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Design & Characterization of Functionally Graded Aluminium Metal Matrix with SiC Reinforcement using powder metallurgy

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***Abstract*: Functionally Graded Material (FGM) characterises to a class of advanced material in the category of composite materials which has variation in properties as the volume of the material varies. The overall properties of FMG are excellently unique and different from any of the individual material that composes it and also from conventional materials. it has vast and wide variety of applications for FGM and it is expected to decrease the cost of the material processing and also the manufacturing processes. In our experimental work we mainly concentrated to produce FGM by powder metallurgy processes and applying it for specific area of application. Recent research studies are mainly focussing on the processing and applications of functionally graded materials. New processing routes for metal-matrix functionally graded materials (FGMs) and structures through combinations of powder metallurgy are described. Pure Aluminium of 98% purity with 100 microns size with good fluidity and corrosion resistance is taken as matrix material and Silicon carbide as reinforcing material and to increase bondage between mixed ratios from one another Zinc stearate is acted as binding agent for manufacturing of FGM. the specimens are blended elementally using compaction machine followed by sintering through tubular furnace using Aluminium, silicon carbide and zinc stearate. The specimens are then tested for their mechanical properties such as compression strength, hardness and also examined for tribological properties.**

***Keywords*: Functionally graded material, Compaction, Sintering, Powder metallurgy and Micro structure.**

I. INTRODUCTION

Functionally graded materials (FGM) are developed by layered mixing of two or more constituent materials of different thermo-mechanical properties with different volume ratio by gradually changing from layer to layer such that the first layer has only a few particles of second phase and the last has the maximum volume ratio of the first phase.[2]

This experimental work aims at the processing of functionally graded metal matrix composites (MMCs), reinforcing with silicon carbide (SiC) with pure Aluminium as matrix material to produce composite material by adopting powder metallurgy methodology. Functionally graded composites are widely used in various components of automobile and aeronautical industries because of their superior material properties in functional and operational requirements than that of conventional composite materials. They not only possess high stiffness to weight ratio and high impact strength but also posess superior qualities in functional and operational requirements of the materials. Its inefficiency is only lies in developing sharp interfaces between the molecules in structural level. The green compacts have been prepared by incorporating SiC particles to pure Aluminium matrix material in different weight fractions (5%, 10%, 15%, & 20%)[3]. The mechanical and tribological properties of these compacts are determined to assess various functional requirements and effectiveness of the adopted fabrication technique. This method is an effective way to change the properties of the materials as required in different directions.

II. EXPERIMENTAL WORK

The main work consists of selecting the materials in an effective way to obtain the required properties.

A. Selection of Materials

For this work Pure Aluminium is taken as matrix material and Silicon Carbide, Zinc stearate is taken as reinforcement materials. Aluminium is one of the lightest engineering metals and does the third most common element comprises 8% of the earth's crust having Low strength and hardness, which limits its use in many engineering applications, could be increased due to their low density and high specific stiffness. [4]

Pure Aluminium is a silvery- white coloured metal with a bluish tinge and with high reflectivity for both heat and light. It forms a tightly adherent transparent oxide film when exposed to air. This film is resistant to corrosion in ordinary media. Although this property is useful in resisting corrosion, it is troublesome when soldering, welding and electroplating. Particle size of received Aluminium is of 50microns used for the experiment. Melting point: 660.4 °C, Density: 2.7 g/cm³.

TABLE I: CHEMICAL COMPOSITION OF PURE ALUMINIUM (98%)

Element	Weight (%)
Si	0.41
Fe	0.15
Mn	0.023
Mg	0.38
Ti	0.016
Al	Balance

Micro-sized SiC particles are commonly used as reinforcement materials for ceramics, metals and alloys for various structural and Tribological applications. It has high mechanical strength, high hardness, low density, high thermal conductivity, low thermal expansion coefficient, large band gap and excellent oxidation and corrosion resistances. Silicon carbide is also known as “carborundum”. Particle size of received silicon carbide is in the range of 50microns is used for the experiment. Melting point: 2,730 °C, Density: 3.21 g/cm³.

TABLE III: CHEMICAL COMPOSITION OF SILICON CARBIDE (99%)

Element	Weight (%)
C	29.0
O	1.5
Fe	0.05
Al	0.03
Ca	0.01

B. Sample Preparation

The FGM material composition obviously considering ball milling and die preparation and the preoccupation of each layer was performed at a lower pressure before stacking the adjacent layer under high pressure to ensure on exact compositional distribution with in the layers.[2][3]

Each specimen consists of 4 individual layers and each layer has specific composition of Al and SiC weight fractions.

TABLE IIIII: CHEMICAL COMPOSITION OF SPECIMEN

Layers	Chemical Composition (%)
I	90% Al + 10% SiC
II	90% Al + 5% SiC + 5% Zinc Stearate
III	85% Al + 10% SiC + 5% Zinc Stearate
IV	80% Al + 10% SiC + 10% Zinc Stearate

C. Specimen Size and Specifications

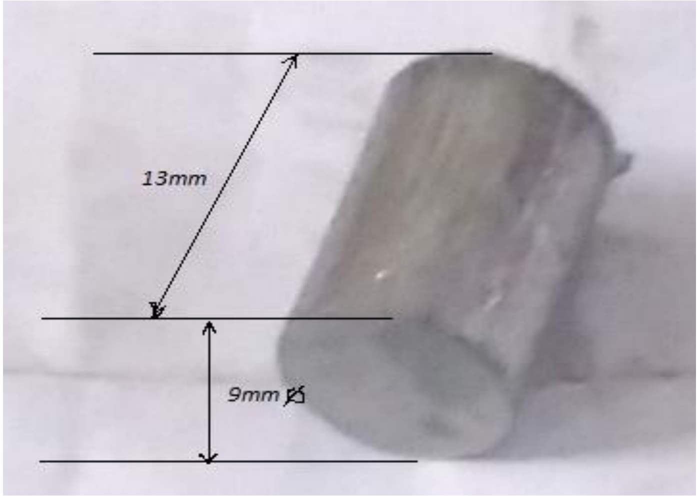

Fig. 1 Fabricated Specimen after Compaction

For this purpose of study four specimens were considered and each of size ø9mm and thickness of 13mm as shown in Fig. 1. For each specimen is fabricated at 17kN compaction pressure. Therefore all together four specimens are fabricated and attribution within the layers.[5]

Each specimen is fabricated Al with different weight percentages of SiC. Specimens are prepared according to the following composition in the Table III.

Mass of Al = density× volume

Volume of specimen=area of specimen × thickness.

$V = \frac{\pi}{4} D^2 \times L$

Mass of Al = ρ × v (grams)

III. EXPERIMENTAL PROCEDURE

For this, Powder Metallurgy method is chosen due to its advantages. The following are the considered steps.

A. Powder Metallurgy

Powder Metallurgy may be defined as the art of producing metal powders and using them to make serviceable objects. This method has gained popularity because of the high strength, ductility and toughness that can be obtained by this route. One of the outstanding uses of powder metallurgy is the combination of hard materials in a metallic matrix. Moreover, powder metallurgy is more economical than most other manufacturing processes.

Powder Metallurgy processing involves the following stages:

- Preparation of the powder materials in powder form,
- Forming operations which has an open interconnected pore structure to remove volatile contaminants water vapor, and gases,[6]
- Processing of the powder i.e., compacting (cold pressing) the homogeneous blend to roughly 80% density,
- The sintering or pressure-assisted hot Isostatic pressing.

Powder metallurgy methods involve cold pressing and sintering, or hot pressing, to produce MMCs. The matrix and the reinforcement powders are blended to produce a homogeneous distribution. The blending stage is followed by cold pressing to produce what is called a green part, which is about 80% dense and can be easily handled. The cold pressed green part is canned in a sealed container and degassed to remove any absorbed moisture from the particle surfaces. The final step is hot pressing, uniaxial or Isostatic, to produce a fully dense composite. The hot pressing temperature can be either below or above that of the matrix alloy solidus

B. Sintering

Sintering is the process of heating the green part in a furnace to cause some of the constituent materials of the FGM to be melted or surface melted. The sintering process is usually carried out at a temperature below the highest melting constituent. Sintering occurs by diffusion of atoms through the microstructure. This diffusion is caused by a gradient of chemical potential – atoms move from an area of higher chemical potential to an area of lower chemical potential. The different paths the atoms take to get from one spot to another are the sintering mechanisms[10]

The six common mechanisms are:

- 1.Surface diffusion – Diffusion of atoms along the surface of a particle,
- 2.Vapour transport – Evaporation of atoms which condense on a different surface,
- 3.Lattice diffusion from surface – atoms from surface diffuse through lattice,
- 4.Lattice diffusion from grain boundary – atom from grain boundary diffuses through lattice,
- 5.Grain boundary diffusion – atoms diffuse along grain boundary,
- 6. Plastic deformation – dislocation motion causes flow of matter.

Also one must distinguish between densifying and non-densifying mechanisms. 1–3 above are non-densifying – they take atoms from the surface and rearrange them onto another surface or part of the same surface. These mechanisms simply rearrange matter inside of porosity and do not cause pores to shrink. Mechanisms 4–6 are densifying mechanisms – atoms are moved from the bulk to the surface of pores thereby eliminating porosity and increasing the density of the sample.

Fig. 2 Tubular Furnace

The compacted pellets were taken and heated in a tubular furnace as shown in Fig. 2. in a closed atmosphere at temperatures of 500^{0}c and 550^{0}c to densify the compacted powder samples. A heating rate of 5^{0}c/min was maintained and the holding time for the samples was 30 min. after initial sintering of the specimens the specimens are cooled for a period of 24 hours adopting furnace cooling to avoid brittle nature of the specimens. [11]The densities of the sintered samples were calculated and the theoretical density of the samples was calculated. The sintered density for each of the specimen was measured using Archimedes' Principle. The densification parameter was also calculated to get an idea of amount of densification.

$$\text{Densification Parameter(DP)} = \frac{\text{Sintered Density} - \text{Green Density}}{\text{Theoretical Density} - \text{Green Density}}$$

$$\text{Percentage densification} = \frac{\text{Experimental Density}}{\text{Theoretical Density}} \times 100\%$$

IV. RESULTS AND DISCUSSIONS

A. Compression strength:

The specimens are tested for the ability to resist loads in compressive direction by placing them on the compression testing machine and applying the loads gradually from the hydraulic controller onto the ram such that the specimens fracture uniformly and no unnecessary excessive force is generated on the specimens. We observed that at the initial condition the stress is linear upto 40MPa but after sometime it suddenly increased to 250MPa and goes on increasing when the specimen has reached plastic zone and ultimately it has reached 545 Mpa which is 21% more than the conventional pure aluminium.

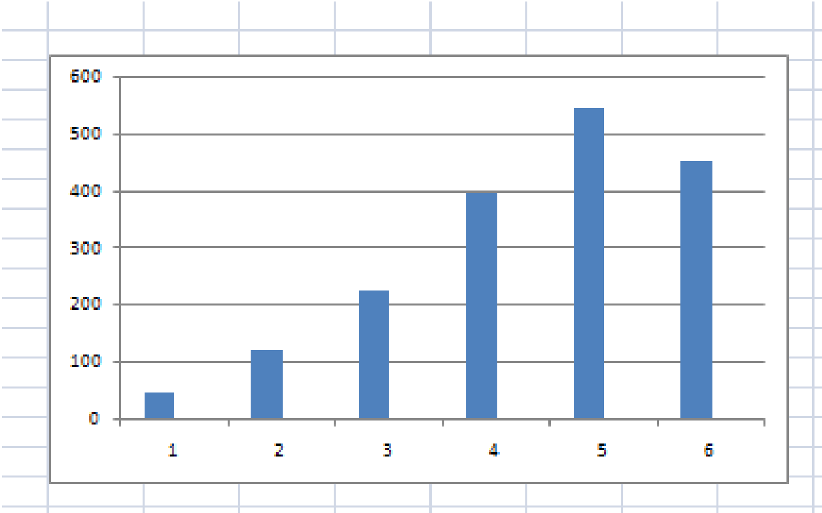

Fig 3: Compression strength vs % Increase of composition

B. Hardness Measurement

The hardness of the composite specimens were measured by Brinell hardness tester. The samples was measured under a load of 187.5kgf and ball diameter of 3 mm is used for a dwell time of 15 seconds. The impressions are taken down and measured through optical microscope. For each sample at least five measurements were taken at equivalent positions of the sample and resulted graph Fig.4.

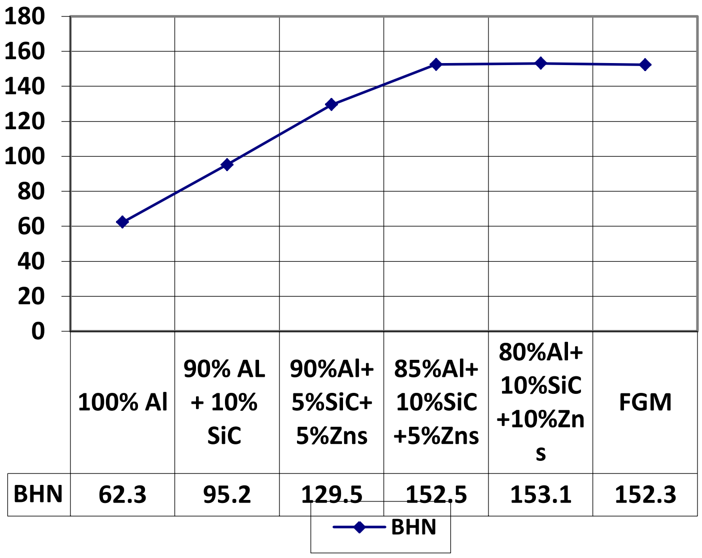

Fig. 4 Hardness Test Results

C. Wear Testing

To study wear behaviour of composite specimens ball-on-plate type wear testing instrument. The wear specimen with a diameter of 9mm and a height of 15mm was prepared. The ends of the specimens were polished using abrasive paper with a grade of 600 first, and then with a grade of 1000. The sliding end of the pin-and disc surface was cleaned with acetone before testing.

TABLE IVV: WEAR RATE CONDITIONS

Condition	Data
Pin Material	80% Al + 10% SiC + 10% Zinc Stearate
Disc Material	EN 31 disc steel with a hardness of 75HRC
Pin Dimensions	15*9*9mm^3
Time(minutes)	30
Load(N)	50
Track diameter (mm)	70
Disc speed(rpm)	400

The composites are mounted on pin on disc wear test apparatus of model TR-201 and To study wear behavior of composite specimens pin on disc methodology is adopted.[1]

Tests were carried out with an 9mm diameter, 400 rpm rotational speed for a period of 30 minutes and resulted graph as shown in Fig.5.

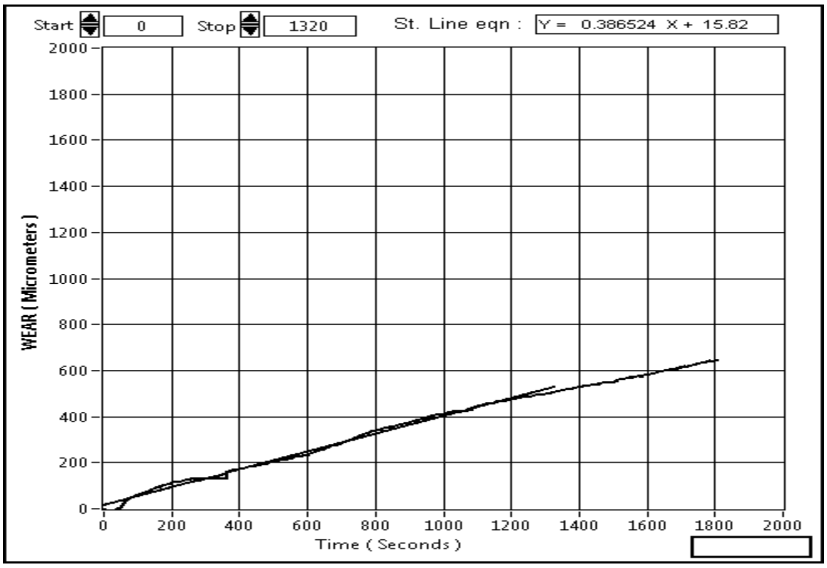

Fig. 5 Wear Test Results

V. CONCLUSION

Aluminium Metal matrix composites with different weight proportions of Silicon carbide (SiC) are fabricated successfully. Compression strength of the FGM is attained a value of 545 MPa which is 21% more than the pure Al.Hardness test on the composites have done successfully and it was found that specimen of two different compositions 85% AL + 10% SiC + 5% Zinc stearate attained hardness of 152.588 BHN highest among other reinforcement. Hardness of material with goes on increasing with percentage of SiC

Wear test of composites have done successfully by using pin on disc wear test apparatus (TR 201) and found out that highest coefficient of friction is 0.59 at frictional force 30N having the wear rate of 610 microns

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