Investigation effect of process parameters of Al6061 composites fabricated by FSP on microstructure, mechanical properties with minitab and designexpert

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Abstract

In this research, Al6061 aluminum sheets and carbon nanotube particles were used at 0, 0.1, 0.5, and 1.5 percent by volume, respectively, to produce FGM material by friction-stirring process, and important parameters such as rotational speed, tool traverse speed, The tool angle on the impact strength and microhardness of the manufactured composite was investigated. The process was carried out in the range of rotational speed of 950, 1225 and 1500 rpm, traverse speeds of 30, 37.5 and 45 mm / min and angles of 2, 3, 4 degrees and the mechanical properties and microstructure of the created composite were investigated. they got. To ensure the effectiveness of the parameters for the samples, the response surface design method has been used using Design Expert and Minitab software.By increasing the rotational speed and tool angle, the fracture energy decreases and by increasing the traverse speed, the fracture energy increases, and by increasing the rotational speed and tool angle, the hardness decreases, and by increasing the traverse speed, the hardness of the composite increases. Investigating the effect of nanotube percentage carbon on the hardness, showed that with the increase in the percentage of nanotubes, the hardness also increases.

Keywords: Friction Stir Process, Composites ,Carbon Nanotubes, Functionally Graded Materials

Introduction

Composite materials are materials with a heterogeneous microstructure and their mechanical properties continuously change from one surface to another surface of the object, which is a continuous and variable combination of ceramic and metal, and from mixing metal and ceramic powder to are obtained[1]. The change of metal and ceramic from one surface to another is completely continuous and gradual in such a way that one surface is made of pure ceramic material and one surface is pure metal, in other words, two surfaces are a continuous combination of both materials, and the mechanical properties of this According to the type of composition, the material has continuous changes in the direction of the thickness of the material, and due to the continuity and gradualness of the composition of the constituent materials, they have effective mechanical properties compared to layered composite materials [2].Due to its low heat transfer coefficient and high resistance to temperature, ceramic can withstand very high heat and the metallic structure of the material causes the flexibility of the produced composite, in other words, the integration and disruption of ceramic and metal with continuous changes One level to another level in a structure can be built easily, and due to continuous and gradual changes in mechanical properties, the problems of discontinuity that exist in composite structures do not arise in FGM [3]. There are different methods for making FGMs, and the appropriate method, FSP, was chosen[4]. Friction Stirring Process (FSP) was invented in 2003 to modify the surface characteristics and create surface composite [5] In the FSP process, like FSW, the movement of non-consumable rotating tools is used to modify the structure [6]. Severe deformation along with increasing temperature during FSP leads to microstructural changes in the desired position [7]. Also, in materials with a low melting point such as aluminum and magnesium, cooling can prevent the growth of recrystallized grains and the dissolution of strengthening deposits in and around the stirred area, and on the other hand, increasing the rotational speed of the tool causes an increase in the rate of applied strain and reducing the probability of defects in the piece [8].The appropriate selection of the ratio of tool rotational speed to the traverse speed of the tool is an important factor in creating a continuous flow and a region without defects, and the time the materials are exposed to temperature in the flow, as well as the intensity of their plastic deformation, depends on the traverse speed and the tool rotational speed [9]. On the other hand, increasing the tool traverse speed increases hardness and strength, which is due to low heat input and a higher level of dynamic recrystallization [10]. Increasing the number of passes leads to a decrease in the size of the particles and thus leads to the creation of a more homogeneous structure, and also, increasing the number of passes leads to an increase in the hardness of the composite and alloy sample, which is due to its fineness and more uniform distribution in particles [11]. By examining the mechanical and wear properties of AA6061-T6 aluminum alloy at three speeds, 900, 1120 and 1400 rpm and with a feed speed of 40 mm / min with the FSP process and the effect of the volume percentage of reinforcing particles and tool rotational speed on that alloy , a composite layer including silicon carbide and graphite was created, and as a result, with the increase in volume percentage of SiC particles from 4% to 8%, the microhardness of the composite layer increased [12]. By examining the microstructure and mechanical properties of aluminum 6061 with AL_2O_3, SIC particles, the optimal conditions for maximum tensile strength were found at a rotational speed of 900 rpm, a linear speed of 15 mm / min, and a combination of 60% SiC: and Al_2O_3: 40% [13]. On the other hand, carbon nanotubes (CNT) were added to Al5083 aluminum alloy by FSP to produce metal matrix composites, where pure single-walled carbon nanotubes (CNT) produced by electric arc discharge method were used as the dispersed phase to fill the groove. It was used on the workpiece and it was assumed that 70% of the groove was filled with CNT and also, based on the preliminary tests, processing with a rotational speed of 1800 rpm and a linear speed of 25 mm / min. It was done and the composite shows a higher hardness compared to Al5083 due to grain refinement and CNT integration into Al5083 [14]. To investigate the potential of surface nanocomposites based on AA6061, with its reinforcement by carbon nanotubes (CNTs) in order to make composites, by filling grooves of different sizes with CNTs, by the friction stir process, microhardness and tensile tests were carried out for The mechanical properties were evaluated, which resulted in a 47.3% increase in hardness and 32.4% in the ultimate tensile strength (UTS) of the base materials on which the process was performed, and also, from a tool with a shoulder diameter of 25 mm, a threaded cylindrical pin (1.5 10 degree taper with a base diameter of 4 mm.5 mm and length of 4 mm with rounded edges were used and by examining figures 5, 6 and 7, it can be seen that increasing the purity (CNTs) increased the mechanical properties due to less defects in the purified CNTs and increasing the rotation speed of the tool for FSP improved the mechanical properties because the CNTs in the material were better mixed at higher revolutions because the higher the revolutions per minute(RPM), the more stirring of the material, resulting in better mixing of the reinforcements [15]. In addition, by investigating the effect of carbon nanotubes (CNTs) of Al matrix composites reinforced by friction stir process (FSP) on the wear performance and hardness of aluminum matrix composites, the results showed that CNTs are suitable particles for the production of aluminum matrix composites reinforced by FSP Also, CNTs can effectively strengthen the matrix composites and obviously improve the stiffness of the composites, and by increasing the content of CNTs, CNTs can also improve the wear performance of the matrix composites that aluminum alloy plates. (1060; thickness 5 mm) as the matrix material, used nanotubes with a diameter of 10 to 20 nm and a length of 5 to 15 μm, a tool pin with a constant diameter of 8 mm and a length of 8 mm, a constant linear speed process 30 mm / min, rotational speed of 950 rpm and an angle of 2 degrees were used, and the volume fraction of carbon nanotubes was considered to be 0, 1.3, 3, 3.5% and 5%, respectively, when the volume fraction of CNTs is smaller. Therefore, a good composite material is more easily obtained, and with the increase of CNTs content, the phenomenon of separation of CNTs and even small holes outside the friction friction zone is created [16]. By examining the above results, in order to find the optimal conditions for the desired composite, this research was carried out.

Materials and Methods

In this research, Al6061-T6 sheets with dimensions of 120*100 and thickness of 10 mm were prepared. Table 1 shows the chemical elements in this alloy.Due to the fact that in the stirring friction process, very high thermal cycles are created during the process, it is necessary to use a tool that maintains its function in high heat and temperature and its mechanical properties do not change. In this research, H13 heat-treated steel was used to make the tools used. This hot-worked steel has been used in most of the researches conducted by researchers as a raw material for making tools for friction stirring process.

Table 1- Chemical composition of aluminum alloy AA6061

Element	Mg	Si	Fe	Cu	Cr	Mn	Ti	Al
(wt%)	1	0.59	0.5	0.3	0.2	0.05	0.2	Rem

The particles used in this research are multi-walled carbon nanotubes with an outer diameter of 20-30 nm and a length of 30-10 microns, with a purity of over 95%, made by CVD method. Table 2 shows some of the characteristics of these particles.

Table 2- Characteristics of multi-walled carbon nanotubes used in this research

Chemical formula	C
Appearance	Powder
Color	Black
Density	2.1 g/cm3
Special level	m2/gr>110
Purity	Above 95%
Intenal diameter	5-10 nm
External diameter	20-30 nm
length	10-30 microns
Electrical conductivity	Above 100 S/cm
Method of production	CVD
Manufacturing Country	America

A powerful milling machine was used to perform the friction stir process. One of the most important features of this machine is the rotational speed of the tool up to 1500 rpm, the ability to move the machine table in three directions, complete control using mechanical and adjustable equipment, the ability to assign a constant traverse speed in three directions, the ability to angle the spindle and the powerful engine. Figure 1 shows the fixture used.

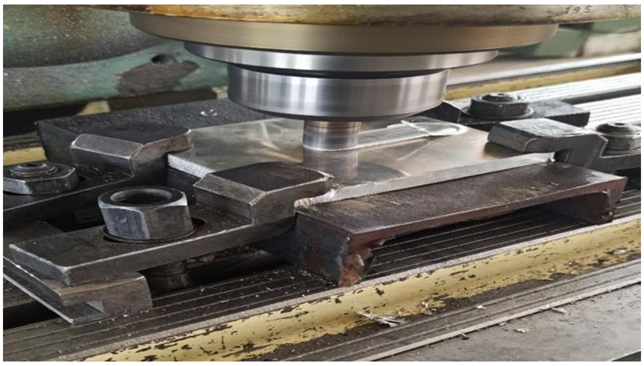

Figure 1- Fixture designed to carry out the process

Considering that the goal of this research is to produce FGM material, this work has been done in layers and each layer has its own percentage of carbon. To create FGM material, the layers are stacked with increasing percentage of carbon nanotube. This means that from the bottom to the top, the percentage of nanotubes were placed in the layers in 0, 0.5, 1, and 1.5 volume percent, respectively.

To create this composite with the mentioned characteristics, first, with a tool whose pin length is 9 mm, an FSP pass is made in the middle of the sheet, and the first layer is made without particles. Then, a groove is created in the center of the FSP area with a depth of approximately 7.5 mm and a width of 1 mm using a milling machine and a milling blade, as shown in the figure. 0.5 percent of the volume of particles, which amount is placed in the groove according to the density of the obtained sheet and particles. Then, the sheet inside the fixture is closed and first, using a pinless tool, an FSP pass is performed on the groove to close the groove. Then, the process has been done with a tool with a 7/5mm long pin to form the next layer with half percent of carbon. After this step, a groove is created in the middle of the sheet according to the previous step, this time with a depth of 5 mm and the same width as the previous one, which is 1 mm. According to the previous step, we put the particles in the groove. Considering that we added 0.5% particles in the previous step, the upper layers have 0.5% nanotubes. So, to create a 1% layer, 0.5% of the particles are placed in the groove. The sheet is placed inside the fixture and according to the previous step, a pinless tool is used to close the groove. After the tool without pin, we go to the tool with pin length of 5 mm and with this tool, FSP is done to make the layer with 1% volume of particles. To make the 1.5% layer, it works like the previous layers, with the difference that the groove is made 2.5 mm deep and a tool with a pin 2.5 mm long is used.

In this research, effect of three parameters were examined rotational speed, linear speed and tool tilt angle. For rotational speed, speeds of 950, 1180, 1500 rpm, for linear speed, speeds of 30, 37.5, and 47.5 mm. per minute and 2, 3, 4 angles are considered for the angle. The depth of penetration for all samples is considered to be 0.2. The design of the experiments in this research was done using the response level method. In order to take advantage of this surface response and also to improve graphic works, two softwares, Minitab9 and Designexpert7, have been used. In this research, three main factors are considered as independent variables of the problem and one parameter as the answer. The three parameters of traverse speed, rotational speed and spindle angle are considered as independent variables and the impact strength is considered as the answer to the problem. In order to design the experiments, the response level statistical method was used and the BBD statistical scheme was used for this purpose. Three factors have been examined at three different levels. Table 3 shows the test design matrix.

Table 3- Test design table

Run	Block	Factor 1 A:rotational sp rpm	Factor 2 B:translational mm/min	Factor 3 C:tilt angle deegre
1	Block 1	950.00	30.00	3.00
2	Block 1	1500.00	30.00	3.00
3	Block 1	950.00	45.00	3.00
4	Block 1	1500.00	45.00	3.00
5	Block 1	950.00	37.50	2.00
6	Block 1	1500.00	37.50	2.00
7	Block 1	950.00	37.50	4.00
8	Block 1	1500.00	37.50	4.00
9	Block 1	1225.00	30.00	2.00
10	Block 1	1225.00	45.00	2.00
11	Block 1	1225.00	30.00	4.00
12	Block 1	1225.00	45.00	4.00
13	Block 1	1225.00	37.50	3.00
14	Block 1	1225.00	37.50	3.00

One of the mechanical tests that is performed to evaluate the mechanical properties of materials is the impact test. Charpy impact test method is used in this research. The device used was the 200 Joule Charpy impact test machine manufactured by Santam Iran. Impact set was performed using ASTM A370 standard. According to the ASTM A370 standard, the impact sample is a piece with a length of 55 mm and a square section of 10 x 10 mm, which has a V-shaped groove with an angle of 45 degrees and a depth of 2 mm and a root radius of 0.25. The samples were cut perpendicular to the direction of the FSP area using a wire cutter.

In this research, Vickers microhardness test was also used to calculate the hardness of the processed samples. In this research, the hardness test has been done for each sample once in the direction of the thickness of the FSP area from the bottom to the top and in the direction of increasing carbon nanotube particles and once perpendicular to the FSP area on the surface. To perform the hardness test, 16 points on the surface of the processed samples and 10 points in the direction of thickness from bottom to top were selected and the hardness of these points was obtained. Finally, the hardness of these points was reported graphically as the result of the hardness of the sample. The microhardness test of the samples was done by means of a microhardness tester made by Buhler, America, in a time of 10 seconds under a load of 300 grams and at ambient temperature.

A scanning electron microscope or SEM was used to examine the microstructure of the produced composites and it is a type of electron microscope capable of photographing surfaces with a magnification of 10 to 500,000 times with a resolution of less than 1 to 20 nm.

Results and Discussion

Impact test

The purpose of this research is to create a functional aluminum-based composite with carbon nanotube particles using the FSP method and to investigate the properties of this composite. In this chapter, the effect of process parameters, i.e. rotational speed, linear speed and tool angle on fracture energy has been investigated. Then the effect of the percentage of particles on the microhardness and also the effect of the process parameters on the hardness of the composite will be investigated and finally the microstructure of the produced composites will be investigated.

Figure 2- Sample of produced composite

Fracture Energy

One of the important issues in the industry and especially in the field of welding, which causes a lot of damage, is the breaking of parts due to the brittleness of their material, therefore, the study of failure and its factors can be very effective. Figure 3 shows the fracture surface of the base piece without the process. Figure 4 shows the cross-section of one of the samples from the top view,

Figure 3- Cross section of base material fracture

Figure 4- Top view of the fracture surface

As mentioned earlier, in this research, the response level method and Design Expert and Minitab software were used to design and analyze the experiments. BBD method was used to develop the test design matrix. In total, based on the experimental plan used in the current research, 14 samples were prepared and subjected to the process. Table 4 shows the test design matrix and the fracture energy obtained from each situation (problem answer).

Table 4- Fracture energy for different samples

Sample number	Rotational speed (rpm)	linear speed (mm/min)	Spindle angle (degree)	Failure Energy (jol)
1	950.00	30.00	3.00	12.1
2	1500.00	30.00	3.00	8.4
3	950.00	45.00	3.00	9.8
4	1500.00	45.00	3.00	7.7
5	950.00	37.50	2.00	13.1
6	1500.00	37.50	2.00	8.1
7	950.00	37.50	4.00	9.1
8	1500.00	37.50	4.00	7.3
9	1225.00	30.00	2.00	11.4
10	1225.00	45.00	2.00	9.3
11	1225.00	30.00	4.00	9.3
12	1225.00	45.00	4.00	7.9
13	1225.00	37.50	3.00	9.4
14	1225.00	37.50	3.00	9.5

In studies based on the statistical design of the experiment, one of the things that determine the accuracy of the model is the value of the coefficient of determination (R-Squared) and the coefficient of determination adjusted (Adjusted R-Squared). The closer the value of these components is to 1 or 100 percent, the higher the accuracy of the model adaptation and the higher the quality of the proposed model. The coefficients of the statistical model used in this study are shown in Table 5.

Table 5- Statistical model determination coefficients

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.61	0.9008	0.8710	0.7846	8.07	
2FI	0.24	0.9895	0.9804	0.9433	2.12	Suggested
Quadratic	0.31	0.9901	0.9677	0.8425	5.90	
Cubic	0.071	0.9999	0.9983		+	Aliased

In the statistical analysis, a confidence level of 95% was used, and ANOVA technique was used to check the participation and effectiveness of the model factors. Table 4-3 shows the ANOVA for the fracture energy parameter.

Table 6- ANOVA for fracture energy parameter

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	37.06	6	6.18	109.66	< 0.0001	significant
A-rotational spe	17.89	1	17.89	317.57	< 0.0001	
B-translational :	5.28	1	5.28	93.76	< 0.0001	
C-tilt angle	7.95	1	7.95	141.07	< 0.0001	
AB	0.64	1	0.64	11.36	0.0119	
AC	2.56	1	2.56	45.45	0.0003	
BC	0.12	1	0.12	2.17	0.1838	
Residual	0.39	7	0.056			
Lack of Fit	0.39	6	0.065	12.98	0.2094	not significant
Pure Error	5.000E-003	1	5.000E-003			
Cor Total	37.45	13				

Based on the statistical model used, the final regression equation of the fracture energy parameter is based on a function of the independent variables of the problem, in the form of equation (1)

Fracture Energy =+45.87305 - (0.021727 * w) - (0.41591* v) – (5.47614 * t)+(1.93939E-004 * w * v) + (2.90909E-003 * w * t) + (0.023333 * v * t)

In the above relationship, w represents the rotational speed of the tool, v represents the linear speed, and t represents the tool's angle.

To verify the validity of the model, three other tests that were not included in the test design table have been performed. Table 7 shows the parameters of three experiments with the size obtained from the model and the size obtained from the impact test.

Table 7- Specifications of tests performed for model validation

Test number	Rotational speed	linear speed	Tool angle	Model size	Impact test size	Error percentage
1	1500	30	2	8.706	7.93	%9
2	950	37.5	2	12.519	14.1	%12
3	1225	45	3	8.118	7.23	%11

According to the numbers in Table 7 and the percentage of errors from the tests, it can be seen that the model is reliable.

Optimization

To optimize the fracture energy, ten points with the highest fracture energy are considered. The obtained optimal points are shown in Table 8.According to Table 8, ten optimal points have been obtained, which shows that the highest fracture energy occurs when the rotational speed is close to 950 rpm and the linear speed is 30 mm/min with an angle close to 2 degrees.

Table 8- Optimization of process parameters for fracture energy

Number	rotational speed	translational speed	tilt angle	fracture energy	Desirability
1	955.93	30.29	2.01	14.1144	1.000
2	952.15	30.05	2.01	14.1975	1.000
3	957.37	30.14	2.02	14.1233	1.000
4	951.09	30.15	2.00	14.2169	1.000
5	959.23	30.07	2.00	14.1459	1.000
6	950.74	31.28	2.01	14.0002	1.000
7	951.01	30.82	2.01	14.0817	1.000
8	959.79	30.19	2.02	14.0906	1.000
9	963.93	30.09	2.04	14.0283	1.000
10	957.11	30.15	2.03	14.0725	1.000

Microhardness test

The micro-hardness test results of five samples 5, 8, 13, 11 and 12 and the base sample are shown in Table 6-4, as well as the graph of the hardness test in Figure 10-4. The backward region is shown with negative numbers and the forward region is shown with positive numbers.

Table 9- Microhardness test results

Distance from the center	-8	-7.5	-7	-6	-5	-4-	-3	-2	0	2	4	5	6	7	8	10
Sample hardness 5	42	60	70	95	95	93	103	100	111	95	83	89	79	65	59	45
Sample hardness 8	43	42	50	65	62	78	79	80	88	71	73	70	79	57	45	41
Sample hardness 6	44	52	65	83	89	85	95	100	102	101	79	86	73	61	53	42
Sample hardness 11	41	50	68	78	88	87	92	96	96	91	70	78	70	60	49	44
Sample hardness 12	40	49	54	69	69	80	84	88	94	86	75	74	66	59	51	42

Basic sample	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106

As it is clear from Table 9 , the highest and lowest hardness values were measured in the center of the agitation zone and near the base metal, respectively. Considering that the hardness value of the used aluminum alloy Al6061-T6 was measured as 106 Vickers and since aluminum alloy 6061 is one of the alloys that can be heat treated, the frictional stirring process creates a soft area around the center of the processing area. A number of aluminum alloys undergo heat treatment, this condition is caused by the annealing conditions as a result of the dissolution of reinforcing deposits in the processed area that have undergone severe plastic deformation and experienced high temperatures during the FSP process. So, by doing the process, the hardness of this alloy decreases.Also, due to the fact that plastic deformation is more in the regressive region and the grain size is finer, the hardness of this region is higher than the advancing region of the samples, and this issue can be understood according to the diagram and hardness values. According to the obtained results, it can be said that reducing the size of particles and increasing their number, the fineness of grains in the turbulent region caused by dynamic recrystallization, as well as creating a more homogeneous structure in turbulent regions, under the influence of heat and under the influence of mechanical work, are important reasons for increasing the hardness of the sample. The processed samples are in the disturbed area, which is clear in the graphs, and the samples have the highest hardness in the middle of the processed area. Hardness in the aluminum-based composite area depends on the grain size, density of dislocations, nano reinforcement particles and heat input to this area. According to the Hall-Patch relationship, hardness increases with decreasing grain size.The dislocations that are created as a result of the heterogeneous distribution of nano particles in the metal field cause an increase in hardness. Reinforcing particles have a double effect on hardness. Both the particles themselves have high hardness and the effect they leave due to the phenomenon of locking increases the hardness of the samples. In the absence of nano particles, the only effective factor is the input heat, which, despite the granulation inside the FSP region, greatly reduces the hardness of this region. On the other hand, the input heat caused by the continuous stirring frictional process does not allow the hardness to increase to a great extent, the reason being the complete annealing effect. On the other hand, the heterogeneous distribution of nanotube particles in the FSP region, and as a result, the improper flow of materials during the process can be one of the main reasons for the strong clumping of reinforcing particles in these samples and sometimes local reduction of hardness.

Investigating the influence of the tool rotational speed parameter on the size of Microhardness

Two samples 5 and 6 have been used to investigate the effect of the rotational speed of the tool. In these samples, the linear speed is the same and is equal to 37.5 mm / min, and the tool angle is also equal to 2 degrees for both samples. Sample 5 has a rotational speed of 950 rpm and sample 6 has a rotational speed of 1500 rpm. According to Table 9, the hardness of sample 5 is higher than sample 6. It can be said that by increasing the rotational speed, the input heat increases, and because the input heat decreases the hardness, and also if the heat is higher than the optimal value, it causes an increase in the size of the grains and reduces the hardness, so increasing the rotational speed causes a decrease in the hardness. Sample 6 is compared to sample 5.

Investigating the effect of traverse speed parameter on the size of Microhardness

Two samples 11 and 12 were tested for the effect of traverse speed on hardness.Both samples have the same rotational speed and angle of 1225 rpm and 4 degrees, respectively. The traverse speed for sample 11 is 30 mm / min and for sample 12 is 45 mm / min. According to the results of the micro-hardness test of these two samples, the hardness of sample 12 is higher than sample 11. The reason for this can be understood as that by reducing the traverse speed, the incoming heat increases and causes the grains of the sample to enlarge, and as a result, the hardness decreases

Microstructural examination and SEM images

To check the microstructure of the fracture section of three base samples, SEM pictures were taken of sample 5 with the highest fracture energy and sample 8 with the lowest fracture energy. Figure 5 shows the fracture surface of the mentioned samples. Figure 5 (a) shows the fracture cross-section of the base material, in this figure, depressions and pits are observed, which shows that our base sample has a flexible fracture. In Figure 5 (b), where the fracture surface of sample 5 is shown, the pits and depressions have become bigger and also the crack line can be seen and it shows a brittle and soft mixed fracture. Figure 5 (c) shows the fracture surface of sample 8, which indicates a brittle fracture according to the crack line.Examining Figure 5 shows that the process has changed the soft fracture to a brittle / soft fracture, which is evidenced by the presence of larger dimples and crack lines, and these results are consistent with the impact test results, which show that the base sample is more flexible. From the produced composites, sample 5 is more rigid than sample 8.

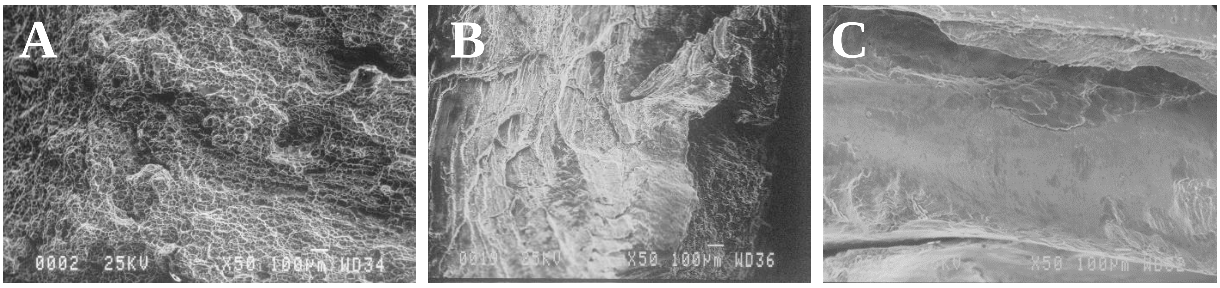

Figure 5-Fracture cross section: a) base sample b) sample 5 c) sample 8

In sample 5 (Figure 6), the distribution of nanoparticles is more uniform than in sample 8, which is due to the process with more mechanical load due to the lower angle of the tool and more optimal heat due to the lower rotational speed, which causes less The gaps between the common layers of the processing area and structural defects have become.The distribution of nano particles in sample 8 (Figure 7) is more in the form of accumulation, which were mostly trapped in the place of discontinuities and cracks in the joint layer of some mixing layers, which is the result of less disturbance and weaker mechanical mixing of carbon nanotubes with The base metal material in the sample is 8. According to the larger clusters of carbon nanotubes in this sample that can be seen in the pictures, it can be said that sample 8 is less flexible than sample 5.By examining Figures 6 and 7, at low rotational speed, heat generation is less and stirring is more uniform, resulting in proper plastic deformation by the pin and shoulder of the tool. In other words, at a higher rotational speed, the heat and stress created by the comb and pin increases and causes structural porosity and holes in the composite. Also nano particles in sample 8 are agglomerated with larger sizes than sample 5.

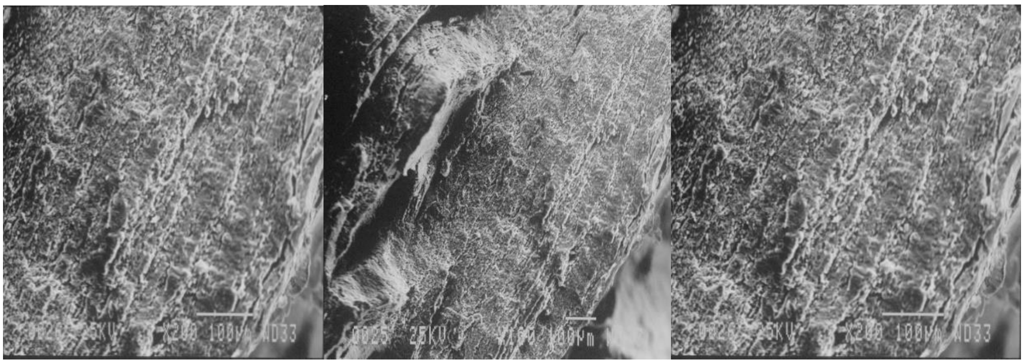

Figure 6- SEM images of the fracture surface of sample 5

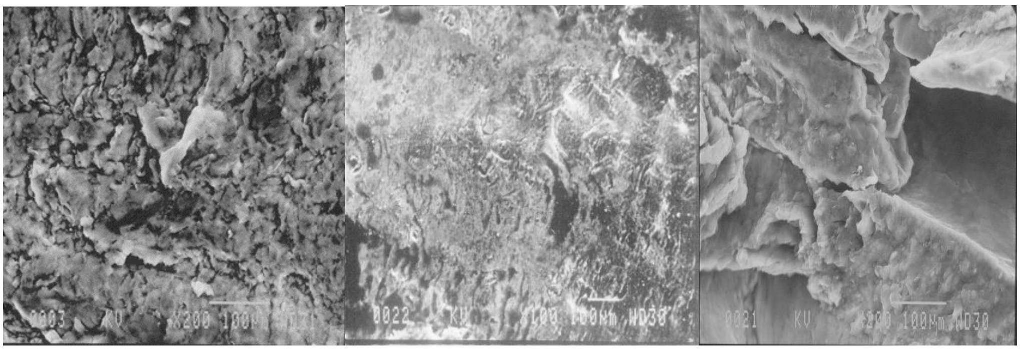

Figure 7- SEM images of the fracture surface of sample 8

Conclusion

The use of metal-based functional materials is due to the fact that it is microscopically inhomogeneous and the structural characteristics, including the type of distribution, the size of the phases, gradually change from one surface to another, and this gradual change leads to a gradual change in the properties of FGM, is increasing .One of the methods of producing these materials is by using frictional stir process. This process is a method for surface improvement that has been developed for the production of surface composites. The friction stir process is a method for stirring the material, which is based on the principles of the friction stir welding process, with the difference that only the change in the microstructure is proposed and basically there is no welding connection. In this process, it uses a non-consumable pin to generate heat and disturbance. Due to the fact that the frictional process of a lot of agitation was done on aluminum and magnesium alloys and also the very good properties of carbon nanotube particles such as high surface density, tensile strength, etc. It was decided to make and investigate Al-CNT composite, parameters of rotational speed, linear speed and tilt angle of the tool, which were new parameters in the field. In this research, the effect of the process and process parameters, including the rotational speed of the tool, the traverse speed, and the tilt angle of the tool, on the mechanical properties, including impact strength and microhardness, were fully evaluated. Design Expert and Minitab software were used to check the impact strength. The microhardness was investigated both in the direction perpendicular to the weld and in the thickness direction from bottom to top due to the variable volume percentage of the particles. The fracture cross-section was examined for microstructural examination using a scanning electron microscope and the following results were obtained from these examinations:

1. By increasing the rotational speed and decreasing the linear speed, the microhardness decreases due to the higher input heat that causes the grains to grow larger.
2. By increasing the rotational speed, the heat of the process increases and the cooling effect decreases, as a result, the material does not flow well and the fracture energy decreases.
3. By increasing the linear speed, because the heat of the process does not reach the optimal amount and the process is not performed well, it causes a decrease in the energy of failure.
5. The decrease in the hardness of the produced composites compared to the base sample is due to the effect of complete baking and the input heat caused by the process. In some places, the microhardness of the produced composite was measured to be less than 50% of the base sample.
6. The 60% reduction in the fracture energy of the produced composites compared to the base sample is due to the non-uniform distribution of the particles and as a result of not achieving the locking effect of the nanoparticles and the complete annealing effect of the input heat caused by the process.
7.The presence of carbon nanotube particles increases the hardness of the produced composites.
8. The hardness increases with the increase in volume percentage of carbon nanotube particles.

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