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Effect of Strontium on Microstructure and Mechanical Properties Al-7Si-0.2Cu Alloys

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Abstract
The rapid increase in the utilization of aluminum-silicon alloys, particularly in the automobile industries, due to their high strength to weight ratio, low density and low coefficient of thermal expansion and possibility of inherent silicon platelets in the microstructure which reduces the ductility of the cast alloy properties necessitate the use of strontium as a modifier. The effects of Sr on the eutectic Al-7Si-0.2Cu alloy were investigated. The results show that Sr has a refining effect on the eutectic Si and its refinement behavior increases with increasing Sr content up to 0.09 wt.%. At 0.06 wt.% Sr addition, the porosity level in the cast alloy reduces drastically.

Key words: Al-7Si-0.2Cu alloy, silicon platelets, strontium, porosity.

1. Introduction

Aluminum alloys are economical in many applications. They are widely used in the automotive industry, aerospace industry, in construction of machines, appliances and structures, as cooking utensils, electronic equipment, and in innumerable other areas [1], [2]. Aluminum silicon based alloys generally exhibit high strength to weight ratio, high wear resistance, low density, and low coefficient of thermal expansion among others.

However, silicon imparts high fluidity and low shrinkage, which result in good castability and weldability. Reduced thermal expansion, decreased lattice parameter and excellent flow characteristics provided by relatively high silicon content in aluminum alloys combined with micro addition of other alloying elements make it widely acceptable has alternative to steel in certain engineering industries [1], [7[, [9]. For instance, the material for engine blocks which is one of the heavier parts is being switched from cast iron to aluminum resulting in significant weight reduction. In automotive power train, aluminum castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission [8], [10].

Major variation in the sizes of the primary Si particles can be found between different areas of the cast structure, causing significant deviation in the mechanical properties of the materials.

The primary crystals of Si must be refined so as to accomplish better hardness and wear resistance. Due to these reasons, eutectic alloys are not very cost-effective to fabricate because they have a broad range of solidification that results in poor castability and requires extra foundry processes to control the microstructure and the high heat of fusion [3], [4], [5], [6], [7].

It is widely accepted that the Group IA and IIA elements (Na, Mg, Ca, Sr) are effective modifiers of Al-Si eutectic [9], [10]. Therefore, alloys with a predominantly eutectic structure must be modified to ensure adequate mechanical strength and ductility.

2. Experimental Procedure

A commercial Al-7Si-0.2Cu ingot with the chemical composition listed in Table 1 was used. The melt was prepared by charging pieces of the alloy into a **quartz** ceramic crucible using an electrical resistance furnace under nitrogen. The melt temperature was maintained at 720 ± 10 °C for 10 minutes to allow complete melt homogenization. Different amounts of Sr were added to the Al-Si alloys, Table 2, in the form of AlSr10 master alloy. After strontium addition, the molten alloy was left for a period of 20 min and gently stirs before pouring into the prepared mold. The molten alloy was then poured within this temperature range into a prepared silica sand mold so as to produce bars 15 by 150 mm. The amounts of Sr in the cast samples were analyzed using Spark Optical Emission Spectrometer (ARL 3460 Metals Analyzer) and are listed in Table 1.

2.1 Materials characterization

The as-cast samples were etched by 0.5 vol% HF solution and the microstructures were examined using an optical microscope (Nican-M300 microscope). Brinell-hardness value was measured with the load of 2.94 N and holding time of 10 s. The average values of four independent measurements taking for the hardness per sample were recorded.

The ultimate tensile strength (UTS) and elongation of the samples were also measured. The as-cast samples were machined to a diameter of 5 mm and a gauge length of 30 mm (ASTM B557M specification) and then pulled to fracture in a screw driven Instron tensile testing machine (INSTRON 1195) at a cross-head speed of 1 mm/min in air at room temperature. Image-F software analyzer developed was used to analysis and measures the effect of Sr modifications on the Si platelets. The mean diameter and aspect ratio of Si particles were calculated with Image-F analyzer software. Approximately 40 different areas of each micrograph were measured to minimize the errors. The two parameters were defined according to the follow equations:

$$\text{Mean diameter} = \frac{1}{m}\sum_{j=1}^{m}\left[\frac{1}{n}\sum_{i=1}^{n} D_i\right]_j \quad (1)$$

$$\text{Aspect ratio} = \frac{1}{m}\sum_{j=1}^{m}\left[\frac{1}{n}\sum_{i=1}^{n} \frac{L_l}{Ls}\right]_j \quad (2)$$

Where "D_i" is the diameter of a single eutectic Si phase, "L_l/L_s" is the ratio of longest to shortest dimensions of a single Si particle, "n" is the number of particles of a single field, "m" is the number of the fields.

Table 1. Chemical Composition of Cast alloy (wt. %)

Alloy	Si	Cu	Mg	Fe	Ti	Mn	Sr	Al
Unmodified	7.00	0.20	0.35	0.20	0.15	0.01	—	Bal.
0.02% Sr	6.82	0.20	0.33	0.21	0.15	0.01	0.01	Bal.

0.05% Sr	6.81	0.18	0.34	0.19	0.14	0.01	0.05	Bal.
0.09% Sr	6.75	0.18	0.32	0.17	0.14	0.01	0.09	Bal.

3.0. Results and Discussion

3.1 Effects of Sr addition on microstructures

Fig. 1 shows the microstructure of Al-7Si-0.2Cu alloy and it may be seen that primary aluminum (light areas, α-solid solution) are crystallized surrounded by fine eutectic silicon (dark areas). The micrograph of modified alloy in Figs. 1(b and c) shows the refinement of the eutectic silicon particles.

Figs. 1 (d and e) show the micrographs of the tensile test rods. In both cases the refinement of eutectic silicon brought about by the strontium is clearly visible and the outlines of α-Al phase are depicted. Here, silicon has networked structure. With the addition of 0.09 wt% Sr, as shown in Fig. 1c, the microstructure is best refined and the Si phase is fully modified to fine fibrous structure. It can be inferred that Sr addition obviously modifies the eutectic Si phase and reduce the intermetallic compound within the alloys.

Table 2 depicts the quantitative metallography results of the as-cast Al-7Si-0.2Cu alloys with different Sr additions. It can be seen that the mean diameter and aspect ratio of Si phases both decreases with the addition of Sr. With increase addition of Sr up to 0.09 wt%, the mean diameter and aspect ratio of Si phase decreased to 5.92 (μm) and 8.17, compared with unmodified alloys. It is reasonable to conclude that Sr has an effect on refinement of *α*-Al and modification of Si phases.

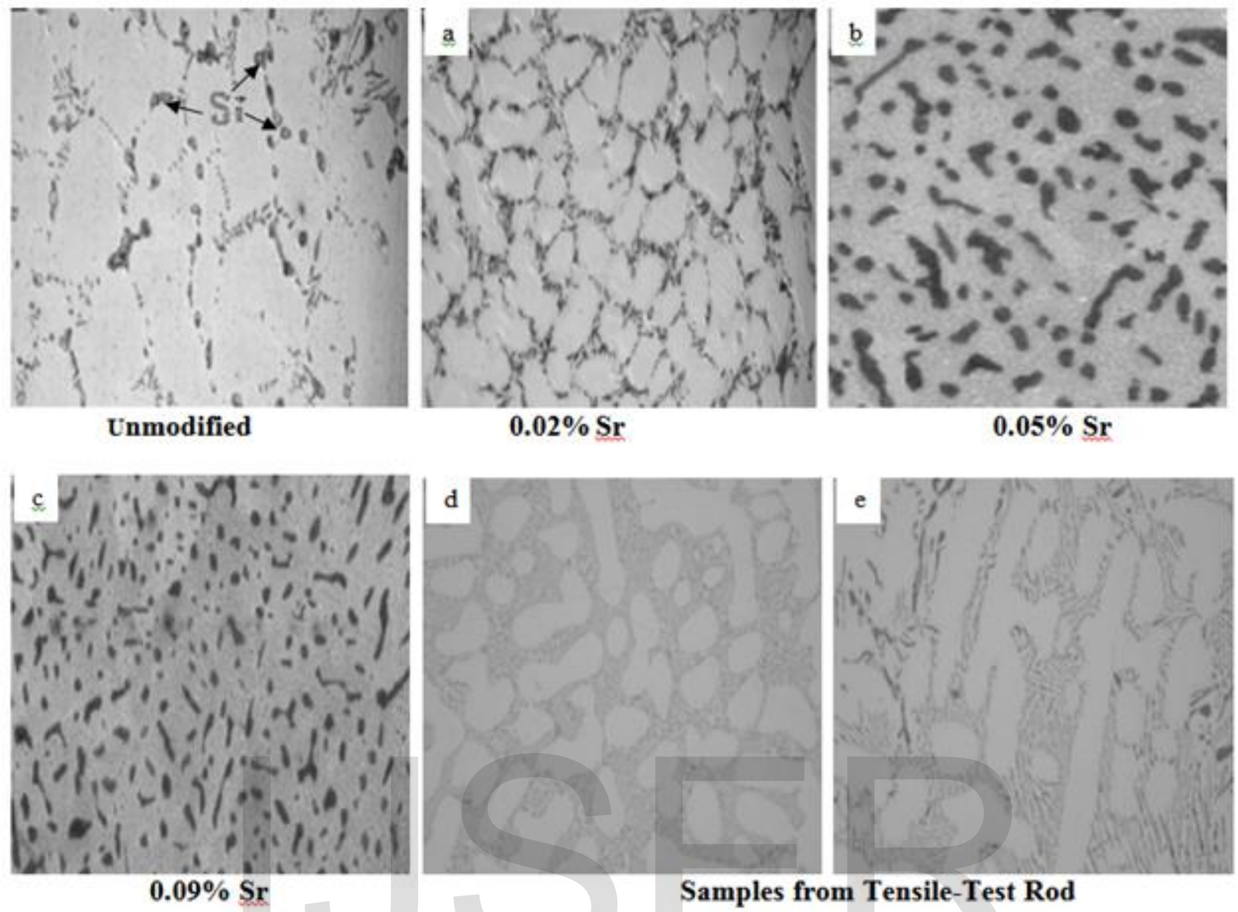

Fig. 1: Microstructures of as-cast alloys with different Sr addition

Table 2: Quantitative metallography results of as-cast alloys with different Sr additions

Alloy	Mean diameter of Si Phase (µm)	Aspect ratio of Si phase
Unmodified	19.85±3.5	35.25±2.9
0.02% Sr	11.32±1.2	21.03±0.8
0.05% Sr	9.211±1.5	13.79±2.5
0.09% Sr	5.915±1.2	8.17±1.3

3.2 Effects of Sr additions on tensile properties

Fig. 2 shows the mechanical properties of the as-cast alloys with varying amount of Sr at room temperature. The ultimate tensile strength, yield strength and elongation improve when the Sr addition increases from 0.02 to 0.09 wt%. It is known that the mechanical properties are largely dependent on the size, shape and distribution of primary Si phase, the α-Al phase and presence of intermetallic compounds (Jahromi, 2004). The effect of Sr in reducing or eliminating porosity level in the as-cast alloys were more effective at ≈ 0.06 wt.% Sr as shown in Fig. 3.

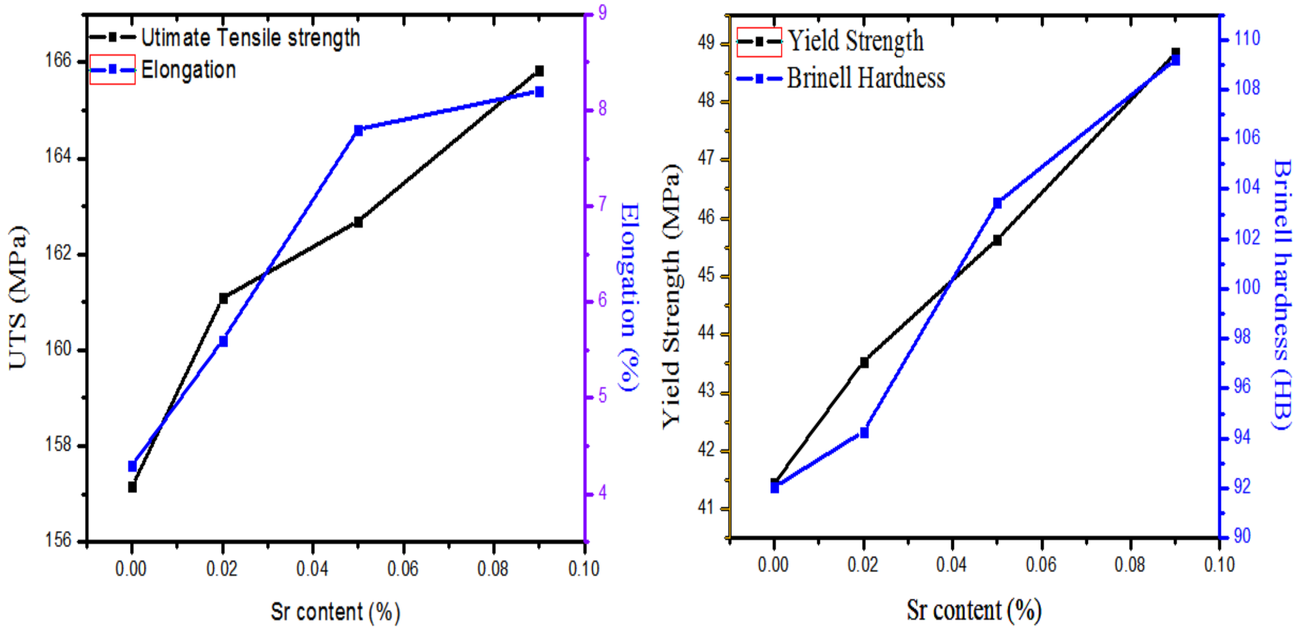

Fig. 2. Effects of Sr additions on mechanical properties of as-cast alloys

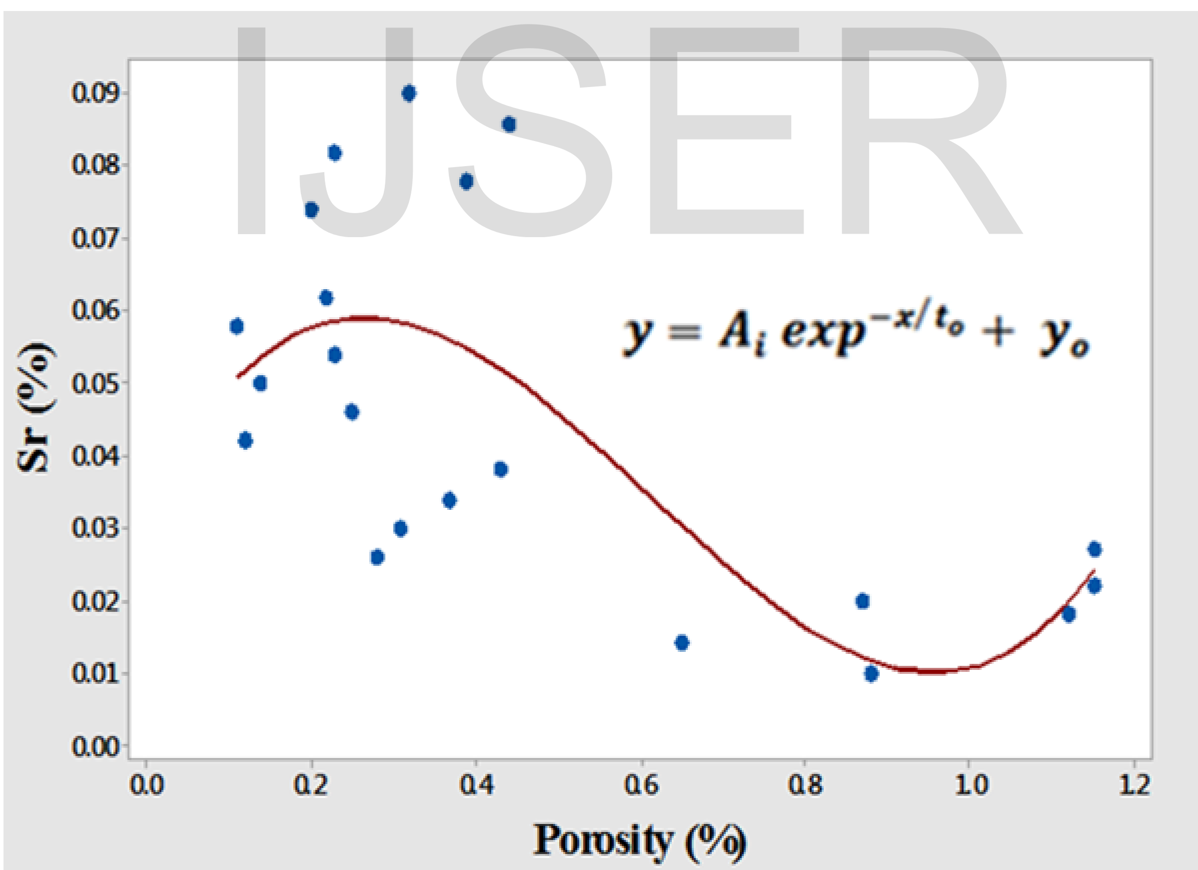

Fig. 3: Effects of Sr on porosity formation in as-cast alloys

Conclusion

The effect of Sr addition on eutectic Al-7Si-.0.2Cu was investigated. The addition of Sr results in the modification of eutectic Si phase, reduction of intermetallic phase and thus improves the mechanical properties of the alloys. Partial modification in the microstructure of the as-cast alloy at 0.02% Sr was observed above which the effect of Sr on the as-cast samples were noticed. Similarly, the refinement behavior of Sr causes a continuous decrease in the mean diameter and aspect ratio of Si phases up to 0.09% St addition.

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