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Characteristics of Al6061-SiC-Al_2O_3 Surface Hybrid Composites Fabricated by Friction Stir Processing

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A B S T R A C T

Friction stir processing (FSP) has successfully evolved as an alternative technique of fabricating metal matrix composites. (MMC). FSP has been used positively to produce surface composite that offer good surface properties such as higher hardness and wear resistance, also help in the development of finer-grain structure during thermomechanical processing of the material. This work aims to fabricate a surface composite upon the AA6061-T6 Al alloy via FSP. The effect of SiC and/or Al2O3 particles on microstructure, microhardness, and wear behavior of the surface composite was investigated. Many drilled holes were made to incorporate the ceramic particles within the matrix at the optimal friction stir processing circumstances, The optimal parameters of (FSP) were (32 mm/min), (1250 rpm), and (2) passes in a similar track.. It was obtained that the maximum microhardness being in the stir zone center of FSP of the base alloy and all composites. The results of XRD and EDX mapping confirmed the incorporation of SiC and Al2O3 particles within the surface of Al alloy using FSP which will improve the surface properties. The improvement in microhardness was (89.3%) in the case of FSP composite sample reinforced with hybrid addition (SiC+Al2O3) particles in comparison to FSP unreinforced base alloy (75 HV). It was showed that the wear resistance of the FSP composite sample reinforced with hybrid addition of (Al2O3 and SiC) particles was slightly better than that of the FSP composite sample reinforced with single Al2O3 or SiC particles and base Al alloy.

1. INTRODUCTION

Friction stir processing (FSP) is a lately evolved solid-state treating method that is a variant form the Friction Stir Welding (FSW) method initiated in 1991 at The Welding Institute (TWI) [1]. The softening and plasticization of base metal occur due to frictional heat generation between the rotating tool and the workpiece. Therefore, the mixing action of material and the thermo-mechanical feature of the procedure are likely to incorporate particles as a second phase within the (SZ) and create a surface composite [2, 3]. The micro and nano strengthening particles distribution upon the surface of Al alloy and its governing is intricate for achieving in the methods of the conventional surface modification[4]. FSP can be operated at a temperature below the melting temperature of the metal matrix for the fabricated surface composites that can avoid the exceeding certain difficulties. Friction stir processing is the best method for surface composites preparation as well as surface adaptation. Also dynamic mixing of the area of the material beneath the tool leads to the incorporation and/or dispersion of the hard particles into the material of matrix [5, 6]. The enhancement of properties is associated with refining the grain size within the nugget due to the big treating strain.

FSP has become a positive procedure in adapting to obtain different material properties, like corrosion resistance, fatigue, yield strength, hardness, and formability. It's becoming more active in the production of metal matrix composites. Also, FSP has been very successful in the manufacture of materials with superplastic conduct [7]. The mechanical characteristics and microstructure and the treated region depth can be governed via the optimization of the tool's design and the parameters of the friction stir processing [8, 9]. Although such needs, nevertheless, there's a no. of ways for modifying the material surface for enhancing its functional characteristics [10]. Alloys of Al are too suitable for structural uses in the transportation industry, military, aerospace, etc. The Al alloy (6061-T6) is broadly utilized in marine areas, automobiles, aircraft, and industries. This is attributed to its virtuous strength, less weight, and well corrosion characteristics. But, it displays low tribological characteristics if it has been widely utilized. The low strength and the low hardness of Al alloys limited their usage, particularly for tribological uses [11, 12]. When Al alloy matrix composites (MMCs) strengthened by the ceramic particles revealed higher hardness and strength, increased resistance to fatigue and creep. Also they exhibited improved tribological characteristics and better wear resistance compared to conventional metals and alloys [13]. Many research studies focused on friction stir processing parameters on the microstructure, mechanical properties, and wear behavior of aluminum alloys.

Kwon et al. [14] studied the effect of rotational speed on the mechanical properties of AA1050 aluminum alloy treated with a single pass of the friction stir processing under rotational speeds range from (560 to 1840) rpm and a fixed welding speed (155 mm/min). It was found that the highest hardness and tensile strength values of the FSPed sample were at rotational speed 560 rpm. Shafiei Zarghani et al. [15] utilized friction stir processing for producing ultrafine-grained materials via severe plastic deformation. Friction stir processing was implemented upon the Al alloy 6082-T4 to create an ultrafine-grained microstructure having size ranges from 0.5 to 3 μm. The hardness of the FSP 6082 aluminum alloy rose with the decrease in tool rotational speed. Adem Kurt et al. [16] used friction stir processing for introducing the SiC particles into the pure aluminum for fabrication particulate surface composites. It was found that increasing the rotating speed and traverse rate led to create a more uniform distribution of SiC particles. The hardness of produced composite surfaces has enhancement three times in comparison with the base metal. Mazaherithat et al. [17] found that the orderly spreading of the particles of Al2O3 into A356 matrix FSP can enhance the mechanical properties of sample. FSP was performed at different tool rotational speeds (560-1840 rpm) and a fixed travel speed (155 mm/min) with using a single pass into work piece. It was found that the hardness values of the surface-composites after FSP were about (90 and 110 HV) when compared to the base alloy A356 and sample of FSP (without Al2O3 particle) which were about 67 HV and 80 HV, respectively. Wais et al. [18] studied the influence of FSP parameters, including the rotational speed (560, 710, and 900 rpm) and the transverse speed (86, 189, and 393 mm/min) upon the mechanical properties and microstructure of sand casting hypereutectic pure Aluminum. The measurements of impact and hardness were conducted across the friction stir process (FSP) Zone. It was found that the friction stir processing caused in highly refined the microstructure of cast aluminum alloy. Nevertheless, friction stir processing resulted in too slight variations in the hardness of FSPed sample. While, the impact and tensile properties are highly enhanced. Hussain Zuhailawati et al. [19] studied the FSP of 1100 aluminum with the incorporation of rice husk ash. Friction stirring of silica powder was filled into a groove which produced in the line of joining the aluminum (AA1100) plates. The high rotational speed (1140 rpm) contributed to refine the size of the grain (10-30 μm) of the Al matrix due to the dynamic re-crystallization. They found a good distribution of silica powder in the aluminum matrix which lead to improve wear resistance and increased the hardness of re-crystallized Al grains in the (SZ).of the FSP aluminum 1100. Magdy et al. [20] utilized FSP to locally modify the microstructural and mechanical properties of 6082-T6 Aluminum Alloy. They used a fixed rotational speed 850 rpm and three various traverse speeds (90, 140 mm/min). They reported that by raising the no. of passes which reduces and softened the maximum tensile strength, where raising the traverse speed increased the hardness strength.

Naseem Ahamad et al. [21,22] studied the mechanical properties of Al–Al2O3–TiO2 hybrid metal matrix composites prepared by stir casting [21]. Also they studied the hardness, wear behavior and optimization of wear data for pure Al-Al2O3-TiO2 hybrid metal matrix composites [22]. The results showed that the impact strength and Vickers hardness increase with an increase in weight percentage of reinforcements. Hybrid composite of aluminum matrix and (5%Al2O3+5%TiO2) reinforcements have maximum engineering and true ultimate strength. They found that the wear resistance of the hybrid composite increases with the variation of percentage of TiO2 particles due to its lubricating properties.

The present work aims to study the influence of single and hybrid addition of SiC and/or Al2O3 particles on the microhardness, microstructure and wear behavior of FSP samples at optimum conditions.

The present work investigates the effect of adding SiC and Al2O3 particles on the wear rate and the mechanism of wear under sliding circumstances by changing the exerted load and keeping both the speed and sliding time are constant. Surface hybrid composite of Al-alloy AA6061- SiC-Al2O3 has light weight, high strength and good wear resistance with a wide range of applications in automobile and aerospace industries. It is expected that the present hybrid MMCs will be useful for aircraft parts.

2. MATERIALS

Plate of aluminum AA6061-T6 with thickness of (6 mm) was chosen for the friction stir processing due to its wide uses, such as aircraft, automotive, aerospace industry, etc. The chemical composition analysis of this alloy was conducted by using the spectrometer analysis device accessible in Baghdad, General Company for Examination and Rehabilitation Engineering (GCERE), and the nominal values were taken from the ASTM [23], as shown in Table 1.

Table 1. Chemical composition for the alloy AA6061-T6.

Elements Wt%	Si	Cu	Fe	Mn
Standard	0.8 max	0.4max	0.7 max	0.15 max
Measured	0.636	0.258	0.586	0.105
Elements	Mg	Ni	Cr	Zn
Standard	1.2 max	0.05 max	0.35 max	0.25 max
Measured	0.916	0.003	0.183	0.035
Elements	Ti	Al		
Standard	0.15 max.	Bal.		
	0.051	Bal.		

The SiC and Al2O3 particles with different particle sizes were selected as a reinforcement phase in AA6061-T6 alloy as a matrix. Table 2 shows the properties of SiC and Al2O3 particles.

Table 2. Properties of SiC and Al2O3 particles.

Powder	Origin	Purity %	Density , gm/ cm3	Average Powder size, nm
Silicon Carbide SiC	China JJugan Chemicals and Alloys Limited	99.9	3.21	120.8
α -Al2O3		99.9	3.95	123.5

2.1 Preparation of the plate and tool design

A Plate of aluminum AA6061-T6 having a thickness of (6 mm) was prepared by utilizing a punch cutter to the sizes (150 mm×100 mm). After that, the surface was cleaned from the aluminum oxide layer by employing a polishing brush and SiC papers with grade 500 micron.
The tool used for friction stir processing was designed and fabricated from high-speed steel (HSS) using a turning machine. A geometry shape consists of a shoulder 16 mm diameter and a pin

of 6 mm with 3 mm depth. Then, the tool was subjected to a heat treatment. The tool hardness after heat treatment is 50-53 HRc.

2.2 Friction stir processing

A milling machine (WMW-HECKERT-Germany) was used in this study. With rotational and travel speeds changes, the plate was fixed to prevent it from moving out of the position. After determining the optimum friction stir processing parameters, the plate was fixed. The processing was initiated by revolving the tool having a cylindrical shoulder and a threaded pin, the rotating direction was clockwise, and the spindle were positioned at the center. The machine table was gradually erected and was raised vertically until the tool shoulder plunged with (0.2 mm) into the surfaces of plates. After that, the spindle revolved at its position for a dwelling time of (10 sec) to preheat the plate before the process of FSP. Friction stir processing was conducted at different variables. The angle of tilt was (2 degree), plunging depth was (3.2 mm), and dwelling time (10 sec) was kept constant. FSP was performed at best constant travel speed (32 mm/min) and rotational speed (1250 rpm) with two passes of FSP. These FSP conditions were used in study of researchers Muna and Noor Alhuda [24].

2.3 Fabrication of surface composites by FSP

Friction stir processing (FSP) was performed to the aluminum alloy (AA6061-T6) after sequential holes were prepared in the workpiece center to add the microparticles in the holes of plate at center axis. The distance between every hole was (1.5 mm), and every hole possesses the sizes of (2 mm) depth and (2 mm) diameter, and the number of holes was 40 at the axial distance (140 mm) via using CNC milling machine type (C-TEK). SiC or/and Al2O3 particles were mixed with ethanol liquid, and consequently, the holes were packed by powders. The volume percent for every SiC or Al2O3 particles was (10%vol). FSP composites are undergoing friction, and to prevent the sputtering of powder during this process, the holes are closed by a tool without a pin. A cylindrical shoulder and threaded pin made of high-speed steel (HSS) with a shoulder diameter of 16 mm and 6 mm pin diameter of length 3.2 mm were utilized in this work. The tool pin is plunged into the holes which are made in the base plate for a (3.2 mm) prearranged depth as the tool advanced and friction stir processing along the centerline of the drilled holes as depicted in Figure 1.

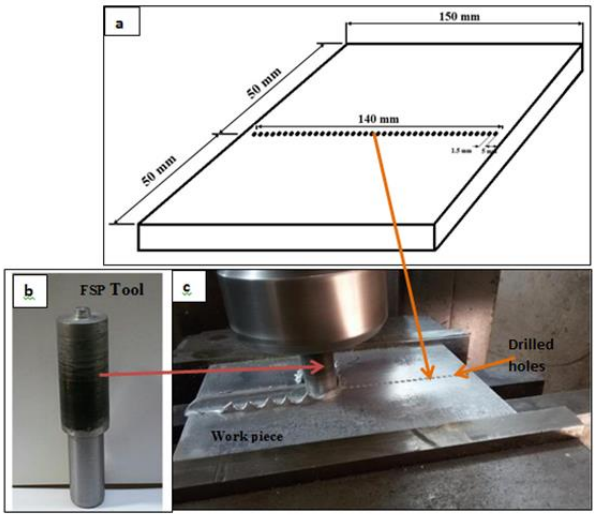

Fig. 1. (a) Schematic illustration of the work piece dimensions and drilling holes on the top surface of work pieces, (b)FSP Tool, (c) Shows the friction stir processing along the center line of the drilled holes.

The microstructure examination process of the base alloy and FSPed composite specimens was carried out via making the surface by grinding, polishing, etching, and then seen beneath an Optical microscope (Model MTM-1A). The etching procedure was conducted on the polished surfaces via utilizing etchant reagent for the alloys of Al. Keller's reagent consists of 95 mL H2O, 2.5 mL HNO3, 1.5 ml HCL, and 1.0 mL HF. After that, the specimens were cleaned with water and alcohol and dried in the oven. The test of Vickers hardness was done utilizing a Digital Microhardness Tester (Type Laryee, Model HVS-1000). According to the (ASTM), the hardness measurements were performed at the locations of the FSP on two sides (Advancing Side and Retreating Side) at the best conditions. The reading was performed at several points positioned the two sides. A (200 g) load was exerted upon a cross-section for a time of (15 sec). XRD analysis the SiC and Al2O3 particles and for alloy AA6061-T6 after the FSP and composite samples beyond the friction stir processing. This X-ray analysis was conducted by using X-ray apparatus (Shimadzu, XRD6000) (Shimadzu), and the samples were cut from the SZ. The samples' dimensions are (10 mm × 6 mm). The measured circumstances of the XRD test were the Cu target, (1.540 A◦) wavelength, (30 mA) current, (40 KV) voltage, and (5 deg/min) speed of the scan.

Scanning Electron Microscope (SEM) equipment, type (VEGA3LM) provided with Energy Dispersive Spectroscopy (EDS) model (Oxford, MAX3) has studied the microstructure of SiC and Al2O3. Additionally, the alloy microstructures beyond the friction stir processing and the composite samples with a single and hybrid after FSP were performed to study the topography of the wear surfaces after the wear test.

2.5 Wear rate measurement

The weight loss method was used to measure the wear rate of the sample being weighed before and after the test with using a sensitive balance (Type DENVER device, Max-210 gm) having (0.0001 gm) accuracy. The weight loss (ΔW) was divided by the sliding distance to obtain the wear rate (W.R) using an equation (1) [25]:

$$\text{Wear Rate(W.R)} = \Delta W / \pi D.N.t \quad (1)$$

W.R: The wear rate (gm/cm)

D: The sliding circle diameter (cm) of the sliding circle

T: The time (min) of sliding

N: The speed (rpm) of the steel disc

The device of wear comprises a motor with a fixed rotational speed (510 rpm). The test of wear was done in dry sliding conditions by changing the applied load for all samples at a fixed sliding time and speed. Variable loads being (5, 10, 15, and 20 N), with (20 min) constant time, (5 cm) distance, and (2.8 m/sec) fixed speed of sliding. The steel disc hardness was (32 HRC). Figure 2 shows the locations of specimens taken from FSPed Al- alloy for wear test, hardness test as well as for microstructure examination

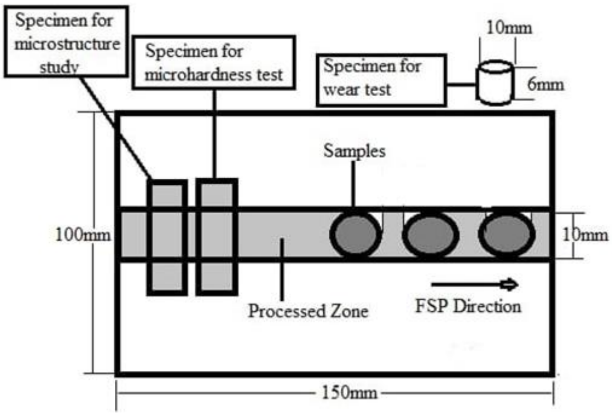

Fig. 2. Schematic illustration of the specimens preparation for different tests from friction stir processed zone.

3. RESULTS AND DISCUSSION

3.1 Examination of microstructure

Figure 3a shows the microstructure of the base metal (BM) of alloy AA6061-T6.

Figure 3b shows four zones of various microstructure features noted in the friction stir processing specimen strengthened by silicon carbide particles (SiC): The composite material zone, CMZ; stir zone, SZ; TMAZ; and HAZ.

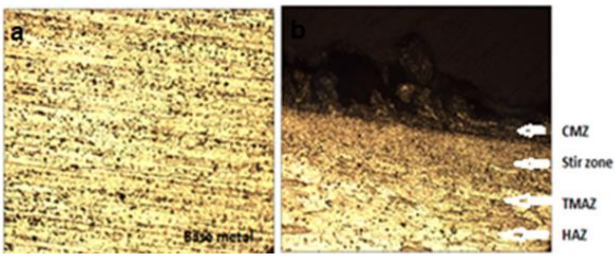

Fig. 3. Microstructures of FSP sample reinforced with SiC particles at 1250 rpm, 32 mm/min and one pass at 100x. (a) base alloy AA6061-T6, (b) CMZ, SZ, TMAZ and HAZ.

Figure 4 shows the microstructures of FSP composite sample showing reinforcement particles distributed in stir zone at FSP processing optimum conditions (1250 rpm, 32 mm/min and two passes) which gave the fine and highly consistent grain structure.

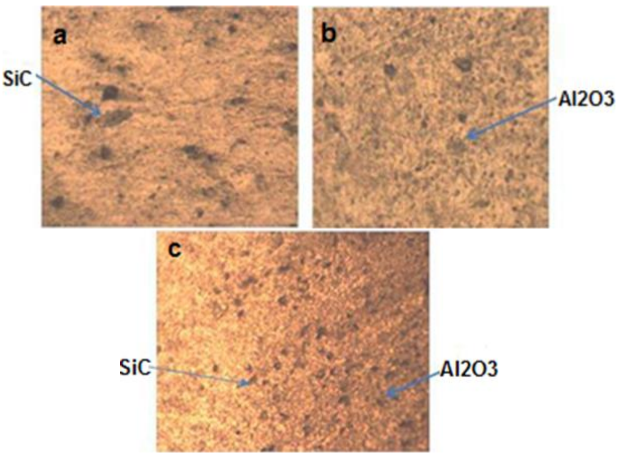

Fig. 4. Microstructures of FSP composite sample showing reinforcement particles distributed in stir zone at optimum conditions at 100x; (a) sample with SiC particles, sample with Al2O3 particles and (c)sample with hybrid (SiC+ Al2O3) particles.

The SEM micrographs in Figures 5a and 5b view the microstructure of the base alloy and FSP composite sample respectively, reinforced with hybrid addition (SiC+Al2O3) distribution of particles is homogenized totally. That's because the rotating tool gives adequate heat and circumferential force for dispersing the particles of (SiC) or (Al2O3) to become full in the broader region. In relation to the metal flow's nature in SZ through the friction stir processing, some clusters of SiC or Al2O3 are being developed at SZ. The multi passes friction stir processing is regarded as an active technique for improving the distribution of the ceramic particles in the Al Metal Matrix. These results are confirmed by several studies [26-29]. The EDS analysis is presented in Figure 5c for a composite reinforced with the hybrid addition of (SiC + Al2O3) particles.

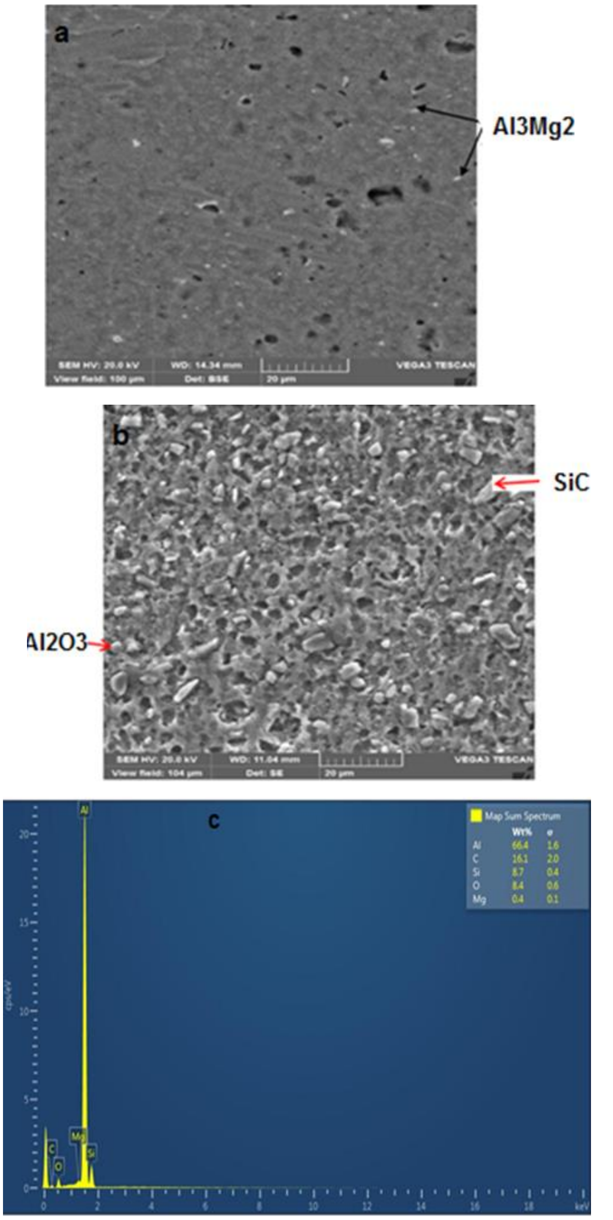

Fig. 5. (a) SEM micrograph of base alloy FSP at the best conditions of 1250 rpm, 32 mm/min and two passes at 20 µm,(b) SEM Micrograph of FSP composite sample reinforced with hybrid (SiC+Al2O3) particles with (c) EDS analysis.

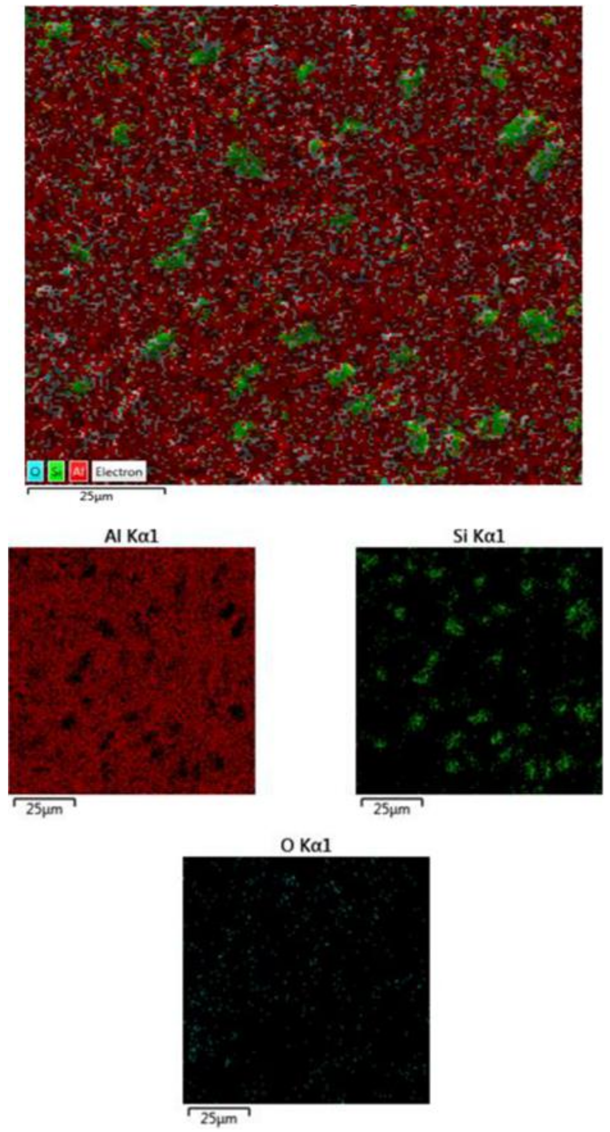

Fig. 6. illustrates SEM-Mapping of FSP composite sample reinforced (SiC and Al2O3) particles obtained with EDS analysis.

Figure 6 illustrates the SEM-Mapping of FSPcomposite sample reinforced with (SiC and Al2O3) particles presented with regions of SZ of the friction stir processing specimens that the particles of (SiC) as well as (Al2O3) are present in the Al matrix as elements Si, O, Al, Mg, and C. Such particles are regularly possessed optimistic influences upon the structure and the Al alloy (AA6061-T6) properties.

3.2 X-ray diffraction analysis

The XRD, with the assistance of EDS analysis, gives the elemental distribution to predict the forming phases. Figure 7 shows the XRD patterns of composites samples after friction stir processing at optimum conditions. The principal phases are (α-Al), (Al3Mg2), as well as (Al2O3) and (SiC) particles are seem in the chart of the X-ray diffraction for specimens of composite. SEM-EDS outcomes showed elements (Si, C, Al, and O) present in the EDS spectrum. Consequently, this confirms the presence of SiC and Al2O3 particles in the matrix of Al for the friction stir processing specimens of composites. The base Al alloy (AA6061-T6) also includes a large quantity of (Al3Mg2) 2nd phase particles uniformly distributed in the aluminum matrix. These particles were identified by EDS spectrum and X-ray diffraction analysis as intermetallic phases that contain (Fe, Mg, Mn, Si, and Si) like (AlFeSi). These results are in agreement with the outcome of researchers [23, 30].

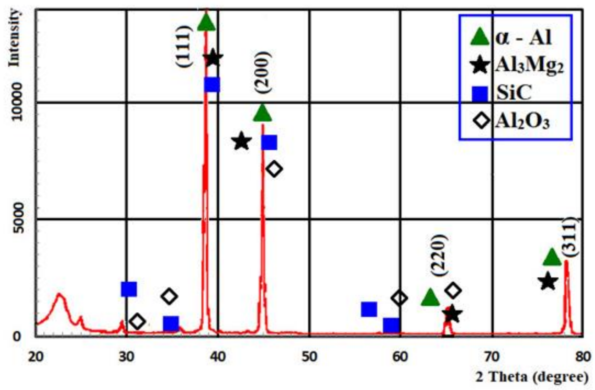

Fig. 7. XRD analysis result for sample reinforced with hybrid particles (SiC+Al2O3) after friction stir processing at optimum conditions.

3.3 Microhardness

The distribution of Vickers microhardness upon the cross-section is normal to the transverse direction of the tool of the FSP sample made at the optimal circumstances.

The stir zone (SZ) manifested a higher hardness than those for thermal-mechanically affected zone (TMAZ), heat-Affected zone (HAZ), and Base material (BM). The ultimate hardness was (75 HV) in the (SZ) center. That's due to the refined grain and the dynamic recrystallized SZ and the Al3Mg2 phase existence as precipitates of the 2nd phase particles. Figure 8 elucidates the distribution of Vickers microhardness on the cross section of FZPed sample. The researchers [30, 31] verified such outcomes in their investigations of the friction stir welding of Al alloys. The values of microhardness for the friction stir processing base alloy and the Al alloy (AA6061-T6) metal-matrix composites strengthened by the particles of (SiC) or/and (Al2O3) are presented in Table 3.

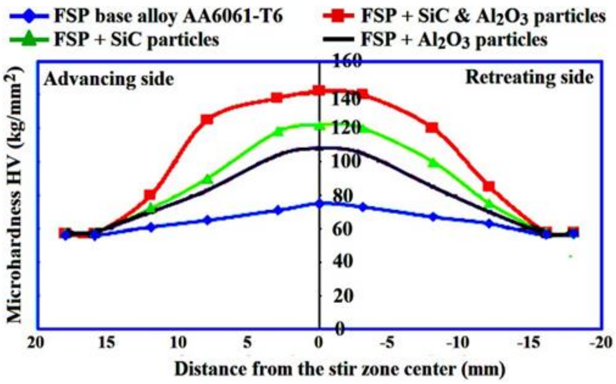

Fig. 8. Microhardness distribution on the cross section of FSP for base alloy and samples with reinforcement particles.

Table 3. Microhardness values in stir zone.

Specimens	Micro hardness in center of stir zone	Improvement %
AA 6061-T6 as FSP as compared to base alloy(HV=58)	75HV	22.66
AA6061-T6 reinforcement with Al2O3 Particles	108HV	44
AA6061-T6 reinforcement with SiC Particles	122HV	62.6
AA6061-T6 reinforcement with hybrid (SiC and Al2O3) particles	142HV	89.3

The microhardness of the friction stir processing composite sample with strengthening are displayed in Figure 8. It is noticed that the value of microhardness in the state of surface hybrid composite strengthened by the particles of (SiC + Al2O3) being higher than that in other samples in friction stir processing regions in the stir zone (SZ). Hardness reaches the maximum value of (142 HV) as compared to the base alloy which was (58 HV) and FSP sample (75 HV). This is due to the dispersion of SiC and Al2O3 particles in SZ and the refinement of the grain size of the base material. Also the frictional heat and plastic flow of metal during the FSP create fine equiaxed dynamic recrystallized grains in the stir zone (SZ) and elongated with recovered grains in the (TMAZ). Additionally, there was an important discrepancy in hardness distribution between the retreating side (RS) and the advancing side (AS). That's, the hardness in the stir zone (SZ) was more upon (RS) than upon (AS). It was observed that the hardness for two passes of FSP is more than that for one pass. The 2nd pass homogenizes the distribution of particles, reduces grain size, and creates a uniform hardness profile. In relation to the Hall-Petch relation, reducing the grain size raises both the yield stress and the value of hardness. These results are in agreement with the outcomes of investigators [32, 33].

3.4 Wear test results

The rate of wear was measured via the technique of the loss of weight for the base materials and the friction stir welded specimens treated at the virtuous conditions and the whole composites samples. The loss of weight and rate of wear increase with the loads rising at constant speed and time of sliding. From Figure 9, it's noted that the conduct of wear is similar to the whole specimen.

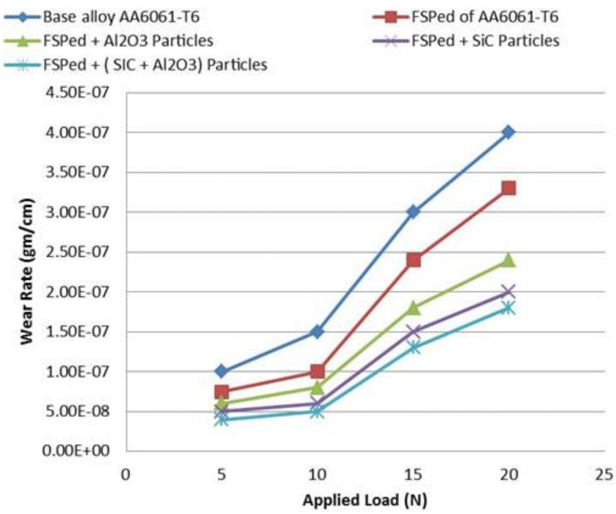

Fig. 9. Effect of applied load on the wear rate for the base alloy AA6061-T6.

The wear rate for the friction stir processing specimen was lesser than that for the base material. That's due to the finer grains as determined in SZ of the friction stir processing specimen in comparison with the as-received specimen of Al alloy (AA6061-T6) because of the severe plastic deformation and dynamic recrystallization. The hardness of a material is one of the most important mechanical properties in wear and has been widely employed as a criterion to determine the abrasive wear resistance. It was seen from Table 3 that the FSPed hybrid composite sample showed the highest hardness and wear resistance as comparison with other samples.

It was noticed that the rates of wear of the friction stir processing composite specimens strengthened by SiC, Al2O3, and hybrid (SiC+Al2O3) particles are lesser than for the friction stir processing base material, and that's owing to the strengthening (SiC) and (Al2O3) particles which work as the particle of reinforcement of the Al alloy (AA6061-T6) that distributed into the matrix of Al. Good particles dispersion into the matrix decreases the rate of wear and enhances the resistance to wear resistance. The good resistance to wear was found at hybrid (SiC+Al2O3) due to the improved hardness distribution of the particles of (SiC+Al2O3). The addition of strengthening particles reduces the rate of wear since the hard particles being dragged out from the composite specimen by the pin through the procedure of wear developed on the steel disc and worked as an obstacle. Further, it changes the adhesive wear into abrasive wear, which causes a higher quantity of the worn-out material from the composite specimen. All samples possess similar conduct of wear but in various values. The conduct of wear is oxidative wear or mild wear at low loads (5 N). After that, it converts into transition wear, becoming drastic or metallic wear at higher loads (20N). Similar outcomes were found by Deepak et al. [34] and Narayana Yuvaraj et al. [33] for Al5083/TiB2 and Al5083/B4C, respectively, who fabricated the surface composites by FSP.

3.5 Topography characterization of worn surfaces

It is noticed from SEM images that the tracks or wear paths and grooves of wear rise in the friction stir processed specimen, and the cracks alongside the track raise the worn-out surface fundamentally comprising incompletely uneven pits as well as longitudinal grooves. One can conclude from the study of microstructure that abrasive wear mainly occurs with certain adhesive wear traces. With the loads increasing, the wear lines width is augmented and causes grooves with the remark of big and small cracks propagated upon the specimen's surface, where such cracks convergence being developed. FSP with reinforcement particles SiC and/or Al2O3 is better in the resistance to wear than the specimens at the whole exerted loads. That's owing to the particles' role of (SiC+Al2O3) in refining the grains of the matrix of Al alloy as well as the hardness of the high particles of (SiC+Al2O3). Figure 10 presents the scanning electron microscope (SEM) images of the worn surface of the friction stir processed specimen treated at the best conditions as well as the FSP with reinforcement particles SiC and/or Al2O3 particles after wear test at (15 N) load and sliding time (20 min). The deep and broad grooves and tracks take place in the friction stir processed specimen. That's owing to the intensive removal of material and the plastic deformation, which resulted in work-hardening of the metal surface and formation of cracks that raise the cattered or debris of wear upon the worn surfaces.

Sareh et al. [35] showed that the wear debris could act as abrasive particles between two surfaces of specimen and rotating disk. Also they were concluded from SEM micrographs of the worn surface of unreinforced alloy, the predominate wear mechanism was adhesive wear. While in the Aluminum-SiC nanocomposites, the wear mechanism changed from adhesive to abrasive.

From Figure 11, one can see the shallow and small grooves without possessing deep tracks. As well, the approximately smooth surface is noticed when compared to the friction stir processing base specimen. That's owing to the existence of ceramic particles that spread uniformly upon the worn surface, which does not permit the wear and severe material removal. It means that reducing the wear debris formation on the surface can improve the composite's wear resistance. Such outcomes are similar to the Narayana Yuvaraj et al.[36]. Mohamed and Muna [32] investigated the conduct of the wear of aluminum alloy fabricated by powder metallurgy.

Additionally, Kishan et al. [37] investigated the wear morphology of (Al-TiB2) surface nanocomposites. They inferred that the tribo-mechanically blended layer transforms the wear way as of 2-body to 3-body wear and reduces the rate of wear which works as a solid lubricant. It was found that the particles of (Al2O3) and (SiC) can highly enhance the hardness and the surface composites' wear resistance.

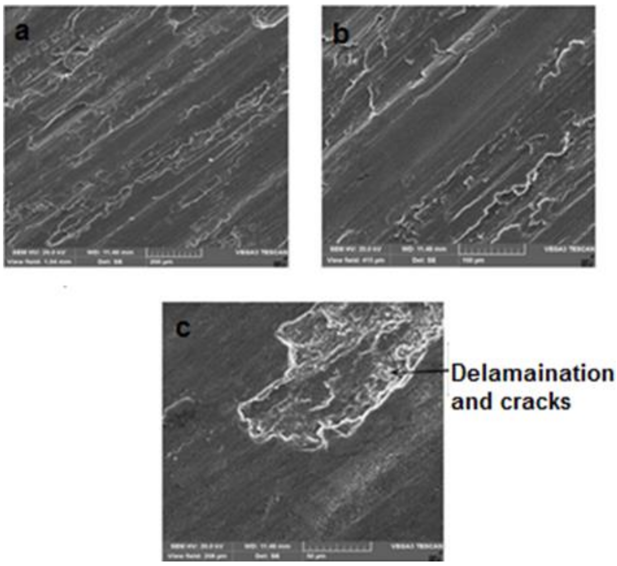

Fig. 10. SEM micrographs for the worn surface of base alloy FSPed sample after wear test at 15 N load for 20 min;); (a) at 200 μm, (b) at 100 μm,(c) at 50 μm.

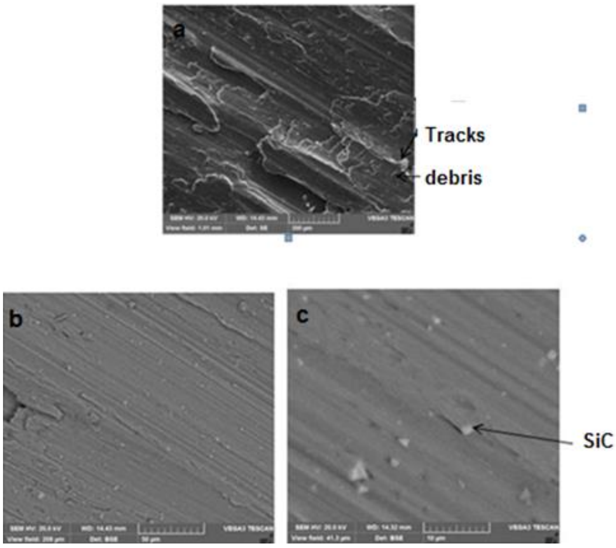

Fig. 11. SEM micrographs for worn surface of FSP sample with SiC particles after wear test at 15 N load for 20 min ; a) Secondary electron image at 200 μm (b&c) Backscatter images.

4. CONCLUSION

The novelty in this research is to fabricate the new surface hybrid composites of aluminum base alloy (AA6061-T6) reinforced with hybrid particles of (Al_2O_3 + SiC) using friction stir processing. The mechanical, microstructural characteristics and wear resistance of produced composites are evaluated by performing many tests and inspections, optical microstructure, hardness and dry wear behavior also wear mechanisms are studied.

The above results noted that the friction stir processing had been successfully utilized to produce fine microstructure surface modification and grain refinement for the base alloy and composite materials. It was found that the highest hardness was in the stir zone (SZ) center, and it decreased toward (TMAZ), (HAZ), and then toward the base material for the FSP specimen.

An improvement in hardness was 89.3% in the case of FSP specimen with the hybrid of particles (SiC+Al_2O_3) compared to the friction stir processing base material (75 HV). The wear test results showed that the composite specimen strengthened with the hybrid has hardness and resistance to wear better than one of particles (SiC) or (Al_2O_3) to the base material, and the wear conduct altered from adhesive kind to abrasive kind. The scanning electron microscope images of worn surfaces revealed cavities, pits, and cracks due to the plastic deformation and the delamination mechanism at higher loads (20N).

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