

FABRICATION OF HYBRID MMC (AL-SiC-B₄C) AND EVALUATION OF MECHANICAL AND MACHINABILITY CHARACTERISTICS

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Abstract

Hybrid (MMC) metal matrix composite are materials which combine a tough metallic matrix with two different hard ceramic reinforcements. Engineering industries such as Automobile, Aerospace, Sports goods, Industrial plants use the hybrid composite materials for their superior mechanical properties. Metal composite in general possess certain superior properties like low density, greater modulus of elasticity, greater hardness, high specific stiffness and high specific strength, controlled coefficient of thermal expansion, increased fatigue resistance and superior dimensional stability at elevated temperature. In this direction, the aluminium hybrid composite is fabricated using stir casting method. 10% by weight of SiC particles with an average size of 45 μ m along with 5% by weight of B₄C particulates of an average size of 40 μ m were reinforced in to the molten aluminium alloy of designation Al 356. The hardness, chemical composition and the micro-structure of the hybrid composite were investigated. Turning operation is conducted in a medium duty lathe to study the machinability characteristics like surface roughness and tool wear using SEM images.

Key words: MMC, Turning, Stir casting, Mechanical properties, Surface Roughness, Tool wear, SEM images.

I. INTRODUCTION

Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements. Now a days the particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components.

Cast aluminium matrix particle reinforced composites have higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys. The particulate composite can be prepared by injecting the reinforcing particles into liquid matrix through liquid metallurgy route by casting. Casting route is preferred as it is less expensive and amenable to mass production. Among the entire liquid state production routes, stir casting is the simplest and

cheapest one. The only problem associated with this process is the non uniform distribution of the particulate due to poor wet ability and gravity regulated segregation. The matrix phase may be of Polymers, Metals, Ceramics and the reinforcement phase may be Fibers, Particles, or Flakes. [3,11]

Metal Matrix Composites are composed of a metallic matrix (Al, Mg, Fe, Cu etc) and a dispersed ceramic (oxide, carbides) or metallic phase (Pb, Mo, W etc). Ceramic reinforcement may be silicon carbide, boron, alumina, silicon nitride, boron carbide, boron nitride etc. whereas metallic reinforcement may be tungsten, beryllium etc. Aluminium is the most popular matrix for the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Aluminium matrix composites (AMCs) have been widely studied since the 1920s and are now used in sporting goods, electronic packaging, armours and automotive industries. They offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix. In this present work Aluminium Matrix Composites are reinforced with particles of 10% Silicon Carbide (SiC) and 5% Boron Carbide (B₄C).[4]

Table 1. Chemical composition of Al-SiC (10p) B₄C (5p) – HybridMMC

Type of Hybrid MMC	Reinforcement	%Si	%Mg	%Fe	%Cu	%Mn	%Zn	%Ti	%Al
Particulate MMC	SiC and B ₄ C %m	7.85	0.68	0.25	0.14	0.07	0.07	0.16	Balance

Table 2. Properties of Aluminium Alloy Al 356

Property	Value
Density	2670 kg/m ³
Brinell Hardness	70.0 - 100
Ultimate Tensile Strength	>= 255 MPa
Yield Tensile Strength	>= 179 MPa
Modulus of Elasticity	72.4 GPa
Poissons Ratio	0.330
Shear Strength	155 MPa
Thermal Conductivity	151 W/m-K
Melting Point	557.2 - 612.8 ° C
Casting Temperature	677 - 788 ° C

Table 3. Properties Of Particulates

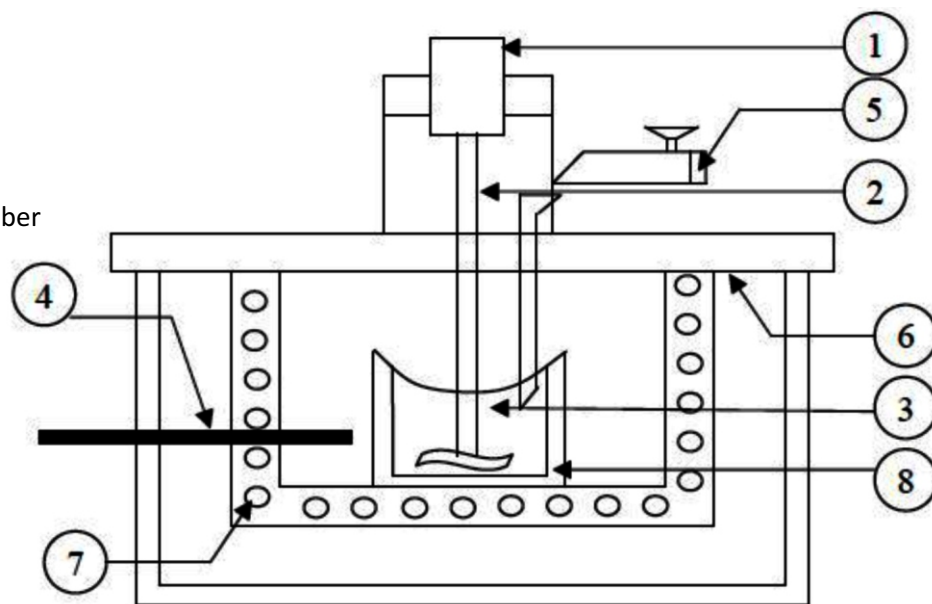
Property	Silicon Carbide	Boron Carbide
Density	3.21 g.cm ⁻³	2.52 g.cm ⁻³
Melting Point	2730°C	2763°C
Bulk Modulus	220 Gpa	260 Gpa
Mesh Size	320 mesh (45 μ m)	325 mesh (40 μ m)

II. FABRICATION PROCESS OF MMC:

A. Stir Casting Method:

In the stir casting process, the alloy is melted at a controlled temperature and the desired quantity of fly ash is added to the molten aluminum alloy. The molten alloy is stirred continuously to create a vortex to force the slightly lighter particles into the melt. Stirring continues to disperse the fly ash particles as uniformly as possible in a short time. The matrix is then

1. Motor
2. Shaft
3. Molten aluminium
4. Thermocouple
5. Particle injection chamber
6. Insulation hard board
7. Furnace
8. Graphite crucible



Schematic view of setup for Fabrication of composite

Fig. 1. Stir Casting Process



Fig. 2. Stir Casting Setup

transferred into a preheated and pre-coated transfer ladle. The material is stirred again and then poured into preheated permanent dies. It is then cooled, cut to shape, and surface cleaned. [5,6,17,18]

B. Steps Involved In Stir Casting Process:

1. Aluminium alloy Al 356 of 1500 g in weight is taken in a crucible and Coverall of 5 g is added. The purpose of adding coverall is to form a protective layer over the molten aluminium alloy to prevent the heat from escaping.
2. Then the crucible with the aluminium alloy is kept in the muffle furnace for melting. The aluminium is heated upto 850 ° C in the muffle furnace 1. This muffle furnace is equipped with stirring equipment for stirring purpose.
3. The Ceramic materials 10%SiC and 5%B₄C are taken in separate crucibles in weight, of the total weight of aluminium alloy and the crucibles containing the ceramic materials are kept in muffle furnace 2 and preheated to 850 ° C.
4. The steel alloy die used for casting is preheated to ° C in the muffle furnace 3.
5. The aluminium alloy after melted is taken out from the furnace 1 and the floating impurities are removed from the molten aluminium.
6. Then 5 g of Degasser is added to the molten aluminium alloy to remove the unwanted gases.
7. After the impurities and unwanted gases are removed from the molten aluminium alloy, 5 g of Nucleant is added to make particles uniform in size.
8. At last another 5 g of Cover all is added to form a protective layer over the molten aluminium alloy preventing the heat from escaping.
9. The preheated ceramic particles are taken out of the furnace 2 and they are transferred to the crucible containing the molten aluminium alloy and made ready for stirring.
10. The crucible with the mixture of molten aluminium alloy and ceramic particles is kept in the muffle furnace 2 equipped with stirrer and the stirring process starts.
11. The stirring blade is made of stainless steel and it is a three blade vertical stirrer. The stirring takes place at 200 rpm for about 15 minutes.



Fig. 3. Transfer of Molten Substance to Die

12. After the stirring is over, the crucible is taken out of the furnace and the molten substance is transferred to the preheated steel alloy die.
13. After the molten substance is transferred to the die it is allowed to cool for approx. 6 – 7 hours.
14. After sufficient cooling and setting time the rod is taken out of the die with the help of ejector pin assembly.

The MMC cylindrical rod is thus fabricated and it is machined for testing.

III. MICROSTRUCTURE EXAMINATION

Preparation of a specimen for microscopic examination is carried out by following the stages namely cutting, grinding polishing. Then the specimen is mounted in a metallurgical microscope and the micro structure is observed. The matrix shows the script and spike like eutectics of Al-Si in aluminium solid solution. The matrix also consists of very fine particles of SiC and B₄C which are dispersed uniformly through out the volume. [1,2,18]



Fig. 4. Fabricated MMC rod

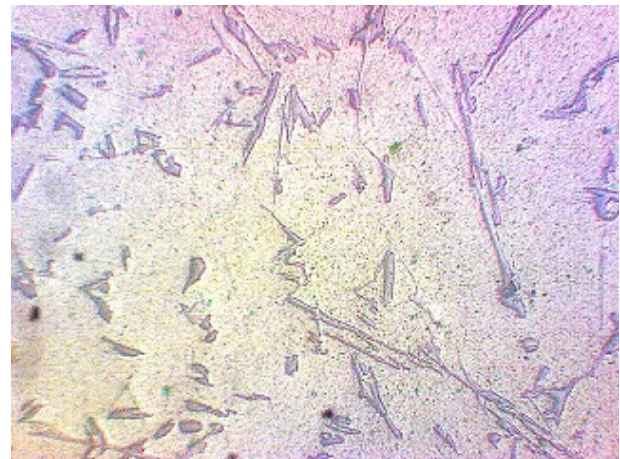


Fig. 5. Magnification 100X

IV. HARDNESS MEASUREMENT AND COMPARISON USING BRINELL:

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds

in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell hardness number is calculated by dividing the load applied by the surface area of the indentation. The Brinell hardness values are obtained from the test results of the fabricated cylindrical rod (Al356+SiC+B₄C) and compared with conventionally available standard BHN values of Al+SiC composite. [14,18]

A. Comparative Analysis of Aluminium Matrix Composites:

The hardness of the fabricated alumina matrix composite (Al 356+SiC+B₄C) has been greatly improved compared to the available Aluminium Silicon Carbide composites with varying proportions. As per literature survey the mechanical properties have also improved substantially. The main advantage of introducing boron carbide as a reinforcement material along with silicon carbide is that, at lower weight ratios it gives improved hardness than the aluminium silicon carbides. In various types of composition Of Aluminium Silicon Carbide composites the highest value of hardness is 45.5 BHN, which is given by 25% SiC

composite. Compared to the other available aluminium silicon carbide composites, the MMC of composition 85% Al 356, 10% SiC, 5% B₄C has shown improved hardness of 62.6 BHN with respect to aluminium silicon carbide composites. [7,8]

B. Evaluation of Surface Roughness:

a. Experimental Procedure:

In this present investigation the experiment is designed by Taguchi method following orthogonal array L₉. The machining parameters considered are cutting speed (v), feed rate (f) and depth of cut (d) each of three levels as shown in Table 4 The dry turning operation is carried out in a medium duty lathe. The surface quality of the machined workpiece is determined by finding the surface roughness values using a Mitutoyo make Surftester instrument. The observed readings are tabulated as shown in Table 5. The evaluation of the surface quality characteristics of Aluminium metal matrix composites require more analysis due to the presence of abrasive phase in the reinforcing SiC and B₄C particles. When it is machined, discontinuous chips are produced, resulting different machining characteristics. The least roughness value (2.244 micrometer) is observed for the experimental

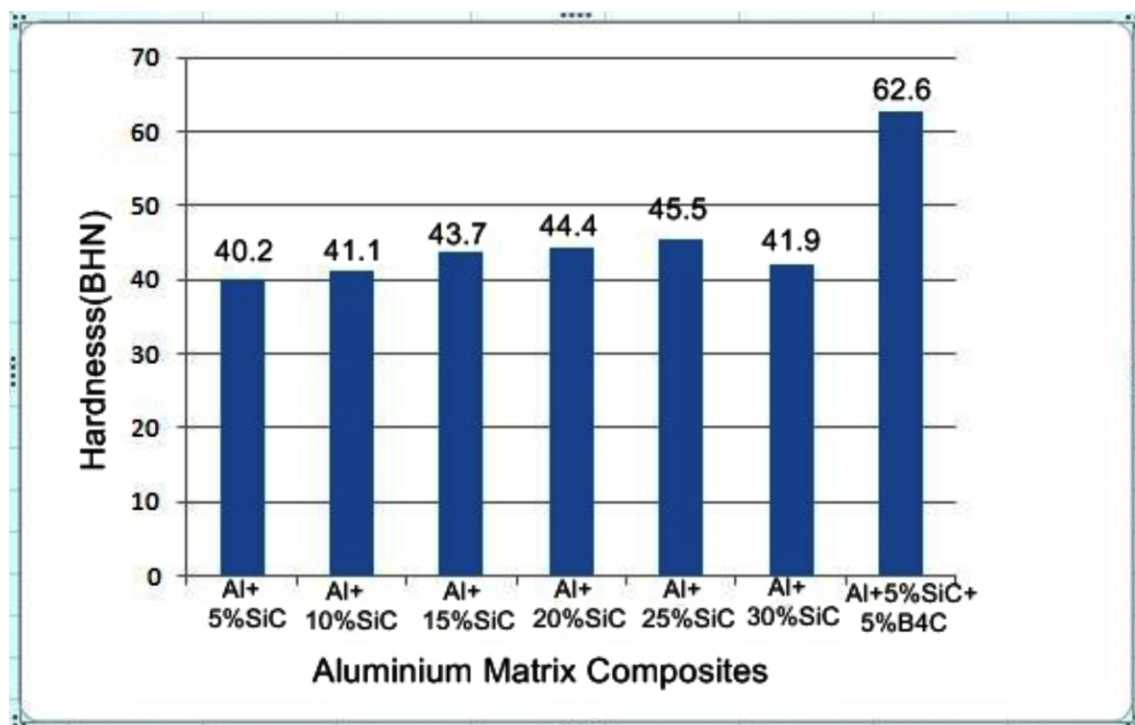


Fig. 6. Comparison Chart

reading (7). The surface roughness pattern is represented as contour plot as shown in fig -7. [9,10,15]

Table 4. Machining parameters & levels

Parameters	Unit	Symbol	Levels		
			1	2	3
Cutting Speed	m /min	v	50	75	90
Feed	mm/rev	f	0.1	0.2	0.3
Depth of Cut	mm	d	0.5	0.75	1.0

Table 5. Taguchi's Experimental Design (L_9) for surface roughness

Sl. No	v m/min	f mm/rev	d mm	Surface Roughness (R_a)			
				R_{a1}	R_{a2}	R_{a3}	R_{aAVG}
1	1	1	1	2.461	3.123	2.941	2.842
2	1	2	2	4.162	7.273	5.122	5.519
3	1	3	3	8.314	5.021	6.444	6.593
4	2	1	2	2.562	2.861	2.612	2.678
5	2	2	3	4.523	4.681	4.821	4.674
6	2	3	1	6.762	6.551	6.841	6.718
7	3	1	3	1.942	2.441	2.361	2.244
8	3	2	1	3.522	3.662	4.032	3.738
9	3	3	2	7.262	6.841	6.241	6.781

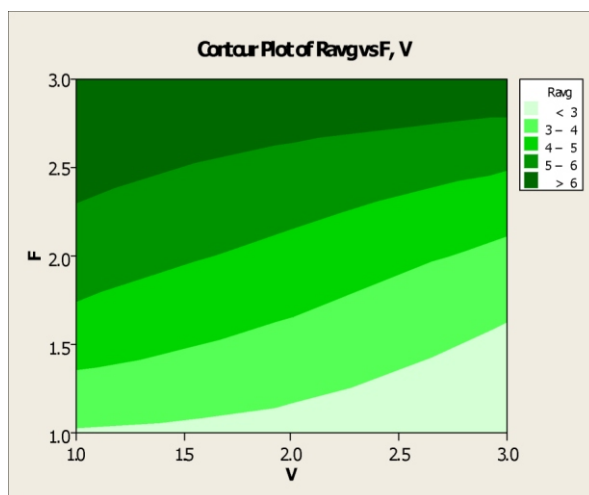


Fig. 7. Contour plot R_a w.r.t. f & v

C. Evaluation of Tool wear:

From the above observations best machining parameter was determined as cutting speed 90 m/min, feed rate 0.1 mm/rev and depth of cut 1.00 mm (experimental reading number – 7). Now setting this cutting condition as a constant parameter and machined the samples for a time duration of 15 minutes and the tool flank wear study was carried out. Tool was monitored for normal types of wear namely flank wear, crater wear and nose wear using a tool maker's microscope. Tool flank wear was caused by abrasive nature of the hard particles present in the work piece. At low cutting speed worn flank encourages the adhesion of work piece material on the tool insert and formed Built-Up-Edge Fig- 6 shows the Scanning Electron Microscope (SEM) image of fresh insert. Fig- 8 shows SEM image of PCD 1600 grade insert after machining the work piece for 15 minute duration. [12,13,16]

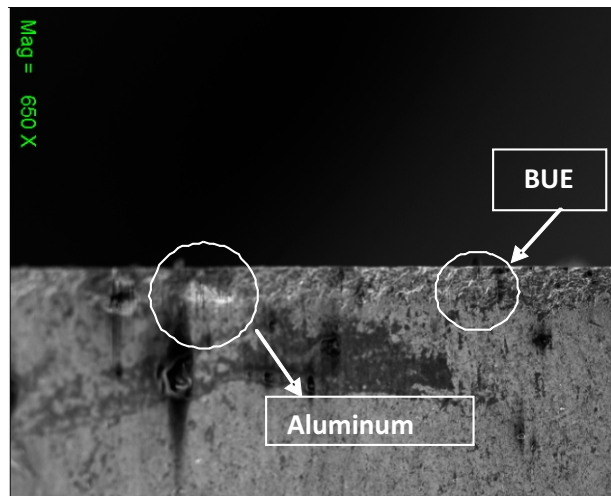


Fig. 8. SEM image of worn out insert

V. CONCLUSION

1. Fabrication of cylindrical rod made of Al-SiC-B₄C is carried out by stir casting method.
2. The Micro structure supports the homogeneous distribution of hard reinforcing particles in the matrix alloy.
3. The Brinell Hardness value is determined and compared with that of Al-SiC composites.

4. The average surface roughness of the machined material is evaluated and observed that the R_{avg} fall in the range of fine finish.
5. The tool wear characteristics of the PCD1600 when turning is also studied using SEM image.

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