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CHARACTERIZATION OF DEVELOPED AL 6061-SIC METAL MATRIX COMPOSITES PRODUCED BY THE STIR CASTING METHOD

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ABSTRACT

Composite materials which main constituent part is a metal are called Metal Matrix Composites. The other compounds may be metal too, ceramics or even organics. They are well known for their excellent thermo physical and mechanical properties. Reinforcement is used to improve different properties of main material, such as wear resistance, hardness, fatigue resistance, friction coefficient, thermal conductivity and others. As a result, during the last years, MMCs have found a lot of application in automobile industry for the production of breaks and parts of engines and in aerospace industry for the production of structural components, as well as in electrical and electronic industry and in many other applications. MMCs can be produced by many ways, such as, powder blending and consolidation, foil diffusion bonding, electroplating, spray deposition, stir casting and others. In this research stir casting was used as processing technique for the production of Aluminum Metal Matrix composites reinforced by silicon carbide (SiC) particles. The morphologies of the produced composite material were examined using optical microscope. The compositions of their micro structural features were determined by chemical spectrometer. And also mechanical properties like hardness and surface roughness of developed composite material with varying SiC weight percentage were tested.

Keywords: Aluminum 6061, Metal Matrix Composite, Reinforcement Silicon Carbide, Stir Casting, Orthogonal Array, Microstructure analysis, Chemical analysis, Hardness, Surface Roughness.

I. INTRODUCTION

Aluminum metal matrix composites (MMCs) reinforced by ceramic particles are well known for their low density along with high mechanical properties, such as high strength, improved toughness, fatigue and wear resistance. Low density and high mechanical properties make Aluminum MMCs ideal materials for construction of lightweight structural and engine parts for the automobile and aerospace industry. Aluminum MMCs produced by the stir casting method are economically competitive with steels and cast irons produced by traditional methods. On the other hand,

Aluminum MMCs are lighter, tougher and their wear resistance and thermal conductivity are better than those of cast iron. The usage of Aluminum MMCs can make able the construction of more fuel efficient vehicles and airplanes, without any reduction of their properties. This paper is concerned with the study of Aluminum metal matrix reinforced by varying silicon carbide weight percentage, pouring temperature, stirring time, produced by the stir casting method [1].

Particulate reinforcement metal matrix composites have combination of low density, improved stiffness and strength, high wear resistance and isotropic properties [2-4]. Metal matrix composites is their low ductility which has been overcome recently by introducing special processing technologies, such as squeeze casting, stir casting [6-8]. Many aluminum alloys such as Al 6061, Al 6063, Al 7075, Al 2024, LM-25 reinforced with various ceramic particles have been investigated extensively [5-14]. The mechanical behavior of aluminum matrix composites has been investigated thoroughly in various research works. Many successful studies on the development of the mechanical properties of the SiC particles composites, by second phase particles, have been reported for example, SiC-Al_2O_3, SiC-TiC and also the reinforcement of Rice hush ash, B_4C, Zircon sand, alumina, fly ash, ZnO and $ZnAl_2O_4$, NiTi fibers etc. were extensively searched [15-21].

In this paper, The fabrication of composites using stir casting method was used, in which high strength SiC particles reinforcement were employed, and were also investigated characterization of developed Al MMC. This developed Al MMCs can be used for manufacturing of automobile part like dovetail after the evaluation of properties. Thus, it offers unique opportunities to tailor materials to specific design needs. These materials can be tailored to be lightweight and with various other properties.

II. METHODOLOGY OF WORK

2.1 Material and Experimental Setup

Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weld ability, and corrosion resistance. Aluminum alloys are alloys in which aluminum (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc.

Table 1. Applications of Aluminum alloys [1]

Aluminum Alloy	Common Use
1050/1200	Food and Chemical Industry
2014	Airframes
5251/5052	Vehicle paneling, Structures exposed to marine atmospheres, mine cages.
6063	Architectural extrusions (internal and external) window frames, irrigation pipes.
6061/6082	Stressed structural members, Bridge cranes, Roof trusses, beer barrels.
7075	Armoured vehicles, Military bridges motor cycle and bicycle frames.

Aluminum alloy 6000 series is alloyed with magnesium and silicon, are easy to machine, and can be precipitation hardened. For the fabrication process aluminum alloy, 6061 is used as matrix metal that has been reinforced with SiC particles of 60-90 µm. The reinforcement percentage is varied in the range of 0%, 5% and 10% by weight. The chemical composition and properties of the matrix material Al 6061 is given below.

Table 2. Properties of Al 6061[17]

Sr. No.	Melting Point	Approx 580˚C
1	Modulus of Elasticity	70-80 GPa
2	Poisson's Ratio	0.33
3	Density	2.7 g/cm^3
4	Thermal Conductivity	173 W/Mk

Table 3. Chemical Composition of Al 6061 by wt % [17]

Elements	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr
Percentage	Balance	0.8-1.2	0.4-0.8	Max 0.7	0.15-0.40	Max 0.25	Max 0.15	Max 0.15	0.04-0.35

Table 4. Properties of Silicon Carbide [19]

Sr. No.	Melting Point	2200-2700˚C
1	Hardness (Kg/mm^2)	2800
2	Density(g/cm^3)	3.1
3	Coefficient of thermal expansion	4.0 (µm/m˚C)
4	Fracture toughness	4.6 MPa
5	Poisson's Ratio	0.14
6	Colour	Black

Silicon carbide is used as reinforcement particle. it is a compound of silicon and carbon with chemical formula SiC. It is used in abrasives, refractories, ceramics, and numerous high performance applications. Silicon carbide is composed of tetrahedral of carbon and silicon atom with strong bonds in the crystal lattice. This produces a very hard and strong material. It has characteristics like low density, high strength and thermal conductivity, low thermal expansion and high hardness.

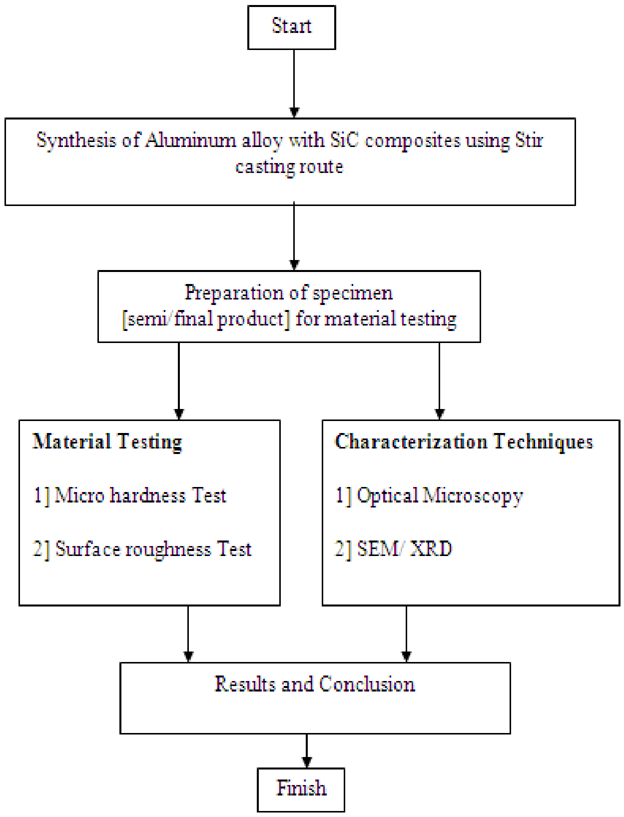

Figure 1. Flow chart of work plan for Experiments

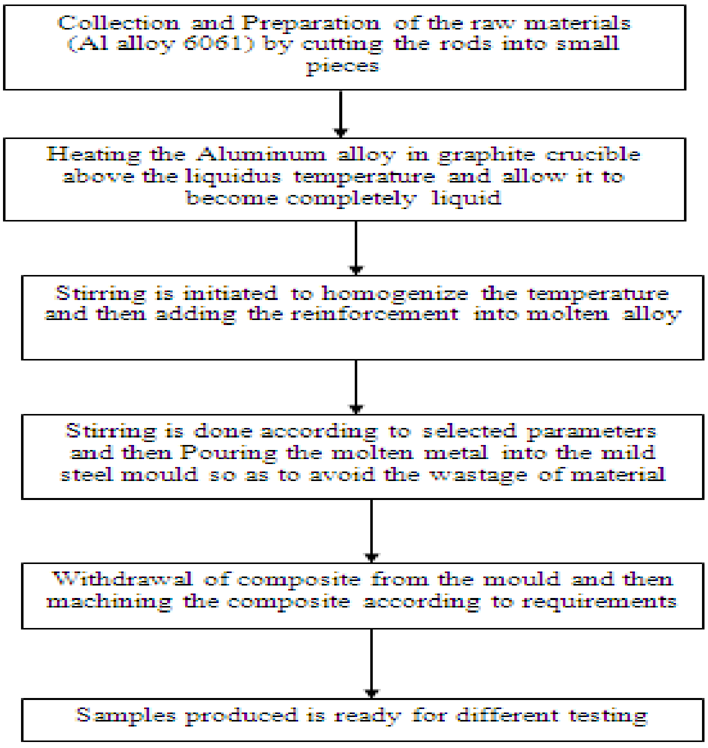

Figure 2. Flow chart showing steps involved in Stir casting

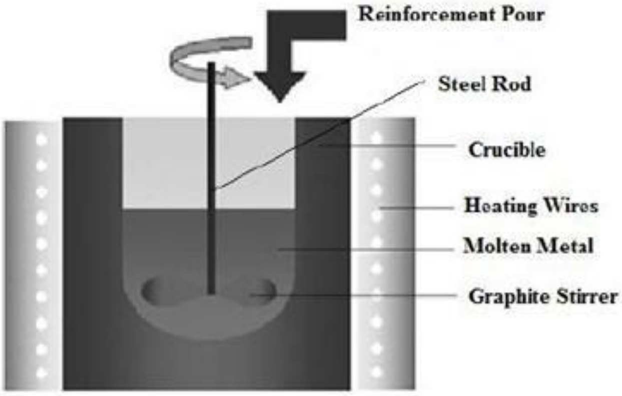

Figure 3. Graphical representation of stir casting [10]

The fabrication process of Al 6061-SiC composites were carried out by stir casting process. The graphical representation of the experimental set up for making of these composites was shown in figure 1. Approximately 1 Kg of alloy in solid form (hexagonal rod) was melted at 820˚C in the resistance furnace. Preheating of reinforcement silicon carbide at 800˚C was done for one hour to remove moisture and gases from the surface of the particulates. The reinforcement particles were sieved by sieve shaker. Preheated reinforced particles were added with a spoon into the melt manually. After addition of reinforcement, stirring was continued for 20-40 seconds for proper mixing of prepared particles in the matrix. The composite slurry was then reheated to a fully liquid state and stirring is carried out. The final temperature was controlled to be around 750˚C. The melt was kept in the crucible for approximate half minute in static condition and then it was poured in the mould.

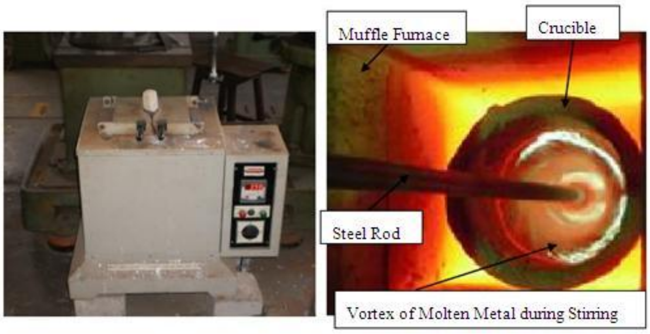

Figure 4. Muffle furnace and Preparation of samples

Figure 5. Synthesis of Al alloy with SiC composite using Stir casting route [As cast Dovetail]

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Figure 6. Finished product for Micro hardness and Surface roughness [After machining Dovetail]

2.2 Selection of Parameters and Levels

Process parameters are based on Stir casting method. Function parameters are nothing but control parameters. Parameters which really affect the response of uncontrollable parameters such as Hardness, Surface roughness, Microstructure etc. are known to be critical function parameters. In stir casting route, there are many factors affecting for mechanical and physical properties of developed composite. Reinforcement of SiC wt %, Pouring temperature, Stirring time, Particulate preheat temperature, Stirring speed are few of effecting parameters. These levels decided from manufacturers control plan and present casting procedure of stir casting.

Table 5. Levels of Critical Parameters

Sr. No.	Factors	Notations	Units	Level 1	Level 2	Level 3
1	SiC weight %	A	Percentage	0	5	10
2	Pouring Temperature	B	˚C	660	710	760
3	Stirring Time	C	Second	20	30	40

2.3 Response and Measurement

The response variables considered in this work are Hardness and Surface roughness. Hardness of developed MMC is measured on desired surface of part by using Brinell Hardness Testing machine in terms of BHN [500Kgf load × 10mm Ball], Surface roughness (Ra value in µm) is measured using surface roughness tester on sample pieces as per the tagging applied to the samples. And microstructures with varying weight percentage of silicon carbide particles of developed aluminum metal matrix composite were also examined.

2.4 Experimental Design

Optimal process parameters is obtain from multi response characteristics, the orthogonal array with Grey relational analysis is used for experimentation. To do full factorial design for 3 parameters and 3 levels, it requires 33=27 experimental runs, to perform all these experiments it requires more time and cost. To reduce experimental cost and time, L9 Array is selected, instead of L27. Orthogonal array is selected based on degree of freedom, so the degree of freedom is calculated as follows;

Degree of Freedom (DOF) = No. of levels selected – 1

Total Degree of Freedom for the experiment is DOF = Total no. of Experiment – 1

DOF = (9-1) = 8

For each factor, DOF is

For Factor (A) = 3-1 = 2 , For Factor (B) = 3-1 = 2 , For Factor (C) = 3-1 = 2.

Orthogonal array is selected greater than degree of freedom. Total degree of freedom is 8. Hence we select L9 orthogonal array because 9 > 8.

III RESULTS AND DISCUSSIONS

Various Experiments were conducted on fabricated Metal matrix composites by varying weight fraction of Silicon carbide (0%, 5% and 10%) to analyze the casting performance characteristics of Al/SiC MMCs.

3.1. Microstructure

Metallographic samples were sectioned from the sample pieces of casted parts. A 0.5% HF solution was used to each the samples wherever required. Following Figures shows microstructures with different weight percentage of Silicon carbide reinforcement.

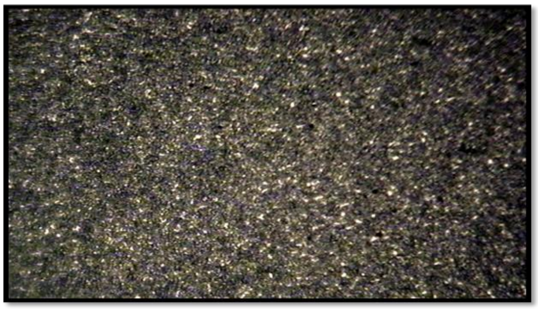

Figure 7. Microstructure of Pure Aluminum [10X]

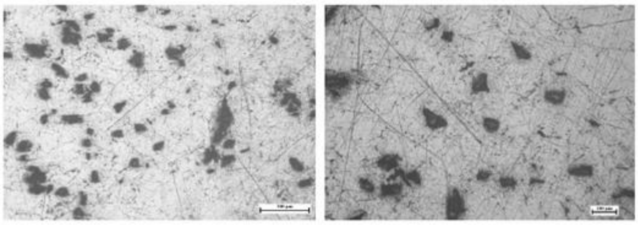

Figure 8. Optical micrographs of MMC with 5 wt.% of SiC[50X,100X]

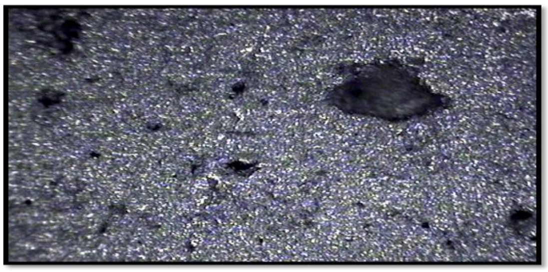

Figure 9. Microstructure of wt.10% of SiC [10X]

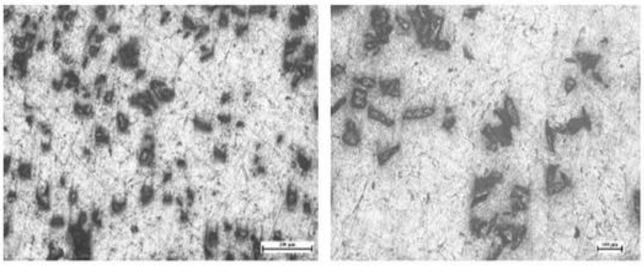

Figure 10. Optical micrographs of MMC with 10 wt.% of SiC [50X,100X]

3.2. Chemical Analysis

Chemical analysis of pure aluminum and with 10 weight % of silicon carbide reinforcement is done by using Chemical Spectrometer.

Figure 11. Chemical Spectrometer

Table 6. Chemical Analysis of Pure Aluminum

Element	Observed %
Mn %	0.019
Si %	0.512
Ni %	0.004
Cu %	0.214
Ti %	0.009
V %	0.007
Sn %	0.005
Fe %	0.673
Cr %	0.046
Zn %	0.106
Mg %	0.824
Al %	Rem.

Table 7. Chemical Analysis of Al-SiC composite with weight 10% SiC

Element	Observed %
Mn %	0.026
Si %	9.473
Ni %	0.005
Cu %	0.222
Ti %	0.012
V %	0.009
Sn %	0.008
Fe %	0.684
Cr %	0.114
Zn %	0.049
Mg %	0.831
Al %	Rem.

3.3 Hardness

In this current study hardness is measured using Brinell Hardness Testing Machine with 500 Kgf (Load) × 10 mm Ball. Range of hardness on desired surface of the part is measured.

3.4. Surface Roughness

Surface roughness tester is used for measuring arithmetic roughness (Ra) value in µm. after machining of the dovetail automobile part the desired surface of the part were checked under roughness tester. Mean value of Ra is calculated by averaging three roughness values.

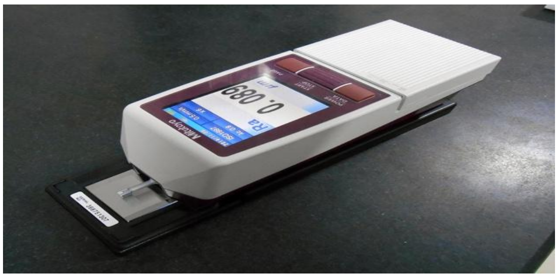

Figure 11. Surface Roughness Tester [Mitutoyo]

For Table 8 Selected three process parameters are [A = SiC wt.% , B = Pouring temperature, C = Stirring time]

Table 8. Experimental observations for Hardness and Surface Roughness

Trail No.	Process Parameters			Response Variables	
	A	B	C	Hardness (BHN)	Surface Roughness (µm)
1	1	1	1	30.00	1.610
2	1	2	2	30.50	1.625
3	1	3	3	31.00	1.590
4	2	1	2	65.00	1.605
5	2	2	3	66.50	1.630
6	2	3	1	67.00	1.625
7	3	1	3	90.50	1.595
8	3	2	1	95.00	1.615
9	3	3	2	102.00	1.620

IV. CONCLUSIONS

The Al-SiC composites were produced by stir cast route with varying SiC wt. % (0%, 5%, 10%) of reinforcement and the microstructure, mechanical properties are evaluated. From the experimental study reveals following conclusions:

a] **Microstructure:** Optical micrographs showed reasonably uniform distribution of SiC particles and this is good agreement with earlier work. Homogenous dispersion of SiC particles in the Al matrix shows an increasing trend in the samples prepared by applying stirring casting technique.

b] **Hardness:** Hardness increases with increase in reinforcement particulate of silicon carbide powder. 5 wt. % of Silicon Carbide gives hardness 65 BHN. And maximum hardness 102 BHN is obtained at 10 wt. % of Silicon Carbide as a reinforcement in aluminum metal matrix.

c] **Surface Roughness:** From the values obtained it is observed that no adverse effect of increase in weight percentage of silicon carbide on the surface roughness values its variations are in microns.

d] Developed Aluminum Metal Matrix composite shows improvement in mechanical and physical properties compared to pure aluminum which also offer unique opportunities to tailor materials to specific design needs.

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