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Research paper



Mechanical Characterization of Aluminium-Silicon-Titanium Diboride (Al-Si-TiB_2) Reinforced by Scandium (Sc) and Strontium (Sr)

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Abstract

Aluminium based metal matrix composites (MMCs) have better properties and performance. They are commonly used in transport applications which require combinations of high strength and ductility. They are quite attractive due to their low density, capability to be strengthened by precipitation, good corrosion resistance, high thermal and electrical conductivity. Grain refinement plays a crucial role in improving characteristics and properties of aluminium-silicon (Al-Si) alloy. In this investigation, scandium (Sc) and strontium (Sr) elements were added to aluminium-silicon-titanium diboride (Al-Si-TiB_2) alloy for refinement of grains. The compositions of 93 wt.% Al-Si, 6 wt.% TiB_2, 0.5 wt.% Sc and 0.5 wt.% Sr were melted into induction furnace. Then the composites have been characterized on the mechanical properties and microstructure characterization. Instron tensile machine and vickers hardness tester were used to characterize the mechanical properties of the composite alloy. Microstructure and phase composition were characterized by Field Emission Scanning Electron Microscope (FESEM) and X-ray Diffraction (XRD). From the results obtained, addition of Sc and Sr, into Al-S-TiB_2 improved the tensile strength and hardness of composite alloy. Results also showed that the inoculants addition able to enhance the refinement of grains and escalate the values of hardness and tensile strength of Al-Si-TiB_2 composite. Mechanical properties related much on the microstructure as it can be seen that the addition of grain refiners produced much higher value of mechanical properties.

Keywords: *Aluminium-metal matrix composites, Aluminium-silicon-titanium diboride (Al-Si-TiB_2), Scandium, Strontium. Grain refinement, Mechanical characterization,*

1. Introduction

In order to meet the demands of the aerospace, automotive and military industries, the necessity of lightweight and high-performance structural materials has been provided. These MMCs are attractive and viables alternatives to the traditional engineering alloys, with the majority of them having the metallic matrices reinforced with high strength, high modulus and brittle ceramic phase [1].

Huge applications of aluminium (Al) based alloy had been favourable due to its outstanding properties especially by adding grain refiner that will intensify the performance [2]. This MMC usually used Al, magnesium (Mg) and titanium (Ti) as the matrix elements. Reinforcements will be added into the metallic to improve stiffness, strength, wear, creep and fatigue. For the casting technique, this technique able to produce more excellent mechanical properties [3]. Good features of alloy lead to high demands from industries, which can be achieved by producing more ultrafine grain size. This had been done by adding Sc and Sr as the nucleating agents during solidification process to control the morphology changes of the eutectic phase [4]. The changes of morphology were contributing in the enhancement of solidification, lower chances of porosity and decrease the defect formation.

In previous research, researchers found that addition of 6 wt.%TiB_2 that synthesized by in-situ technique exhibit the presence of uniform distribution of reinforcement that tends to be fine and associated with a clean interface with the metallic matrix [5]. The hexagonal morphology with straight and sharp edge were observed. In order to achieve a good mechanical and good performance in wear behavior, it's important to control the Al_3Ti phase formation during the synthesis of in-situ Al-Cu/TiB_2 composites.

Previous study by Ibrahim et. al., [6] found that the microstructure of Al-Si with TiB_2 had much finer microstructure compared to unfine Al-Si alloy. It showed that the eutectic silicon microstructure in Al-Si alloy changed from needle-like or acicular to fine grain size or globular when TiB_2 is added. The mechanical studies showed that the ductility of Al-Si alloy was much lower in the absent of grain refiner, TiB_2. The tensile strength of unrefined Al-Si and Al-Si with 6 wt.%TiB_2 as grain refinement were recorded 275 and 312 MPa respectively. The hardness value for the unrefined Al-Si alloy shows less compared with Al-Si with grain refiner, 6 wt.%TiB_2 which were 74 and 78 Hv respectively. This showed the results were significant improvements in mechanical properties have been obtained with the usage of TiB_2 as a grain refiner to Al-Si alloy.

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The addition of TiB_2 will increase the hardness of Al-based alloy. The increase in hardness will decrease the TiB_2 particle grain size. When TiB_2 content is added to an alloy, the corrosion potential and corrosion current are decreased. Therefore, the addition of TiB_2 has positive factors to the corrosion resistance in Al. This behavior leads to positive factors of TiB_2 addition on the grain size refinement [7].

Generally, this study focused more on the microstructure and phase composition of the alloy, investigated by using FESEM and XRD and also to identify how grain refiner can give affects towards the cast Al-Si alloy. In addition, testing on the hardness and tensile properties also involved by using Vicker Hardness tester and Instron tensile machine.

2. Experimental

Al-Si alloy were firstly undergoing the melting process in induction furnace at 780°C. Then, the inoculants were poured into the melt and stirred constantly at 700°C. At the same time, permanent die, used to form the cast molten metal to a mold, was pre-heated at 250°C. After mixing process, the molten metal was poured into the mold and removed after solidified. Table 1 below shows the composition of alloy and metallic elements according to their contents used in this investigation.

Table 1: Al-Si Alloys and the Composition of Metallic Elements Used

Metallic elements	Contents used (wt.%)
Al-Si	93.0
TiB_2	6.0
Sc	0.5
Sr	0.5

For XRD, samples were cut into (0.5 x 0.5 x 0.1) cm, while FESEM and hardness samples were cut into (2 x 2 x 0.2) cm. Cutting process involved the usage of 95-C1805-400 abrasive cutter machine. Differs with tensile, samples were molded into dumbell shape in the volume of 100 cm^3. Next, XRD samples only experienced coarse grinding process with 120 grit of silicon carbide (SiC) abrasive paper. FESEM and hardness samples were firstly mounted before processes of grinding, polishing and etching. The cold mounting process included the proportion value of 9:1 mixture of hardener and epoxy resin into a plastic mounting ring for about 30 minutes after hardened. Next, surfaces were flatten by coarse and fine grinding process involving the usage of 120, 240, 600, 800, 1000 and 1200 grit of the SiC sand papers. Samples then polished by using 1, 3 and 6 microns of diamond slurry and different abrasive paper for each stage of polishing. Both grinding and polishing process using a grinder-polisher machine. The phase composition and microstructure were then characterized by using XRD and FESEM, while the mechanical properties were characterized by Vicker hardness and Instron tensile testing.

3. Results and Discussion

3.1. XRD characterization

XRD linear patterns are shown in Fig. 1. The diffraction patterns proved that all elements in the composite alloy can be detected. Phase composition analysis is shown by the intensity of the phase of elements in the alloy. It can be seen that at 38°, peak produced, consisted of Al, Si and TiB_2, is the most intense peak of the phase. Meanwhile, other minor elements only displayed small intensity of peaks.

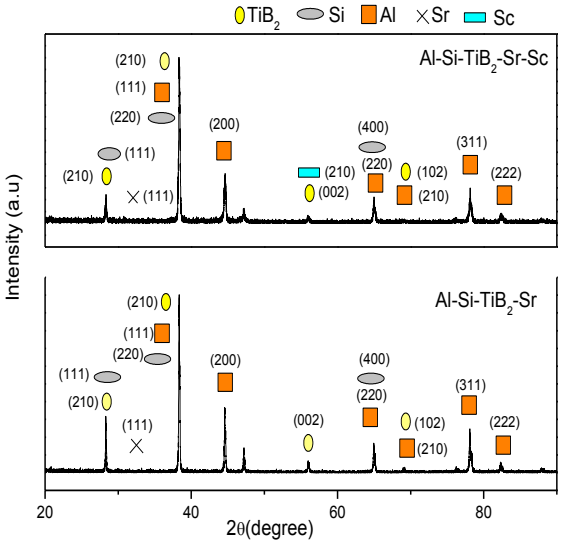


Fig. 1: XRD patterns for Al-Si-TiB_2-Sr-Sc and Al-Si-TiB_2-Sr.

The highest value of intensity defined the highest number of x-ray observed in the peak due to their high proportion value in the composite. Area of peak determined the intensity of the peak. According to the patterns, all elements presented in small-scale area that proved the x-ray photons were diffracted in little amount. The patterns also defined the shape and width of the peaks. Based on the patterns shown, all peaks showed sharp shape and lower width since the diffraction occurred at small value and lower angle. For sample Al-Si-TiB_2-Sr-Sc, the broadest peak is at 38°, which can be claimed that the diffraction occurred had the largest value and highest angle among other peaks.

3.2. FESEM characterization

Micrographs from FESEM characterization are shown in the Fig. 2. The magnifications ranged from 500, 1000 and 7000x. Same spot was focused on each magnification to form clear images. Based on Fig. 2 (a) and (b), the dispersion of the elements existed on each magnification are more difficult to be seen rather than Fig. 2 (c), that showed very clear dispersion between major and minor elements.

Fig. 2 (a): Micrograph of Al-Si-TiB_2-Sc-Sr composites alloy observed by FESEM with 500x magnification.



Fig. 2 (b): Micrograph of Al-Si-TiB_2-Sc-Sr composites alloy observed by FESEM with 1000x magnification.

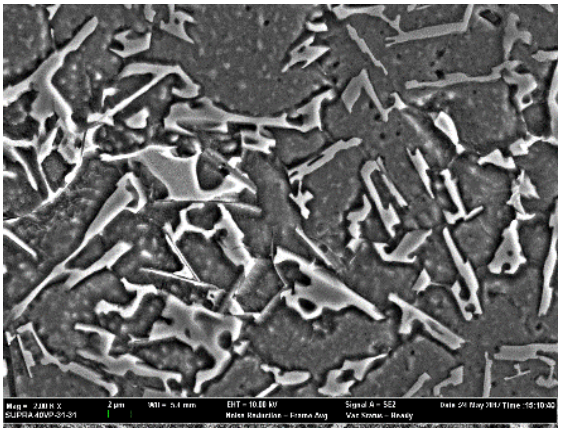


Fig. 2 (c): Micrograph of Al-Si-TiB_2-Sc-Sr composites alloy observed by FESEM with 7000x magnification.

Fig. 3 shows the electron mapping image that produced the details of elements located in the alloy at 500x magnification from EDX analysis. Darker grey phase indicated Al and the lighter grey phase indicated the existence of Si. Both elements produced good contrast indicated their existence as the major elements. Meanwhile, the phase compositions of inoculating agents are proven by using EDX analysis due to the small proportion in the alloy.

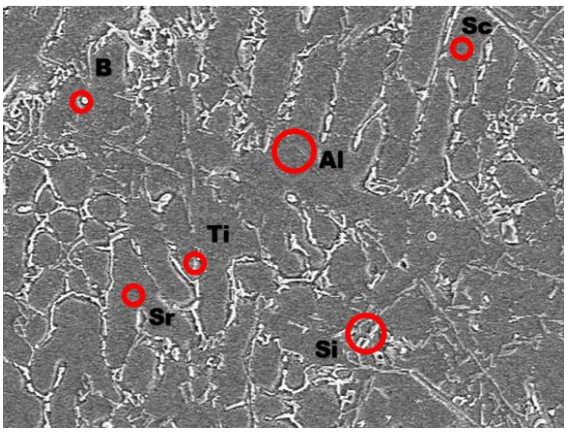


Fig. 3: Electron mapping of Al-Si-TiB_2-Sc-Sr composites alloy with 500x magnification

The existence of pores and scratches during the solidification and sample preparation were directly directed to the mechanical and physical properties of the materials. Based on the Fig. 4 (a) and (b), there are the pores and scratches existed in the microstructure that possibly decrease the mechanical and strengthens value for the materials.

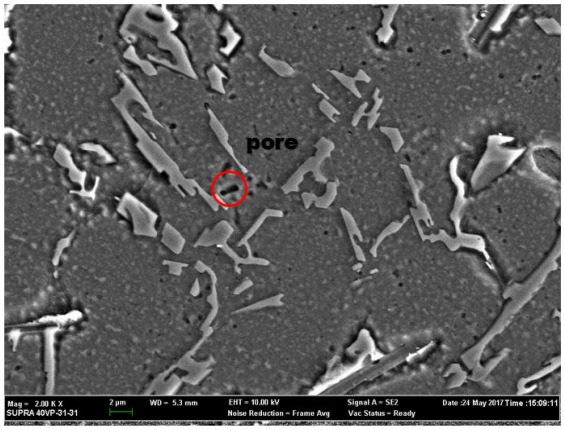


Fig. 4 (a): The existence of pores in Al-Si-TiB_2-Sc-Sr composites alloy.

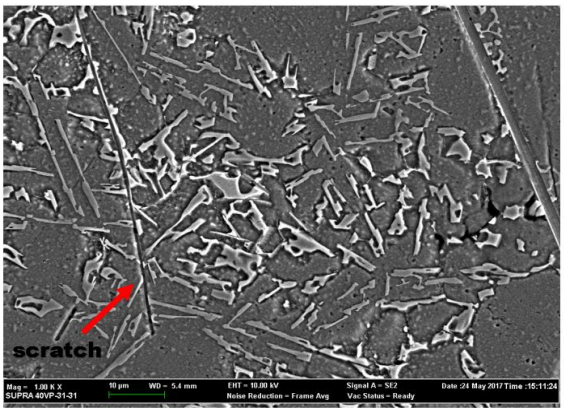


Fig. 4 (b): The existence of scratches in of Al-Si-TiB_2-Sc-Sr composites alloy.

3.3. Tensile strength test

Fig. 5 showed the results of tensile testing between different compositions of alloy by using fixed rate at 2 min/mm. Highest tensile strength is produced by Al-Si-TiB_2-Sr-Sc which is 399 MPa and the Al-Si showed the lowest tensile strength which is 275 MPa. The addition of grain refiners able to produce good effects in the terms of tensile strength due to the reduction of stress concentration that occurred by process of uniforming the distribution of finer second phases.

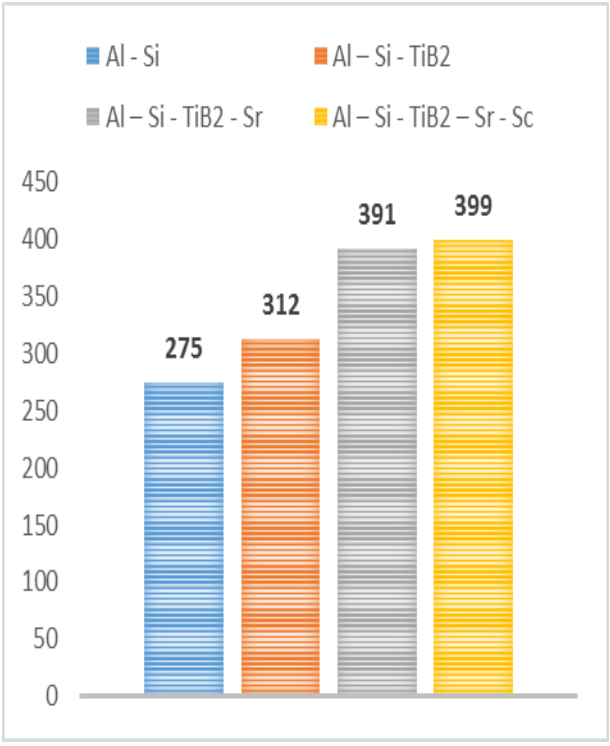


Fig. 5: Tensile strength (MPa) of composites alloy based on different metallic elements contents.

The differences between Al-Si-TiB_2-Sr and Al-Si-TiB_2-Sr-Sc are verified by comparing the microstructures and the tensile strength value of each alloy as shown in Table 1. The micrographs shown are taken from the same 500x magnifications. Alloy with the minor addition of Sc tends to produced more higher in the value of tensile strength since the grain size and crystal structure produced are more refine. Refine microstructure also increase the amount of time taken of the alloy to fracture during the testing due to lower vacancy. Compared with Al-Si-TiB_2-Sr, Al-Si-TiB_2-Sr-Sc had more refine grain size and less vacancies.

Table 2: Tensile strength of Al-Si-TiB_2-Sr and Al-Si-TiB_2-Sr-Sc composites alloy

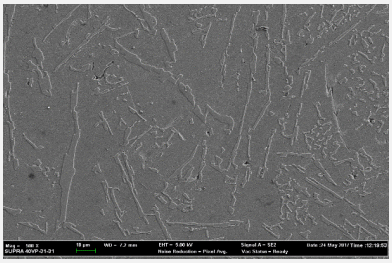
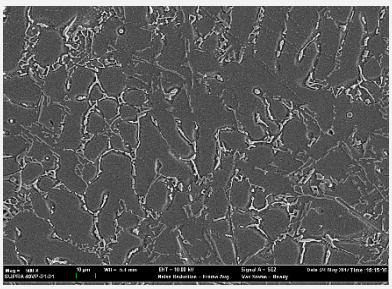
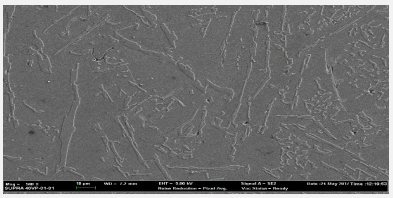
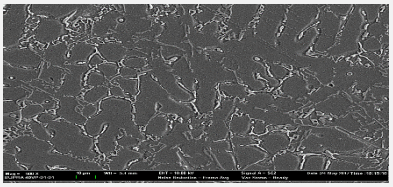
	Microstructure at 500x magnification	Tensile Value
Al-Si-TiB_2-Sr		391 MPa
Al-Si-TiB_2-Sc-Sr		399 MPa

Table 3: Hardness value for Al-Si-TiB_2-Sr and Al-Si-TiB_2-Sr-Sc composites alloy

	Microstructure at 500x magnification	Hardness Value
Al-Si-TiB_2-Sr		83.02 Hv
Al-Si-TiB_2-Sc-Sr		96.30 Hv

3.4. Vickers hardness test

Figure 6 showed the hardness value based on different composition of alloy. It is proven that the addition of grain refiners acted as the main strengthening medium to the alloy. Highest value is been proved by Al-Si-TiB_2-Sc-Sr, which is 96 Hv, while Al-Si alloy showed the lowest value which is 69 Hv. The addition of Sr to Al-Si-TiB_2-Sc tend to increase the mechanical properties by producing smaller indentation compared with other samples with less inoculating elements. Value of hardness related much on the microstructure as it can be seen that the addition of Sc as the grain refiner to the alloy produced much higher value. Compared with Al-Si-TiB_2-Sr, Al-Si-TiB_2-Sr-Sc had more refine grain size and smaller size of dendrites as well as eutectic phase.

The differences between Al-Si-TiB_2-Sr and Al-Si-TiB_2-Sr-Sc composites alloy were verified by comparing the microstructures and the hardness value of each alloy as shown in Table 3. The micrographs shown were taken from the same 500x magnifications. Value of hardness related much on the microstructure as it can be seen that the addition of Sc as the grain refiner to the alloy produced much higher value. Compared with Al-Si-TiB_2-Sr, Al-Si-TiB_2-Sr-Sc had more refine grain size and smaller size of dendrites as well as eutectic phase.

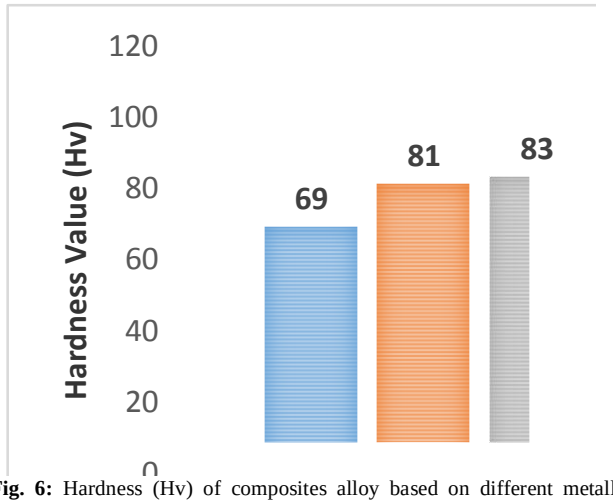


Fig. 6: Hardness (Hv) of composites alloy based on different metallic elements contents.

4. Conclusions

The addition of inoculating elements into the Al based alloy produced more refine and uniform microstructure due to changes of morphology structure. Microstructure characterization using FESEM verified that all elements can be clearly seen. Meanwhile, phase composition analysis by using XRD proved that all major and minor elements existed in the alloy. Addition of Sc and Sr, proved by vickers hardness test, leads to produce higher hardness. Higher strength also been proved by conducting Instron tensile testing. Mechanical properties related much on the microstructure as it can be seen that the addition of grain refiner produced much higher value of mechanical properties.

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