ANALYSIS OF MECHANICAL PROPERTIES OF ALUMINUM MATRIX COMPOSITES REINFORCED WITH ALUMINA

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ABSTRACT

The development of Composites of Aluminium Metallic Matrix (AMMCs) has made the manufacturing cheaper, lighter and user friendly. The AMMCs possess characteristics of low weight with highly strength. In this research studied the effect of Al_2O_3 particles on mechanical properties like Hardness, Compressive strength and Wear characteristics of Al metallic matrix composite manufactured by stir casting technique. The reinforcement added in different weight percentages (0, 4, 6, 8 and 10). The microstructure of specimens is analysis by optical microscope and measured the hardness, compressive strength and wear characteristics which increase with increase weight percentage of Al_2O_3. Finally, can be noticed that volume loss was decreased drastically with increasing aluminum oxide percentage, even it reaches the minimum value at the composite that contained maximum aluminum oxide percentage (10%).

Key words: Aluminum Metal Matrix Composites (AMMCs), Al_2O_3 particles, stir casting method, reinforcement and optical microscope.

1. INTRODUCTION

Aluminum and Aluminum alloys have many different applications purposes such as cars and aerospace manufacturing because of the special characteristics for this metal like low density with highly strength comparison to weight ratio as well as high thermal conductivity. Nevertheless, poor surface-dependent characteristics are considered a serious problem for long time use [1, 2]. In the present, Composites Metallic Matrix for Aluminum (AMMCs), which produced from the combination of hard ceramic particles into aluminum alloys, which is widely used to upgrade the mechanical behavior of the aluminum alloys. A pure interface with low pores or reaction production, also homogeneous spreading of the particles in order to upgraded characteristics [3-5].

Moreover, Aluminum has a great and rapidly attraction for oxygen in air conditions. Where Aluminum is oxidized to provide an oxide thin layer on the surface of the metal. This layer on the surface of the Aluminum is (Al_2O_3) which is can't be penetrated by oxygen, thus it provide a metal protection against corrosion or any attack from different conditions [6, 7].

Several researches have been conducted in order to investigate the influences of the second phases as SiC [8, 9], Al_2O_3/TiB_2 [5, 10] and ZrO_2 [11] on aluminum matrix reinforcement. All reports confirm the favorable influence for these materials on enriching the mechanical characteristics of the resultant composites.

Mishra et al. [12], they using an Al5083 alloy with SiC particles (0.07 cm size) in order to produce a surface composite, and found that the hardness of the produced surface composite was increased 10% comparison with the base metal (BM) because of adding the hard particles (SiC) in the resultant material. As well as Shafiei et al. and Mahmoud et al. [13, 14], they adding

Al_2O_3 and SiC particles into base materials like Al, Cu, and Fe alloys, and they found that wear resistance and the abrasion were improved in the substrates. Moreover, Dolatkhah et al. [15] study the microstructural and mechanical characteristics of Al–SiC metal matrix composites produced by FSP. Where they observed that the changing in the direction of instrument rotational between passes of FSP, increment in the number of passes, and decrement of size of SiC particles lead to enrich wear and hardness characteristics. Lee et al.

[16] study the mechanical and microstructure characteristics of an Al–Fe in situ nanocomposite fabricated by FSP. They detected a constant spreading of the second phase particles ($Al_{13}Fe_4$) in the Al matrix. The fine dispersion of particles caused in an aluminum matrix with ultrafine-grained structure. Moreover, Qian et al. [17] synthesized Al–Al_3Ni in situ composites using the FSP route, and they described that the composite had increased tensile and hardness characteristics.

Baghchesara, et.al, [11] they using a Vortex technique in order to produce Al-ZrO_2 by using the powder of ZrO_2 with diameter average 1 micron as reinforce particles and Al-356 as the metallic matrix. Stirring the melting composites for thirteen min., and then casting into a metal mold. Thus, various specimens have been prepared by (5, 10 and 15) volume percentage of ZrO_2 in various temperatures of casting as following 750°C, 850°C and 950°C. The optimum production conditions of Al- ZrO_2 composites are 750°C and 15 vol. % ZrO_2.

So that the aim of this research is to produce, characterize and identify the hardness and wear behavior for A1–Al_2O_3.

2. EXPERIMENTAL WORK

2.1. Preparing of Aluminum Reinforced Aluminum Oxide Specimens

All of the composite specimens were produced by consuming a high aluminum pureness wires according to Table 1.

Table 1 Chemical composition of pure aluminum

Si	Fe	Cu	Mn	Mg	Zn	Ti	B	V	Cr	Others each	Others total
6%	12%	1%	1%	2%	3%	1%	0.5%	1%	1%	3%	10%

Specimens with different reinforcement percentage were produced by two-steps stir casting technique. The compositions of each specimen are shown in table 2.

Table 2 Specimens prepared in the present work

Aluminum (wt. %)	Magnesium (wt%)	Al_2O_3 (wt%)
98.0	2	0.0
96.0	2	2.0
94.0	2	4.0
92.0	2	6.0
90.0	2	8.0

The high purity aluminum wires were cut to small pieces in order to facilitate its melting in the furnace. Each of aluminum wires, magnesium, and aluminum oxide with 15-20µm grain size were weighted in desired amount (weight percentage wt%). The weighted aluminum oxide particles were divided to many groups, each group have about (0.5 g) in weight, then, each group was covered with aluminum foil and preheated to (300°C) for 2 hours in dry oven type (SRJX-5-13) to remove the moisture content and improve the wettability.

Aluminum wires pieces were charged into the graphite crucible which was put in electric furnace type (ORH5-F102200), and the furnace temperature was raised up to liquidus

temperature (750°C) in order to melt the aluminum completely. Then, slags were removed using alumina spoon, and the melt temperature was dropped to just below the liquidus temperature (620°C) to attain the semi-solid state. The magnesium ribbon were rolled and covered by thick aluminum foil, and then immersed inside the melt to reduce its combustion.

The molten aluminum slurry was stirred with mechanical mild steel stirrer with stirrer speed (870 rpm) for (7 min) and the preheated, covered, aluminum oxide particles were slowly added to the molten metal. The stirring process was done under a shield of argon gas to prevent the entering of gases inside the molten metal, which cause the oxidation of molten aluminum. The design of the stirrer blade is very important factor, which effect on particle distribution and strength of the composite. The result of microstructure analysis shows acceptable particle distribution for composite prepared with four-blade stirrer.

The temperature during stirring was observed using thermocouple type-K, to be (610-620)°C. Then, the temperature was raised above the liquidus temperature (750°C) again. The molten composite was stirred at this temperature for the same speed and time. Finally, the molten composite was poured in preheated steel mold to solidify. The operation was repeated for each aluminum oxide percentage to produce alloyed rods. For comparison, aluminum was casted in the same procedure without adding aluminum oxide particles.

All prepared samples were put in an electrical furnace at (350°C) for (5 hours) and cooled inside the furnace to remove all thermal stresses. Then, the composite samples are ready to prepare for physical and mechanical tests.

2.2. Physical Tests

2.2.1. Tests of Chemical Composition

The analysis was conducted at the General Company for Engineering Inspection and Qualification (X-ray Fluorescence Spectrometer). The tests included all specimens preparing.

2.2.2. Optical Microscopic Examination

Specimens, with (13 mm) in diameter, were cut from each rods. These specimens were flattened using SiC grinding papers having different roughness (180, 220, 320, 400, 600, 800, 1000, 1200, 1500, 2000, 2500 grit size). The water was used during grinding operation as a coolant in order to avoid temperature raising as a result of friction between the sample and the grinding papers. Then, the specimens were polished using diamond paste to produce flat, scratch free, mirror like surface. Grinding and polishing operations were done using polishing machine model (MP-2B grinder polisher). The specimens were etched by (0.5% HF, 99.5% Distilled H_2O) for (15 second) at room temperature [18], then washing the specimens with distilled water, and dried them by an electrical dryer. An optical microscope with suitable magnification was applied to identify the micro-structure of each specimen.

2.2.3. X-Ray Diffraction Analysis

The X-ray diffraction analysis is a vital tool in which the constituent phases can be monitored. This analysis conducted on all the selected sample. The measuring conditions were target: Cu, wave length of 1.54060 A°, voltage (40 Kv) and current (20 μA).

2.3. Mechanical Tests

2.3.1. Test of Brinell Hardness

There is no standard shape or size for a Brinell test specimen, according to ASTM (E10-15a) [19]. A specific specimen size was cut from each rod, and 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 indenter diameter of (5mm) and load of (31.25Kg) for (10 seconds). The hardness values were recorded by getting the average of three measurements for every

specimen.

2.3.2. Test of Compression

This test was conducted on cylindrical samples with the following dimensions (1.3cm diameter and 2.5 cm height). Where the specimens prepared according to the ASTM standard [20]. The cylindrical samples with standard dimensions prepared by traditional machining operations.

All compression tests were carried out at temperature of room by using a computerized common testing machine type (Gunt / Hamburg,china) with (0.1 mm\min) as a loading ratio.

2.3.3. Wear Test

Specimen of (1.3 cm) diameter and (0.8 cm) height were prepared for each composite specimen, according to ASTM (G99-04) [21,22]. Prior testing, the specimens were ground with SiC papers until the average surface roughness reached (0.8 µm). The specimens were cleaned, and dried in vacuum furnace at (100°C) for (30 min) to remove all traces of the cleaning fluids that may be entrapped in the material. Then, the specimens were weighted using sensitive electric balance model (M254A) with $\pm$0.0001 accuracy. Pin on disk concept was used to study dry wear using wear tester device type (MT-4003, version 10.0). The tested specimens were set as a pin against standard rotating steel disk with a hardness of (850 HV).

Where: Normal force on the pin (F): (10, 20, and 30) N, Pin diameter (d): 10 mm, Disk diameter: 30 mm, Wear track radius (R): 5 mm, Rotating speed of the disk (ω): 300 rpm. The specimen was weighted after (5, 10, 15, and 20) min to determine the weight lost. Then, weight loss was converted to volume loss according to following equation:

Volume loss (mm³) = $weight\ loss\ (g) / density\ (g/mm^3)$

Where: weight loss = weight before the test – weight after the test. Wear rate was determined from this test in addition to studying the microstructure of the worn surface under optical microscope. The test was carried out without any lubricant, and at the temperature of room.

3. RESULTS & DISCUSSION

3.1. Optical Microscope Analysis

The microstructures of aluminum-aluminum oxide composites are shown in Figures 1 and 2. The microstructures show a constant distribution of aluminum oxide particles and good connection between aluminum oxide particles and aluminum; where there is no gap between the aluminum oxide particles and the aluminum matrix. It is clearly shown that the use of stir casting during preparation of these composites induced an acceptable spreading of the reinforcing aluminum oxide particles in the medium with very little segregation. The optimal choice of each stir casting parameters as stirring speed, stirring time, design of stirrer blade, stirring at two steps in different temperatures and using of argon gas, played a vital role in enhancement of aluminum oxide particles distribution in aluminum matrix.
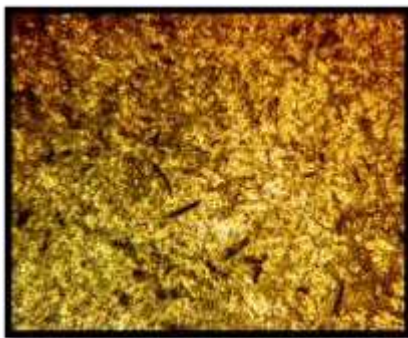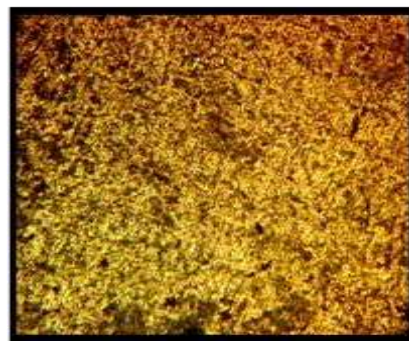

Figure 1 Optical Microscopy of Composite

Figure 2 Optical Microscopy of Composite

(Al – 4 % Al$_2$O$_3$) (200 X)   (Al – 10 % Al$_2$O$_3$) (200 X)

4.2. Brinell Hardness Test

The results of Brinell hardness test are shown in Fig. 3. It is concluded that hardness is increased with increasing of aluminum oxide particles percentage, and the greatest value was recorded for specimen with aluminum oxide percentage of (10%).

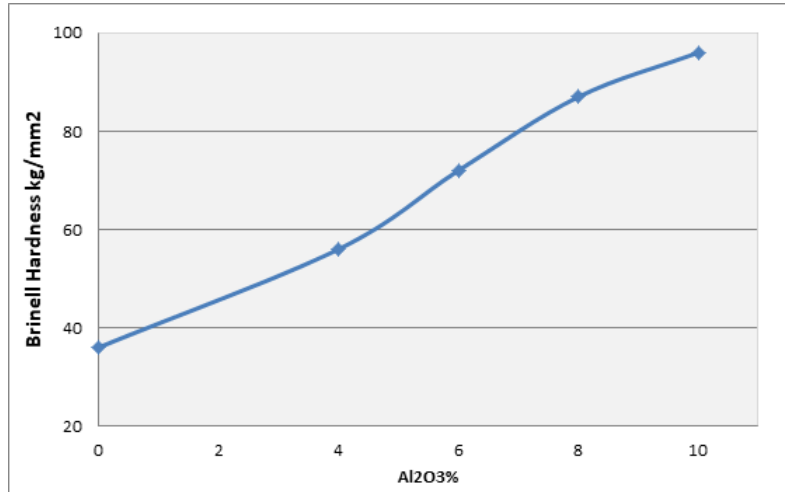These increment could be caused by aluminum oxide particles hardness which is high enough to work as barriers against dislocations movement.

Figure 3 BHN vs Al percentage.

The increment percentage of Brinell hardness is (53%), (100%), (141%) and (172%) for aluminum reinforced with 4, 6, 8, 10 wt. % Al$_2$O$_3$ particles specimens respectively comparing with unreinforced specimen. These results are in agreement with references [23, 24] with an acceptable difference that belong to the difference in chemical composition and average size of used reinforcements and aluminum alloy.

3.3. Compressive Strength Test

The resulted values from compressive strength test are listed in Fig. 4. Also, the variation of compressive strength with the different weight fractions of aluminum oxide particles in aluminum matrix is indicated in Fig. (4.).
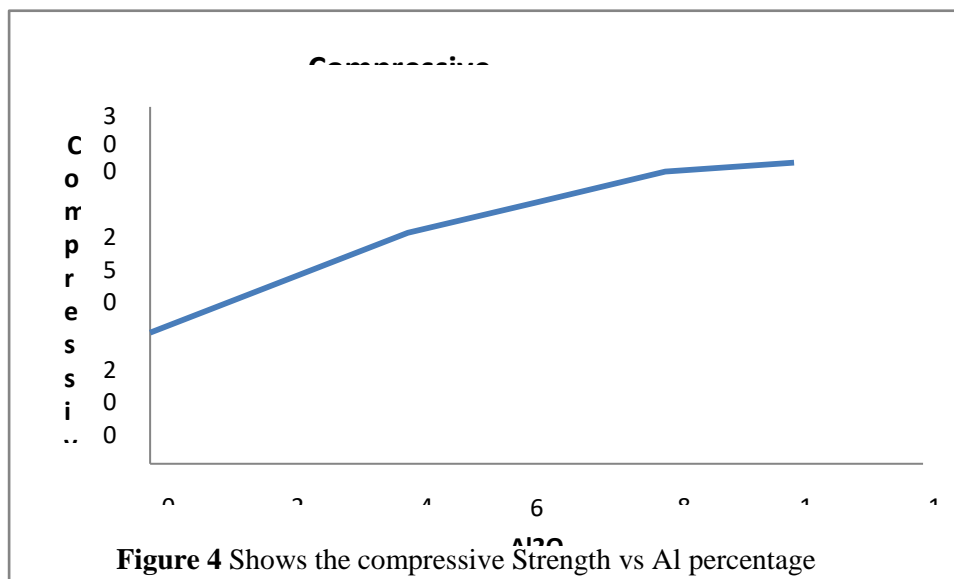

Figure 4 Shows the compressive Strength vs Al percentage

From these results, it is easy to show that the compressive strength improved by increasing

aluminum oxide percentage in aluminum base. The improvement in compressive strength are belong to the role of aluminum oxide particles which served as obstacles impeded the dislocation motion thereby strengthened the matrix. In addition, the presence of magnesium in the aluminum matrix enhanced the interfacial bonding between the aluminum oxide particles and the aluminum matrix thereby this strong bonding contribute in this improvement. A maximum improvement of 129% in compressive strength was recorded for Al+ 10% Al_2O_3 specimen.

3.4. Wear Tests

Converting the weight loss to a volume loss using the density of each sample. Figures 5 to 8 show the results of this test under the same conditions mentioned previously (F: 10, 20, and 30 N; ω: 300 rpm; t: 5, 10, 15, and 20 min.).
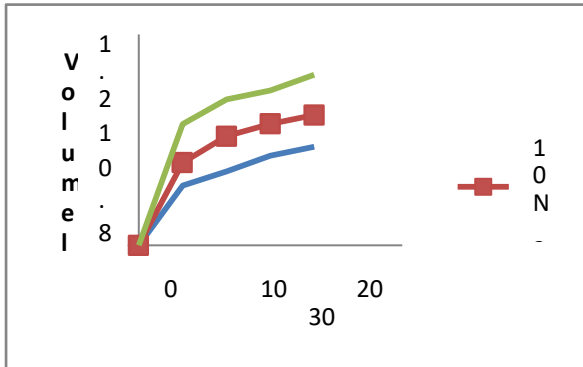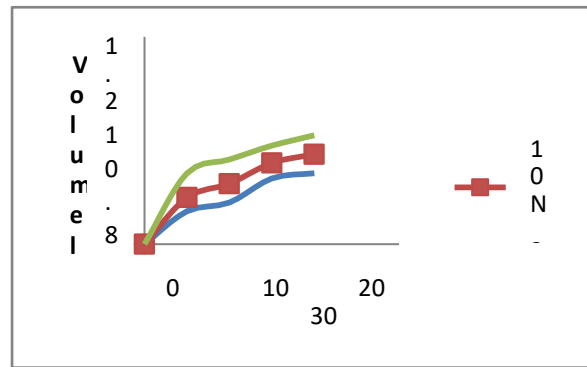

Figure 5 Wear rate of Al specimen
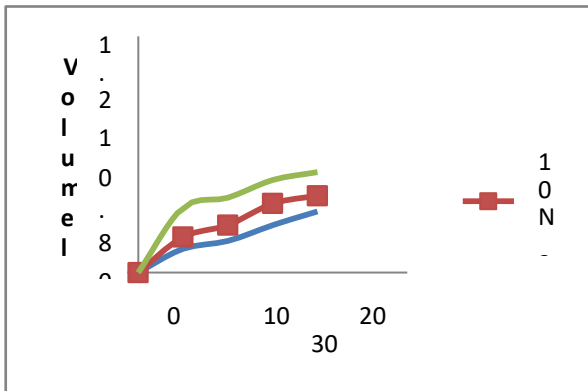

Figure 6 Wear rate of Al +4 % Al_2O_3 specimen

Figure 7 Wear rate of Al +6 % Al_2O_3 specimen
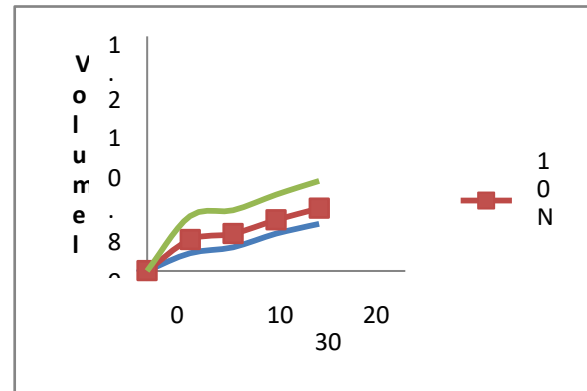

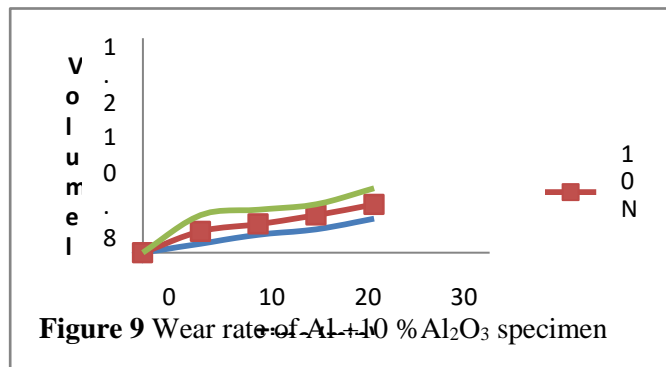**Figure 8** Wear rate of Al+8 % Al_2O_3 specimen

Figure 9 Wear rate of Al +10 % Al_2O_3 specimen
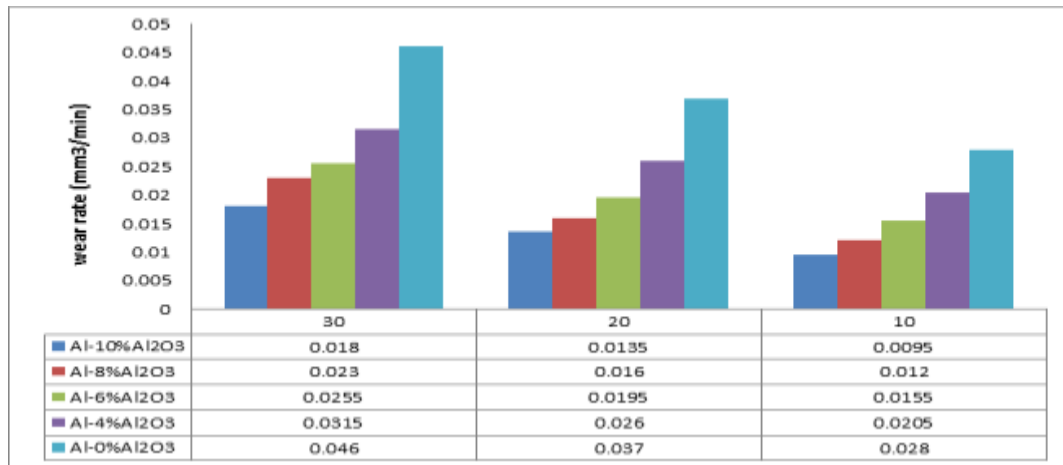
From these figures, it is clear that volume loss is increased with increasing the applied load, where the highest volume loss was recorded under (30 N) and vice versa. This is predicted behavior, where the increment in load leads to increase the friction between specimen surface and the rotating disk. Also, the volume loss was increased with increasing time due to the

increment of specimen's particles loss with increasing friction time. Further these figures show the effect of aluminum oxide particles addition on wear rates at different conditions. It can be noticed that volume loss was decreased drastically with increasing aluminum oxide percentage, even it reaches the minimum value at the composite that contained maximum aluminum oxide percentage (10%). This may duo to the role of aluminum oxide particles in blocking dislocation motion, so, hardness was increased and thereby wear resistance was also increased.

Figure 10 wear rate at the steady state for Al specimens at (time=20 min.).

The above figures shows at 10 N the highest wear rate in Al specimen and the wear rate is decreased by 66% in aluminium reinforced by 10% Al₂O₃, At 20 N the highest wear rate in Al specimen and the wear rate is decreased by 64% in aluminium reinforced by 10% Al₂O₃, At 30N the highest wear rate in Al specimen and the wear rate is decreased by 61% in aluminium

	30	20	10
Al-10%Al2O3	0.018	0.0135	0.0095
Al-8%Al2O3	0.023	0.016	0.012
Al-6%Al2O3	0.0255	0.0195	0.0155
Al-4%Al2O3	0.0315	0.026	0.0205
Al-0%Al2O3	0.046	0.037	0.028

reinforced by 10% Al₂O₃

The damaged surface has been studied due to the adhesion wear for aluminium and aluminium reinforced by 10% Al₂O₃alloys and images have been taken by the light microscope as shown in the following figures:

Figure 11 Microstructure for aluminium and aluminium reinforced by 10% Al₂O₃alloys by use light optical

microscope with magnification 100X after wear test under 10 N load and 20min time.

Figure 12 Microstructure for aluminium and aluminium reinforced by 10% Al_2O_3alloys by use light optical microscope with magnification 100X after wear test under 20 N load and20min

Figure 13 Microstructure for aluminium and aluminium reinforced by 10% Al_2O_3 alloys by use light optical microscope with magnification 100X after wear test under 30 N load and 20 min

Figures (11)- (13) showed the light optical microscope for aluminium and aluminium reinforced by 10% Al_2O_3 alloys after wear test, The mentioned figures illustrated the effect of wear process on the surface of the samples and the grooves are found in the direction of rotation of disk. Due to friction, the increase in temperature is observed.

Where the grooves were clearer and deeper in aluminium alloy compared to samples aluminium reinforced by 10% Al_2O_3 alloy due to the presence of aluminium oxide, which increases the hardness and gives relatively high wear resistance. It also notes that grooves are deeper and larger at (30) N load compared to loads (10 and 20)N.

4. CONCLUSIONS

In the current research the $A1–Al_2O_3$ was produced by stir casting technique. Where the hardness, compressive strength and wear behavior were assessed in order to observe the Al_2O_3 particles' dispersion and these characteristics increasing with increase wt.% of Al_2O_3 as following:

1. The results illustrated at 10 N the highest wear rate in Al specimen and the wear rate is decreased by 66% in aluminium reinforced by 10% Al_2O_3, at 20 N the highest wear rate in Al specimen and the wear rate is decreased by 64% in aluminium reinforced by 10% Al_2O_3, At 30N the highest wear rate in Al specimen and the wear rate is decreased by 61% in aluminium reinforced by 10% Al_2O_3

2. The increment percentage of Brinell hardness is (53%), (100%), (141%) and (172%) for aluminum reinforced with 4, 6, 8, 10 wt. % Al_2O_3 particles specimens respectively.

3. A maximum improvement of 129% in compressive strength was recorded for Al+ 10% Al_2O_3 specimen.

4. The optimum production conditions of Al- Al_2O_3 composites are 750°C and 10 wt. % Al_2O_3.

REFERENCES

[1]   A. Rahimzadeh Ilkhichi, R. Soufi, G. Hussain, R. Vatankhah Barenji and A. Heidarzadeh "Establishing mathematical models to predict grain size and hardness of the friction stir-welded AA 7020 aluminum alloy joints", Metal Mater Trans B 2015; 46: 357–365.

[2]   A. Heidarzadeh, R. Vatankhah Barenji, M. Esmaily, A. Rahimzadeh Ilkhichi, "Tensile properties of friction stir welds of AA 7020 aluminum alloy", T Indian I Metals, Epub ahead of print, 1 March 2015. DOI: 10.1007/s12666-014-0508-2.

[3]   A.Salemi Golezani, R. Vatankhah Barenji, A. Heidarzadeh, H. Pouraliakbar, "Elucidating of tool rotational speed in friction stir welding of 7020-T6 aluminum alloy", Int J Adv Manuf Tech, Epub ahead of print 2015.

[4]   Farhanchi M, Neysari M, Vatankhah Barenji R, Heidarzadeh, A.; Taherzadeh Mousavian, R., "Mechanical activation process for self-propagation high-temperature synthesis of ceramic-based composites", J Therm Anal Calorim, Epub ahead of print, Oct2015, Vol. 122 Issue 1, p123-133. 11p. May 2015. DOI: 10.1007/s10973-015-4704-z.

[5]   Reza Vatankhah Barenji, Vahid M Khojastehnezhad, Hamed H Pourasl and Amin Rabiezadeh," Wear properties of $Al–Al_2O_3/TiB_2$ surface hybrid composite layer prepared by friction stir process", Journal of Composite Materials, 2015.

[6]   Marwan Abbas Madhloom, "Mechanical Behavior of Hollow Cylinder made of Functionally Graded Materials Using Centrifugal Casting", MSc thesis, University of Technology, 2015.

[7]   Miyamoto, Y., W.A. Kaysser, B.H. Rabin, A. Kawasaki and R.G. Ford, "Functionally Graded Materials, Design, Processing and applications", Materials Technology Series, Kluwer academic publishers, 1999.

[8]   Kumar S, Subramanya Sarma V and Murty BS. "Effect of temperature on the wear behavior of Al-7Si-TiB2 in-situ composites", Metall Mater Trans A 2009; 40: 223–231.

[9]   Michael Rajan HB, Ramabalan S, Dinaharan I, et al. "Effect of TiB_2 content and temperature on sliding wear behavior of $AA7075/TiB_2$ in situ aluminum cast composites", Arch Civil Mech Eng 2014; 14: 72–79.

[10]   Duddukuri R, Koc R, Mawdsley J, Mathur S, Ray SS, Widjaja S. "Synthesis of Nano-Size TiB_2 Powders using Carbon Coated Precursors", Nanostructured Materials and Nanotechnology V: Ceramic Engineering and Science Proceedings, Vol. 32. Hoboken, NJ, USA: John Wiley & Sons, Inc. DOI: 10.1002/9781118095362.ch16.

[11]   M. A. Baghchesara, H. Abdizadeh and H.R. Baharvandi, "Fractography Of Stir Casted Al-

ZrO$_2$ Composites", Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 33, No. B5, Pp 453-462, 2009.

[12] Mishra RS, Ma ZY and Charit I. "Friction stir processing: a novel technique for fabrication of surface composite", Mater Sci Eng A 2003; 341: 307–310.

[13] Shafiei-Zarghani A, Kashani-Bozorg SF and Hanzaki AZ. "Wear assessment of Al/Al$_2$O$_3$ nano-composite surface layer produced using friction stir processing", Wear2011; 270: 403–412.

[14] Mahmoud ERI, Ikeuchi K and Takahashi M. "Fabrication of SiC particle reinforced composite on aluminium surface by friction stir processing", Sci Tech Weld Join 2008; 13: 607–618.

[15] Dolatkhah A, Golbabaei P, Besharati Givi Molaiekiya, "investigating effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing", J Mater Des 2012; 37: 458–464.

[16] Lee IS, Kao PW and Ho NJ. "Microstructure and mechanical properties of Al-Fe in situ nanocomposite produced by friction stir processing", Intermetallics 2008; 16: 1104–1108.

[17] Qian J, Li J, Xiong J, et al. "In situ synthesizing Al$_3$Ni for fabrication of intermetallic-reinforced aluminum alloy composites by friction stir processing", Mater Sci Eng A2012; 550: 279–285.

[18] Awham Jumea Salman,"Experimental Analysis of In- situ Composite Al-Si Eutectic Alloy ", MSc thesis, University of Babylon, 2009.

[19] ASTM E10-15a, "Standard Test Method for Brinell Hardness of Metallic Materials", ASTM International, West Conshohocken, PA, 2015.

[20] ASTM E9-, "Standard Test Method for the Compression Testing of Metallic Materials at Room Temperature", ASTM International, West Conshohocken, PA, 2015..

[21] ASTM G99-04a," Standard Test Method for Wear Testing With a Pin-on-Disk Apparatus ", ASTM International, West Conshohocken, PA, 2004.

[22] K.N. Kadhim and Ahmed H."The Effects Of Uniform Transverse Magnetic Field On Local Flow And Velocity Profile".International Journal of Civil Engineering and Technology (IJCIET) Volume 7, Issue 2, March-April 2016, pp. 140–151.

[23] Prakash Kumar Dalai, Ajit Senapati "Experimental Investigation &Analysis of Process Parameter in Machining of Aluminum Based Metal Matrix Composite", International Journal of Engineering Sciences & Research Technology, Dalai, 3 (1), January 2014.

[24] Sundus Abbas Jasim, "Improving of some Mechanical properties , Microstructure and Electrical Conductivity of Pure Aluminum by adding Zinc, Journal of Babylon University/Engineering Sciences/ No.(1)/ Vol.(25): 2017.