MECHANICAL TESTING OF AL6061/SILICON CARBIDE METAL MATRIX COMPOSITE

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ABSTRACT

Metal Matrix Composites (MMCs) have evoked a keen interest in recent times for potential applications in aerospace and automotive industries owing to their superior strength to weight ratio and high temperature resistance. The widespread adoption of particulate metal matrix composites for engineering applications has been hindered by the high cost of producing components. Although several technical challenges exist with casting technology yet it can be used to overcome this problem. Achieving a uniform distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite material. In the present study a modest attempt has been made to develop aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two step-mixing method of stir casting technique has been adopted and subsequent property analysis has been made.

Aluminium6061 (97.06% C.P) and SiC (320-grit) has been chosen as matrix and reinforcement material respectively. Experiments have been conducted by varying weight fraction of SiC (2.5%, 5%, and 10%) while keeping all other parameters constant. The results indicated that the 'developed method' is quite successful to obtain uniform dispersion of reinforcement in the matrix. An increasing trend of Tensile Test with increase in weight percentage of SiC has been observed. The results were further justified by comparing with other investigators.

Keywords: *Metal Matrix Composites MMC's, Silicon Carbide SiC.*

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1. INTRODUCTION

History is often marked by the materials and technology that reflect human capability and understanding. Many times scales begins with the stone age, which led to the Bronze, Iron, Steel, Aluminium and Alloy ages as improvements in refining, smelting took place and science made all these possible to move towards finding more advance materials possible.

Progress in the development of advanced composites from the days of E glass / Phenolic radome structures of the early 1940's to the graphite/ polymide composites used in the space shuttle orbiter-is spectacular. The recognition of the potential weight savings that can be achieved by using the advanced composites, which in turn means reduced cost and greater efficiency, was responsible for this growth in the technology of reinforcements, matrices and fabrication of composites. If the first two decades saw the improvements in the fabrication method, systematic study of properties and fracture mechanics was at the focal point in the 60's. Since than there has been an ever-increasing demand for newer, stronger, stiffer and yet lighter-weight materials in fields such as aerospace, transportation, automobile and construction sectors. Composite materials are emerging chiefly in response to unprecedented demands from technology due to rapidly advancing activities in aircrafts, aerospace and automotive industries. These materials have low specific gravity that makes their properties particularly superior in strength and modulus to many traditional engineering materials such as metals. As a result of intensive studies into the fundamental nature of materials and better understanding of their structure property relationship, it has become possible to develop new composite materials with improved physical and mechanical properties.

These new materials include high performance composites such as Polymer matrix composites [1, 2], Ceramic matrix composites [3, 4] and Metal matrix composites [5] etc. Continuous advancements have led to the use of composite materials in more and more diversified applications. The importance of composites as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 200 are composite [6].

A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale.

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

As defined by Jartiz, [7] Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form.

Kelly [8] very clearly stresses that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength or resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them.

Berghezan [9] defines as “The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their shortcomings”, in order to obtain an improved material

Van Suchetclan [10] explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property

1.1 Metal Matrix Composite

Metal matrix composites in general, consist of at least two components, one is the metal matrix and the second component is reinforcement. The matrix is defined as a metal in all cases, but a pure metal is rarely used as the matrix. It is generally an alloy. In the productivity of the composite the matrix and the reinforcement are mixed together.

In recent years, the development of metal matrix composite (MMCs) has been receiving worldwide attention on account of their superior strength and stiffness in addition to high wear resistance and creep resistance comparison to their corresponding wrought alloys. The ductile matrix permits the blunting of cracks and stress concentrations by plastic deformation and provides a material with improved fracture toughness.

Cast composites, where the volume and shape of phases is governed by phase diagrams, i.e. Cast iron and Aluminium-silicon alloys have been produced by foundries for a long time. The modern composites differ in the sense that any selected volume, shape and size of reinforcement can be introduced into the matrix. The modern composites are non-equilibrium mixtures of metals and ceramics where there are no thermodynamic restrictions on the relative volume percentages, shapes and size of ceramic phases [15].

The high toughness and impact strength of metals and alloys such as aluminum, titanium, magnesium and nickel-chromium alloys which undergo plastic deformation under impact is of interest in many dynamic structural applications of metallic composites. These materials have also been strengthened considerably by means of various strengthened principles (like grain boundary strengthening, cold working, solid solution strengthening, etc.) to improve their properties. But these approaches are often found to affect the toughness and durability at elevated temperatures and/or under dynamic service conditions. One of the important objectives of metal matrix composites, therefore, is to develop a material with a judicious combination of toughness and stiffness so as to decrease the sensitivity to cracks and flaws and at the same time increase the static and dynamic properties.

This necessity eventually leads to the efficient reinforcement of metals and metal alloys by uni or multidirectional implantation of whiskers or continuous fibers. The reinforcement effect occurs due to the extraordinary high strength of whiskers and fibers with diameters below a few micrometers. Thus, the field of Metal Matrix Composite (MMCs) began in the mid of 1960’s with the realization that whisker reinforced MMCs can be competitive with continuous fiber reinforced composites [16], from the standpoint of mechanical properties [17].

The complex fabrication routes, limited fabricability [17, 18] and the small difference in property enhancement between whisker and particulate reinforcement [19] and moreover, the health hazards associated with handling SiC whiskers [20, 21] have shifted the emphasis recently more towards particulate or chopped fibers rather than whisker reinforcement of metals, especially aluminium, because of its light weight and good wettability with silicon carbide [22]. The important shift in metal matrix composite technology began in the mid 80’s with more and more discontinuous reinforcement taking the place of continuous reinforcement such as carbides, nitrides, oxides and elemental materials like carbon and silicon

While discontinuous whisker reinforced MMCs are still under development for aerospace applications, automotive components fabricated from particulate and discontinuous fiber reinforced MMCs, which exhibit essentially isotropic properties, are already in mass production, led by the introduction of diesel piston by Toyota in 1983 followed more recently by engine and cylinder blocks from Honda [23,24].

1.2 Material Selection (Matrix Material)

Lloyd, Riek, enlightens that the matrix alloy should be chosen only after giving careful consideration to its chemical compatibility with the reinforcement, to its ability to wet the reinforcement, and to its own characteristics properties and processing behaviour [28, 29].

One very crucial issue to consider in selection of the matrix alloy composition involves the natural dichotomy between wettability of the reinforcement and excessive reactivity with it [45]. Good load transfer from the matrix to the reinforcement depends on the existence of a strongly adherent interface [46, 47]. In turn, a strong interface requires adequate wetting of the reinforcement by the matrix. However, the attainments of wetting and aggressive reactivity are both favored by strong chemical bonding between the matrix and reinforcement. Adjusting the chemical composition to accomplish this delicate compromise is difficult as many subtleties are involved.

1.3 Why Aluminium Matrix Selection

MMC materials have a combination of different, superior properties to an unreinforced matrix which are; increased strength, higher elastic modulus, higher service temperature, improved wear resistance, high electrical and thermal conductivity, low coefficient of thermal expansion and high vacuum environmental resistance. These properties can be attained with the proper choice of matrix and reinforcement.

Composite materials consist of matrix and reinforcement. Its main function is to transfer and distribute the load to the reinforcement or fibres. This transfer of load depends on the bonding which depends on the type of matrix and reinforcement and the fabrication technique.

Lowshenko, Kunter, Jangg, explain certain fundamentals that the matrix can be selected on the basis of oxidation and corrosion resistance or other properties [34]. Generally Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn and Si are used as the matrix material, but Al, Ti, Mg are used widely.

Sarala, Jean, Claude, suggest that now a day’s researchers all over the world are focusing mainly on Titanium [30] has been used in aero engines mainly for compressor blades and discs due to its higher elevated temperature resistance properly.

The reason for aluminium being a success over magnesium is said to be mainly due to the design flexibility, good wettability and strong bonding at the interface

1.4 Reinforcement

Reinforcement increases the strength, stiffness and the temperature resistance capacity and lowers the density of MMC. In order to achieve these properties the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix and the following aspects must be considered while selecting the reinforcement material.

- Size – diameter and aspect ratio:
- Shape – Chopped fiber, whisker, spherical or irregular particulate, flake, etc:
- Surface morphology – smooth or corrugated and rough:
- Poly – or single crystal:
- Structural defects – voids, occluded material, second phases:
- Surface chemistry – e.g. SiO_2 or C on SiC or other residual films:
- Impurities – Si, Na and Ca in sapphire reinforcement;
- Inherent properties – strength, modulus and density.

Even when a specific type has been selected, reinforcement inconsistency will persist because many of the aspect cited above in addition to contamination from processing equipment and feedstock may vary greatly [31-33]. Since most ceramics are available as particles, there is a wide range of potential reinforcements for particlereinforced composites [34-38].

Zhang, Perez, gungor et al, explain the use of graphite reinforcement in a metal matrix has a potential to create a material with a high thermal conductivity, excellent mechanical properties and attractive damping behaviour at elevated temperatures [39]. However, lack of wettability between aluminium and the reinforcement, and oxidation of the graphite [40] lead to manufacturing difficulties and cavitations of the material at high temperatures. Alumina [41] and other oxide particles like TiO_2 [42] etc. have been used as the reinforcing particles in Al-matrix. Alumina has received attention as reinforcing phase as it is found to increase the hardness, tensile strength and wear resistance [43] of aluminium metal matrix composites. Rohatgi and co-workers [44-46] have studied mica, alumina, silicon carbide, clay, zircon, and graphite as reinforcements in the production of composites.

It is proven that the ceramic particles are effective reinforcement materials in aluminium alloy to enhance the mechanical and other properties [47-49]. The reinforcement in MMCs are usually of ceramic materials, these reinforcements can be divided into two major groups, continuous and discontinuous. The MMCs produced by them are called continuously (fibre) reinforced composites and discontinuously reinforcedcomposites. However, they can be subdivided broadly into five major categories: continuous fibres, short fibres (chopped fibres, not necessarily the same length), whiskers, particulate and wire (only for metal). With the exception of wires, reinforcements are generally ceramics, typically these ceramics being oxides, carbides and nitrides. These are used because of their combinations of high strength and stiffness at both room and elevated temperatures. Common reinforcement elements are SiC, $A1_20_3$, TiB_2, boron and graphite.

2. DESIGN, DEVELOPMENT AND FABRICATION OF COMPOSITE

2.1 Objectives:

1. Design and Development of Mould
2. Fabrication of AL6061/SiC MMC
3. Experimental Analysis of Mechanical Properties of MMC on UTM

2.2 Design Requirements For Casting Of Composite

The following principles of casting design must be observed to obtain sound castings

1. The form of casting should allow free withdrawal of the pattern from the mould. This may be accomplished by allowing a draft on the vertical surfaces of casting, the draft value being taken as a function of the surface height. For internal surfaces, draft values should be higher that those of external ones.
2. The position of the surfaces of the casting, when the metal is poured, is a major factor. It is necessary to avoid large horizontal surfaces at top of the mould, since gas evolved by the metal and in the mould may get trapped and cause cavities and pinholes in the casting.
3. The form of casting should ensure unimpeded filling of the mould with molten metal, both in the direction and velocity of flow.
4. Other important factors in casting design are shrinkage and its restriction by the friction of the mould and cores, as well as restriction by the difference in the rate of cooling of different parts of the casting.
5. The form of casting should be such that all the feeding heads, risers, runners, sprues and gates can be easily cut off, all cores knocked out and core irons are removed.
6. The size and weight of casting, the type of alloy employed, and the casting method should be taken into account while designing the wall thickness of the casting.
7. Rib design depends upon overall dimension of the casting and their size is in definite relation with the wall thickness.
8. The rate of cooling for outside corners is always greater than that of inside corners.
9. Bosses are provided at places where holes are to be drilled to reinforce the walls of the casting.

2.3 Design of The Composite

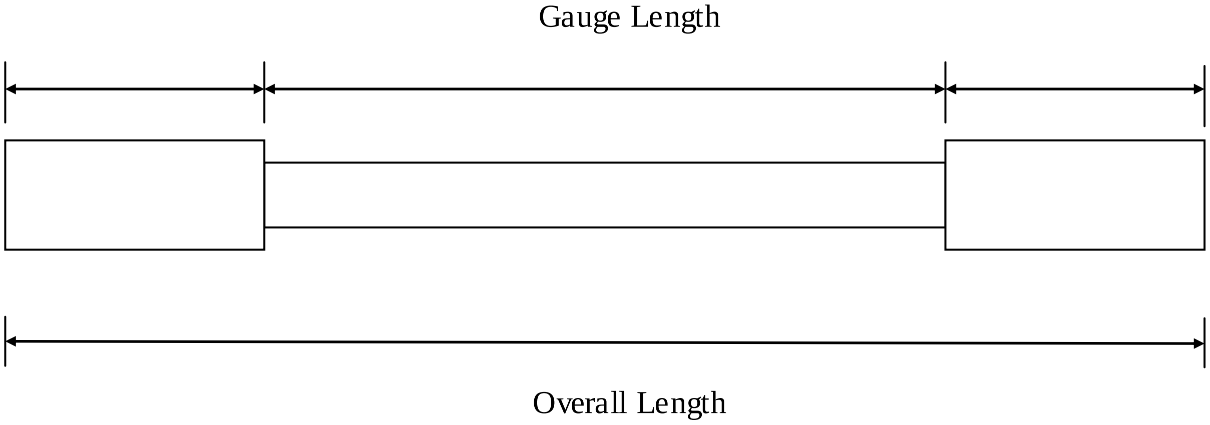


Figure 2.3.1 Test Specimen

Gauge Diameter: 15mm

Gauge Length: 75 mm

Overall Length: 175 mm

2.4 Development and Fabrication of Composite

2.4.1 Pattern and Mould Making

Figure 3.3.1.1 pattern is produced on lathe Figure 3.3.1.2 Finished Pattern of Test Bar

Firstly pattern is made as per the drawings of test bar from wood on lathe machine. Then the pattern is used to produce the moulds in Green sand specifically used for mould making then add some binder like molasses and bentonoite to make it little sticky add water as per requirements and mix it properly manually or electric operated mixer

Finally the pattern is placed in mould and sand is poured in the mould to get the required shape of pattern. Moulds are ready after some preparations figure 3.3.1.3 shows the finished moulds.

Figure 3.3.1.3 Final prepared moulds with cavity

2.4.2 Chemical Compositon of Aluminuim 6061 and Silicon Carbide (SiC)

2.4.2.1 Chemical Composition of AL 6061

Table 3.3.2.1 shows the percentage of different elements in AL 6061

Weight (%)	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others
6061	Bal.	0.40-0.80	0.70 max	0.15-0.40	0.15	0.8-1.2	0.04-0.35	0.25 max	.15 max	.05 max

Figure 3.4.2.1.1 AL 6061

2.4.2.2 Chemical Compostion of SiC

Table 3.3.2.2 shows the percentage of different elements in SiC (320 grit)

Weight (%)	SiC	SiO2	Si	Fe	Al	C
320 grit	98.73	0.48	0.3	0.09	0.1	0.3

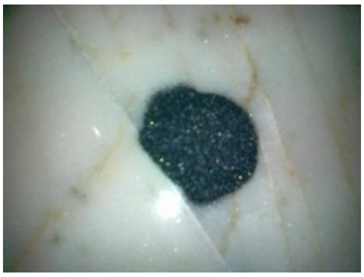


Figure 3.4.2.2.1 SiC (320 grit)

2.4.3 Casting Process

The melting was carried in a tilting oil-fired furnace in a range of 760 ± 100C. A schematic view of the furnace has been shown in Figure 3.4.3.1

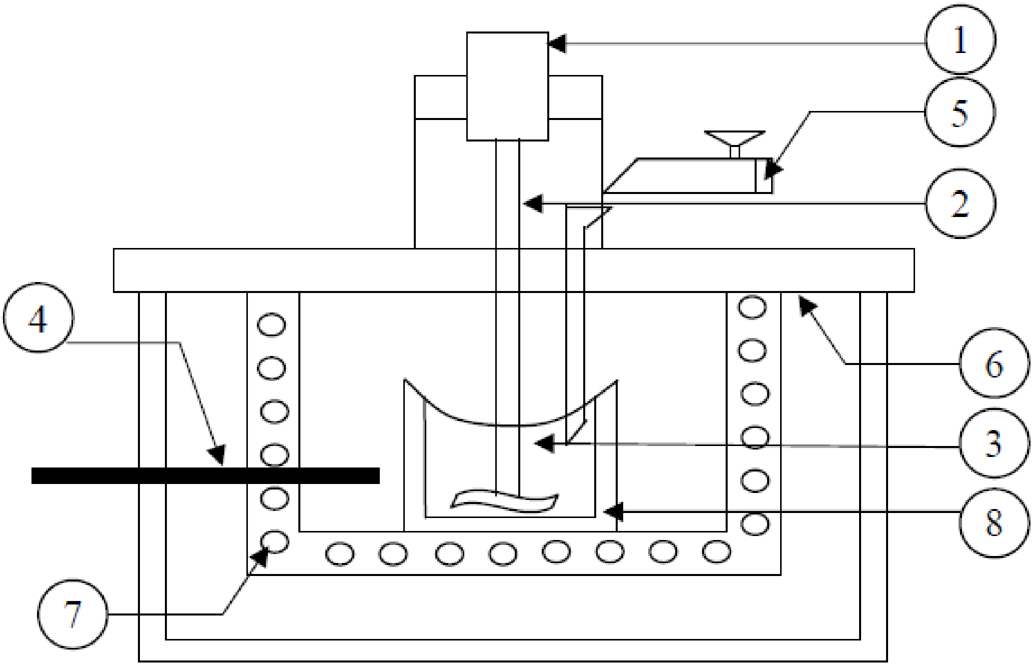


Figure 2.4.3.1 Stir casting Process [62]

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

In the present study, an oil fired tilting furnace has been used. The crucible material was graphite. Diesel was used as the fuel. A forced draft fan equipped with 02 H.P 2820-rpm motor has been used for supplying the required quantity of air. Aluminium was preheated up to a temperature of 450°C and particles of silicon carbide up to a temperature of 110°C in core drying oven. Crucible used for pouring of composite slurry in the mold was also heated up to 760°C.

In the present study, a new stir caster was developed to fabricate MMC. It has been used to obtain an output of 600 rpm [50]. The stir caster was mounted on the furnace with the help of four legs. Mild steel was chosen as stirrer and impeller material. During experimental work, a four bladed 45° angled stirrer was chosen. The stirrer position should be such that 35% of material should be below the stirrer and 65% of material should be above the stirrer [51]

First of all stirring system has been developed by coupling motor with gearbox and a mild steel stirrer. All the melting was carried out in a graphite crucible in an oil-fired furnace. Aluminium were preheated at 450°C for 3 to 4 hours before melting and mixing the SiC particles were preheated at 110°C for 1 to 3 hours to make their surfaces oxidized.

The furnace temperature was first raised above the liquidus to melt the alloy scraps completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed manually. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state.

After sufficient manual mixing was done, the composite slurry was reheated to a fully liquid state and then automatic mechanical mixing was carried out for about 10 minutes at a normal stirring rate of 600 rpm [50]. In the final mixing process, the furnace temperature was controlled within 760° ± 100°C.

3. EXPERIMENTAL PLANNING

3.1 Tensile Test

Although tensile testing is not recommended in examining the fracture behavior of SiC reinforced aluminum composite, tensile tests were performed to get stress – strain graphs, to find out Young's Modulus and ultimate tensile strength values. But unfortunately, specimens fractured in the early stages of tensile tests and lower strength values were obtained. Almost all specimens broken from the curved parts. Agglomeration of silicon carbide particulates was observed in some of the tensile test specimens

APPARATUS: Universal Testing Machines, Dumbbell Test Specimen, Micro Meter 0-25 mm, Vernier Caliper 0-25cm.

SPECIFICATION:	Maximum capacity	200kN
	Number of Graduation	500
	Range	0-200kN, minimum graduation 0.4kN
	Range	0-100kN, minimum graduation 0.2kN
	Range	0-50kN, minimum graduation 0.1kN
	Range	0-20kN, minimum graduation 0.04kN

Working hydraulically operated and driving is profound by the help of electric motor.

DESCRIPTION: Universal testing machine serves for conducting tests in tension, compression, bending, shearing and flexural tests can be performed on these machines with suitable grips and fixtures for metal and other materials.

These machines re designed for testing various materials like rubber, plastics, cables, leather, paper, ploy wood and metals. These machines are powder coated for elegant look and each critical component is plated for rust prevention and durability.

The test machines are hydraulically operated and driving is performed by the help of electric motor. The machines are equipped with pendulum dynamometer, recording device for registering load deformation diagram.

SALIENT FEATURES:

- High accuracy of (+/- 1%) as per IS1828
- Four measuring ranges for accurate testing
- Easy to operate and less maintain
- Attachment for conducting compression, bending, shear tests
- Different range of grips for various materials and shapes
- In corporate with requisite safety devices
- Variable speed to suit various materials
- High reading accuracy due to large size design of dial
- Enables testing of standard specimens as well as structures

THEORY: A tensile test also known as tension test is probably the most fundamental type of mechanical test you can perform on material. Tensile test are simple, relatively in expensive and fully standardized. As the material is pulled, you will find its strength along with how much it will elongate.

PROCEDURE:

1. Select the proper jaw, insert and complete the upper and lower chuck assemblies.
2. Take necessary reading for diameter and gauge length of the test piece.
3. Then operate the upper cross head grip operation handle and grip fully the upper end of the test piece.
4. The left valve in fully closed position and right valve in normal open position.
5. Open the right side valve and close it after the lower table is slightly lifted. Now adjust the lower pointer to zero with the zero adjusting knob.
6. Then turn the right control valve slowly to open position until you get desired loading rate.

7. Operate the lower grip operation handle and lift the lower cross head up and grip fully he lower part of the specimen. Then lock the jaws in this position by jaw locking handle.
8. When the specimen under load, unclamp the locking handle.
9. Notice the occurrence of yield point by indication of load pointer.
10. When the rest piece is broken, close the right control valve, and take out the broken test piece. Then open the left control valve to take the piston down.
11. Note down the maximum load, pointer shows the maximum capacity of the specimen.

OBSERVATIONS:

Table 3.3.3

S.No.	Material of Test piece	Gauge Diameter of Test specimen, mm	Cross sectional area, mm^2	Load at yield point, N	Ultimate load, N	Gauge Length, mm	Increase in length, mm
1.	AL6061/SiC (2.5p)	15	176.625	1800	7000	75	84
2.	AL6061/SiC (5.0p)	15	176.625	2900	9200	75	89
3.	AL6061/SiC (10.0p)	15	176.625	3500	12200	75	93

CALCULATIONS:

Tensile strength (N/mm^2): Ultimate Load (N) / Cross Sectional Area in mm^2

Yield Stress (N/mm^2): Yield Load (N) / Cross Sectional Area in mm^2

Elongation (%): {(Increase in length – Original length) x 100} / Original length.

Table 3.3.4

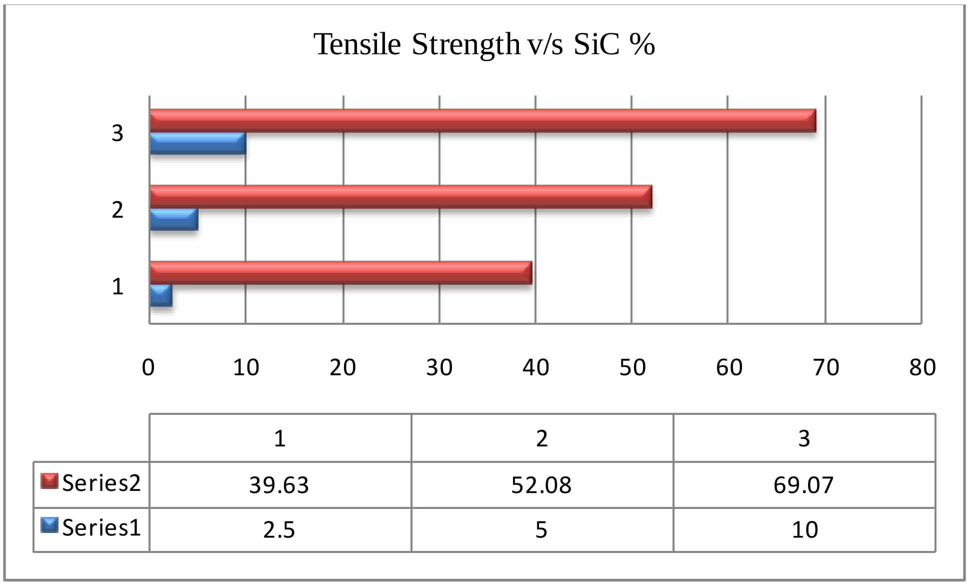
S.No.	Material of Test Piece	Tensile Strength, (N/mm^2)	Yield Stress (N/mm^2)	Elongation (%)
1.	Al6061/SiC (2.5p)	39.63	10.19	11.25
2.	Al6061/SiC (5.0p)	52.08	16.41	17.50
3.	Al6061/SiC (10.0p)	69.07	19.81	22.50

PRECAUTIONS:

1. Apply the load in a uniform rate without any jerk.

2. Load should not go beyond the capacity of machine.
3. Always check the grips which should be as per the specimen.
4. The specimen should fail within 20% to 80 % of the scale range selected.
5. Check the oil level in the tank.

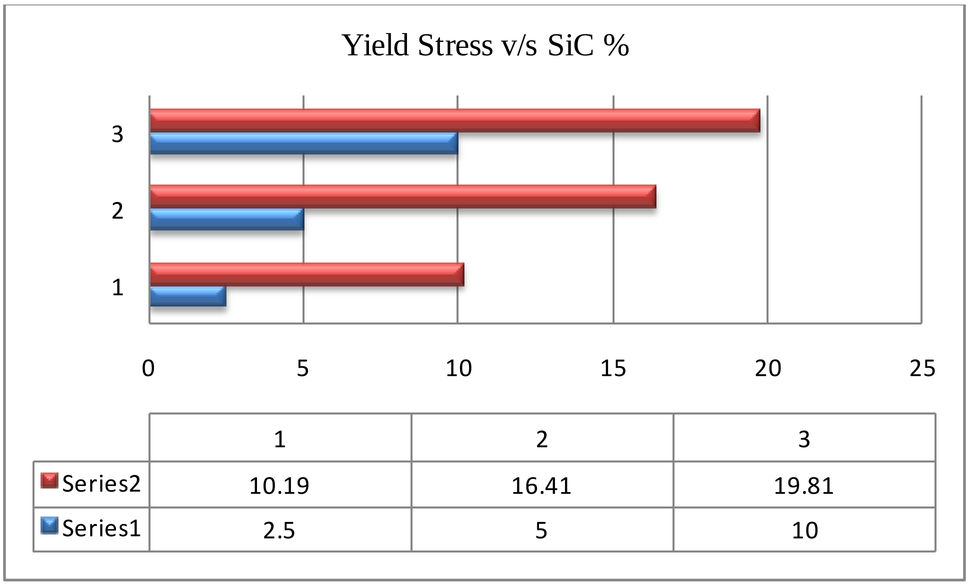
RESULTS AND DISCUSSIONS



	1	2	3
🟥 Series2	39.63	52.08	69.07
🟦 Series1	2.5	5	10

Graph 4.1.1 Show the variation of Tensile Strength (series 2) with increase in SiC (series 1) at various percentage

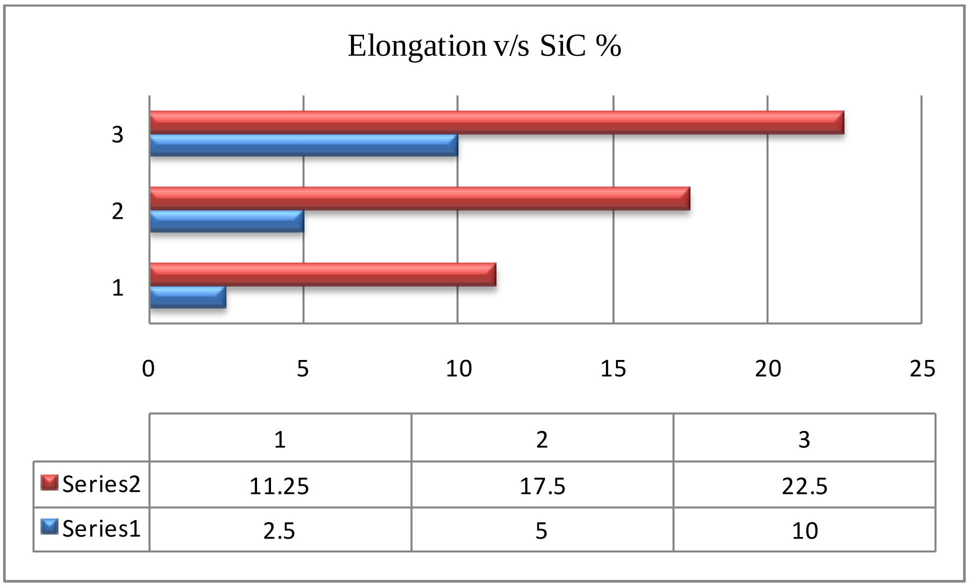
In Graph 4.1.2 their is increase in tensile strength of composite as the percentage of SiC is increased. The maximum value is obtained at 10% of SiC addition in AL 6061, the value is 69.07 N/mm^2 at minium is obtaien at 2.5% additon of SiC, the value is 39.63 N/mm^2



	1	2	3
🟥 Series2	10.19	16.41	19.81
🟦 Series1	2.5	5	10

Graph 4.1.2 Show the variation of Yield Stress (series 2) with increase in SiC (series 1) at various percentage

In Graph 4.2.2 their is increase in value of yield stress of composite as the percentage of SiC is increased. The maximum value of yiels stress is obtained at 10% of SiC addition and value is 19.81 N/mm^2 and minimum value is 10.19 N/mm^2 obtained at 2.5% of SiC addition in AL 6061.



	1	2	3
🟥 Series2	11.25	17.5	22.5
🟦 Series1	2.5	5	10

Graph 4.1.3 shows the variation of the Elongation (series 2) with increase in SiC (series 1) at various percentage.

In Graph 4.1.3 their is increase in elongation from 11.25% to 22.5% as the addition of SiC is increased from 2.5% to 10% respectively.

Figure 4.1.1a Al6061/SiC composite Test Bars

Figure 4.1.1b Test bar under Tensile Test

1. The results of study suggest that with increase in composition of SiC, an increase in tensile strength, yield stress and elongation have been observed.
2. The maximum value has been obtained at 10% weight fraction of 320 grit size SiC particles. Maximum tensile strength = 69.07 N/mm^2, Maximum yield stress = 19.81 N.mm^2, and Maximum elongation = 22.50 %

Figure 4.1.1c Test bar under Tensile Test

Figure 4.1.1d Readings noted during Test

Figure 4.1.1e Test bar after Tensile Test

3. Homogenous dispersion of SiC particles in the Al matrix shows an increasing trend in the samples prepared by stir casting technique

REFERENCES

1. A.K.Dhingra, (1986) “metal replacement by composite”, *JOM*, Vol 38 (03), p. 17.
2. K.Upadhya, (1992) “composite materials for aerospace applications, developments in ceramic and metal matrix composites”, Kamaleshwar Upadhya, warrendale, PA: TMS publications, pp. 3-24.
3. Greg Fisher, (1993) “Composite: Engineering the ultimate material”, Am. Ceram. Soc, Bull. Vol. 63 (2), pp. 360-364.
4. T.G.Nieh, K.R. Forbes, T.C. Chou and J. Wadsworth, (1990) “Microstructure and deformation properties of an Al_2O_3-Ni_3Al composite from room temp to 1400°C”, High performance Composites for the 1990’s Eds. S. K. Das, C. P. Ballard and F. Marikar, TMS-New Jersey, pp 85-96.
5. T. W. Clyne, (2000) “An Introductory Overview of MMC System, Types and Developments, in Comprehensive Composite Materials,” Vol-3; Metal Matrix Composites, T. W. Clyne (ed), Elsevier, pp.1-26.
6. L.M.Manocha & A.R. Bunsell, (1980) “Advances in composite materials”, Pergamon Press, Oxford, , Vol.2, p 1233-1240.

7. Jartiz, A.E., Design 1965, pp. 18.
8. Kelly, A. (1967) Sci. American 217, (B), 161.
9. Berghezan, A. Nucleus, 8(5), 1966, (Nucleus A. Editeur, 1, rhe, Chalgrin, Paris, 16(e).
10. Van suchetclan, Philips (1972), Res. Repts. Vol. 27., pp. 28.
11. B.D.Agarwal and L.J.Broutman, (1980), "Analysis and performance of fiber composites" John Wiley & Sons, New York, pp.3-12.
12. J.O.Outwater, (1956), "The Mechanics of Plastics Reinforcement Tension", Mod. Plast: March.
13. R.Wetter, (1970), "Kunststoffe in der Luft-und Raumfahrt", Kunststoffe, 60, Heft 10
14. P.H.Selden, (1967), "Glasfaserverstarkte Kunststoffe", SpringerVerlag,.
15. Pradeep Rohatgi, IUNIDO's State-of-the-art series: (1990), "Advances in Materials Technology: MONITOR", Compiled by the Industrial Technology Development Division Department of Industrial Promotion, Vienna, Austria, No.17, Feb.
16. N.J. Parrat, (1964), "Reinforcement effects of Silicon Nitride in Silver and Resin Matrices", Powder Metallurgy, Vol. 7(14), pp 152-167.
17. R. R. Irving, (1986), "Composites Go After Commercial Markets", Iron Age, Sept.5th, pp 35 38.
18. A. Mortensen, J.A. Cornie and M. C. Flemings, (1988), "Solidification processing of Metal Matrix Composites", JOM, Vol. 40(2), p 12-19.
19. D.L. McDanels and C.A. Hoffman, (19840, "Microstructure and orientation effects on properties of discontinuous Silicon Carbide/ Aluminum Composites" NASA Tech. Pap. 2303, Cleveland, OH, , pp 1-29.
20. J.L. Cook and Walter R. Mohan, (1987) "Whisker-reinforced MMCs' Metal, Carbon / Graphite and Ceramic Matrix Composites", pp 896-902.
21. Milton W. Toaz, "Discontinuous Ceramic Fiber MMCs" International Encyclopedia of Composites, Vol. 3. ed. Stuart M. Lee, VCH Publishers, NY, p. 903-910.
22. D. L. McDanels and A. R. Signorelli, (1983), "Evaluation of low cost Aluminum Composites for Aircraft engine Structural Applications", NASA Tech. Memo. No. 83357, Washington, DC.
23. William J. Baxter, (1992), "The strength of MMCs Reinforced with Randomly oriented Discontinuous Fibers", Mett. Tran. Vol. 23A, Nov., pp 3045-3053.
24. David M. Schuster, Michael D. Skibo and Williams R. Hoover, (1989) "Production and Semi-Fabrication of an Aluminum Composite Material", Light Metal Age, Feb., pp 15-19.

25. S. Skolianos. *Mater. Sci. Eng.* **A210** (1990), pp. 72–82.
26. Shen, Y.L., Williams, J.J., Piotrowski, G., Chawla, N. and Guo, Y.L. (2001), "Correlation between tensile and indentation behavior of particle reinforced metal matrix composites: a numerical and experimental study," Acta Materialia, Vol. 49 (16), pp. 3219- 3229.
27. Poletti C, Merstallinger A, Schubert T, Marketz W, Degischer HP. (2004), "Materialwissenschaft und Werkstofftechnik";35:741–9.
28. R. Mehrabian, R.G. Riek and M. C. Flemings, (1974), "preparation and casting of Metal- Particulate Non-Metal Composites," Metall. Trans, Vol. 5A, , pp 1899-1905.
29. D. J. Lloyd, "Particulate Reinforced Composites Produced by Molten mixing," High Performance Composites for the 1990's, eds. S.K.Das, C.P. Ballard and F.Marikar, TMS-New Jersey, 1990, pp 33-46.
30. Djanarthany Sarala, Viala Jean-Claude, Bouix Jean. Mater Sci Eng A 2001;300(12):2118
31. N.Eustathopoulos, D.Chatain and L.Coudurier, (1991), "Wetting and Interfacial Chemistry in Liquid Metal Ceramic Systems", Mat.Sci and Engg. Vol.135A, pp 83-88.
32. R.J.Arsenault, (1984), 'The Strengthening of Al Alloy 6061 by Fiber and Platelet Silicon Carbide,' Mat. Sci. Engg., Vol. 64, pp171-181.
33. I.Adeqoyin, F.A.Mohamed and E.J.Lavernia, (1991), "Particulate Reinforced MMCs- A Review", J. Mat Sci., Vol.26, pp1137-1156.
34. Von F. Lowshenko, F. Kunter and G.Jangg, (1997), "Eigenschaften Von Dispersion geharteten Al-Al_4C_3 Werkstoffen", Planseeberichtefur Pulvemattallurgie, Bd. Vol.25, pp. 205-213.
35. R. Tiwari, H. Herman, K. Kowalsky and D.R. Marantz, (1990), "Mechanical behaviour of thermal sprayed Metal-Matrix Composites", High Performance Composites for the S.K.Das, C.P. Ballard and F. Marikar, TMS-New Jersey, 1990, p 195.
36. A.H. Nakagawa and M.N.Gungor, (1990) "Microstructure and Tensile properties of $A_{12}O_3$ Particle Reinforced 6061 Al Cast Composites", eds. P.K.Liaw and M.N.Gungor, "Fundamental Relationship Between Microstructure and Mechanical Properties of MMCs", The Minerals, Metals & Materials Society, pp 127-143.

37. A. K. Kuruvilla, V.V. Bhanuprasad, K. S. Prasad and Y.R. Mahajan, (1989) "Effect of different reinforcements on Composite-strengthening in aluminium", Bull. Mater. Sci., Vol. 12(5), , pp 495-505.
38. R.L. Mehan, (1968) "Fabrication and Evaluation of Sapphire Reinforced Al Composites", Metal Matrix Composites, ASTM-STP, Vol. 438, pp 29-58.
39. J. Zhang, R.J. Perez, M. N. Gungor and E.J.Lavernia, (1992) "Damping Characteristics of Graphite Particulate Reinforced Aluminium Composites", Developments in Ceramics and Metal Matrix Composites. Kamleshwar Upadhya, ed., Warrendale, PA: TMS Publication, pp 203-217.
40. Thomas D. Nixon and James D.Cawley, (1992) "Oxidation Inhibition Mechanisms in coated Carbon-Carbon Composites", J. Am. Ceram. Soc., Vol. 75(3), pp 703-708
41. M.V Ravichandran. R.Krishna Prasad and E.S.Dwarakadasa, J. Mater. Sci. Letts; Vol-11, 1992, p.452.
42. P.K.Balasubramanian, P.Srinivasa Rao, et.al. J.Mater.Sci.Letts., Vol-8, 1989, p.799.
43. J.Singh, S.K.Goel, V.N.S.Mathur and M.L.Kapoor; (1991)J.Mater. Sci., Vol-26..
44. Deonath and P.K.Rohatgi, (1980) 'Fluidity of Mica Particle Dispersed Aluminum Alloy: J. Mat. Sci., Vol. 15,. pp 2777-2784.
45. Deonath, R.T.Bhat and P.K.Rohatgi, (1980) "Preparation of Cast ALLOY-Mica Particle Composites": J. Mater. Sci., Vol. 15, pp.1241-1251.
46. M.K.Surappa and P.K.Rohatgi, (1981) 'Preparation and Properties of Cast Aluminum Ceramic Particle Composites, 'J.Mat. Sci., Vol.16, pp.983-993.
47. A.Banerji, M.K.Surappa and P.K.Rohargi, (1983) "Cast Aluminum Alloys Containing Dispersions of Zircon Particle", 'Metall. Trans. Vol. 14B, PP.273-283.
48. M.Taya and R.J.Arsenault, (1989), "Metal Matrix Composites–Thermo mechanical behaviour" New York, Pergmon Press, p -238-243.
49. K.K.Chawla, (1987), Composite materials–Science and Engineering, New York Springer Verlag, pp. 67-72.
50. Balasivanandha, S., Kaarunamoorthy, L., Kaithiresan, S. and Mohan, B. (2006), "Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite", Journal of Material Processing Technology, Vol. 171, pp. 268-273.
51. Hashim, J., Looney, L. and Hashmi, M.S.J. (2001), "The wettability of SiC particles by molten aluminum alloy", Journal of Materials Processing Technology, Vol. 119 (1-3), pp. 324-328.