Fabrication and Analysis of Aluminum – Alumina Metal Matrix Composites Using Powder Metallurgy Technique

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Abstract: Powder Metallurgy is the very advanced method of manufacturing the varied range of engineering composites by mixing/blending the powders. The compacting mixture of powders to the necessary shape into a die, which is manufactured for this process, is carried out by a hydraulic press. The force applied for pressing is 30 tons. The sintering process is achieved with a controlled atmosphere. The best value for sintering temperature is 600 °C for one hour. Composite specimens prepared from Al-alloy reinforced with different weight percent (2, 4, 6 and 8%) of Al₂O₃. The testing of the samples includes compression, flexural stress, hardness, Energy Dispersive Spectroscopy (EDS), X-Ray diffraction (XRD) and corrosion resistance. The best mechanical and physical properties of the prepared samples happened at 6 wt% of Alumina. The improvement of the corrosion resistance value is about 35.67 wt%.

Keywords: Metal matrix composite, powder metallurgy, aluminium, alumina.

1. Introduction
By scientists of materials, the scientific investigations are continuing to improve the materials properties and their performance. The conventional mechanical, chemistry modifications, thermal and thermo-mechanical processing methods led to improvements in the physical, chemical, and mechanical properties. However, the need for stronger, lighter, hotter, and stiffer than traditional materials led to advanced materials development and design [1]. The composite materials are a type of advanced materials; it can be defined as the combination of two or more constituents better properties than those of individual materials used alone. In comparison to metallic alloys, each constituent holds their separate mechanical, physical, and chemical properties. The two materials are the matrix and reinforcement. A reinforcing band improves the strength and stiffness. Reinforcement is stronger, stiffer, and harder than a matrix. Usually, the reinforcement material is a fiber or particles. Particulate composites dimensions are exactly equal in all directions. These particles may be platelets, spherical, or may be any other regular or irregular geometry [2]. In numerous areas of daily life, metal composite materials have found the implementation. From the processing and conventional production of metals, the metal matrix composites (MMCs) are produced [3]. A technology of MMCs is in rivalry with the other technologies of modern material, such as powder metallurgy [4]. Metals reinforcement may have
several dissimilar objectives. Light metal composite materials development objectives are high yield strength and tensile strength, high creep resistance at high temperatures, high fatigue strength, increase in low temperature creep resistance, wear behavior improvement, ductile composite superconductors production, corrosion resistance improvement. MMCs can be categorized in different ways, one of these classifications is a contemplation of reinforcement components kind and contribution in composite materials (fiber, particle, layer, and penetration). MMCs materials have a wide range of applications in different areas; these applications are vented passenger car brake disk, disk brake caliper, industry of automotive, traffic engineering [5-7]. Metal matrix composite materials may be shaped by several diverse methods. Commonly product engineering types are possible by a different process, such as: melting metallurgical processes, powder metallurgical processes, squeeze casting or pressure casting, finishing by machining techniques [8]. Powder metallurgy (PM) is an extremely advanced method of manufacturing dependable ferrous and nonferrous parts; prepared by elements mixing or alloys as powders and compressing a mix in the die. Resulting forms are heated (sintered) in the furnace of controlled atmosphere [9].

2. Materials and Experimentation

Aluminum Al, copper Cu, magnesium Mg, manganese Mn, and alumina Al₂O₃ powders are used in this work. The experimental work procedure conducted could be summarised as follow in figure 1.

Figure 1. Flow chart of the experimental work procedure.
An already existing die has been employed to fabricate the required specimens. The dimensions of the
die cavity are \((77 \times 10 \times 10)\) mm to meet the standard dimensions of the most important mechanical tests
after the machining of the specimens. The weight fraction of every compound (Al, Cu, Mg, Mn and
\(\text{Al}_2\text{O}_3\)) has been determined. Collecting these measured powders weights in the vessel and mixed
manually together to prevent the agglomeration. Then the mixed powder is carried to a container with
a well-closed gate. The container put into the mixer for 1hr with stable velocity of 100 rpm, this is the
second step in PM technology. After turn off the mixer, the powder elicted from its container and put
again in the vessel. The mixing powder blended with a very small amount of ethanol alcohol to hold
the bands between the powder particulate stronger. The die and the punch must wipe by a very small
layer of lubricant. Then, the powder was distributed into the cavity of the die manually to obtain the
best distribution of powder before the next step. The die thereafter transferred to the hydraulic press
device, put the punch over the powder that obeyed the cavity of the die. Turning on the hydraulic press
device and pressure was applied gradually until reach to 30 ton for 2 min at room temperature.
Releasing the sample from the die as a green compact specimen. These processes were repeated with
the different weight percent of alumina powder (2, 4, 6 and 8\%) of the composite. As the alumina
weight percent increased, the weight percent of the aluminium decreased whereas the other
components were kept constant. Table 1, gives the percent compositions of the composite formed.

| No. | %Al | %Cu | %Mg | %Mn | %Al\(_2\)O\(_3\) |
|-----|-----|-----|-----|-----|---------------|
| 1   | 95  | 4   | 0.5 | 0.5 | 0             |
| 2   | 93  | 4   | 0.5 | 0.5 | 2             |
| 3   | 91  | 4   | 0.5 | 0.5 | 4             |
| 4   | 89  | 4   | 0.5 | 0.5 | 6             |
| 5   | 87  | 4   | 0.5 | 0.5 | 8             |

The green compact specimens with different percentages of alumina powder transferred to the
automatic furnace, which was full by continuous argon gas to obtain inert environment such as to
prevent the oxidation at a high temperature inside the furnace during the sintering process. Turn on the
furnace with constant temperature increment (10 °C/min), until the temperature reached to 600 °C for
1hr, after that the samples are leaved to cool slowly inside the furnace also for 1hr. Bringing out the
specimens from the furnace and prepared it for different tests by using machining to obtain the
standard dimensions of the tests.

Hardness tester of INNOVATEST, model no. 703 A, Europe BV/Netherland was used to measure the
hardness. Scanning electron microscope (SEM) model INSPECT S50, made in Holland was used to
investigate the morphology the sample surface X-Ray diffraction (XRD) inspector of Shimadzu X-ray
diffractometer model XRD 6000 to the district of the crystal structure of solid materials by the X-ray
beam. Corrosion tests were performed using potentiostat device. Elemental analysis performed using
energy dispersive X-ray spectroscopy.

3. Results and Discussion
The results and discussion that are obtained from powder metallurgy process tests are shown below.

3.1. Density of Composite
Figure 2 presents the effect of applied pressure on the percentage density (the percent of the product
density to the theoretical density of the composite). The figure shows that the density increased with
increased applied pressure, where the pressure reduces the porosity between the particles. The density
of the composite material is reached about 90\% of the theoretical density of composite at the 30 ton.
This increasing in density due to reduce of avoids that existing between the particles of products.
The porosity and the density has been determinate according to the equations below [10]:

\[
\text{Sp.Gr for sample} = \frac{W_1}{W_1-W_2} \times \text{Sp.Gr} \tag{1} \\
P = \frac{W_3-W_1}{W_3-W_2} \times \text{Sp.Gr} \tag{2}
\]

where:
- \(P\) = Porosity of sample
- \(W_1\) = weight of sample in air (g)
- \(W_2\) = weight of sample suspended in liquid (g).
- \(W_3\) = weight of wet sample i.e. weight of soaked sample air (g).
- \(\text{Sp.Gr for sample}\) = specific gravity of material.

3.2. The Porosity of the Composite

Figure 3 depicts the variation between the porosity content into the composite specimen with the sintering temperature. The porosity content into the part decreased with increased sintering temperature until 600 °C due to the solid state effusion that occurs between particles.

3.3. Flexural Test Results

Figure 2. Variation the percentage density with applied pressure.

Figure 3. Variation the percentage porosity with sintering temperature.
Figure 4 displays the alumina content with the flexural stress of the specimens of the composite with different alumina weight percent (2, 4, 6 and 8). This figure also presents that the flexural stress increased with the increase of alumina content and reached to a maximum value at 6 wt% alumina and then this value of flexural stress decreased to a minimum value at 8% alumina because of the high content of alumina in this specimen, and bad wettability.

![Graph of Figure 4](image1)

**Figure 4.** Variation the flexural stresses with alumina content.

3.4. Compression Test Results

Figure 5 exposes the alumina content with the compression stress of the specimens of the composite with different alumina weight percent. Figure 5 also indicates that the compression stress increased with the increase of alumina content and reached to a maximum value at 6 wt% alumina. This value of compression stress then decreased to a minimum value at 8 wt% alumina because of the high content of alumina in this specimen. According to ASTM E9-19, the primary specimens shaped to obtain the desired dimensions that met the selected standard for compression test by using a milling machine in the workshop [11].

![Graph of Figure 5](image2)

**Figure 5.** Compression stress versus alumina content.
3.5. Hardness Test Results

Figure 6 manifests the relation between the hardness and the percentage of reinforcement material (alumina). This figure indicates that the hardness increased with the increasing percentage of alumina until the percentage 6% and this value then decreased at the percentage of 8% alumina because of the high content of porosity, where the porosity is higher than other percentage of alumina. The hardness test was done according to ASTM E 18-19 [12].

![Figure 6](image)

**Figure 6.** Hardness versus alumina content.

3.6. Energy Dispersive Spectroscopy(EDS) Tests

Figure 7 exhibits the EDS of cross-section side of the specimen of 6 wt% alumina content and the metallic elements with their percentages.

![Figure 7](image)

**Figure 7.** EDS map cross section of 6 wt% alumina content.
Figure 8 evinces the EDS map test cross-section of the specimen of 6% alumina without cladding layer. This figure shows the distribution of metallic elements, the concentration of these elements and their diffusion through the specimen.

![EDS Layered Image 3](image)

**Figure 8.** EDS for the cross-section of 6 wt% alumina content.
3.7. X-Ray Diffraction Results
Figure 9 is identified with the base material, which is aluminium composite with 6 wt% alumina content.

![X-Ray Diffraction of 6 wt% alumina content.](image)

**Figure 9.** X-Ray Diffraction of 6 wt% alumina content.

3.8. Corrosion Test Results
Figure 10 shows the Tafel plot for specimen has 6 wt% alumina content, which makes this specimen less active and near to the behaviour of the inert material to the corrosion attack.
Figure 11 illustrates the Tafel plot for specimen of 0 wt% alumina (no alumina content) where it was appeared more active to the corrosion attack.

The results of the corrosion test in the above figures show that the corrosion resistance of specimen with alumina content is higher than specimen without alumina. The improvement of corrosion resistance is about 35.67 wt% with alumina content.

4. Conclusions

1. The sample with high alumina content has a high corrosion resistance than that has lower alumina content. The improvement value is about 35.67 wt%.
2. The value of hardness, bending, and compression strength for prepared composites increase with increasing the percentage of alumina (Al₂O₃) until 6 wt%, then decreased thereafter.

3. The percentage of porosity of composite material used decrease with increasing the sintering temperature till 600 °C for 1 hr.

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