In-situ Mg_2Si/Al-Si-Cu composite modified by strontium

Y. G. ZHAO, Q. D. QIN, Y. H. LIANG, W. ZHOU, Q. C. JIANG
The Key Laboratory of Automobile Materials and Ministry of Education, Department of Materials Science & Engineering, Jilin University at Nanling Campus, No. 142 Renmin Street, Changchun 130025, People's Republic of China
E-mail: Zhuzao@mail.jlu.edu.cn

Recently, a large number of metal matrix composites (MMCs) have been developed for high-performance applications in automotive industries [1–5]. The specific characteristics of aluminum MMCs, such as low density, excellent castability, good wear resistance, and fine physical properties, make it the ideal candidate to replace steel and iron in the car to meet the demand of weight reduction and fuel economization in the automotive industry. However, the various conventional *ex-situ* processes of fabricating aluminum MMCs possess some inherent defects, such as poor wettability of the reinforcement, reaction of matrix–reinforcement interface, much larger sizes of the reinforcement, and scaling-up of the process for industrial utilization and processing cost [6, 7]. To overcome the limitations that are associated with conventionally processed aluminum MMCs, new *in-situ* processing techniques have been developed. *In-situ* Mg_2Si/Al-Si-Cu composite has high potential as a wear resistant material because an intermetallic compound of Mg_2Si exhibits the high melting temperature, low density, high hardness, low thermal expansion coefficient [8], equilibrium interface, excellent workability and the potential for cost reduction as well. For further improvement of mechanical properties, rapid solidification and mechanical alloying have been used to produce the material with very fine matrix structure and *in-situ* Mg_2Si particles [8–10]. Unfortunately, such techniques are too expensive and complex to be accepted by the engineering community for general applications [9]. Therefore, to prepare the *in-situ* composite by simple cast modification process seems to be the most hopeful and effective solution while facing increasing commercial competition.

The modification treatment in Al-Si alloys was first done by Pacz [11] in 1921 using Na and it is widely applied in the commerce [12]. However, owing to the limited solid solubility of Na in aluminum and a very high vapor pressure, Na is readily volatilized during the modification processes. Like Na, the addition of Sr promotes the formation of fibrous silicon by retarding the growth rate of silicon [12–15]. The Sr modifier is usually added into molten Al-Si alloys using the Al-Sr master alloy.

In the present study, the feasibility of modification with Al-Sr master alloy on hypereutectic Al-Si-Mg-Cu alloy was investigated. It was expected that the preliminary results could be significant in promoting the development of *in-situ* Mg_2Si/Al-Si-Cu composite.

Commercial Al-13 wt% Si master alloy (ingot), pure Cu (ingot, >99.7% purity) and magnesium (ingot, >98.0% purity) were used as starting materials. About 400 g of Al-Si master alloy melt was prepared in a graphite crucible in an electric resistance furnace. About 75 g of magnesium and 20 g of Cu preheated at 300 °C were added into the Al-Si melt at 680–700 °C. After 10 min, about 2.5 g (0.05 wt%) of Al-10 wt% Sr master alloy preheated at 300 °C was added into the melts at 800 °C. After holding for 15 min, the *in-situ* composite melts were poured into a steel die to produce ingots. The chemical compositions of the studied as-cast alloys are listed in Table I. Microstructure and phase of the *in-situ* composite were investigated by using optical microscope and X-ray diffraction (D/Max 2500PC Rigaku, Japan).

The lateral section schematic diagram of the composite samples is shown in Fig. 1. Region B is the edge of the sample where cooling rate is higher than that in region A. The microstructures of *in-situ* Mg_2Si/Al-Si-Cu composites prepared by a conventional casting route are shown in Figs 2 and 3, respectively. The results reveal that both modified and unmodified composites consist of dark Mg_2Si, white α-Al, and eutectic microstructures. Microstructures of region A of composite samples without and with modification are compared in Fig. 2a and b. From Fig. 2a and b, three microstructures changes can be observed: (i) with Sr addition, the average size of primary Mg_2Si decreased from ~80 to ~30 μm; (ii) the morphology of the Mg_2Si changed from an irregular shape to the polyhedral shape; and (iii) the white α-Al phase in the middle of primary Mg_2Si particulate disappeared. Microstructures of region B of the composite samples without and with modification are compared in Fig. 3a and b. With increasing cooling rate, the morphology of primary Mg_2Si appears in the form of dendritic structure and the size of it decreased to ~30 μm (Fig. 3a). After Sr addition,

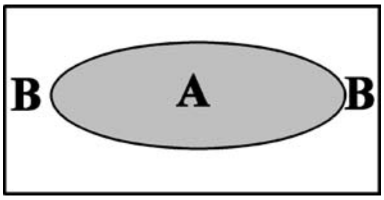

Figure 1 Lateral section schematic diagram of the Mg_2Si/Al-Si-Cu composite samples.

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TABLE I Chemical compositions of the Mg_2Si/Al-Si-Cu composites: (a) unmodified and (b) modified by Sr (wt%)

Alloy	Al	Si	Cu	Mg	Sr	Cr	Zn	Ni
Al-Si-Cu-Mg	Bal.	12.126	2.946	11.562	—	<0.005	<0.016	<0.002
Al-Si-Cu-Mg+Sr	Bal.	12.123	2.943	11.569	0.052	<0.005	<0.015	<0.001

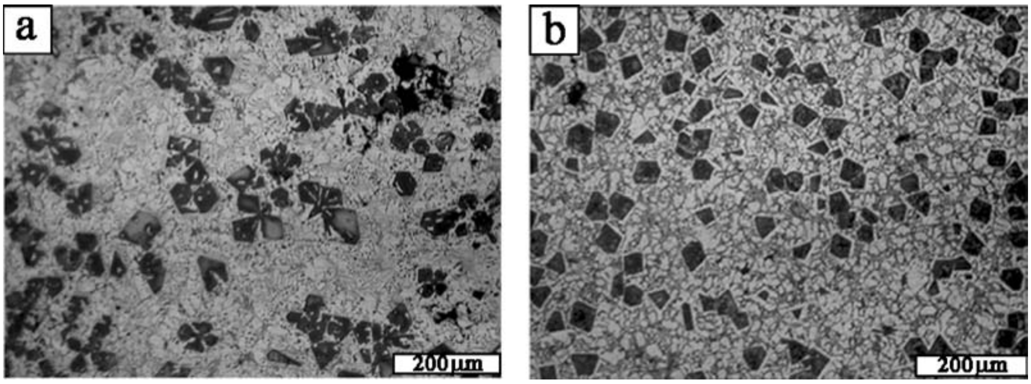

Figure 2 Optical microscope microstructures of composites: (a) unmodified and (b) modified by Sr.

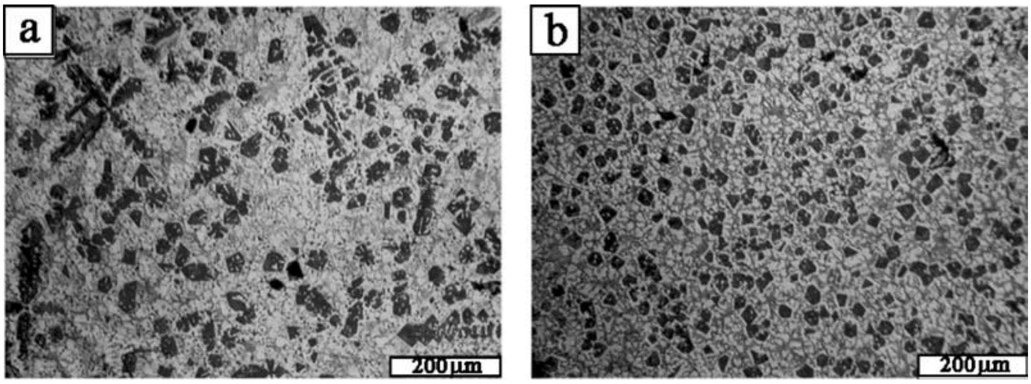

Figure 3 Optical microscope microstructures of composites: (a) unmodified and (b) modified by Sr under higher cooling rate condition.

however, the morphology of Mg_2Si changed to polyhedral shape and the size of it further decreased from ~30 to ~10 μm (Fig. 3b). The results reveal that Sr atoms not only change the morphology, but also eliminate the dendritic structure of primary Mg_2Si phase.

Influence of cooling rate on the morphology of Mg_2Si phase in unmodified Al-Mg_2Si alloys has been investigated in the literature [16]. On one hand, with increased cooling rate, a dendritic structure appeared and the dendritic structure of Mg_2Si phase is maintained at a higher cooling rate. On the other hand, the particle size of primary Mg_2Si phase has significantly decreased. The phenomenon is in good agreement with Fig. 3a.

The morphological and size change of the Mg_2Si particle (Fig. 2) indicated that the anisotropic growth of the Mg_2Si particle during the solidification was suppressed by the addition of the Sr. This effect might be caused by the fact that Sr atom is adsorbed in the forehead growth interface of Mg_2Si phase; accordingly the growth and nucleation of Mg_2Si phase is prevented. The exact behavior of Sr in the molten alloy and during solidification is not clear.

Also, previous investigations indicate that the addition of Sr to A1-7%Si, A1-12%Si, 319 and 356 alloys depress the eutectic temperature between the modified and unmodified alloys [17]. In the present study, a probable explanation of the elimination of the dendritic structure of primary Mg_2Si phase (Fig. 3b) is related to the changes of the eutectic temperature. However, the exact mechanism of Sr-modification *in-situ* Mg_2Si/Al-Si-Cu composite is not clear. It is the subject for further study in our group.

In conclusion, Al-Sr master alloy was found to be modifying the primary Mg_2Si in *in-situ* Mg_2Si/Al-Si-Cu composite. The morphology of primary Mg_2Si changed from equiaxed or irregular to polygonal shape and its size decreased from ~80 to ~30 μm. The formative dendritic structure of Mg_2Si under a higher cooling rate condition changed to regular polygon shape.

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