Effect of Volume fraction $(Al_2O_3+SiC)_p$ on the Mechanical properties of Al (6061) Hybrid Metal Matrix Composite

Mr. Ravindra Mamgain[1], Dr. Alakesh Manna[2], Dr. K.K.S MER[3], Mr. Ashish Chauhan[4]

[1]Department of Mechanical Engineering, Graphic Era University, Dehradun (India)
Email: ravi_mamgain2002@yahoo.co.in

[2]Department of Mechanical Engineering, Punjab Engineering College (PEC), Chandigarh (India)

[3]Department of Mechanical Engineering, GBPEC Pauri (India)

[4]Department of Mechanical Engineering, Phonics Group of Institutions, Roorkee (India)
Email: a.chauhan81286@gmail.com

ABSTRACT

The present work deals with the Effect of Volume fraction $(Al_2O_3+SiC)_p$ on themechanical properties of Al (6061) Hybrid metal matrix compositeusing aluminum alloy Al 6061 as matrix and alumina, silicon-carbide as a reinforcing material prepared by stir casting technique. The alumina and silicon-carbide amounts varied as 10, 15, and 20 percent by volume.

The mechanical properties like hardness, tensile strength, and impact strength have been investigated. On addition by volume percent of alumina and silicon-carbide, the effect on mechanical properties has been studied. The properties like hardness and impact strength increases with Al_2O_3 and SiC. The change in these properties is moderate for 10 percent addition of alumina and silicon-carbide and marginal changes with 15 and 20 percent. The tensile strength of composite increases with the addition of alumina and silicon-carbide.

INTRODUCTION

Humans have been using composite materials for thousands of years. Take mud bricks for example. A cake of dried mud is easy to break by bending, which puts a tension force on one edge, but makes a good strong wall, where all the forces are compressive. A piece of straw, on the other hand, has a lot of strength when you try to stretch it but almost none when you crumple it up. But if you embed pieces of straw in a block of mud and let it dry hard, the resulting mud brick resists both squeezing and tearing and makes an excellent building material. Put more technically, it has both good compressive strength and good tensile strength.

CLASSIFICATION OF COMPOSITE

Composites are of following types:

1. Polymer matrix composites.
2. Ceramic matrix composites.
3. Metal matrix composites

1. POLYMER MATRIX COMPOSITES:

Polymer-matrix composites consist of high-strength fibers, carbon glass, or other materials in a matrix of thermosetting or thermoplastic polymers. The fibers provide high strength at a very low weight, and the matrix holds the fibers in place. Throughout history, people have capitalized on the synergistic effect of combining dissimilar materials, first with adobe (twigs embedded in clay) and later with steel-reinforced concrete. The human body, which embeds a skeleton of bones in flesh and muscles, is perhaps the most astounding example of combined dissimilar materials.

The most outstanding characteristic of polymer-matrix composites is the materials' ability to replace lightweight, high-strength metals or wood with an even lighter-weight and higher-strength alternative. In the transportation sector (aerospace, automobiles, and railroad cars), this property permits lower fuel consumption and/or increased payload; sporting goods and biomedical devices also place a premium on low weight and high strength. Polymer-matrix composites' resistance to corrosion is widening their appeal in the construction industry (bridges, scrubber towers, and wastewater tanks). In addition, composites' vibration-dampening properties protect athletes from tennis elbow and enable fishermen to cast with increased accuracy. Polymer-matrix composites provide other benefits as well: In manufacturing, they permit parts consolidation, flexibility of design, and lower assembly costs, and in the military, their transparency to radar is valuable for strealth applications. Because of their high cost, relatively price-insensitive markets such as military and civilian aerospace and sporting goods have led the development of polymer-matrix composites. However, since 1991, the market has experienced a substantial increase in the growth rate for use in transportation and construction, with these two markets dominating the field while other markets have relatively or absolutely declined. No other material surpasses PMCs in light weight and good mechanical properties. PMCs' continued growth faces no technical limits; drawbacks stem only from its often higher cost and its role as a newcomer in many applications where it confronts entrenched technologies. Process development and experience of use will overcome both these impediments. [2]

2 CERAMIC MATRIX COMPOSITE:

The class of materials known as ceramic matrix composites, or CMCs, shows considerable promise for providing fracture-toughness values similar to those for metals such as cast iron. Two kinds of damage-tolerant ceramic-ceramic composites are being developed. One incorporates a continuous reinforcing phase, such as a fiber; the other, a discontinuous reinforcement, such as whiskers. The major difference between the two is in their failure behavior. Continuous-fiber-reinforced materials do not fail catastrophically. After matrix failure, the fiber can still support a load. A fibrous failure is similar to that which occurs in wood. Incorporating whiskers into a ceramic matrix improves resistance to crack growth, making the composite less sensitive to flaws. These materials are commonly described as being flaw tolerant. However, once a crack begins to propagate, failure is catastrophic. Of particular importance to the technology of toughened ceramics has been the development of high-temperature silicon carbide reinforcements. Although other reinforcement materials are available, such as glass and carbon fiber, metal whiskers, and alumina-based products, this discussion focuses on SiC-based products because they are more applicable to high-temperature use.

3.METAL MATRIX COMPOSITES

Metal matrix composites are the engineered material having the combination of two or more materials in which the tailored properties are achieved. In the past decade, the need for lighter materials with high specific strength coupled with major advances in processing, has led to the development of numerous composite materials as a serious competitor to traditional engineering alloy of particular interest in aerospace and defence industry. [3]

The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties. Numerous metals have been used as matrices. The most important have been aluminum, titanium, magnesium and copper alloys and super alloys. The most important MMC systems are:

PROCESSING TECHNIQUES

The fabrication of metal matrix materials may be considered in two stages: the fabrication of the composite material from base metal and fiber reinforcement and the subsequent fabrication of laminates from the composite material. In some cases, the two steps occur simultaneously depending on the final material product desired and the method of fabrication used in the process. The choice of methods used to fabricate a composite material depends on the mechanical and chemical properties of the fiber and matrix, the fiber length and size, the fiber packing, and the desired fiber configuration. Furthermore, it is necessary to know the thermodynamics and kinematics of possible fiber matrix reactions and service temperatures to which the composites are subjected. A short overview of some of the methods used to fabricate aluminum matrix composites (AMCs) are discussed below.

SOLID STATE PROCESSING

Different solid state processing techniques can be used for preparing composites. Few of these techniques are:

- POWDER METALLURGY TECHNIQUE
- DIFFUSION BONDING
- STEP PRESSING
- HOT-DIE MOLDING
- SUPERPLASTIC FORMING
- HOT ISOSTATIC PRESSING

LIQUID STATE PROCESSING

In liquid state processing of composite, liquid metal is combined with reinforcing phase and solidified in a mould. Few of these techniques are:

- Squeeze casting
- Infiltration casting
- Investment casting
- Pressure casting
- Stir casting

EXPERIMENTAL DETAIL

In the present work aluminum based alumina and silicon-carbide reinforced particulate metal matrix was prepared. The material used and procedure for its casting is explained as follow:

MATERIAL USED:

A metal matrix composite of Al 6061 aluminum alloy reinforced with Al_2O_3 and SiC was prepared by varying composition of alumina and silicon carbide. Aluminum alloy Al 6061 with composition given in table 3.1 has been used as matrix.

Elements	Sn	Si	Zn	Cr	Mn	Mg	Cu	Fe	Ti	Pb	Ni	Al
Al 6061	0.025	0.79	0.07	0.045	0.17	0.98	0.19	0.6	0.03	0.024	0.03	Rest

PREPARATION OF COMPOSITE

The process for composite casting is shown in fig 3.1b. The Matrix alloy used in the study is Al-Mg-Si-Fe-Cu-Mn wrought alloy matrix (6061) reinforced with Al_2O_3 and SiC. Commercial Al-6061 (Al-97.04%, Mg-0.98, Si-0.79, Fe-0.6, Cu-0.19, Mn-0.17) alloy reinforced with 10, 15& 20 % by vol. The Matrix alloy was first melted in a graphite crucible in a electric furnace and before mixing, the Al_2O_3 and SiC particles were preheated at 300°C for 1 hour to make the surface of Al_2O_3 and SiC particle oxidized. The furnace temperature was first raised above the liquidus temperature to melt the alloy completely at 750°C and was then cooled down just below the liquidus temperature (700˚C) to keep the slurry in a semi solid state. The stir made of stainless steel attached with graphite blade was made to move at a rate of 200 rpm up to 15 minutes. The mixing was done for a short time period of 1 to 1.5 minutes. The composite slurry was reheated to a fully liquid state and the automatic mechanical mixing was done for about 30 minutes at stirring rate of 250 rpm. In this experiment, the molten composite was transferred from the crucible into the mould.

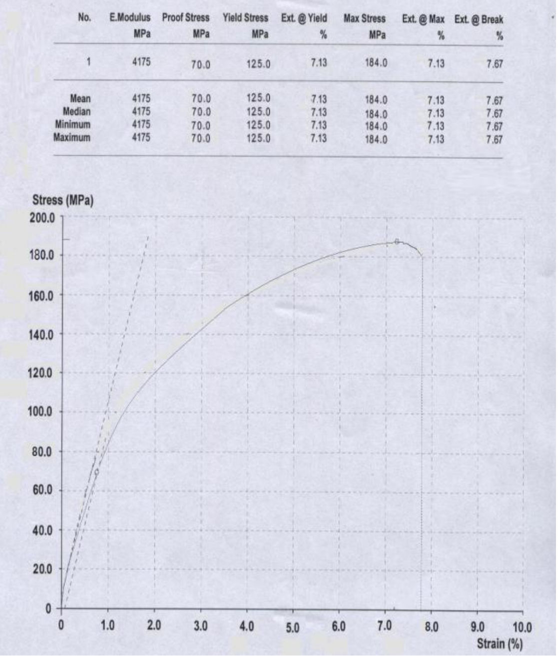
RESULTS

Composition	Yield Strength N/mm^2	UTS Mpa	Elongation (%)
Al 6061 base alloy	125	184	7.67
Al 6061 +10%alumina and silicon-carbide (Al_2O_3+SiC)	145	270	3.20
Al 6061 +15%alumina and silicon-carbide (Al_2O_3+SiC)	300	359	1.90
Al 6061 +20%alumina and silicon-carbide (Al_2O_3+SiC)	352	415	0.85

In present work the three composites, one by addition of 10% alumina and silicon-carbide, second by 15% alumina and silicon-carbide and other by 20% addition of alumina and silicon-carbide have been cast by stir casting technique and their mechanical properties like tensile strength ,impact strength and hardness have been determined. These properties have been reported and compared with base alloy Al 6061 in the following section.

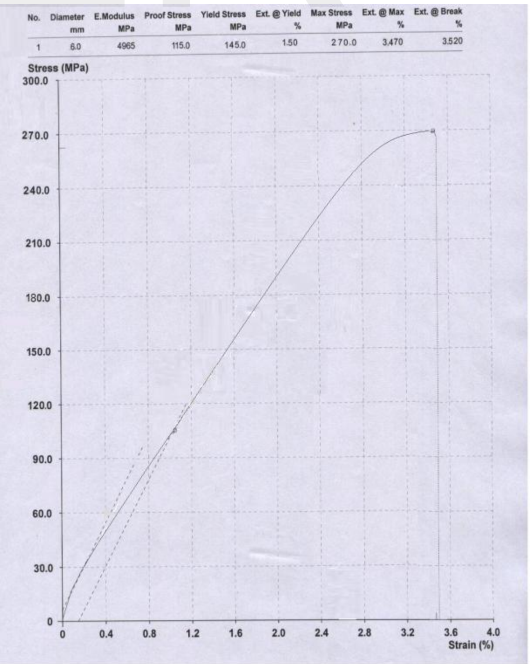
TENSILE STRENGTH

The tensile strength of Al6061 base alloy, Al6061 +10% alumina and silicon-carbide, Al6061 +15% alumina and silicon-carbide and Al6063 +20% alumina and silicon-carbide by vol. was measured at room temperatures. The stress-strain curves for different composition of alumina and silicon-carbide i.e. Al6061 base alloy, Al6061 +10% alumina and silicon-carbide, Al6061 +15% alumina and silicon-carbide, Al6061 +20% alumina and silicon-carbide by vol. percent are shown in fig 4.1, 4.2, 4.3 and 4.4 respectively.



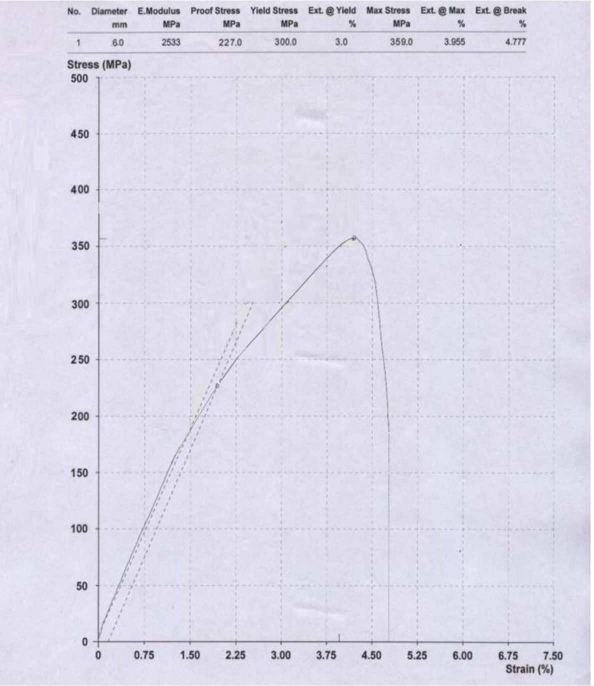
No.	E.Modulus MPa	Proof Stress MPa	Yield Stress MPa	Ext. @ Yield %	Max Stress MPa	Ext. @ Max %	Ext. @ Break %
1	4175	70.0	125.0	7.13	184.0	7.13	7.67
Mean	4175	70.0	125.0	7.13	184.0	7.13	7.67
Median	4175	70.0	125.0	7.13	184.0	7.13	7.67
Minimum	4175	70.0	125.0	7.13	184.0	7.13	7.67
Maximum	4175	70.0	125.0	7.13	184.0	7.13	7.67

Fig 4.1: Stress-strain curve for Al6061 base alloy



No.	Diameter mm	E.Modulus MPa	Proof Stress MPa	Yield Stress MPa	Ext. @ Yield %	Max Stress MPa	Ext. @ Max %	Ext. @ Break %
1	6.0	4965	115.0	145.0	1.50	270.0	3.470	3.520

Fig 4.2: Stress-strain curve for Al6061 base alloy + 10% alumina and silicon-carbide



No.	Diameter mm	E.Modulus MPa	Proof Stress MPa	Yield Stress MPa	Ext. @ Yield %	Max Stress MPa	Ext. @ Max %	Ext. @ Break %
1	6.0	2533	227.0	300.0	3.0	359.0	3.955	4.777

Fig 4.3: Stress-strain curve for Al6061 base alloy + 15% alumina and silicon-carbide

Fig 3.3: Tensile Strength Specimens of different composition

IMPACT STRENGTH

Impact test was carried out at room temperature using Impact tester to calculate toughness. The specimen is supported at one end like a cantilever beam in the test and reading was taken by breaking the specimen due to the impact of the pendulum. It can be noted that the toughness increased with an increase in the weight percentage of alumina and silicon carbide. This is due to proper dispersion of alumina & silicon carbide into the matrix or strong Interfacial bonding between aluminium alloy 6061 and alumina & SiC interfaces. As shown by the graph the toughness of sample 1 is 6.9 and it increase with increase percent of alumina and Silicon carbide and reaches to a maximum value of 8.7 for sample 3 which has maximum value of SiC (20%) and alumina (20%).

Table 4.2: Variation of impact strength with Alumina and silicon-carbide (Al_2O_3+SiC) content

Composition	Impact Load Nm
Al 6061 base alloy	5.8 Nm
Al 6061 +10%alumina and silicon-carbide (Al_2O_3+SiC)	6.9 Nm
Al 6061 +15%alumina and silicon-carbide (Al_2O_3+SiC)	7.9 Nm
Al 6061 +20%alumina and silicon-carbide (Al_2O_3+SiC)	8.7 Nm

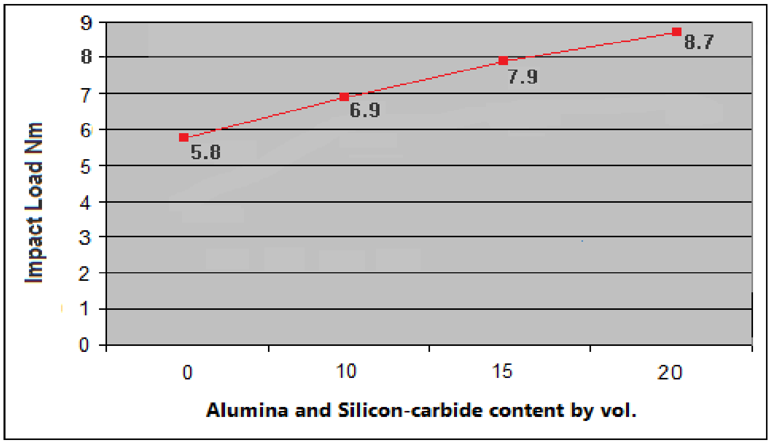


Fig 4.6: variation of impact strength with alumina and silicon-carbide content.

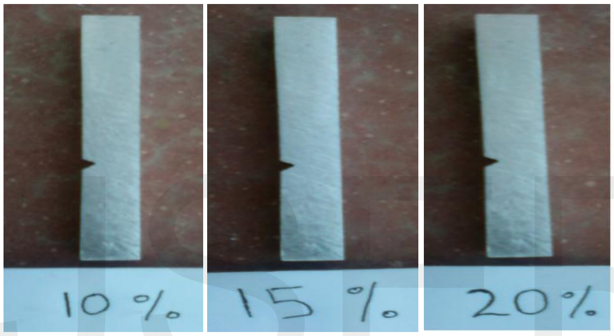


Fig 3.4: Impact Strength Specimens of different composition

HARDNESS

The hardness of Al 6061 base alloy is as low as 60BHN and with 10% addition of alumina and silicon-carbide it increases upto 85BHN and further with 15% and 20% addition of alumina and silicon-carbide it reaches at 105BHN and 122BHN. The variation of hardness with alumina and silicon-carbide content is shown in fig 4.12, the hardness of the composite increases with increase in vol. percent of alumina and silicon-carbide reinforced in the alloy.

Composition	BHN
Al 6061 base alloy	60
Al 6061 +10%alumina and silicon-carbide (Al_2O_3+SiC)	85
Al 6061 +15%alumina and silicon-carbide (Al_2O_3+SiC)	105
Al 6061 +20%alumina and silicon-carbide (Al_2O_3+SiC)	122

Table 4.3: Variation of hardness with Alumina and silicon-carbide (Al_2O_3+SiC) content

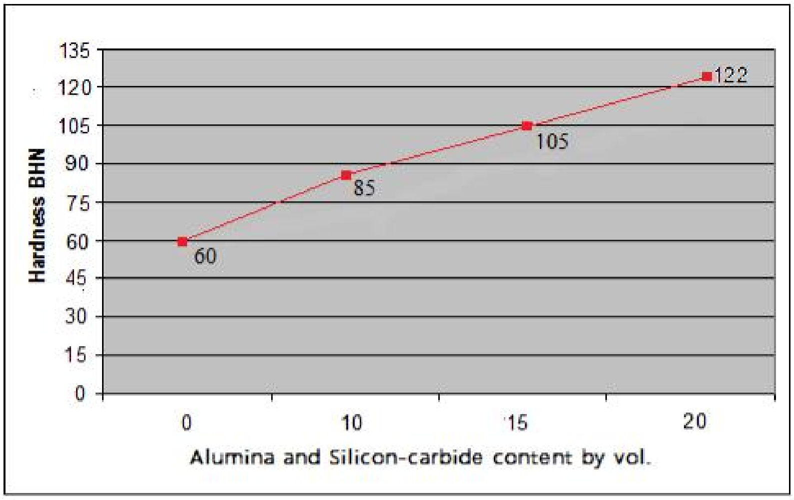
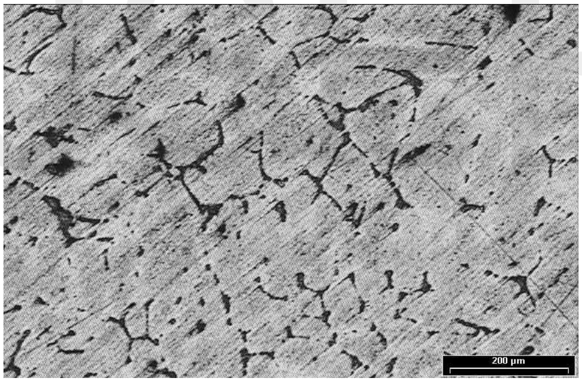


Fig 4.7: variation of hardness with alumina and silicon-carbide content.

MICROSTRUCTURE

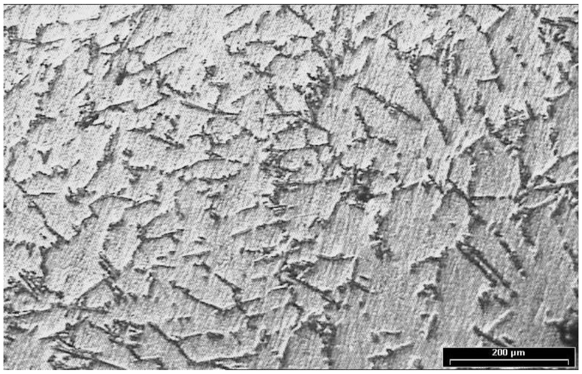
4.4.1. 10% Alumina and Silicon carbide is mixed with Al6061



Sample 1 50 X

Fig 4.8: optical micrograph Al6061 with 10% alumina and silicon-carbide content.

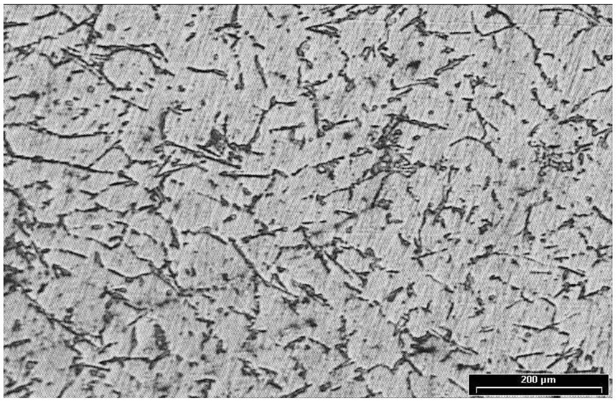
4.4.2. 15% Alumina and Silicon carbide is mixed with Al6061



Sample 2 50 X

Fig 4.9: optical micrograph Al6061 with 15% alumina and silicon-carbide content.

4.4.3. 20% Alumina and Silicon carbide is mixed with Al6061



Sample 3 50 X

Fig 4.10: optical micrograph Al6061 with 20% alumina and silicon-carbide content.

DISCUSSION

The ultimate tensile strength of the composite increase with addition of alumina and silicon-carbide. The increase in ultimate tensile strength may be due to the segregation of particles at some specific zones.

The second reason for increase in tensile strength may be due to the presence of the interfacial gaps between the matrix and the reinforcement, which is unable to transfer the load from the matrix to reinforcing phase as can be seen from the optical micrograph.

The hardness of the composite increases with the addition of alumina and silicon-carbide. Hardness of the Al 6061 base alloy is 60 BHN, with the addition of 10% alumina and silicon-carbide it increases to 85 BHN and with addition of 15% and 20% it increases to 105 BHN and 122 BHN. The hardness of the Composite increases because hard nature of particles. With the 10% addition of particles the hardness increases by 25 BHN and with 15% and 20% it increases by 45 BHN and 62 BHN. This increase in hardness is attributed of the hard nature of particles as compared to base alloy. The result show the average value of hardness there are variations in the hardness observed for same surface of composite, this may be due to the difference in the distribution of the alumina and silicon-carbide particles as observed from optical micrograph.

The Impact Load (Nm) for the base alloy is 5.8 Nm’ for the addition of 10% alumina and silicon-carbide it increase to 6.9 Nm and with the addition of 15% and 20% it reduces to 7.9 Nm and 8.7 Nm. For 10% addition there is no significant increase in impact load but with 15% and 20% the increase is more as compared with 10% addition of alumina and silicon-carbide, this may be due to the brittle nature of the particles and more segregation of the particles at some specific places.

CONCLUSIONS

The conclusions drawn from the present investigation are as follows:

1. The result confirmed that stir formed Al6061 with Al_2O_3/SiC reinforced composites is clearly superior to base Al6061 in the comparison of tensile strength, Impact strength as well as Hardness.
2. It is found that elongation tends to decrease with increasing particles wt. percentage, which confirms that alumina and silicon carbide addition increases brittleness.
3. It appears from this study that UTS and Yield strength trend starts increases with increase in weight percentage of Al_2O_3 and SiC in the matrix.
4. Impact strength is increase by adding Al_2O_3 and SiC.

5. The mismatch between reinforcement and matrix leads to a large stress concentration near particulate and matrix in that region fails prematurely under application of load.
6. With the increase in vol. fraction a strong tendency of clustering of particulates [as is evident from the optical micrograph] leads to a very inefficient load transfer mechanism causing low strain to failure.
7. The hardness of aluminum alloy Al 6061 is 60 BHN. There is increase in hardness from 60 to 122 BHN, on addition of 10%, 15% and 20% alumina and silicon-carbide by vol. respectively. This increase in hardness is attributed of the hard nature of particles as compared to base alloy.

REFERENCES

1. Manoj Singla[1], D. Deepak Dwivedi[1], Lakhvir Singh[2], Vikas Chawla[3] Department of Mechanical Engineering India (Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, pp 455-467, 2009) "Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite"
2. D. Abdul Budan Department of Mechanical Engineering, U.B.D.T. College of Engineering, Davangere - 577 004, India (J. Machining and Machinability of Materials, Vol. 10, Nos. 1/2, 2011) "Comparative study on the machinability aspects of aluminium - silicon carbide and aluminium – graphite - silicocarbide hybrid composites"
3. M. Asif, K. Chandra, P . S. Misra Department of Metallurgical and Materials Engineering Indian Institute of Technology Roorkee, Roorkee – 247667 (INDIA) (Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.14, pp.1337-1344, 2011) "Development of Aluminium Based Hybrid Metal Matrix Composites for Heavy Duty Applications"
4. Department of Nano – Material Engineering, Faculty of Engineering, Tarbiat Modares University, Tehran, Iran. Iranian Journal of Materials Science & Engineering Vol. 8, Number 1, Winter 2011. "Microstructure study on Al -5% SiC nan composite powders".