EFFECT OF SUPERHEAT MELT TREATMENT ON STRUCTURE AND MECHANICAL PROPERTIES OF IN-SITU ALUMINUM MATRIX COMPOSITES

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Abstract

The results of investigations of the structure and mechanical properties of in-situ aluminum matrix composites based on the Al-Mg-Si system reinforced with primarily crystallizing silicides Mg_2Si are presented. The main advantage of such materials is the usage of relatively inexpensive initial components with absence of the necessity for the use of powders, which greatly simplifies technology and reduces the production cost of castings. However, coarse morphology of primary crystals Mg_2Si and needle structure of eutectic phase Mg_2Si in cast composites have negative influence on the strength characteristics of obtained products. To control the morphology and size of endogenous Mg_2Si particles, thermo-temporal treatment of the Al-Mg-Si melts has been tested. It was shown that the thermo-temporal treatment had a grain refining effect on the primary crystals of the Mg_2Si reinforcing phase. With an increase in the duration of isothermal holding of the composite melt from 15 to 30 minutes at 900 °C, the average size of the reinforcing particles decreased substantially, and their total amount increased. A further increase in the holding time to 45 min led to coarsening of the morphology and growth of the inclusions, and upon holding for 60 min the amount of primary Mg_2Si crystals decreased sharply and eutectic colonies were formed. Under the conditions of the experiments, the most favorable structural characteristics and mechanical properties of cast specimens were attained by isothermal holding of the melt at 900 °C for 30 min.

Keywords: Al-Mg_2Si in-situ composites, superheat melt treatment, microstructure, mechanical properties

1. INTRODUCTION

Aluminum matrix composites are considered as one of the most promising materials for replacing traditional alloys, which practically exhausted the potential for increasing the mechanical and operational properties of products for functional and structural purposes [1]. However, most of the technological processes used to produce aluminum matrix composites are based on the introduction of exogenous reinforcing particles into matrix melts, which is often associated with coagulation and rejection of particles due to their poor wettability, as well as with oxidation and gas saturation of aluminum melts [2]. To solve these problems, new technologies for the endogenous reinforcement of aluminum alloys have been developed [3], as well as new compositions of in-situ aluminum matrix composites based on the Al-Mg-Si system, reinforcing phase in which is the primary crystallizing silicides Mg_2Si, have been proposed [4-6]. The main advantage of such materials is the use of relatively inexpensive starting components in the absence of the need for the use of powders, which greatly simplifies the technology and reduces the cost of manufacturing of finished products. However, the coarse morphology of the primary Mg_2Si crystals and the needle structures of the eutectic phase of Mg_2Si in cast composites adversely affect the strength characteristics of materials [8].

To control the morphology and size of the primary crystals of Mg_2Si reinforcing phase in cast aluminum matrix composites, different methods have been proposed, such as the introduction of various grain refining additives (for example, La, Mn, Bi, Gd, etc. [9-11]), ultrasonic and electromagnetic treatment of Al-Mg-Si melts [8,12], solution and aging heat treatment of composite castings [13,14], etc. At the same time, the search for new cost-effective methods for controlling the structure of Al-Mg_2Si in-situ composites to provide the required mechanical and operational properties continues to be an urgent task for expanding the industrial applications of these promising materials.

In the present work, to control the size and morphology of endogenous Mg_2Si particles, the superheat (thermo-temporal) treatment of composite melts of the Al-Mg-Si system was tested. This technique is considered as one of the effective methods for melts treatment by physical (thermal) effects, as has been shown in [15].

2. MATERIALS AND METHODS

Experimental materials were prepared in alundum crucible in an electric resistance furnace. During the melting, pure components were used: aluminum (≥ 99.99% Al), magnesium (≥ 99.9% Mg), silicon (≥ 99% Si) based on the composition of Al + 12 wt.% Mg + 6 wt.% Si. Silicon was introduced into the melt at 750±5 °C, magnesium at 720±5 °C wrapped with aluminum foil. After dissolution of the charge components, the melt was manually stirred and superheated to a temperature of 900±5 °C followed by a holding for a time from 15 to 60 minutes. The temperature conditions of the melting process were controlled during the entire experiment by a K-type thermocouple. The processed melt was poured at 720±5 °C into steel and copper molds with a wall thickness of 30 mm to produce ingots with a diameter of 20 mm and a length of 100 mm.

The microstructure of experimental alloys was studied in as-cast state on unetched sections using a digital metallographic microscope Raztek MRX9-D (Russia). Samples for metallographic studies were cut from the ingots at a distance of 15 mm from the bottom. Statistical processing of metallographic images was carried out using the program ImageJ v.1.51 (https://imagej.nih.gov/ij). The hardness of the samples was determined on a stationary hardness tester TH301 (Time Group, China) by the Rockwell method (HRB scale) by a 1/16" ball indentor at a load of 981 N with the subsequent calculation of the arithmetic average of the hardness value according to ten measurements.

3. RESULTS AND DISCUSSION

Figure 1 shows the microstructure of Al-Mg_2Si composite samples under different thermo-temporal treatment conditions poured into a steel mold. To quantify the structure parameters of the obtained samples, statistical processing of metallographic images was carried out on the segments with dimensions of 0.625 μm × 0.470 μm (the section field at magnification of ×100), the results of which are summarized in **Table 1**. With an increase in the duration of isothermal holding of the composite melt from 15 to 30 min the size of the reinforcing particles was substantially reduced (up to ~19 μm), and their total quantity was increased (**Figure 1**, b). However, the expected change in the morphology of the Mg_2Si particles to the polygonal and more compacted in the experiments was not observed. This indicates the expediency of continuing research in the direction of optimizing the temperature-time treatment modes of Al-Mg-Si composite melts. Subsequent exposure (45 min) led to an increase in size and coarsening of the morphology of the inclusions (**Figure 1**, c), and upon exposure for 60 min there was a sharp decrease in the amount of Mg_2Si primary crystals (with a certain decrease in their sizes) and the formation of eutectic colonies.

Table 1 Quantitative parameters of primary Mg_2Si particles at different melt holding time at 900±5 °C

Parameter	Holding time (min)			
	15	**30**	**45**	**60**
Quantity of particles	30	46	40	33
Maximum size (μm)	76	36	65	39
Average size (μm)	40	19	31	25

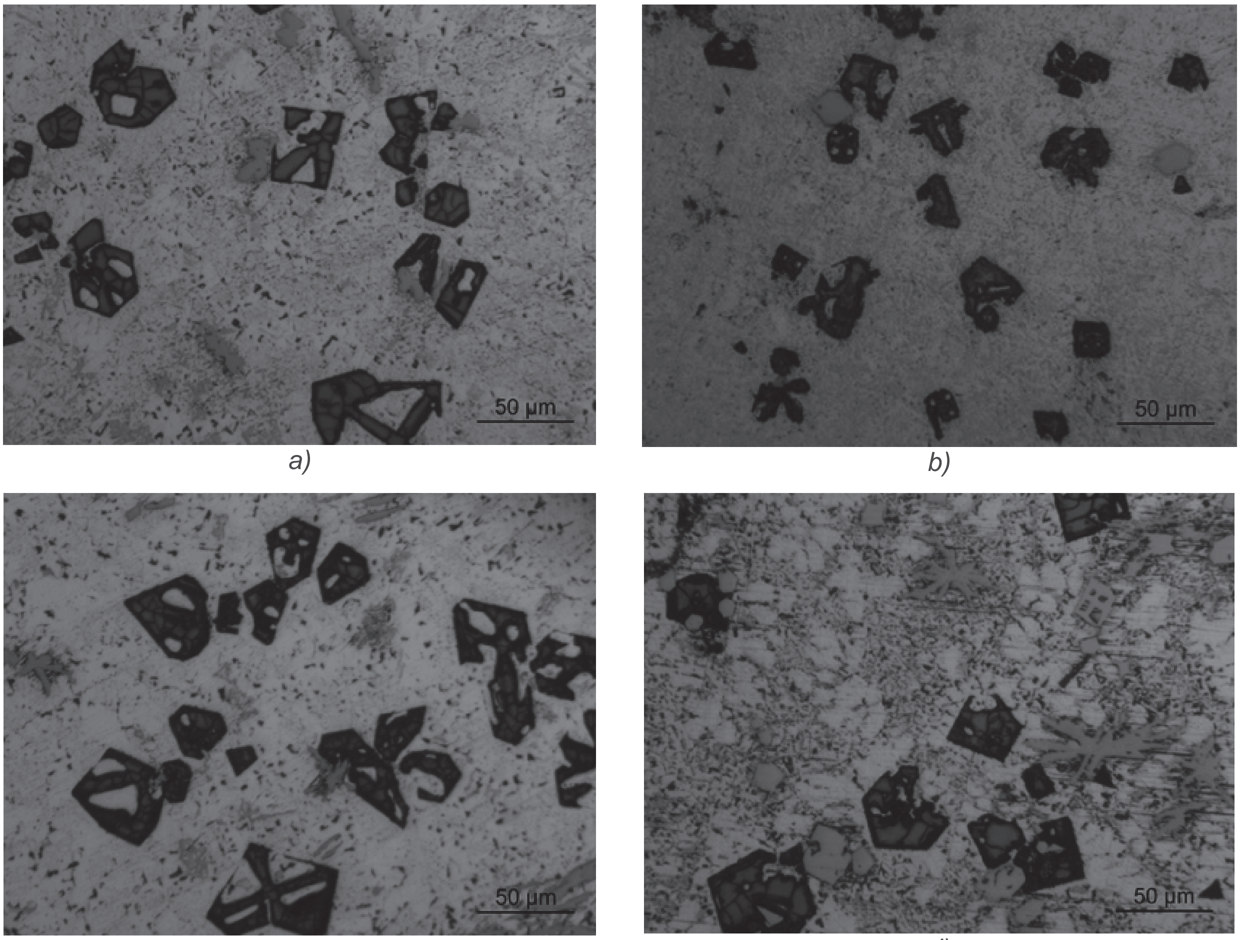

Figure 1 Microstructure of Al-Mg_2Si aluminum matrix composites in as-cast state (steel mold, ×200): melt isothermal holding at 900±5 °C for 15 (a), 30 (b), 45 (c) and 60 (d) min

According to the pseudo-binary phase diagram of the Al-Mg_2Si system [16], at the initial stage of crystallization of the composite melt, the formation of particles of excess Mg_2Si phases occurs. In general, the process of crystallization of a composite melt with a hypereutectic composition can be represented by the following reaction:

$$L \rightarrow L_1 + Mg_2Si_P \rightarrow Mg_2Si_P + (\alpha\text{-Al} + Mg_2Si)_E,$$

where the indices P and E refer to the primary crystals and eutectic phases, respectively. As shown in [17], the primary particles of the excess phases of Mg_2Si under normal conditions form imperfect octahedral crystals or dendritic-like complexes growing along the first stable dendrite in the <100> direction. It can be seen from **Figure 1** that the thermo-temporal treatment can contribute to the refining of Mg_2Si particles. However, in order to specifically control their morphology and change it to a more compact, additional studies are needed to establish optimal modes of superheat melt treatment.

The results of Rockwell hardness measurements of composite samples under different melting and casting conditions are shown in **Figure 2**. In the case of isothermal holding of the Al-Mg-Si melt at the temperature of 900±5 °C for 30 minutes, the highest hardness values of composite samples, poured in both steel and copper mold, was observed. It is assumed that the achieved hardness values are caused by the positive effect of thermo-temporal treatment under the appropriate processing modes on the size and distribution of primary crystals of the Mg_2Si reinforcing phase.

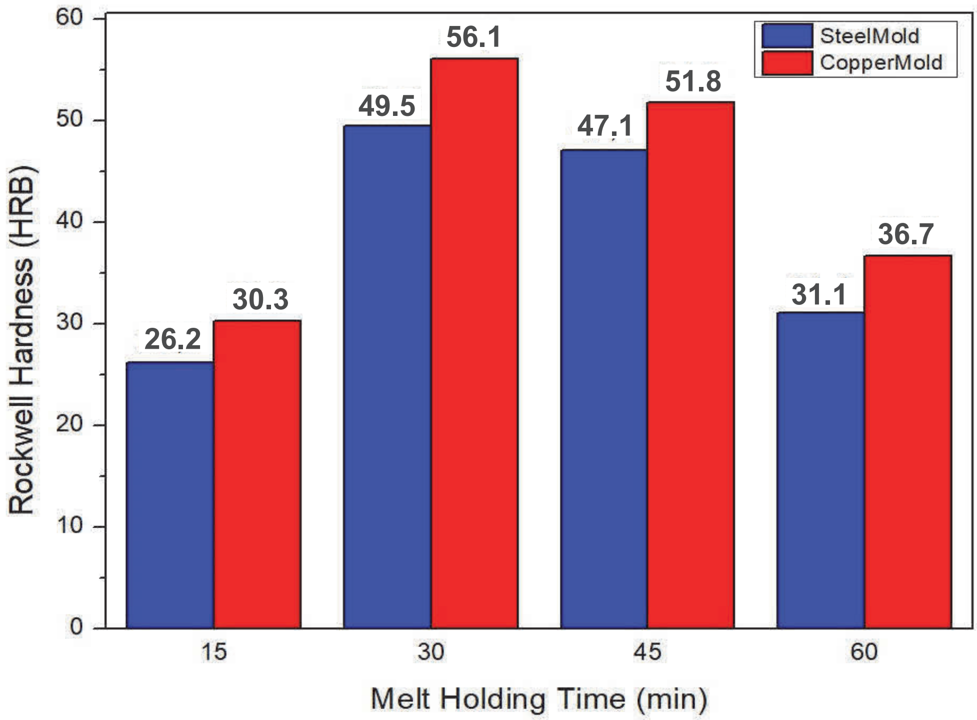

Figure 2 Average Rockwell hardness of Al-Mg_2Si samples as a function of a composite melt holding time at 900±5 °C and thermal conditions of crystallization

4. CONCLUSION

1) It is shown that the superheat treatment of composite melts based on the Al-Mg-Si ternary system can have a modification effect on the primary crystals of the Mg_2Si reinforcing phase.

2) Under the conditions of the experiments, the most favorable structural characteristics and the highest hardness values of cast specimens were achieved at isothermal holding of composite melt at 900±5 °C for 30 min.

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