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Effect of Ceramic Reinforcement Amount on the Hardness of the Aluminum Matrix Composite

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Abstract: ***Composite are one of the necessity of the current industrial infrastructure because of change in day to day requirements of the consumers. One of the most useful composite in aeronautical and automobile industries are aluminum ceramic composites because of their improved mechanical and thermal properties. However, amount of reinforcement has significant effect the properties of the composites material. Therefore, it is necessary to find out optimum amount of reinforcement that has the significant effect on the particular property of the composite material. Therefore, in the current study, Al-SiC (Aluminum-Silicon Carbide) metal matrix composite was fabricated using stir casting method. Parameters like stirring speed and temperature were kept constant during the process. Sic particle of 200 mesh size was used in different proportions. The reinforcement amount was varied from 0 to 12.5%. The influence of the percentage variation of the composite was studied based on the hardness test, microstructure analysis, optical Emission Spectroscopy (OES) and SEM-EDX. The OES, microstructure analysis and SEM-EDX analysis show retention of SiC in pure aluminium. The SEM-EDX of composite with 7.5% SiC addition shows 5.94% SiC retention that suggests the 79 % efficiency of the process. Moreover, it was observed from the hardness analysis that increases in the percentage of SiC increases hardness. Optical Emission Spectroscopy (OES) and EDS show the inclusion of iron [Fe] from stirrer blade material in results.***

Keywords: Hardness, MMC, Stir casting, SEM

I. INTRODUCTION

In recent years, the transport industry and aerospace industry utilizes composite materials for their structural and non-structural applications, thanks to their superior mechanical properties [1]. A metal matrix composite (MMC) generally consist of matrix and reinforcement materials, where base metal is considered as matrix material and different reinforcement material as per the requirement being added to produce desired properties. In the current study aluminium and silicon carbide were used as matrix and reinforcement material respectively. Al matrix composites possess low density, high stiffness and strength, superior wear resistance, controlled coefficient of thermal expansion, higher fatigue resistance and better stability at elevated temperature [2]. Therefore, these composites are used for the design of a wide range of components for advanced applications [3]. Rahman and Al Rashed [4] investigated the microstructure, mechanical and wear characteristics of Al-SiC composite with different composition (0, 5, 10 and 20 wt. %). It was observed by the researchers that at 20% SiC amount wear and tensile strength of composite becomes optimum compared to other specimens. Table 1 shows the comparison of the stir casting process with other possible methods of fabrication. It is evident from the table that there are various processes available for fabrication of composite metal. However, stir casting is most suitable due to its wide range of shape, size of casting, high metal yield, no damage to reinforcement and its cost-effectiveness [5]. An aluminium metal matrix composites have high application potential in the oscillating construction units of the engine like valve train, piston rod, piston, piston pin etc. in the cylinder head and crankshaft main bearing [6]. Fuel entrance door covers and ventral fins of F-16 fighter jet are made of AMMCs. Eurocopter EC120 and N4 helicopters consist of rotor blade and swash plates made of AMMCs [1].

Table 1 Comparison of various processes of composite fabrication [7]

Process	**Range of shape**	**Range of size**	**Metal yield**	**Damage to reinforcement**	**Cost**
Stir casting	Wide	Larger size	Very high, >90%	No damage	Least expensive
Squeeze casting	Limited	Restricted size	Low	Severe damage	Moderately expensive
Powder metallurgy	Wide	Restricted size	High	Reinforcement fracture	Expensive
Spray casting	Limited	Larger size	Medium	---	Expensive
Lanxide processing	Limited	Restricted size	---	---	Expensive

II. MATERIALS AND METHODOLOGY

In the current experiment, pure aluminium (i.e. 99.02%) was used as a matrix material and SiC was used as a reinforcement material with a mesh size of 200.

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The different amount of SiC particles were added in a different proportion from 0 to 12.5% in aluminium base metal. Figure 1 shows 200 mesh SiC powder used in the current study. Metal powder of pure Al and SiC were mixed using ball mill for around 15 minutes. The aluminium powder was added with SiC powder during ball milling so that both powder mix homogeneously and that helps to improve the wettability of SiC powder with liquid aluminium. Preheating of mixed reinforcement was performed at 600 °C electric furnace for 20 minutes. Table 2 shows the specification of the furnace which was used to fabricate composite materials. Then aluminium ingots were poured into the graphite crucible and heated above 800 °C. After complete melting of aluminium ingot, flux and degasser were used for segregation of slag and removal of gases respectively. Then mechanical stirrer was applied into the graphite crucible that contains liquid metal. The speed of the stirrer was maintained at 1400 rpm for 12-15 min and simultaneously, SiC ball milled powder was poured in liquid metal. Degassing was again performed to remove the unwanted gases before pouring of the mixture into the specially designed mould. Afterwards, the liquid composite mix was poured into the specially designed mould for desired shape (i.e. round bar) of the specimen. The obtained specimens were quenched in water to increase its hardness compared to as-cast composite. The fig. 2 shows the specimen prepared for the current study. Then specimens were cut according to the different test requirements and then sent for the specific analysis elsewhere. The hardness test, microstructure study and OES were performed at Hertz laboratories, Ahmedabad while SEM-EDX was performed at TCR, Vadodara. The Vickers hardness test with ASTM E-384 the standard was used for hardness test.

Table 2 Furnace specifications

Rating	6 KW
Power	640 V; 50 Hz AC
Max Temp	1500 C

Figure 1 SiC powder of 200 mesh

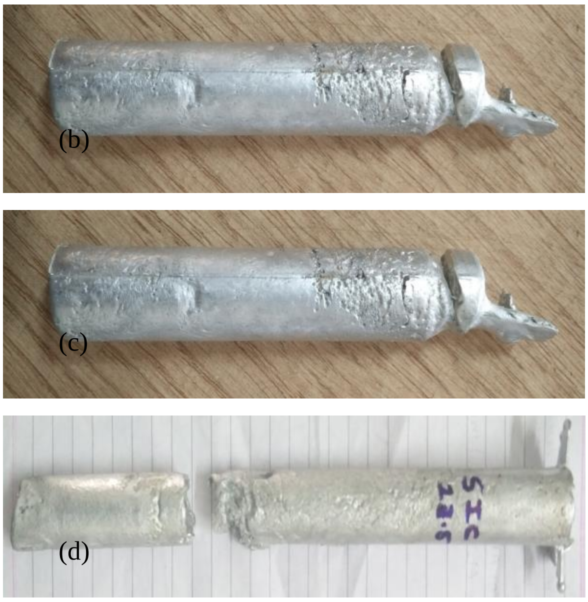
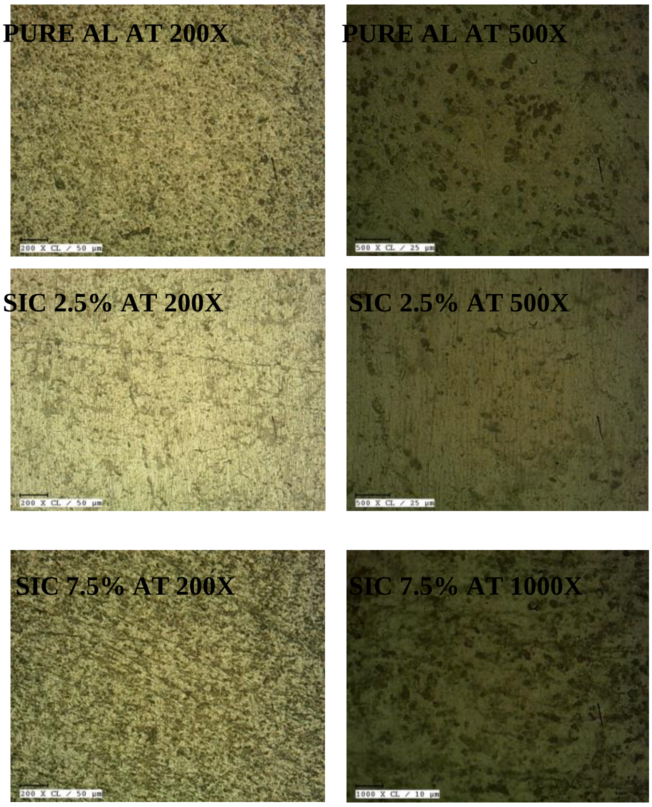


Figure 2 Composite specimen with different Al-SiC compositions; (a) Pure aluminum; (b) 2.5% SiC; (c) 7.5% SiC; (d) 12.5% SiC

III. RESULTS AND DISCUSSION

Microstructure images of composites are shown in fig. 3. The retention of SiC is clearly evident from the microstructure analysis. The microstructure of pure aluminium shows porosity clusters. The lower strength of the pure aluminium is attributed to porosity clusters as well. Similarly, in all specimens porosity was observed in varying amount. Porosity is one of the factors that significantly affect the mechanical properties of the materials. This is evident from the hardness results as shown in table 3. Optical emission spectroscopy (OES) results of 2.5% SiC is shown in table 4. It is evident from the result that 1.471 % of Si particles are present in the specimen which proves the efficiency of the method (i.e. stir casting) adopted with precautionary steps. The reinforcement retention efficiency is approx 58% that is less compared to the result shown in table 1 but for the current study (i.e. initial study) it is sufficient for further development. Moreover, Fe inclusions were also observed in OES results and it was found that these inclusions came into the composite because of deterioration of stirrer during stir casting process. Therefore, it was advisable to use graphite as stirrer material for better thermal shock resistance compared to mild steel. Table 3 shows hardness results and it is evident that as the amount of SiC increases the hardness of material increases as well. However, it is apparent that after 7.5%, marginal hardness improvement is possible. Therefore, 7.5% SiC addition is considered optimum for the hardness improvement using current stir casting setup. All the composite material show improved hardness compared to the pure aluminium sample. The wettability is considered as the bonding strength between reinforcement and matrix material. The mechanical properties of the composite material improve if the material has low porosity and good wettability between reinforcement and matrix material.

The increase in hardness also indicates the wettability improvement between SiC reinforcements and aluminium matrix and reduction in porosity as well. However, from fig.2 it is evident that as the amount of SiC increases the castability of the composite reduces because of reduction in flowability of the liquid metal. The flowability reduces because of the increase in viscosity of the liquid metal that becomes viscous due to the addition of the SiC material. The validation of hardness result completes with Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis as shown fig. 5. SEM image shows the SiC reinforcement agglomeration in a certain area that is validated by EDS result. The result shows the presence of 5.94% SiC reinforcement while Al 81.92%, Fe 6.51% and O2 5.63%. Here, the retention rate of SiC is almost 79% which is pretty impressive compared to the initial result obtain during trial and error method (i.e. in publication somewhere else). However, the presence of O2 is critical and this would be possible due to mainly two reasons ;(i) porosity produced during solidification process due to entrapment of O2 ;(ii) oxidation of specimen took place due to the corrosive environment before tests were carried out. In the author's opinion, the second reason is most probably because it took around 1week for SEM-EDX testing after samples were prepared and meanwhile specimen were exposed to a tropical environment for 1 week. Moreover, the authors observed no homogeneous distribution of particles in the aluminium matrix which is evident from the SEM image itself that shows the agglomeration of the reinforcement materials.



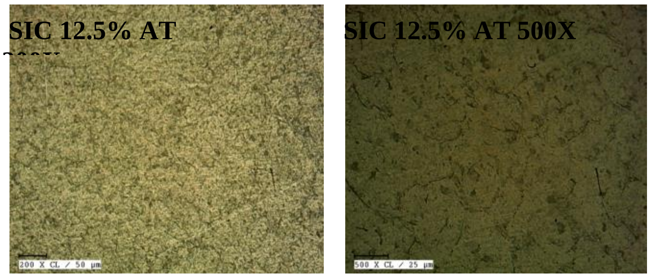


Figure 3 Microstructureal analysis

Table 3 Hardness table for different composition of Aluminum metal matrix

	Hardness in HV1 [Kgf]			Average
Pure AL	36.00	36.00	38.00	36.67
SIC 2.5%	40.00	39.00	40.00	39.67
SIC 7.5%	40.00	42.00	39.00	40.33
SIC 12.5%	40.00	40.00	42.00	40.67

Table 4 OES result of 2.5% SiC

Material	Percentage (%)
%Fe	3.620
%Mn	0.213
%Cr	0.650
%Zn	1.450
%Si	1.417
%Al	92.650

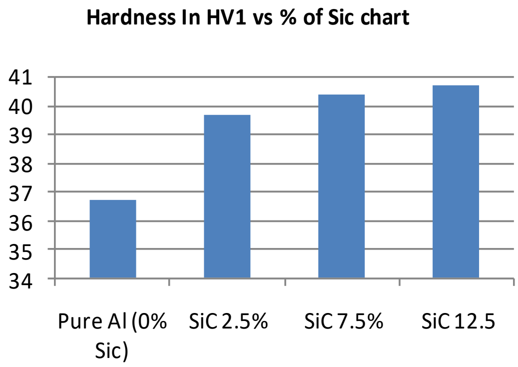


Figure 4 Hardness test reults for diffrent specimens.

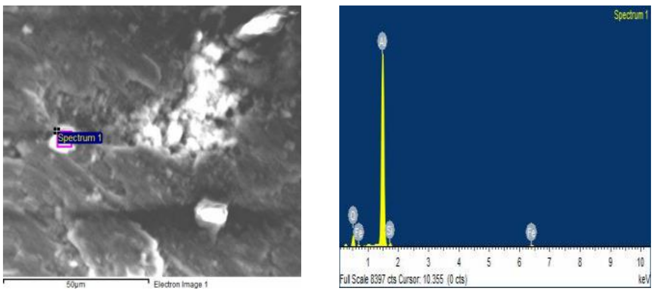


Figure 5 Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis of 7.5% w/v Al-SiC specimen.

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IV. CONCLUSION

Aluminium metal matrix composite with varying 0, 2.5.7.5, 12.5% amount of SiC were successfully developed using stir casting process. Composite metal matrix of 2.5%, 7.5%, 12.5% shows increase of 8%, 10%, 11% increase in hardness compare to pure aluminum. it is apparent that after 7.5%, marginal hardness improvement is possible. Therefore, 7.5% SiC addition is considered optimum for the hardness improvement using current stir casting setup. OES analysis of 2.5% SiC reinforced composite shows 1.417% retention of Si which suggests good retention rate. Microstructure study shows the presence of SiC particles. EDX analysis of 7.5% SiC shows 5.94% retention of Si which again shows good retention rate.

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