VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# EFFECT OF YTTERBIUM ADDITION ON MICROSTRUCTURE AND HARDNESS OF AL-6.5SI-1ZN SECONDARY CAST ALLOY

R. Ahmad, M. B. A. Asmael and M. Amzar
Department of Manufacturing and Industrial Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
E-Mail: roslee@uthm.edu.my

## ABSTRACT

The effects of Yb additions (0.3 wt.% and 0.8 wt.%) on Al-6.5Si-1Zn cast alloy was investigated using optical microscopy (OM) and scanning electron microscopy (SEM/EDS) analysis. The purpose of this research is to investigate the variations occurred in Si morphology and the formation of intermetallics with different Yb additions, as well as their effect on hardness value. The experimental results indicates that the Yb affected the silicon eutectic morphology of Al-6.5Si-1Zn secondary alloy, when 0.8 wt.% was added to the alloy and the coarse plate Si was modified into a fine fibrous structure. Two kinds of Yb-rich intermetallics were found, such as AlSiYb and AlSiYbMg. The hardness measurements revealed that the hardness values of base alloy were higher with the Yb addition.

**Keywords:** aluminum cast alloys, ytterbium, microstructure, hardness.

## INTRODUCTION

Aluminium alloys have acquired increasing markets in the aircraft and automotive industries (Stefanescu and Ruxanda 2004). Al-Si alloys constitute an important class of aluminium foundry alloys. Aluminium alloys with silicon as major alloying element offer excellent castability, good corrosion resistance and can be easily welded and machined. Sand and permanent mould cast binary aluminium silicon alloys are used in automotive, domestic food and pump castings (Asmael, Ahmad *et al.*, 2014). Aluminium–silicon alloys are widely used for shape casting due to their high fluidity, ease of casting, low density and controllable mechanical properties. Commercial Al-Si alloys are available in alloys with silicon additions of up to 11 wt.% ( hypoeutectic), 11 to 13 wt.% (eutectic) or over 13 wt.% (hypereutectic) (Ahmad and Asmael 2015). A hypoeutectic alloy in the Al–6-7 % Si has widespread applications, especially in the automotive and aerospace industries. Alloy composition plays a significant role in determining the final mechanical properties and values of quality index of Al-Si casting alloys. This parameter includes either impurities or alloying elements. The alloying elements are usually added with the intention of improving a specific property of the casting (Ammar, Moreau *et al.*, 2008) . Properties of Al are typically enhanced by the addition of major alloying elements such as Si, Cu, Mn, Mg, Li, Zn, Ni, and then subjecting the alloys to various mechanical, thermal and thermo-mechanical treatments. Zinc is present merely as an acceptable impurity element in many secondary (scrap- based) dies casting alloys (Carroll, Gouma *et al.*, 2000). The presence of Mg in the alloy offers the ability to heat treat Al-Si castings to high strength levels. Mg combines with Si to form the age hardening compound Mg2Si (Wang and Davidson 2001).

The mechanical properties of Al-Si cast alloys depend not only on chemical composition, but also more importantly, on microstructure features such as eutectic Si flakes, morphologies of dendrite α-Al and other intermetallics that present in the microstructure. Various additives are usually added to modify industrial alloys. Modified Al-Si alloys gave better mechanical properties than unmodified alloys (Asmael, Ahmad *et al.*, 2014). Studies on rare earths as micro-alloying elements showed that they had beneficial effects on the microstructure and mechanical properties of aluminium alloys (Asmael, Ahmad *et al.*, 2014). All rare-earth metals had some effects on the eutectic silicon. Of all elements tested, Europium was the only element to cause fully modified, fine fibrous eutectic silicon. The other elements only resulted in a minor refinement of the plate-like eutectic silicon morphology. Some rare earth elements including Eu, La, Yb , Y, Ce and Sc reported that they can change Al-Si from a coarse plate or flake to a fibrous or laminar morphology (Knuutinen, Nogita *et al.*, 2001, Asmael, Ahmad *et al.* 2014, Pramod, Rao *et al.*, 2015). Generally, the mechanical properties of Al-Si alloys depend mainly on microstructure parameters, such as intermetallic phase and Si particles. The intermetallics are generally formed in an Al-Si alloy system because of the presence of additional alloying elements (V. Vijeesh 2013). The effectiveness of mischmetal as a modifier may be determined by monitoring the Si particle characteristics obtained under different alloying, solidification, melt treatment and heat treatment conditions, while the consequent effect on the alloy properties may be estimated through testing of hardness (El Sebaie, Samuel *et al.*, 2008). Hardness measurements are capable of providing a good indication of the strength and ductility of alloys, since strength is related to the number, type and spacing of second phase precipitates in the matrix. Moreover, hardness testing may be carried out quickly and with relative ease (Gray, Kuhn *et al.*, 2000).

In spite of reported literature, there is no clear explanation on forming compounds of Al-Si-Mg-Zn with Yb and their effects on hardness. Thus, in the present work, the influence of rare earth Yb on microstructure and hardness value of hypoeutectic cast alloy was investigated.

VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Furthermore, the mechanism of the formation of intermetallics was also investigated and discussed.

## EXPERIMENT PROCEDURE

In this research, the hypoeutectic Al-6.5%Si-1%Zn secondary cast alloy was used. The alloy was melted in graphite crucible, heated to 750°C using induction furnace. Different concentration of Yb was introduced separately into the melt. The selected levels of Yb were 0.3 wt.% and 0.8 wt.% respectively. The melt was maintained for 15 min to ensure homogeneous dissolution and mixing. All melts were stirred for 30 s with zirconia coated graphite rod, and pored at 730 ± 5°C into a 250°C permanent preheated steel mould. Metallographic examinations were made on Al-6.5Si-1Zn cast alloy specimens mounted in thermo-hardening resins. To reveal a particular structure by metallographic process, the samples were sectioned horizontally at center of the mould and were mounted in resin and grounded with a series of progressively finer SiC paper size from 250 grit to 4000 grit. Then, the specimens were subjected to a final polishing with Struers Silica OPS suspension 0.5 µm until a mirror-smooth surface was obtained. In order to disclose the Si structure and to distinguish precisely the particular precipitations in Al-6.5Si-1Zn alloys as an etching reagent, a HF5 acid was used. The observations of the investigated cast materials were made on the light microscope by Nikon optical microscope at magnification 200x, as well as on the scanning electron microscope JEOL JSM-6380, using a secondary electron detection. The EDS analysis provided the means to determine the chemical compositions and formula of the Yb intermetallics. For comprehensive characterization of the Si structures, an Image Analysis System I-Solution image analyser was used to examine the microstructure. Five different areas were selected to evaluate the modification rating (M.R.) value for each sample. In order to evaluate the modification rate of Yb addition, two parameters (mean area and aspect ratio) were measured for the quantitative metallographic analysis. Mean area and aspect ratio are calculated as follows:

$$\text{Mean area} = \frac{1}{m}\sum_{j=1}^{m}\left(\frac{1}{n}\sum_{i=1}^{n} Ai\right)_j$$

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

Where A*i* is the area of a single silicon particle, $L_l/L_s$ is the ratio of longest to shortest dimensions of a single silicon particle, n is the number of particles in a single field and *m* is the number of the fields. Therefore, 5 fields were measured on each sample in order to get an accurate data. The mean area and aspect ratio values of a specimen were the average values for the 5 fields (m=5).

## RESULTS AND DISCUSSION

The microstructure of hypoeutectic Al-Si-Mg-Zn alloy with different concentration of Yb is shown in Figure-1. As shown in Figure-1(a), the coarse plater like silicon morphology was observed in unmodified alloy (base alloy).

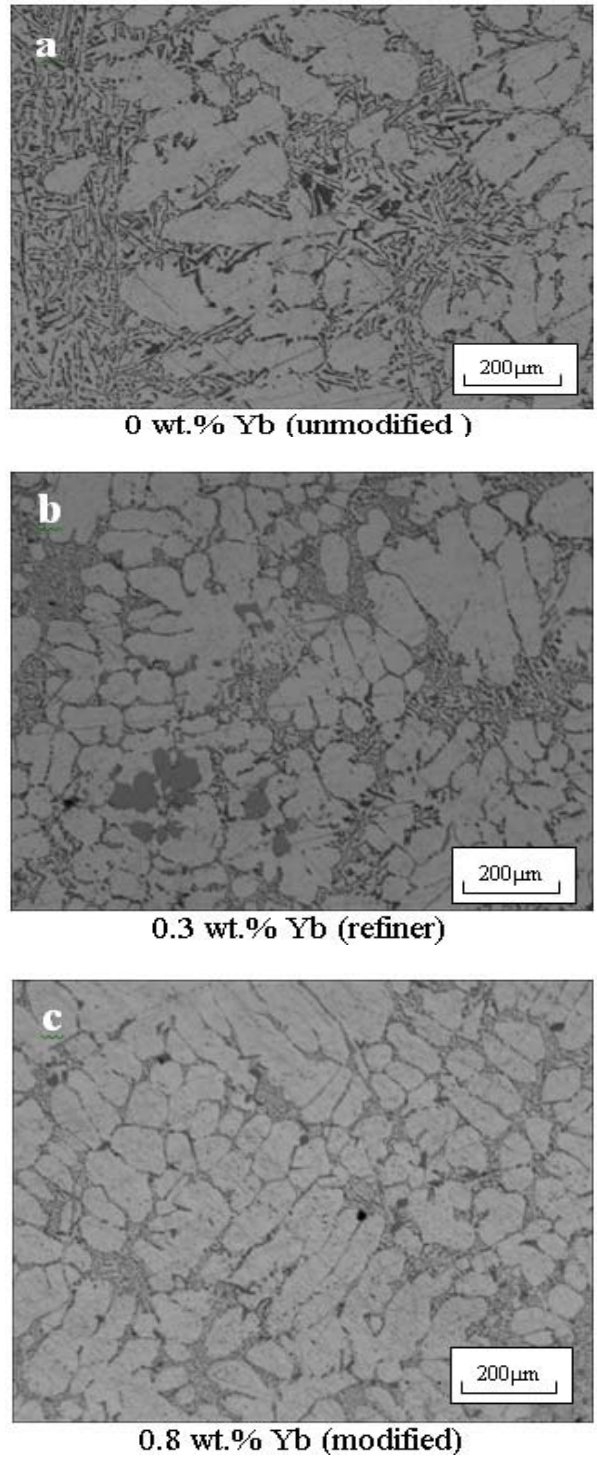


**Figure-1.** The as-cast microstructure of Al-Si-Zn (base alloy) with different concentration of Yb.

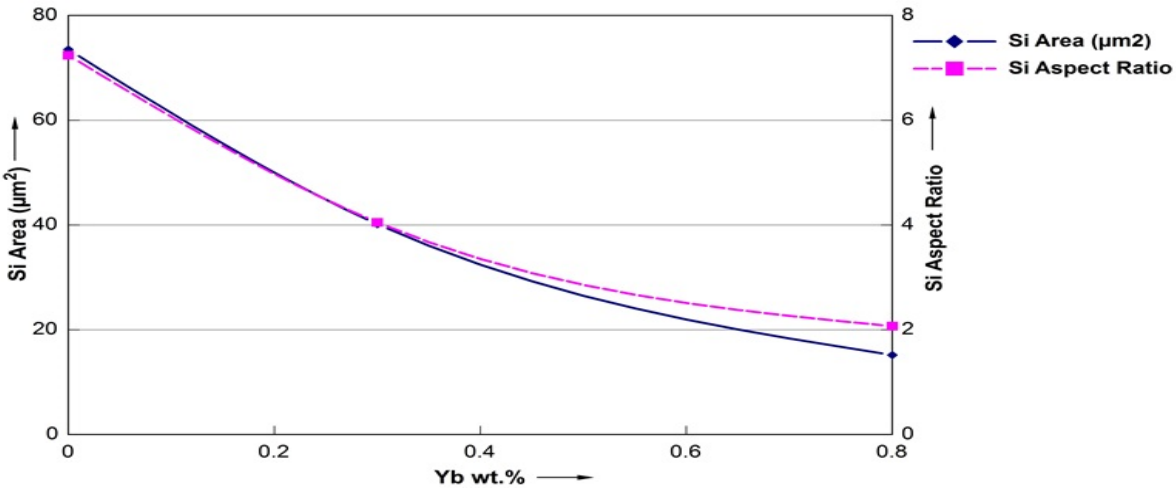


**Figure-2.** Variations of the mean area and the aspect ratio of the eutectic Si in Al-6.5Si-1Zn alloys with different Yb additions.

The eutectic silicon particles of 0.3 wt.% Yb modified to short rod, with most of them turned to be smooth and no sharp edges as shown in Figures-1(b) and (c). Similar result was obtained of Al-7Si with another rare earth material, such as Sm, La and Ce, at the same value of 0.3wt.% (Tsai, Chou *et al.*, 2009, Tsai, Lee *et al.*, 2011, Qiu, Yan *et al.*, 2013). However, with 0.8 wt.% Yb addition, it successfully modified to fibrous rounder eutectic silicon particles.

The mean area and aspect ratio of eutectic silicon particles of testing alloy were measured by image analyzer and plotted in Figure-2. The mean area of eutectic Si decreased with the increase of Yb concentration. The mean area of silicon of Al-6.5Si-1Zn alloy was decreased from 73.5 µm2 to 40.17 µm2 with 0.3.wt.% Yb and sharply decreased to 15.21 µm2 with high level of Yb (0.8 wt.%). Same scenario was observed with aspect ratio, which decreased with the increase in Yb concentration from 7.2 to 2.07 of base alloy and 0.8 wt.% Yb concentration alloy respectively. Similar result was obtained with Sm, Ce and La with A356 and Al-7Si-Mg alloys (Tsai, Chou *et al.* 2009, Tsai, Lee *et al.* 2011, Qiu, Yan *et al.* 2013). The modification of eutectic silicon is due to the depression of growth eutectic temperature (Knuutinen, Nogita *et al.* 2001). In addition, Lu and Hellawell discovered that a growth twin will be caused at the interface when the atomic radius of the element has the correct size relative to the radius of silicon (relement/rSilicon = 1.64). According to the impurity induced twining theory, which was proposed by Lu and Hellawell, a value of 1.646 is proposed as the ideal ratio of the atomic radius of the impurity element compared to silicon. The atomic ratio of Yb is 1.58 which is close to the idea value (Knuutinen, Nogita *et al.* 2001). Figure-3 shows a plot of relative atomic radius versus the atomic radius of silicon for a range of elements. It can be observed that Yb element fall within the atomic radius range (Lu and Hellawell 1987).

When Yb is added into aluminum alloy melt, the intermetallics of Yb-rich will form. In order to investigate the morphology and chemical composition of the Yb-rich intermetallics, SEM and EDS were used, as shown in Figure-4 (a). The Yb showed ability to forming rich intermetallics, with alloy elements such as Al, Si, Mg. It is worth mentioning that the similar Al-Si-Ce phases were observed in Al-Si-Cu aluminum alloy (R and Asmael 2015). The dark area is α-Al and more bright plate area (marked A) than dark area is Al-Si-Yb phase with needle shape. Another bright area with bigger plate than Al-Si-Mg-Yb phase (marked B) with plate-shape is Al, Si, Yb, and contains Mg elements while marked C is Al-Si-Zn particles. Based on the EDS result, the Yb-Rich intermetallic phase is likely to be ternary Al-Si-Yb phase. Therefore, the Al-Si-Yb phase may be growth out, forming the plate-like phase during the final eutectic reaction in Al-Si-Mg (Qiu, Yan *et al.* 2013).

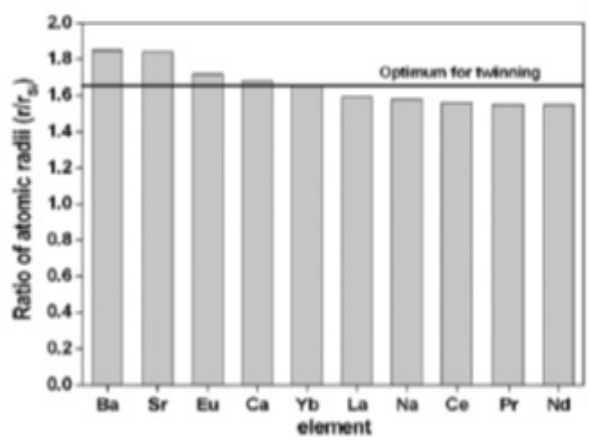


**Figure-3.** Plot of ratio of atomic radii versus atomic radius of silicon for a range of alloy elements and modifiers (Tsai, Chou *et al.* 2009).

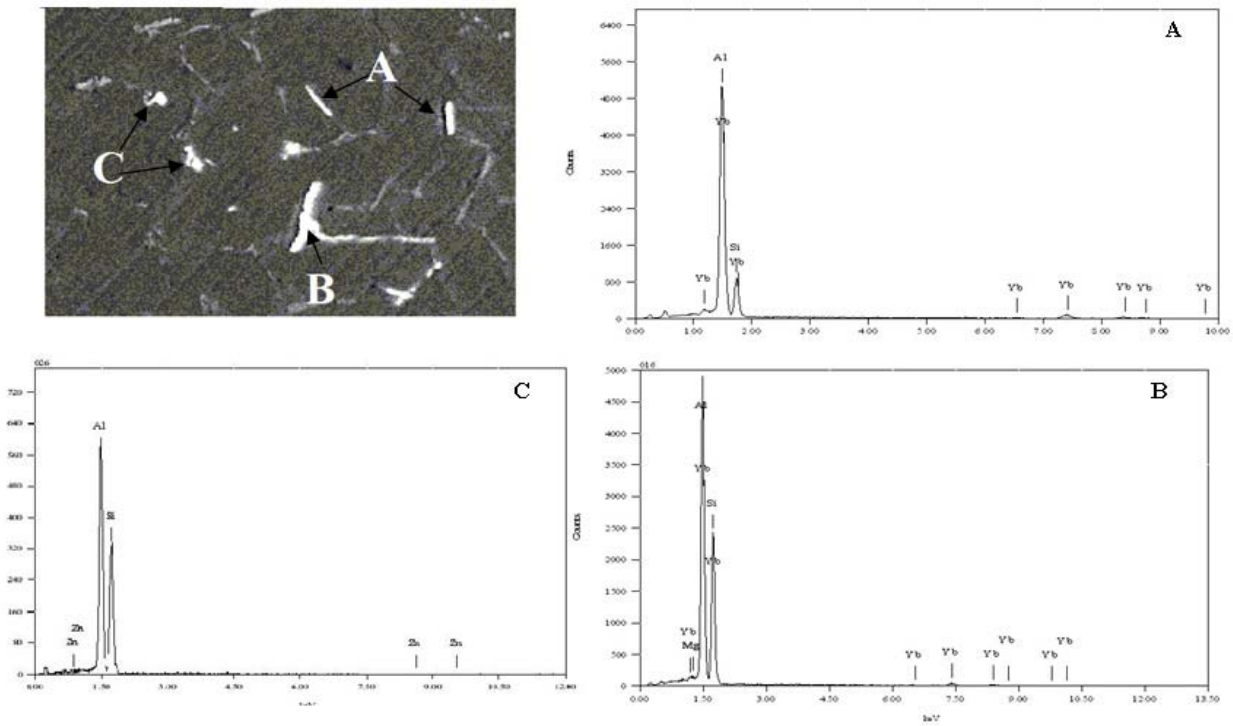


**Figure-4.** SEM–EDS image of Yb-rich intermetallic compounds in Al-6.5Si-1Zn with 0.8 wt.% Yb.

## HARDNESS TEST

In the as-cast base alloy, the hardness was the lowest value when compared to the modified Yb alloy, which obtained 65.5 HV as shown in Figure-5. The hardness increased to 69 HV with 0.3 wt.% Yb addition, whereas it was slightly increased about 2% with the increase of 0.8 wt.% Yb. The increase in hardness values of alloys with Yb addition may be explained by the fact that the degree of modification, while the rare earth and mischmetal achieved less than that by Sr addition (El Sebaie, Samuel *et al.* 2008).

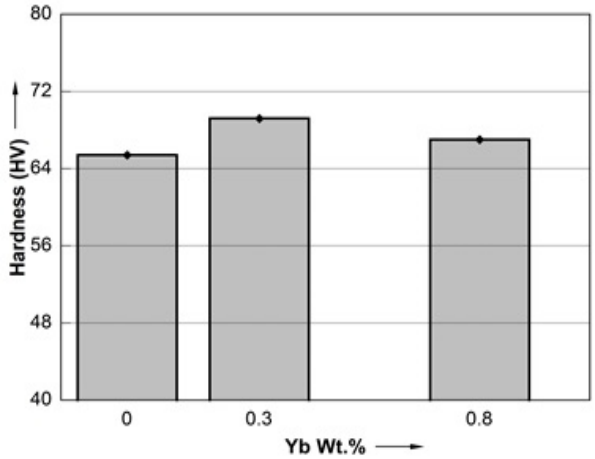


**Figure-5.** The hardness value with different concentration of Yb.

In addition, it is due to the Al RE intermetallic , with different addition value of rare earth or mishcmetal caused different sequence (Agarwal and Menghani 2002). The slight increase with 0.8 wt.% may be ascribed to the reaction of Yb with Mg to form complex compounds, leading to a reduction in the amount of free Mg available to form the Mg2Si phase (Ravi, Pillai *et al.*, 1996, El Sebaie, Samuel *et al.* 2008). This result observation is in good agreement with (El Sebaie, Samuel *et al.* 2008).

## CONCLUSIONS

The effect of the addition of Yb on microstructure and hardness of Al-6.5Si-1Zn secondary cast alloy was investigated and the following can be summarized:

- The Yb can modify eutectic silicon from a coarse plate-like morphology to a fine fibrous one, with the addition of Yb reached 0.8 wt.% and the area & aspect ratio decreased around 79% .
- For the 0.8 wt.% Yb alloy, two kinds of Yb-rich intermetallics were found: the needle-shaped Al-Si-Yb phase and associates with plated-shape Al-Si-Yb-Mg phase .
- In the base alloy, the hardness was improved around 5.6%, with Yb addition of 0.3.wt.% and slightly improved around 2%, with 0.8 wt.% Yb.

## ACKNOWLEDGEMENTS

This research is funded by Fundamental Research Grant Scheme (FRGS), Vot number 1422, Ministry of Education, Malaysia.

**REFERENCES**

[1] Agarwal, Sk and Menghani, J. (2002). Effect of Rafe Earth Additions on Age Hardened Behaviour of LM 25 Alloy. Indian Foundry Journal, 48(8), pp.27-31.

[2] Ammar, Hr., Moreau, C., Samuel, Am., Samuel, Fh and Doty, Hw. (2008). Influences of alloying elements, solution treatment time and quenching media on quality indices of 413-type Al–Si casting alloys. Materials Science and Engineering: A, 489(1), pp.426-438.

[3] Asmael, M.B.A., Ahmad, R and Ourdjini, A. (2014). Effect of High Cerium and Lanthanum on Impact Toughness of Al-11Si-Cu Eutectic Cast Alloy. Applied Mechanics and Materials, 660, pp.195-198.

[4] Asmael, M.B.A., Ahmad, R and Ourdjini, A. (2014). Effect of Mish Metal Cerium Addition on Fluidity of Aluminum Eutectic Silica Alloys-LM6. Applied Mechanics and Materials, 465, pp.839-842.

[5] Asmael, M.B.A., Ahmad, R., Ourdjini, A and Farahany, S. (2014). Effect of Elements Cerium and Lanthanum on Eutectic Solidification of Al-Si-Cu near Eutectic Cast Alloy. Advanced Materials Research, 845, pp.118-122.

[6] Carroll, Mc., Gouma, Pi., Mills, Mj., Daehn, Gs and Dunbar, Br. (2000). Effects of Zn additions on the grain boundary precipitation and corrosion of Al-5083. Scripta materialia, 42(4), pp.335-340.

[7] El Sebaie, O., Samuel, Am., Samuel, Fh and Doty, Hw. (2008). The effects of mischmetal, cooling rate and heat treatment on the hardness of A319. 1, A356. 2 and A413. 1 Al–Si casting alloys. Materials Science and Engineering: A, 486(1), pp.241-252.

[8] Gray, Gt., Kuhn, H and Medlin, D. (2000). ASM Handbook, vol. 8, Mechanical Testing and Evaluation. ASM International, Materials Park, pp.462.

[9] Knuutinen, A., Nogita, K., Mcdonald, Sd and Dahle, Ak. (2001). Modification of Al–Si alloys with Ba, Ca, Y and Yb. Journal of light metals, 1(4), pp.229-240.

[10] Lu, Shu-Zu and Hellawell, A. (1987). The mechanism of silicon modification in aluminum-silicon alloys: impurity induced twinning. Metallurgical Transactions A, 18(10), pp.1721-1733.

[11] Pramod, Sl., Rao, Ak Prasada., Murty, Bs and Bakshi, Srinivasa R. (2015). Effect of Sc addition on the microstructure and wear properties of A356 alloy and A356–TiB 2 in situ composite. Materials & Design, 78, pp.85-94.

[12] Qiu, Hongxu., Yan, Hong and Hu, Zhi. (2013). Effect of samarium (Sm) addition on the microstructures and mechanical properties of Al–7Si–0.7 Mg alloys. Journal of Alloys and Compounds, 567, pp.77-81.

[13] R, Ahmad and M.B.A, Asmael. (2015). Effect of Lanthanum Addition on Fluidity of Complex Al-11Si-Cu-Mg Cast Alloy. Advanced Materials Research, 1119, pp.490-494.

[14] Ravi, M., Pillai, Uts., Pai, Bc., Damodaran, Ad and Dwarakadasa, Es. (1996). A study of the influence of mischmetal additions to ai-7si-0.3 mg (lm 25/356) alloy. Metallurgical and Materials Transactions A, 27(5), pp.1283-1292.

[15] Stefanescu, Doru M and Ruxanda, Roxana. (2004). Solidification Structures of Aluminum Alloys. Materials Park, OH: ASM International, 2004., pp.107-115.

[16] Tsai, Yu Chou., Chou, Cheng Yu., Lee, Sheng Long., Lin, Chih Kuang., Lin, Jing Chie and Lim, Sw. (2009). Effect of trace La addition on the microstructures and mechanical properties of A356 (Al–7Si–0.35 Mg) aluminum alloys. Journal of Alloys and Compounds, 487(1), pp.157-162.

[17] Tsai, Yu Chou., Lee, Sheng Long and Lin, Chih Kuang. (2011). Effect of trace Ce addition on the microstructures and mechanical properties of A356 (AL–7SI–0.35 Mg) aluminum alloys. Journal of the Chinese Institute of Engineers, 34(5), pp.609-616.

[18] V. Vijeesh, M. Ravi, K. Narayan Prabhu. (2013). The Effect of the Addition of Strontium and Cerium Modifiers on Microstructure and Mechanical Properties of Hypereutectic Al-Si (LM30) Alloy. Materials Performance and Characterization, 2(1), pp.296-307.

[19] Wang, Q.G and Davidson, C.J. (2001). Solidification and precipitation behaviour of Al-Si-Mg casting alloys. Journal of materials science, 36(3), pp.739-750.