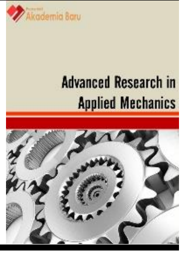
Journal of Advanced Research in Applied Mechanics 87, Issue 1 (2021) 1-10

Penerbit Akademia Baru

Journal of Advanced Research in Applied Mechanics

Journal homepage:
http://www.akademiabaru.com/submit/index.php/aram/index
ISSN: 2289-7895



Effect of Gd Addition on Microstructural and Mechanical Properties of Al-18%Si Alloy for Automotive Applications

Saif Yasir Ali, Hamidreza Ghandvar, Muhamad Azizi Mat Yajid*

[1] Department of Materials, Manufacturing and industrial Engineering, School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia

ABSTRACT

When comparison to other metals, aluminium-silicone alloys have a higher strength, good wear resistance, and a lower thermal conductivity which makes them appealing to a variety of industries and automotive applications. These technological advances require a comprehensive study of their mechanical behaviour. The goal of this research is to examine how rare-earth elements like Gadolinium, at concentrations of 0.3, 0.5, 0.8, and 1 wt. %, influence microstructure and mechanical characteristics of Al-18%Si alloy. Microscopic studies include optical, scanning electron, and X-ray diffraction, as well as mechanical characteristics testing including tensile, and hardness testing. The results of microstructure and mechanical properties were found to be in good agreement. EDS analysis show that the adjustments cause the production of intermetallic compounds, which could be a major factor in increasing mechanical characteristics. The grain size of silicon decreases from 49 to 23µm, and the aspect ratio decreases from 1.4 to 1.1 when the alloy is added with 0.8 wt. % Gd. The addition of Gd to Al-18Si would an increase in ultimate tensile strength from 47 MPa to 69 MPa. The mechanical characteristics of the alloy reduced when further Gd is added (1.0 wt. %).

Keywords:
Al-18%Si alloy; Gd; addition; Refinement; Mechanical properties

Received: 11 September 2021 Revised: 30 October 2021 Accepted: 15 November 2021 Published: 5 December 2021

1. Introduction

Aluminum alloys are extensively utilized in automotive industries. This is due to the requirement to save lightweight to reduce fuel consumption. currently replacing steel panels in many automotive industries [5]. For a long time, Al-Si alloys have been used in the tribological parts of diesel engines in both dried and lubrication contacts [11]. Low Al-Si alloy characteristics are caused by the brittleness of coarse Si crystals (alike eutectic and primary silicon), and coarse silicon crystals cause premature crack formation and stress fracture [3]. To get the required morphologies and characteristics, it is important to refine the microstructure of the alloy. Significant research has been done to modify the microstructure of Al-Si by castings with alloying elements that have excellent modification effects, such as cerium and phosphorus [13], praseodymium [1], and erbium [14]. Rare earth elements have also been shown to have important refinement/modification effects on the size and shape of the Si phase in certain studies. Experiments on three hypereutectic alloys (14.5 percent, 17 percent, and 25 percent Si alloys) under reciprocating sliding conditions revealed that wear resistance was most likely governed by the distribution of silicon particles and aluminum, with the

* *Corresponding author.*
E-mail address: azizi@utm.my

17 percent Si alloy having the best wear resistance [11]. The P and RE complex adjustments refine the rough block primary silicon and modify the big needle eutectic silicon to fine fiber or lamella one. The alloys with 0.08 percent P and 0.60 percent RE added to them have the best microstructure and mechanical characteristics. The primary silicon of alloys can be reduced from 66.4 µm to 23.3 µm, and the eutectic silicon can be reduced from 8.3 µm to 5.2 µm, comparing to the unmodified alloy. Tensile strength has increased from 256 MPa to 306 MPa, and elongation has increased from 0.35 to 0.48 percent [3]. The as-cast microstructure, tensile characteristics, and fracture characteristics of a secondary hypereutectic Al-18%Si-20% Cu alloy are investigated after fast quenching from a partly liquid and solid state. The metallographic link between primary and eutectic silicon showed that primary silicon functioned as a nucleus site for eutectic silicon. The microstructure refinement along with a favorable morphological transition, led in significantly improved tensile characteristics and more ductile fracture behavior in the investigated alloy [2]. It was discovered that adding 1.5 wt.% Gd–Sb to rough dendritic primary Mg_2Si grains resulted in a perfectly truncated octahedral shape with a reduction in average size from 40µm to 12µm and a decrease in aspect ratio from 1.34 to 1.17 [4]. The strength of the alloy can be improved by refining the grains and widening the grain boundaries [9]. Typical star-shaped and irregular morphology present in the primary silicon phase. It is very coarse, and the phase scale also exceeds 120 µm, offers a sample optical micrograph changed by 0.3 wt. percent Nd. Primary silicon morphology improves from star-shaped and irregular morphology to fine polyhedral, reducing primary silicon size to 20-50 µm [10]. Hypereutectic Al–20%Si alloy with rare earth cerium microstructure development and mechanical characteristics (Ce). Tensile tests with various Ce concentrations were used to evaluate mechanical characteristics. The ultimate tensile strength (UTS) and elongation (El) of primary and eutectic Si crystals rose by 68.2% and 53.1%, respectively, as the size of the crystals shrank and the shape changed [7]. Although there is research on the influence of Gd additions in the literature, there are limits to the ability of Gd elements to modify the 18Si phase, particularly on the mechanism and microstructure behavior of Al-18Si composites. The influence of modifiers on microstructural changes of Al–18Si series alloys is thus of considerable interest and significance. As a result, the purpose of this research is to determine the influence of various Gd concentrations on the microstructural development of Al-18Si alloy.

2. Experimental Procedure

2.1 Material Fabrication

Firstly, the ingot was sliced into a smaller piece by using cutter, then washed and dried, measured, and melted using an electrical furnace in a silicon carbide crucible. The melt's temperature was held for 5 minutes at 750 °C to allow complete homogenization of the melt. To eliminate dross and other impurities, the alloys were stirred and skimmed off the surface before casting. Then the molten alloy poured into the pre-heated mold (250 °C) at the temperature of 750 °C.

2.2 Addition of Gd

According to various concentrations and addition sequences, Gadolinium was introduced in solid form to the molten alloy to investigate the interaction of the additional element and its effects on microstructural characteristics and mechanical properties. To specify their optimum concentration, the addition levels were 0.1, 0.3, 0.5, 0.8, 1.0 wt. % Gd. Gadolinium was wrapped in aluminum foil and dipped into the molten to guarantee that it melted well and uniformly throughout the melt. It was then swirled for approximately 30 seconds for improved dissolving. Each addition of material was allowed for homogenization 5 minutes before pouring. The melt was also blended immediately before sample pouring.

2.3 Microstructural Characterization

A cutter machine was used to cut the smaller piece of ingot for microstructure characteristics. Then the samples need to do undergone grinding and polishing process so that the samples will be ready for seeing of silicon grain obvious. In base and Gadolinium added Al-18Si alloys for microstructural measurements and crystallographic studies. Each sample was ground to 4000 grain using emery (SiC) paper and polished with colloidal silica liquid (5 µm). A microscopy (Nikon-MIDROPHOT-FXL) equipped with an ImageJ app analyzer was utilized to perform quantitative study on the microstructure. The average size, and aspect ratio were calculated. Scanning electron microscopy was used to examine microstructures in combination with energy dispersive spectroscopy (EDS).

2.4 Tensile strength

Tensile testing will be performed on the prepared test bars utilizing an Instron Universal Mechanical Testing System (model 5982). Tensile measurements were carried out at room temperature with a crosshead speed of 1 mm/min, and the observed tensile characteristics comprised ultimate tensile strength (UTS), 0.2 percent inset yield strength (YS), and % elongation (percent E). The recorded values are the sum of at least two quantities.

2.5 Hardness

Using a Vickers tester, hardness tests conducted according to the ASTM E10 standard. Samples were finished on the first surface, and at least ten tests were done at random in each piece to achieve an estimate of the exact hardness of the sample.

3. Results and discussion

3.1 Effect of Gd Additions on microstructure characterization of Al-18Si Alloy by optical microscopy

Optical microscopy was utilized to describe the characteristic grain patterns of the Al-18Si alloys utilized in this research to show the effect of Gd additions, as shown in Fig. 1. Silicon particle size and aspect ratio in base alloy are about 42~63 µm and 1.1~1.62, respectively. As shown in Fig. 2. and Fig. 2, the particle size and aspect ratio were significantly decreased as a result of the amount of Gd. In Fig. 1c shown that when measured the grain size and aspect ratio of silicon with addition 0.8% of Gd on the Al-18Si alloy it will be about 17~27 µm and 1.1, respectively. This behavior is fully similar with previous research which found that the rare earth element can reduce the grain size of Al-Si alloy [7]. However, when the content of Gd increases the size and aspect ratio of Si particles increases as well (Fig.1d, Fig.2). This effect may be due to the over modification phenomena for 1% of Gd. A similar reaction was seen when Sb addition reaches 1.0 wt.% in cast Al–12%Si alloys [12].

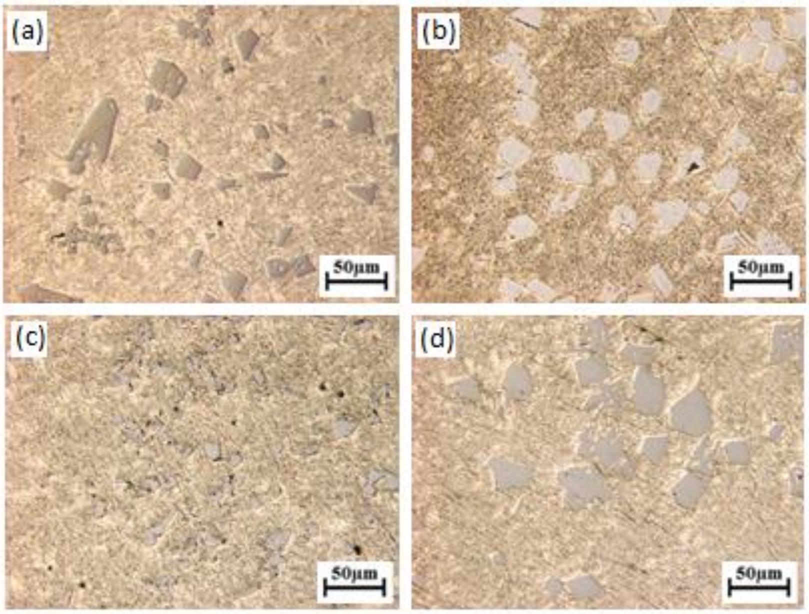


Fig. 1. Optical images of Al-18Si with Gd addition, (a) 0, (b) 0.3, (c) 0.8 and (d) 1.0 wt.% need to insert the optical images

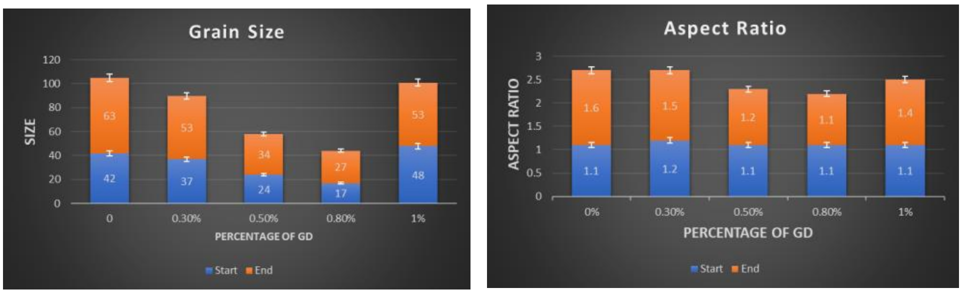


Fig. 2. a) Grain size of silicone. b) Aspect ratio of silicone particles as a result of Gd addition.

3.2 Effect of Gd Additions on microstructure characterization of Al-18Si Alloy by scanning electron microscopy

scanning electron microscopy was utilized to describe the characteristic grain patterns of the Al-18Si alloys utilized in this research to show the effect of Gd additions, as shown in Fig. 3. Silicon particle size and aspect ratio in base alloy are bigger than Al-18Si with addition of Gd and in 0.8% Gd is the smallest grain size, and the shape of grain goes to be more round give good mechanical properties

Journal of Advanced Research in Applied Mechanics
Volume 87, Issue 1 (2021) 1-10

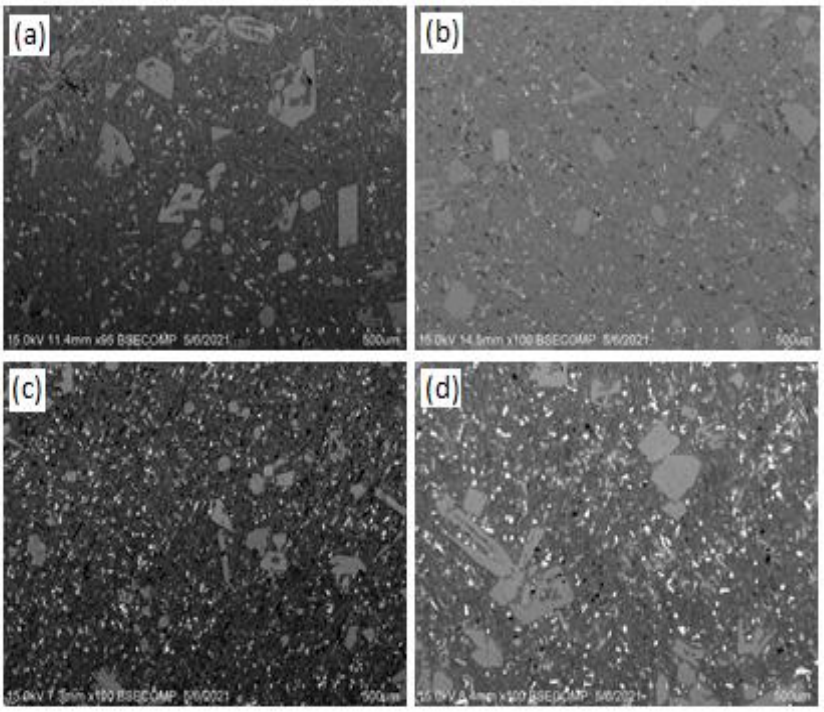


Fig.3 SEM images of Al-18Si with Gd addition, (a) 0, (b) 0.3, (c) 0.8 and (d) 1.0 wt.%

3.3 Elemental Mapping Test

Elemental dot mapping was performed on the Al region in both base and Gd added specimens to ensure that rare earth elements such as Gd are successfully formed with the components Al and Si. It was clearly seen that the Al has covered most of the area followed by the Si due to the high percentage in the alloy, while the other elements are uniformly formed in the scanned area. On the other hand, after the addition of 0.8 wt. % of Gd, it seems that the entire alloying elements of the modified alloy have been uniformly formed along with the formation of Gd element/compounds on the boundaries of dendritic and precipitated inside as well, as shown in Fig. 4.

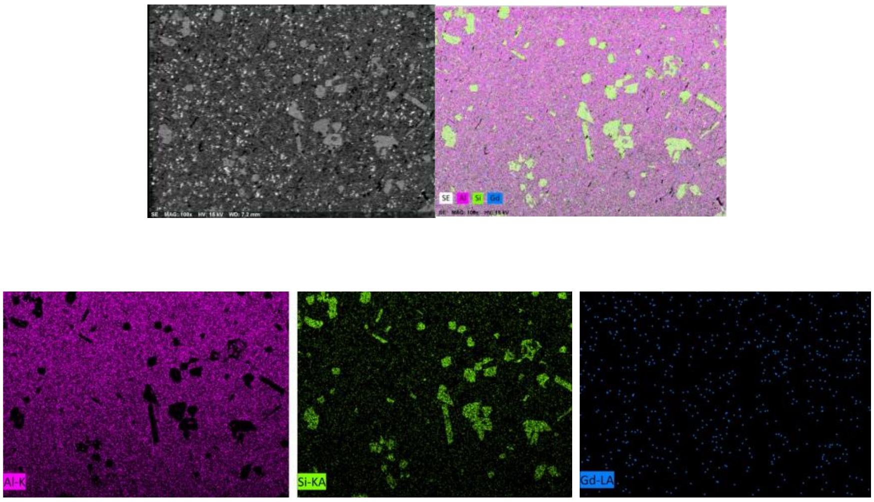


Fig. 4. Elemental dot mapping of modified sample containing 0.8 wt.% Gd

In order to examine these Gd compounds the EDS analysis has been conducted. As can be seen in Fig. from the EDS analysis of Al-18Si alloy with Gd wt. %, they are comprised of Al and Si elements with distinct atomic weight and the EDS analysis of 0.3 percent, 0.8 percent, and 1 percent Gd Al-18Si alloys, which are composed of three components: Al, Si, and Gd elements with various atomic weight. The mass percentage of Gd will increase by adding Gd up to 0.8 % according to EDS analysis, whereas by increasing the percentage of Gd to 1 % of Gd adding the mass percentage of Gd is reduced to 42 % because more Gd is consumed to produce binary Al-Gd and ternary Al-Si-Gd as it detected in XRD analysis (Fig.6).

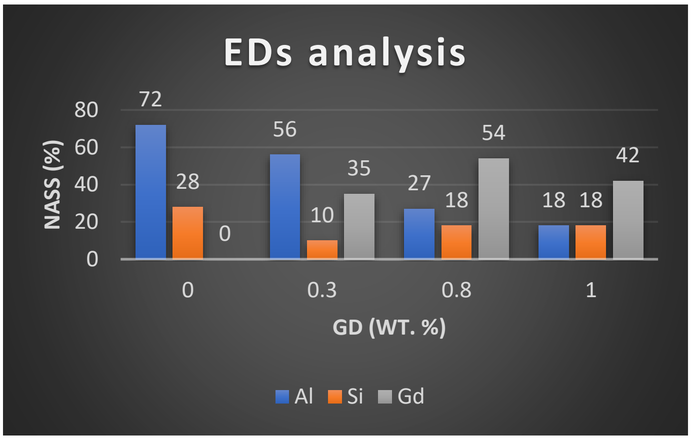


Fig. 5. The EDS analysis of Al-18Si alloy with Gd wt.%

3.4 phase constituents' identification of Al-18Si-x Gd Alloys by XRD

X-ray diffraction was used to describe the development of phases caused by the alteration of Gd in Al-18Si alloy (XRD). The X-ray spectra of the unmodified and modified alloys is shown in Fig. . Al and Si phases were discovered, as well as binary and ternary Al_2Si_2Gd phases. Because to the large volume fraction of all these intermetallic compounds, the patterning peaks of (011), (111), and (200) of these compounds vary based on the quantity of Gd added, with the greatest intensity achieved with the 0.8 wt. percent Gd additions.

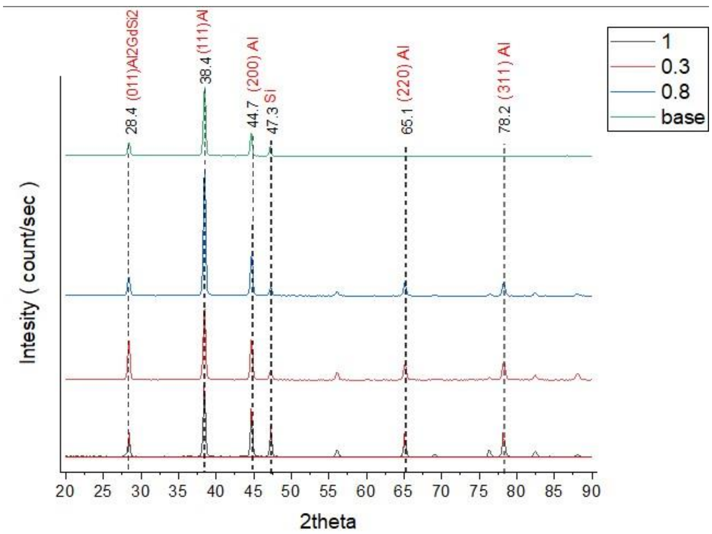


Fig. 6. Various amounts of Gd additions produce different X-ray diffraction patterns

3.5 Effect of Gd Additions on Mechanical Properties of Al-18Si Alloy

3.5.1 Tensile Test

At room temp, Fig. shows the mechanical characteristics of Al18Si alloys with various Gd amounts. The mechanical characteristics of Al18Si alloys are significantly influenced by the adding of Gd. With Gd increase from 0.3 percent to 0.8 percent, both ultimate tensile strength (UTS) and elongation are improved. As a result, the Al-18Si alloy with the adding of 0.8 wt. % has the best mechanical characteristics. For 0.8 percent Gd the UTS and elongation, respectively, are 69 MPa and 14.95 GPa. The mechanical characteristics of the material are reduced as more Gd is added. As a result, the quantity of Gadolinium that may be added to Al18Si alloys must be kept within a reasonable range. The mechanical properties of Al-18Si alloys are well known to be highly dependent on the size and shape of silicon, as well as silicon features. The smaller the particle size, the greater the resistance to deformation, and hence the tensile strength and elongation. (Liu *et al.*, 2017) Gadolinium may efficiently alter the size and morphology of the Al and Si phases, minimizing the effect of their separation from the alloy matrix and enhancing the Al18Si alloy's mechanical characteristics.

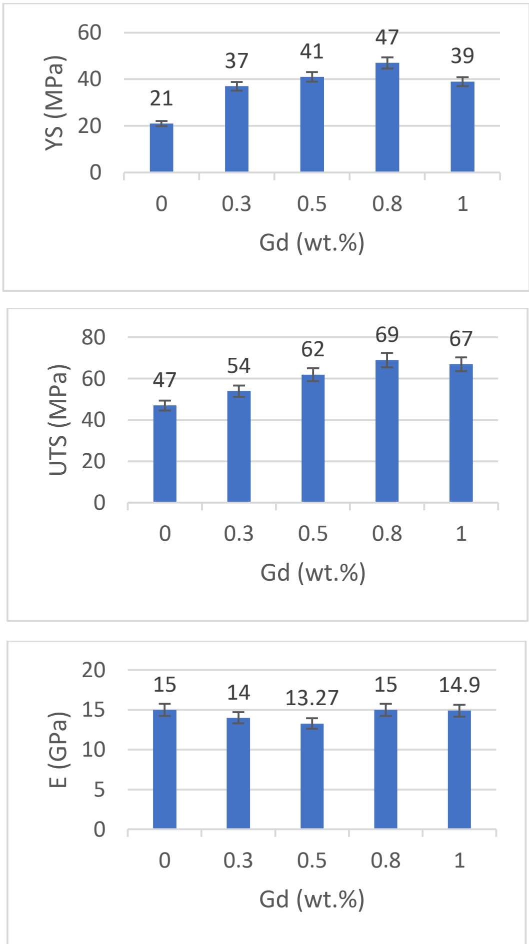


Fig. 7. Tensile test results for base alloys with various amounts of Gd modifications, including YS, UTS, and E.

3.5.2 Hardness test

Fig. 8. shows the Vickers harness results for the base and Gd added alloys of the Ai-18Si. After the adding of Gd, the hardness results improved from 62.95 MPa to 71.3 MPa, reaching their highest amount with the adding of 0.8 % Gd. When an additional 1.0 wt. percent of Gd was applied; therefore, the hardness was decreased to 65.75 MPa. These improvements are mostly due to microstructural changes, such as grain size, and round shape which resulted in the limiting of dislocation movement and therefore improved hardness.

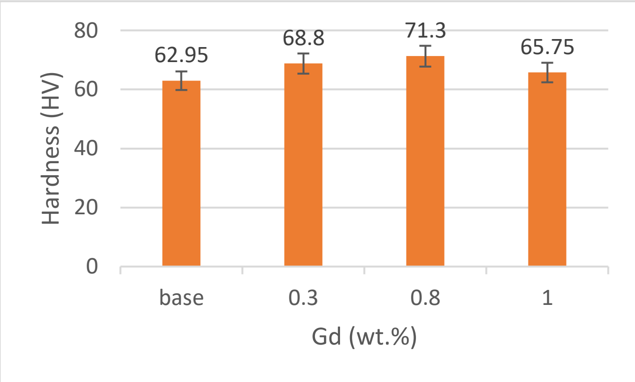


Fig. 8. Hardness test results for base alloys with various amounts of Gd modifications.

4. Conclusions

The follow conclusions are drawn based on the experimental findings drawn:

1- Melt treatment influences the microstructure and mechanical characteristics of Al-18Si cast alloys. Modifying of aluminum alloys with rare earth materials, especially gadolinium, helps to microstructure refining, which is a cause for Al-Si alloys, according to this research.
2- The primary silicon is clearly affected by Gd modifications and the refining influence of Gd on the primary silicon is much more noticeable. With increased Gd amount, the size of primary silicon reduces. The addition of Gd to an Al-18Si alloy may effectively modify the primary Si. Meanwhile, adding up to 1% Gd to Al–18Si alloy may cause particle size to increase.
3- The Al-18Si-0.8 wt. percent Gd alloy, owns greater UTS, Young modulus, elongation, and maximum value These improvements may enhance the service life of the Al-18Si enhanced alloy as compared to unaltered alloy.

Acknowledgement
The authors would like to thank the Ministry of Education Malaysia (MOE), Universiti Teknologi Malaysia (UTM), School of Mechanical Engineering, Faculty of Engineering for providing research facilities and financial support under Grants: Fundamental Research Grant Scheme (FRGS), UTM-High Impact Research (UTM-HIR), UTM-Fundamental Research (UTM-FR) and UTM-Transdisciplinary Research Grant (UTM-TDR) (FRGS/1/2018/TK05/UTM/02/17, R.J130000.7851.5F023, Q.J130000.2424.04G38, Q.J130000.2551.20H66 and Q.J130000.3551.06G66).

References

[1] Aziz, I., Ghandvar, H., Asma Abu Bakar, T. and Chin Yee, C. (2020) 'Effect of praseodymium addition on wear properties of Al-15%Mg2Si composites', *Materials Today: Proceedings*. Elsevier Ltd, (xxxx).

[2] Chaus, A., Marukovich, E. and Sahul, M. (2020) 'Effect of rapid quenching on the solidification microstructure, tensile properties and fracture of secondary hypereutectic al-18%si-2%cu alloy', *Metals*, 10(6), pp. 1–13.

[3] CHEN, C., LIU, Zhong xia, REN, B., WANG, M. xing, WENG, Y. gang and LIU, Zhi yong (2007) 'Influences of complex modification of P and RE on microstructure and mechanical properties of hypereutectic Al-20Si alloy', *Transactions of Nonferrous Metals Society of China (English Edition)*, 17(2), pp. 301–306.

[4] Ghandvar, H., Idris, M. H., Bakar, T. A. A., Nafari, A. and Ahmad, N. (2020) 'Microstructural characterization, solidification characteristics and tensile properties of Al-15%Mg2Si-x(Gd-Sb) in-situ composite', *Journal of Materials Research and Technology*. Korea Institute of Oriental Medicine, 9(3), pp. 3272–3291.

[5] Kumar, V., Mehdi, H. and Kumar, A. (2015) 'Effect of Silicon content on the Mechanical Properties of Aluminum Alloy', *International Research Journal of Engineering and Technology*, 2(4), pp. 1326–1330.

[6] Li, Q., Xia, T., Lan, Y., Li, P. and Fan, L. (2013) 'Effects of rare earth Er addition on microstructure and mechanical properties of hypereutectic Al-20% Si alloy', *Materials Science and Engineering A*. Elsevier, 588, pp. 97–102.

[7] Li, Q., Xia, T., Lan, Y., Zhao, W., Fan, L. and Li, P. (2013) 'Effect of rare earth cerium addition on the microstructure and tensile properties of hypereutectic Al-20%Si alloy', *Journal of Alloys and Compounds*, 562, pp. 25–32.

[8] Liu, W., Xiao, W., Xu, C., Liu, M. and Ma, C. (2017) 'Synergistic effects of Gd and Zr on grain refinement and eutectic Si modification of Al-Si cast alloy', *Materials Science and Engineering A*, 693(March), pp. 93–100.

[9] Ma, P., Wei, Z. J., Jia, Y. D., Zou, C. M., Scudino, S., Prashanth, K. G., Yu, Z. S., Yang, S. L., Li, C. G. and Eckert, J. (2016) 'Effect of high pressure solidification on tensile properties and strengthening mechanisms of Al-20Si', *Journal of Alloys and Compounds*, 688, pp. 88–93.

[10] Shi, W. X., Gao, B., Tu, G. F. and Li, S. W. (2010) 'Effect of Nd on microstructure and wear resistance of hypereutectic Al-20%Si alloy', *Journal of Alloys and Compounds*, 508(2), pp. 480–485.

[11] Torabian, H., Pathak, J. P. and Tiwari, S. N. (1994) 'Wear characteristics of Al-Si alloys', *Wear*, 172(1), pp. 49–58.

[12] Uzun, O., Yilmaz, F., Kölemen, U. and Baman, N. (2011) 'Sb effect on micro structural and mechanical properties of rapidly solidified Al-12Si alloy', *Journal of Alloys and Compounds*, 509(1), pp. 21–26.

[13] Wang, A., Zhang, L. and Xie, J. (2013) 'Effects of cerium and phosphorus on microstructures and properties of hypereutectic Al-21%Si alloy', *Journal of Rare Earths*. The Chinese Society of Rare Earths, 31(5), pp. 522–525.

[14] Xing, P., Gao, B., Zhuang, Y., Liu, K. and Tu, G. (2010) 'Effect of erbium on properties and microstructure of Al-Si eutectic alloy', *Journal of Rare Earths*. The Chinese Society of Rare Earths, 28(6), pp. 927–930.