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Investigation of Hematite Nanoparticles According to Mechanical Characteristics of Aluminium Matrix Composite

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Aluminium seems to be a highly valuable structural metal that is utilized in a variety of industrial sectors; especially, it is utilized in considerable quantities in the nautical, aeronautic, and automotive industries. Aluminium is additionally utilized in small amounts in several other industrial sectors. The composite materials are now extensively utilized in a variety of applications after their introduction. In this research, composite samples of aluminium are prepared with adding hematite nanoparticles of 2, 4, 6, 8 wt.% and by means of the powder-metallurgy technique. The tests are made for microhardness, compression, and wear. The results show that, when increase hematite percent, the hardness and wear values increase.

Алюміній, здається, є дуже цінним конструкційним металом, який використовується в різноманітних галузях промисловости; зокрема, він використовується у значних кількостях у морській, авіяційній та автомобільній промисловостях. Крім того, алюміній у невеликих кількостях використовується в кількох інших галузях промисловости. Композитні матеріяли зараз широко використовуються в різних сферах застосування після їх появи. У даному дослідженні готували композитні зразки алюмінію з додаванням наночастинок гематиту в кількості 2, 4, 6, 8 мас.% і методом порошкової металурґії. Випробування включали мікротвердість, пресування та зношування. Результати показують, що зі збільшенням відсотка гематиту збільшуються показники твердости та зносу.

Key words: hematite nanoparticles, aluminium, testing, hardness, wear.

Ключові слова: наночастинки гематиту, алюміній, твердість, знос.

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1. INTRODUCTION

Composites made of the aluminium matrix are becoming more popular as cutting-edge technical materials for various fields, including aerospace, military, automotive, and others [1, 2]. The widespread utilization of microsize ceramic powders and fibres was observed in manufacturing aluminium-based composites [3]. Compared to unreinforced aluminium alloys, these composites have significantly enhanced strength and stiffness. However, unlike the unreinforced aluminium alloy, these composites have a dramatically lower ductility, preventing broad utilization [4]. Metallic matrix nanocomposites, often known as MMNCs for short, are an emerging category of nanostructured nanoparticle materials that serve as reinforcements 1–100 nm. The flexibility of the aluminium matrix is anticipated to be maintained, although the strength of aluminium that ceramic nanoparticles have strengthened is anticipated to be significantly increased.

Currently, there are various ways to manufacture MMNCs, including the in situ approach [5], the fragmented melt deposition method, the powder metallurgy process [6], the vortex process, and the ultrasonic method [7]. The powder metallurgy (PM) technique is a theoretically viable, energetically efficient, economically cost-effective, and practicable for creating simple and complicated components to the appropriate dimensions. It is also a technique having the potential to be used. Recently, it has been shown that the PM method has an advantage over traditional casting procedures when it comes to producing metal matrix composites (MMCs) [8–10]. The reinforcement in these composites is ceramic particles. MMCs based on powder metallurgy are now being selected and utilized for the creation of components in various industries, including aerospace, automotive, and even electronics, to mention a few of them [11]. In more recent times, approaches from PM have additionally been utilized in additive manufacturing [12]. Compared with composites made by stir casting [13], those made using powder metallurgy (PM) have been seen to have a lower density and a greater level of hardness in conjunction with a higher level of porosity. In contrast to the usual stir-casting procedures, the PM technology ensures that the reinforcements are dispersed evenly throughout the metallic matrix [14]. Therefore, an inhomogeneous distribution of the strengthening particles inside the metallic matrix remains uncontrolled by the typical casting process, which typically leads to inhomogeneous physicomechanical characteristics of the selected composite material.

Aluminium composites and nanocomposites may be produced using a wide variety of reinforcing materials [15], and they can be utilized for a wide variety of purposes, including in airplanes and electrical motors [16]. Numerous studies have been carried out in the same sectors in order to generate composites and nanocomposites with distinctive features [17]. These characteristics are thought to be connected to the size of the reinforcing elements, their dispersion within the matrix, and the particle size of the matrix particles.

At the current time, a variety of additive materials may be used to increase either the mechanical qualities (including TiC, ZrO_2, and Al_2O_3) or the magnetic and electrical characteristics (including Co, Ag, Fe_3O_4, and Fe_2O_3). Some of these materials are listed below. Furthermore, additional additive materials like $BiVO_4$, WO_3, TiO_2, ZnO, and Fe_2O_3 are utilized to increase the efficacy of solar cells. These compounds have been identified as semiconductor photoanode materials [11]. Fe_2O_3 and Fe_3O_4 have garnered a lot of interest due to their distinctive qualities. These qualities include the fact that they are simple to produce, that they are inexpensive, that they are non-toxic, and that they are thermodynamically stable. Because Fe_2O_3 may exist in several crystal phases, including α, β, γ and ε, so, it can be used in various contexts, including photocatalysts, adsorbents, and biological and medicinal uses [12], as well as solar cells. Numerous studies were conducted on the topic of hybrid nanocomposites using aluminium matrices.

Iron oxide (Fe_2O_3) is another material that may be utilized to build hybrid composites [18]. This material can be utilized in place of ceramic reinforcements. In addition, the hybrid composite has a complicated structure consisting of several reinforcing particles. The overall characteristics of hybrid composites are strongly impacted by factors such as the surface area of the sample, the volume fraction, the size, and the sintering circumstances [19, 20]. Among them there is the fact that the samples' surface area is altered by the compaction pressure, which in turn results in non-homogeneous densification owing to the friction between the die wall and the powder contact. Because of this, it is essential to research the porosity level, density, and hardness of the part as a function of the materials' sintering time and elastic modulus.

Wear properties of hematite (Fe_2O_3) strengthened aluminium 6061 composites with metal matrix were investigated by Phanibhushana *et al.* [21]. The additional strength is provided in the form of particulate 40–45 μm in size, and the percentage is increased by 2% from 0% to 8% (by wt.). Composites are manufactured via the liquid metallurgy method. The microstructural investigation on as-cast Al6061–Fe_2O_3 composites shows that reinforcing particles are distributed uniformly throughout the material. The specimens were put through the wear test, which included changing the speed (from 200 to 400 rpm) and the load (from 50 to 100 N). The rate of wear was determined by calculating the percentage of weight loss experienced by the specimen. According to the findings, there is a correlation between the reinforcement percentage and the wear resistance rise over time. Compared to the material comprising the base matrix, the wear factor has lowered by 30–40%, when 8% reinforcing is comprised.

Alalkawi *et al.* [22] studied the manufacture of a hybrid composite material consisting of aluminium, iron oxide and alumina. Aluminium is the base metal for the superimposed material, in addition to the nanomaterials Fe_2O_3 and Al_2O_3. The reinforcement is done with varying proportions of nanomaterials, consisting of 2.5, 1.5, and 5% of Fe_2O_3 by weight, while Al_2O_3 remains constant with the three different ratios and is 2%. This compound was manufactured. The results showed that the microscopic images of the compounds showed a homogeneous distribution of Fe_2O_3 and Al_2O_3 in the aluminium matrix. The behaviour of the surface properties was studied in a dry environment (wear rate, weight loss, and friction coefficient). The experimental results included calculating the amount of wear resistance in the hybrid nanocomposites, which increased with the increase of the reinforced nanomaterials $Al_2O_3 + Fe_2O_3$, but the best wear resistance was obtained with the weight ratio (1.5% Fe_2O_3 + 2% Al_2O_3. It was observed that the maximum reduction in wear rate, weight loss and coefficient of friction was (8–10)·4.87 g/m, 0.0023 g and 0.59, respectively, for the nanocomposite (1.5% Fe_2O_3 + 2% Al_2O_3). The magnetic saturation of the compounds indicates that the best response to the magnetic properties was with the nanocomposite.

The purpose of the investigation that has been presented is to investigate the effect that Fe_2O_3 nanoparticles have on the mechanical characteristics of Al matrices while they are being produced *via* the process of powder metallurgy.

2. EXPERIMENTAL PART

In this part, we will discuss the tools and resources utilized throughout the course of this project, the order, in which operations and assessments have been carried out, too.

The materials which are utilized in this work are aluminium and hematite powders, the above powders high purity (99.9 wt.%). The elemental powders (*i.e.*, Al and Fe_2O_3) utilized in this research with an average particle size are (for $Al = 33$ μm and $Fe_2O_3 = 25$ nm).

2.1. Plan of Work

The following is one possible explanation for the plane of work:

1. preparation of several nanocomposite materials as indicated with nano-Fe_2O_3 added as 0, 2, 4, 6 and 8 wt.% to aluminium matrix;
2. wet-mixing the powders for a period of two hours;
3. the addition of powders to the die cavity in a step-by-step, precisely regulated way;
4. pressing powders at a pressure of six tons;
5. sintering of all of the prepared specimens in a vacuum oven at 350°C for one hour, and then, increasing the sintering temperature to 600°C for the next three hours.

After sintering process, go to samples tested.

3. TESTS

3.1. Microhardness Measurements

Microhardness Type of the Vickers tester (Digital Display microhardness Tester model Hv-1000). Utilizing a standard 136° Vickers diamond pyramid indenter and optical microscopy to evaluate the diagonal length of Vicker's impression, this apparatus was utilized to determine the hardness of the specimen by applying a load of 100 g and holding it in place for a period of 20 seconds on the specimen's outermost layer. The following is a specification of the microhardness (HV) of Vicker [23]:

$$HV = 1.854\, P/d^2\,, \tag{5}$$

whereas P is applied loading, d is mean diagonal length μm.

Each specimen has its own unique sequence of the three measurements.

3.2. Test of Compression

The following are the dimensions of the cylindrical specimens that were subjected to the compressive load: 1 cm diameter and 2 cm height. In this instance, the samples were created in accordance with the ASTM standard [24]. The compression tests were conducted at a room temperature utilizing a computerized conventional test machine kind (Gunt/Hamburg, China) with a loading proportion of (0.1 $\text{mm}\cdot\text{min}^{-1}$).

3.3. Wear Test

In accordance with ASTM (G99-04) [25], specimens with a diameter of 1.3 cm and a height of 0.5 cm were created for each composite sample. In order to prepare the samples for testing, a surface roughness of 0.8 micrometers on mean was achieved by grinding them with SiC sheets. After that, the samples have been given a weight with the use of a sensitive electric balance model (M254A) that had an accuracy of +0.0001. The pin on disk idea was utilized in the research of dry wear with several types of wear tester devices (MT-4003, version 10.0). The samples that were put through the test have been pinned *vs.* a standard disk made of steel that had a hardness of (850 HV), whereas F is normal force on the pin = 10 N, d is pin diameter = 1 cm, disk diameter = 3 cm, R is radius of wear track = 0.5 cm, ω is rotating disk speeding = 250 rpm.

In order to calculate how much weight had been lost, the sample was weighed after 5, 10, 15, and 30 minutes. The following formula was utilized to translate the total loss in weight to an equivalent loss in volume:

$$\text{volume loss [mm}^3\text{]} = \frac{\text{weight loss [g]}}{\text{density [g}\cdot\text{mm}^{-3}\text{]}},$$

whereas weight loss = weight before the test – weight after the test.

Furtherance of observing the deterioration of the surface's microstructure utilizing an optical microscope, the rate of wear was calculated utilizing the results of this test. The experiment was conducted out at room temperature and with no lubrication present at any point.

4. RESULTS AND DISCUSSION

The findings of experiments involving the microhardness of composite specimens produced of Fe_2O_3 and aluminium are examined in depth. In addition to that, the findings of the wear test specimens are included in the discussion.

4.1. Microhardness Measurement

For determining the microhardness of the samples that were created utilizing a powder metallurgy technique (compaction and sintering), the tests were carried out by taking the average of three readings taken

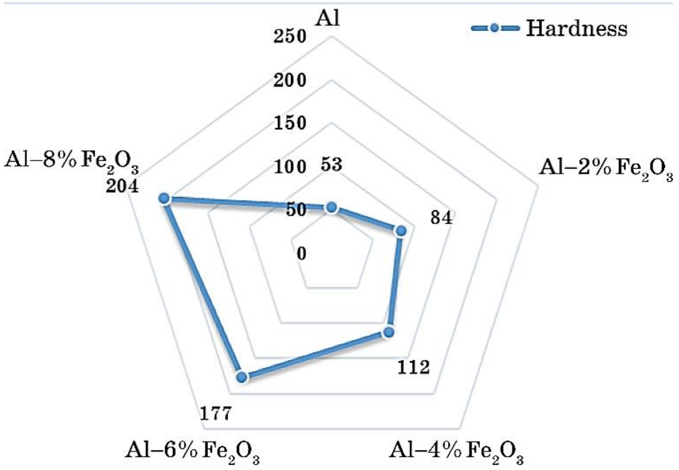

Fig. 1. Show the microhardness values of composite samples.

at each position. The graphical representation of the findings that were obtained may be seen in Fig. 1.

The determined hardness magnitude for the nanocomposite specimens is shown in Fig. 1. Since it is common knowledge that Fe_2O_3 has a higher hardness and a higher level of brittleness compared to Al, and since Al has a lower level of strength and a higher level of softness in this system [20] and since the specimens consist of both Fe_2O_3 and Al, it can be deduced (based on the hardness magnitudes) that, when the amount of Fe_2O_3 increases, the level of hardness also increases. Because of this, one might also reason that a phase composed entirely of Fe_2O_3 would have a greater value for its hardness (which is said to have a greater strength than the other).

4.2. Compressive Strength Test

The results of the compressive strength test are shown in Fig. 2, which include a list of the magnitudes. Figure 2 also illustrates how the percentage of hematite particles in the aluminium matrix affects the compressive strength of the material.

Because of these findings, it is simple to demonstrate that increasing the proportion of hematite in the aluminium base led to an increase in the compressive strength. The increase in compressive strength may be attributed to the function that micro iron oxide particles play in the material. These particles acted as impediments that hampered the migration of dislocations, which resulted in the matrix being reinforced. The sample with Al + 8% Fe_2O_3 showed the greatest increase in compressive strength, 129%, when compared to the control.

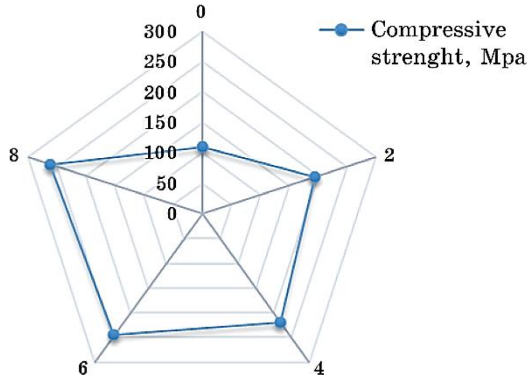

Fig. 2. The compressive strength against hematite percent.

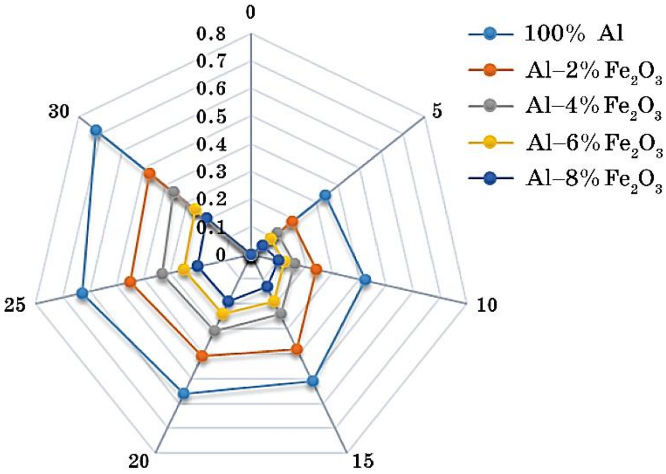

Fig. 3. Wear rate of specimens.

4.3. Wear Tests

Utilizing the density of every specimen to do a conversion from the loss in weight to a reduction in volume. The outcomes of this test are shown in Fig. 3 and were carried out under the same settings as those described earlier ($F = 10$ N; $\omega = 300$ rpm; $t = 5$, 10, 15, 20, 25, and 30 minutes).

It is obvious from these numbers that volume loss increases with a rise in the applied load, where the largest volume loss was recorded under (10 N), and *vice versa*. The highest volume loss was recorded under (10 N), and *vice versa*. This is the behaviour that was expected to occur, in which the increase in load leads to an increase in the friction between the sample surface and the revolving disk. In addition, the loss of volume was shown to grow with the passage of time because of an increase in the amount of specimen particles that were lost with increasing friction duration. In addition, this data demonstrates the impact that the addition of iron oxide particles has on wear rates under a variety of situations. It is clear that the volume loss experienced by the composite fell dramatically as the percentage of iron oxide in the composite increased. In fact, it reached its lowest value in the composite that included the highest amount of iron oxide (8%). This may be due to the function that iron oxide particles play in inhibiting the mobility of dislocations; as a result, the materials' hardness was raised, and its resistance to wear was improved. According to the data presented before, the wear rate in the Al specimen is at its peak at 10 N. However, this rate is reduced by 66% in aluminium that has been reinforced with 8% Fe_2O_3.

5. CONCLUSION

The following are some possible inferences to make after looking at the findings.

The sintering at 600°C ± 5°C for 3 hours of prepared specimens is very effective to satisfy sintering completely Al and Fe_2O_3 into structure, which gained. Almost all the prepared samples resulted in a three-phase structure (*i.e.*, Al and Fe_2O_3) at room temperature. All the specimens compacted at 6 tons and sintered at 900°C ± 5°C for 3 hrs.

The Al–Fe_2O_3 prepared resulted increasing the hardness, compression strength and wear resistance relatively with increasing Fe_2O_3.

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