symposium on Experimental Methods in Solid Mechanics, Monticelli Terme / Parma – Italy, September 28 – October 1, 2005

[6] Pan Y., Liu X., Yang H.: Microstructural formation in a hypereutectic Mg–Si alloy (Mg_2Si). Materials Characterization 55 (2005), pp 241 – 247

[7] Schueller R. D., Wawner F. E., Sachdev A. K.: Nucleation mechanism of the cubic a phase in squeeze-cast aluminium matrix composites. Journal of Materials Science 29 (1994), pp 424 - 435.

[8] Chen H., Liu J., Huang W.: Corrosion behavior of silicon nitride bonding silicon carbide in molten magnesium and AZ91 magnesium alloy. Materials Science and Engineering A 415 (2006), pp 291–296