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CONVENTIONAL AND SEMI-SOLID A356 ALLOY WITH ADDITION OF STRONTIUM

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ABSTRACT

In this study, modification of aluminium silicon eutectic alloy by grain modifier, strontium was investigated on conventional and slope cast A356 alloy. A356 alloy with addition of 0 to 0.97 wt.% Sr was prepared by conventional and slope casting in melting furnace. The molten metal of A356 alloy was casted into steel mould. Microstructure was observed using SEM. Phase analysis was done using XRD. Microhardness was conducted using Vicker microhardness. Microstructure of conventional cast displayed dendritic structure whereas slope cast displayed globular structure. Addition of Sr refined eutectic structure in both conventional and slope cast alloy. Phase analysis revealed the presence of Al_2Sr phase in conventional cast Al-6Si-0.97Sr. Microhardness of the conventional cast alloy decreased with increasing of Sr up to 0.97 wt.%.

Among aluminum alloy system, hypoeutectic Al-Si alloys are widely used in aerospace and automotive industries, with the composition of low silicon element (<12 wt%). Their outstanding performances such as low density, high specific strength, high wear resistance, high stiffness, high weldability, corrosion resistance, damping capacity, low CTE value and good castability features allow their popularity wide spread in commercial application [1]. A356 alloy has wide solidification ranges which suitable for semisolid processing. Cooling slope is a very cheap and simple technique to produces non dendritic microstructure [2]. In this process, molten metal with suitable superheat is poured over the steel slope plate and flow into the mould situated at the end of the slope. The eutectic microstructure determines the mechanical properties of the Al-Si alloys because eutectic phase contains a hard, brittle silicon phase in a softer α-Al phase. Therefore, controlling the eutectic silicon morphology by modification had been extensively used in industry to improve the mechanical properties of the castings. A significant quantity of research work has been conducted in recent years to study the efficiency of various modifier elements such as Sr, Na and Sb on microstructure and mechanical properties of cast and semi-solid A356 alloys. However, addition of strontium has a greater effect in transforming morphology of eutectic silicon from a coarse plate-like structure to fibrous structure. In this study the effect of strontium on conventional and semi-solid casting was investigated.

Before casting, raw materials are prepared and weighed accordance to the sample's requirement. The raw materials used are Al-Si ingot, pure aluminum, pure magnesium and Al-10Sr master alloy. The composition of Al, Si, Mg and Sr were calculated based on weight percentage. The raw materials are placed together into a graphite crucible. The crucible is placed into the bottom loading furnace with temperature increment rate of 25°C/minutes until 800°C for 1 hour. The molten alloys was stirred at 800°C using a stirrer to homogenize the molten mixture and then maintained at 680°C for 30 minutes. The layer slag formed at top is skimmed and removed. In normal casting, the melt was transferred into the preheated 300°C steel mould via bottom opening. The dimension of the sample obtained was 14 mm in diameter and 80 mm in length. The sample was left to be cooled down in room temperature for 30 minutes. For slope casting, the molten melt was poured onto a steel slope and flow down into a preheated steel mould (300°C). The parameters for slope casting are; slope angle of 60°, cooling slope distance of 200 mm and pouring temperature 680°C.

Microstructure Figure 1 shows microstructure of A356 with addition of 0-0.97 wt% Sr for conventional and slope casting. The starting aluminium-silicon ingot material has coarser eutectic silicon and plate like silicon morphology. The microstructure of conventional cast A356 alloy without addition of Sr revealed fibrous eutectic structure. Anett et al. [3] have conducted a research on modification of eutectic in Al-Si alloys through combination of Sr modifier and cooling rate. The cooling rate is based on diameter of mould and narrower diameter brings higher cooling rate. They have reported that the faster cooling rate produce finer eutectic microstructure at same Sr level. Studied conducted by Fatahalla et al. [4] have found that Si-particle size in Al-Si alloy is smaller when solidified in metal mould than that in sand mould. Thus, fibrous eutectic structure formed in conventional cast

A356 aluminium alloy with addition Sr due to higher solidification cooling rate using steel mould. The addition of Sr refines the eutectic structure of Al-Si in A356 alloy for both conventional and slope casting as shown in Figure 1 (b, c, d, f, g and h). According Jigajinni et al. [5], addition of strontium only affects the morphology of the eutectic silicon without altering the α-Al phase. By increasing addition of Sr from 0.36 wt,% to 0.97 wt.% eutectic structure was further refined for both conventional and slope casting. Eutectic structure in slope casting seems to be refined more compared with conventional casting. Sr block and needle shaped intermetallic phases was detected in alloys containing more than 0.60 wt.% Sr for both conventional and slope casting (Figure 1 c, d, g and h). Above 0.60 wt.%, the addition of Sr can be classified as over-modification of eutectic Al-Si alloys. Over-modification can easily be detected by segregation of Sr based compounds to form Al_2Si_2Sr [1,5].

Figure 2 shows the comparison of grains size and shape factor of 0 wt.% Sr and 0.93 wt.% Sr for conventional casting and 0 wt.% Sr and 0.97 wt.% Sr for slope casting. The shape factor for slope casting is 0.76 for alloys without addition of Sr and 0.78 for alloy containing 0.93wt.% Sr. Conventional casting with dendritic structure have shape factor of 0.70 for 0 wt.% Sr and 0.68 for 0.97 wt.% Sr. Higher shape factor indicated higher globularity of the phases. Therefore, slope casting alloys have higher globularity compared with the conventional casting. The grains size of α-Al also appears smaller in slope casting. Cooling slope provides necessary under cooling region for solid (*α*-Al) nucleation. α-Al crystals nucleate and grow on the wall slope and constantly detached from the wall by descending fluid motion forming globular structure. The α-Al crystals also do not have sufficient time to grow into dendritic structure before fully solidified.

Phase analysis Figure 3 shows the XRD analysis for Al-10Sr master alloy and . Based on the analysis, Al_4Sr phase (ICDD No: 98-008-4684) and Al_2Sr phase (ICDD No: 98-007-0272) were detected in Al-10Sr master alloy. The Al_4Sr phase is the main phase in Al-10Sr master alloy. Due to neglectable solubility of Sr in Al, Sr mainly exists in form of intermetallic Al_4Sr in master alloy and decomposed readily into Al and Sr atoms when added in alloy. Compared to Al_2Sr phase, Al_4Sr exhibits lower energy and chemical activity, which has better modification performance [6, 7].

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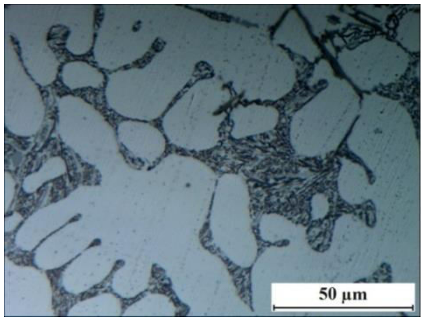
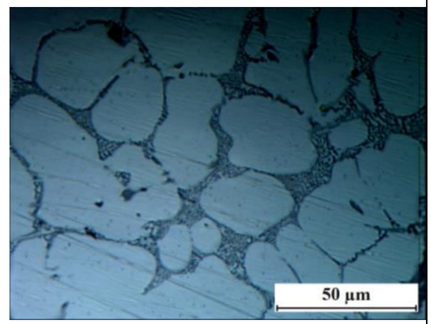
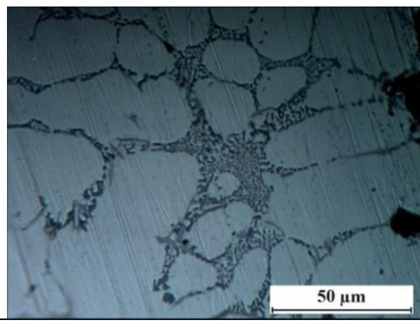
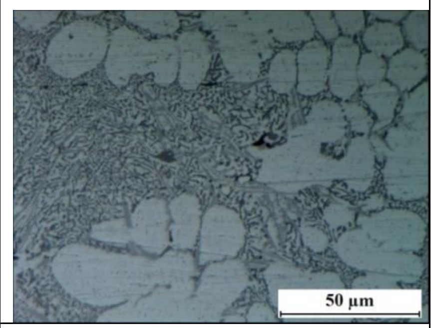
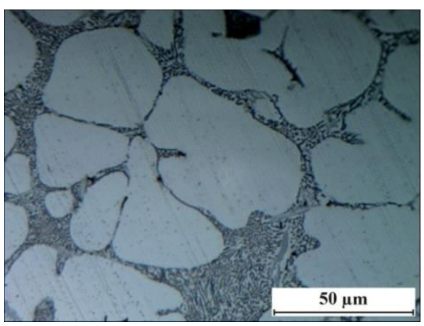
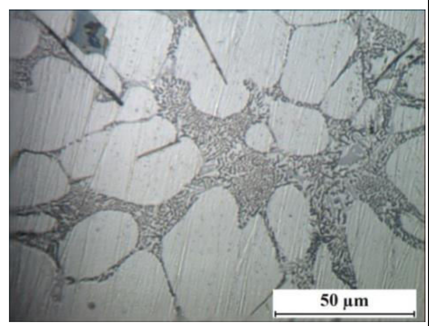
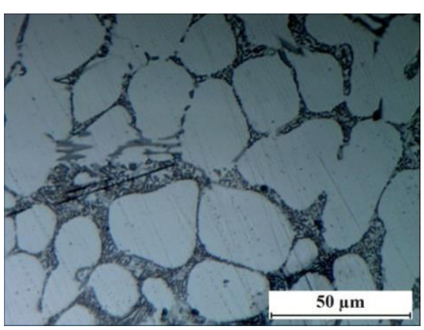
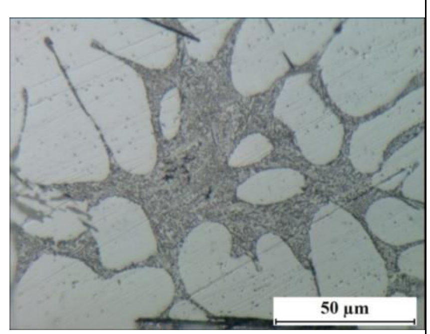
Amount of Sr (wt.%)	**Conventional casting**	**Amount of Sr (wt.%)**	**Slope casting**
a) 0		**e) 0**	
b) 0.36		**f) 0.43**	
c) 0.60		**g) 0.62**	
d) 0.97		**h) 0.93**	

Figure 1: Optical micrographs of conventional and slope cast A356 alloys modified with different wt.% of Sr

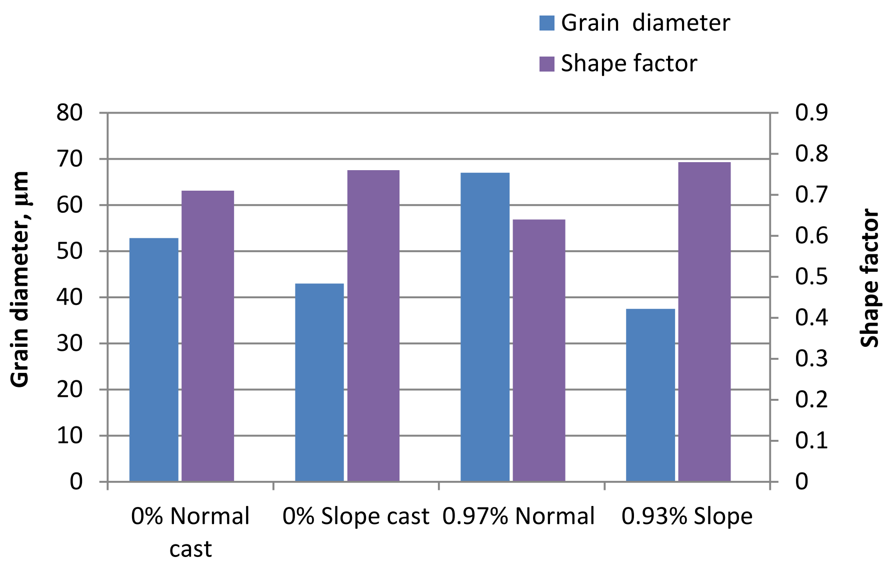
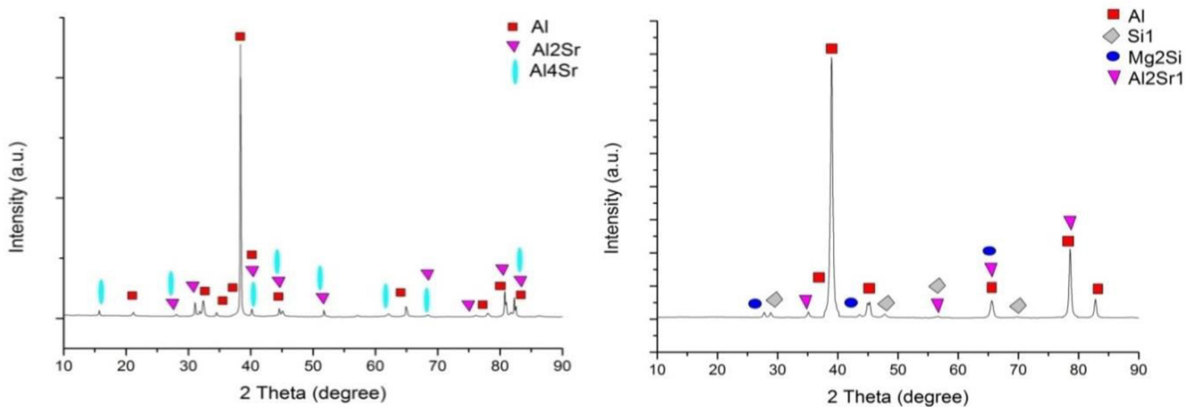


Figure 2 : Grain size and shape factor of primary α-Al for conventional and slope casting



(a) (b)

Figure 3: XRD analysis of a) Al-10Sr master alloy; b) Conventional cast, Al-6Si-0.97Sr

Figure 4 shows the result of Vickers microhardness of conventional and slope cast A356 alloys with different strontium addition from 0% to 0.9 wt.%. Microhardness for conventional cast A356 alloy without addition of Sr records a value of 68 HV and decreases to 63.8 HV when 0.35 wt.% Sr was added. Addition of 0.60 wt.% Sr further decreased its hardness till 60 HV and addition of 0.97wt.% Sr increased the hardness of alloy to 63 HV. The reduction in hardness of conventional cast alloy with addition of strontium was due to stress release in the alloy by refining the eutectic structure. The hardness increase back by addition of 0.97 wt.% of Sr because the formation of more intermetallic phase containing Sr. Slope casting alloy behaves differently from conventional casting in term of microhardness. The slope cast alloy showed lower hardness for alloy without addition of Sr. The hardness of slope cast alloy increases as the Sr contents increase up to 0.43 wt.%. Further increment of Sr resulted in decrease in hardness of slope cast alloy [4]. Addition of Sr may leads to depression in eutectic temperature causing a shift of eutectic point to a higher Si content resulting increase amount of soft α-Al phase [8]. High amount of Sr will degrade hardness value because of softer α-Al phase. Overall, hardness of slope casting was higher than conventional casting due to globular structure of α-Al grains and smaller grain size.

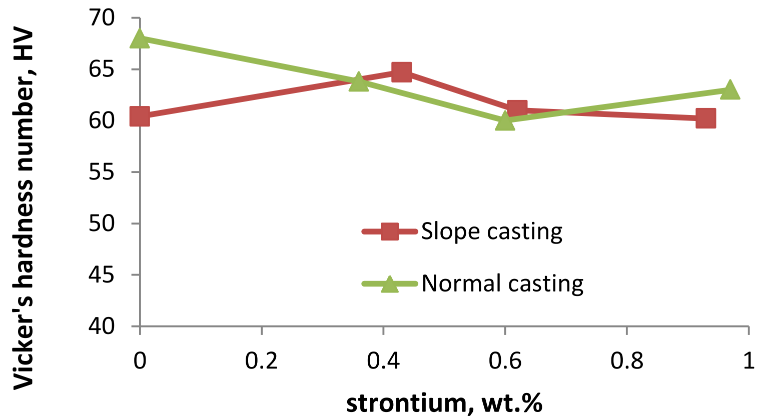


Figure 4: Microhardness of conventional and slope cast alloy with variation wt.% of strontium

Conventional casting produced dendritic structure and slope casting is able to produce a globular structure with smaller grain size. Higher shape factor and smaller grain diameter obtained for slope casting. Addition of 0.6-0.97 wt.% Sr of Al_2Si_2Sr phase. Strontium as a grain modifier refines the coarse silicon plate structure into fine fibrous eutectic silicon which leads to increment of hardness. in conventional and semisolid casting formed needle pate like and cuboid shaped Sr intermetalics with high possibility.

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