IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. I (Jul. - Aug. 2015), PP 32-38
www.iosrjournals.org

Effect of Strontium and Silicon Carbide on Mechanical Properties of Aluminum Alloy (Lm6)

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Abstract: *A study of the addition different weight percentages of strontium and its influence on the mechanical properties and microstructure of Aluminum LM6 modified by (0.01, 0.02, 0.5) wt% strontium (Sr) was conducted, with the purpose of evaluating the properties of particulate silicon carbide (Sic), as reinforcement as well as the effect of a high Sr content. The obtained results indicated that addition of Al-10Sr improves the UTS and hardness of Aluminum and composite. Moreover, it is observed that adding Sr to the Al–SiC composite increased the amount of α-Al. The mechanical properties of the composite can be related to the volume fraction of dendritic α-Al, which can improve the mechanical properties of Aluminum or Al-Sic composite. it is concluded that the tensile for the composite did not increase dramatically because of weak interface between particles and matrix decrease the UTS, on the other hand strong interface between particles or fibers in the matrix show high stiffness and strength but typically a low resistance to fracture. Before tensile testing, heat treatment should apply to the samples to increase the ductility and ultimately UTS. In this research, a scanning electron microscope equipped with EDS is used to define the modification effects on microstructure and as result, on mechanical properties.*
Keywords- *AL-SiC composite; Stir casting; Sand casting; Modifier; LM6.*

I. Introduction

Aluminum matrix composites reinforced with silicon carbide particles are expected to find many applications in the automobile and electronic industries. In addition, it was found that Al-SiC composite materials have a distinctive set of material characterizations, which are appropriate for all electronic industrial usage that requires thermal management, It is often used for Advanced Microelectronic Packaging [1,6]. Furthermore, it is included that reinforcing Aluminum alloys with discontinuous second-phase particles offers high strength, high modulus, greater wear resistance and desirable thermal expansion. Nowadays, Aluminum-Silicon alloys are typically used in the electronic and different industries due to their good casting ability, lightweight, brilliant corrosion resistance, and lower coefficient of thermal expansion. Although in recent years, the development of lightweight aluminum alloys has improved, their properties still cannot encounter with the requirements of productive application. Hence, it is well known Strontium as an alloy modifier is a usefull method of refining grain size microstructure and reducing LM6 porosity of improving formability for composites. Strontium is reportedly effective and can positively influence porosity formation, but has lower effect on reducing the amount of visible porosity on samples [2,3].

It has been reported by some researchers that multi-axis surface stiffness in MMCs reduces the ductility of the Aluminum matrix. There is an optimum amount of added particles to fabricate composites by increasing 10 to 15% SiC in aluminum. Furthermore by adding strontium it should be mentioned that the tensile properties of the composite has to be increased [4]. Effective reinforcement needs good bonding of the filler and matrix, principally for short fibers. Chemical bonding, inter-diffusion, van der Waals bonding, and mechanical joining are interface mechanisms referred to as filler–matrix bonding. The concentration of chemical bonds may be enhanced in several ways: (i) chemical treatment of the filler, (ii) consuming an appropriate sizing (coating) on the filler particles or fibers, and (iii) applying a molecular coupling agent. Among the consequences of weak interfaces is lower stiffness, hardness and strength but higher resistance to fracture. On the other hand, a strong interface between particles or fibers in the matrix exhibits high stiffness and strength but typically low resistance to fracture, i.e., the features of the interface affect the brittle behavior, resistance to creep, and fatigue [5,10]. Good wettability between matrix and particles also increases the tensile strength of composites [8].

II. Experimental

The materials in this experiment are defined below:

Aluminium-11.8% silicon alloy (LM6) is used as the matrix for the MMC. The chemical composition of the alloy is given in Table1. LM6 alloy is basically a hypoeutectic Al-Si alloy (naturally containing 11.5 wt% Si and less than 12.6 wt% Si of the eutectic composition) with little copper content (<0.1 wt%).

LM6 (aluminum casting alloy) was melted at 700°C in an electrical induction furnace. The exact amount of Aluminum can be defined based on the capacity of each pattern and mold. It takes around 1 hour to completely melt LM6 inside the furnace. after melting temperature reached 740 ℃ roughly, the Al-10Sr alloys (0.01%, 0.02% and 0.5%), were added to the melt.

It is important to note that Strontium was not pure in this experiment. For the first and second experiments, the Strontium was held for 10 min, and for the third experiment, it was held for 15 min in the melt. After that the melt was poured into a a ladle and then into a sand mold. The sand consisted of silica sand, sodium silicate, calcium and water, which was mixed in a mixer. The pouring temperature was below 650°C but still above the melting temperature [7].

Table 1.The chemical composition of LM6

Cu	Mg	Si	Fe	Mn	Ni	Zn	Lead	Tin	Others	Al
0.1	0.1	1	0.6	0.5	0.1	0.1	0.1	0.05	0.2	85.95

II.1 composite prepration

The LM6 aluminum casting alloy was melted at 750°C in the electrical induction furnace. 10 wt% Silicon carbide was preheated at 800°C for 1 hour to eliminate moisture and gas from the surface of the particulates. The Sic powder was poured into metal cups, in which it was kept for 1 hour inside the muffle furnace. The muffle furnace is JELRUS Temp-Master brand with maximum temperature of 1000°C. In this research, 800°C was selected for 1 hour. Subsequently, the furnace was opened carefully; the particles were poured into the melted Aluminum and mixed.

The main challenge with MMC fabrication is to acquire homogenous dispersion of the ceramic particles by applying low-cost equipment for commercial applications. A stir casting setup consisting of an induction furnace and stainless steel mixer assembly was employed to synthesize the metal matrix composite. The vortex method is a cost-effective approach used for particle distribution in molten metal, as the particles mix homogenously through the matrix.

III. Result And Discussion

III. 1 Hardness Test

The central part of each sample was prepared. The surface of each one was polished to eliminate coarseness in preparation for hardness testing. The hardness was tested with a Rockwell Hardness tester. The device used for this experiment is MITITOYO ATK-600. The ball indenter was 1/16 inches in diameter and the total load selected was 15 kgf. The tests were carried out on 5 different, random areas on each sample surface, and then the average was calculated for each sample. The Rockwell hardness number was obtained by calculating the average of the obtained data is shown in Fig 1. The best result is obtained by adding 0.5 wt% Al-10Sr and 10 wt % Sic to Aluminum.In Table 2 Hardness of Al by various amount of Sr and Sic is given. The mixer assembly contained a stirrer, which was attached to an adjustable speed vertical motor of maximum 400 rpm by means of a shaft. After mixing 10% Sic with Aluminum, 0.02 and 0.5 wt% Sr was added to the molten LM6 inside the furnace. Strontium remained in the molten Aluminum for 10 and 15 min respectively. The speed of the stirrer was slowly raised from 100 to 400 rpm and the preheated reinforced particles were added to the molten metal. After adding the reinforcement, the materials were continuously stirred for 3-4 minutes so the prepared particles would mix adequately in the matrix.

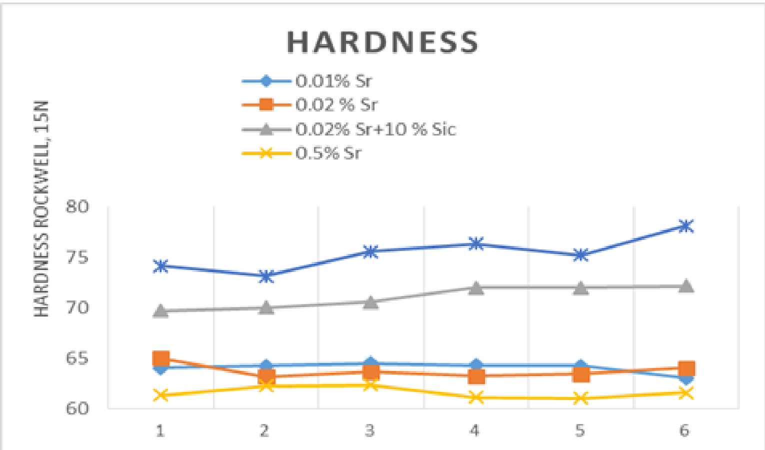


Fig. 1 Hardness test result by Rockwell

Table 2 Hardness of Al by various amount of Sr

Number	Sample	Hardness
1	Al-0.01 % Sr	64.03
2	Al-0.02 % Sr	63.71
3	Al-0.5% Sr	61.59
4	Al-10% Sic+0.02 Sr	71.05
5	Al-10% Sic+0.5 Sr	75.41

III.2 Ultimate Tensile Testing Strength

Tensile testing was done with INSTRON 3382 equipped with a digital controller. The dimensions of each sample should be defined before testing and then be input into the device. All samples were labeled and their widths and thicknesses measured. Software was connected to the device to measure the stress and strain data until the samples fractured. The speed used for this experiment was 1 mm/min. Although UTS prediction can be very complicated in some cases when producing composites. Figure 2 shows that the highest UTS was for Al with 0.5% Sr [11]. It is observed that the composite's UTS not improved. The strong interface between particles or fibers in the matrix shows high stiffness and strength but typically low resistance to fracture

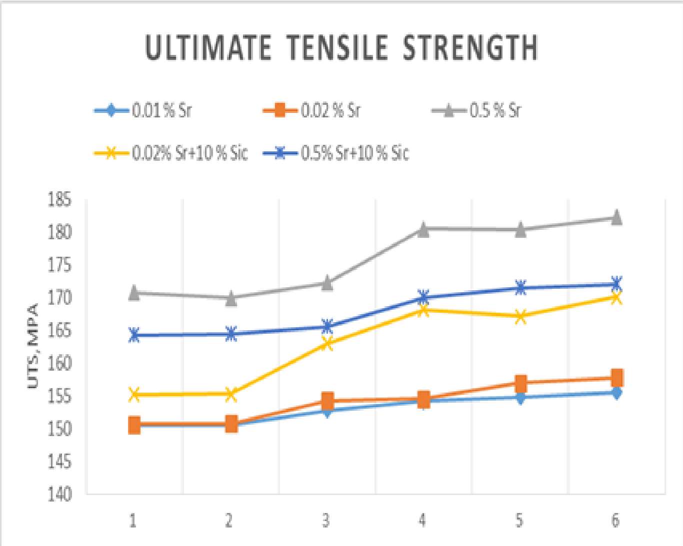


Fig 2. UTS with various amount of Sr, SiC

Table 3.UTS with various amount of Sr,SiC

Number	Sample	UTS (Mpa)
1	Al-0.01 % Sr	153.09
2	Al-0.02 % Sr	154.165
3	Al-0.5% Sr	175.96
4	Al-10% Sic+0.02Sr	163.15
5	Al-10% Sic+0.5 Sr	167.94

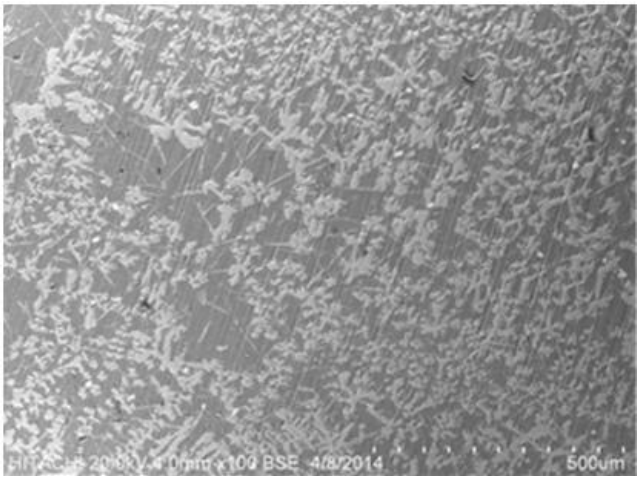
III.3 Microstructure Analysis

Samples of the metal matrix composite and aluminum LM6 were prepared for metallographic examination. A sample size of 10x10 mm was cut from each section. Abrasive paper of 320, 400, 600, 800, and 1200 grit was used for sample preparation using a machine. The samples were then polished using the same machine. For grinding, as well as coarse polishing and finally fine polishing, Buehler suspension with 0.05 micron fineness was used. The available machine was Hitachi S-3400. The microstructure of casted LM6 was tested at different locations on the sample surfaces.

The eutectic phase of unmodified Al-Si alloy contains a silicon phase with rod-angular and flake-like morphology, which causes poor ductility and brittleness. As mentioned before, modification was done to change the form of the silicon phase from flaky to fibrous.

Generally, modification can be attained by quick solidification (quench solidification) or chemical modification. Small quantities of strontium can transform the morphology of the eutectic silicon phase existing in Al–Si casting alloys from coarse plate-like to fine fibrous networks.

It is observed that adding Sr to Al–SiC composite increases the amount of α-Al. The mechanical properties of the composite are related to the volume fraction of dendritic α-Al, which can improve the mechanical properties of Aluminum or Al-Sic composite [9]. Al4C3 was also produced at the interface between the Sic and Aluminum matrix. Figure 3(a) shows the composite microstructure consisting of three main phases: Aluminum, eutectic phase-Si and Al4C3. The Al4C3 composition is not desirable for several reasons. It clearly damages reinforcement, and Al4C3 may also be at risk of corrosion and it could be accompanied by a rise in Si levels. An alternative method of restricting the reaction is surface treatment, which would also favorably improve wettability and ductility.



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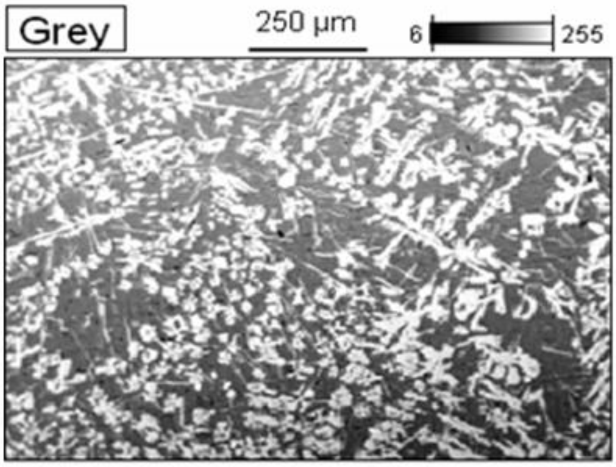

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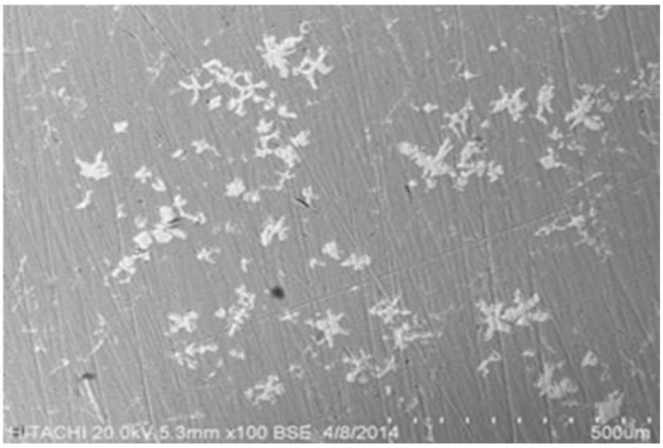
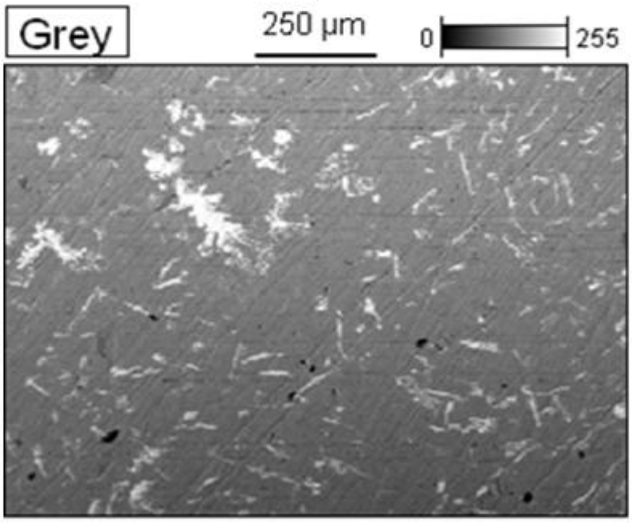
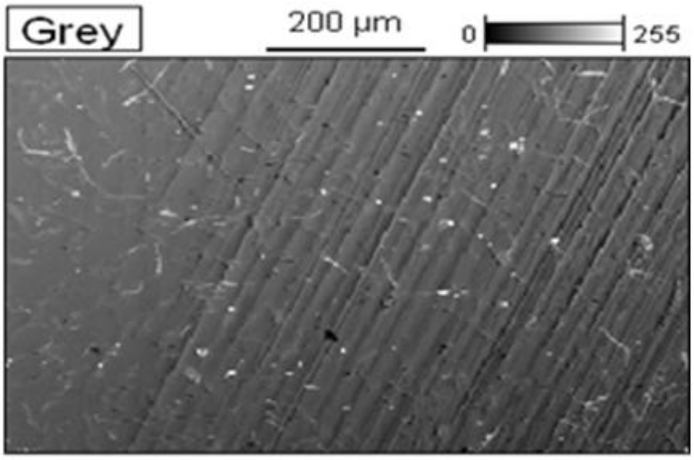


b)



b-1)



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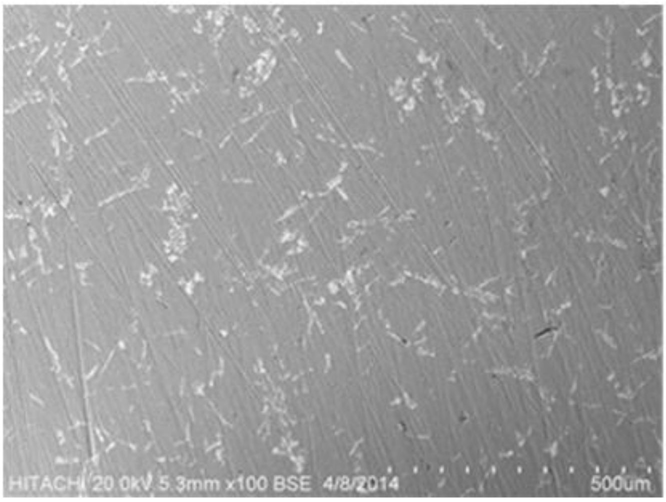

D

Fig 3. a,a-1) Al-10wt % Sic-0.5wt % Sr, b,b-2) Al-10wt % Sic-0.02wt % Sr , c)Al-0.02wt % Sr, d) Al-0.5% Sr

III.4 EDS (Energy Dispersive Spectroscopy)

In Figure 4 it is shown that the Sr component is obviously not detected among the other chemical components .The spectrum of Sr-modified LM6 is similar for samples of Aluminum modified with different amounts of Sr due to the similar amounts of chemical present. In Tables 4, the oxygen content shows significant variation; however, the weight percentage of Al was decreased compare to LM6. on the other hand, the Al-0.02% Sr has a highest amount of silicon detected by EDS on the surface. it is included that this may because of higher silicon was precipitated in the eutectic Si phase because of more area of eutectic solidification.

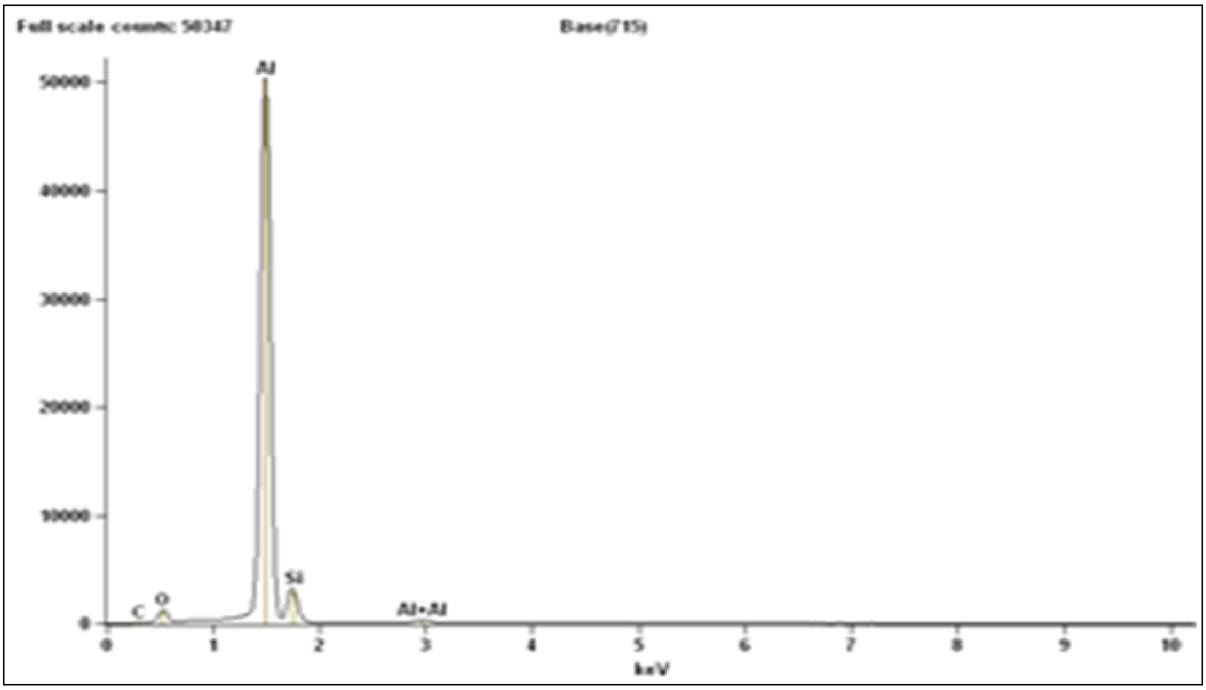

Fig.4 Chemical composition Al-0.01%Sr

Table 4. Quantitative of Chemical composition

Element Line	Al-0.01%Sr	Al-0.02% Sr	Al-0.5% Sr	Al-0.02%Sr-10%SiC	Al,LM6
	Weight %	Weight %	Weight %	Weight %	Weight %
C K	7.43	7.33	6.68	6.31	4.16
O K	13.30	2.90	7.33	5.47	3.24
Al K	69.52	74.20	75.66	75.21	82.05
Si K	9.75	15.56	9.60	13.00	9.40
Si L	---	---	---	---	---
Total	100.00	100.00	100.00	100.00	100.00

IV. Conclusion

The following conclusions can be drawn from the experimental results:

- The microstructure of the Aluminum has been changed dramatically by adding Al-10Sr. By increasing the amount of Al-10 Sr white blobs of primary alpha dendrites, surrounded by a fine, fibrous eutectic mixture of alpha and Si increased. Modification treatment altered the Silicon morphology from a needle-like structure to a fibrous structure, which enhanced the mechanical properties.
- The best result for hardness is obtained by adding 0.5 wt% Al-10Sr and 10 wt % Sic to Aluminum by vortex method. The microstructure modification can be reason which effect on improving the hardness of composite. Addition of Al-10Sr improves the hardness of Aluminum. The maximum amount of hardness is gained by adding 0.5 wt % of Al-10Sr modifier

- The UTS of Aluminum increased by adding SiC and Sr as well as hardness. the Maximum amount was 175.96 for LM6. It is evident that the composite's tensile strength did not increase dramatically. Thus, it is concluded that the weak interface between the particles and matrix decreased the UTS. Nonetheless, the strong interface between particles or fibers in the matrix demonstrated high stiffness and strength but low resistance to fracture. Prior to tensile testing, heat treatment should be applied to the samples to increase ductility and ultimately UTS.

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