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# Tribological Behavior of Aluminium (Al) - Magnesium Oxide (MgO) Composite

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**Abstract—***Aluminium matrix composites (AMCs) are widely used for high performance applications such as automotive, military, electricity and aerospace industries because of their improved physical and mechanical properties such as light weight, high strength, good corrosion resistance, malleability, etc., Al 6061 aluminium alloy is reinforced with 1.0, 1.5, 2.0, 2.5 weight percentage of Magnesium Oxide (MgO) particles through powder metallurgy method with optimum sintering temperature. The composites were then characterized by scanning electron microscopy (SEM) and Energy-Dispersive spectroscopy (EDS). The tribological behavior is investigated using pin-on-disc equipment and mechanical properties (Micro hardness, Compressive strength) were analyzed at varying weight percentage ratios. Introduction of MgO particles to the Al matrix caused increasing of wear resistance and mechanical strength. The results reveal that the Metal Matrix Composite (MMC)'s containing 2.0 Wt. % reinforcement particle has improved mechanical properties.*

**Keywords:** *Aluminium, MgO, Powder metallurgy, SEM, Wear test*

## 1. INTRODUCTION

The modern material scientists and engineers have shifted their interest towards composite materials rather than monolithic materials for the development of light weight, environment friendly and high performance appliances. As aerospace technology continues to advance, there is a rapidly increasing demand for advanced materials with high mechanical and thermal capabilities for such ultra-high applications. Its application extended to automobile, electronic and computer industries to replace the existing materials including plastics [1]. Aluminium is a relatively, soft, ductile, durable, light weight and malleable (formability) metal with appearance ranging from silvery to dull grey, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminium serves as a good reflector (approximately 92%). It is the third most abundant element (after oxygen and silicon), and the most abundant metal in the Earth's crust. It is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. Corrosion resistance can be excellent due to a thin surface layer of aluminium oxide that forms when the metal is exposed to air, effectively preventing further oxidation. It has large co-efficient of linear expansion, easy joining and good conductivity. The light weight property of Aluminium alloys, reduces the fuel consumption. It makes huge demand in automobile industry. These growing requirements of materials with high specific mechanical properties and light weight stimulates research activities in recent times targeted primarily for further development of Aluminium based composites [3]. A recent industrial review revealed that there are hundreds of components from structural to engine in which Aluminium alloy is being developed for variety of applications. It is also predicted that for Aluminium alloys demand increased globally attain average rate of 20% every year [1]. It is noticed that the limited mechanical properties (strength and hardness) of Aluminium and its alloys affect its applications in automobile and aerospace industries. Meanwhile, reinforcing the Al, with ceramic particles enhances wide spectrum of properties including yield and tensile strength at room temperature, creep and fatigue resistance at higher temperatures, hardness, compressive strength, and thermal shock resistance. Different types of ceramic nanoparticles such as Al2O3, B4C, Tic and SiC, have been implemented for Al matrix composites. MgO due its high melting point (Tm = 2800C), compressive strength, hardness, and also excellent thermodynamic stability is an appropriate choice for reinforcement. Various kinds of methods have been used for fabrication of Al matrix composites like infiltration, squeeze casting, mechanical alloying, powder metallurgy, ball milling, and stir casting. Stir casting and powder metallurgy are two widespread methods which have been utilized in various works and both have advantageous and drawbacks. A review in the existing literatures indicate that little attention has been made to uniaxial pressing although it is the most economical production technique [4]. The other main reasons for preferring uniaxial pressing in manufacturing PM components are: material and energy severity, possibility of pressing components that have large geometrical shape, even distribution of reinforcement, precision and repeatability tolerances in pressed component dimensions and high rate productivity (250–1250 component per hour) [2]. Al matrix composites with different MgO contents of 1, 1.5, 2, 2.5 Wt. % were produced and their various mechanical properties, micro structure and tribological behavior were studied separately as well as together. The ceramic particulates have shown their potential superiority in improving tribological (wear resistance) and mechanical properties (hardness, compressive strength) and microstructure with noticeable weight savings [1].

## 2. EXPERIMENTAL PROCEDURE

Al–MgO composite was produced via powder metallurgy methods using Al 6061 aluminium alloy as the matrix material and MgO particles as the reinforcement materials. In the presence study, elemental composition of Al 6061 Aluminum alloy Specimens are listed in the Table 1

**Table 1: Composition of aluminium alloy**

| Elements | Wt. % | Elements | Wt. % |
|---|---|---|---|
| Al | 96 | Zn | 0.25 |
| Mg | 1.2 | Ti | 0.15 |
| Si | 0.8 | Mn | 0.15 |
| Fe | 0.7 | Cr | 0.35 |
| Cu | 0.4 | Acrawax | 0.05 |

In powder metallurgy route, Al powder alloy has been mixed with MgO particles by ball mill, and then conventional powder metallurgy (uniaxial pressing (UP) was employed to produce the samples. 400 Mpa compaction load was given by the universal testing machine to compact the powder inside the die [4, 5]. Finally, green compacts were placed in the muffle furnace (non-inert) for sintering process. The samples are preheated to 150 degree Celsius and maintained at that temperature for 30mins. Then temperature is increased to 600 degree and the samples are maintained in that temperature for 1hour 30minutes. After that the sample is taken out and cooled in the atmospheric air (Normalizing).

## 3. RESULT AND DISCUSSION

### 3.1 Microstructural Characterization

The microstructure analysis was carried out by using SEM and EDS. Fig.1 show microstructure of the fabricated Al alloy. It's observed that Al was bonded well by compacting and sintering process.

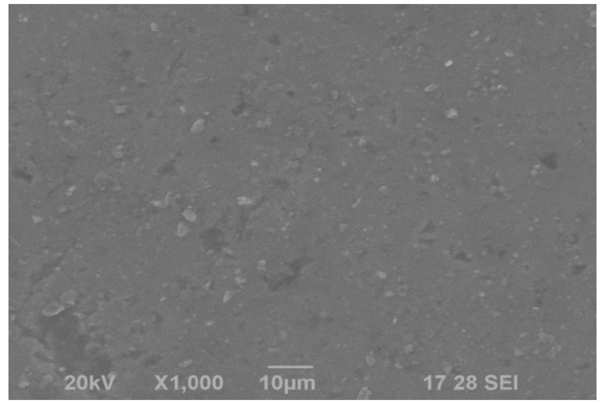


**Fig. 1: SEM image of aluminium alloy**

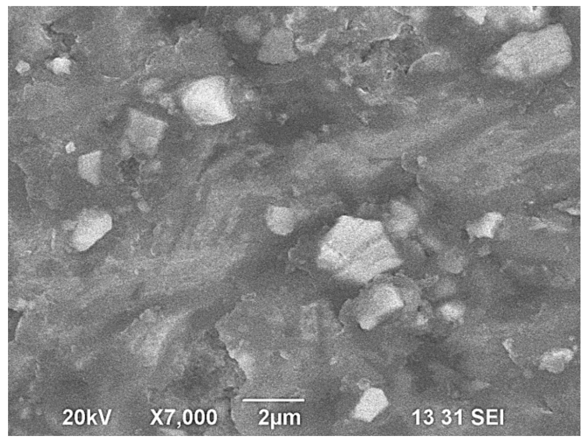


**Fig. 2: SEM image of Al-MgO composite of 2.0 Wt. %**

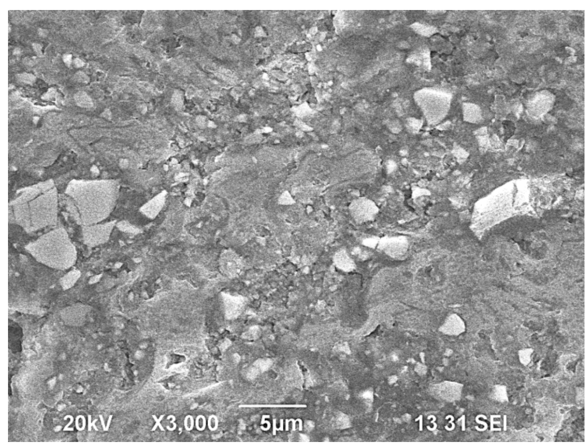


**Fig. 3: SEM image shows the even distribution of MgO particle in the matrix.**

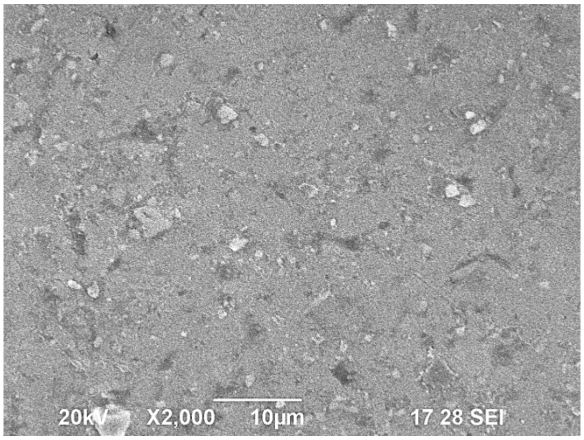


**Fig. 4: Shows the presence of pores in the Al-MgO composite of 2.5 wt. %**

Fig. 2. Clearly shows the MgO particles are well bonded and distributed evenly with the Al matrix. Fig. 3. Shows the SEM micrograph of the fabricated Al-MgO composite having constant weight fraction of 2.0 wt. %. Although some clusters of MgO particulates could be observed, the distribution generally appeared to be fairly homogeneous throughout the Aluminium particulates. A typical Al-Mgo interface has been obtained. Fig. 4. Shows the presence of porosity in 2.5 wt. %. It reveals that the addition of reinforcement percentage after an increasing trend the sintering process is affected. Because the thermal conductivity of MgO particle is very low.

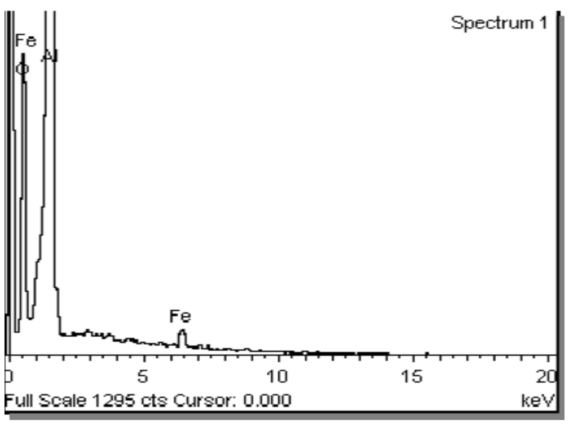


**Fig. 5: Shows the EDS of Al 6061 aluminium alloy.**

The micro hardness test was carried out in Micro Vickers Hardness Tester. To test the specimens of different wt. % 50 g load was given for 15 sec. Fig. 8. represents hardness measurement of Al–MgO composite samples which were prepared with different MgO wt. %. Comparison of the hardness of pure Al sample with sintered composites proved that addition of MgO particles boosts hardness of pure Al samples, in general. This can be attributed to the harder MgO nanoparticles compare to the Al and also its role in enhancement of the density of dislocations and prohibiting of Al grain growth [2]. Increasing of MgO content from 1.0 to 2.0 wt. % results in hardness increasing that is due to the mentioned effective role of MgO in increasing of the hardness values. On the contrary, 2.5 wt.% of MgO have lower hardness compare to the 2.0 wt.% sample which can be due to the formation of micro pores in the interface of MgO–Al matrix that decrease the hardness of sample. Increasing the content of MgO results in decreasing of the hardness (after an increasing trend) is due to the low effect of sintering, increasing of MgO–Al interfaces and porosities [10, 11].

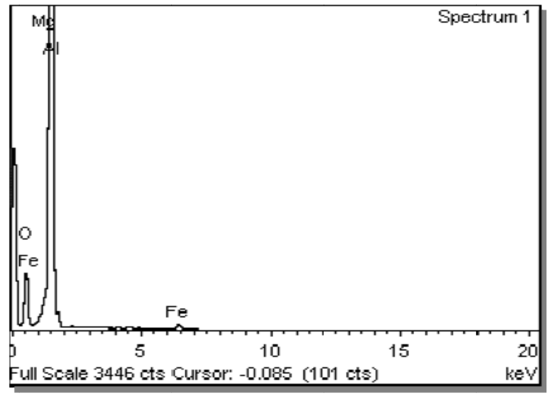


**Fig. 6: Shows the EDS analysis of 2.0 wt. % of Al-MgO Composite.**

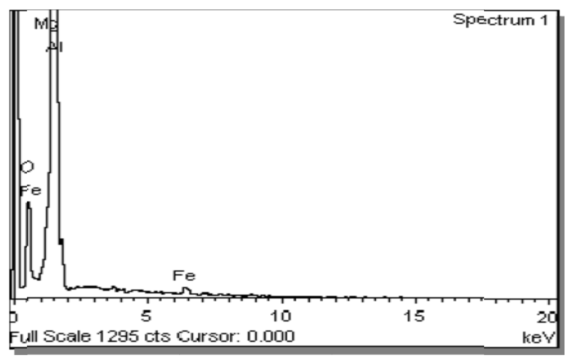


**Fig. 7: Shows the EDS of 2.5 wt. % of Al-MgO composite.**

### 3.2 Micro Hardness

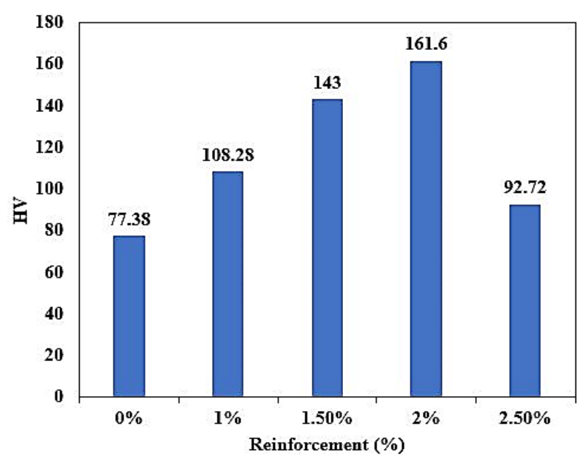


**Fig. 8: Micro Hardness values of varying wt. % Al-MgO composites.**

### 3.3 Compression test

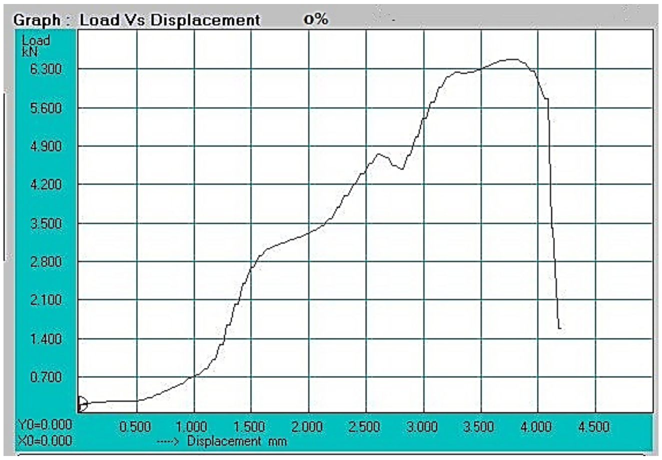


**Fig. 9: Compression test result graph of Al 6061 alloy.**

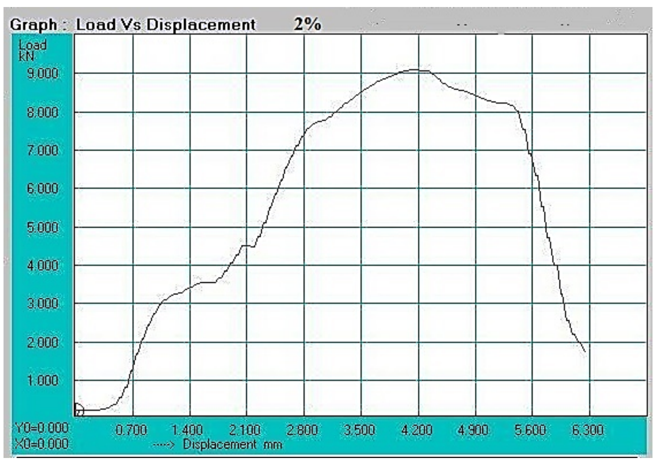


**Fig. 10: Compression test result graph of Al-MgO composite of 2.0 wt. % reinforcement.**

Compression tests were carried out by servo controlled Universal Testing Machine of specimen cross section 100 $mm^2$. Fig.10. represents the compressive strength of sintered Al–MgO composite. The compressive strength of 2.0 wt. % composite sample is more than unreinforced Al 6061 aluminium alloy (Fig. 9) specimens that proves the vital role of MgO particles in work hardening and prohibition of grain growth which enhance the mechanical properties of composites compare to the unreinforced Al 6061 aluminium alloy samples. The ultimate compressive stress of 2.0 wt. % reinforcement MMC's (91 Mpa) greater than the Al 6061 aluminium alloy (65 Mpa). Sintering is one of the most important parts of powder metallurgy processing and higher temperatures would be able to facilitate it. Also, the uniformity and compressive strength of specimen is strongly dependent on sinterability of powders. The increase in sintering temperature causes the easier diffusion of atoms which helps the ability of specimens to sinter, and finally the better mechanical properties such as compressive strength can be obtained [10,11]. As a matter of fact, appropriate Al–MgO interface will be generated that causes better stress transformation among particles and matrix.

### 3.4. Wear Analysis

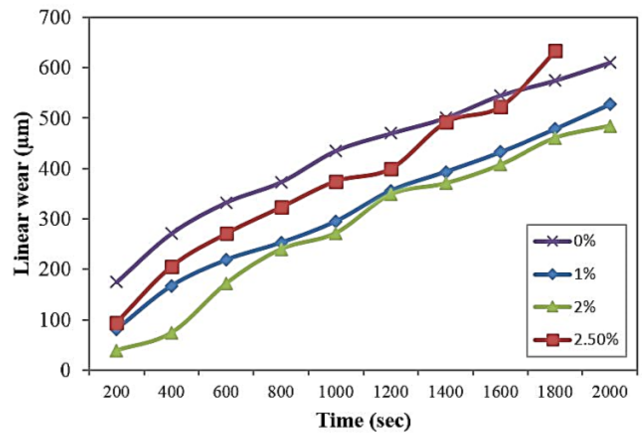


**Fig. 11: Linear wear Vs Time for different wt. % reinforcement for constant load and constant velocity**

Wear test was conducted employing a Pin-on-Disc Tribometer with preferred constant load (30 N) and velocity (1 $ms^1$). Most requirements of the ASTM G99 standard on Wear Testing were followed. However, substantial modifications were considered, mainly regarding the Pin shape. Square bar pins with dimension of 10×10×25 mm were made of the Al 6061 Aluminium alloy reinforced with Magnesium particles at varying Wt. % ratios. A constant nominal area was maintained during the wear test. The counterpart disc was made of high carbon EN31 steel having a hardness of HRC60. The radius of the sliding track on the disc surface was 120 mm. Before the wear test the surface of each Pin was ground using 240,320,400,600-grit SiC abrasive papers. Wear testing was performed in a dry sliding condition for varying Wt. % ratios with varying Time. All worn-out Pins were cleaned in Acetone and weighed to an accuracy of ±1mg prior to testing. Wear weight loss was determined. Based on the results reinforcement of MgO particle into the base alloy, Wear gradually decreases with increasing reinforcement content as seen from the Fig.11 the wear loss for Al 6061 Aluminium alloy at a sliding distance of 1953.673m and at a speed of 160 rpm is 0.1647g. By increasing the reinforcement to 2.0 Wt. % of MgO particles wear loss decreases to 0.1292g for same speed and sliding distance. The 2.0 wt. % shows better wear resistance compared to other Wt. % MMC's. Wear rate is severe in the region where the reinforcement particles were not present [10, 11]. Operating Time is proportional to wear, as shown in the Fig.11. Based on the this graph, for Al 6061 aluminium alloy at the operating time of 1080sec, linear wear is 435.39 µm and for the same time with 2.0 Wt. % reinforcements of MgO particle to base alloy the linear wear decreases to 276.81µm. But the 2.5 wt. % reinforcement composite has linear wear value of 633.26 µm for same operating time. It graph shows the poor wear resistance property of 2.5 wt. % reinforcement composite because of exceeding effective role percentage.

## 4. CONCLUSION

In the current study Al 6061 Aluminium alloy successfully reinforced with Magnesium Oxide MMC's at varying Wt. % via Powder Metallurgy technique. To evaluate the effect of varying Wt. % reinforcement of particles with the base alloy on mechanical properties of MMC's, the hardness, compression and wear tests were carried out. SEM and EDS indicated that Magnesium MMC's particles are successfully reinforced with Al 6061 Aluminium alloy and particles dispersed throughout the matrix. Hardness and Compressive strength of the particle reinforced composites were higher than that of Al 6061 Aluminium alloy, with increasing the Weight % of reinforcement particle hardness and compressive strength are consistently increased within effective role percentage of reinforcement, result reveals that 2.0Wt.% of reinforcement content shows increased hardness compared to other reinforcements. Wear resistance of the composite was found to be considerably higher than that of matrix alloy increased with increase of reinforcement particle content. The hard particles resist against destruction action of the abrasive and protect the surface. So, MgO reinforcement enhances wear resistance property of Al 6061 aluminium alloy.

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