Kufa Journal of Engineering
Vol. 14, No. 1, January 2023, P.P. 67-80
Article history: Received 15 November 2022, accepted 17 January 2023

MECHANICAL PROPERTIES CHARACTERIZATION OF AL- 7075 / PHOSPHOGYPSUM METAL MATRIX COMPOSITES

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HTTPS://DOI.ORG/10.30572/2018/KJE/140105

ABSTRACT

Recent years have seen a movement in research from monolithic to composite materials due to the worldwide need for low-cost, high-performance, and high-quality materials. Aluminum matrix composites are used extensively in structural applications and the aerospace and car industries, owing to their high strength-to-weight ratio, cheap cost, and excellent wear resistance. A simple and cost-effective process for producing composites is also critical for broadening their use. Using the inexpensive and commonly used stir-casting process, reinforcements including particle alumina, silicon carbide, graphite, fly ash, etc. may be readily integrated into the melt. In the present paper, the 7075 Aluminum alloy metal matrix composite, with varied Phosphogypsum (PG) contents (2, 5, and 10% wt.%) reinforced particles having 53-106 µm in size, have been created utilizing the stir casting process. The influence of Phosphogypsum particle content on the mechanical characteristics of Metal Matrix Composite has been investigated, and the results manifested that the material reinforcement significantly improved the BHN hardness, tensile strength, and wear. These enhancements were made possible by the regular distribution of Phosphogypsum and the refining of Al-7075 grains. The most significant improvement in BHN hardness (123), tensile strength (160 MPa), and wear (0.2032 gm) were recorded at 10% Phosphogypsum.

KEYWORDS

AL-7075, Hardness, Phosphogypsum, Composite, Stirring casting, Tensile strength, Wear rate.

Article information: This manuscript was handled by Abbas Al-Hdabi, Managing Editor.

1. INTRODUCTION

Composite materials are combinations of two or more materials in which specific properties are created by carefully combining a variety of constituents. Metal matrix, ceramic matrix, and polymer matrix composites are examples of designed composites used in industry. Metal matrix composites consist of a continuous metallic matrix and one or more discontinuous reinforcing layers (Ansar K., et al 2021). Fibers, hairs, or tiny particles might make up the reinforcing phase. They are replacing traditional materials in many applications due to superior properties, such as high strength-to-weight ratio, hardness, stiffness, and wear and corrosion resistance (Ajith, A., et al 2017). Due to their less weight and superior thermal conductivity qualities, aluminum alloys are the chosen engineering material for the automotive, aerospace, and mineral processing sectors for creating high-performing components for a variety of applications. Because of its superior strength and hardness, aluminum alloy 7075 is favored in the automotive and aerospace industries (Ajith, A., et al 2017). The creation of intermetallic particles such phases during the solidification of the 7xxx series aluminum alloys, which include roughly 5% zinc (Zn) and 2.5% magnesium (Mg), increases the strength of the alloy (Anita O. et al 2020) . Aluminum alloy composites are of great interest because of their high strength, fracture toughness, wear resistance, and stiffness. Furthermore, when reinforced with particles or other materials, these composites are superior in nature for high-temperature applications (Arvind S., et al 2022). Phosphogypsum (PG) is a solid by-product obtained during the production of phosphoric acid from the manufacture of phosphate fertilizers. In addition to impurities like P2O5, fluorine, organic waste, heavy metals, and radioactive materials, the PG is composed of hydrated calcium sulfate (Adeolu A., et al 2020). Phosphate gypsum was used in several key industries, including the production of plaster of Paris, wallboard, chalk, blackboards, and roadwork. In general, PG is dumped in vast stockpiles near the manufacturing companies, producing air pollution as well as poisoning the groundwater, surface water, and soils (Abhishek K., et al 2013). As a result, it is believed that enforcing rigorous policies would be necessary to both reduce the pollution and promote the value-adding of PG (Halil K., et al 2019). Actually, only 15% of the PG generated globally has been recycled (Israa A., et al 2020). The purpose of present study is to create Al7075/PG composites with different particle weight percentages in order to determine their tensile strength, wear, and hardness properties by adding inexpensive and waste material (PG).

2. EXPERIMENTAL PROCEDURE

2.1. Materials and Production of Metal Matrix Composite

Aluminum alloy (Al7075) was used as the matrix material in the experimental inquiry. This research employed the Iraqi phosphogypsum materials available in the Al-Qaim Fertilizers Complex at Al-Anbar Government. Table 1 shows the chemical composition of phosphogypsum. The X-Ray Fluorescence (Shimadzu 1800, XRF) study of phosphogypsum was performed at the Iraqi-Germany laboratory at the College of Geology/University of Baghdad and it was utilized to do the chemical analyses. The detailed procedure used to produce composites is shown in Fig.1. Fig. 2 shows the SEM and graph of a PG sample. The chemical composition of the phosphogypsum sample is shown in Table 1.

Table 1. Chemical composition of the phosphogypsum sample.

Element	Wt%
MgO	0.3536
SO_3	46.42
CaO	36.91
P_2O_5	2
SiO_2	1.152
SrO	0.6326
K_2O	0.0675
Cl	0.05028
Ba	0.02104
Fe_2O_3	0.01769
L.O.I	12.3753

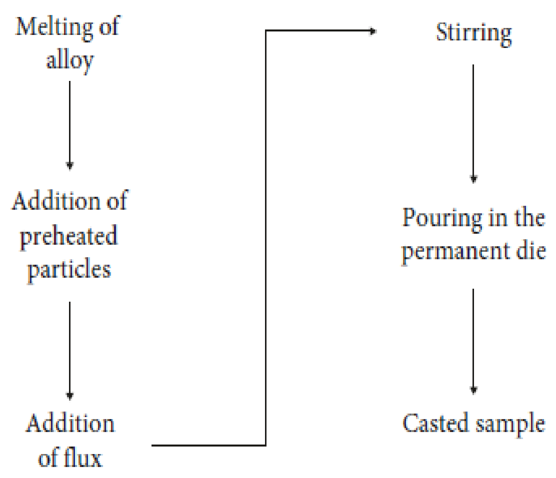

Fig. 1. Composites manufacturing steps (Kumar B., et al 2022).

Fig. 2. SEM and graphic of PG sample.

The current research employed Al7075 alloy as the matrix metal in the tests for the manufacture of composites reinforced with PG particles (2, 5, and 10% wt.% of 53-106 µm), as indicated in Table 2. Table 3 reveals the chemical composition of the matrix material (Al7075). The composites were produced by liquid metal stir casting. Before combining the PG particles with the liquid Al alloy, the melt was first physically swirled by a mild steel impeller, and the particles were first pre-heated at 600^{o}C for 1 hour to eliminate the moisture and then mixed with the stirred liquid metal. The composite was processed at a temperature of 700 ^{o}C and a stirring speed of 500 rpm. At a temperature of 710 ^{o}C, the melt was injected into a steel mold. Fig. 3A and B displays the electric furnace and the cast samples.

Table 2. Formulation of Al-7075 and composite.

Code	Al-7075wt%	PG wt%
A1	100	0
A2	98	2
A3	95	5
A4	90	10

Table 3. Al-7075 alloy of chemical composition.

Element	Mg	Si	Cu	Fe	Mn	Zn	Al
Wt%	2.52	0.51	1. 60	0.63	0.06	4.96	Bal

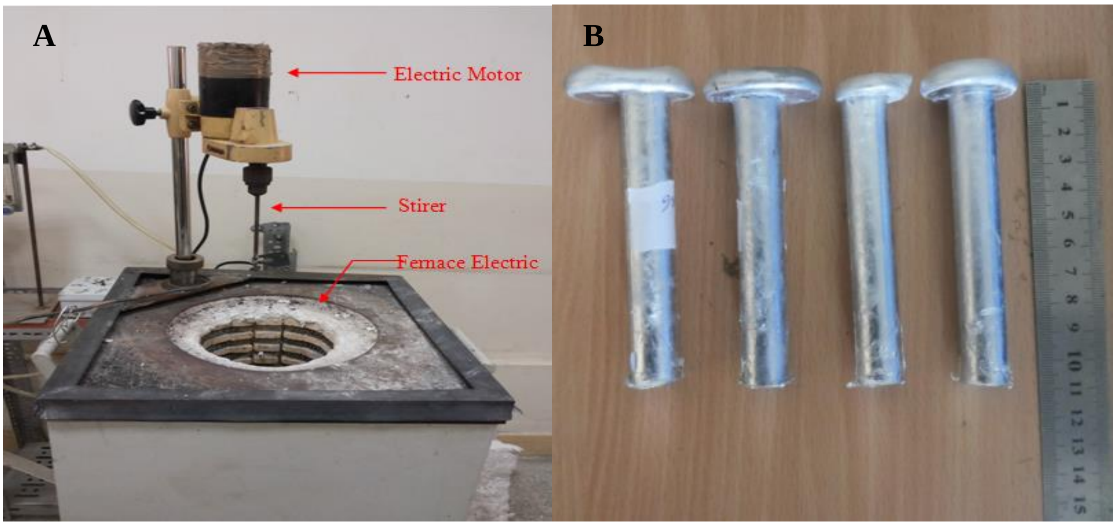

Fig. 3. A: the electric furnace; B: the cast samples.

2.2. Tensile test

Tensile testing of the Al-7075 and composite was performed on Instron testing equipment available in the Production Engineering and Metallurgy Department/University of Technology. Tensile tests were conducted on all specimens generated in this study in accordance with ASTM E-8 standards (Kumar G., et al 2019). The sample was extended at a rate of 1 mm/min, and the experiment was conducted at the room temperature. The ultimate tensile strength was obtained using standard specimens of 7 mm diameter and 36 mm gauge length. Tensile strength specimens are illustrated in Fig. 4.

Fig. 4. Tensile strength specimens.

2.3. Brinell test for hardness

The hardness of composites and Al7075 alloy were measured using a Brinell hardness tester. Before conducting this test, specimens were first cut from each composite composition and then polished to provide a flat and smooth surface finish. This test was carried out in the service laboratory at Ibn Al-Haytham College of Education. In order to test a material's Brinell hardness, stiff steel or carbide sphere of a specific diameter and load is first pressed into the material's surface for a predetermined amount of time. The diameter of the indentation that remains after the test is then recorded. It is calculated by dividing the actual surface area of the indentation in square millimeters by the applied force in kilograms. In this test, a (500 kg) weight was applied for a (20 sec) dwell time. Multiple hardness tests were done on each sample, and the average result was used to determine the specimen's hardness. Fig. 5 evinces the harness of specimens.

Fig. 5. Hardness specimens

2.4. Wear rate test

For the wear test, a pin on flat wear test device was employed. All wear experiments were conducted at a sliding velocity of 1 (m/sec) with an applied weight of 10 (N). A cylindrical pin having a diameter of 10 mm and a height of 20 mm was made from base alloy and composite. The specimen was loaded against a horizontal reciprocating flat surface using a vertical specimen holder. This flat surface is composed of carbon steel and has a dimension of (160 mm) in length, (70 mm) in width, and a hardness of 35 HRC. Wear testing was performed in a dry environment at the ambient temperature. The wear rate was determined using the weighing technique according to the standard ASTM G133 pin on flat. The wear rate was computed using the equation (1) shown below (Kumar G., et al 2021). Fig. 6 manifests the wear test specimens, which were 10 mm in diameter and 20 mm in height, and Fig.7 depicts the wear test equipment.

$$\text{Wear } Rate = W1 - W2 \quad (1)$$

Where: W1 and W2 are the values weight of the sample before testing (gm) and weight of the sample after testing (gm) respectively.

Fig. 6. Wear test samples.

Fig. 7. Reciprocating wear test device.

3. RESULTS & DISCUSSION

3.1. Microstructure of Al-7075 and composite

Fig. 8 exhibits the FE-SEM micrographs of Al7075 and Al7075-PG composites. The size, density, type, and distribution of reinforcing particles all have a significant impact on the characteristics of particulate composites. The factors influencing particle dispersion include solidification rate, fluidity, kind of reinforcing and technique of inclusion. During particulate composite manufacture, it is necessary to distribute the particles equally throughout the matrix (Kanchiraya S.et al 2022). The initial aim was to have the particles distributed evenly throughout the liquid melt, followed by preventing particle segregation/agglomeration during pouring and solidification development. Fig. 8a depicts the FE-SEM micrographs of unreinforced Al7075, whereas Fig. 8b exhibits the composite with 10% wt%. The dendrite-shaped structures were broken down by continuously stirring the molten before and after the PG particles were inserted to create an equiaxed form that would encourage the PG particle inclusion in the molten matrix in 10 wt.%.Strong particle and matrix bonding, uniform particle distribution, and reinforcement of PG were found as shown in Fig. 8b.

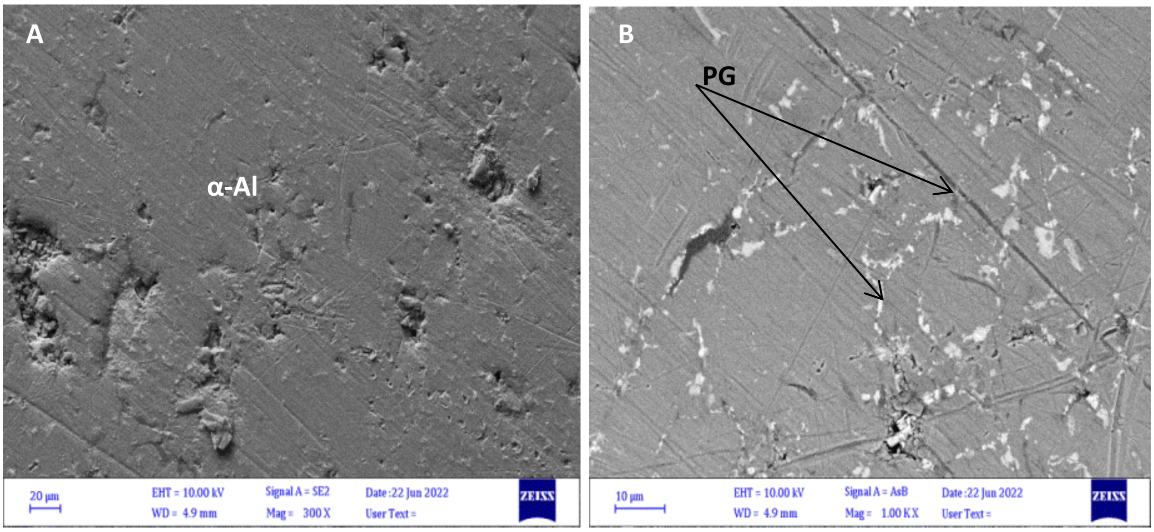

Fig. 8. FESEM micrographs (A) Al-7075(A1), (B) Composite with 10 %wt PG(A4).

3.2. Effect of phosphogypsum particles on the BHN hardness.

Fig. 9 elucidates the influence of particle % on the hardness of composite specimens. The hardness (BHN) values of the Al7075 matrix improved significantly in all compositions studied. The hardness test demonstrated that as the weight proportion rises, the hardness value raises also. The addition of hard PG reinforcement particles increased the material's characteristics, which might be attributed to the dislocation blockage and limitation (Mugdha W., et al 2016). The mechanical characteristics of AMCs were shown to be substantially linked to the degree of reinforcing content. This finding is consistent with the outcomes of other studies (Nand J., et al 2022).and (Praveen S., et al 2021).

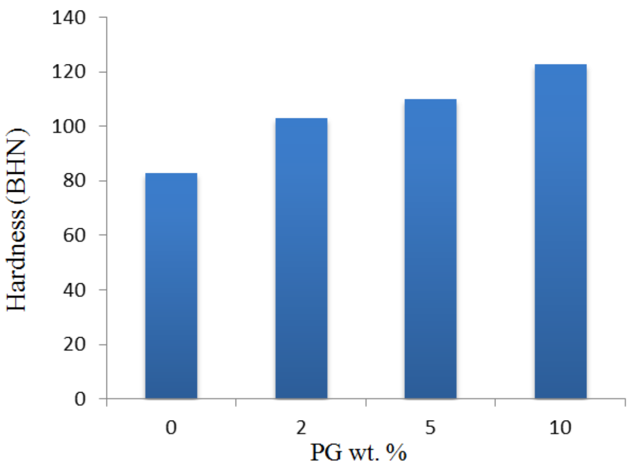

Fig. 9. Hardness values of Al- 7075 composites.

3.3. Effect of phosphogypsum particles on the tensile strength.

Fig. 10 portrays the tensile strength attained during the testing. The substantial improvement in material properties is realized using all the percentages added. The tensile strength was the greatest with 10% reinforcement. The increase in tensile strength is due to the increase in hardness and the excellent distribution of the support within the structure. This result is in agreement with studies (Rabindra B., et al 2011) and (Raja Z., et al 2020).

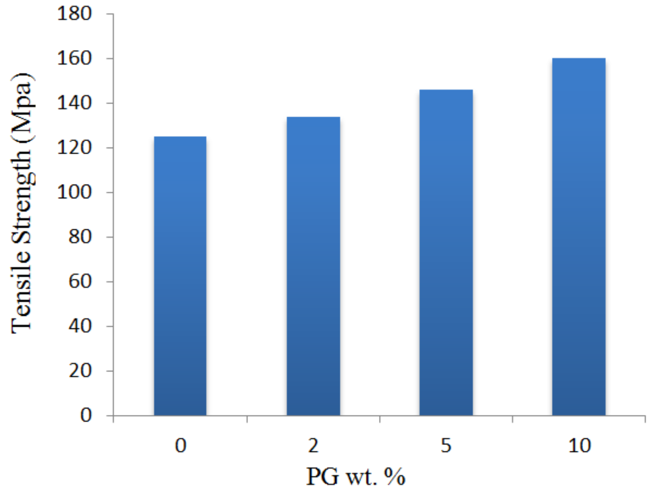

Fig. 10. Tensile strength of Al-7075 and composites.

3.4. Effect of phosphogypsum particles on the wear resistant.

Fig. 10 illustrates the effect of PG particle weight fraction on the wear behavior. Wear characteristics of Al7075 and hybrid composites containing a varying percentage of PG were analyzed at fixed parameters that were applied at a load of 10 N, a time of 20 min, a sliding velocities of 1 m/sec, and a sliding distance of 1000 m, for the all alloys to investigate the wear behavior of hybrid composite. The Al7075-PG graph manifests less wear when compared with the Al7075 and the other hybrid composites because of their high hardness. The wear resistance of hybrid composite is further increased by the addition of PG particles. This result almost is in agreement with studied (Sivananthan S., et al 2020).

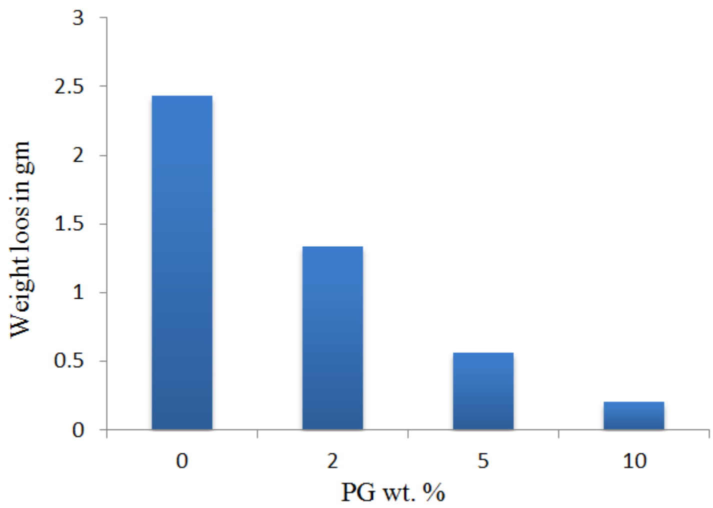

Fig. 10. Wear loss of Al-7075 and composites.

A light microscope was used to study the effect of PG addition on the wear topography of worn surfaces of samples. Fig. 11 depicts the effect of different additions of PG, and it was noted that at a low percentage, the surface suffers from severe wear due to the formation of grooves and deep wear tracks, and clear wear lines. In addition, some cracks spread on the surface, because of the ductility experienced by the matrix the abrasive wear can be noted, and a few wear debris are separated from the surface of the aluminium alloy (Al7075) leading to lowering wear resistance (Veeresh G., et al 2018) and (Waleed R.,et al 2016) . But, at height addition, it was noticed that the surface suffers from less severe wear, and the wear lines are shallow and not deep.

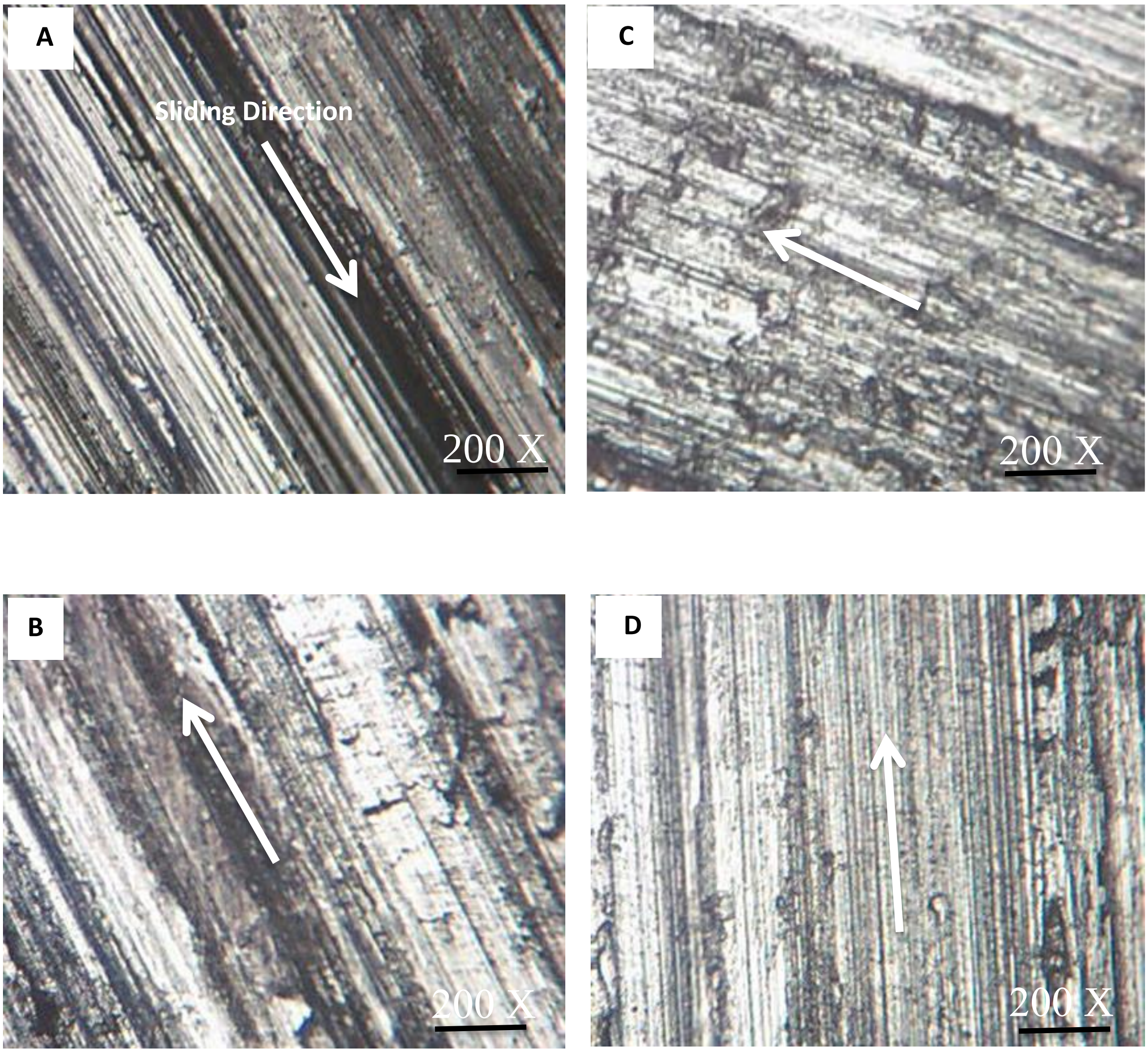

Fig. 11. Optical microstructure of worn surfaces, A (0wt.% PG), B (2wt.% PG), C (5wt.% PG), D (10 wt.% PG).

4. CONCLUSION

This work effectively produced Al7075-Phosphogypsum composites employing a stir casting arrangement with a uniform dispersion of phosphogypsum particles throughout the specimen. In terms of mechanical characteristics, the finding revealed that the stir-produced Al-7075 alloy with the phosphogypsum-reinforced composites is obviously superior to the Al-7075 alloy, where the excellent distribution of phosphogypsum particles in the aluminium matrix increases the mechanical parameters, like hardness and tensile strength. So for the optimum service performances of these composite materials, the phosphogypsum addition should be between 5% wt. % and 10% wt. % depending on the application area. In addition, they displayed that with an increase in the percentage of reinforced phosphogypsum, there is a decrease in wear. The lower wear rate it is due to several reasons, the high hardness of the reinforcement particles and their work as a filler. Also, the removal of the reinforcement particles during the wear test and their embedding in the rotating disc leads to scratching the disc, which requires higher amounts of the necessary frictional forces. In order for the overlay to slip on the disk, a large amount of energy is consumed. The friction between the particle and the disc decreases with direct contact between Base metal and test disc.

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