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SURFACE IMPROVEMENT OF 7075 ALLOY USING FRICTION STIR PROCESSING

Rashed S. E.[1], Hassan H. A.[2], Abu-El-Yazied T. G.[2] and El-Shabasy A. B.[2]

[1]MSc. Student, [2]Professor, Department of Design and Production Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

ABSTRACT

In current work, aluminium surface composites were developed via friction stir processing (FSP). AA7075-T6 was reinforced with ultrafine size SiO_2 particles to prepare either surface composite or double surface (i.e. sandwich) composite. In addition, AA7075 hybrid surface composites were prepared using ultra- fine size SiO_2 and Al_2O_3 particles. These surface composites were developed using FSP parameters of 600 rpm, 50 mm/min and 3 degrees tilt angle. FSP tool with a square profiled pin of 3.5 mm length and of 5mm side enabled sound surface composites and uniform particle distribution. The developed surface(s) composites were being evaluated using different metallographic techniques to investigate the macro and micro features across the stirring zone. The hybrid surface (SiO_2 and Al_2O_3 particles/ AA7075) composites showed enhancement in particle distribution composites and microhardness measurement compared to AA7075/ SiO_2 surface composites. The current results are compared with those from other similar composites reported in the literature.

KEYWORDS

Friction stir processing, Surface composite, Double surface composite (sandwich), Hybrid composites, Microhardness, Aluminum alloys.

INTRODUCTION

Metal matrix composites (MMCs) have great impact during the last century for their superior mechanical properties and high damage tolerance, [1, 2]. Discontinuous reinforced aluminium (DRA) was emerged in aerospace and in high end sophisticated sporting application which represents breakthrough in growing acceptance of these composite materials, [3]. There are several techniques to produce MMCs, some of these techniques have many draw backs such as formation of detrimental phase, limitation of particle size, interfacial reaction between reinforcement and metal matrix which led to degradation in strength of MMCS especially in liquid state techniques, [1, 3, 4]. Friction stir processing (FSP) was developed recently to overcome these drawbacks in preparing metal matrix composites and number of previous works focused on preparing MMC surface composites

as Enhancement of both strength and ductility with grain refinement have been reported, [4 - 5].

Temperature rise and plastic deformation around the stirred zone during FSP have significant effect on microstructural evolution, including grain size, grain boundary character, and dissolution of precipitates, breakup and redistribution of dispersions, [4]. Hybrid surface composite is a composite but with more than one type of reinforcement. Hybrid composites exhibited an enhancement in the mechanical properties compared with single particles reinforced composites as it combines advantages of each reinforcement particles, [7]. An optimum ratio of both the constituents is required to achieve better properties in the hybrid composites properties. The reinforcement particles were distributed homogenously inside the nugget zone without any defects except some voids that appeared around the Al_2O_3 particles as reported by Essam et. al., [8].

Tool geometry plays a great role in the material flow. Tool geometry includes shoulder diameter, shoulder feature, probe shape, probe size and probe feature. Flow of plasticized material in processed zone is affected by tool geometry as well as traverse and rotational motion of the tool which provide material flow and heat localization, heat results from friction between pin and work piece and also from material deformation, [6 - 7]. Tool pin outer profiles that are responsible of material stirring were extensively studied in a number of works, [9, 10, 11].

EXPERIMENTAL

Discontinuous reinforced aluminium surface composites were developed via friction stir processing (FSP). Aluminium alloy (AA7075-T6) with the chemical composition as shown in Table1. These composites were reinforced with ultrafine SiO_2 particles to prepare either surface composite or double surface (i.e. sandwich) composites. In addition, SiO_2 and Al_2O_3 particles were used to prepare hybrid composites (50% SiO_2 and 50%Al_2O_3). The average particle size of Al_2O_3 was 20 ± 5 µm and the average particle size for SiO_2 is from 0.5 to 5 µm. Particles size analysis was carried out using scanning electronic microscopy (SEM).

Table 1. Describe the chemical composition of AA7075 aluminium alloy (wt. %).

Mn	Si	Cr	Cu	Fe	Zn	Mg	Ti	Al
0.3	0.4	0.18-0.3	1.2-2	0.5	5.1-6.1	2.1-2.9	0.2	Reminder

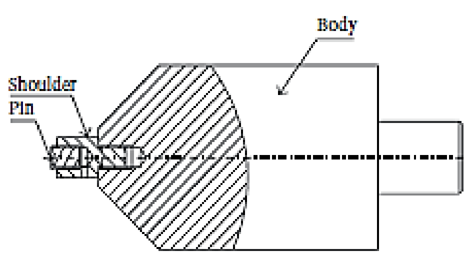


Fig. 1 Friction stir processing tool.

The tool material selected for this work was tool steel K110. The tool was hardened to 60 HRC to maintain the tool geometry during processing. Two types of pin were used one is cylindrical pin tool with shoulder diameter 20 mm and pin diameter 7 mm and a flat bottom and the other is square pin tool. The tool has shoulder diameter 20 mm, square pin side length of 5 mm and pin length 3.5mm, a taper bottom pin and concave shoulder bottom surface. Square pin tool is also used to produce both sandwich composite material (double surface) and hybrid composite of 50% SiO_2 and 50%Al_2O_3.The spindle rotation speed, traverse speed and pressure (axial force) parameters illustrated in Fig. 2 are the main dependent process parameters. The rotational speed has a great effect on heat generation due to friction between tool and aluminium sheet, [4].

Milling saw was used to prepare all the grooves in this work with 1.2 mm width and 3 mm depth and a flat tool pinless is used to close the surface of the groove to trap the powder inside the groove. A single pass is done in the total length of groove using the pinless tool with 800 rpm revolution speed in clock wise (C.W.), 50 mm/min traverse speed, tilted with 3 degrees and axial load from 900 to 1180 KG to enclose the powder in the groove working. The pinless tool was replaced by square or cylindrical pin tool to produce surface composites via FSP.

The main parameters used in FSP using FSW machine were tool rotation speed of 600 rpm, feed rate 50 mm/min, tilting angle is 3 degrees. Plunging (vertical feed) was given 3mm/min. Plunging action stops when the optimum axial load of 900 kg is reached then traverse feeding starts. At the end of the pass the feed stops and the tool is retreated upward until it reach a safe elevation from sheet then return to the start position of the pass.

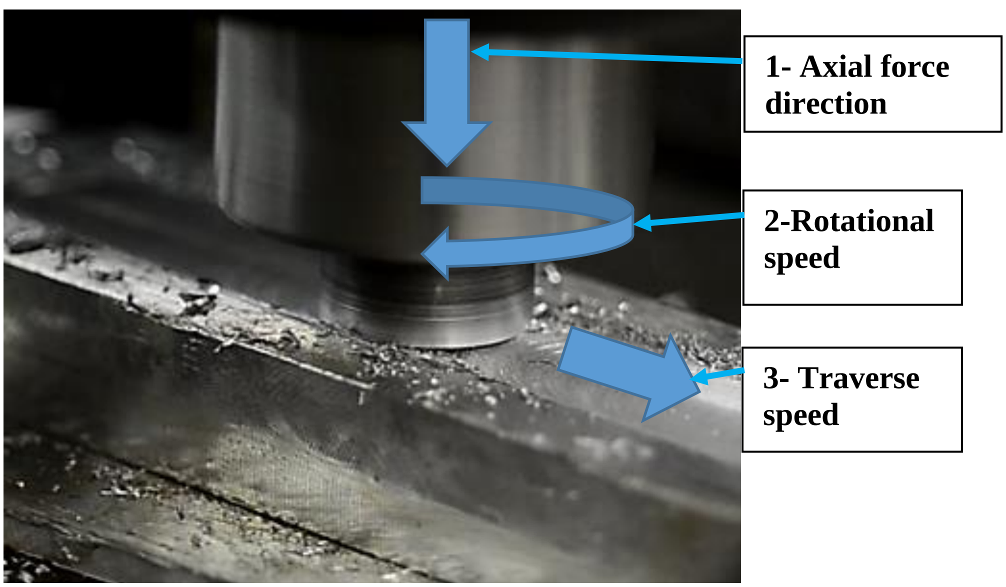


Fig. 2 Friction stir processing parameters.

Surface was ground using 2400-grit SiC paper and was polished to a mirror finish using diamond paste. The Specimens were prepared for macrostructure examination after

polishing and etching with Keller's reagent according to the ASM Metals Handbook, [12] to clarify the macrostructure. Optical microscope was used with 200X and 400X magnification to show material flow and stirring zone area.

Specimens selected for hardness measurements, macro and micro examination were taken from different positions starting from 15 mm after tool indentation center point as shown in, Fig. 3, and at the middle. Vickers microhardness indentations were obtained using a microhardness machine with a diamond Vickers indenter, 1 kg indentation load, and an indentation time of 15 seconds as shown in, Fig. 4. The hardness was measured in two directions at least five indents were made on both sides around the stirring zone centreline.In addition, five indents were made at different depths i.e. 1, 2, 4 and 5mm from the surface in both AA7075/ SiO_2 and AA7075/ Al_2O_3 surface composites .In case of hybrid surface composites, the hardness measurement was conducted at 4 mm depth from the surface.

Fig. 3 The way of cutting the samples for microhardness preparation.

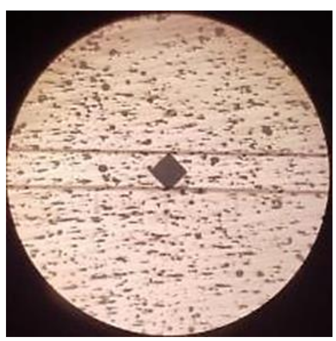


Fig. 4 Microhardness Indentation with 1 kg load.

RESULTS AND DISCUSSION

The microhardness measurements on the processed surfaces revealed that the microhardness values in the stirring zone are higher than in the thermomechanical affected zone TMAZ. The source behind this is the grain size as the grains are coarser in TMAZ compared with stirring zone as shown in, Fig. 5.

The hardness was measured for two specimens AA7075/ Al_2O_3 and AA7075/ SiO_2. Both specimens processed with same condition. For AA7075/Al_2O_3, Fig. 6, it is obvious that the hardness value near the surface of the sheet has the highest values due to the higher aluminium oxide content and as the distance from the surface increase the hardness values decrease.

For AA7075/SiO2 surface composites reinforced with ultra-fine particle, there is small change in hardness values from near the surface and to 4 mm below the surface, Fig. 7. This is attributed to uniformity in particle distribution obtained with ultra-fine SiO_2 compared to processed composites with Al_2O_3.

The hardness measurement drops moving from the surface to the bottom of the specimen. This decrease in hardness is due to decrease in reinforcement percentage as distance from surface increase hardness decrease This observation is consistent with number of previous work, [6, 13, 14].

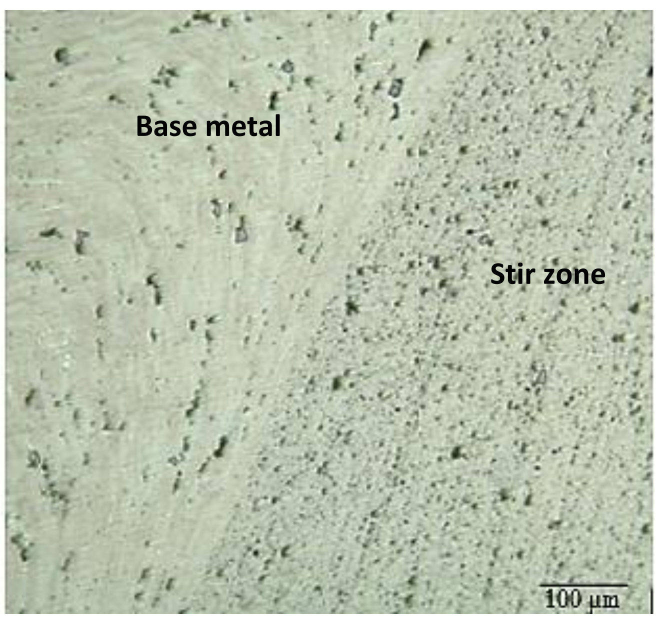
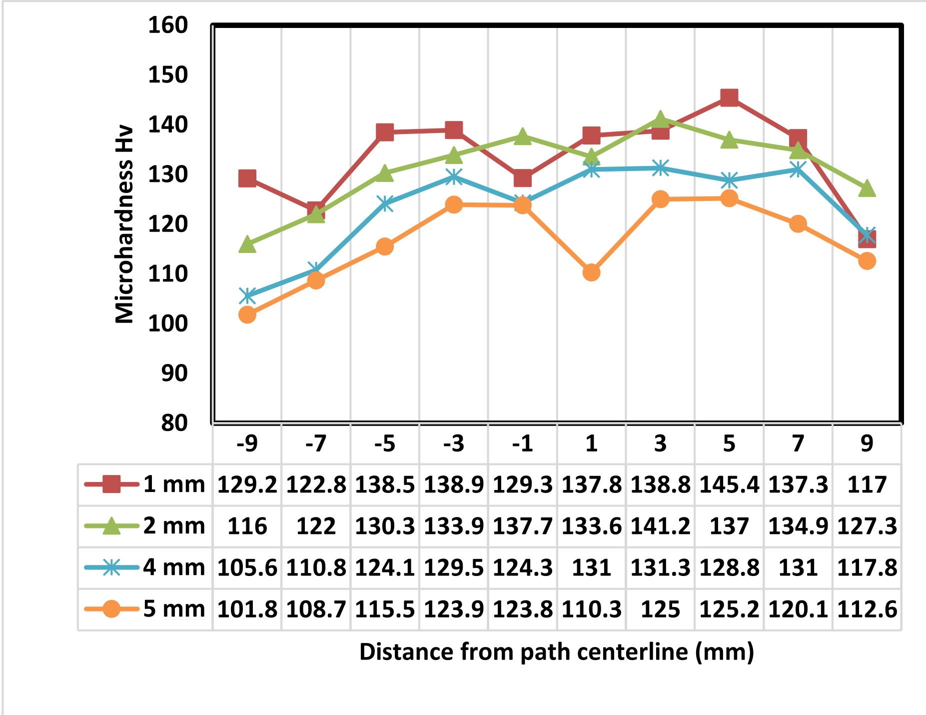
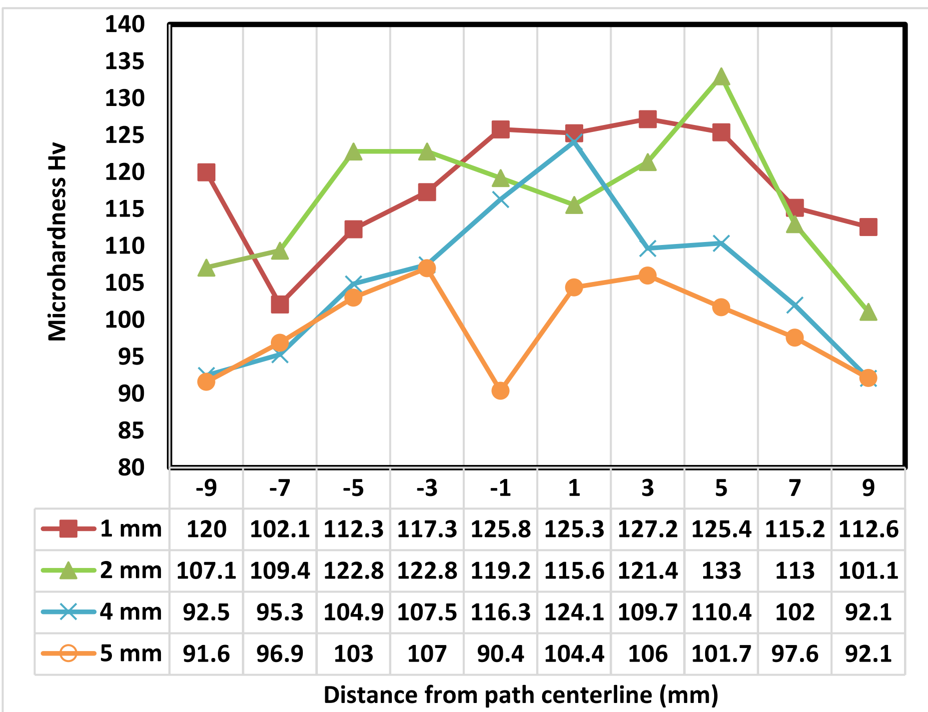


Fig. 5 Micrograph shows grain refinement in stirring zone compared to base metal after FSP.



	-9	-7	-5	-3	-1	1	3	5	7	9
1 mm	129.2	122.8	138.5	138.9	129.3	137.8	138.8	145.4	137.3	117
2 mm	116	122	130.3	133.9	137.7	133.6	141.2	137	134.9	127.3
4 mm	105.6	110.8	124.1	129.5	124.3	131	131.3	128.8	131	117.8
5 mm	101.8	108.7	115.5	123.9	123.8	110.3	125	125.2	120.1	112.6

Fig. 6 Microhardness measurement on AA7075/ Al_2O_3 surface composite.



	-9	-7	-5	-3	-1	1	3	5	7	9
1 mm	120	102.1	112.3	117.3	125.8	125.3	127.2	125.4	115.2	112.6
2 mm	107.1	109.4	122.8	122.8	119.2	115.6	121.4	133	113	101.1
4 mm	92.5	95.3	104.9	107.5	116.3	124.1	109.7	110.4	102	92.1
5 mm	91.6	96.9	103	107	90.4	104.4	106	101.7	97.6	92.1

Fig. 7 Microhardness measurement on AA7075/ SiO_2 surface composite.

A groove was processed with 3 consecutive paths to enhance microstructural, properties and particle distribution in agreement with El-Rayes et.al. ,[15]. The grain size is reduced in the stirring zone compared to the base material after three paths, Fig.7. The two surface composite surfaces of AA7075/ Al_2O_3 and AA7075/SiO_2 showed defect free surface with no flash as shown in, Figs. 8a and 8b.The composite surface prepared with ultra-fine particles of SiO_2 exhibited smoother surface in general compared to the one with aluminium oxide powder.

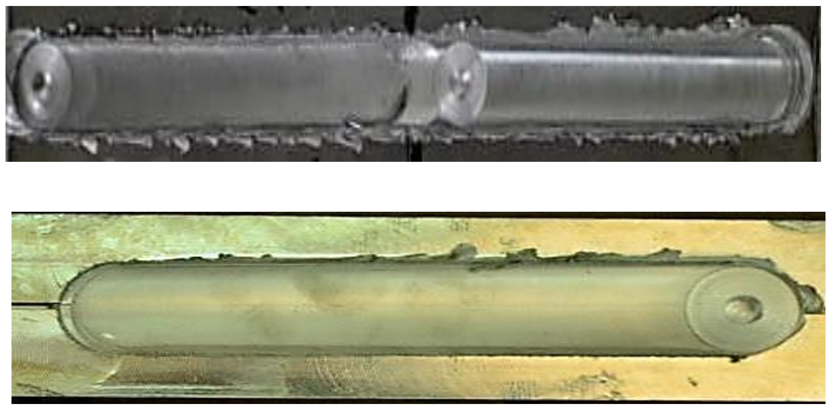


Fig. 8 FSP surface appearance a) AA7075/Al_2O_3, b) AA7075/SiO_2.

Fig. 11 shows the microhardness value of both top and bottom surfaces of sandwich material and middle at 8mm below processed surface. It is clear that surface (B) (the first surface processed) has higher hardness values compared with surface A and the base metal exhibits the lowest hardness readings. This difference between the hardness values of surface A and B can be attributed to the difference in grain size of each surface. The sheet thickness, backing plate and machine table acted as a heat sink. This increased hardness through grain refinement. The lower surface had no backing plate due to double surface processing. To restrict grain growth the samples should be immersed in water immediately after processing as mentioned in, [16-17-18]. Hardness distribution horizontally is uniform which an advantage of square pin tool.

In case of hybrid composites, the microhardness measurements exhibited higher microhardness values than 100% SiO_2 surface composite and slightly lower than 100% Al_2O_3 surface composite. The reason behind this is the difference in hardness values of alumina and silicon oxide particles, Fig. 14 show the results reported by Akbrai et. al., [19] on A356 alloy reinforced with SiO_2 particles, Al_2O_3 particles and by mixture of $SiO_2$and Al_2O_3 with different ratios. These results are in good agreement with the results obtained in the current work, Table 2. Akbari et al., [19] attributed the higher hardness obtained adding Al_2O_3 powder to 356 Al-alloy to its hardness while, the lower hardness obtained by adding SiO_2 powder to its acting as lubricating agent.

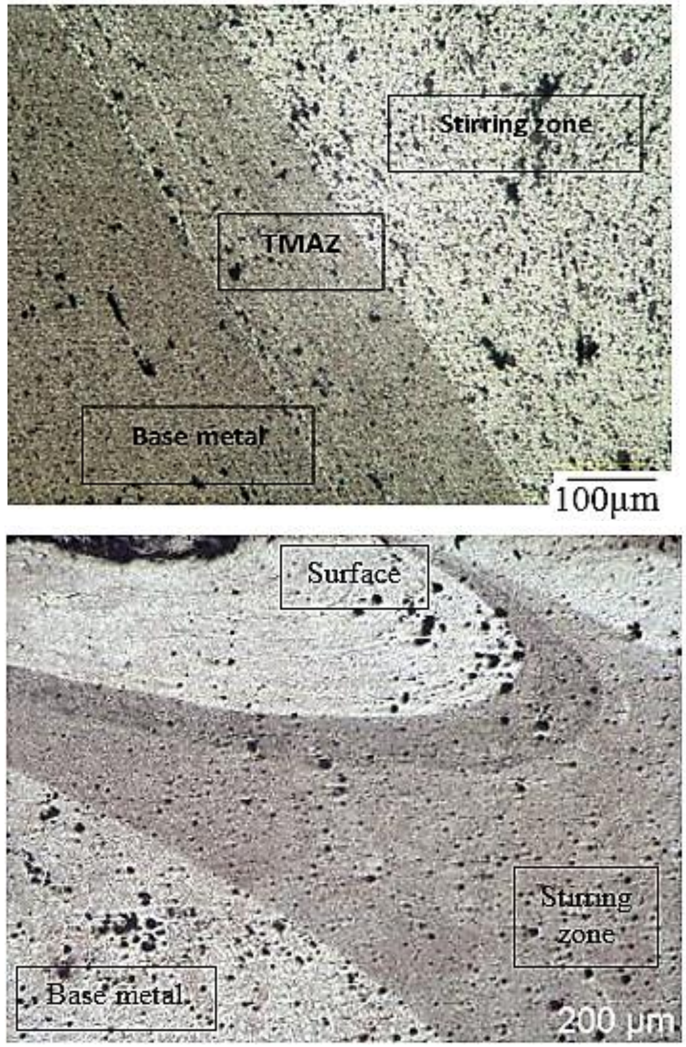


Fig. 9 Metallography of FSP a) AA7075/SiO_2, b) AA7075/ Al_2O_3.

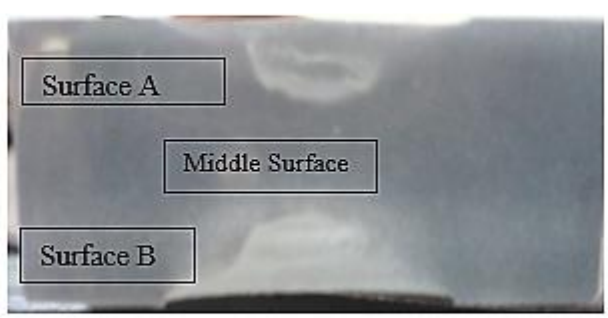
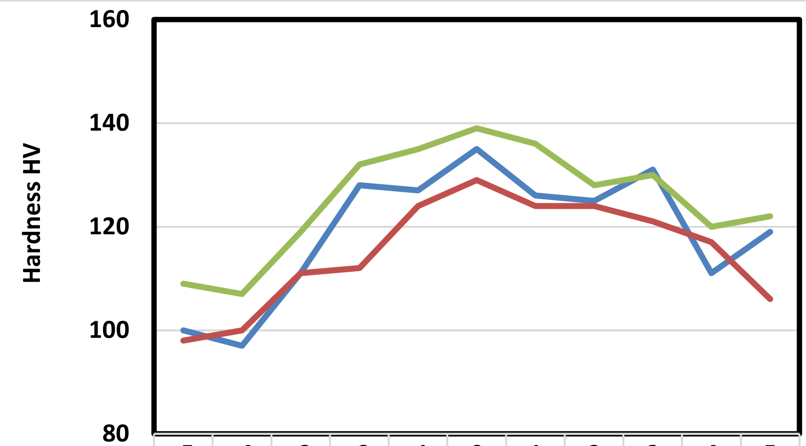


Fig. 10 Macro-appearance of sandwich structure composite (double surface composite).



	-5	-4	-3	-2	-1	0	1	2	3	4	5
surface A	100	97	111	128	127	135	126	125	131	111	119
middle of sample	98	100	111	112	124	129	124	124	121	117	106
surface B	109	107	119	132	135	139	136	128	130	120	122

distance from path centerline

Fig. 11 Microhardness value of sandwich material for both top and bottom surfaces and middle at 8mm below processed surface.

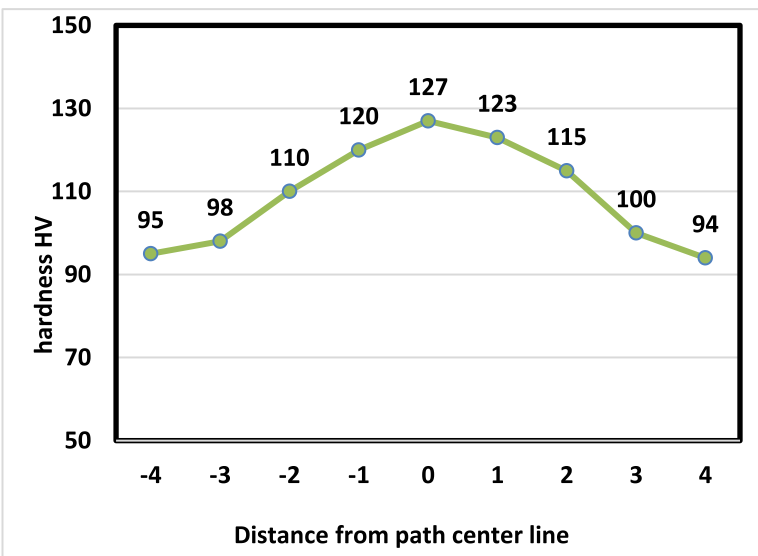
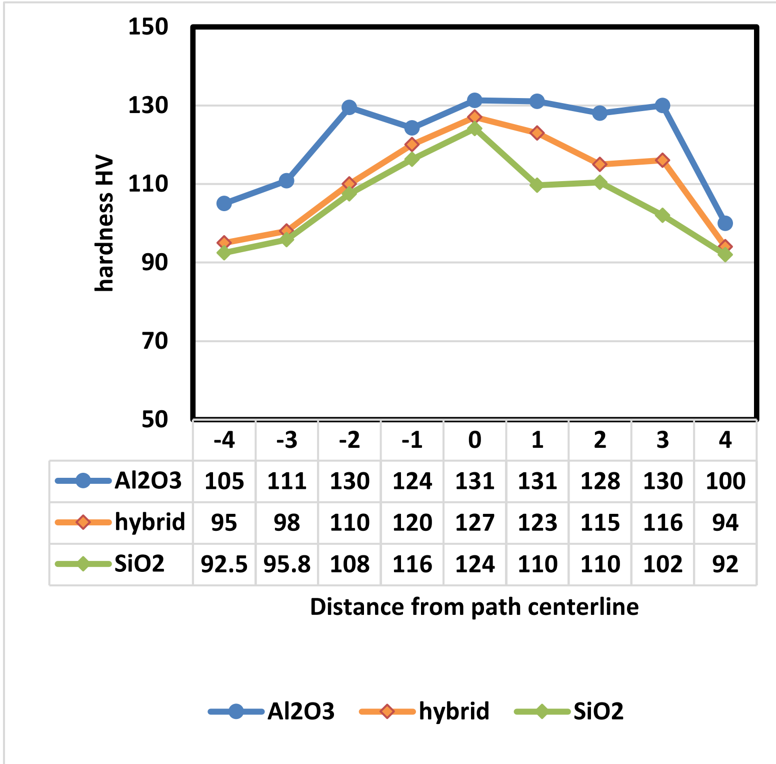


Fig. 12 The microhardness of hybrid composite(50% SiO_2- 50%Al_2O_3).



	-4	-3	-2	-1	0	1	2	3	4
Al2O3	105	111	130	124	131	131	128	130	100
hybrid	95	98	110	120	127	123	115	116	94
SiO2	92.5	95.8	108	116	124	110	110	102	92

Fig. 13 Microhardness values for 100%SiO_2, 100%Al_2O_3 and (50% SiO_2 -50%Al_2O_3) hybrid composite.

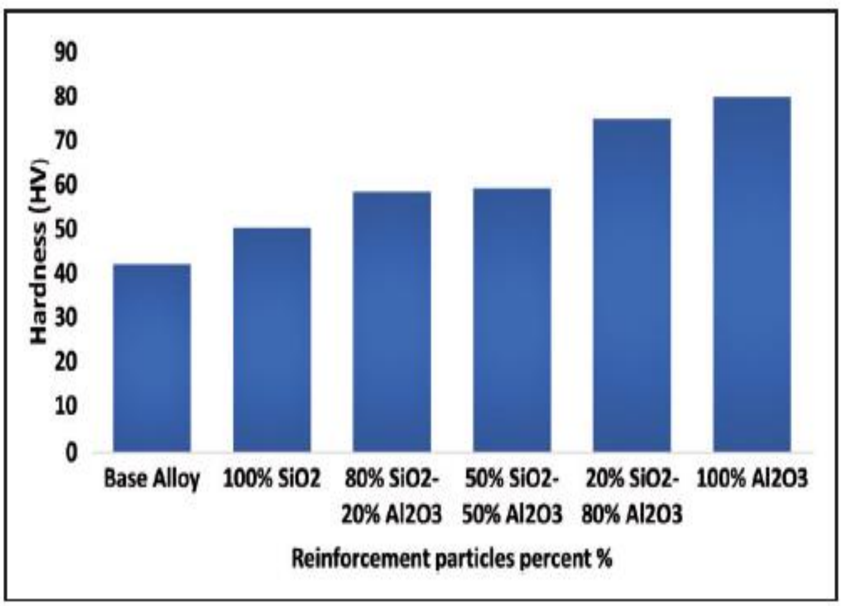


Fig. 14 The average hardness of different composites reported by Akbari, [19].

Table 2. Comparison between average microhardness of different composites of AA7075 andA356, [19].

	Microhardness HV			
	Base Metal	**100%SiO_2**	**50% SiO_2-50% Al_2O_3**	**100%A_2O_3**
A 356, [19]	**40**	**50**	**60**	**80**
7075, (current work)	**90**	**106**	**111**	**121**

CONCLUSIONS

Based on the experimental results obtained from this work, the following conclusion can be drawn:

1. Improvement of 7075 Al-alloy surface was achieved by developing composite layer using friction stir processing.

2. Surface hardness for the developing composite layer increased by 15% to 35% compared to unprocessed base metal.

3. High quality of surface composite was obtained with processing parameters of 600 rpm, 50 mm/min, and 3 degrees tilting angle.

4. The hybrid surface (SiO_2 and Al_2O_3 particles/ AA7075) composites showed enhancement in particle distribution composites and microhardness measurement compared to AA7075/ SiO_2 surface composites.

5. Square shaped pin tool enhanced the reinforcement particle distribution than cylindrical shaped pin tool.

6. Three consecutive paths of FSP are the least requirement to prevent reinforcement clusters and enable almost similar microstructure properties in both advanced and retreating side.

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