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Research paper

Studying the effect of alumina on the mechanical properties of aluminum alloy prepared from waste using powder metallurgy

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Abstract

Nowadays, there is an increasing request worldwide for the advanced materials so as to get the preferred properties. This is for the reason that a particular material normally cannot meet the requirement of severe engineering environment that is why the need for composites arises. Metal matrix composite is a- main class of materials with high potential for structural applications needing high specific modulus, strength and toughness. Metal matrix composites with unique properties are growing every day and widely used in different industries because of their high mechanical properties and wear resistance. The mechanical and physical tests carried out in this work involve hardness, wear rate, microstructure, and XRD. The results showed that there was an improvement in mechanical properties of the composite which was achieved by adding ceramic reinforcement phase. In comparison with the base metal.

Keywords: *Microstructure; Powder Metallurgy; Composite Materials.*

1. Introduction

Aluminum recycling is the operation of re-melting aluminum so as to reuse it in the production stage. The main advantage of recycling aluminum is knowing cost reduction, that it is cheap and needs less energy to produce a can from recycled aluminum than from the bauxite. In accordance with Aluminum Association (2014), currently the aluminum is the most commonly recycled material in the world that can be recycled several times without changing its properties. As a matter of fact, the aluminum packaging needs 60 days to be recycled and reused in markets [1].

Aluminum is very important metal in the construction, packaging, and transportation industries as well as its alloys used to manufacture structural components needed for the aerospace industry. The electricity required to produce one ton of Aluminum from bauxite is about (17000) kWh, while we need approximately (750) kWh to recycle it with the same amount. Therefore, the recycling process needs only (5%) of the total production energy. The powder of Aluminum is utilized as a power source (fuel) in the reusable solid rocket engines [2].

Aluminum cans are usually the highest recycled packaging containers due to its important characteristics and flexibility as well as its alloys can be utilized with a wide range in industry such as packaging, construction, furniture, electronics and industrial installations. It is the main packaging containers that is (100%) recycled at highest recycling rate than other any packaging container [3].

Recycling process preserves energy and diminish raw material extraction as well as combats weather change. It is better for the environment rather than burning or landfilling it. Until now, there has been a large possibility for councils to develop collection schemes and enhancing the benefits of recycling to the maximum extent by implementing the best practice outlined in this briefing.

Aluminum metal is widely utilized in industrial applications due to its low density and corrosion resistance. Furthermore, it used in the transmission of electrical applications because it is a good metal conductor of electricity as well as to manufacture of utensils (gears). The majority of the Aluminum recycling is too re-formed into other Aluminum products are utilized in the production of different compounds such as Alums (known as Potassium Aluminum Sulfate Dodecahydrate ($KAl(SO_4)_2$-$12H_2O$) which is the most common Aluminum compound [5].

Aluminum can be a supportable product that can be recycled and reused more than once. Therefore, recycling of Aluminum can maintain money, energy, time and precious natural resources which will enhance the economy and local communities [6].

The main object of recycling process was in the development of sustainable system loop that can transform all the valuable resources which are landfilled or burned as waste materials into convenient products [7].

The poor strength of aluminum can be improved by the addition of alloying elements such as Si, Zn, Mg, and Cu. These elements are added so as to improve the aluminum strength, but the recycled aluminum from beverage cans does not need to these elements because it contains alloying element. However the main defect of aluminum (wear resistance) stays poor [8].

The wear resistance of pure aluminum can be improved by the addition of ceramic reinforcing phase such as Al_2O_3 which is controlled the microstructure, Tribology and mechanical properties of the composite by controlling weight fraction, size and distribution of constituents. The ceramic reinforcing phase is preferable be-

cause it does not react with the base metal at elevated temperature and does not form unrequired phases [8].
Relatively, the addition of high weight fraction of the ceramic reinforcement phase (higher than 10wt. %) as (particle, short fiber, continuous fiber, or whisker) strongly influences the behavior of aluminum metal matrix in AMCs during fabrication, heat treatment of composite, and their common usage in industrial application. These variations in composite involve both extrinsic and intrinsic effects [9] & [10].

2. Experimental work

2.1. Aluminium ingot, chemical composition

Firstly, the aluminum beverage cans has been collected, sorted, cleaned, cut and squeezed to reduce its quantities as well to facilitate the smelting process later. One kg of aluminum beverage cans has been weighted for the remitting process so as to determine the aluminum ratio after separated from the slag. Aluminum smelt is poured into ingot. (1Kg) is melting in an electric melting furnace as shown in figure (1) to temperatures above (660℃) so as to ensure that most of the components that found within the chemical composition of aluminum beverage cans will be melting. Thereafter, the molten was poured into a steel mold after the removal of the slag outside. Chemical composition analysis was carried out for aluminum ingot to determine the components in of the alloy.

Fig. 1: A) Melting Furnace, B) Ingot of Aluminium Beverage Cans.

Table 1: Chemical Composition of Al Alloy Powder Prepared from Beverage Cans

Elements	Al	Mg	Si	Mn	Fe	Cu	Zn
%	94.17	2.55	1.5	0.83	0.7	0.179	0.056

2.2. Aluminum powder preparation

This stage includes the preparation of aluminum powder from Aluminum ingots by cutting up into small pieces (chips) by using turnings machine with power off (2.2 kW), (2000 rpm) speed of the spindle and feed rate of (0.6 mm/rev) so as to facilitate the milling process by planetary ball mill later.
Aluminum chips were milling by utilizing planetary ball mill after being saved by using an electrical sieve shaker. The number of cycles in the planetary ball mill was (5000 rev/min) for several hours (more than 12hr) so as to get aluminum powders with minimum particle size. Figure (2) shows the planetary ball milling.

Fig. 2: The Planetary Ball Milling.

2.3. Powders mixing

The aluminum oxide (Al_2O_3) powders were mixed with the aluminum which prepared from beverage cans by four point planetary ball mill. Four different sets of metal matrix composites were prepared given in the Table 2. Initially, all elemental powders were taken as its weight percentage and it was alloyed by a ball mill with the presence of acetone. A wet mixing was applied in the presence of acetone after preparing of powders according to the percentage mentioned in the table (2). The mixing procedure was achieved by top planetary ball mill mixer with speed of (3500 rpm) and number of balls with different radii for three hours at least in order to get a homogenous and perfect distribution of aluminum oxide powder particles in aluminum matrix so as to reduce the agglomeration to a minimum. Finally, the product mixture was utilized for the next stage (compaction stage).

Table 2: Composition of Al Alloy/Al2O3 Alloy and Composite

Sample	Mg	Si	Mn	Fe	Cu	Zn	Bal.
Al Alloy	2.55	1.50	0.83	0.70	0.179	0.056	94.17
5%Al_2O_3	2.55	1.50	0.83	0.70	0.179	0.056	90.17
10%Al_2O_3	2.55	1.50	0.83	0.70	0.179	0.056	90.17
15%Al_2O_3	2.55	1.50	0.83	0.70	0.179	0.056	90.17

2.4. Powders compaction

Uniaxial compacting by double action die was done by using an electro hydraulic compaction device with the pressures of (350 & 450) Mpa. Cylindrical samples with (17 mm) in diameter and (5.5mm) height were prepared to be used for the microstructure, X-Ray diffraction, hardness, and wear tests.
In order to prepare samples, the dwell time and load used to eject the samples outside the die were (3 min.) and (2 tone) respectively. The inside walls of the die lubricated with graphite to facilitate the samples to eject outside.

Fig. 3: Electro Hydraulic Compaction Device.

2.5. Sintering

In this stage, samples compacts are sintered after compaction stage in vacuum sintering furnace (high temperature tube furnace) by raising the temperature of the samples to (500℃) for (2 hr.) and let it cool down inside the furnace till the temperature of the samples drops up to room temperature. Thereafter, the samples will be ready for mechanical testing. The temperature of vacuum sintering furnace utilized to prepare aluminum composite, raised with rate (10℃/min).

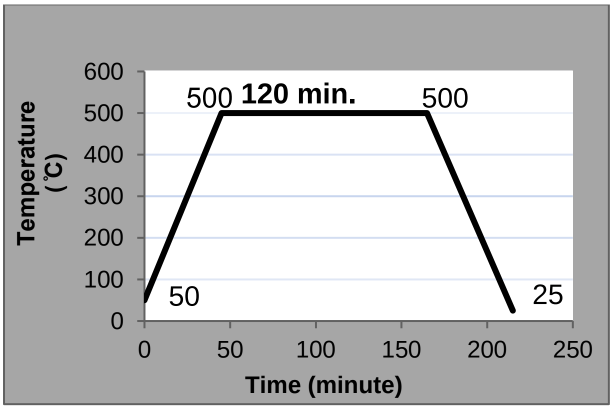

Fig. 4: The Program of Sintering Process.

The sintering process of the samples prepared for this study in vacuum furnace may be dangerous because of the presence of magnesium element in aluminum powder which prepared from beverage cans may be sublimate at a temperature (250℃) leading to emission gases and fumes causes failure and breaks the vacuum furnace tube. Figure (5) shows the vacuum tube furnace used for sintering process.

Fig. 5: Vacuum Sintering Tube Furnace.

2.6. X-Ray diffraction (XRD) test

The test of X-ray diffraction analysis utilized to determine the interface of each element powder used in this study separately, and compare the results with standard charts. In this test, the speed used was (6 deg. /min.), the step was (0.02 deg.), and the angle from (20-80) deg. with copper (Cu) target, wave with length (1.54060) Angstrom, the voltage of (40 KV), and the current used was (30 mA). The analysis aluminum alloy, and aluminum oxide powder have been done in Babylon university/college of engineering materials, department of ceramics and construction materials. The figure below shows the XRD device used for this test in this work.

Fig. 6: X-Ray Diffraction (XRD) Analyzer Device.

2.7. Microstructure test

In this test, a smoothing process for samples (Grinding) was done by using paper grits of aluminum oxide (Al_2O_3) with various degrees of smoothness (180, 220, 320, 400, ٦٠٠, 800, 1000, 1200, 1500, 2000, 2500) particle per square inch (pin^{-2}). A polishing process of samples using diamond and then the samples washing with distilled water and alcohol; and the samples dried after each step using electrical drier shown in figure below. An appearance process (Etching) using a reagent of Keller with (0.5HF, 1.5HCl, 2.5HNO_3, and 95.5H_2O) chemical composition, that's by immersing the samples for (10-20) second in the solution so as not too burned, and then washing the samples with distilled water and alcohol. An optical microscope used to see the microscopic structure of the samples.

Fig. 7: Optical Microscope.

2.8. Hardness test

For hardness testing, suitable grinding and polishing processes were carried out with alumina paper grits of (180, 220, 360, 400, 600, 800, 1000, 1500) pin^{-2} before subjecting all the samples to this test. The test was conducted on Micro Vickers hardness device as shown in figure (8) below, where a square-base diamond pyramid is falling down on the sample surfaces with a weight of (200g) for (10 Sec).

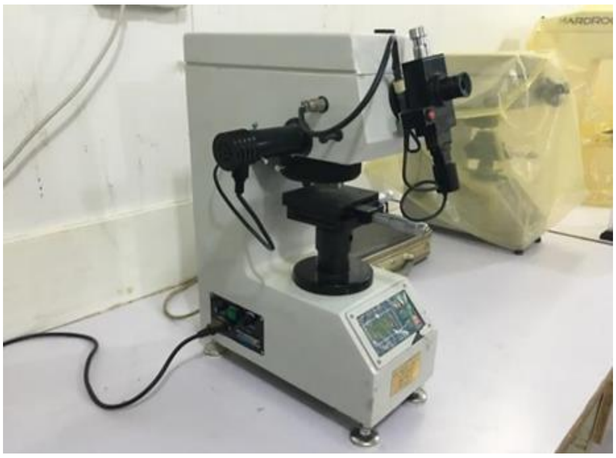

Fig. 8: Micro Vickers Hardness Device.

The hardest of all samples was recorded at an average of four hardness value at least taken from the surface of samples.

2.9. Wear test

The testing technique utilized for examining the sliding wear and the friction coefficient is pinned-on-disc technique. In this test, the material removed from the samples that were calculated by weighing (weight loss).

The samples prepared in this study, and wanted to be tested for wear were set as a pin against a steel disc. The features of steel disc that used for wear testing involve the chemical composition of martensitic with minor carbides and austenite; the mean surface roughness of (0.113 µm) and Vickers hardness of (852 ± 14) g/µm². The test was performed at room temperature (25ºC), utilizing loads (10N), rotational speed of steel disc is (200rpm), four different intervals of time (5, 10, 15 and 20) min., and sliding radius of (5mm). The wear rate is calculated according to the equation below:

$$R.W = \Delta w/2\pi rnt$$

Where:-

R.W: Wear rate (g/m).

Δw: Weight lost (g) which is the difference in weight of the samples before and after the test.

r: The radius of the sample to the center of the disc (5mm).

n: Disc rotational speed (200 rpm).

t: Sliding time (min.).

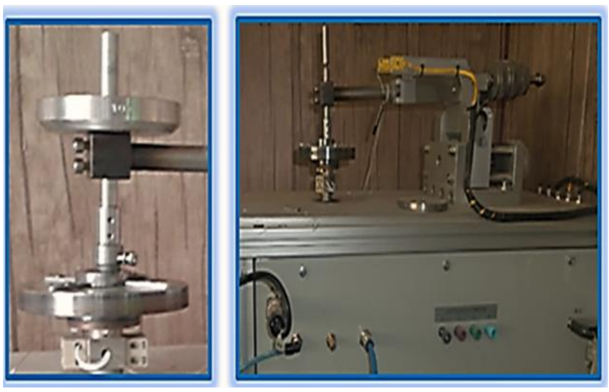

Fig. 9: Wear Test Device.

3. Results and discussion

3.1. X-ray diffraction analysis

Figures (10) and (11) represent the diagrams of the X-Ray diffraction test for aluminum alloy, and aluminum oxide powders.

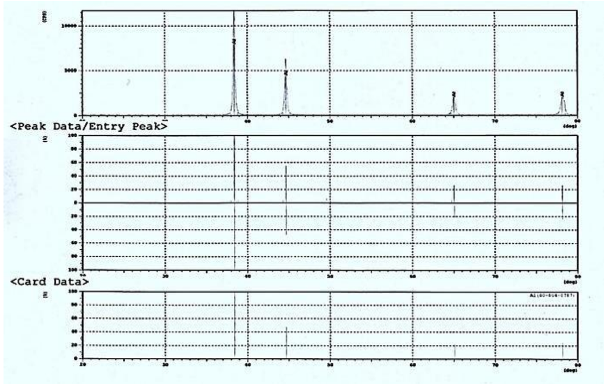

Fig. 10: X-Ray Diffraction Analysis of Al Alloy Powder.

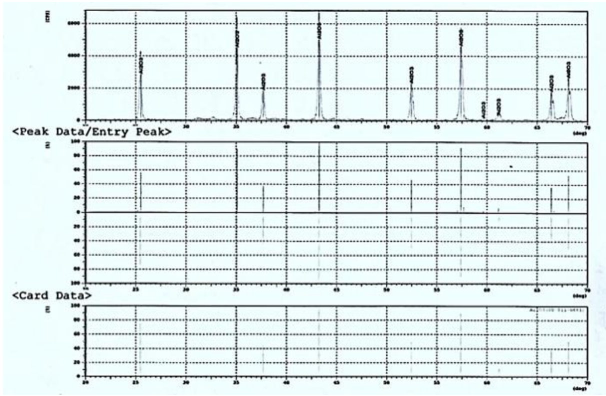

Fig. 11: X-Ray Diffraction Analysis of Alumina Powder.

3.2. Optical microscopic analysis

The microstructure in figure below shows the presence of aluminum oxide particles in aluminum alloy matrix. It is clearly shown that, the utilization of the powder metallurgy technique of composite leads to get a homogeneous distribution of the strengthening phase in the matrix which may enhance wear and mechanical properties of the composite.

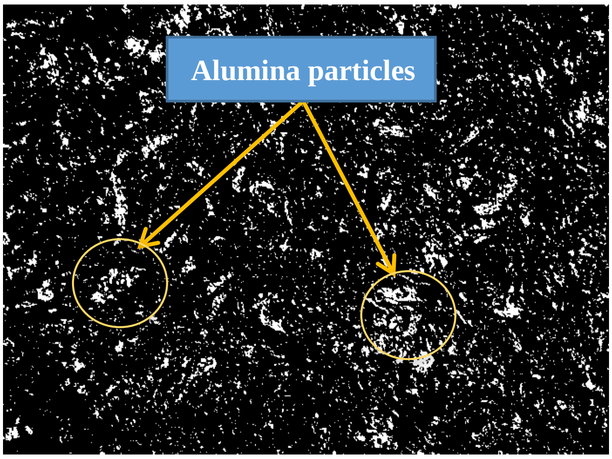

Fig. 12: Microstructure of (Al - 15% Al_2O_3), (600 X Magnifications).

3.3. Hardness

The results show that the variation of hardness values of all the samples prepared in this study is a function of aluminum oxide content and compaction pressure that the addition of aluminum oxide leads to an increase in hardness. The high hardness values were recorded for the sample with (15wt. %) aluminum oxide and compaction pressure equal to (450 Mpa). The figure below shows the variation of hardness of the prepared samples with respect to alumina content and compaction pressure. The red curve represents the variation of hardness with an alumina content of (350 Mpa) compaction pressure, and the blue carve represents the variation of hardness with an alumina content of (450 Mpa) compaction pressure.

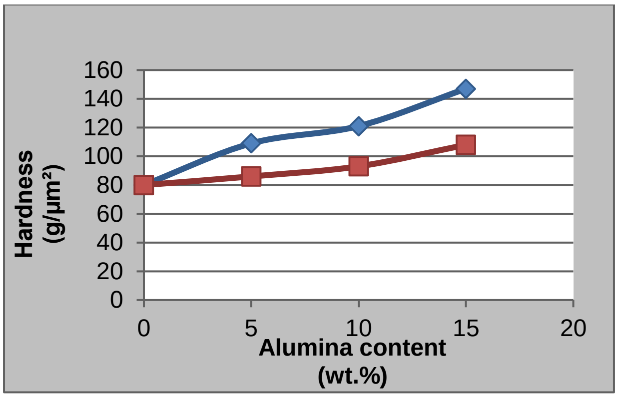

Fig. 13: Hardness V's Alumina Content of Composite at (350 & 450) Mpa Compaction Pressure.

3.4. Wear rate

The results of wear rate give us an indication that the samples reinforced with aluminum oxide essentially be with a lower wear rate compared to the base metal as well as increasing compaction pressure decreases the wear rate. The aluminum alloy samples have maximum wear rate, but with the increasing addition of aluminum oxide content and increasing compaction pressure, the wear rate reduced step by step. Figure (15) shows the effect of aluminum oxide content and compaction pressure on wear rate.

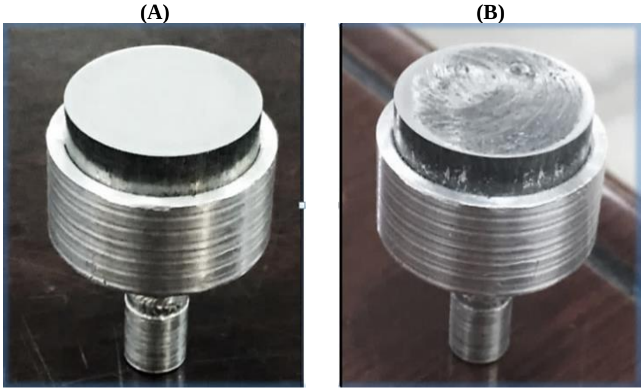

Fig. 14: Wear Test Samples: A) before Testing, B) after Testing.

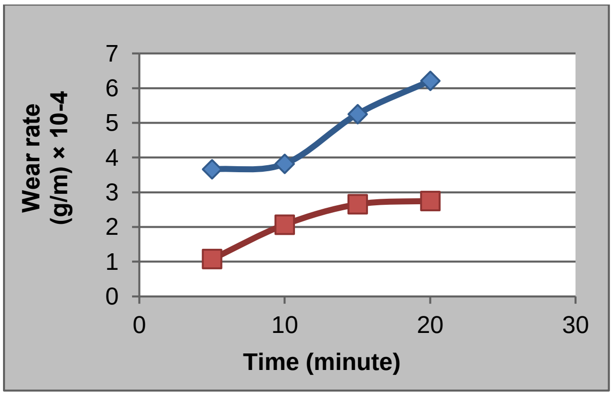

Fig. 15: The Influence of Alumina Content on Wear Rate of Composite at 25°C Using A) Load of 10N, B) Rotational Speed of 200rpm.

The red curve represents the variation of wear rate with an alumina content of (450 Mpa) compaction pressure, and the blue carve represents the variation of wear rate with (350Mpa)

4. Conclusions

The conclusions from the results of the present work can be listed in the following items.

1) The procedure by which the used aluminum beverage cans are recycled is usually very quick, easy and inexpensive.
2) Recycling is a way used to prevent accumulation of high waste quantity through their second processing so as to utilize in the production of new materials.
3) The recycling process of aluminum beverage cans, not only reduces pollution environment problems which result from waste, landfill sites, but also provides economic benefit to the country.
4) The perfect and homogeneous distribution of reinforcing phase within the matrix were achieved by using powder metallurgy technique. Therefore, powder metallurgy cab be utilized as a substitute process for casting in some cases where the small size manufacturing applications were required.
5) The addition of reinforcing phase (aluminum oxide) and increasing compaction pressure lead to enhancing the hardness and the wear rate.
6) As a comparison with silicon element, the aluminum oxide leads to improvement in mechanical properties of composite with less weight fraction. So, aluminum oxide can be used as a substitute reinforcing phase within the aluminum matrix to manufacture disk brake rotor and automotive piston in cars.

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