ABSTRACT

Magnesium is an energy efficient material having least density among all the light weight metals like aluminium, titanium, etc. There has been extensive studies on Mg based materials in past two decades due to huge pressure among researchers to search for materials having high specific strength for weight reduction. This weight reduction improves the engine efficiency and reduces fuel consumption especially in aerospace and automotive sector. Magnesium also has good damping capacity, superior machinability, good electromagnetic shielding and biocompatibility properties in addition to low density which makes it very suitable for use in automobile, aerospace, sports, electronics, and biomedical applications. But the low strength, low wear resistance and corrosion properties limits its widespread use. Reinforcing magnesium with ceramic particulates imparts high strength and wear properties to pure magnesium. Therefore, magnesium matrix composites having combination of properties like low weight coupled with high strength, hardness and wear resistance has potential to replace many aluminium and some polymer based parts in different applications. MgO is a ceramic particle having high melting point, hardness, high compressive strength and high chemical and thermal stability even in harsh conditions making it an appropriate choice for reinforcement which can improve hardness, strength, and wear properties of pure Mg. Moreover, it is cheap, easily available, and easy to handle. It is also compatible with human body.

Therefore, fabrication of Mg/MgO composites have been attempted by different processing techniques like stir casting, disintegrated melt deposition technique, in situ process, reactive cryomilling and high pressure consolidation, powder metallurgy, etc., but all processes have common disadvantage of high cost of production. Powder metallurgy is a near net shape process which imparts refined microstructural features and give superior strength levels. Very few studies are on Mg/MgO MMCs by powder metallurgy and most of them are for in situ

MgO reinforced Mg. Therefore, in the present work ex situ Mg/MgO composites have been fabricated by powder metallurgy process using two different low cost sintering processes - rapid microwave sintering process which has above 90 % power saving than conventional sintering and a cost effective sintering process which uses aluminium foil to prevent oxidation of compacts during sintering without the use of vacuum or inert gases. These two sintering processes reduces overall cost of powder metallurgy process for Mg/MgO composites.

Owing to various research gaps, following objectives are drawn for current study.

1. To fabricate Mg/MgO MMCs through powder metallurgy route assisted by rapid microwave sintering method.
2. To study different physical and mechanical properties of microwave sintered Mg/MgO composites.
3. To fabricate Mg MMCs through powder metallurgy utilising a novel cost-effective sintering method.
4. To study the distribution of phases and its effect on properties through diffraction and microscopy techniques.
5. To study the effect of varying weight fraction of MgO particulates on physical and mechanical properties like density, hardness, and compressive behaviour of composites.
6. To study the dry sliding wear behaviour of composites fabricated by cost effective sintering method under varying load of 5, 10, and 15 N and at each sliding velocity of 0.6, 0.9 and 1.2 m/s.

The thesis work has been summarized in eight chapters which are briefly described below:

Chapter 1 describes the introduction of composites and its historical journey. It points out the importance of MMCs especially Mg MMCs and potential advantages of MgO reinforced Mg MMCs. Finally the chapter ends with brief description of present work.

Chapter 2 begins with introduction of metal matrix composites particularly particulates reinforced metal matrix composites. Then a detailed description is provided for different fabrication methods for Mg MMCs and an extensive literature of previously reported Mg/MgO MMCs fabricated by different techniques. A brief about friction and wear laws is also given along with the previously reported works on dry sliding wear of Mg based MMCs. The chapter ends with formulation of problem and major objectives of present work.

Chapter 3 outlines the details of the experimental procedures followed for fabrication of Mg/MgO composites. Both the sintering methods have been elaborated separately. Details of testing equipment, testing parameters and calculation methods for density and porosity, phase analysis and quantification, phase and elemental distribution, hardness, compression tests and dry sliding wear test of MMCs have been described separately for both sintering methods.

Chapter 4 describes the results of fabrication of pure Mg and Mg/5MgO composites at varying sintering temperature of 450 °C, 500 °C and 550 °C by rapid microwave sintering. The chapter comprehensively discusses the effect of varying sintering temperature and hard MgO addition on different metallurgical and mechanical properties of composites.

Chapter 5 describes the results of Mg/xMgO, x = (0, 5, 10, 15) wt. % composites fabricated by cost effective sintering technique. The chapter discusses the effect of MgO weight fractions on different metallurgical and mechanical properties of Mg/MgO composites.

Chapter 6 describes the comparison of physical, mechanical and microstructural features of pure Mg and Mg/MgO composites fabricated by rapid microwave sintering and the novel sintering approach.

Chapter 7 describes the results of pin on disc dry sliding wear test of Mg/xMgO, x = (0, 5, 10, 15) wt. % MMCs. Each composition of sample was tested at 5 N, 10 N and 15 N load at each sliding velocity of 0.6 m/s, 0.9 m/s and 1.2 m/s for a constant sliding distance of 1000 m. The results of variation in wear rate and coefficient of friction have been described for each combination of sample, load and sliding velocity. The dominant wear mechanism at different load and sliding velocity have been identified by studying the micrographs, elemental maps and topographical images of worn surfaces.

Chapter 8 presents the salient conclusions on microstructural, mechanical and tribological characteristics of Mg/MgO composites synthesised by both sintering methods along with the scope of future study.

The important findings are mentioned below.

- Pure Mg and Mg/MgO composites were successfully fabricated by rapid microwave sintering method. The composites showed presence of only Mg and MgO phases and MgO particles are homogeneously distributed and are settled at grain boundary of Mg matrix. Agglomeration at few places were observed in Mg/MgO MMCs sintered at 500 °C. The grain size gradually decreases with increasing sintering temperature in both pure Mg and Mg/MgO MMCs.
- Pure Mg and Mg/MgO composites were nearly 97 % and 96 % dense respectively. The density increases with increase in sintering temperature in pure Mg but vice versa occurred in Mg/5MgO MMCs. The addition of hard MgO reinforcements improves the hardness of composites due to uniform distribution of MgO particles and grain refinement effect.

However, there is very modest change in hardness value due to change in sintering temperature. The compressive yield strength of pure Mg samples showed nominal improvement due to increase in sintering temperature. However, when 5 wt. % MgO is added in pure Mg, considerable improvement in CYS is observed due to load bearing effect, grain refinement and coefficient of thermal expansion mismatch. Ductility in pure Mg is improved as sintering temperature increases but the addition of MgO particles deteriorated the ductility in composites.

- Mg/xMgO, x = (0, 5, 10, 15) wt. % MMCs were successfully fabricated by cost effective sintering method. The attempt to employ carefully wrapped aluminium foil on samples to effectively prevent oxidation from the surrounding environment was successful during the entire sintering duration. Composites were nearly 97 % and 98 % dense for Mg/5MgO and Mg/10MgO samples respectively. The porosity decreases by 6.4 % and 33.3 % compared to pure Mg in Mg/5MgO and Mg/10MgO respectively. However, porosity sharply increases in Mg/15MgO sample.
- The composites showed an increase of 9 %, 13 % and 29 % hardness value with respect to pure Mg in Mg/5MgO, Mg/10MgO, and Mg/15MgO samples respectively. Also an improvement of 6 % and 23 % in compressive yield strength for Mg/5MgO and Mg/10MgO samples was observed when compared to pure magnesium.
- The wear rate of all samples generally increases with increase in load as well as sliding velocity. The coefficient of friction was lowest for pure Mg samples compared to the composite samples owing to soft nature of Mg and absence of MgO particles. The COF value generally increases as load is increased. There is very minimal variation in COF value with respect to change in MgO weight fraction in composite samples.
- Wear in Mg/MgO composites does not occur by single wear mechanism. In fact, multiple mode of wear mechanism works simultaneously. In Mg/0MgO samples, wear due to

abrasion was dominant at low load followed by plastic deformation at higher loads. In composite samples, wear due to oxidation and delamination were dominant. Adhesive wear was dominant at high load and high sliding velocity conditions.

This study explores the performance of MgO reinforcement for strength and wear characteristics improvement in pure Mg matrix through rapid microwave and cost effective sintering method. It also explores the effectiveness of cost effective sintering approach for its use in the fabrication of Mg MMCs. The knowledge generated through this study is expected to provide a better understanding of Mg/MgO MMCs system.