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# Effect of various melt and heat treatment conditions on impact toughness of A356 aluminum alloy

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**Abstract:** The microstructure and impact behavior of A356 aluminum alloy were studied after melt treatment processes of grain refinement and modification under both non-heat treated and T6 heat treated conditions. The modification and grain refinement were done with the addition of Al−10%Sr and Al−5Ti−1B master alloys, respectively. All casting parameters were kept constant in order to focus on the influence of mentioned treatments. The results indicate that the eutectic silicon morphology is the main parameter to control the impact behavior of alloy. Consequently, the individual grain refinement of as-cast alloy does not improve the impact toughness as the modification does. While, simultaneous grain refinement and modification provide higher impact toughness in comparison with individual treatments. T6 heat treatment of the alloy improves the impact toughness under all melt-treated conditions. This is related to the further modification of eutectic silicon particles. To verify the results and clarify the mechanisms, three-point bending test and fractography were used to interpret the improvement of impact toughness of the alloy.
**Key words:** A356 aluminum alloy; modification; grain refinement; impact toughness

## 1 Introduction

Some of the main properties of Al−Si cast aluminum alloys are the superior wear resistance, low coefficient of thermal expansion (CTE), high corrosion resistance, high specific strength and excellent castability, which make them one of the most applicable alloys in the automotive industry and other engineering sectors [1,2]. A356 aluminum alloy is one of well-developed alloys as a result of superior properties. In this alloy, Mg is added to Al−Si systems to make them heat treatable through Mg−Si precipitate. However, the microstructure of as-cast hypoeutectic aluminum alloys contains coarse primary $\alpha$(Al) dendrites and acicular-shaped eutectic silicon particles, which reduces the mechanical properties [3,4]. Particularly, their low fracture toughness limits the broader application of these alloys. To control the type and morphology of second-phase particles, the matrix microstructure and defects are the key to improve the impact toughness of these alloys [1,5].

Common grain refiners are produced from Al−Ti−B ternary system with excess amount of Ti which is needed to form $TiB_2$. $TiB_2$ particles are potential nucleating zones and $TiAl_3$ particles dissolve in the melt to create solute Ti which not only enrich the nucleating potency of $TiB_2$, but also reduce the growth rate of $\alpha$(Al) grains during solidification.

As a result of precipitation heat treatment, the mechanical properties of Al−Si−Mg alloys can be improved noticeably. Moreover, eutectic silicon morphology acts a considerable role on the mechanical properties of these alloys. Acicular-shape eutectic silicon particles can be modified to fibrous or spherical ones by the addition of modifiers such as strontium. Heat treatment can also change the eutectic silicon morphology [6,7].

A few numbers of researches investigated the impact behavior of casting aluminum alloys under various melt or heat treatment conditions. ALEXOPOULOS et al [8,9] have studied the impact behavior of A357 aluminum alloy in different artificial aging processes. IBRAHIM et al [10] have investigated the impact toughness and fractography of Al−Si−Cu−Mg alloy. MOHAMED et al [11] have studied the influence of additives on the impact toughness of Al−10.8% Si alloy. They clarified that the modification with Sr

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improves the impact toughness because of its effect on crack initiation and crack propagation energy. Total absorbed energy in impact test consists of crack initiation and crack propagation energies, and crack initiation energy is much greater than the crack propagation energy in high strength aluminum cast alloys [11,12]. MERLIN et al [13] have investigated the impact behavior of A356 aluminum alloy for low pressure die casting automobile wheels. The recent studies conducted by SAMUEL et al [14,15] concentrated on the relationship between the impact and tensile properties of Al−Si−Cu−Mg alloys and the effect of grain refinement and modification on the impact properties of Al−Si−Mg alloys. In this research, the effects of grain refinement, modification and heat treatment on the impact toughness of A356 alloy were investigated.

## 2 Experimental

Commercial A356.1 ingot was used in the present study. The chemical composition of the alloy was Al−7.18Si−0.33Mg−0.31Fe−0.12Cu−0.01Mn−0.01Zn (mass fraction, %). Melting was performed in a clay−graphite crucible in an electrical resistance furnace. The melt was degassed at (740±10) °C with 0.5% $C_2Cl_6$ (mass fraction) and stirred with graphite rod for 2 min. It was poured into the mold at (710±10) °C. Modification and grain refinement were done by the addition of 0.2% (mass fraction) of Al−10%Sr and 1% (mass fraction) of Al−5Ti−1B master alloys, respectively, and stirred for 1 min to homogenize the melt. Four individual blocks (The first without grain refinement and modification, the second with grain refinement, the third with modification and the fourth with both grain refinement and modification) were produced through casting in a cast iron standard Y-block mold having bottom pour running system and preheated to 250 °C. About 2.5 kg melt was prepared for each process.

Figure 1 shows the locations where samples were prepared from Y-block. It was tried to prepare samples from positions having the same solidification condition. Charpy V-notched impact and three-point bending tests were prepared according to ASTM E−23 and ASTM D−790, respectively.

The samples were divided into two main sets: non-heat treated and solution heat treated at 540 °C for 6 h, then quenched in water at 20 °C, followed by artificial aging at 155 °C for 4 h. The heat treatment process of the samples was carried out in an electric muffle furnace with a programmable temperature controller and temperature accuracy of ±3 °C. The delay between solution and aging heat treatments was less than 30 s. Table 1 represents the codes of samples and their descriptions.

**Table 1** Samples codes and their descriptions

| Sample code | Description |
|---|---|
| S | As-cast condition |
| G | Grain refined with Al−5Ti−1B |
| M | Modified with Al−10%Sr |
| GM | Grain refined and modified |
| HTS | T6 heat treated of as-cast sample |
| HTG | T6 heat treated of grain refined sample |
| HTM | T6 heat treated of modified sample |
| HTGM | T6 heat treated of grain refined and modified sample |

A Charpy impact test machine was used to measure the impact toughness of the samples. Three-point bending test was done by a 200 kN Schenck universal testing machine. The values reported are the averages of at least three distinct tests. Some specimens were prepared for metallographic observation and etched in 0.5% HF for 15 s, and then studied with an optical

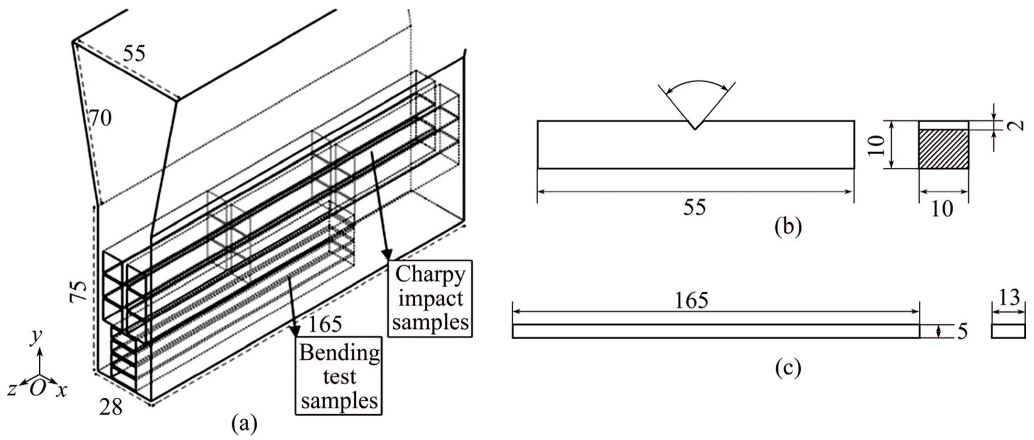


**Fig. 1** Sample preparation from Y-block: (a) Locations of samples; (b) Charpy V-notched impact test samples; (c) Three-point bending test samples (unit: mm)