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Erosions- Corrosion Behavior of (Al-Y_2O_3) Composite Prepared by Powder Metallurgy

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ABSTRACT

Aluminum has found many engineering applications due to its great formability, low density and high resistance to corrosion. Since aluminum is not very strong compared to other structural materials, it is usually strengthened by introducing second phase, reinforcing particles or fibers. The first aim of this work is to strengthenaluminum using powder technology. Yttria is selected as reinforcing particles. It is demonstrated that by adding yttria particles (3, 5, 7 and 10wt% with particles size 5.54 μm as reinforcing phase, aluminum can be strengthened and the microstructure of aluminum becomes finer with an increase in yttria content. The second aim of present work is to improve the erosion –corrosion behavior of aluminum metal matrix composite. An erosion-corrosion test for the prepared composite were carried out in slurry solution (1wt%SiO_2 sand in 3.5wt% NaCl solution as the erodent) with impact angles (90°). Comparing with the base aluminum sample, Brinell hardness was increasedby (83%) while erosion corrosion rate decreased by (91%) for the best sample which contained (10 wt.%) Y_2O_3 The improved properties of aluminum by the yttria addition may thus be attributed to residual yttrium in the Al matrix, and the resultant finer microstructure.

KEYWORDS

Y_2O_3; Aluminum; Corrosion; Corrosive wear; erosion- corrosion

INTRODUCTION

Discontinuously reinforced-aluminium matrix composites (DRA) are widely used for transporting medium for sands, gravels, coals, limestone and various metal ore but, due to suspended particles in materials causes erosion-corrosions in pipelines component such as constriction, automobile industry, valve, bend and tee junction [1-7]. Compared with commons ceramic Y_2O_3 particles possess greeting Mechanical and Thermal property [8]. Materials losses by corrosion effect aggravated by erosive abrasive action and create a massive problem in industrial application such as turbine, agriculture equipment, pump put-differentially. Study of erosion - corrosion of Al alloy composites demanded by situation where mechanical and corrosive wear are in actions. Furthermost of studies on Al alloy composites are carried out to evaluates physical and tribological property. Various experiments done to assess individual effect of erosion -corrosion in different medium [9 -11].

Nguyene et al. [12] has studied erosion rate on stainless-steel for different testes time- impact velocity. In their work, erosion rate decrease with time and increase with increases in velocities. Nguyene et al. [13] reported transitions on erosion profile from ‘‘W” shape to a ‘‘U” shape. Kumare et al. [14] revealed that Al alloy with TiB2 appearances superior corrosion resistances. Ceramic such as SiC, Al_2O_3, TiC, B_4C, and TiB_2, etc.., are being used as reinforcement. Between all reinforcement, SiC is chemically favorable and form adequate bond with the metals matrix without form intermetallic phases. SiC has another use as good thermal conductivity, hardness, mechanical properties, machinability and wear-resistances [15-18].

More Recent studies has displayed that RE. or oxygen -active element can considerably enhances corrosive wear - resistance of passive materials. The situation alike to the increases in high-temperatures wear-resistance of Stellite 6 alloyed with yttrium. When oxidation suppressed by RE, the synergism wear and

oxidation diminished, thus-leaded to lower wear-rate. Recent studies displayed that not simply oxygen-active element, but compounds was beneficial, e.g., yttria were establish to improve resistance of aluminum to corrosion and corrosive wear. Application of R-E compound rather than R-E must be more feasible to industry, then would be no problems with R-E degradation during material processes. In this work, yttria particles was additional to aluminum use powder technology for improved-performance of aluminum during erosion corrosion. The objective of the research is to investigate changes in microstructures, hardness and erosion-corrosion performance in sea-water (3.5% wt NaCl solution) and slurry solution with 1wt%SiO_2.

EXPERIMENTAL PROCEDURES

Composites-samples was prepared via powder-metallurgy processes, which consist of mix, compacting and sintering processes. The purity, particle size and powders used in this study are presented in Table 1. Pure Al was used as the matrix material. The composites were prepared by mixing different proportion (3, 5, 7 and 10) wt.

% Y_2O_3 The mixing process was achieved by electrical rolling mixer type typeSTGQM-15⁄-2. In order to ensure mixing , alumina ball with different diameter (5mm and 10mm) to mixing and refines metal-powders for about 6 hr. and 300 r.p.m according- kotresh procedure [22]. The ball powder weight ratio was 3:1 by weight. Wet mix is done via used 0.5 cc of ethyl-alcohol to every 25 g of powder-mixture. wet mixed used to min. temperature-generated by friction between balls with walls and powders. After mix wet-mixtures leftward to dry in room temperature for about 30 min after that put in polyethylene zip-locked bags.

Table 1. Powders Used in this Study

Powders	Average size(µm)	Purity %	Origin
Aluminum (Al)	19.90	99.99	Bucks Fluka AG Co.Germany
Yttria (Y_2O_3)	5.54	99.95	Fluke - Swiss made

After mixing, cold uniaxial pressing in double actions steel dies has been achieved. Electric-hydraulic press one channel device, type CT340-CT440 is used to compact green samples as disc samples for physical and microstructural tests. All samples compacted at 700 MPa according to [21] with loading rate (1 ton/ min) and period of applied pressure time is (5 min) with a diameter 12.5 mm. The same thing is done again with the samples containing (3, 5, 7 and 10) wt. % Y_2O_3. To minimize friction compaction process carried out using zinc stearate as die wall lubricant. The green compacts de lubricated for 30 minutes at 250 ℃. Then sintered for (6) hours at (540 °C) then slow cooling in the furnace with continuing vacuum to room temperature. The sintering process of the green compact was performed via vacuum high temperature tube furnace (type GSL 1600X) with (10^{-4} torr) pressure. Table 2 showed a description of prepared sample in detail.

Table 2. Detail description of prepared sample

Code of sample	**Descriptions (wt. %)**
A	pure Aluminum
B1	pure Aluminum +3% Y_2O_3
B2	pure Aluminum +5% Y_2O_3
B3	pure Aluminum +7% Y_2O_3
B4	pure Aluminum +10% Y_2O_3

TESTS

Particle size Analysis

Particle size analysis has been done for all elemental powders (AL, Y2O3) by using laser particle size analyzer type (Better size 2000 laser)

X-ray Diffraction Analysis (XRD)

Sintered samples with (12. 5 mm) in diameter and (4 mm) in height were tested by using X R D instruments type a (SH I MA DZ U L a b X R D-6 0 0 0), Japan. The measures conditions are: Target: Cu, wave length of 1.54060 A°, voltage and current are 30 KV and 15 mA respectively, scanning speed 2deg/min, the scanning range 30^{o}-80^{o}. The X ray diffraction was used in order to determine the phases produced after sintering and compare it with standard chart.

Optical Microscope Analysis

Sintered specimens of (12.5 mm) in diameter and (4 mm) in height were ground by using SiC paper grits as (400,600, 800, 1000 ,1200 and 2000) then polished by using diamond solution. The specimens were etched by using a Keller's reagent (2mL HF (48%), 3mL HCl (con), 5mL HNO_3 (con) and 190mL water) at room temperature [24]. After etching, the samples were washed with distilled water and dried by using an electric drier, after this stored in a desiccator for microstructure observation. . An optical microscope type (1280 XEQMM300TUSB)with suitable magnification was used to capture the microstructure of the specimen.

Porosity and Density Measurement

The density and porosity of sintered samples are measurement according to A S T M B- 3 2 8 [10], as following:

- After drying at100°C for 5 hours, the samples weighted and weight represent mass A.
- At room temperature, the sample is completely immersed at oil with a density of 0.8 g/cm³ for 30 mins.
- Weighting fully impregnated sample in air, to get the mass B.
- Weighting the fully impregnated specimens in water, to get the mass C.

The density and porosity have been considered by following equations

$$P = \left[\frac{B-A}{D_o(B-C)}\right] * 100\ [Dw] \quad (1)$$

$$D = \left[\frac{A}{(B-C)D_o}\right] D_W \quad (2)$$

Where:

Do = density of oil (0.8 g/cm³) at 25°C

Dw = density of water (1g/cm³) at 25°C

Brinell Hardness tests

There is no standard shape or size for a Brinell test sample, according to ASTM (E10-15a) [26]. A sintered samples (12.5 mm) in diameter and (4 mm) in height were subjected to appropriate grinding and polishing operation. The test was carried out on a Brinell hardness testing device type (HBRVS-187.5) with a ball indenters diameter of (5 mm) and load of (31.25 kg) for (10 seconds). The hardness was recorded as an average of three hardness measurements for each sample.

Erosion – Corrosion test:

Erosion is a mechanical process includes removing parts of the material surfaces due to the effects of collision with gases or liquid. The erosion/corrosion apparatus was designed based on (G 73) ASTM [27], as shown in Figure 1. The erosion-corrosion apparatus consists of generator motor, tank, tubes to fall the water by nozzle on the sample. This test was achieved at room temperature in slurry solution (1 wt. % SiO_2 particles in 3.5% NaCl) which causing erosion- corrosion process fall from the nozzle at 90° at (1.12 meter for a second). The nozzle has one mm diameter and far 10 mm from the sample. Note that Sodium chloride salt dissolves in water so the solution will cause corrosion while remaining SiO_2 particles will pound the sample surface and cause erosion.

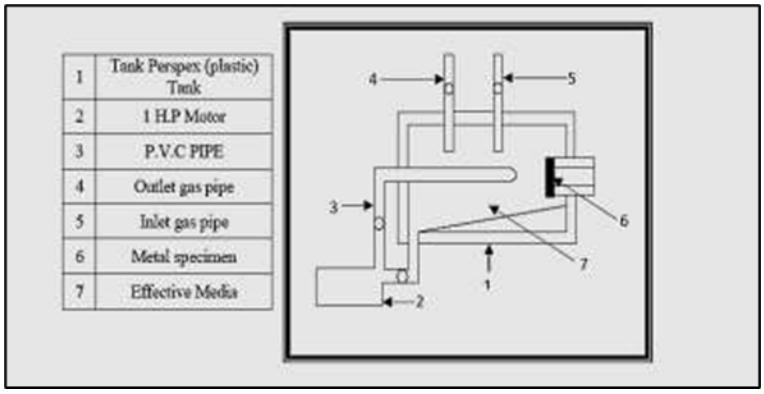


Figure 1. Schematic diagram of erosion-corrosion device [27]

RESULTS AND DISCUSSION

Particles sizes measurement

Figures 2 and 3 show particles size-distribution of (Al and Y_2O_3) powder-respectively. It evident that average-size of particles about 19. 90 μ m to Al, and 5.54 μ m for Y_2O_3 respectively.

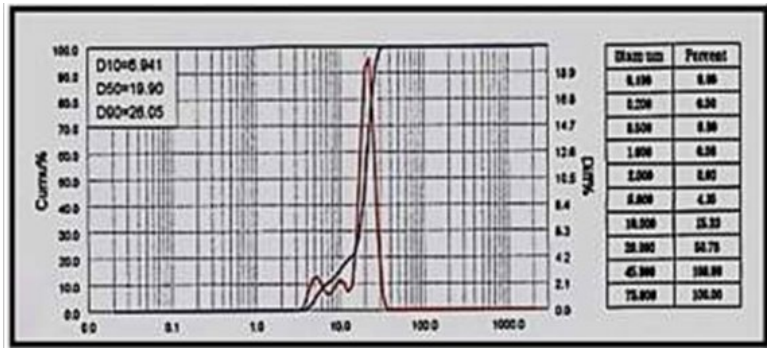


Figure 2. particles Size Analysis for Al Powder.

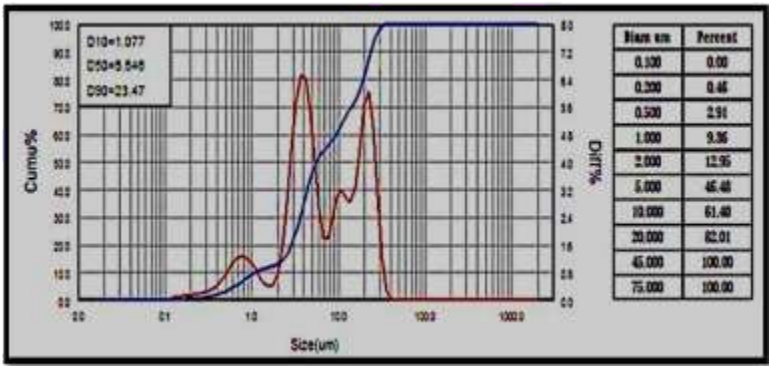


Figure 3. particles Size Analysis for Y_2O_3 Powder.

X-ray diffraction analysis

The phases identified by X R D analysis was comparable for all composite samples, therefore X-Ray diffraction test was done for (B4) sample after sintering. It can be observed that only Al and (Y_2O_3) were detected as expected.

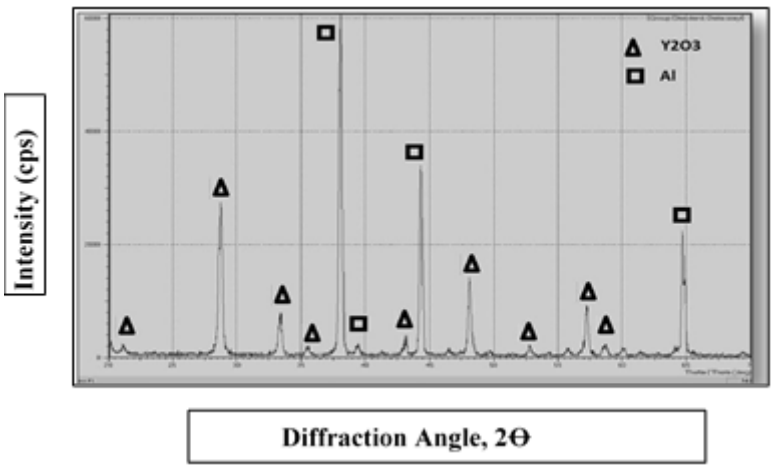
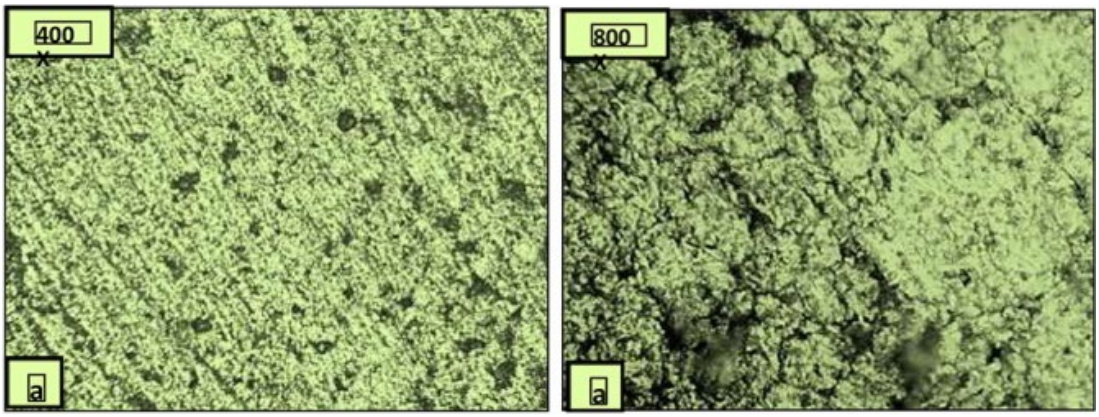


Figure 4. XRD pattern of sample B4 after sintering

Microstructural observation of the sintered samples

The micrograph gained from optical microscope for all samples (with different additives of Y_2O_3) after being etched with the above-mentioned etching solution are shown in Figure 5. The micrographs are taken with different magnification (400 X, 800 X) as shown in the figure 5. From the microscopic examination, it was observed that the reinforcement particle was distributed uniformly over the matrix material and the presence of Yttria and the absence of inclusions and segregations were also confirmed. Bright grey Al matrix and dark particles of Y_2O_3 can be clearly observed the phase are indicated by arrow on the above image. It should be noted that Y_2O_3 particle were well dispersed in the matrix of aluminum and just a partial agglomeration in composite with highs content of Y_2O_3 can be detected in Figure5. Also, similar microstructures wereobserved for composites fabricated in various weight percentage of Y_2O_3. The only minor difference wasrelated to the content of porosity and agglomeration. As demonstrated, there are some black point representing porosities of composite which are formed during powder metallurgy process .These results are identical to those of other researchers



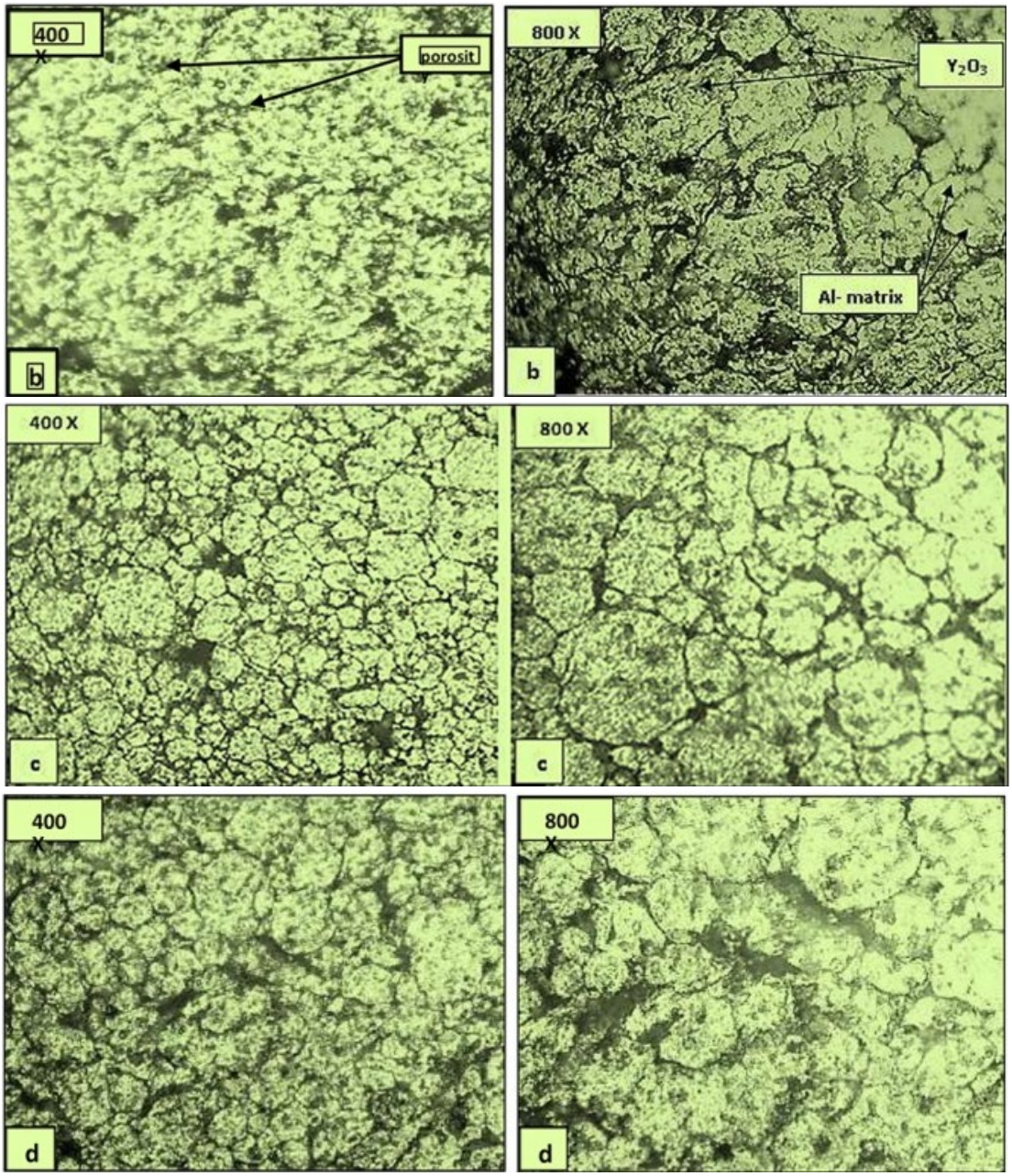


Figure 5. Microstructure of (a) Al-3 wt.% Y_2O_3, (b) Al-5 wt.% Y_2O_3, (c) Al-7 wt.% Y_2O_3 and (d) Al-10 wt.% Y2O3 alloys after sintering and etching with different magnification.Porosity of compacts after sintering

Porosity after sintering is the amount of open pores in the volume of sintered compact The effect of weight percentage of Y_2O_3 on Porosity of the Al- Y_2O_3 composite produce by powder metallurgy are shown in Figure 6. It has been shown that open pores volume fraction or porosity after sintering decreased by increasing weight percentage of Y2O3, due to the small particle size of Y_2O_3 which enters between the pores and fills them leads to the process of densification and therefore the pores will decrease

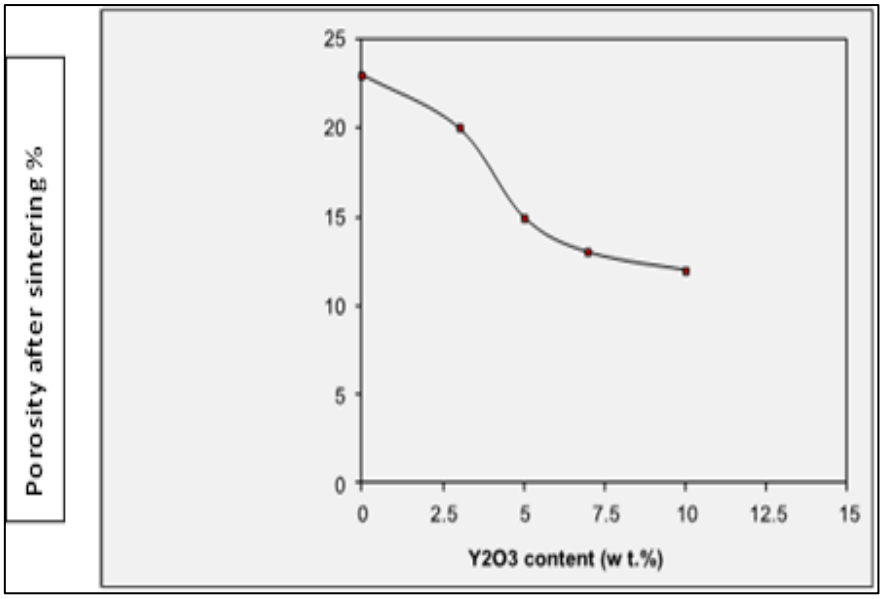


Figure 6. Effect of Y_2O_3 content on porosity of sintered samples.

Density of compacts after sintering

The effect of weight percentage of Y2O3 on density of the Al- Y2O3 composite produce by powder metallurgy are shown in Figure 8. From experimental results observed in Figure 7, it shows that presence of reinforcement particulates caused increment of sintered densities.

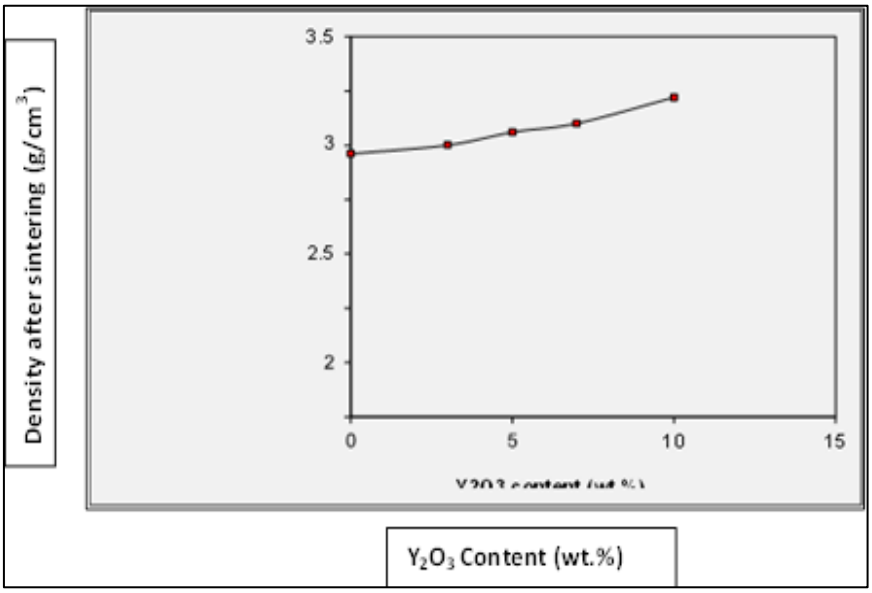


Figure 7. Effect of Y_2O_3 content on density of sintered samples

Hardness test

The effects weight percentage of Y_2O_3 particle on hardness of arranged composite shown at Figure 8. Its determined hardness increased with increase of Y_2O_3 percentage, and highest values record for B4 sample with (10 wt.% Y_2O_3). growth could be attribute to rather high-hardness of Y_2O_3 particle itself act as barrier to a dislocation motion [29][30], increment percentage of Brinell-hardness is 11%, 20%, 26%, and 83% for samples (3 wt.%), (5 wt.%), (7 wt.%), and (10 wt.%) Y_2O_3 respectively comparing with Al sample.

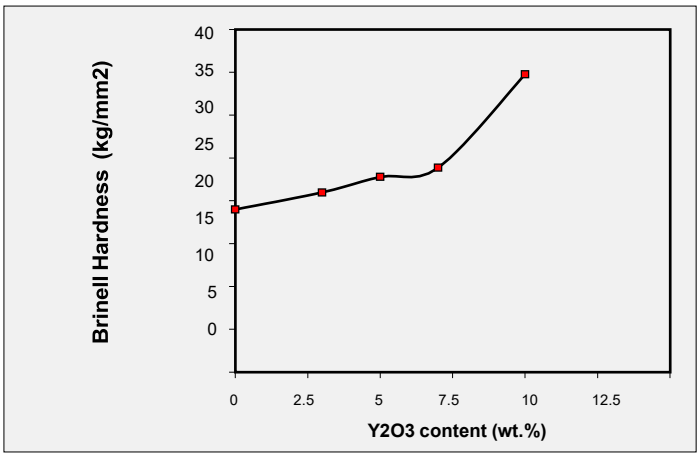


Figure 8. Effect of Y_2O_3 content on hardness of sintered samples.

Erosion- Corrosion Test

Figure 9 indicates the results of erosion-corrosion of aluminum and composite samples in slurry solution (3.5 wt% NaCl with 1% SiO2) after exposure times for) 21 hr. at 1 hr. cycle) at impact angle 90 °. This angle was choose according to Das et. al. [15] who noted that the erosion corrosion rate is significantly higher at normal incidence angle (impact angle 90 °) and higher in sand slurry media as compared to that occurred at lower speed and smaller incidence angle . They observed that interface between aluminum and hard particles (SiC) in composite material play an important role in the process of material removals under synergistic effectof erosion and corrosion. Further, It was seen from Figure 9 that, at first time of immersion in corrosive solution, the erosion corrosion rate is expected to be higher because of easy removal of corrosion product and occurrence of fresh metal surface in contact with corrosive media. Additionally, the extent of deformed zone (created due to the impact of erodent) at the site of impact on the sample surface increases with increasing exposure time at a constant speed of slurry [16]. So the erosion corrosion rate is generally increased slowly then accelerated and decreased then followed by a steady state. At the beginning of the test, the surface ofthe sample hardness by drops of water. Then spalling occurs, and an increase in erosion corrosion rate occurs, thendecreased and followed by a steady state. Steady state occurs due to the formation of grooves on the surface of thesample. These grooves then filled with salty water and the jet of salty water will make impact with this water ratherthan the alloy.

As can be seen in this figure the erosion corrosion rate decreased when the aluminum sample as reference samplewas reinforced with 3, 5, 7 and 10 wt.% Y_2O_3 and the composite sample containing 10% Y_2O_3 has the lowest erosion corrosion rate. This is due to presence of hard Y_2O_3 particles in matrix of aluminum which have more resistance to erosion –corrosion than that soft aluminum. In addition to, when the silica particles bombardment ofthe surface increase the hardness of metal surface due to deformation and hardening the surface. Further, the combined effect of sand in the slurry will lead to pitting corrosion [17].

Figure (10a-b) show the micrographs of pure aluminum and 10% Y2O3 composite samples respectively after erosion –corrosion test in slurry solution (1 wt.% SiO2 in 3.5% NaCl) after exposure time 21 hrs. It was observedthat the pits in the composite sample (Al- 10% Y2O3) were smaller and more shallow than that in base alloy whenexposed to quiescent 3.5%NaCl solution. It is seen that the presence of sites of large pit at the surface of aluminum exposed to 3.5%NaCl solution is higher than that of composite sample. This is attributed to higher chloride ion contents and lows PH inside the pit tend to accelerate the anodic dissolution reaction within the pit which leads to growing pit and increasing the corrosion rate of samples. This is consistent with results of researchers [12], they noticed that the number of pits initiation sites decreases with the volume fraction of the reinforcement in composite material.

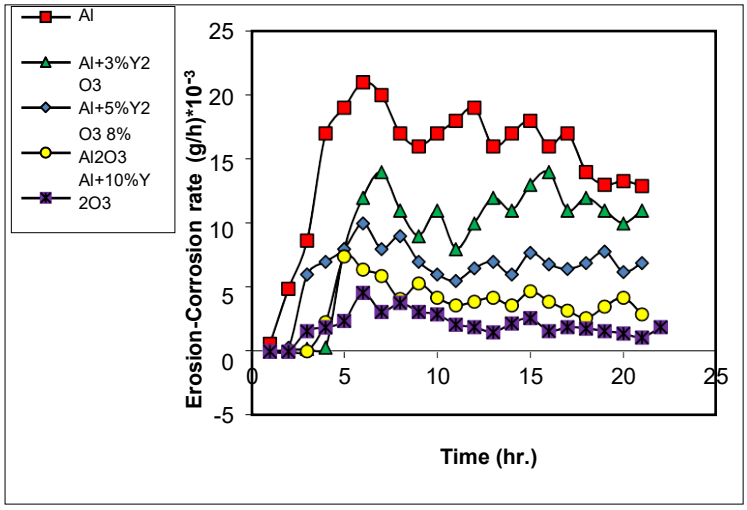


Figure 9. Effect of exposure time on weight loss of aluminum and composite samples in slurry solution (3.5wt% NaCl with 1% SiO_2)

It produces horse shoe like traces. which are a distinctive characteristic of erosion- corrosion with slurry. This type of corrosion produces great weight loss as a result of removing large and clear –cut metal portions due to impingement, cavitation, erosion and corrosion. The horse shoe like area are dark, distinctive and orientated to ward flow direction of the erosive –corrosive medium. The horse shoe like area are distinctively deep because the metals is soft and easily eroded and spelled by sand grains which are considered erosive manner in the corrosive media. This is in good agreement with that shown by [18], who studied common feature typically observed with erosion corrosion of horse shaped and comet tail pitting damage.

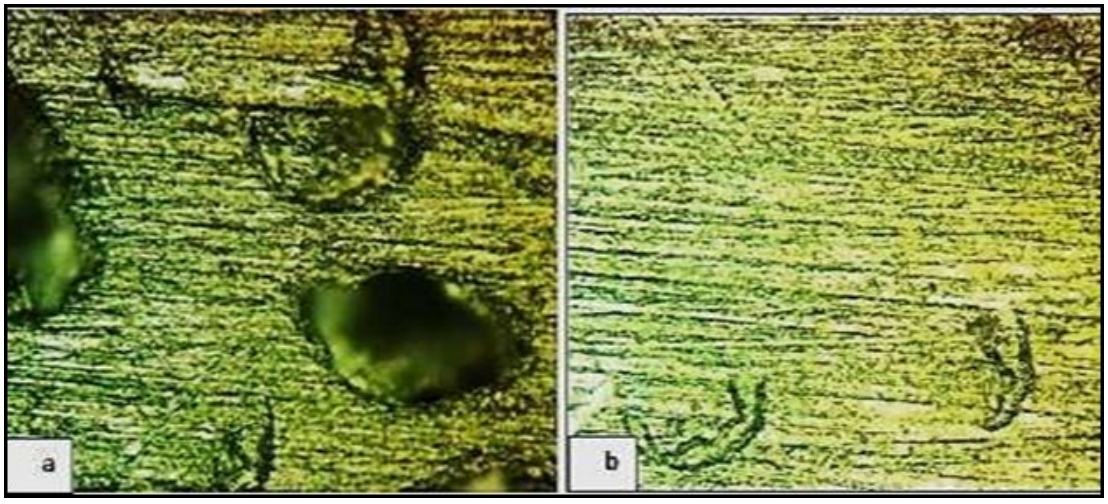


Figure 10. Microstructure of (a) pure Al and (b) Al-10 wt.% Y_2O_3 alloys after erosion- corrosion test in slurry solution (1 wt.% SiO_2 in 3.5% NaCl) with (200 X) magnification.

CONCLUSIONS

1. Powder metallurgy is an effective method in manufacturing of metals matrix composite, where the optical microscope images show uniform distribution of Y_2O_3 particles in the aluminum matrix.

2. Brinell hardness is increased with addition of Y_2O_3 particles by 11%, 20%, 26%, and 83% for samples of (3 wt.%), (5 wt.%), (7 wt.%), and (10 wt.%) Y_2O_3 respectively.

3. Erosion –corrosion rate in slurry solution (1 wt.% SiO_2) in 3.5 %NaCl is decreased with addition of Y_2O_3 particles by 15%, 47%, 76%, and 91% for samples of (3 wt.%), (5 wt.%), (7 wt.%), and (10 wt.%) Y_2O_3 respectively under same conditions

4. In erosive – corrosive media the removal of material is due to combined effect of erosion and corrosion

and hence erosion corrosion rate is significantly higher.

5. LOM images of damaged surface of composites showed that damage mechanism is dominated by plugging and indentation.
6. Experimental densities are increased gradually with addition of Y_2O_3 particles by (4%), (8%), (11.5%), and (21%) for samples of (3 wt.%), (5 wt.%), (7 wt.%), and (10 wt.%) Y_2O_3 respectively
7. Sample of (10 wt.%) Y_2O_3 has the best combination of properties. It has low weight and low porosity and good hardness and good erosion corrosion resistance that makes it eligible for uses in many engineering applications.

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