DEVELOPMENT AND EVALUATION OF MECHANICAL PROPERTIES OF CHILLED METAL MATRIX COMPOSITE

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Abstract – *Composite Material is a substance which is made up of a combination of two or more different materials. The efforts for developing materials having superior properties lead to the invention of advanced materials which is specified by various conditions like low density, high strength, excellent durability, design flexibility and economical. The chilled metal matrix composite (MMC) materials are prepared by using stir casting technique. Development of chilled Aluminium silicon (Al-Si) alloy based metal matrix composites reinforced with Silicon carbide (SiC) particulates of (400micrometers) mesh size with varying weight percentage of 0% to 9% in steps of three. Experimental study was carried out to investigate the mechanical properties such as hardness, peak load, tensile strength, yield stress, percentage of elongation and microstructure analysis and comparing the results with the base metal. As a result hardness increases with increase in SiC grain sizes. peak load, tensile strength, yield stress increases with the addition of reinforcement. Percentage of elongation decreases with increase in SiC addition. Micro structure analysis shows the particles are tightly packed with a homogeneous spatial distribution in each composite.*

Key Words*: *Metal matrix composite(MMC), Reinforcement, Aluminium silicon alloy (Al-Si), Silicon carbide (SiC), Stir casting.

1. INTRODUCTION

During the past 40 years, materials design has shifted emphasis to pursue lightweight, environment friendliness, low cost, quality and performance. Parallel to this trend, metal matrix composites have been attracting growing interest , metal matrix composites attributes include alterations in mechanical behavior (e.g., tensile and compressive properties, creep, notch resistance and tribology) and physical properties (e.g., intermediate density, thermal expansion and thermal diffusivity) by the filler phase.

To date, much of the research has focused on the high performance lightweight needs of the aerospace industry, where the unique needs of the defense and advanced research organizations render cost a minor factor and reductions in structural weight are affected by reducing the alloy density and increasing its modulus. Composite materials are known as advanced materials for their high strength, high wear resistance, good damping characteristic and their enhanced high temperature performance. Many fields need to replace steel and cast iron in mechanical components with lighter high strength composite materials. Extensive use of composite different manufacturing process and machining conditions sensitive cost and fabrication challenges including machining must be overcome for successful applications of these components. There has been an increase interest in the use of composite materials in the recent past due to its unique physical and mechanical properties.

Reinforced metal matrix composites offer advantages in applications where good capability to withstand relatively high temperature is needed. Aluminum matrix composites possess many advantages such as low specific density, high strength and good wear resistance with the development of some non-continuous reinforcement materials, whiskers, fiber or particulates. Therefore SiC particulate-reinforced aluminum composite have found many applications in aerospace and automotive industries.

Styles C.M et al. [1]reported that particulate silicon carbide (SiC) reinforced aluminum alloys has been observed to posses improved specific strength and stiffness over those of equivalent monolithic materials while maintaining good secondary formability and isotropic properties. Investigations of short fiber, whisker, or particle reinforced alloys were carried out with the purpose of reducing fabrication cost and obtaining materials, which are easy to use and with improved mechanical properties.

Divecha A.P et al. [2] discussed several processing routes in production of aluminium matrix composites reinforced with SiC_W and SiC_P. Casting roots seems to be most attractive out of these methods. Several variants of casting route namely compocasting, liquid pressure forming, spray casting and squeeze casting have been tried successfully to fabricate Al-SiC_W, Al-SiC_P and Al-SiC_f composite.

Vasudevan.M and Surappa M.K [3] They carried out the research on preparation on aluminium matrix composites reinforced with SiC particles by a process, which involved pre-treatment aluminium ingot and SiC particles. This was followed by addition of particles into an impeller-agitated melt. They found out the presence of SiC particles appreciably improved the hardness, elastic modulus, tensile strength. Ductility and fracture toughness significantly less than that of reinforced matrices.

Mc Daneals D.L [4] evaluated the mechanical properties and stress-strain behavior for several types of discontinuous SiC/Al composites, containing SiC-whiskers, nodules and particulate reinforcement. He studied the effects of type of reinforcement, matrix alloy, and reinforcement content by analyzing the stress-strain curves.

David L Davidson [5] conducted the tensile and fracture toughness tests on Al alloy/SiC composite consisting of 15 vol. per cent SiC particulates. Overall tensile elongations values ranged from 1.6 to 2.4 per cent and fracture toughness values from 18.7 to 29.5 MPa. He observed that tensile ductility and fracture toughness were controlled by two factors namely; deformation characteristics of the matrix and SiC particles distribution.

Vincent.C et al. [6] fabricated two different types of composites. The approach, referred to as micro structurally toughened composites, consists of segregating the composite into particle-reinforced regions and continuous ductile toughening regions. Composites consisting of SiC particle-reinforced 6061 Al (SiCp/6061) with monolithic 6061 and pure titanium toughening regions were fabricated.

2. MATERIALS

2.1 Aluminium-12%Si alloy

The material used in the present study is aluminium silicon alloy. Its chemical composition is as shown below, owing to its properties like fluidity, corrosion resistance, better mechanical properties and is heat treatable alloys.

Table -1: Chemical Composition of LM13

Elements	Composition Wt. %
Zn	0.01
Mg	1.0
Si	12
Cu	0.8
Fe	0.2
Ni	1.0
Mn	0.04
Al	Balance

2.2 Silicon carbide

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800°C. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C.

2.3 Mild steel chills

A chill is an object used to promote directional solidification in a specific portion of a metal casting mold. Normally the metal in the mold cools at a certain rate relative to thickness of the casting. When the geometry of molding cavity prevents directional solidification from occurring naturally, a chill can be strategically placed to help promote it. A chill that is commonly used in sand casting is made of iron, which has a higher density thermal conductivity, thermal capacity than the mold material, including iron, copper, bronze, can also be used as chill. Table 2 shows the dimensions of material used for the preparation of chilled metal matrix composite using stir casting technique.

Table -2 : Dimensions of materials used

Pattern preparation	Material	Teak wood
	Dimension	160mm×65mm×25mm
Base material	Material	Al-12%Si alloy
	Dimension	160mm×65mm×25mm
Reinforcement	Material	Silicon carbide (3%, 6%, 9%)
	Dimension	400micrometers
Chills	Material	Mild steel
	Mesh size	160mm×25mm×25mm

3. METHODOLOGY

3.1 Melting

The synthesis of metal matrix composites in the present study was carried out by using stir-casting method. Al-Si (12%) alloy in the form of ingots were used for the trials. The measured quantity of Al-alloy (LM13) is melted in graphite crucible upto 750^0 C (super heated temperature) in electrical resistance furnace of capacity 9KW with temperature controlling device was used for melting.

3.2 Degassing

The super heated molten metal was degassed at temperature of 780^0C of all the gasses, which come in contact with molten aluminium, hydrogen is the only gas dissolvable to a considerable extent. The hydrogen solubility decreases from 0.036 cm^3 per 100 gms of metal as the liquid metal cools down to just below its melting point. The gas, which is rejected during solidification from solution, gets entrapped in the interdendritic region. This ultimately gives rise to porosity in the solidified the presence of porosity in the casting effect the mechanical properties such as tensile strength, yield strength, toughness, ductility and corrosion resistance to a considerable extent. In order to maximize the propertied of solidified casting, it is usual practice to degas melt before pouring into moulds. The usual degassing practice, which is followed in foundries, is to bubble gases like nitrogen and chlorine through melts.

3.3 Impregnation of silicon carbide particulates

Silicon carbide particulates, preheated to around 500^0C were then impregnated to the molten metal at 720^0C and stirred continuously by using mechanical stirrer. The stirring time was maintained at 5 to 8 minutes at an impeller speed of 300 rpm.

3.4 Pouring

The mixture is poured in to the mold cavity in the presence of mild steel chills. The pouring temperature was maintained at 680^0c.The melt was allowed to solidify in the mould. for the purpose of comparison, the base alloy without sic particles was cast under similar processing conditions as described.

3.5 Heat Treatment

Heat treatment can be defined as a combined of heating and cooling operations carried out on a metal or alloys in the solid state so as to produce a particular microstructure and hence the desired properties. Purpose of heat treatment is to refine grain size of the metal, to relive internal stresses, to improve the mechanical properties.

3.6 Formulae

We have, $W=\rho vg$

But, $W=mg$

Therefore, $mg=\rho vg$

i.e., $m=\rho V$

Where, W=Weight of material in kg

ρ= Density of material in kg/m^3

v= Volume of mold in m^3

g= Acceleration due to gravity= $9.81m/s^2$

Table -3 : Particulates composition of different specimens

Sl. No.	Mass of Base metal (A)	Percentage of SiC	Mass of SiC (B)	Total mass of Aluminium (A+B)
1	0.7722	-	-	0.7722
2	0.7492	3 percent	0.023	0.7722
3	0.7262	6 percent	0.046	0.7722
4	0.7032	9 percent	0.069	0.7722

Note: All the mass of materials in kg

Fig -1: casted chilled MMC model

4. PREPARATION OF SPECIMENS FOR TESTING

4.1 Tensile Test

The cast specimens were machined to the dimensions as per ASTM E8-82 standards for UTM tensile testing. The machining involves facing and turning. Before testing, the surface of the specimens was finished by using 400 grid emery sheets. The dimensions of the finished tensile test specimen are as shown in below table 4.

Table -4 : Dimension of tensile test specimen

Sl.no.	Dimensional Parameters	Dimensions in mm
1	Diameter (d)	10
2	Gauge length	35
3	Min Parallel length	75
4	Grip dia (D)	20
5	Grip length	25
6	Radius (R)	5
7	Total length	135

4.2 Hardness Test

The cast specimens were machined to the dimensions of 28 mm×28 mm×15 mm. Preparation of specimen involves turning and polishing of the specimen.

4.3 Microstructure Test Specimen

The specimens used for studying micro structure are in cylindrical shape. The specimens were turned to dimensions of 15mm diameter and 15mm thickness. The stages of preparation of specimen are, Finishing the surface to be analyzed using emery sheets, Polishing the specimen and Etching

5. RESULTS AND DISCUSSIONS

5.1 Tensile Test Results

Tensile test was conducted on chilled MMC in Universal Testing Machine (UTM) for base metal without the addition of reinforcement and three composition of each wt. % of 3%,6% and 9% addition of reinforcement respectively. The results of which are shown in the table 5.

Tensile properties are tabulated in the tabular column (Table 5). Peak load, yield stress and ultimate tensile strength increases with the increasing in percentage of reinforcement(SiC). As the percentage of Sic goes up neck formation becomes vague. The fractured surface of the base material showed cup and cone formation. Brittleness is induced with the introduction of SiC. The reduction in diameter also decreases when the reinforcement percentage is more. The percentage of elongation decreases with increase in SiC addition.

Table -5 : Tensile test results

Sl.NO.	Specimen composition	Peak load in KN	Yield stress in N/mm^2	Ultimate Tensile strength in N/mm^2	% of elongation
1	Base metal	5.44	60.36	68.98	3.30
2	3% of sic	10.16	110.28	129.19	2.28
3	6% of sic	10.92	126.54	139.86	2.06
4	9% of sic	11.09	145.51	149.91	1.26

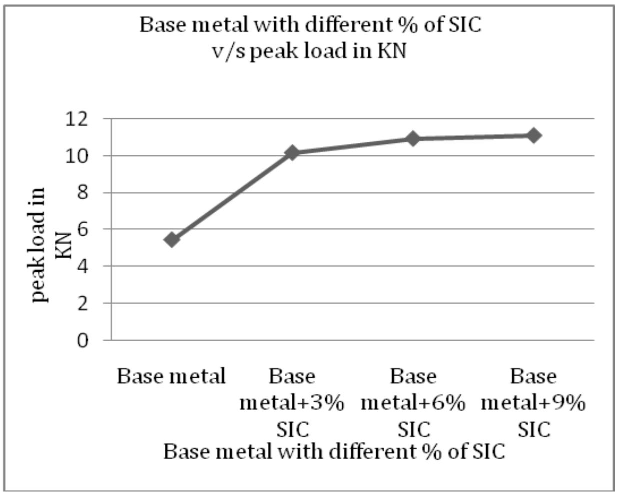

Chart -1: Peak load comparison plot

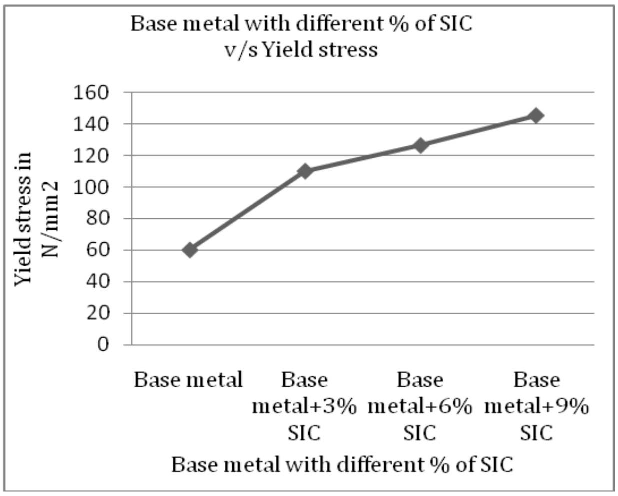

Chart -2: Yield stress comparison plot

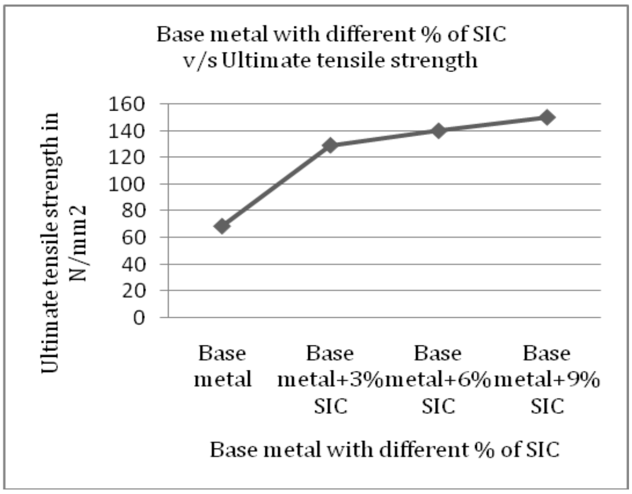

Chart -3: Tensile strength comparison plot

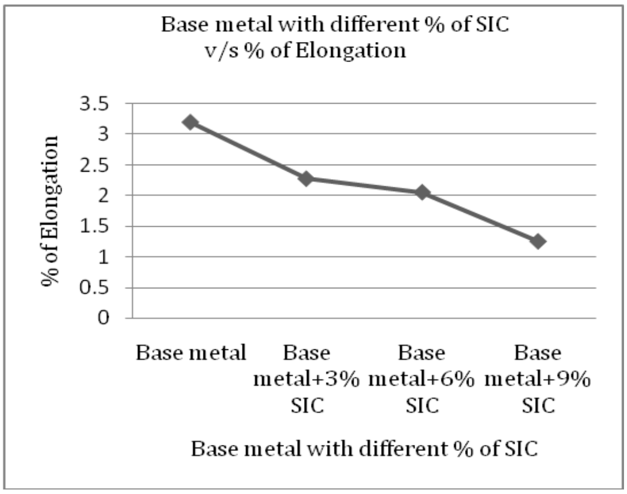

Chart -4: Percentage of elongation comparison plot

5.2 Hardness Test Results

Hardness test was conducted on chilled MMC in Brinells Hardness testing machine for base metal without the addition of reinforcement and three composition of each wt. % of 3%, 6% and 9% addition of reinforcement respectively. The results of which are shown in the tabular column(Table 6.)

Hardness number are tabulated in the above tabular column(table 6). we can see that the hardness increases with increase in SiC grain sizes. This can be attributed to the characteristics of ceramic material added (SiC) as reinforcement, which is extremely hard and brittle. However the machinability and surface finish reduces with the addition of SiC. This can be traced to the inhomogeneous of the mixture.

Table -6 : Brinell Hardness test results

Type of material	Trial no.	Force applied in (kg)	Time taken in (sec)	BHN	Average BHN
Base metal	1 2	1000	15	102 104	103
3% of sic	1 2	1000	15	106 108	107
6% of sic	1 2	1000	15	110 112	111
9% of sic	1 2	1000	5	118 120	119

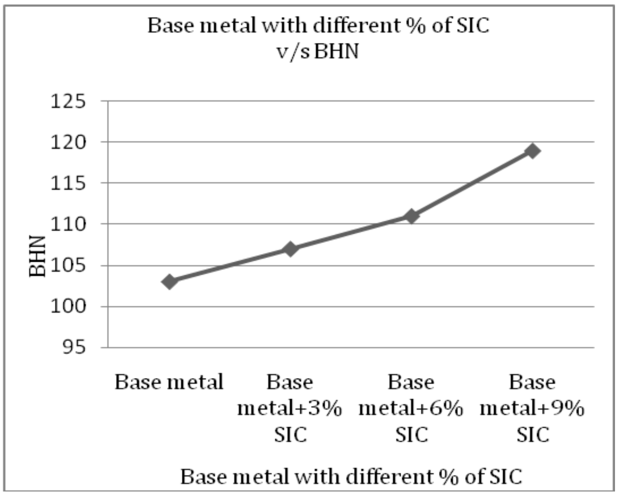

Chart -5: Brinell Hardness number comparison plot

5.3 Microstructure Analysis Test Results

specimens were removed from the metal by specimen cutter. Dry and wet grinding was performed with abrasive belts. Polishing is performed in two stages namely rough and finish polishing. The purpose of etching is to make visible the many structural characteristics of metal or alloy.
The etched specimens observed under the microscope revealed the following structure, by using optical metallurgical microscope.

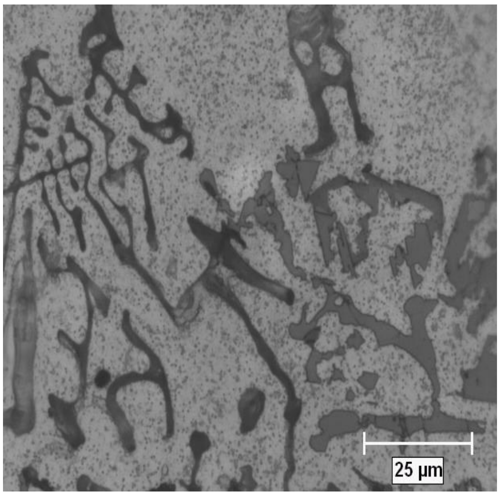

Fig-2: Microstructure of Base metal without chills

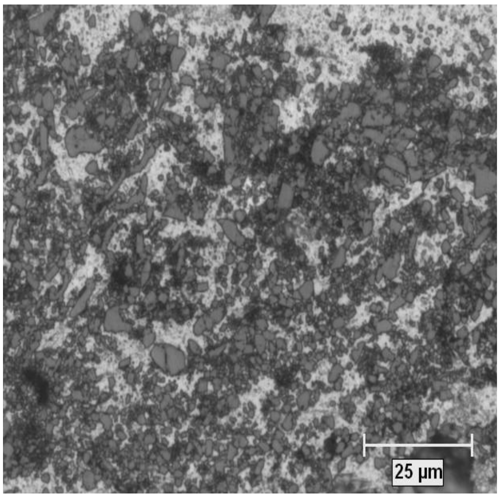

Fig-3: Microstructure of chilled Base metal with3% SiC

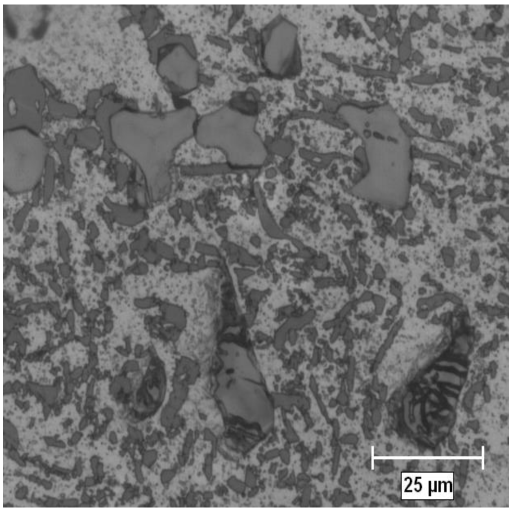

Fig -4: Microstructure of chilled Base metal with 6% SiC

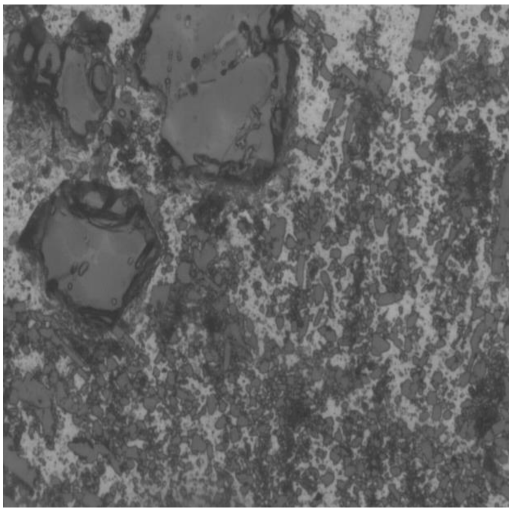

Fig -5: Microstructure of chilled Base metal with 9% SiC

In the microstructure shown above, the aluminium is seen as relatively large and oval grains. Silicon carbide particles can be prominently seen on the top of the surface of aluminium grains as dark spots. The particles are tightly packed with a homogeneous spatial distribution in each composite. The distribution of particulate reinforcement is rather uniform.

6. CONCLUSIONS

Chilled Metal matrix composite was synthesized successfully by using stir casting method with varying weight percentage of SiC particulates (mesh size 400 micro meters) as reinforcement. Tensile test result shows that the ultimate tensile strength values increases in comparison with unchilled base metal, due to chilling effect and increased in weight percentage of SiC.
The percentage of elongation decreases with increase in SiC addition, due to more brittleness of SiC particulates.
Hardness picks up with increasing reinforcement. This can be attributed to the characteristics of ceramic material added SiC as reinforcement, which are extremely hard and brittle. Microstructure revealed near uniform distribution of SiC particles in the center portion of the casting. Microstructure revealed the distribution of SiC particles in the inter-dendritic region between the aluminium grains. SiC particles were prominently seen on the aluminium surface as dark spots. Surface finish also reduced with the increase in percentage of SiC particulates, due to the hard nature of the reinforcement.

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