Preparation of magnesium metal matrix composites by powder metallurgy process

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Abstract
Magnesium is the lightest metal used as the source for constructional alloys. Today Magnesium based metal matrix composites are widely used in aerospace, structural, oceanic and automobile applications for its light weight, low density(two thirds that of aluminium), good high temperature mechanical properties and good to excellent corrosion resistance. The reason of designing metal matrix composite is to put in the attractive attributes of metals and ceramics to the base metal. In this study magnesium metal matrix hybrid composite are developed by reinforcing pure magnesium with silicon carbide (SiC) and aluminium oxide by method of powder metallurgy. This method is less expensive and very efficient. The Hardness test was performed on the specimens prepared by powder metallurgy method. The results revealed that the micro hardness of composites was increased with the addition of silicon carbide and alumina particles in magnesium metal matrix composites.

Keywords: Magnesium, Powder metallurgy, Magnesium MMC, Hardness, Hybrid MMC.

1. Introduction
In many of today’s industries like aerospace, automobiles etc. finding increasing applications of metal matrix composites due to their properties. The magnesium alloys and composites have attracted significant research intention due to their low densities [1]. The hardness plays a significant role in selecting the metal matrix composites for using in various industries, automobiles etc. Metal matrix composites (MMCs) are the composite materials, with two ingredient elements, one being metal essentially, the other constituent may be a dissimilar metal or a different material, such as a ceramic or organic compound. For e.g. Al2O3 particle reinforced in a magnesium matrix and Silicon carbide reinforced with the Magnesium matrix composites. With the different types of metal matrix composites, light-weight MMCs such as magnesium(Mg) based composites are of more interest due to their potential applications in aerospace, sports equipment, and automobile industries. Magnesium Metal Matrix Composites have better properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures and significant weight savings over unreinforced alloys.

In a composite material the function of the reinforcement is basically one of enhancing the mechanical properties of the efficient resin system. The unlike fibres / particulates used in composites have various properties and thus change the properties of the composite in special ways. The matrix is the continuous phase in which reinforcement is scattered, and due to this there is a lane through the matrix to any location in the material, which is not occurs in sandwich structure. The matrix used usually a lighter metal such as magnesium, aluminium, or titanium, and gives a better support for the reinforcement in structural applications.
Magnesium is available plentifully about 13% by weight of the Earth's crust as like iron, oxygen and silicon. The Atomic number of magnesium is 12. Magnesium is a soft, long-lasting, low weight, high yielding and pliable metal with appearance of gray-white. Magnesium has about two-third the density of aluminium. It can be machined without difficulty, ease of casting, drawing and extruded. Magnesium has high corrosive resistance due to presence of a thin surface layer of magnesium oxide, which prevents further oxidation more effectively.

The reinforced magnesium MMCs are prepared by several methods including squeeze casting, stir casting, infiltration and mechanical alloying, powder metallurgy. Among these, powder metallurgy (P/M) technique is most likely used to fabricate Mg metal matrix composites. A uniform distribution of reinforcement particulates in the metal matrix can be achieved by using powder metallurgy technique with or without the chemical reactions between the reinforcements and matrix and the composites can fabricate by using powders without melt [3].

Powder metallurgy is the process of mixing the fine powdered particles firstly, then compressing them to get a required shaped green compact. It is then heated in a fully controlled atmosphere to bond the material (sintering) [4].

This study focuses on synthesis and characterization of Mg MMC’s reinforced with silicon carbide and alumina which have been prepared by powder metallurgy technique. The mechanical behaviour such as density and hardness of sintered composite specimens have been investigated. Hybrid Composites are relatively new and prepared by using a common matrix material with two or more different types of reinforcement materials. A hybrid composite provides various properties that is not obtained by using only a single reinforcement phase.

The properties of magnesium, silicon carbide and aluminium oxide are shown in below table 1.1;

| Properties          | Magnesium(Mg) | Silicon carbide(sic) | Aluminium oxide(Al₂O₃) |
|---------------------|---------------|----------------------|------------------------|
| Density (g/cm³)     | 1.73          | 3.1                  | 3.69                   |
| Melting point(°C)   | 650           | 2200-2700            | 2072                   |
| Poisson Ratio       | 0.29          | 0.14                 | 0.21                   |
| color               | Shiny grey    | Black                | White                  |

Silicon carbide (SiC) is a composition of silicon and carbon denoted as SiC. It was initially formed by electro-chemical reaction of carbon and sand at high temperature. Silicon carbide is used as abrasive particles in grinding wheels since from many years. It is used in various applications like as abrasives, refractories, ceramics, electrical conductors, flame igniters, and floor tiles, etc. Structural and wear applications of silicon carbide are continuously developing. Silicon carbide is a composition of tetrahedra of silicon and carbon atoms with strong bonds in the crystal lattice. Silicon carbide having 16-100grit size [5].

Aluminium oxide is available in its crystalline form as alumina, or corundum. The chemical formula of aluminium oxide is Al₂O₃. Alumina has widely used in production of aluminium metal, ceramics, and refractories. It is also used as a abrasive because of its hardness [5].
2. Methodology

The magnesium has been selected as the matrix material which is more compatible with the reinforcement and has superior mechanical properties. alumina is selected as a reinforcement, which is more stable with magnesium and withstands high temperature. It is an oxide ceramic having low affinity for the oxygen to form oxides. The Silicon carbide has been selected as one more reinforcement. It has good lubricating effect along with it reduces the noise and vibration during the relative motion. The particulate form of the reinforcement has better distribution in the matrix to provide isotropic property for the composite.

2.1 Mixing:

Mixing the pure magnesium metal powder with silicon carbide and aluminum oxide, with the help of poly-vinyl-alcohol (PVA) which acts as a binding agent. Blending or mixing is an operation of thoroughly intermingling of different powders of various compositions or of same composition. The main intention of blending process is to produce uniform distribution of powder. Different types of blenders and mills are used for mixing purpose. Here ball mill is used for blending operation.

2.2 Compacting:

In this process, the metal powder is compacted in a die by the application of high pressures. Compaction is performed using die and punch which is machined to close tolerances. Typically, the mixed powder is poured into the cavity of die and compacted by punch using Universal Testing Machine as shown in fig 2.1. Here the powder is compacted into green compact of pin shape and then taken out of the die cavity. As the amount of applied load increases, the density of the compacted powder is increases.

2.3 Sintering:

The green compacts were sintered in a vacuum furnace of 550°C for 150 min at the heating rate of 13°C/hour and cooled at low cooling rate. Usually metals are sintered at 70-90% of the melting temperature of base metals. Here vacuum furnace is used for sintering operation. In a vacuum furnace, the green compact is kept in a vacuum by removing the oxygen in order to avoid quick oxidation which is not desirable. During sintering process, the bonding between the powder particles takes place continuously at their areas of contact and results in growth of grain boundaries. Fig 2.2 & 2.3 shows the specimens before and after sintering process respectively.

The Magnesium metal matrix composites were prepared for various compositions are as shown in Table 3.1

| Specimen code | Magnesium(Mg) | Silicon carbide(sic) | Aluminium oxide(Al2O3) |
|---------------|---------------|----------------------|------------------------|
| 1             | 100%          | 0%                   | 0%                     |
| 2             | 90%           | 5%                   | 5%                     |
| 3             | 80%           | 10%                  | 10%                    |
| 4             | 70%           | 15%                  | 15%                    |
3. Results

3.1 Density measurement:

The graph below shows that the density of prepared specimens before and after sintering operation for different composition of magnesium metal matrix composites. It is seen that, with the increase in reinforcement percentage, the density of composites also increases before and after sintering process due to the higher density of silicon carbide and alumina compared to magnesium matrix. It is also observed that rate of change of sintered density is higher for the 10% and 15% of SiC and Al₂O₃ reinforcement due to the higher density of reinforcement than the base metal. Sintering involves bonding among particles and densification, so the density of composites after sintering process decreases than the before sintering is as shown in below graph 3.1.
3.2 Hardness value:

The hardness value was determined for various samples by using vicker’s hardness tester as shown in below table 3.2. In this test a diamond indenter is used to apply load. A load of 200gm mass applied on the specimen without any jerk for about 40 seconds. Figure 3.2 shows the graph plotted for vicker’s hardness number against the varying percentage of reinforcements of specimens. From the graph it is clear that, hardness of magnesium metal matrix composites is increases with increasing weight percentage (up to 10%) of alumina and silicon carbide than that of its base metal. It is evident from the graph that the hardness of pure magnesium increased by the addition of 5wt% and 10wt% of SiC and Al₂O₃. This may be due to the harder silicon carbide and alumina particles. The presence of these particles offers additional resistance against to plastic deformation which leads to increase in the hardness of composites. However, hardness of 15wt% of SiC and Al₂O₃ reinforced composite material decreased due to may be inadequate interface bonding between matrix and reinforcement particles.

| Composition               | Mean hardness number in HV |
|---------------------------|----------------------------|
| Pure Magnesium            | 36.3                       |
| 5%SiC + 5%Al₂O₃ + 90% Mg  | 42.54                      |
| 10%SiC + 10%Al₂O₃ + 80% Mg| 45.39                      |
| 15%SiC + 15%Al₂O₃ + 70% Mg| 39.28                      |

Figure 3.1: Variation of density of specimen after and before sintering
Figure 3.2: Graph of Percentage composition v/s Vickers Hardness Number

3.3 Microstructure:

The microstructure of sintered specimens has been analyzed for mg matrix material with 0%, 5%, and 10% of SiC and Al₂O₃ reinforcement, which as shown in above fig 3.3. The SEM micrograph represents the presence of sic and al₂o₃ reinforcements in the magnesium matrix composites. The uniform particle distribution was achieved in the samples and pore defects were created in some areas of the microstructure. The better bonding was achieved in between reinforced particles and matrix as shown in fig 3.3.

3.4 Wear test:

The wear test was conducted for various samples having dimensions of 10mm diameter and 35mm length by using ducom pin-on-disc wear testing machine. By using emery paper, the surface of the samples was cleaned before conducting the test in order to ensure that flat surface of the specimen make contact with the steel disc. The surface of wear track and samples were cleaned with acetone and samples were weighed before and after conducting the each test. The wear test was conducted for magnesium metal matrix composites with 0%, 5%, 10%, and 15% of silicon carbide and alumina reinforcement. Fig 3.4 shows the graph plotted for disc speed 200rpm having sliding distance 282.7m, time 5min, sliding velocity 0.942m/s and track diameter 90mm. From the graph, it is evident that, weight loss of the mg mmc’s are increased with the increase in the load. As the reinforcement percentage increases, weight loss of specimens decreases due to the strength of reinforcements. From
the graph it is clearly visible that wear resistance of pure magnesium is increases with the increase in the percentage of reinforcements. At 15% composition, weight loss is increases for higher load as compared with 5% and 10% composition due to the weak bond between matrix and reinforcement particles.

![Graph load v/s weight loss at speed of 200rpm](image)

**Figure 3.4:** Graph load v/s weight loss at speed of 200rpm

### 4. Conclusion

Magnesium metal matrix composites reinforced with 5wt%, 10wt% and 15wt% Silicon carbide and alumina particles were successfully fabricated by powder metallurgy process. The experiment was successfully carried out on test ready specimen for the compaction of magnesium as matrix and silicon carbide, alumina as reinforcement by using powder metallurgy technique. Due to the higher density of silicon carbide and alumina, with the increase in reinforcement percentage, the density of composites also increases before and after sintering process. The density of composites after sintering process decreases than that of before sintering. It was also conclude that, as compared with pure magnesium the hardness values of magnesium metal matrix composites reinforced with 5wt%, 10wt% SiC and Al₂O₃ particulates were increased. The weight fraction of reinforcement in the microstructure as low as 5% and as high as 10% plays a major role in the powder consolidated Mg-MMCs. A microstructure observation shows a good bonding & distribution of reinforcement particles achieved through this method of fabrication. The wear behavior of magnesium metal matrix composites has been studied for various load of different composition at disc speed of 200rpm. It is found that wear rate is increases with the increasing of applied load, wear resistance of composites also increases with the increasing of reinforcement percentage.

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