ALUMINUM METAL MATRIX COMPOSITES FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Aluminium alloys are widely used in aerospace and automobiles industries due to their low density, corrosion resistance, low thermal coefficient of expansion as compared to conventional metals but its low strength and low melting point were always a problem. An effective method of solving these problems is to use a reinforced element as Al_2O_3 particles. The high-strength, low density aluminium alloy-based composites with alumina reinforcement have generated significant interest in the industries where strength to weight ratio is the primary concern. Present work is to study the behaviour of pure aluminium powder reinforced with Al_2O_3 which is produced by the powder metallurgy technique by varying the percentages of alumina by weight. The fabricated composite samples were trimmed according to the ASTM standards for different experiments and its characterization is performed. Finally the research work deals with fabrication of Al/Al_2O_3 composite for automotive applications to replace the existing aluminium alloys

KEYWORDS: *Aluminium alloys, Al/ Al2O3, Powder metallurgy, Mechanical properties, Automotive applications.*

I. INTRODUCTION

Aluminium has played and continuous to play a key role in the development of metal matrix composites (MMCs) reinforced with a variety of ceramic materials including Al_2O_3, TiC, B_4C, and SiC. From the wide range of MMCs systems studied thus far and on account of the attractive properties of Al_2O_3. Al/Al_2O_3 composites have drawn the attention of a plethora of research scientists and technologists. Like with any other composite material, the materials behaviour lies much in the matrix characteristics as in the reinforcement properties. Several aspects are to be considered with regard to the metallic matrix namely composition, response to heat treatments, mechanical and corrosion behaviour. Since aluminium offers flexibility in terms of these aspects accordingly, a number of aluminium alloys have been used in studies intended for research and technological applications. The combination of light weight, environmental resistance and useful mechanical properties such as modulus, strength, toughness and impact resistance has made aluminium alloys well suited for use as matrix materials [1-4]. Moreover, the melting point of aluminium is high enough to satisfy many application requirements. Among various reinforcements, alumina is widely used because of its high modulus and strengths, excellent thermal resistance, good corrosion resistance, good compatibility with the aluminium matrix, low cost and ready availability. The main objective of using alumina reinforced aluminium alloy composite system for advanced structural components to replace the aluminium alloys The choice, however, for one or another alloy depends also on other factors as the composite processing route, which in turn can be dictated by the volume fraction of the reinforcement in the composite. Another important factor for selection of the aluminium alloy is the composites application and specific requirements in service. For instance, one composite may behave better under certain loads or in corrosive environments. In the present investigation aluminium (commercially pure having an assay of >99% of Aluminium) and Al_2O_3 particulates have been used for the MMC fabrication.[5-9].

II. MATERIALS AND METHODS

In the present investigation aluminium alloy particulates (150 mesh), Aluminium oxide (150 mesh) are used in fabrication.

2.1. Specimen Fabrication

The alumina is heated to a temperature of 600°C in a muffle furnace in the presence of air and kept at the temperature for sixty minutes prior to using it for fabrication of the MMC samples. This is done in order to form a thin layer of oxide on the alumina surface to make it inert to aluminium so that the direct reaction between aluminium and aluminium is avoided. Based on the exhaustive literature survey, it is concluded that powder metallurgy method of the solid phase processing methods serves better than other process. Powder metallurgy (P/M) is one of the processing techniques adopted for alumina reinforced aluminium composites because relatively lower temperatures (below melting point) are involved in P/M processing. Homogenous, high strength and net shape components of aluminium-alumina composites can be produced through powder metallurgy (PM) route. The undesirable interfacial reactions and development of detrimental intermetallic phases are negligible in Al/Al_2O_3 composites as compared to the cast composites. Compared to fibrous composites, particulate composites offer improved ductility and reduced anisotropy in mechanical properties and hence, can be subjected to extrusion, forging and rolling. On a cost-benefit scale, the particulate composites are generally far superior. However, homogeneity, machinability, and interfacial reaction of the constituents represent the large problems pertaining to these composites.

2.1.1 Powder Metallurgy Method

The MMC test specimens are fabricated by powder metallurgy route using ball mill mixing, solid state sintering.

2.1.2 Mixing of Powders

The MMC test specimens are fabricated by the powder metallurgy route adopting the usual mixing and solid state sintering. 90% , 85 %, 80 %, 75% Aluminium powder with a size of 150 mesh and 10%, 15 %, 20 %, 25 % by weight of alumina with a size of 150 mesh are mixed for fabricating the composite. Total four categories of mixture were prepared (90% Al+ 10 % Al_2O_3, 85% Al+ 10 % Al_2O_3, 80% Al+ 20 % Al_2O_3, 75% Al+ 25 % Al_2O_3.

2.1.3 Compaction of powder mix

About 10gms of the powder mixture was taken adopting a method of coning and quartering for compaction in a cold uniaxial press in a metallic die-punch arrangement. The powder sample is pressed in the cold uniaxial pressing machine to render the green circular test samples of 25mm outer diameter applying a load of 18 tons, which accounted 3600 bar pressure. A stainless steel die of 25 mm internal diameter was used for this purpose.

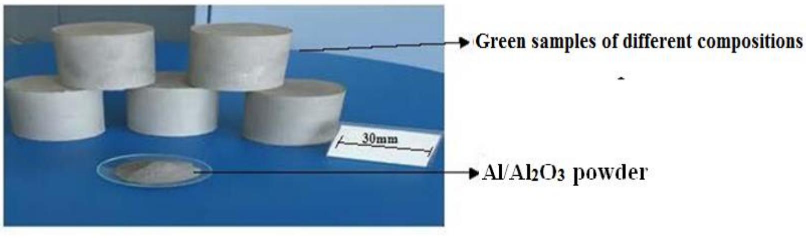

Figure 1. Green samples

To allow the powder to flow freely and to prevent the specimen from sticking on to the walls, stearic acid was used as a lubricant that was applied to the walls of the die and punch. A dog bone shaped die was also prepared for the purposes of tensile testing in UTM.

2.1.4 Sintering of green samples

In the experimental setup the green samples are carefully baked at an elevated temperature in a controlled atmosphere environment but just below the melting point of major constituent for a sufficient time. It is carried out in a muffle furnace in an atmosphere of air at pressure of 1 bar. A batch of eight samples from each of the two dies were sintered just below the melting point of major constituent at (350 ˚C , 450 ˚C, 550 ˚C) for a holding time of 1 hour and cooled for 24 hour.. The high temperature sintering process cause the aluminium surrounded by the oxide layer in the particle to melt and expand in volume to rupture the oxide envelope surrounding it and makes contact with melted aluminium leaking from nearby particles and welding take place. The oxide layer broke into small shell fragments impeded in the aluminium matrix restricting the movement of dislocation and increase strength. The presence of alumina particles also hinders the aluminium melt from one particle to join melt from one another. So increasing alumina content increase the sintering temperature needed to achieve high strength composite. Then furnace is allowed to cool to room temperature for a span of 24 hours. Then, the pallets and dog bone shaped samples were removed from the furnace.

III. RESULTS AND DISCUSSIONS

3.1 XRD analysis

To confirm the certainty of the constituents present in the blended powder of the specimen, supplied matrix element (aluminium) and reinforcement element (alumina).After the XRD analysis, the peaks obtained is shown in Figure 2 confirms the presence of only two phases viz., Al and Al_2O_3 crystals. It is shown that aluminium is 99.7% pure and the rest contains aluminium alloys like aluminium silicon, aluminium manganese and aluminium titanium. Again XRD analysis is performed to confirm the constituents present in the blended powder of the specimen. It was found that the specimen was free from chrome steel crystals expected from blending in a chrome steel crucible. These results confirm the suitability of the sample pallets in respect of uniform distribution of particles and confirm that they are precisely accurate for further analysis.

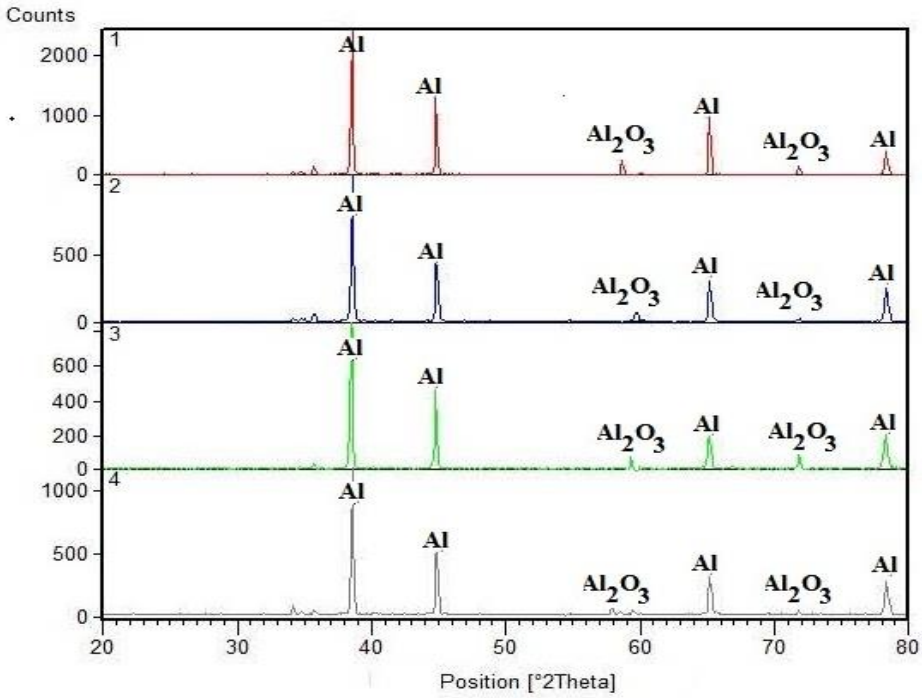

Figure 2. The XRD graphs

3.2 Density

The density of material is the ratio of weight to volume was obtained by accurately measuring the weight and the volume of the composites. Densities of the given samples were obtained by using Archimedes principle. From the table 1 we observed that density value increases as percentage of reinforcement increases. This may be due to the presence of voids between particles with melted aluminium.

Table 1. Variation of density with percentage of reinforcement

S.No	% of reinforcement	Density(g/cm^3)
1	10	2.70
2	15	2.84
3	20	2.87
4	25	2.94

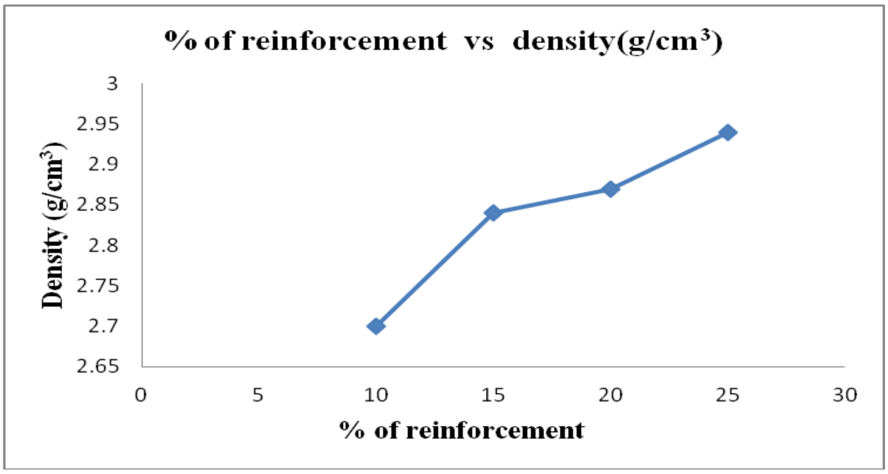

Figure 3. Density values with different percentage of reinforcement

3.3 Micro-hardness

Hardness of the sintered samples is measured by the equipment Vickers micro-hardness measuring machine by using diamond indentor at an applied load of 100N. The effect of the percentage in reinforcement on hardness is shown in the table 2

Table 2. Hardness values with different percentage of reinforcement

S.No	% reinforcement	Load Applied (N)	Mean hardness (HV)
1	10	100	85
2	15	100	94
3	20	100	102
4	25	100	108

It shows that the hardness of Al/Al_2O_3 composite materials for 20 % and 25 % particle reinforcement is higher than that of the aluminium alloy (95 HV) which is caused due to high hardness of Al_2O_3.The higher hardness of the composites can also be attributed to the fact that Al_2O_3 particles prevent the movement of dislocations

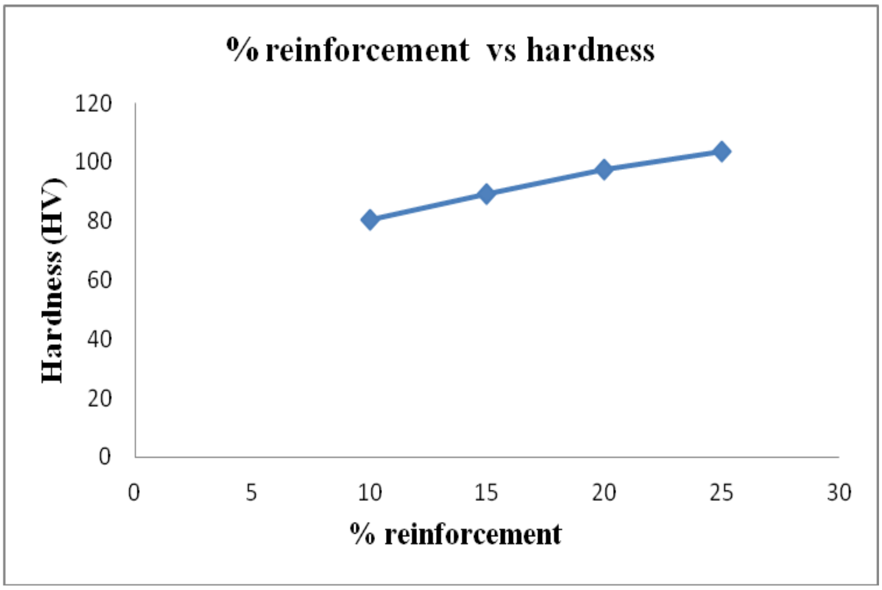

Figure 4. Graph between reinforcement and hardness

Figure 5. Samples after hardness test

3.4 Tensile test

The tensile test is generally performed on flat specimens with different percentages in reinforcement by using universal testing machine. The most commonly used specimen geometries are the dog-bone specimen Figure 6. The standard test method as per ASTM D3552-12 has been used; The value of gauge length (L), width (d) and thickness (t)of the test specimen used in the experimentation as 150 mm, 10 mm and 8 mm.

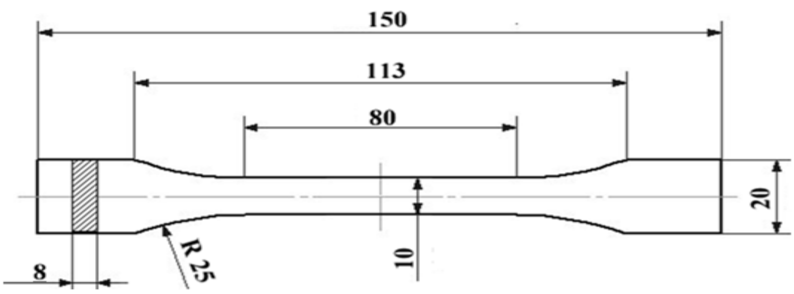

Figure 6. Line diagram of tensile test specimen

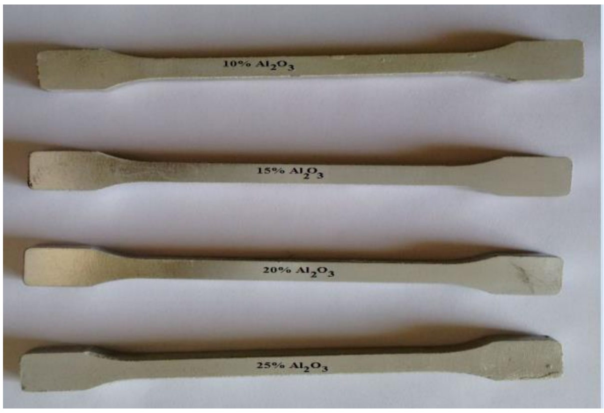

Figure 7. Specimens for tensile test

Table 3. Tensile strength values with varying percentage of reinforcement

S.No	% reinforcement	Tensile strength (MPa)
1	10	263.3
2	15	289.4
3	20	310.2
4	25	337.3

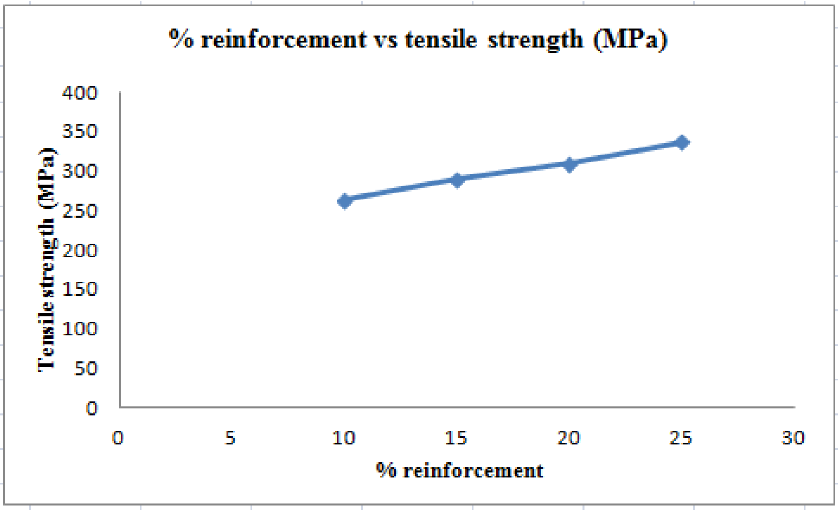

Figure 8. Graph between percentage reinforcement and tensile strength

Table 3 shows that Al/Al_2O_3 for 20% and 25% particle reinforcement exhibit relatively higher tensile strength compared to Aluminum 310 MPa. In fact, in the composites, the reinforcement particles act as a strengthening agent that helps to fill in pores in the metal matrix, thus creating a stronger bond between the matrix's particles. With the stronger bond between particles, the mechanical properties of the material will also improve.

3.5 Microstructure Analysis

Micrographs of samples taken after sintering are shown in the Figure 9. It is observed that alumina particles are homogeneously distributed in the matrix; however there are sparse areas where the alumina particles have not successfully binded to the aluminium particles and are acting as binders in this case. In the Figure 9 (b) voids can be seen in this case which would affect the strength of the material. The non uniformity distribution of the particles can also be seen in both Figure 9 (c) and (d) due to uneven pressure application when compacting the sample. The microstructure thus indicates the potential of an even higher strength of the metal matrix composite than the ones recorded.

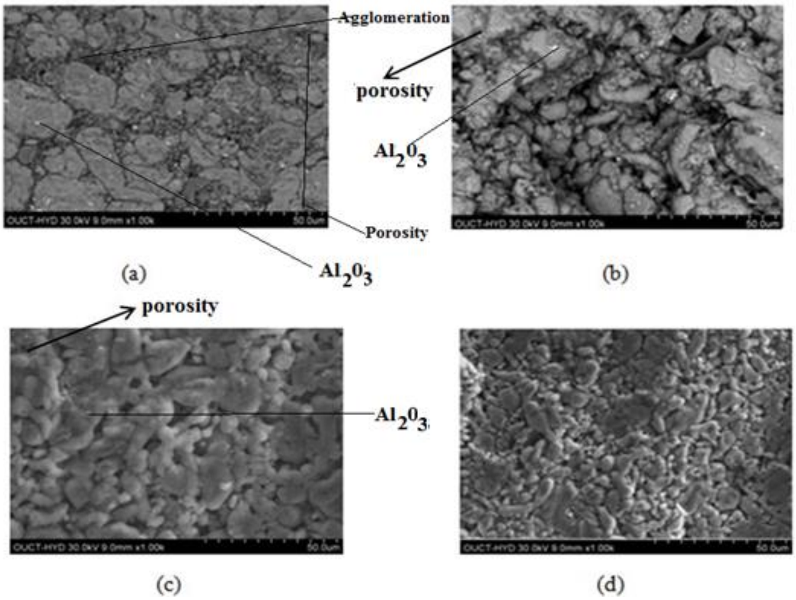

Figure 9. Micrographs showing alumina and porosity in the composite

Table 4. Comparison of properties of Al/Al_2O_3 composite with different materials

Material	Al/Al_2O_3 (25% reinforcement)	Aluminium Alloy (Cylinder head and piston)	Steel (Crank case)
Density (g/cm^3)	2.9	2.7	7.8
Hardness (HB)	103.7	95	180-220
Tensile Strength (MPa)	337.3	310	625-725
Corrosion Resistance	Yes	more than steel less than aluminium	No

IV. CONCLUSION

From the present work, the following conclusions can be drawn, based on the experimental results and the detailed discussions made.

- The samples of Al/Al_2O_3 composite of different compositions were successfully made using powder metallurgy technique. Samples made by powder metallurgy were sintered successfully under vacuum condition.
- The properties of the composite like density, hardness of MMCs under investigation depend on both, the weight percentage and mesh size of Al/Al_2O_3.
- Hardness was improved from 85 HV to 94 HV by adding wt % of alumina into aluminium.

- Tensile strength increases exponentially with increasing composition of reinforcement and at 20 % and above the values of tensile strength are found to be higher than aluminium alloys.
- The prepared composite by means of comparison is found to be suitable for use as connecting rod, cylinder head, crankcase material etc, replacing materials such as aluminium alloys and steel.
- The prepared composite is also found to be corrosion resistant due to addition of alumina as reinforcement.Thus it has been concluded that Al/Al_2O_3 composite prepared by powder metallurgy technique and sintered under vacuum condition gives better mechanical properties and this material could replace conventional materials in various automotive and automobile applications.

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