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The Effect of Element (Sr, Ti, B, and Mg) Modification on Microstructure to Increase Micro-Hardness of A356 Aluminum Alloy

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Abstract. It is known that Sr, Ti, B, and Mg can modify the microstructure of the A356 aluminum alloy, and the heat treatment process causes spheroidization of eutectic silicon. This experiment presents the effect of modifier elements and heat treatment on microstructure and microhardness. The A356 aluminum alloy is modified with a combination of elements containing Sr, Ti, B, and Mg. The microstructure analysis of the modified A356 aluminum alloy revealed that the size distribution of the α-phase and eutectic silicon particles that form spheroid Si particles varies depending on the combination composition. Comparisons between unmodified and modified alloys show that the aspect ratios of the α phase and the eutectic silicon particles are different. The modified A356 aluminum alloy's microhardness can be improved. This could be related to the aspect ratio of the α phase and eutectic silicon phases, spheroidization of fine eutectic silicon, and precipitation hardening.

Keywords: *A356 alloy; microstructure modification; micro hardness.*

1 Introduction

Al–Si casting alloys have an important role in the field of cast aluminium alloys. One of them is the A356 aluminium alloy, which has been widely used in the automobile, aerospace, and engineering industries because of its excellent cast ability, weld ability, high corrosion resistance, and various other desirable properties. Currently, the hypoeutectic alloy A356 (Al–7% Si–0.3% Mg) is used as a casting wheel product that is commonly used in the automotive. However, as-cast A356 aluminium alloy consists of coarse primary α-Al dendrites and acicular-shaped eutectic silicon, which degrades the mechanical properties and limits its industrial applications. The mechanical properties are determined by controlling the microstructure of the alloy. [1].

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Currently, casting wheel A356 aluminium alloy is processed through gravity die casting (GDC) and low-pressure die casting (LPDC) techniques. The composition of the metal alloy, casting process technique, cooling rate, and heat treatment will influence the high-quality of casting wheel. The high requirements of casting wheels specification standard are Ultimate Tensile Strength: min. 277 MPa, Yield Strength: min. 200 MPa, Elongation: min. 7-12 %, and Hardness: 80 – 95 HB [2][3]. According to ASTM B108 standard, A356 aluminium alloy material after the heat treatment process T6 has mechanical properties for Ultimate Tensile Strength min. 260 MPa, Yield Strength min. 150 MPa, and elongation min. 3% [4]. It demonstrates that increasing the strength through heat treatment is achievable, nonetheless the ductility of the A356 aluminium alloy is still poor, this needs to be accomplished.

The parameters affecting the microstructure, strength, and ductility of as-cast alloys are complex from a metallurgical perspective. The resulting microstructure, depending on solidification processing variables, heat treatment, and the addition of alloying elements. Strength will increase with a reduction in grain size only if the production of small grains does not increase the amount of micro porosity and the percentage of second phase. In order to improve the quality of cast Al alloys, grain refinement has generally been employed to decrease grain size and modify grain morphology from columnar to equiaxed, for example, by adding Ti and B. Some researchers observed that adding relatively small amounts of Sr can also modify the eutectic structure [5][6]. In order to create Mg-Si precipitates, Mg is a key alloying element added to Al-Si alloys. [7]. Therefore, the modifier is expected to result in a finer equiaxed structure, which improves secondary phase dispersion, castability, and mechanical characteristics. It also increases feed during solidification and lowers shrinkage porosity [8].

Adding grain refiners to casting processes for aluminium alloys is a common way to achieve grain refinement. According to some published research, grain refiners with particles of TiAl3, TiB2, and AlB2 refine aluminium alloys more effectively than those with only a single particle [9][10]. The effective on grain refinement of aluminium alloys have been observed through the addition of Al–Ti–B refiner. By addition of Sr will modify the eutectic silicon microstructure which can improve the mechanical properties of the Al-Si alloy. Sr has been observed to change the morphology of the eutectic Si phase from a coarse plate to a fine fibre-like network [6][11]. Furthermore, through T6 heat treatment on A356 aluminium alloy, the morphology of the eutectic silicon particles can alter from plate shape to spherical. Thus, this morphology significantly affects the mechanical properties of aluminium alloy, particularly its ductility [12][13]. However, prior research concentrated on the modification mechanism and/or altering the heat treatment process in order to increase the tensile strength and ductility. In this article, it is our aim to study the influence of element Sr by adding AlSr15, after that the effect of grain refiner by addition of ALTAB Ti80 and AlTi5B1 to form Ti and B which influence on grain refinement, and Mg by adding Mg 99% Ingot to form precipitate on matrix α phases. Heat treatment T6 from solution treatment and aging treatment have been performed to modify the microstructure of A356 alloys and to improve the microhardness.

2 Experimental Method

2.1 Preparation

In this experiment, the A356 aluminium alloy ingot was melted in a 200 kg electric resistance furnace at 720 ± 10 °C. The molten metal was treated with the flux to remove impurities that cause slag to form at the melt's surface, and nitrogen gas was used for a degassing process. Then, the liquid metal was poured into a 1.25-kilogram capacity tiny crucible. The A_0 (A356 aluminium alloy ingot melt) melt is designed to be used as a baseline for comparison with additional elements. The A356 aluminium alloy will then be changed by adding AlSr15 (0,75 gr.) for A_1, ALTAB Ti80 (1,25 gr.) and AlSr15 (0,75 gr.) for A_2, ALTAB Ti80 (1,25 gr.), AlTi5B1 (1,5 gr.), and AlSr15 (0,75 gr.) for A_3, and ALTAB Ti80 (1,25 gr.), AlTi5B1 (1,5 gr), Mg (1,5 gr), and AlSr15 (0,75 gr) for A_4. Optical Emission Spectroscopy (OES) Shimadzu was used to determine the chemical compositions of the alloys, and the results are shown in Table 1/

Table 1 Chemical composition of experimental alloys analysed by OES (wt.%).

ITEM	CHEMICAL INGREDIENT (%)							
	Si	Mg	Fe	Mn	Cu	Zn	Ti	Sr
A0 (A356, base alloy)	7,05	0,43	0,09	0,002	0,002	0,02	0,14	0,010
A1 (A356 + AlSr15)	7,03	0,29	0,09	0,003	0,002	0,02	0,14	0,010
A2 (A356 + ALTAB Ti80 + AlSr15)	7,02	0,37	0,08	0,003	0,002	0,02	0,14	0,008
A3 (A356 + ALTAB Ti80 + AlTi5B1+ AlSr15)	7,04	0,38	0,09	0,003	0,002	0,02	0,14	0,008
A4 (A356 + ALTAB Ti80 + AlTi5B1+ AlSr15 + Mg)	6,96	0,48	0,09	0,003	0,002	0,02	0,14	0,010

2.2 Casting Process and Heat Treatment

According to ASTM B-108, the specimen test was carried out by pouring an aluminium melt into a permanent mould. Two sample bars were generated from each casting, as illustrated in Fig. 1. (a). The molten alloys are shown in Fig 1(b) being brought into the crucible before being poured into the permanent mould using the gravity casting technique. Before casting, the mould was heated to 300°C. For each of the A0, A1, A2, A3, and A4 conditions in Fig. 1(c), five castings were made one after the other in 15 minutes. The T6 heat treatment, which includes temperature of solution treatment and artificial aging, was applied to the cast specimen test after it had been maintained at ambient conditions for at least 24 hours. The first stage involved solution treatment for the solution condition (530°C ± 20°C), which was immediately followed by an immediate water quench to room temperature. The aging treatment (160°C ± 20°C) was then carried out, and it was followed by air cooling.

a. b. c.

Figure 1. (a) The Permanent Mould is made according to ASTM B-108, (b) Manual gravity casting (c) Sample Test

2.3 Characterization

Specimen ϕ9 mm round test rod that has been split in half for microstructural analysis. Using a Keyence optical microscope (OM), a. The specimens were examined using OM after being ground using standard methods. After polishing without employing an etching solution, OM observations were made, and the results of metallography using OM were measured using the image J software program. According to ASTMN E384 standard, the ratio of the long diagonal to the short diagonal in the micro-Vickers hardness test is 7:1. This test is performed using a Knoop Indenter in the shape of a pyramid to identify the two separate diagonals, long and short. The properties obtained from 3 to 5 samples are the basis for each data point presented with a standard deviation.

3 Results and Discussion

3.1 Microstructure

Figure 2 illustrates how the addition of Sr, Ti, B, and Mg affected the microstructure of the as-cast A356 alloy. Due to the high solute content of the alloys with an amount of Si of ~7 wt%, it was discovered that Al Phases were dominating. As-cast A356 aluminum alloys modified with AlSr15, ALTAB Ti80, AlTi5B1, and Mg are each shown in Fig. 2 with their different OM morphologies. While the α–Al phase in the heat-treated condition exhibits dendritic development into an equiaxed structure, the α–Al phase in the cast condition exhibits coarse dendrite morphology. Primary α-Al phases and eutectic silicon phases respond differently to heat treatment following solution treatment and aging treatment than when mixed with as-cast A356 aluminum alloys. After solution treatment, it was demonstrated that the eutectic silicon microstructure may transform from fine fibrous to fine spherical structures. In comparison to other samples, the aging treatment can significantly affect microstructure.

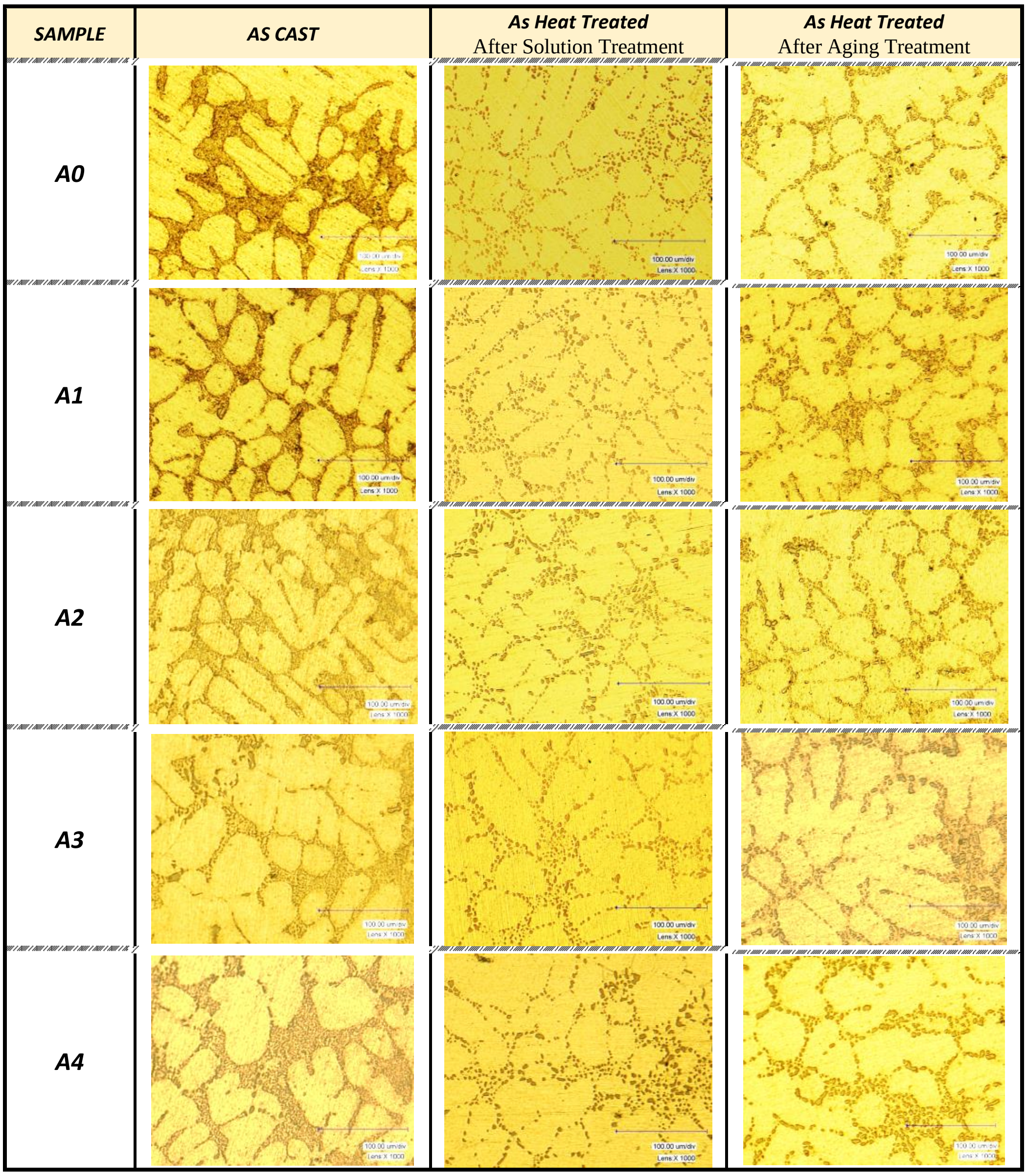


Figure 2. shows the microstructures of the materials A0, A1, A2, A3, and A4 before (as cast), after solution treatment, and after aging treatment (as heat treated), 1000x magnification.

In the A356 alloys with various combinations of Sr, Ti, B, and Mg, the optical micrograph analysis in Fig. 3 illustrates the size area of the primary α–Al phase and the Si eutectic phases, respectively. In the as-cast A356 alloy, the primary α–Al phase exhibits coarse dendritic morphology, and the statistical distribution of α–Al phase size area and Si eutectic phase size area were calculated using the Image J program. Figure 3 demonstrates that the size of the α–Al phase area has a comparatively small size in the as cast state compared to the combined aluminium alloy, but the size of the Si eutectic phases area has a relatively big size in the as cast state. In comparison to the AlTi5B1 or ALTAB Ti combination, the distribution size area of the primary α-Al phase is slightly altered.

The distribution size area of the α -Al phase is unaffected by ALTAB Ti80 and AlTi5B, which is in accordance with expectations that the A356 alloy will have grain refinement. According to the majority of research, Al3Ti precipitates will be created when Ti atoms in the A356 alloy react with Al atoms in the melt. Al3Ti particle size increased with an increase in Ti content [14][15]. The initial α–Al phase should therefore be able to be decreased by it. The size area distribution after solution treatment and after aging treatment (as heat treat), the size area distribution of α–Al phase on Fig 3 has increased compared to as cast and the size area distribution of Si eutectic phase has decreased compared to as cast. Therefore, the mechanical properties of cast aluminium alloys are depended on grain size, phase distribution, secondary phase grain, and precipitation hardening.

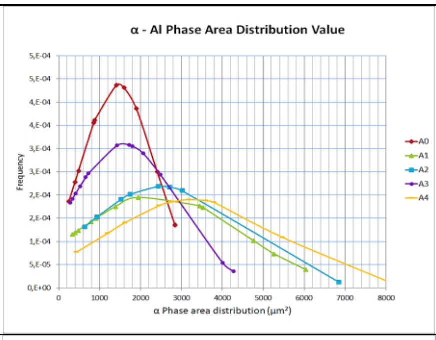
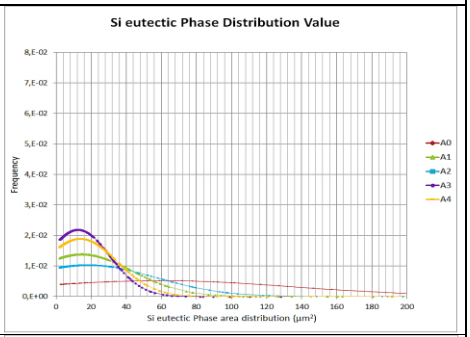
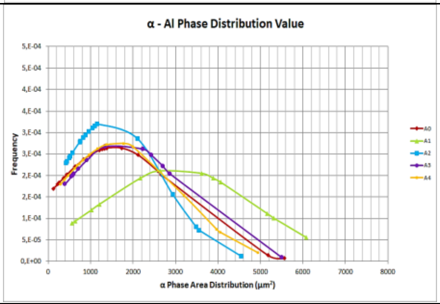
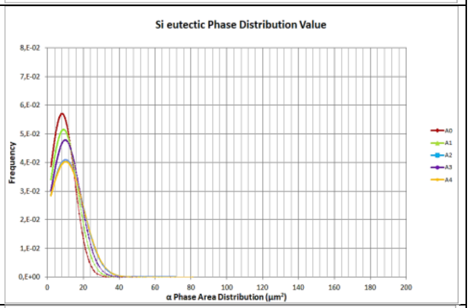
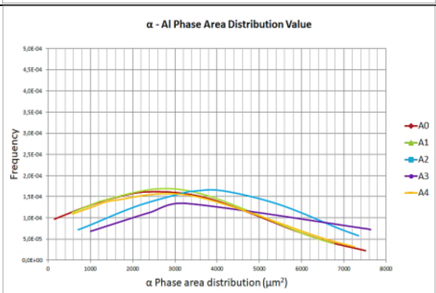
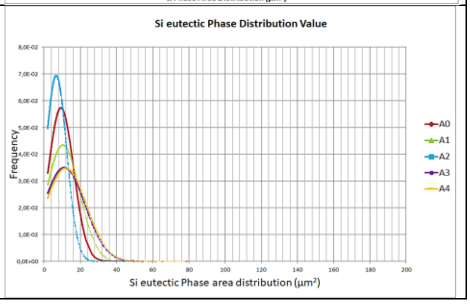
Item	α – Aluminium Phase Distribution	Eutectic silicon Phases Distribution
As - Cast		
As Heat Treated ***After Solution Treatment***		
As Heat Treated ***After Aging Treatment***		

Figure 3. The curve in the α phase size area distribution and the Si eutectic phase size area distribution (as cast and as heat treated: After Solution Treatment and After Aging Treatment)

The microhardness between α–Al phase and Si eutectic phase in figure 4 shows that in the as cast condition, the eutectic phase has a higher hardness than the α – Al phase. After heat treatment, the microhardness increases in both phases and the α – aluminium phase showed a higher hardness than the eutectic phase. This is consistent with the several research that the effect of heat treatment T6 can increase grain size. As a result of the addition of Mg the Mg2Si intermetallic compound is formed which causes increased hardness.

According to Figure 4, which compares the microhardness of the Si eutectic phase and the α - Al phase under as-cast conditions, the eutectic phase is harder than the -aluminium phase. Figure 4 demonstrates that, under as-cast conditions, the eutectic phase has a higher hardness than the α - Al phase after the addition of the components Sr, Ti, B, and Mg via the material of AlTi5B1, ALTAB Ti80, AlSr15, and Mg. The size area distribution of the α - Al phase on Fig. 4 has grown compared to as cast, and the size area distribution of the Si eutectic phase has decreased compared to as cast following heat treatment (as heat treat). As a result, grain size, phase distribution, secondary phase grain, and precipitation hardening all affect the mechanical properties of cast aluminium alloys.

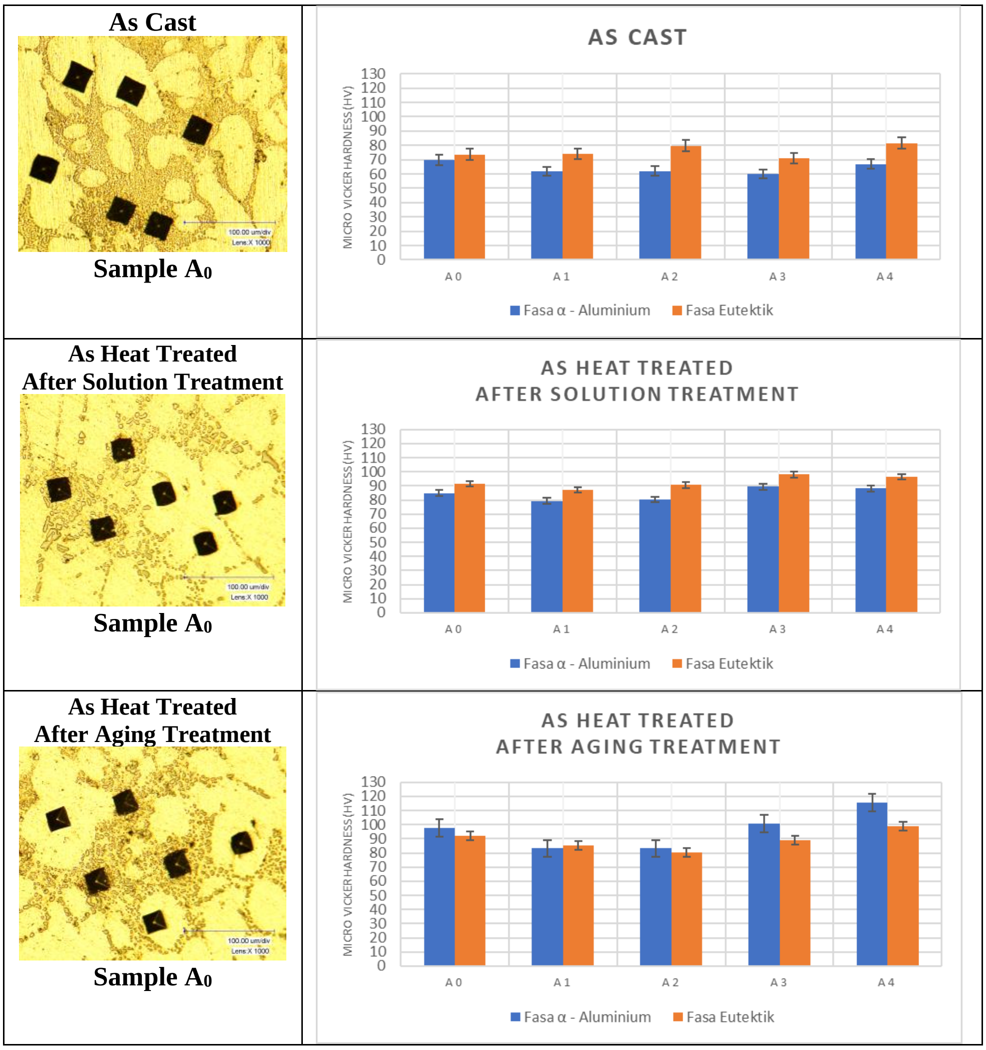


Figure 4. Results of Micro Vickers Hardness
(as cast and as heat treated: After Solution Treatment and After Aging Treatment)

4 Conclusions

The chemical composition of the A356 aluminum alloy did not alter significantly with the addition of a mixture of components, including AlTi5B1, ALTAB Ti80, AlSr15, and 99% Mg Ingot.

The results of the structural study demonstrated the impact of changing Sr to produce Si precipitates with a fine fibrous morphology under as-cast circumstances. The morphology of the precipitates changed to spheroidized Si after the heat treatment (solution treatment and aging treatment).

Results from the Micro Vickers Hardness test reveal that the eutectic phase is harder than the α-aluminum phase. The two phases' hardness increased after the T6 heat treatment process, with the hardness of the α-aluminum phase increasing significantly and exceeding the eutectic phase in hardness.

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