ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

TRIBOLOGY STUDIES IN POWDER METALLURGY AL-LM13 SIC-REINFORCED FUNCTIONALLY GRADED COMPOSITES

Mukilan.B[1], Arun kumar.J[2],
P.G Scholar, Department of CAD/CAM engineering
S.A Engineering College,
Chennai- 600077.
rbmukil@gmail.com .

M.Dhanashekar [3],
Assistant Professor-I,
Department of Mechanical Engineering ,
Anand Institute of Higher Technology,
Chennai- 603103.
dhanashekarm.mech@aiht.ac.in.

Abstract: Aluminum-based metal matrix composite (MMC) materials are used in the design of ground transportation vehicles and aircraft. Compared with conventional, unreinforced alloys, composite materials usually exhibit higher strength, both at ambient and elevated temperatures, as well as good fatigue strength and wear resistance. MMCs could be produced by variety of methods such as Stir cast, Liquid Infiltration, Osprey and Powder metallurgy. Among this, the Powder Metallurgy process is one of the most effective methods for manufacturing Metal matrix composites (MMCs) due to its high volume reinforcement and fairly uniform distribution.

In this experimental study, Aluminum alloys (Al 6061) and silicon carbide reinforced, composite materials were manufactured by powder metallurgy process. The composition of the composites fabricated is (5%, 10% and 15%) vol% of Silicon carbide Particle (20µm). The mechanical properties such as hardness, compressive strength, crushing analysis and micro structural analysis was carried out. The result revealed that the SiC reinforced composites exhibited a lower wear loss compared to the unreinforced alloy. It was found that with an increase in the SiC content, the wear resistance increased monotonically with hardness.

Keywords-* *powder metallurgy, compacting, sintering

I. INTRODUCTION

A. POWDER METALLURGY

Powder metallurgy can be defined as the art of producing powders of metals, alloys, ceramics etc. Mixing them in necessary quantities which are blended, Pressed into a desired shape **(compacted),** and then heated **(sintered)** in a controlled Atmosphere to bond the contacting surfaces of the particles and establish the desired Properties. It is commonly designated as **P/M.**P/M process is a unique part fabrication method that is highly cost effective in producing simple or complex parts close to final dimensions.

B. HISTORY

1. **Early 3000 B.C.** – A crude form of powder metallurgy appears to have existed in Egypt.
2. **Mid- or Late 19th Century** – the mass production of P/M products begin
3. **Early 20th Century** – powder metallurgy was used to produce copper coins and tungsten wires, the primary material for light bulb filaments.
4. **1920s** – Tungsten carbide cutting-tool tips and nonferrous bushings were produced.

Other early products were self-lubricating bearings and metallic filters.

5. **After World War II** – a period of rapid technological development occurred which are based primarily on automotive applications, and iron and steel replaced copper as the dominant P/M material.

6. **Aerospace** and nuclear developments accelerated demand for refractory and reactive materials

7. **1960s** – full-density products emerged.

8. **1970s** – high-performance super alloy components, such as aircraft turbine engine parts.

9. **1980s** – The commercialization of rapidly–solidified and amorphous powders and the development of P/M injection molding technology.

10. **From 1960-1990** – the consumption of iron powder increased tenfold making of fasteners (nuts and bolts) in large volumes.

P/M has become a proven method of parts production and is now considered as an alternative in the manufacture of many components. The automotive applications account for nearly 75% of the powder metallurgy market.

C. STEPS INVOLVED IN POWDER METALLURGY

The following are the steps involved in powder metallurgy.

1. Production of metal powders.
2. Condition and mixing of metal powders in the required ratio.
3. Compacting the powders to the desired shape.
4. Subsequent heating or sintering of compacted objects in the mould with temperature below melting point under non oxidizing atmosphere.

D. METAL MATRIX COMPOSITE

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, alumina, silicon nitride, silicon carbide, silicon nitride etc. whereas Metallic Reinforcement may be tungsten, beryllium etc. MMCs are used for space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications.

From a material point of view, when compared to polymer matrix composites, the advantages of MMCs are strength and stiffness at elevated temperature, good abrasion and creep resistance properties. Most MMCs are still in the development stage or the early stages of production and are not so widely established as polymer matrix composites.

The biggest disadvantages of MMCs are their high costs of fabrication, which has placed limitations on their actual applications. There are also advantages in some of the physical attributes of MMCs such as no significant moisture absorption properties, non-inflammability, low electrical and thermal conductivities and resistance to most radiations.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

E. MMC PRODUCTION BY POWDER METALLURGY

Powder Metallurgy processing is one of the effective methods to manufacture MMCs with high volume of reinforcement with fairly uniform distribution. Powder metallurgy is a forming and fabrication technique consisting of three major processing stages. First, the primary material is physically divided into many small individual particles. Next, the powder is passed through a die to produce weakly cohesive structure (via cold welding) very near the dimensions of the object ultimately to be manufactured. Pressures of 1-10 tons are commonly used to compact the metal powder. Then subsequent heating or sintering of compacted objects in the mould with temperature below melting point under non oxidizing atmosphere.

II.METHODOLOGY

A. METALPOWDER SELECTION

The powders selected are as follows

1. Aluminium powder(Al6061)
2. Silicon carbide powder(SiC)

a) Aluminium 6061 Powder

Purity Aluminium : min 99%

Maximum limits of impurities

Iron (Fe) - 0.5%
Heavy metals (Pb) - 0.03%
Size -
23 micron

1. Aluminum properties include good appearance, ease of fabrication, good corrosion resistance, low density, high strength-to-weight ratio and high fracture toughness**.**

2. Aluminum powder is a light, silvery-white to gray, odourless powder. It is a reactive flammable material. Aluminum powder is a fine granular powder made from Aluminium.

Physical Properties

1. Density - 2.7g/cc

Mechanical Properties:

1. Modulus of Elasticity - 68.0 GPa
2. Poisson Ratio - 0.360

b) Silicon Carbide Powder

Size : 20 micron

Silicon carbide (SiC), also known as carborundum, is a compound of silicon and carbon with a chemical formula SiC. Grains of silicon carbide can be bonded together by sintering to form very hot ceramics which are widely used in applications requiring high endurance, such as car brakes and ceramic plates in bullet proof vests.

It was originally produced by high temperature electro-chemical reaction of sand and carbon. It is used in abrasives, refractory's, ceramics and numerous high- performance applications.

Mechanical Properties:

1. Density - 3.21 g/cc

2. Hardness - 2800 knoop hardness number

3. Flexural strength - 550 MPa

4. Poisson ratio - 0.14

Thermal properties

1. Coefficient of thermal expansion - 4.0 × 10-6 /º C

2. Thermal conductivity - 120 W / m ºK

3. Maximum working temperature - 1650 ºC

4. Specific heat - 750 J/Kg k

B. DESIGN CONSIDERATIONS IN POWDER METALLURGY

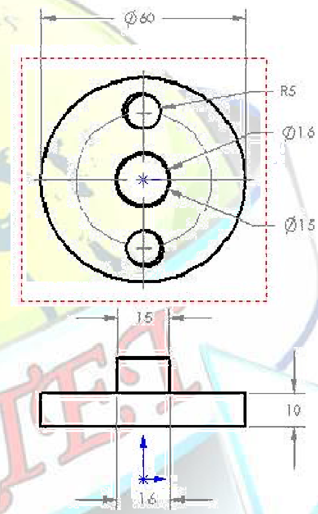
Design requirements are essential for P/M parts:

1. The shape of the parts must be as simple as possible P/M parts should be made with the widest tolerances. The P/M process is capable of achieving tolerances of bigger than 0.1 mm.
2. In the present study, cylindrical specimen of dia 15mm and thickness of about 5mm was selected for the study.
3. Hole and grooves must be parallel to the direction of ejection.
4. Sharp corners, radii, thin section must be avoided. Minimum wall thickness is 1.5 mm.

C. DIE DESIGN

To facilitate the easy removal of compacted specimen, tapered section has been used. Dimension of tapered section used is 16 to 15 mm for overall length of 50mm in punch and (40mm, 10mm) in die.

The front view and top view of die parts and the assembly view are shown in Figure 3.1 to 3.4



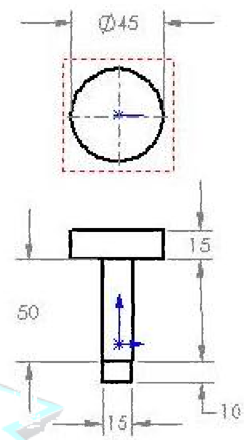


Figure .1 Base plate **Figure.2** Punch

D. DIE SAFETY CALCULATION

$$\text{Area} = 3.14r^2$$

$$= 3.14 \times 7.5^2$$

$$= 176.25 \text{ mm}^2$$

For 14,000kg Load

Stress = load/area

$$= 140000/176.25$$

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

= 794MPa

Ultimate stress of Tungsten Carbide for round bar is **794MPa.**

So up to a load of 14000kg die can withstand.

s.no	Aluminium 6061	Silicon Carbide	Total Weight
1	Al(95%) =16.1082 g	SiC (5%) =1.0079g	17.1161 g
2	Al(90%) =15.2604 g	SiC (10%) =2.0158 g	17.2762 g
3	Al(85%) =14.4126 g	SiC (15%)=3.0237 g	17.4363 g

Table.1 weight of composites

E. POWDER MIXING

Figure .3 Magnetic Mixer

Al 6061 and SiC powders are mixed by Magnetic Mixer. The calculation for mass of aluminum and silicon carbide powder needed for a sample of 20mm thickness and 20mm diameter are as follows

1. Aluminum (100%)

= Density of Aluminium × Volume of Specimen.

= 2.7 × 6.28

=16. 956g

2. Silicon Carbide (SiC) (100%)

= Density of (SiC) × Volume of Specimen.

= 3.21 × 6.28

=20.1588 g

a) Weighing of Powders

F. COMPACTING

The purpose of the compacting is to consolidate the powder into the desired shape and as closely as possible to final dimensions; it is designed to impart the desired level and type of porosity and to provide adequate strength for hardening. Compacting was done in UTM (Universal Testing Machine) as shown in the figure 3.6.The various compacting load from 4000kg to 20000kg were used for compaction.

Figure .4 universal testing machine

Compacting – one of the most critical steps in the P/M process.

Green compact – loose powder is compressed

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

and densified into shape, usually at room

Specimen	Diameter	Length	Weight	Density
Aluminium (95%) & SiC (5%)	20mm	20mm	16.18 g	2.576 g/cm^3
Aluminium (90%) & SiC (10%)	20mm	21mm	17.08 g	2.59 g/cm^3
Aluminium (85%) & SiC (15%)	20mm	21mm	16.94 g	2.57 g/cm^3

temperature.

Compaction with a Single Punch

When pressure is applied at one punch, maximum density occurs below the punch and decreases as one moves down the column.

Before compacting

Sample 1: Al-95% - 2.71× 0.95 = 2.565
SiC-5% -3.21×0.05 = 0.160

2.7255g/cm^3

Sample 2: Al-90% - 2.71× 0.90 =2.43
SiC-10% - 3.21× 0.10 = 0.321

2.751g/cm^3

Sample 2: Al-85% - 2.71× 0.85 = 2.295
SiC-15% - 3.21× 0.15 = 0.4815

After Compacting **2.7765g/cm^3**

Table..2 Density After Compacting

After Sintering

Table.3 Density After Sintering

G. SINTERING

In the sintering operation, the pressed- powder compacts are heated in a controlled – atmosphere environment to a temperature below the melting point but high enough to permit the solid-state diffusion and held for sufficient time to permit bc

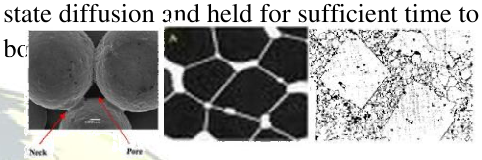


Figure. 5 sintering initial stage, Intermediate, Final stage

a)Muffle Furnace Sintering

A muffle furnace is a front-loading box-type oven for high-temperature applications such as fusing glass,

Specimen	Diameter	Length	Weight	Density
Aluminium (95%) & SiC (5%)	20mm	20mm	16.81 g	2.6767 g/cm^3
Aluminium (90%)& SiC (10%)	20mm	21mm	17.11 g	2.59 g/cm^3
Aluminium (85%) & SiC (15%)	20mm	21mm	16.99 g	2.57 g/cm^3

creating enamel coatings, ceramics and soldering and brazing articles.

The compacted pellets were taken and heated in a muffle furnace in an inert atmosphere (99.99% pure Nitrogen gas) at temperatures of 530° C to densify the compacted powder samples. A heating rate of 5° C/minute was maintained and the holding time for the samples was 1 hour. Pellets of 20mm diameter and 20mm thickness were obtained after sintering. The densities of the sintered samples were calculated and noted.

Fig.6 Muffle furnace

H. HARDNESS TEST

Hardness test was conducted by Micro Vickers testing machine using 136° included angle inverted diamond pyramid indenter.

Vickers / Micro hardness test procedure as per ASTM E-384, EN ISO 6507, and ASTM E-92 standard specifies making indentation with a range of loads using a diamond indenter which is then measured and converted to a hardness value. For this purpose as long as test samples are carefully and properly prepared, the Vickers / Micro hardness method is considered to be very useful for testing on a wide type of materials, including metals, composites, ceramics, or applications such as testing foils, measuring surface of a part, testing individual microstructures, or measuring the depth of case hardening by sectioning a part and making a series of indentations. Two types of indenters are generally used for the Vickers test family, a square base pyramid shaped diamond for testing in a Vickers hardness tester and a narrow rhombus shaped indenter for a Knoop hardness tester.

Fig.7 Vickers testing machine

I. COMPRESSION TEST

Compression testing is a very common testing method that is used to establish the compressive force or crush resistance of a material and the ability of the material to recover after a specified compressive force is applied and even held over a defined period of time. Compression tests are used to determine the material behavior under a load. The maximum stress a material can sustain over a period under a load (constant or progressive) is determined. **Indenter: Ball type**

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

Fig.8Compression Testing Machine

Fig.9 Before compression & After compression

J. CRUSHING TEST

A localized compressive stress at the area of contact between two components which are not having relative motion between them is known as crushing stress. The greatest compressive load a material can withstand without fracturing. The maximum stress a material can sustain over a period under a load is determined.

Fig.10 Crushing Strength Tester

Fig.11 Before crushing & After Crushing

K.WEAR TEST

Friction materials were tested for dry conditions. In this experiment, the wear of developed composites were tested by using Wear and friction test rig (Pin on disc type)

a) Test Procedure

1. Steps to be followed in order to conduct the experiment are:-
2. Place the test metal disc on DC motor.
3. Place the pin over the disc.
4. Run the motor at full speed and ON the range meter.
5. Place the weights in the pan and observe the wear pattern on disc made by pin. Simultaneously, note the reading from range meter.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

6.Take the reading from the graph.


Fig.12 Wear Testing Machine Fig.13 Pin On Disc

Sliding dia in mm	*Expt. No.*	*Applied Load (N)*	*Sliding velocity (m/sec)*	*Sliding Distance (m)*	*r.p.m*	*Time in secs*	*Time in mint*
30	1	5	2	500	1273.89	250	4.166
45	2	5	2	500	849.257	250	4.166
30	3	5	2	500	1273.89	250	4.166

Table.4 Wear Test Specification

III. RESULTS AND DISCUSSION

A. HARDNESS TEST

Hardness: By Micro Hardness tester.
Load: 0.5 Kgf
Dwell time: 10 seconds.

Indentor: 136° included angle inverted diamond pyramid.
Unit: Vickers to be written as "H.V. @ 0.5 Kg load.

Table.5 Hardness values

SAMPLE ID	CENTER	MEAN	EDGES
Al-95%	45	44.3	43.7
Al-90%	46.5	45.6	42.2
Al-85%	45.7	43.4	43.3
Al-100%	39.5	37.3	36

B. COMPRESSION TEST

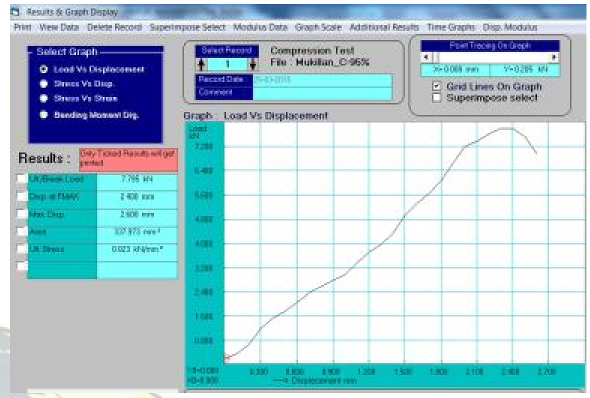


Fig.14 Sample 1: Al-95%, SiC-5%

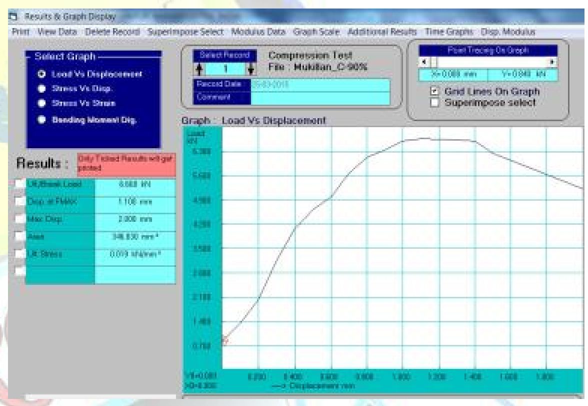


Fig.15 Sample 2: Al-90%, SiC-10%

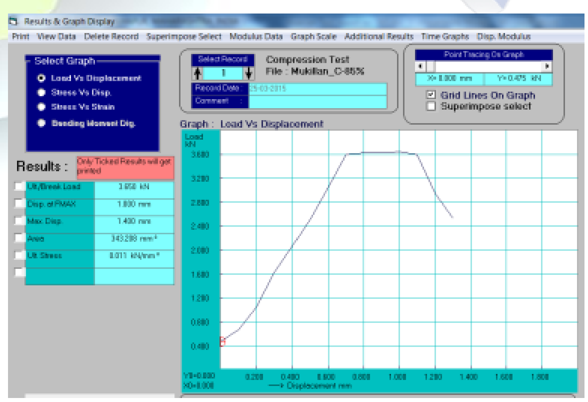


Fig.16 Sample 3: Al-85%, SiC-15%

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

Table 6 Various compression loads

S.No	Composition	Displacement	Load
1	Al-95%,SiC-5%	2.4	7.78
2	Al-95%,SiC-5%	2	6.67
3	Al-95%,SiC-5%	1.4	3.65

C.CRUSHING TEST

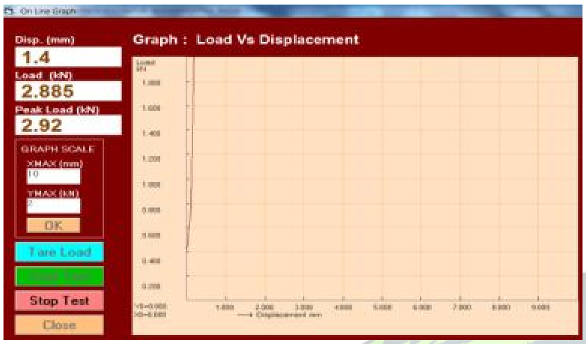


Fig.17 Sample 1: Al-95%, SiC-5%

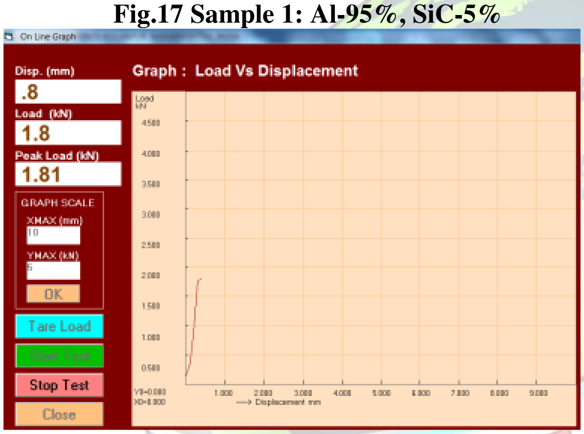


Fig.18 Sample 2: Al-90%, SiC-10%

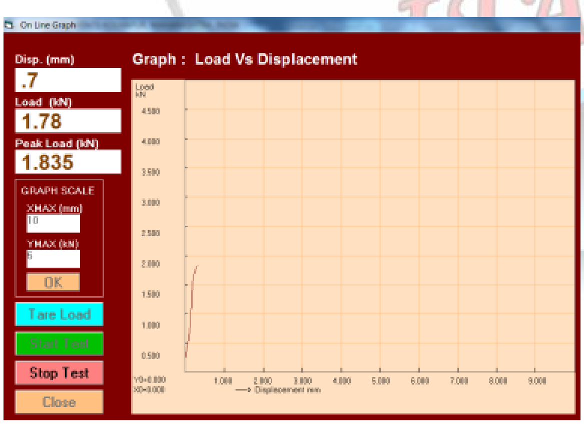


Fig.19 Sample 3: Al-85%, SiC-15%

D. WEAR TEST

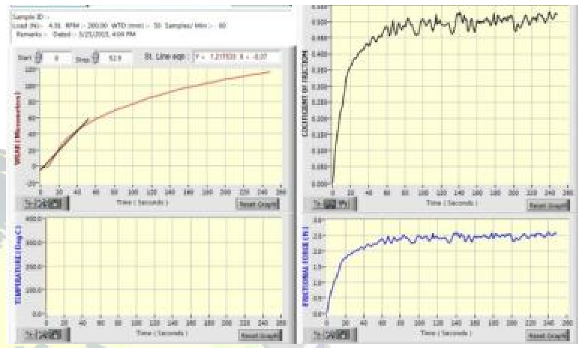


Fig.20 Sample 1: Al-95%, SiC-5%

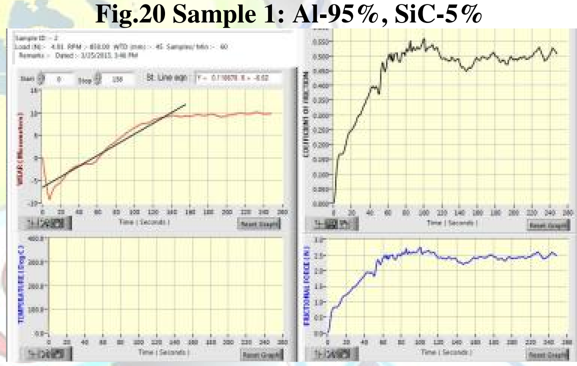


Fig.21 Sample 2: Al-90%, SiC-10%

Fig.22 Sample 3: Al-85%, SiC-15%

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

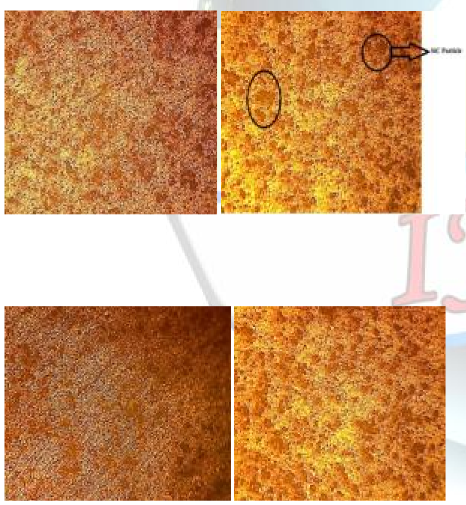
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

Table. 7 Various Crushing loads

S.No	Composition	Displacement	Load
1	Al-95%,SiC-5%	1.4	2.8
2	Al-95%,SiC-5%	0.8	1.8
3	Al-95%,SiC-5%	0.7	1.78

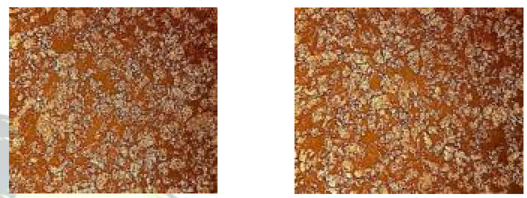
E. MICROSTRUCTURAL ANALYSIS

ALL IMAGES TAKEN BY OPTICAL MICROSCOPE IN 150X MAGNIFICATION UNDER 100 MICRON SCALE

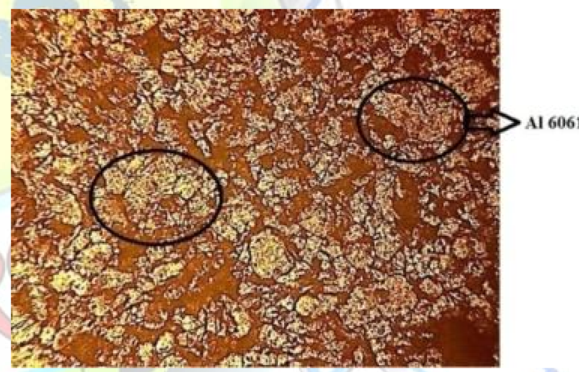


As Polished
Fig.23 Sample ID: Al-95%, SiC-5%

The "As polished" matrix of the metal matrix composite produced by powder metallurgical matrix shows the distortion of the Composite particles. The particles are uniformly distributed in the matrix that has been sintered. Photo-1 shows the distribution of the particles which are very small but in photo-2 the particles are clearly resolved in the matrix. The matrix shows no voids/pores between the grains. This indicates the effective compactness. Christo Ananth et al.[1] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.



As Etched
Magnification: 150X Etchant: Keller's Reagent



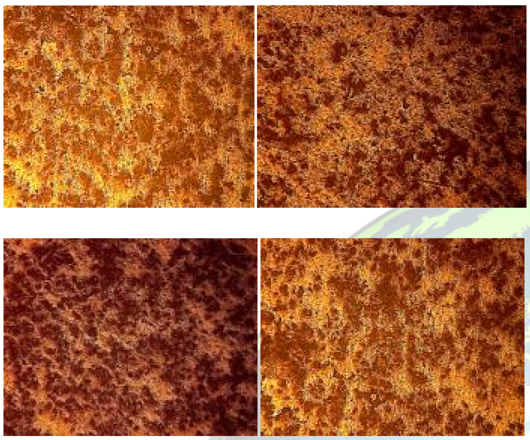
The powder metallurgical metal matrix composite produced from AA 6061 & SiC powder by compacting and sintering is prepared for the microstructure examination. The sample is etched with Keller's reagent solution so as to observe the fusion of the metal grains and composite particles to the metal matrix. The above images of the microstructure are taken from three different locations of the sample to observe the microstructure. The etched matrix shows complete fusion of the metal grains during sintering and no un-fused grain boundary is observed. The microstructure of the matrix shows the 6061 with precipitated eutectic

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

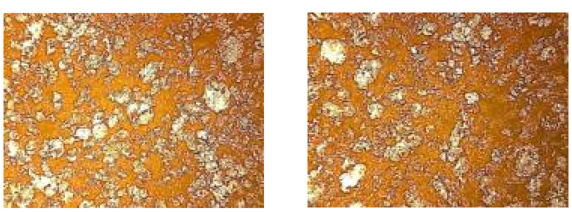
Mg2Si particles in aluminium solid solution. The composite particles are evenly distributed in the metal matrix.

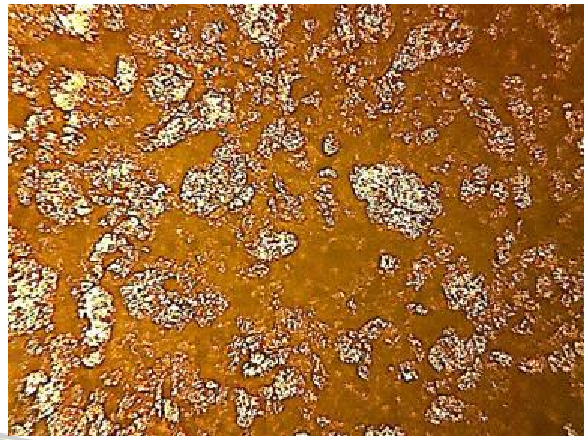
No cluster of particles observed. The effective mixing of the particle with the metal powder could facilitate this.



As Polished
Fig.24 Sample ID: Al-90%, SiC-10%

The "As polished" matrix of the metal matrix composite produced by powder metallurgical matrix shows the distortion of the Composite particles. The concentration of the composite particles is increased from 5 to 10%. The increase in concentration of the SiC increased the concentration in the sintered matrix. The particles are uniformly distributed in the matrix that has been sintered. Photo-1 shows the distribution of the particles which are very small.





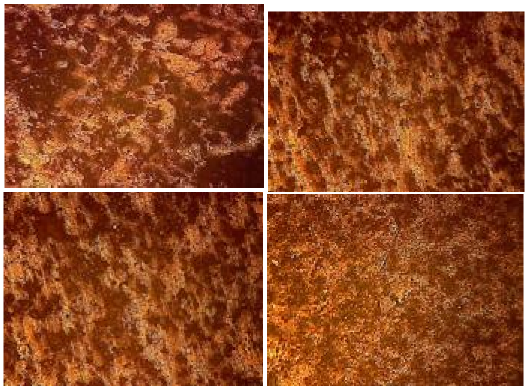
As Etched
Magnification: 150X Etchant: Keller's Reagent

The powder metallurgical metal matrix composite produced from AA 6061 & SiC powder by compacting and sintering is prepared for the microstructure examination. The sample is etched with Keller's reagent solution so as to observe the fusion of the metal grains and composite particles to the metal matrix. The above images of the microstructure are taken from four different locations of the sample to observe the microstructure. The etched matrix shows complete fusion of the metal grains during sintering and no un-fused grain boundary is observed. The microstructure of the matrix shows the 6061 with precipitated eutectic Mg2Si particles in aluminum solid solution. The composite particles are evenly distributed in the metal matrix. No cluster of particles observed.

The effective mixing of the particle with the metal powder could facilitate this. The powder metallurgical product appears like cast or wrought sample as there is no voids could be seen.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

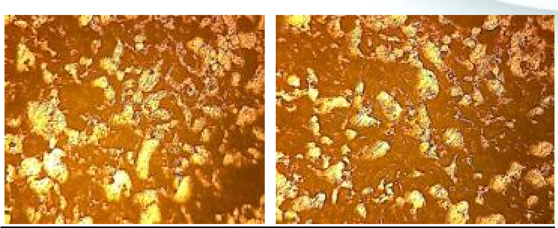
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

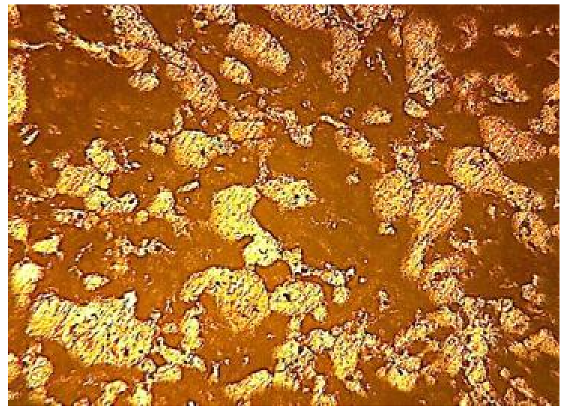


As Polished
Fig.25 Sample ID: Al-85%, SiC-15%

The "As polished" matrix of the metal matrix composite produced by powder metallurgical matrix shows the distortion of the Composite particles. The concentration of the composite particles is increased from 10 to 15%. The increase in concentration of the SiC increased the concentration in the sintered matrix. The particles are uniformly distributed in the matrix that has been sintered. Photo-1 shows the distribution of the particles which are very small but in photo-2 the particles are clearly resolved in the matrix.

The matrix shows no voids/pores between the grains. This indicates the effective compactness. The higher percent of composite is clearly seen as increased concentration of the polished surface.





As Etched

Magnification: 150X
Etchant: Keller's Reagent

The powder metallurgical metal matrix composite produced from AA 6061 & SiC powder by compacting and sintering is prepared for the microstructure examination. The sample is etched with Keller's reagent solution so as to observe the fusion of the metal grains and composite particles to the metal matrix.

The above images of the microstructure are taken from four different locations of the sample to observe the microstructure. The etched matrix shows complete fusion of the metal grains during sintering and no un-fused grain boundary is observed. The microstructure of the matrix shows the 6061 with precipitated eutectic Mg_2Si particles in aluminum solid solution. The composite particles are evenly distributed in the metal matrix. No cluster of particles observed. The effective mixing of the particle with the metal powder could facilitate this. The powder metallurgical product appears like cast or wrought sample as there is no voids could be seen.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

IV.CONCLUSION

Preparation of Al6061/ SiC composites by powder metallurgy technique is attempted during this project work. Composites are prepared by varying percentage of silicon carbide (5%, 10% & 15%). the effects of the processing conditions on the characteristics of the resulting powders and composites were investigated. The results can be summarized as follows.

1. Better properties were obtained when the reinforcement percentage was 10%.
2. Density was decreased when increasing the amount of the silicon carbide in the matrix phase.
3. It was found that maximum densification of (96%) was achieved for the compacting load of 14000kg.
4. The hardness of the composites was increased when increasing the amount of Silicon Carbide in the Matrix Phase.

The micro structural analysis shows that heterogeneous structure is obtained in the all the fabricated composites. Particle in the shape of flake, angular, rounded Can be obtained.

V.REFERENCES

[1] Christo Ananth, S.Esakki Rajavel, S.Allwin Devaraj, M.Suresh Chinnathampy. "RF and Microwave Engineering (Microwave Engineering).", ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-5-8, Volume 1,June 2014, pp:1-300.

[2] A. Hassani, E. Bagherpour and F. Qods, Influence of pores on workability of porous Al/Sic composites fabricated through powder metallurgy + mechanical alloying

[3] Hossein Abdizadeh, Reza Ebrahimifard and Mohammad Amin Baghchesara, Investigation of Microstructure and mechanical properties of nano MgO reinforced Al composites manufactured by stir casting.

[4] Y.Z. Lia, Q.Z.Wang W.G.Wang, B.L.Xiao and Z.Y.Ma, Effect of interfacial reaction on age-hardening ability of B4C/6061Al composites.

[5] B. Vijaya Ramnath, C. Elanchezhian and M. Jaivignesh, Evaluation of mechanical properties of aluminium alloy–alumina–silicon carbide metal matrix composites.