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COMPARISON OF THE MECHANICAL CHARACTERISTICS OF ALUMINIUM SIC COMPOSITES CAST IN SAND AND METAL MOULDS

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ABSTRACT

The consequence of sand and metal moulds on mechanical and microstructural characteristics of Aluminium Silicon Carbide (AlSiC) composite were studied. The composite material was prepared using a liquid-metallurgical technique via stir casting process. The aluminium ingot was melted in a tilting furnace of 5kg for 45 minutes at a temperature of 750ºC. Then 2.5% of silicon carbide (600 grit size) was added to the liquid metal, and to obtain homogeneous dispersion of silicon carbide, two stepwise mixing methods; mechanical and stir processes were applied. Then cast into sand and metal cast moulds respectively which were prepared earlier. The process was repeated for the other percentages of 5%, 7.5% and 10% for silicon carbide. The cast samples were allowed to be solidified and then machined into tensile, hardness and impact specimens according to their specifications. The results of the tests show that for materials which require high impact strength, metal cast process seems to be the best option to be used while for materials that require high hardness resistance, high modulus and high yield strength, the sand cast process should be used.

Key words: Aluminium, Sand Mould, Metal Mould, SiC reinforced, Grain diameter, Mechanical Properties, Stir casting

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1. INTRODUCTION

Composites, are novelty materials containing at least two dissimilar proposed materials (metal, ceramic, plastic) that gives enhanced properties or reduced cost than that of the inherent materials alone [1]. Composites can be grouped using the dominant constituent called the matrix material, which eventually encapsulate other material(s) referred to as reinforcing agents. In these categories, we have polymer-matrix composites (PMCs), intermetallic-matrix composites (IMCs), ceramic-matrix composites (CMCs), metal-matrix composites (MMCs) and carbon-carbon composites (CCCs), encompassing similar basic material for both matrix and reinforcement. Carbon-carbon composites are also called graphite-graphite composites. For all these, the most matured and broadly used of the composites is metal-matrix composites. The MMCs with excellent good stiffness-to-weight and strength-to-weight ratios, superior dimensional stability, abrasion resistance, thermal conductivity, and creep resistance will find application in the aerospace, automobile, mechatronics components (such as a sensor) and other engineering outfits [2].

In this work, Aluminium Matrix Composites (AMCs) was used. It consists of a ceramic material (Silicon Carbide) embedded in aluminium matrix which gives improved properties over base aluminium metal [3]. The aluminium matrix composite processing route can be such as centrifugal casting, compocasting, stir casting, infiltration, pressure die infiltration, gas pressure infiltration, powder metallurgy, co-spray deposition process, vacuum hot pressing, and squeeze casting. This work chose stir casting method because it is not complex, can be commercialised and manufacturing variables could be easily adjusted and evaluated [4-6]. Inegbenebor et al. [3], in their work, reported various parameters that require considerable attention when using stir casting technique which can lead to sound castings. For many years, production of sound castings has been largely a matter of trial and error. In this process, a few general principles of casting which had been well recognized, such as gating, feeding and chilling into the moulds are carefully handled.

In casting operations, metal and sand moulds are the most widely used containment for the liquid melt. Quick solidification of the melt as a result of excellent heat dissipation property of the mould is best achieved with the metal mould. This also help to produce homogenous dendritic cells in the cast components. Such components demonstrate better ductility property than sand moulds [7, 8].

The aim of this work is to compare the mechanical properties of Aluminium Silicon Carbide composites cast in sand and metal moulds.

2. MATERIALS AND METHODS

2.1. Materials preparation

In developing aluminium matrix composite (AMC), a liquid metallurgy route tagged stir casting was adopted. Commercially pure aluminium (99.66%) was fortified with silicon carbide particle with an average diameter of 9µm (600 grit). Table 1 and 2 show elemental constituents of aluminium and silicon carbide respectively. For the stir casting process, oil fired-tilting furnace (Figure 1) with graphite crucible was used to melt 2.0 kg of aluminium to 750^{o}C and then introduced preheated silicon carbide (2.5 vol. wt.%) particles with simultaneous mixing. Mixing was done using motorised impeller at 500 RPM for about 5 minutes [9]. The liquid metallurgy route (stir casting technique) was adopted to prepare the cast composites as described [9]. The melt was poured into both the metal and sand mould for solidification. This experiment was repeated for SiC particles of 5.0, 7.5 and 10.0 vol.wt.%.

The sand mould was prepared using coal sand, bentonite and silica sand which are mixed together with a small amount of water. The drag and pattern were placed on a surface and the sand is rammed into the drag. The drag is then rolled over, the cope placed over it and more sand is rammed into the cope after which the pattern is withdrawn. A gate was then cut in the drag. In doing these, a few general principles of casting which are gating, feeding and chilling were well taken into account for the experiment. The molten material was poured in and allowed to cool. On the other hand, the metal mould was prepared to specification in the machine shop using cast iron.

In this work, twenty-four (24) AlSiC composites were developed through sand cast and metal cast. The specimens were divided into groups A, B, C and D due to different percentage volume of silicon carbide (Table 3) and further subdivided into 1 and 2 under each group, 1 represents sand cast and 2, metal cast. The size of silicon carbide powder used is 600 grit (9µm).

Table 1: Composition of Aluminium (Al) metal

ELEMENT	% COMPOSITION
Si	0.083
Fe	0.295
Cu	<0.0002
Mn	0.0031
Mg	0.0021
Cr	0.0016
Ni	0.0039
Zn	0.0023
Ag	0.0001
Ti	0.0073
B	0.0008
Bi	<0.0010
Be	0.0004
Ca	0.0008
Co	0.0005
Li	<0.0001
Cd	0.0005
Na	0.0005
Zr	0.0022
Sr	<0.0001
V	0.0091
Sn	<0.0010
Pb	0.0022
P	0.0052
Al	99.6

Table 2: Elemental Composition of Silicon Carbide

C	Al	Fe	Si	SiO_2	Magnetic Iron	SiC
0.50	0.30	0.20	0.80	0.60	0.04	97.6

A brief description of the AMC materials is shown in the table below:

Table 3: Specimens and their percentage constituents

Specimen	Particle Size	SiC Content (%)	Al Content (%)
A	600 grit	2.5	97.5
B		5.0	95.0
C		7.5	92.5
D		10.0	90.0

Table 4: The volume fraction percentage of silicon carbide subdivided into 1 and 2 according to mould media of castings

S/N	Specimen number	Volume fraction percentage of silicon carbide	Mould	
			Sand	Metal
1	A	2.5	1	2
2	B	5.0	1	2
3	C	7.5	1	2
4	D	10.0	1	2

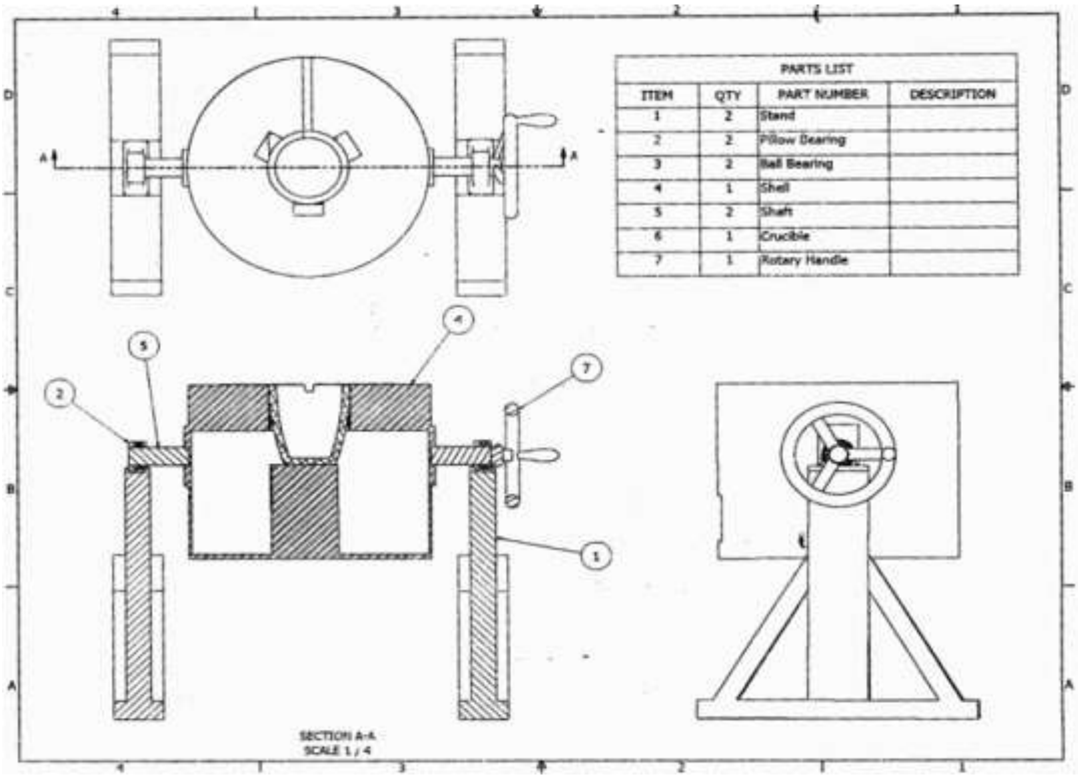


Figure 1. Orthographic projection of the tilting furnace [10] after Babalola et al.

2.2. Tensile test

After a successful preparation of the specimen on lathe machine to have dimension of 5 mm x 10 mm with a gauge length of 25 mm, Instron universal testing machine (Model 3369) was used for the tensile test. 30kN load was used (ASTM International E8/E8M-09). This machine generated electronic results and graphs of mechanical properties (such as modulus, maximum stress, strain at break point, yield point, energy at break point, elongation and so on) for each of the material samples.

2.3. Impact test

Impact test value is an indication of material opposition to abruptly applied force such as falling object, instantaneous blow and collision. The test measures the impact energy, or the energy withstand before fracture according to ASTM E23 standard. Izod (Cantilever-Beam) impact test specimen, type D dimensions were 70mm x 10mm x 10mm with a notch at 28mm from the edge. The angle and depth of notch were 45^{o} and 2mm respectively. The samples of eight (8) were produced for both sand and metal cast.

2.4. Hardness test

Specimen for hardness test were foremost grinded with emery papers down to 1000 mesh before hardness characterization. This was done with the use of LECO 700AT micro-hardness tester of 492.3 mN and a dwell time of 10 s [11]. Hardness values were obtained from average of six readings on each specimen.

2.5. Metallographic studies

Grinding, polishing and etching were the processes involved in the preparation of the specimens for metallographic examination. Overheating of the grinding process was mitigated by continuous removal of the grits using running water. Thereafter, a universal polishing machine was employed for the polishing process and the polished surface was etched in 2% NaOH after which it was viewed under an Accuscope microscope with an integral camera.

The MagniSci software was used to analyze the micrograph images obtained from the microscope. The values obtained using this software are the average grain size and the average grain diameter. The average grain diameter has been stated to determine the yield strength of the microstructure, in which the smaller the grain diameter, the better the tensile strength and yield strength of the sample [12].

3. RESULTS AND DISCUSSION

The mechanical properties of both metal and sand cast of AlSiC composites with powder particles 9µm (600 grit) are shown in Figure 2-4. To assess the effects of the mould media on the mechanical properties of AlSiC produced, twenty-four (24) specimens were divided into groups A, B, C, and D according to the percentage volume fraction of silicon carbide (Table 3). These were further subdivided into 1 and 2 (see Table 4) for the sand and metal casting moulds respectively.

The comparison results of mechanical properties in Figures 2 and 3 showed that for materials which required high modulus, yield strength and hardness, sand casting process should be considered. While for materials that required high impact strength metal casting is the best option.

The measured modulus, yield strength and hardness properties on the samples for sand cast samples have higher values than the metal cast samples. This may be due to the fast dissipation of heat in metal mould hence acting as ‘quenching’ medium when compared to sand mould. A sand mould is a ceramic composite that readily reduces the rate of heat dissipation since it is a bad conductor of heat. This observation could have aided the differences in the values of the properties obtained in the two castings. Also, probably when this happens, it may not help the tightness of the bond between the matrix and particles which could add to the reduction of toughness result observed between the sand and metal.

Mae et al. [7] in their work also observed that the sand-moulding part has greater hardening rate and yield resistance than the metal-moulding counterpart. Their result is in consonance with the recorded result by another investigator [13].

The result of impact test shows in Figure 4, is unlike modulus, yield strength and hardness properties where metal casting samples were lowest in values. However, the measured impact strength for metal cast samples has higher values than the sand cast. The reason for the observation of the metal castings of impact strength to be higher than sand casting may be due to high cooling rates.

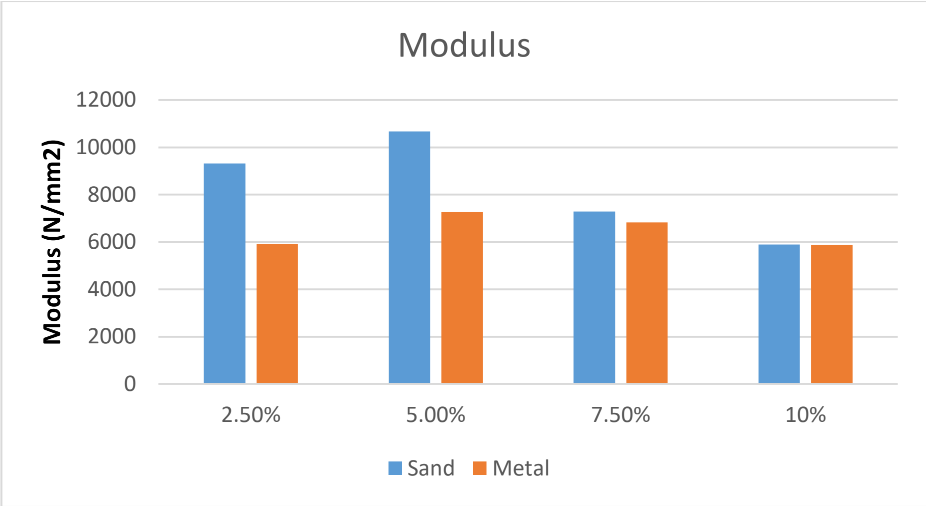


Figure 2. Graph of modulus

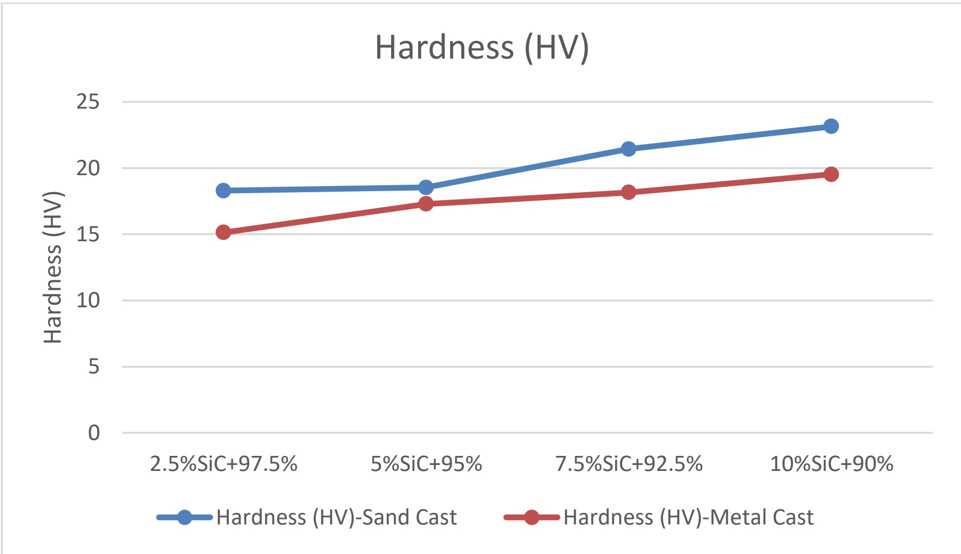


Figure 3. Graph of hardness

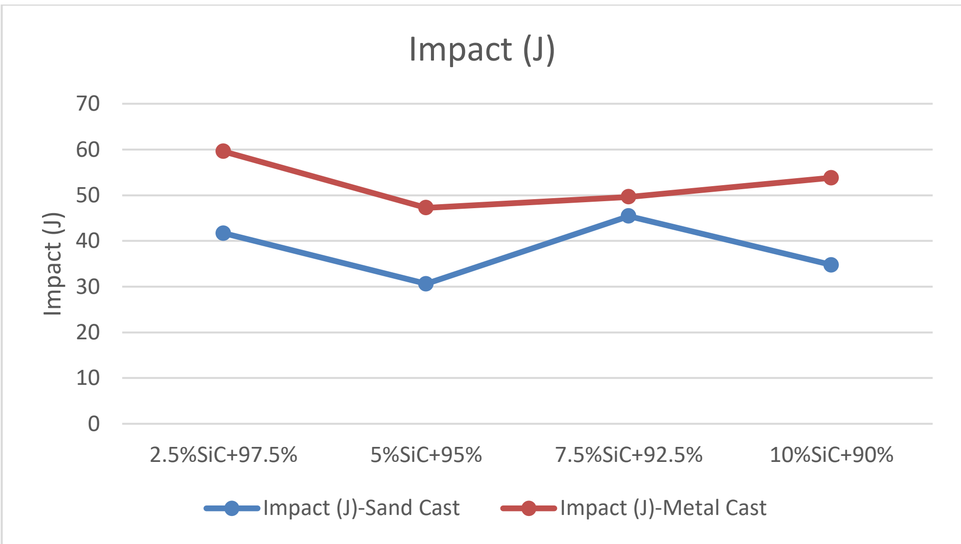


Figure 4. Graph of impact strength

3.1. Microscopic observations

Metallographic inspections were conducted on the metal and sand moulded aluminium silicon carbide composite casting. Images obtained from these tests were analysed with MagniSci software so as to assess the impact of the mould media on the microstructure of the castings. The typical microstructures of the sand-cast of AlSiC composite alloy are shown in Figures 5,7,9 and 11. As we can see in these figures, the sand-cast AlSiC alloy have equiaxed grain structures with an average grain diameter (µm) as indicated in Table 5. In the same vein, metallographic results reveal bigger grain in metal casting processes, as in Figures 6,8,10, and 12. These bigger grains invariably affected the mechanical characteristics of the metal cast composites.

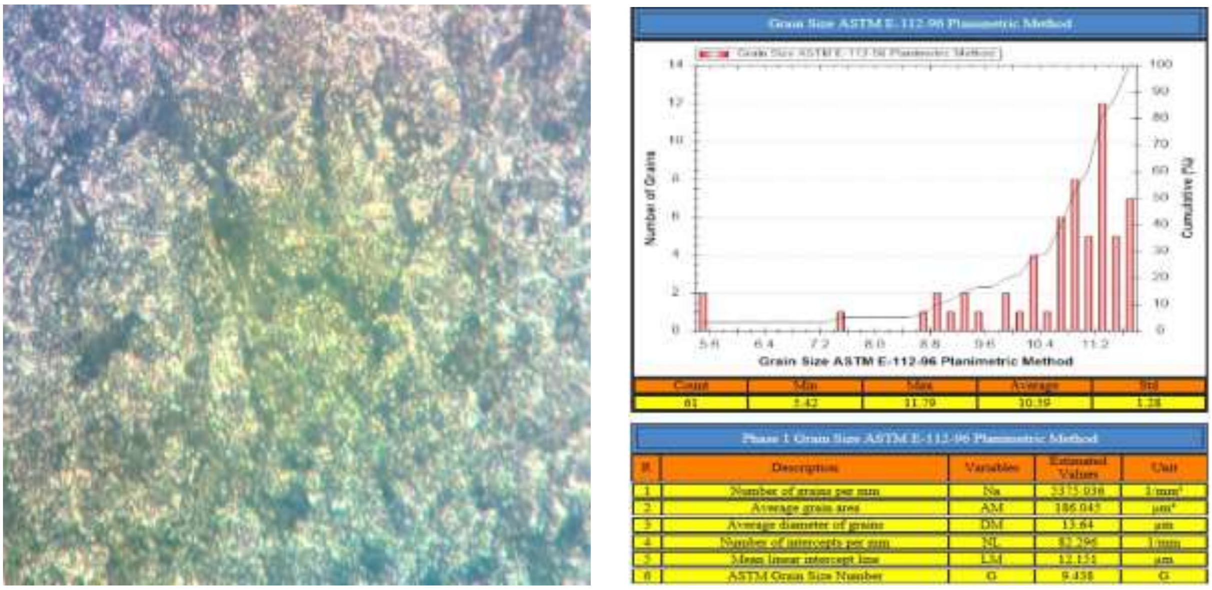


Figure 5 Micrograph of Al/SiC/2.5p sand cast

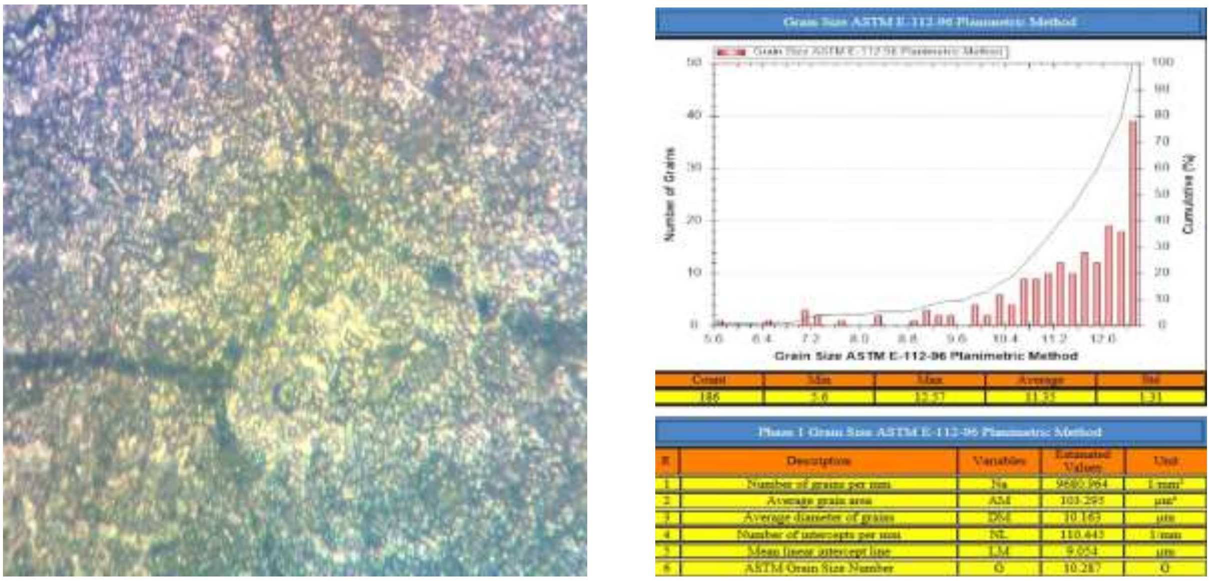
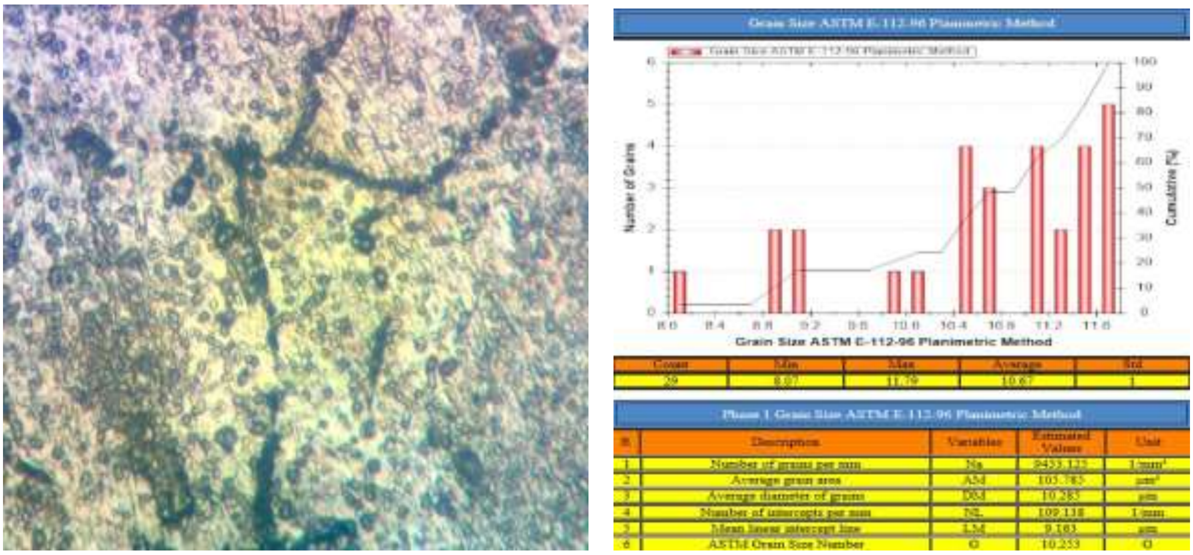


Figure 6. Micrograph of Al/SiC/2.5p metal cast

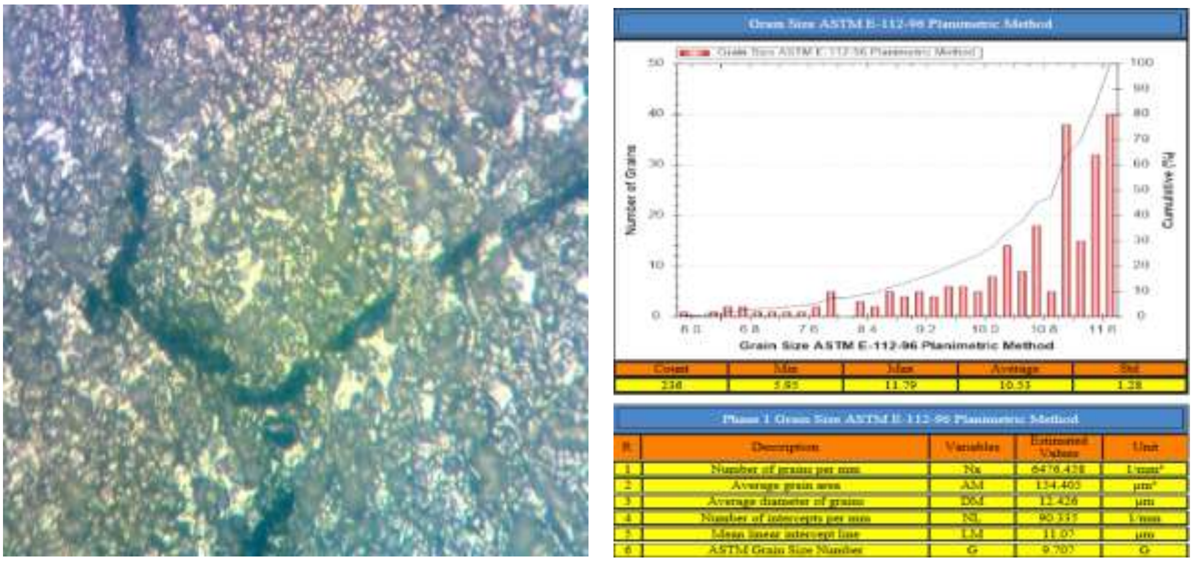


Count	Min	Max	Average	Std
29	8.07	11.79	10.67	1

Phase 1 Grain Size ASTM E-112-96 Planimetric Method

#	Description	Variables	Estimated Values	Unit
1	Number of grains per mm	Na	9433.125	1/mm²
2	Average grain area	AM	103.785	µm²
3	Average diameter of grains	DM	10.283	µm
4	Number of intercepts per mm	NL	109.138	1/mm
5	Mean linear intercept line	LM	9.163	µm
6	ASTM Grain Size Number	G	10.253	G

Figure 7. Micrograph of Al/SiC/5.0p sand cast

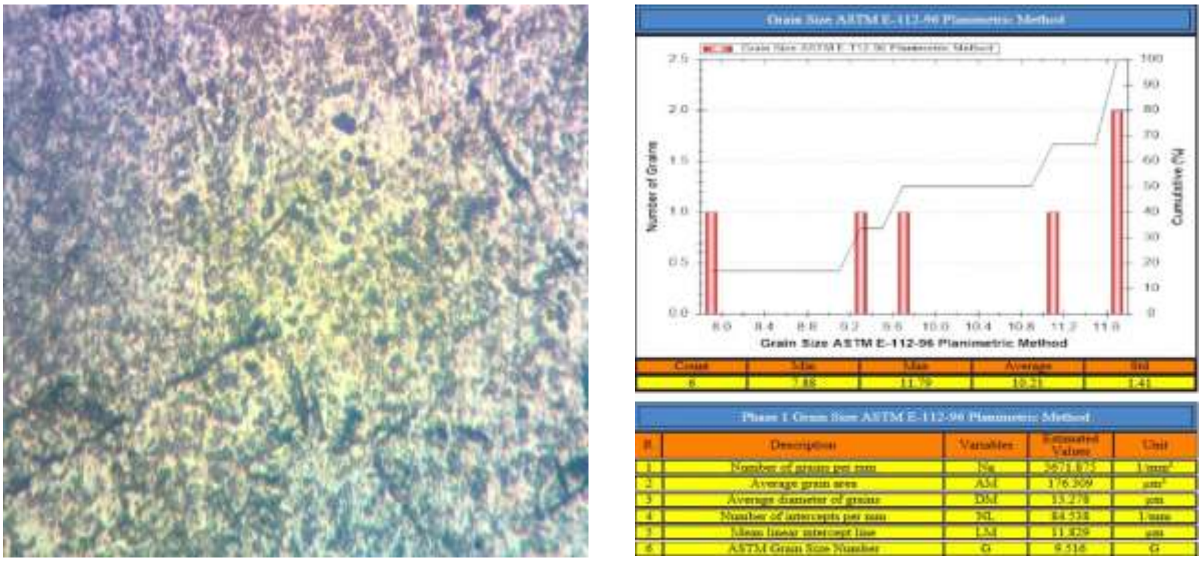


Count	Min	Max	Average	Std
238	5.85	11.79	10.53	1.28

Phase 1 Grain Size ASTM E-112-96 Planimetric Method

#	Description	Variables	Estimated Values	Unit
1	Number of grains per mm	Na	6476.428	1/mm²
2	Average grain area	AM	134.403	µm²
3	Average diameter of grains	DM	12.426	µm
4	Number of intercepts per mm	NL	90.335	1/mm
5	Mean linear intercept line	LM	11.07	µm
6	ASTM Grain Size Number	G	9.707	G

Figure 8. Micrograph of Al/SiC/5.0p metal cast



Count	Min	Max	Average	Std
6	7.88	11.79	10.21	1.41

Phase 1 Grain Size ASTM E-112-96 Planimetric Method

#	Description	Variables	Estimated Values	Unit
1	Number of grains per mm	Na	3671.875	1/mm²
2	Average grain area	AM	176.309	µm²
3	Average diameter of grains	DM	13.278	µm
4	Number of intercepts per mm	NL	84.538	1/mm
5	Mean linear intercept line	LM	11.829	µm
6	ASTM Grain Size Number	G	9.516	G

Figure 9. Micrograph of Al/SiC/7.5p sand cast

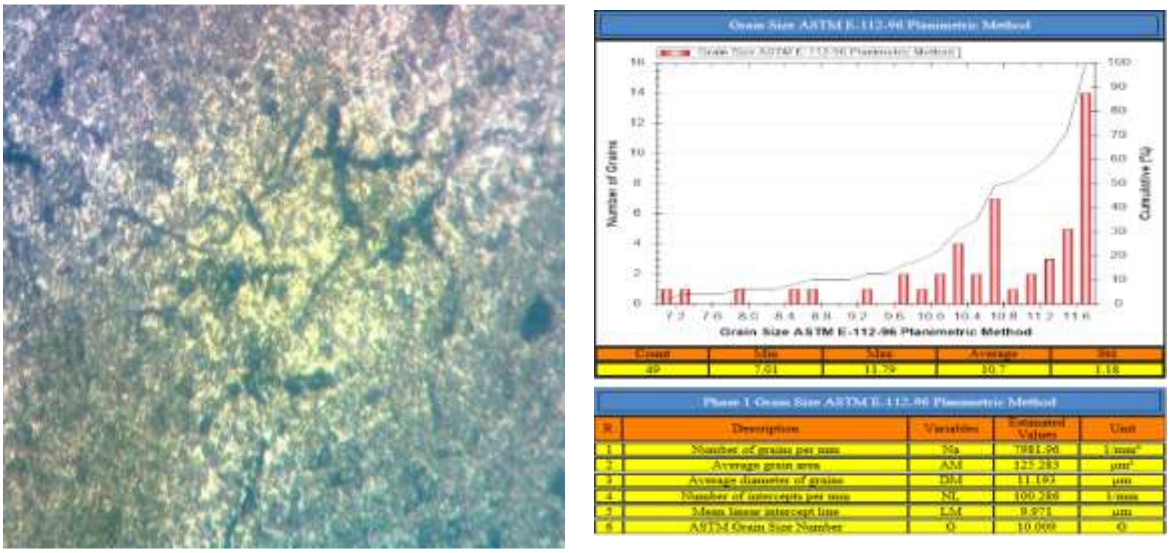


Figure 10. Micrograph of Al/SiC/7.5p metal cast

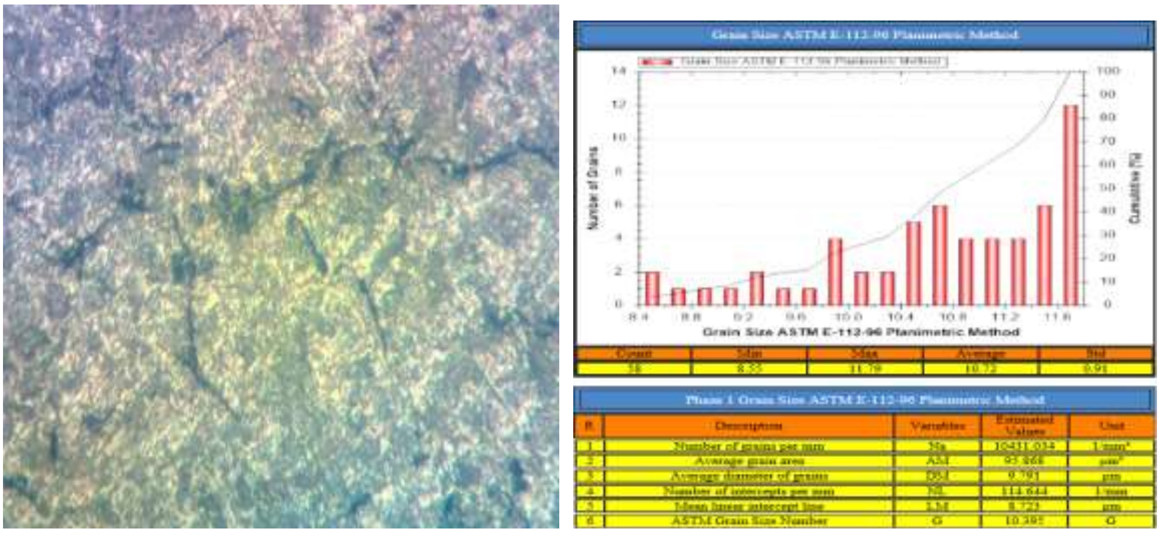


Figure 11. Micrograph of Al/SiC/10.0p sand cast

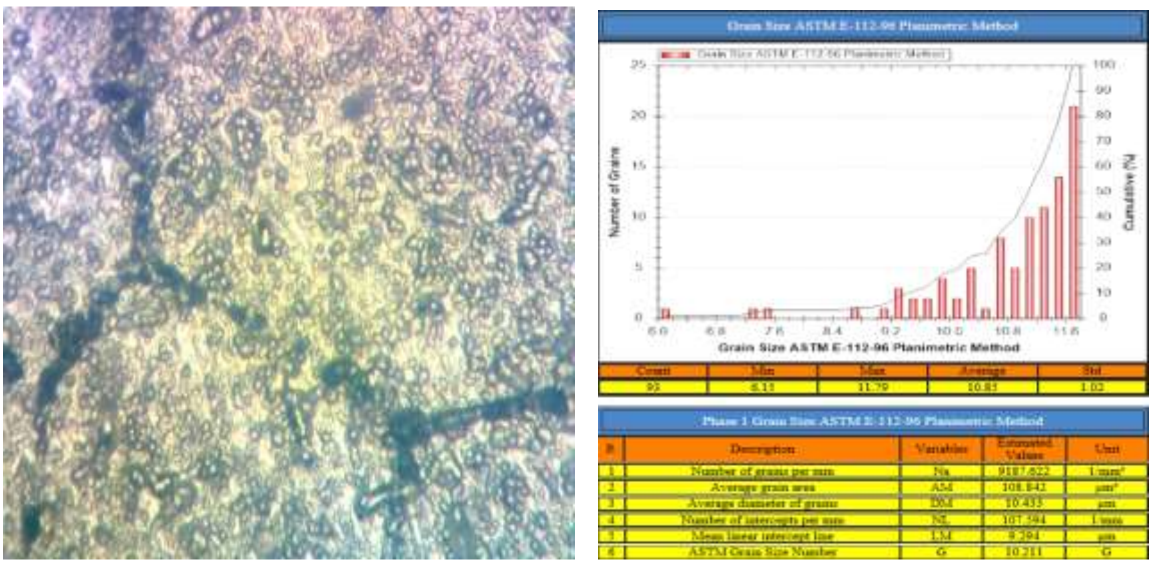


Figure 12. Micrograph of Al/SiC/10.0p metal cast

Table 5: Average grain diameters (μm)

Wt % of SiC	METAL CAST	SAND CAST
2.5%	13.64	10.16
5%	12.42	10.28
7.5%	11.49	11.27
10%	10.43	9.79

4. CONCLUSIONS

This paper studied and presented the mechanical properties of the two types (sand and metal mould) of the cast composite of Aluminium Silicon Carbides. The addition of a reinforcement material to the aluminium metal can alter its properties. In this work, it was found out that these properties can be furthermore altered by the method of casting used for the production of either sand or metal cast. By comparing the moulds media for casting, it can be readily seen that the sand mould casting resulted in higher modulus, yield strength and hardness than the metal casting one. These improvements in mechanical properties were attributed to the equiaxed grains observed by using the MagniSci software. The micrograph images obtained from the microscope was analysed on this basis. However, the metal castings had higher impact testing values than the sand castings.

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