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THE EFFECT OF DIFFERENT CONDITIONS ON THE TENSILE PROPERTIES OF AA7075-T6 DURING THE FRICTION STIR WELDING PROCESS

In this paper the investigation of the FSW result characteristics on AA7075-T6 of the highest grade is carried out using different process parameters. A vertical milling machine with different FSW tool geometry is used to weld AA7075. When the tool rotational speed varies from 1200 and 1800 (rpm), different welding parameters are studied, the plunge depth of tool is between 0.14 and 0.20 mm, the table transverse speed range is between 20 and 50 (mm/min) and the tool shoulder diameter was 20 mm. The welding settings are optimized using the Taguchi approach. In this experimental investigation Taguchi Technique is utilized in this study to optimize three factorial and three level designs. The results show that when the rotating speed increases, the UTS of the welded joint increases, whereas the tensile strength of the welded joint decreases resulting to frictional heat created during the FSW process. Tensile strength decreases as feed increases and increases as rotational speed increases. For a 5 mm thick plate, tensile strength is optimal with a tool shoulder diameter of 20 mm, a rotational speed of 1600 rpm, feed rate of 30 mm/min and plunge depth. The shoulder diameter of 20 mm provides the maximum ultimate tensile strength when it is compared with all other tool shoulder diameter. The Al alloy AA7075-T6 plates, however, concurrently developed an equiaxial grain structure with a substantially smaller grain size and coarsened the precipitates.

Keywords: Tensile Strength; Aluminum Alloy7075; Taguchi technique; Microstructure; FSW

1. Introduction

FSW, or friction stir welding, is a solid-state method for combining several alloys of aluminum and also different materials used in the industries. Friction stir welding (FSW) was developed by The Welding Institute (TWI) of the United Kingdom in 1991 [1]. The turning device moves at a very high rotational speed along the welding center the Friction Stir Welding Process's line, the plunge depth of the tool has a significant impact on weld joint strength [2]. FSW, is a approach for effectively combining aluminum with aluminum alloys, such as casting alloys that are incredibly challenging to weld through conventional welding procedures. This technology is becoming more popular across the world, particularly rail is used in shipbuilding, automobile, and construction sectors. The FSW technique employs a tool for rotating and stirring that enters the substance along the welding line to heat and soften it through friction. After being rotating the tool is moved along the joint line while heating and softening the material around the probe. Extruded backwards around the tool probe, the scalding and plasticized materials used in welded elements are fused together before cooling, by the shoulder. The zone of nuggets is created due to the softened metals of both components fusing behind the stirring tool during the friction stir welding process, in the weld center.

Aluminum alloy (AA 7075) has been more popular in the automotive, aerospace, and aircraft sectors in this current era due to its good ratio of strength to weight, ductility, cracking resistance, corrosion resistance, and harsh environments [3]. During the FSW process, the workpiece material is mechanically stirred by the high rotational speed tool and undergoes intense plastic deformation at a higher temperature generated due to the friction, which extends to beyond the agitation zone (thermo-mechanical affected zone). Furthermore, outside of the thermo-mechanical impacted zone, a significant temperature differential arises across the weld HAZ (zone influenced by heat). As a outcome of these elements, a extra complicated assembly is generated in the weld cross-section, which directly affects its mechanical characteristics. It has been investigated in many studies carried by the researchers worldwide to determine the most effective friction stir welding process parameters, according to the literature reviews.

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The impact of rotational speed and tool profile on the mechanical characteristics of an aluminum alloy is analyzed and also it had been seen that when theincreasing axial force, the tensile strength of the weldment decreases [4]. By using the Friction stir welding procedure, it has been determined that the fabric's tensile strength base substantial, which is greater than the weld joints, as well as the maximum competency in terms of elongation and maximum tensile strength. Mechanical Characteristics by employing the method of friction stir welding, it had remained investigated that grain refinement has a significant impact on automatic parameters like maximum tensile strength, micro rigidity, weld bead quality when compared to the basematerial. The impacted rotational speeds for microstructure and mechanical characteristics drawn through FSW process parameters, and it was shown that grain size has considerable grains are refined in the nugget zone and the thermomechanical impacted zone., and nugget zone by way ofthe nugget zone and the zone with thermomechanical impact are where grains are processed. Changes in the composition of aluminum casting alloys welding are linked to deformation, recovery, and re-crystallization processes, as well as phase alterations in microstructure components, such as hail or dissolution phase of intermetallic [8,17]. Exists a proclivity toward make a joint that is devoid of faults that might develop when using traditional arc welding processes.

2. Experimental set up and material used

In this experimental work, an aluminum alloy (AA 7075-T6) material plate which is having a thickness of 5 mm was used as a workpiece in the FSW procedure. The specimen of size 150 mm × 125 mm × 5 mm is used,as per the special fixture designed for conducting the experimental investigation by using a vertical milling machine. The Aluminum alloy (AA 7075-T6) is widely used in the aerospace automobiles sectors for building an excellent tensile strength structure [16]. The primary mechanical characteristics and microstructure of the joint are carried out with the use of tools. The FSW tool,which comes in a variety of forms and sizes and is manufactured of En-31, is used to execute friction stir welding at various speeds. The instrument used in this experimental research shoulder length was 20 mm, the jot diameter is at the root, 5 mm, and the tool jot length is 4.75 mm. The heat and material movement created by resistance depends on the instrument rotational speed on high rpm, as wellas quick plastic distortion was impacted by the length and tool's design jot, in addition the shoulder diameter of the tool. TABLE 1 shows the Alloying elements of Aluminum alloy (AA 7075-T6) material used in this investigation. The vertical milling machine which is shown in Fig. 5, the rotating tool penetrates 0.5 mm into the workpiece, and takes 1 miniature, resulting in a 0.5 interval in which heat is generated to provide the excellent quality of the FSW welding.

The FSW fuses with the 2 different fragments of workpiece together. 5 mm thick AA-7075 was milled on a vertical milling machine in the Department of mechanical engineering, Jamia University Polytechnic, Delhi, India for executing FSW as depicted in Fig. 1. The dinnerware was milled to the desired dimensions (150×62 mm). Fig. 2 depicts the geometry of many tools. TABLE 2 shows the Alloying elements of workpiece by weight (weight percent) of AA-7075, which was employed in the FSW experiment. The Hercules make milling machine is used for performing the FSWexperimentation along with the specially designed fixture for FSW process.

Fig. 1. Vertical Milling Machine (Hercules) for FSW Process

During this FSW experiment, a non-consumable high strength steel alloy tool made of En-31 which consist Nickel, chromium, and molybdenum contribute to the steel&excellent tensile strength,ductility,and wear resistance. It is used in various shapes and sizes which was utilized to accomplish the weld joints; it has a high temperature, strong heat conductivity, and excellent strength. The FSW tool utilized for performing this experiment had a shoulder diameter ranges between 14 and 20 mm, a tool pin length of 5 mm at the root, then a tool jot length of 4.75 mm. Plastic deformation occurs in FSW as a result of the high-speed rotating tool generating heat produced by rubbing, resulting during regional plastic deformation in the welding region. The instrument pin and tool shoulder purpose are to create heat due to high rotational speed, which aids in the softening of materials control of material flow for a weld with no flaws which creates a high tensile strength joint. The proper tool selection serves a crucial function in performing effective friction stir welding by producing the optimum amount of required temperature for joining the two-metalwork piece together [18,19].

The tool has been designed by keeping the proper parameters into the design consideration. The tool pin,tool shoulder and the tool pin length are selected by going through many of the research articles and by optimizing those tool selection parameters. There has been lot of experiments performed at the primary phase of carrying out this research for the selection of the tool. The tool which are pictured in the below given Fig. 2 are the optimized result of those experiments from which the tool for this experimental work efforts has been selected.

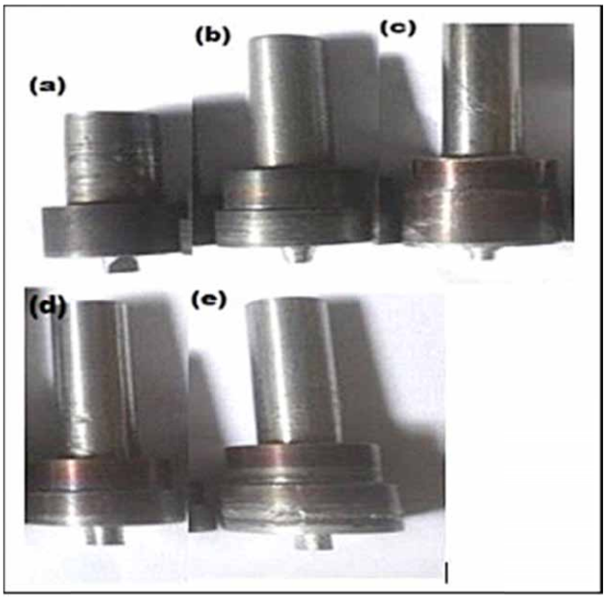


Fig. 2. Different geometry tool used for FSW Process. (a) Cylindrical shaped tool (b) Taper shaped tool (c) Triangular shaped tool (d) cylindrical threaded shaped tool (e) Taper threaded shaped tool

TABLE 1

Alloying element of En-31 for tool according to spectrometer analysis (wt. %)

Alloying Element	wt. %
Chromium	1.00-1.60
Manganese	0.30-0.75
Sulphur	0.10-0.35
Carbon	0.09-1.20

TABLE 2

Alloying element of AA7075-T6 according to spectrometer analysis (wt. %)

Alloying Element	wt. %
Silicon	0.3
Ferrous	0.4
Copper	1.2-2.0
Manganese	0.3
Magnesium	2.0-2.8
Chromium	0.19-0.29
Aluminum	87.1-91.4
Zinc	5.0-6.2
Titanium	0.3

TABLE 3

Process parameters used for FSW Process

Parameters	Units	Symbols	Different Levels			
Rotational Speed of Tool	rpm	N	1200	1400	1600	1800
Welding speed	mm/min	S	20	30	40	50
Shoulder diameter of Tool	mm	D	20	20	20	20
Plunge depth of Tool	mm	h	0.14	0.16	0.18	0.20

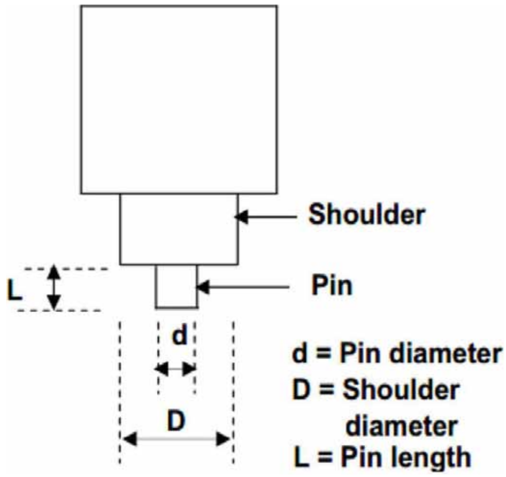


Fig. 3. Nomenclature of FSW tool

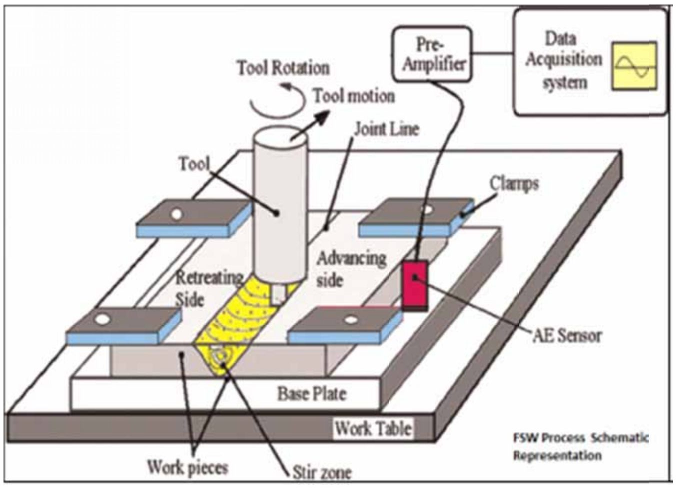


Fig. 4. Schematic illustration of friction-stir welding process [10]

3. Tensile Test

The tensile testing is commonly used in acceptance testing to obtain basic data on material strength. It is a critical metric that is subjected to mechanical testing parameter used to ascertain the tensile strength the FSW procedure. It has been shown in Fig. 5 which represents the standard sample required for tensile test. The accurate shape and dimension of test samples are used for performing the welded joint's tensile testing. To analyze the stretchable characteristics test on welded joints, tensile samples were manufactured the American Society for Testing and Materials claims (ASTM E8M-13a) and tested on a tensile testing machine, as illustrated in Fig. 6. All the test which are carried out for tensile test are performed as per the guidelines mentioned in the ASTM standard [11].

The test specimen for tensile test is made into the proper shape and the required dimensions for performing the tensile test. Test specimen for Tensile testing is made in accordance with the recommendations of ASTM standard ASTM E-8/E8M-13a. The tensile testing has been performed by using the machine setup in the university laboratory.

(a) Tool Rotational speed – 1200, Plunge depth – 0.14 mm, Feed rate – 20 mm/min

(b) Tool Rotational speed – 1400, Plunge depth– 0.16 mm, Feed rate – 30 mm/min

(c) Tool Rotational speed – 1600, Plunge depth – 0.18 mm, Feed rate – 40 mm/min

(d) Tool Rotational speed – 1800, Plunge depth – 0.20 mm, Feed rate – 50 mm/min

Fig. 5. Surface morphologies of AA-7075 weld joints with different process parameters

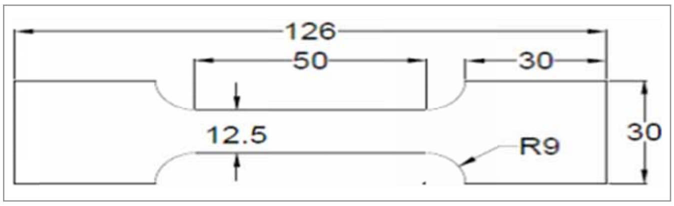


Fig. 6. Test specimen for Tensile testing as per ASTM E-8/E8M-13a [11]

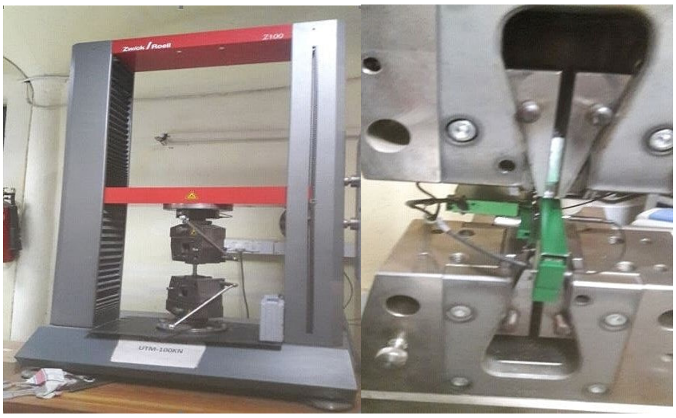


Fig. 7. Machine setup for Tensile testing

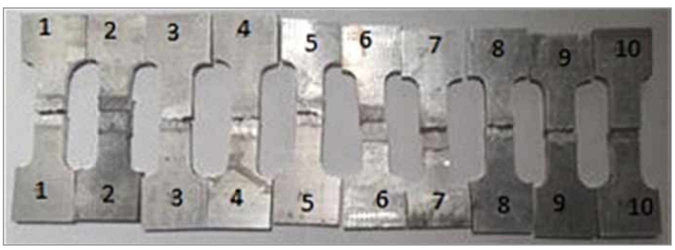


Fig. 8. Actual Figure of Tensile Test Specimen

TABLE 4

DOE and Observation table for Tensile testing

S. No	Tool rotational Speed (rpm)	Welding speed (mm)	Tool Plunge Depth (mm/min)	UTS (MPa)
1	1200	20	0.14	332
2	1200	30	0.16	335
3	1200	40	0.18	341
4	1200	50	0.20	346
5	1400	20	0.16	349
6	1400	30	0.14	360
7	1400	40	0.20	398
8	1400	50	0.18	392
9	1600	20	0.18	395
10	1600	30	0.20	400
11	1600	40	0.14	394
12	1600	50	0.16	391
13	1800	20	0.20	387
14	1800	30	0.18	391
15	1800	40	0.16	390
16	1800	50	0.14	389

Accordingly, to the obtained data set in TABLE 4, Ultimate tensile strength decreases with feed rate and increases with rotating speed of tool. Fig. 7 represents a tensile test broken sample. The tensile strength of a tool with a 20 mm shoulder, a 1600 rpm rotational speed, a 0.20 plunge depth, and a feed rate of 30 mm/min is superior. The parameters that describe the stress and strain curves acquired from (UTS), tensile tests, yield tests, and elongates, among other things. The most crucial aspect is to establish the impact of when using the friction stir welding procedure, the tool shoulder diameter [12,20]. The crosswise feed is related to the bond component tensile strong point in the opposite direction. The mixing of material in a plastic condition is the most significant element in friction stir welding for higher strength, and for analysis, three factor and four level designs for the Design of Experiment (DOE) were used for obtaining the combinations of different parameter value inputs and performing the experimental work.

4. Process Parameter Optimization using Taguchi for FSW Welding process

The Optimization used in this experimental work is Taguchi optimization under the condition that it has the excellent analysis, and the three-factor and four-level designs of the (DOE) design of the experiment have been carefully chosen. The trio factors which were considered are Feed rate, Tool rotation speed, and plunge depth. The four levels are respectively Tool rotating speed of 1200, 1400, 1600, 1800 rpm, feed rate 20, 30, 40, 50 mm/min, and plunge depth 0.14, 0.16, 0.18, 0.20 mm. The optimal conditions for FSW, according to the aforementioned design, are 1800 rotating speed, 30 mm/min feed, and 0.20 plunge depth. Microstructure with relatively near and coarse space has been shown to form alongside grain boundaries. Due to the formation of additional Compared to the T6 condition, grain boundaries have more continuous and closely spaced grain boundaries [13,21]. Many researchers have already created a model for investigating and simulating the interaction between mechanical characteristics and FSW limitations in Aluminized sheets [14,15]. The superior cum optimized process parameter from all other various combinations of process parameters that improves the FSW is determined through the optimization of the FSW process parameters, and that obtained parameter can be employed for a higher-quality FSW process. The process specifications must be optimized in order for the process to run smoothly and efficiently [22].

5. Single-to-Noise (S/N ratio) for FSW Process

L16 Orthogonal Array using 16 rows and 4 columns utilized in this investigation. There are four levels of optimized procedure parameters that may be utilized with this array. Forty studies were carried out to investigate the L16 Orthogonal Array. In this method, the impact on every selected factor the response and Single-to-Noise each factor's ratio were evaluated. The hardness and tensile strength of welded specimens wererecognized „Higher the better and normal the best" is the conclusion for tensile strength." in this study. The primary effect of Single-to-Noise ratio graphs of the means and residuals Ultimate tensile strength is seen in Fig. 9.

6. Effect of Tool Rotational Speed

The influence of input factors on tensile strength was investigated in this study. TABLE 5 shows the single to noise ratio throughout all responses. The effects of various alterations on tensile strength. With 400 MPa tensile strength at 1600 rpm and 0.20 mm of plunge depth, it is obvious that speed has the greatest impact on tensile strength. The examination of variances for UTS is shown in TABLE 6. Fig. 10 shows different surface plots for speed, yield strength plunge depth, and UTS. The impact of speed on the FSW process is substantial, as illustrated in Fig. 10, which may be easily analyzed using SN plots.

TABLE 5

Table for S/N ratio

Level	Toolrotational Speed (rpm)	Welding speed (mm)	Tool Plunge Depth (mm/min)
1	50.59	51.24	51.31
2	51.46	51.38	51.26
3	51.93	51.60	51.57
4	51.80	51.57	51.64
Delta	1.34	0.35	0.39
Rank	1	3	2

The surface plot is drawn from the parameters obtained from the Taguchi design evaluation above. The ultimate tensile

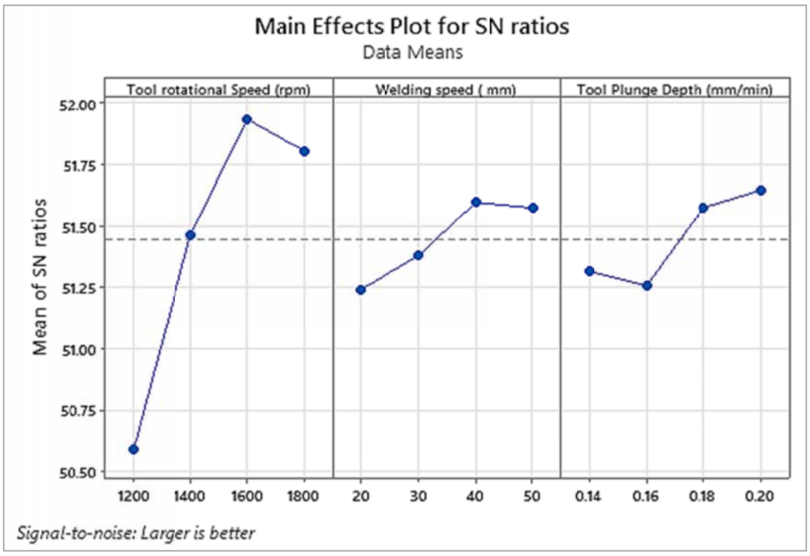


Fig. 9. Main Effect Plot for Single to Noise Ratio

TABLE 6

Analysis of Variance for Ultimate Tensile Strength, using Adjusted SS for Tests

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	7077.4	73.56%	7077.4	2359.1	11.13	0.001
Tool rotational Speed (rpm)	1	5951.3	61.85%	5951.3	5951.3	28.07	0.000
Welding speed (mm)	1	510.1	5.30%	510.1	510.1	2.41	0.147
Tool Plunge Depth (mm/min)	1	616.0	6.40%	616.0	616.0	2.91	0.114
Error	12	2544.4	26.44%	2544.4	212.0		
Total	15	9621.8	100.00%				

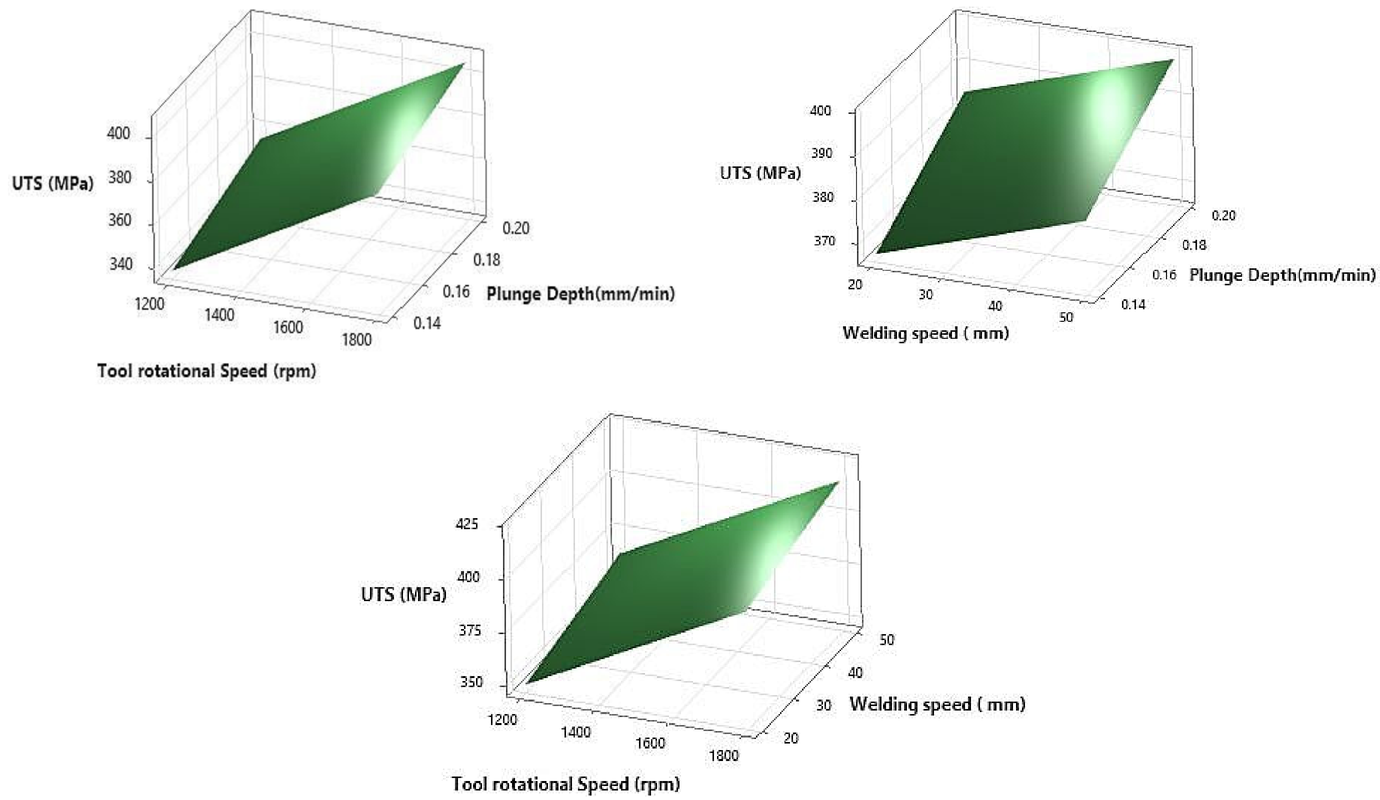


Fig. 10. Surface Plots

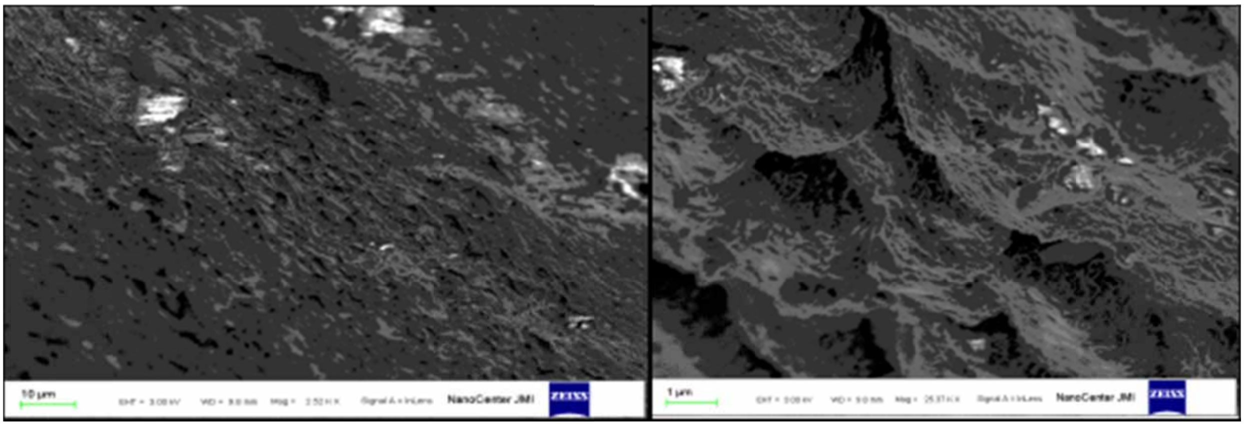
strength with Tool rotating speed (1200, 1400.1600,1800 rpm), feed rate (20, 30, 40, 50 mm/min), Tool shoulder diameter (20 mm) and plunger depth (0.14, 0.16, 0.18, and 0.20 mm).

7. Microstructure

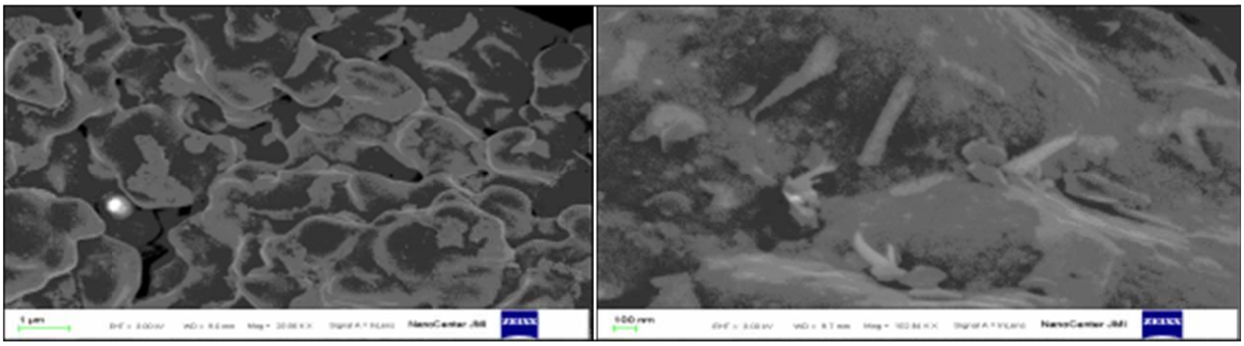
The scanning electron microscopy (SEM) An optical microscope was used to analyses microstructure and Philips 525M an electron microscope for scanning (SEM). The optical microscope was used to perform microscopic interpretations on cross-sections that had been mechanically ground and polished before being etched using a mixture of 190 ml water, 2 ml HF, 3 ml HCL, and 4 ml HNO_3. The weld nugget and the areas near to the thermomechanical enlarged zone were used for SEM analyses (Fig. 11). SEM study has focused on the joints' cross-sectional polished Surface [15]. FSW the optical micrographs obtained from the stir zone (SZ) out of every weld joint, as shown in. Fig. 12. According to the micrographs, there is a notable fluctuation in the weld's average grain diameter zone in AA 7075. During Due to fiction stir welding (FSW), the base metal's abrasive granules are transformed into fine grains. The weld joints were created with a 1600 rpm rotating speed. Superior grains were found in the weld zone at 30 mm/min welding speed and 0.20 mm plunge depth when compared to junctions with other parameters. It is deduced from the collected micrographs that there is a large variance in through the welds, grain size; this happens as a result of inadequate heat contact and plastic movement. Although rotation and crosswise speed had minimal impact on the influence value, the total impact energy rose in the friction stir welding of the (moderate strength) AA7075 alloy at 1600 rpm and 30 mm/min in contrast to the base metal.

8. Hardness test

In the current study, the Rockwell hardness of the welded specimen was determined and reported. When the load applied is 60 kg and the rotational speed is 1200 rpm, the Rockwell hardness values obtained from four trials are 49, 50, 52, and 56, respectively, averaging to a Rockwell hardness value of 52. The weight applied is 60 kg, and the rotating speed is 1400 rpm. Based on four trials, the Rockwell hardness values were 50, 53, 54, and 55, respectively. The average Rockwell hardness value was 53. The force applied is 60 kg, and the rotating speed is 1600 rpm. Based on four trials, the Rockwell hardness values were 53, 57, 58, and 60, respectively, with an average of 57. Similarly The force applied is 60 kg, and the rotating speed is 1800 rpm. Based on four trials, the Rockwell hardness values were 52, 55, 58, and 59, respectively, with an average of 56. The increase in rotational speed results in an increase in the hardness value, as can be seen from the information aboveThe hardenability trait that friction and high temperature provided the welded samples may be the reason. This proves that the rotating speed of 1600 rpm is efficient and dependable for producing a hard surface at the welded zone when compared to other speeds. This might be thought of as the best rate for producing fine, well-welded samples. This might be regarded as the ideal pace for

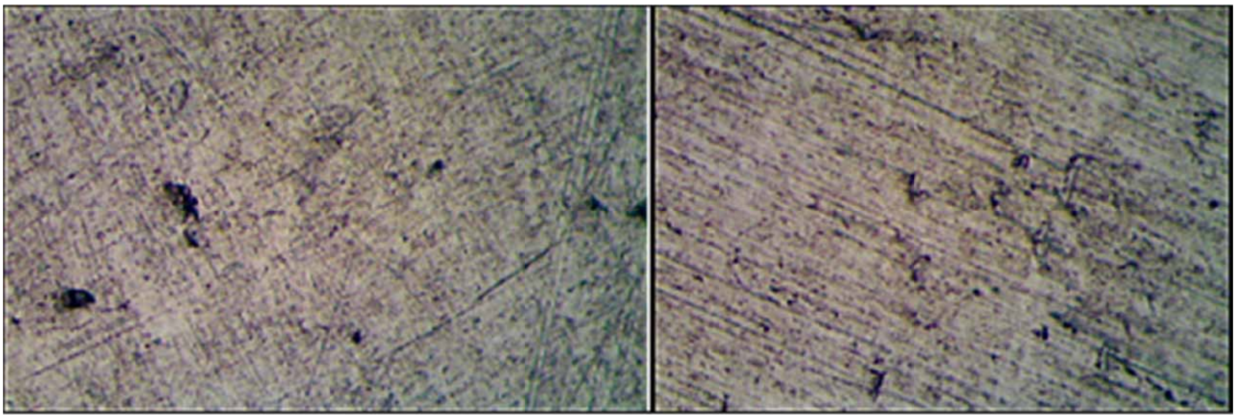


(a) (b)

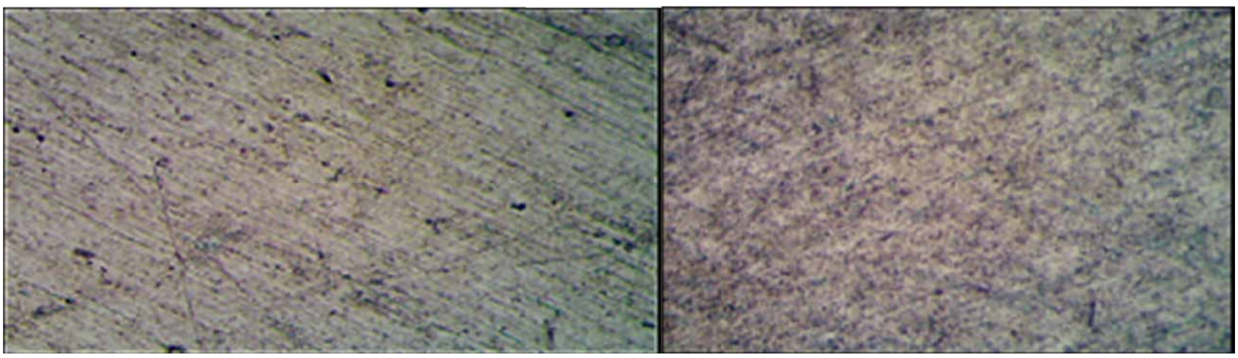


(c) (d)

Fig. 11. Microstructure obtained by Scanning Electron Microscopy at 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm (a) 0.1 mm below top surface, (b) 0.4 mm below top surface, (c) 0.5 mm below top surface and (d) 0.9 mm below top surface in FSW process



(a) 1200 rpm, feed 20 mm/min (b) 1400 rpm, feed 30 mm/min



(c) 1600 rpm, feed 40 mm/min (d) 1800 rpm, feed 50 mm/min

Fig. 12. Optical microscopy Images at different process parameters

creating high-quality, well-welded samples. TABLE 7 displays the hardness value for the stirred zone. High rotating speed results in a higher hardness of 57. The reported hardness values range from 52 to 57, with the stir zone reporting the highest value due to the creation of a hard surface at high temperatures.

TABLE 7

Rockwell Hardness test

S. no.	Rotational Speed (rpm)	Load (kg)	Rockwell Hardness value (RHB)	Average Hardness Value (RHB)
1	1200	60	49	52
2		60	50	
3		60	52	
4		60	56	
5	1400	60	50	53
6		60	53	
7		60	54	
8		60	55	
9	1600	60	53	57
10		60	57	
11		60	58	
12		60	60	
13	1800	60	52	56
14		60	55	
15		60	58	
16		60	59	

9. Conclusion

The following findings may be drawn from this experimental work.

- A friction stir welded joint is classified into three regions: the unevenly stirred area, the evenly stirred region, and the region remaining to be stirred including the „kiss-ing bond," all of which are measured from the top of the plate in the direction of plate thickness. The evenly stirred region's structure is improved to become an equiaxial structure with grains smaller than 5 μm. The „onion ring" was in the disturbed area. The area that friction stimulated had an asymmetrical form that spread in the direction of the advancing side.
- It is derive from the collected micro-graphs that there is a large variance in through the welds, grain size; this happens as a result of inadequate heat contact and plastic movement. Although rotation and crosswise speed had minimal impact on the influence value, the total impact energy rose in the friction stir welding of the (moderate strength) AA7075 alloy at 1600 rpm and 30 mm/min in contrast to the base metal.
- Tensile strength decreases as feed increases and increases as speed increases. For a 5 mm thick plate, tensile strength is optimal having a tool shoulder-length of 20 mm, has a feed rate of 30 mm/min, a spinning speed of 1600 rpm, and. However, because when compared to other shoulder diameters, a 20 mm shoulder diameter does not give the maximum UTS because the heat generated does not concentrate near the welded joint area. tool diameters.
- Taguchi experimental design approach remains well suited to enhancing welding parameters in FSW.
- The optimal welding process parameters are 1600 rpm, 30 mm/min feed rate, and 0.20 mm plunge depth.
  – At 1600 rpm and 30 mm/min of feed, maximal hardness and tensile strength are attained.
  – Shoulder diameter and welding speed are correlated substantial impact on tensile strength.
- Although equivalent forms generated by the growth inside the nugget for materials of crystalloid visual texture, microstructure demonstrates that multiple there are parts made in the joints. They come in a variety of grain sizes and intensities. Because of the increased heat created during the fusing process, Hardness loss in weld joints on thick plates is substantially higher. The grain refinement data displays the weld nugget's maximum hardness.

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