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EVALUATION OF HARDNESS TEST OF SILICON CARBIDE PARTICULATED ALUMINIUM METAL MATRIX COMPOSITES

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Abstract: - Metal Matrix Composites (MMCs) are highly attractive for large range of hi-tech engineering applications because of their useful properties. Stir casting is the most commonly used method for production of particulate reinforced cast metal matrix composites. A recently developed modification of stir casting has been used in the present investigation to produce aluminum-magnesium matrix composites reinforced with silicon carbide. Here Aluminium 5083 is used as a base metal and SiC is a reinforced material. The preferred fabrication process is stir casting. Aluminum 5083 material is fabricated with SiC on various wt% compositions. The fabricated materials were then subjected to mechanical properties such as hardness; SEM analysis and EDS Spectrum were evaluated. The metallurgical test such as phase segmentation test is also evaluated. The mechanical property hardness is improved with the increase in weight percentage of SiC particulates with various weight percentages in the aluminum matrix.

Key words: SiC, Aluminum 5083, Hardness, SEM analysis, EDS, Phase segmentation

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I. INTRODUCTION

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications.

While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals.

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

The metal matrix composites (MMCs), like all other composites consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. For many researches the term MMCs is often equated with the term light metal matrix composites. Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, it is widely used in aerospace automobiles, marine etc.

II. EXPERIMENTAL SETUP

2.1 Fabrication process

Now days with the modern development need of developments of advanced engineering materials for various engineering applications goes on increasing. The simplest and the most cost effective method of liquid state fabrication is stir casting. So, for fabrication process stir casting process is used. A stir casting setup consists of pre-heater, electric furnace with stirrer assembly. Three-phase electrical resistance type 10 KW capacity furnace is used. The temperature range of the furnace is 1000˚ C. The temperature range of pre-heater is about 800˚C. The melting range of aluminium in 700˚C - 800˚C.

When setting up the stir caster before an experiment the rotor was first lowered into the crucible. Its height was accurately adjusted to form a partial seal at the exit such that it was held concentrically during stirring. Only a partial sealing of the outlet was allowed to ensure that torque pick-up from the rotor-crucible interaction was negligible. An external plug attached to the batch casting trolley provided a full seal at the exit. After the caster set-up, metal melted in an induction furnace was transferred to a resistance holding furnace where it was stabilised at a temperature 20 °C above the liquids temperature. The melt was then poured into the stir caster furnace which had been preheated to 570 °C to 595 °C for Al – wt % Si. The Different casting composition for Al-5083 Metal Matrix Composites is presented in Table 1.

S. No	Sic wt%	AL 5083 wt%
1.	5	95
2.	10	90
3.	15	85

Table 1. The Different casting composition For Al-6082 Hybrid Composites

Fig 1 Stir casting furnace

The stirrer was rotated up to 600 – 700 rpm. The depth of immersion of the impeller was approximately one third of the height of the molten metal, from the bottom of the crucible. Stirring was continued until interface interactions between the particles and the matrix promoted wetting. After few minutes of stirring the melt is poured in to the preheated die. The dies were pre heated and coated additives to ease the process of removing the castings. After solidification the required casts are obtained.

2.2 Hardness Test

Vickers Hardness is a very popular test, which is characterized by a square based diamond pyramid indenter, exactly ground to a standard form with 136 degrees between opposite faces and used to leave a mark in metal under a precisely applied force by taking care to avoid impact: the diagonals of the impression have to be measured using a suitable microscope and the results are either calculated using a given formula (see at the end of this section) or looked up in Tables arranged for each of the forces (loads) used.

The ASTM standard for micro force ranges (10g to 1kg) is ASTM E384.

*Vickers Tests Has Two Versions namely*Macro Vickers (load over 1kg) and Micro Vickers (load less than 1kg).

The Vickers macro test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness.

The Vickers micro ranges is in a shape of pyramidal diamond indenter that forms a square indent.

The steps for Vickers hardness test method is as follows:

- Diagonals of the indentation produced are approximately seven times larger than the depth of indentation, especially with high hardness metals it provides better accuracy than that could be obtained with the Brinell or Rockwell.
- This is because of the fact that, by virtue of its indentation, higher measurement accuracy can be obtained even if the indentation depth is small. So this makes the Vickers test especially suitable for hardness measurements in thin layers and very hard alloys.
- Vickers hardness number is nearly independent of the test loads for homogeneous materials due to the fact that the ratio between the diagonals of the impression remains constant under different test loads above 5kg. At lower loads it may be load dependent.

HV = Constant x test force / indent diagonal squared

2.3 Scanning Electron Microscope

The SEM instrument is made up of two main components, the electronic console and the electron column. The electronic console provides control knobs and switches that allow for instrument adjustments such as filament current, accelerating voltage, focus, magnification, brightness and contrast. The FEI Quanta 200 is a state of the art electron microscope that uses a computer system in conjunction with the electronic console making it unnecessary to have bulky console that houses control knobs, CRTs, and an image capture device. All of the primary controls are accessed through the computer system using the mouse and keyboard. The user need only be familiar with the GUI or software that controls the instrument rather than control knobs and switches typically found on older style scanning electron microscopes. The image that is produced by the SEM is usually viewed on CRTs located on the electronic console but, instead with FEI the image can be seen on the computer monitor. Images that are captured can be saved in digital format or printed directly.

2.4 Phase Segmentation Test

This test method is based upon the stereological principle that a grid with a number of regularly arrayed points, when systematically placed over an image of a two-dimensional section through the microstructure, can provide, after a representative number of placements on different fields, an unbiased statistical estimation of the volume fraction of an identifiable constituent or phase (1, 2, 3).

This test method has been described as being superior to other manual methods with regard to effort, bias, and simplicity.

Any number of clearly distinguishable constituents or phases within a microstructure (or macrostructure) can be counted using the method. Thus, the method can be applied to any type of solid material from which adequate two-dimensional sections can be prepared and observed.

III. RESULT AND DISCUSSION

3.1 Hardness Result

The harness test result for various combinations of matrix and reinforcement materials in weight percentage is shown in the table 2.

Table 2 Hardness Test Result

Samples	Vickers hardness (HV)
1.	78
2.	80
3.	83

The hardness property of AA5083 is increased by addition of SiC. Fig shows the hardness of reinforcement particulates of fabricated AMCs. The hardness of the composite is augmented from 78 HV to 83 HV.

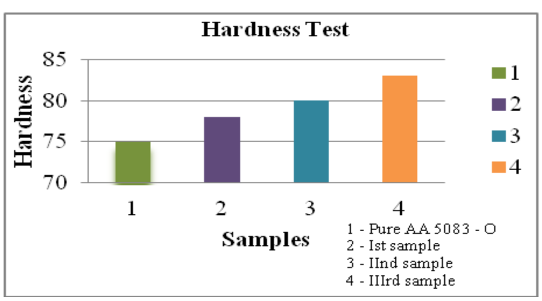

Fig 2 Vickers Hardness Test result

3.2 SEM ANALYSIS

The casted specimen is polished and etched as per the standard metallographic procedure. The microstructures of color etched specimens were observed using a scanning electron microscope (SEM).

Silicon Carbide (SiC) analyzed by scanning electron microscope was shown in Figure 3 with average size of less than 10 microns.

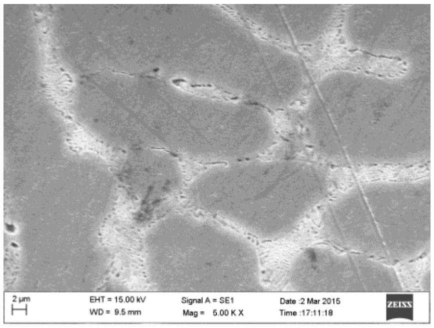

Fig 3 Sem image of Al/5wt%SiC

The figure 3, 4, 5 shows the microstructures of fabricated AA5083 alloy matrix reinforced with different wt% of SiC composites. Microstructure of cast AA5083 alloy matrix is presented in Fig. 3, 4, 5 which reveals the formation of α-aluminum dendritic network structure which is formed due to the super cooling of composite during solidification.

Generally, microstructure of Si is shown in Figure 4 consists of mainly α-Al, and primary silicon carbide surrounded uniformly by sharp edges silicon needles.

Microstructure of the composites presented in Figure 4 clearly reveals the homogeneous distribution of and SiC in the Al alloy matrix and there is no evidence of porosity and cracks in the castings. This might be related to proper process parameters employed for the production of castings.

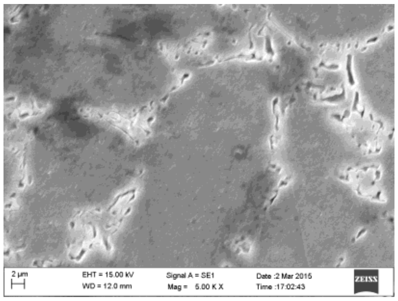

Fig 4 Sem image of Al/10wt%SiC

The microstructure of cast aluminum composites reinforced with SiC is shown in Figure 5 entrapped at the edges of silicon randomly. The presence of reinforced particles in the composite refined the primary silicon crystals while its morphology is relatively unaffected.

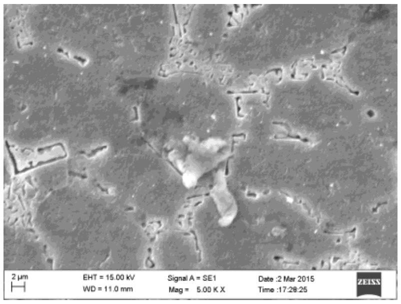

Fig 5 Sem image of Al/15wt%SiC

From the figure 3, 4, 5 it can be observed that, the distribution of reinforcements in the respective matrix are fairly uniform.

3.3 EDS SPECTRUM

The EDS spectrum respectively at the marked location at particle matrix interface of Al – SiC composite processed by stir casting process. The figure 6, 8, 10 shows a wider interfacial reaction zone and the formation of Si and C spinal is evident from the EDS spectra. The infiltration of matrix alloy into the particle is also observed, which may be attributed mainly to the cracked particles and to a lesser extent to interfacial reaction.

Figure 7, 9, 11 shows the Colored SEM micrographs of Al/with different wt% SiC. From this colored SEM micrograph, the matrix element Aluminium and Reinforcement Silicon can be easily viewed.

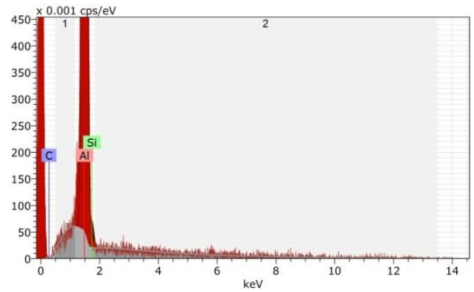

Figure 6 EDS spectra at the particle – matrix interface in Al/5%wt SiC

The table 3, 4, 5 shows the wt. % of Al, wt. % of Si, wt. % C from the EDS Spectra. From this table value we can find that how much the different wt. % composition of SiC is mixed well with the matrix Aluminium.

Table 3 Al and 5wt. % of Silicon from EDS Spectra

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at. %]	Error (3 Sigma) [wt.%]
Al	K	75.73	97.15	97.26	10.72
SiC	K	2.22	2.85	2.74	0.55
C	K	0.00	0.00	0.00	0.00

Total: 77.95 100.00 100.00

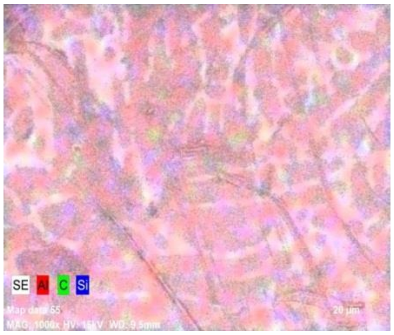

Figure 7 Colored SEM micrographs of Al/5wt%SiC

Figure 6 show the EDS spectrum respectively at the marked location at particle matrix interface of Al – SiC composite processed by modified compocast. In this case, the interface is very smooth and EDS spectra shows both the presence of spinel and eutectic silicon phase at the interface.

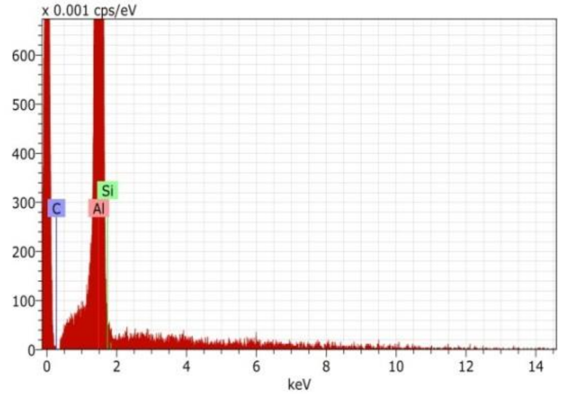

Figure 8 EDS spectra at the particle – matrix interface in Al/10%wt SiC

Hence, the extent of interfacial reaction is severe in a liquid metal stir cast composite than in the case of modified compocast one.

Table 4 Al and 10wt. % of Silicon from EDS Spectra

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at. %]	Error (3 Sigma) [wt.%]
Al	K	104.22	100.00	100.00	14.69
SiC	K	0.00	0.00	0.00	0.00
C	K	0.00	0.00	0.00	0.00

Total: 104.22 100.00 100.00

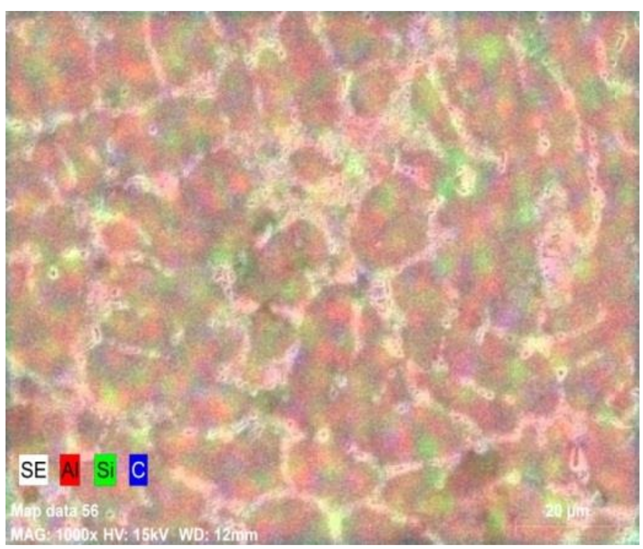

Figure 9 Colored SEM micrographs of Al/10wt%SiC

Figure 8 show the SEM photomicrograph and the EDS spectrum respectively at the marked location of the iron intermetallic phase formed Al – SiC composite processed by liquid metal stir casting. These β-iron intermetallic phases (SiCAl), which a brittle intermetallic compound having monoclinic structure, appears as plates.

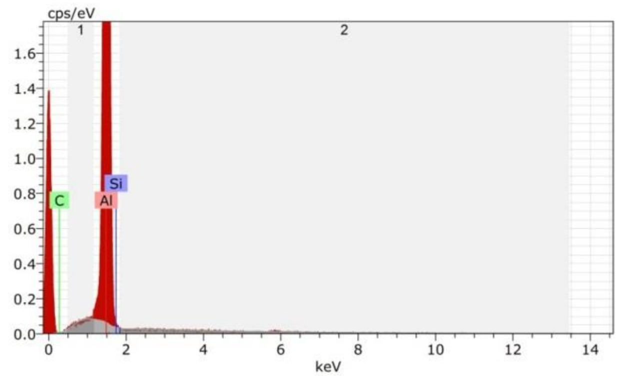

Figure 10 EDS spectra at the particle – matrix interface in Al/15%wt SiC

Table 5 Al and 15wt. % Silicon from EDS Spectra

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at. %]	Error (3 Sigma) [wt.%]
Al	K	104.22	100.00	100.00	14.69
SiC	K	0.00	0.00	0.00	0.00
C	K	0.00	0.00	0.00	0.00

Total: 104.22 100.00 100.00

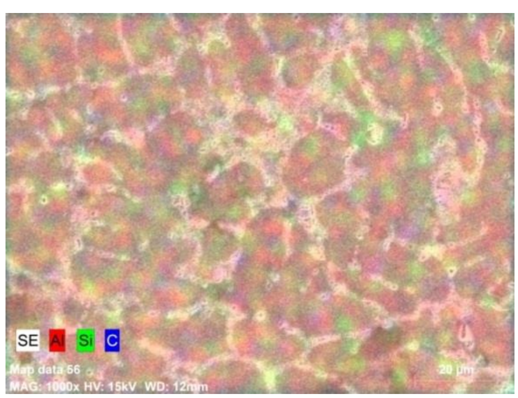

Figure 10 Colored SEM micrographs of Al/15wt%SiC

3.4 Phase Segmentation

Metallurgical Image Analysis System is a window based imaging application that delivers state of the art imaging solutions in Metallography. MIAS provides superior tools for image capturing, visualization, enhancement and analysis the report generation. Our Imaging Solution is a powerful integration of software and hardware that enables metallurgist to automatically capture images, performs metallurgical analysis and generates reports.

The phase segmentation test is done by the Metallurgical Image Analysis System. By using this system we can identify the area occupied by the Aluminum Alloy and reinforcement materials in the casted specimen. Figure

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11, 12 & 13 shows the area occupied by the reinforcement particle (SiC) and matrix material (AA 5083). The value has been shown in Micron Square. The phase segmentation test is conducted under ASTM E562.

From table (6, 7, 8) we can see the value of area occupied by the reinforment materials and matrix materials.

Table 6 Al and 5wt. % Silicon Phase segmentation

S.NO	NAME	AREA
1.	Matrix	128436.234 Micron sqr
2.	Reinforcement	12546.047 Micron sqr

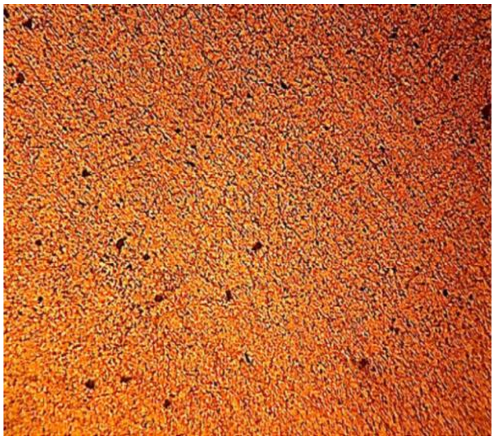

Figure 11 Phase segmentation of Al / 5 wt% SiC

Table 7 Al and 10 wt. % Silicon Phase segmentation

S.NO	NAME	AREA
1.	Matrix	246472.645 Micron sqr
2.	Reinforcement	17563.032 Micron sqr

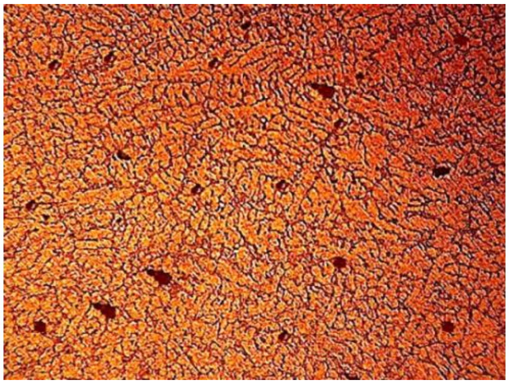

Figure 12 Phase segmentation of Al / 10 wt% SiC

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Table 8 Al and 15 wt. % Silicon Phase segmentation

S.NO	NAME	AREA
1.	Matrix	246472.645 Micron sqr
2.	Reinforcement	17563.032 Micron sqr

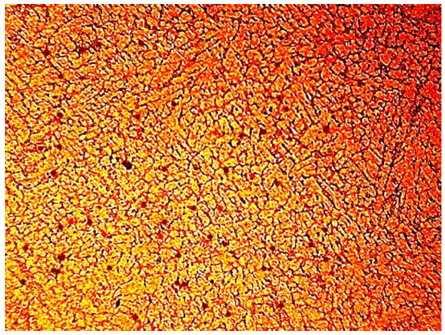

Figure 13 Phase segmentation of Al / 15 wt% SiC

CONCLUSION

Al - SiC composites were produced by modified stir cast route with different weight percentage of reinforcement and the mechanical properties such as hardness, SEM analysis, EDS spectrum and Metallurgical property phase segmentation were evaluated.

From this study, the following conclusions are derived.

- The micro hardness of the composites was increased from 78 HV to 83 HV with respect to addition of weight percentage of SiC. Hardness is an important property of a component which is subjected to heavy load. The reinforcement of particles has enhanced the hardness of aluminum matrix and composites.
- Lack of porosity exhibited in the microstructure of Al-Si matrix composite indicates there is a rather good particulate – matrix interface bonding.
- Thus the phase and the volume fraction of AA5083 and SiC are viewed by using the Metallurgical Image Analysis System. The volume of SiC is increase by increasing the wt.% of SiC
- The aim of this project is to improve the hardness of the AA 5083 alloy which has moderate strength by reinforcing with SiC and the results justify the objective. Al 5083 is available in grades O, H33. With the current project we have enhanced the properties of ordinary Al 5083 O grade property to Al 5083 H33 property which reduces manufacturing cost very much.

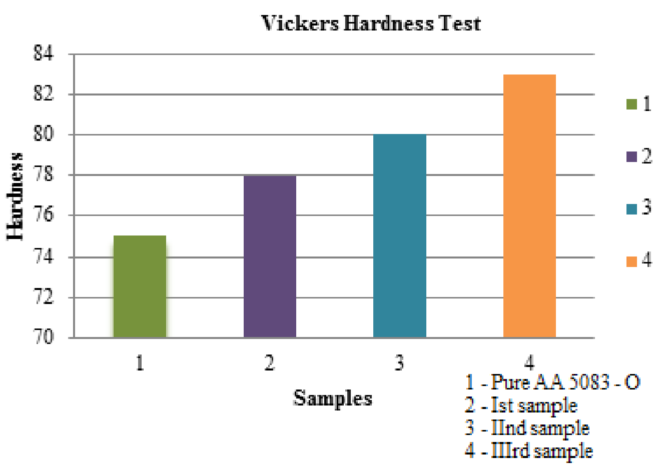

Figure 2 Vickers Hardness Test Result

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