Effect of Process Parameters on Strength and Surface Quality of Friction Stir Welded AA 6063-T6 Aluminum Alloy

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Abstract:
The precipitation-hardened AA 6063 aluminum alloy, which contains magnesium and silicon as its primary alloying elements, is used for general-purpose applications. Friction stir welding is introduced as a versatile and cost-effective solid-state technique for joining such alloys. The focus of the paper is on optimizing the welding process to achieve the highest ultimate strength and the lowest surface roughness of the weld. AA 6063 aluminum alloy, which is precipitation-hardened and contains magnesium and silicon, is commonly used in various applications. The process of connecting these aluminum alloys involves friction stir welding. This technique is known for its versatility and cost-efficiency, especially for solid-state joining of materials. The quality of the weld depends on several important process parameters, including tool profile, rotation speed, and traverse speed. These parameters need to be optimized to produce a defect-free weld.

This paper aims to optimize the ultimate strength of the weld. To do this, micro tension tests are conducted, and the optimization is achieved using Response Surface Methodology (RSM). The highest tensile strength, 133.576 N/mm², with a tiny percentage error of 1.455%, is obtained using a Tapered Threaded (TTH) tool profile and a spindle speed of 1000 rpm and a table feed rate of 20 mm/min, according to the data.

And also examines the impact of the process parameters on surface roughness. A surface profilometer is used for this purpose. The results suggest that the Tapered Threaded tool profile results in both increased weld strength and reduced surface roughness. Current paper notes that tool forces and surface roughness decrease with an increase in welding speed and feed. The lowest surface roughness value obtained is Ra = 0.822 µm, corresponding to a feed rate of 20 mm/min. In order to produce greater ultimate strength and reduced surface roughness, the friction stir welding parameters for AA 6063 aluminum alloy are optimized in this paper. The Tapered Threaded tool profile is highlighted as an effective choice for improving both weld strength and surface quality.

Keywords: Friction stir welding (FSW), Al 6063 alloys (AA 6063), Ultimate Tensile strength (UTS), Response Surface Methodology (RSM), surface roughness.

1. Introduction

Aluminum is a nonferrous white and lustrous metal, with good corrosion resistance in its pure state. It is ductile, malleable and nonmagnetic. Aluminum combined with various percentages of other metals, generally copper, manganese, and magnesium, forms the aluminum alloys, and are used in aircraft construction. Aluminum alloys are commonly available in a wide range of extruded sections. Aluminum alloys are beneficial for fuel economy and in reducing CO_2 emissions. In spite of this they do not possess the corrosion resistance of pure aluminum and are generally treated to prevent deterioration. One of the Al alloys AA6063 which is in the group of 6XXX alloy contains Si and Mg as main alloying elements, with other elements such as Cu and Mn for improving its mechanical properties Among these, alloy with 0.7% magnesium and 0.4% silicon offers good mechanical properties.. AA6063 is heat-treatable and weldable. It has good surface finish, high corrosion resistance, and can be readily suitable for welding; hence it is preferred in the shipbuilding and aerospace industries. Its ready extrudability enables thin walled and intricate hollow shapes, tube, flats, angles, channels and hollow circular and square sections, 6063 responds well to polishing, chemical brightening, anodizing and dyeing. Most commonly available grade of AA6063 is T6 tempers. The T6 temper is one of the most commonly used for AA6063. In the T6 temper, the aluminum alloy undergoes solution heat treatment followed by artificial aging. This results in improved mechanical properties, including higher strength. On the other hand, the T4 temper involves solution heat treatment and natural aging, and it is known for providing good formability. In the T4 condition, the aluminum alloy has reduced strength compared to T6, but it retains better formability, making it suitable for certain applications where shaping or forming is a crucial factor.

Mishra R.M reported that the widespread use of Aluminum alloys are hindered due to the lack of appropriate cost effective joining techniques for similar and dissimilar alloys. Aluminum alloys can be joined by arc welding, friction stir welding, or high-power density fusion joining techniques including laser beam and electron beam welding. Among these, friction stir welding can be effectively applied to these materials owing to the fact that no melting takes place at the weld nugget [1].

G Mrowka reported that, in 1991, the Welding Institute (TWI Ltd., England, and UK) developed friction stir welding, an affordable joining method for both similar and dissimilar high strength aluminum alloys. [2]. A relative cyclic movement between the probe and the work piece material produces frictional heat so as to create a plasticized region in the work piece material around the probe. The plasticized region, on solidification will result in a perfect joint. Friction stir welding (FSW) has numerous benefits compared to conventional fusion welding techniques. FSW offers sound welded joints with coarse dendrite structures, less distortions, little solidification cracking, micro segregation etc. The finished welds are free from gas and shrinkage porosities, solid inclusions, surface oxidation or discoloration.

Thomas V.M, Dawes, C. J mentioned that the friction stir welding (FSW) is carried out between two dissimilar alloys, the temperature distribution may not be uniform. This can lead to residual stresses and distortion. The formation of brittle intermetallics between dissimilar materials, a wide heat affected zone (HAZ), high energy consumption and causes environmental pollution [3, 4].

All the factors affecting parameters have to be taken into consideration to achieve a perfect weld. The tensile strength and surface quality of the corresponding weld joints, as well as the overall performance of the FSW joints of the AA6063 T6 alloy, are assessed in this work.

Mishra R.S reported that in order to determine the ideal welding condition, Response Surface Methodology (RSM) was utilized to establish an empirical relationship between the FSW input parameters, such as rotational speed (rpm), welding speed (rpm), and axial force (KN), and the output response, such as ultimate tensile strength (UTS).[5,6]

The influence of surface roughness on tensile strength of the optimized friction stir welded AA6063 alloys is obtained by RSM. The surface roughness of the optimized friction stir welded AA 6063 alloy and the base alloy have been investigated.

2. Experimental Procedure

The commercially available plates were purchased from industrial suppliers and resized to a dimension of 125mm × 50mm ×6mm. The chemical composition of AA6063 T6 aluminum alloy has obtained from the inductively coupled plasma (ICP) analysis. Single pass butt weld was produced on AA 6063-T6 aluminum alloys of 6mm thickness to fabricate similar friction stir welded square butt joints of 125 mm length.

2.1 FSP Tool Design and Set-Up

Biswas. P, Luis Trueba, A.Scialpi A, Trimble, D reported that the tool's design is a crucial component of FSW.A good tool can improve both the quality of the weld and also render maximum possible welding speed. It is noticeable that the tool material must be sufficiently strong, tough, and hard at all ranges of welding temperatures. Further, it should have a good oxidation resistance and a low thermal conductivity to minimize heat loss and thermal damage to the machinery [7-11].

In this work the three most crucial factors influencing the weld's tensile strength are feed rate (mm/min), spindle speed (rpm), and tool profile. The tool profiles selected here are Tapered Threaded (TTH), Square Cylindrical (SQC) and Hexagonal (HEX). The materials of all the tools are high carbon steel and can be manufactured by a CNC lathe. Tool dimensions are pin length 5.85mm, pin diameter 3mm and shoulder diameter 16mm.The spindle speed is 800 ,1000 and 1200 rpm. The feed rate is 20, 25 and 30mm/min.

Figure 1. FSW Tool Profiles (a) Tapered Threaded [TTH], (b) Square Cylindrical [SQC] and (c) Hexagonal [HEX] configurations.

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2.2 **Design of Experiments**

The experiments have been conducted using parameters of the designed matrix obtained by Box Behnken approaches of response surface methodology (RSM). This approach is employed to design the process parameters. The study assessed the relationship between process parameters, including tool rotational speed, welding speed, and tool axial force, and the ultimate tensile strength (UTS) of comparable welded joints. The number of trial experiments comes to 3^n where, n = 3, therefore it becomes 27. The incorporated process parameters are tool profiles, spindle speed, table feed and with an axial load that is in the order of 8 KN. The maximum range of weld length is 115 mm.

According to Box Behnken design aspects each tool profile has 9 sets of inputs (table feed and spindle speed). There are three types of profiles using a total of 27 sets of inputs and the corresponding response as micro tensile strength in N/mm^2 entered in the RSM. After iteration the obtained output solutions were summarized .The most desirable value of micro tensile strength with desirability factor of unity is preferred and is found to be.

2.3 **Tensile test Samples Preparation**

The welding process is carried out on the specimens based on the sets of parameters (27 sets) from Response Surface Methodology (RSM). By using a friction stir welding machine (NC) (Model: FSW 15-300 Standard Machine), 27 weld joints were created. One test sample was cut out from the steady welded region from each weld as shown in figure 2.b .The test sample, cut being used for tensile test as per ASTM E8M. The FSW welded specimens are cut into the shape specified by ASTM standard (32mmX6mmX6mm) mm area $36mm^2$ of Cuboidal shape in a CNC milling machine.

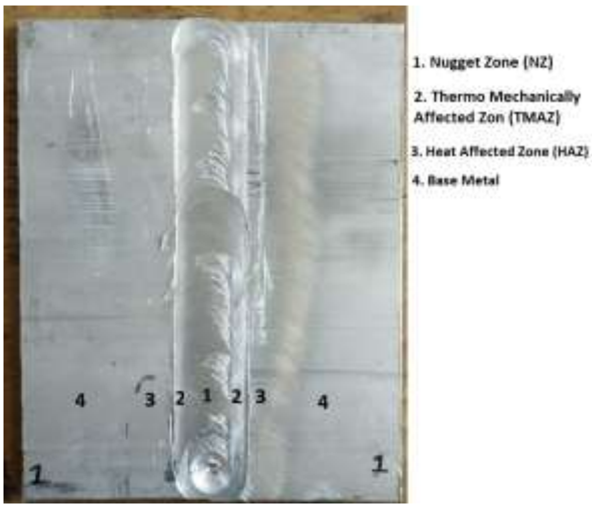
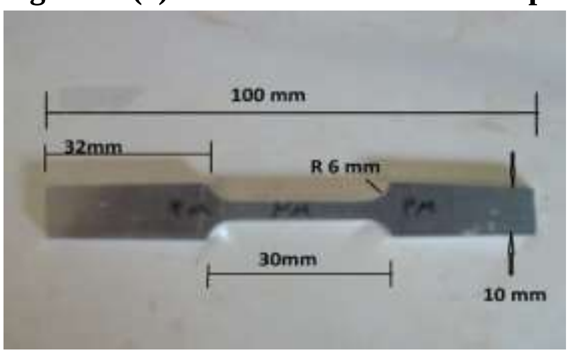


Figure 2. (a) Friction Stir Welded Sample



(b). Schematic diagram of the micro tensile test testing sample.

2.4 Tensile Strength Analysis

Jayaraman, M and V. Balasubramanian was made to study the effect of FSW process parameters on the tensile strength of cast A356 aluminium alloy. Joints were made using different combinations of tool rotation speed, welding speed and axial force [12].

In this current work the micro tensile strength was measured in a computerized tensile testing machine (WDW 200) having a maximum load of 25 KN. The properties that are primarily measured in a tensile test machine are ultimate tensile strength, maximum elongation. Out of the 28 specimens, 27 welds and one base specimens were prepared as per the standard as shown in figure 4. The ductile fracture took place exactly at the stir zone in the case of all welded specimen. Ultimate tensile strength of all the specimens is calculated through the tension test.

2.5 Measurement of Surface Roughness

Kia Wai Liew, Yu Zorn Chung quoted the study was performed using two different types of tool pin geometry, namely, the cylindrical threaded and the taper threaded pins, across varying rotational speeds and feed rates. The mechanical properties of the processed workpiece were inspected and analyzed in terms of microhardness, microstructure, and surface roughness [13-14].

The present work focus on the surface roughness was measured using a Surfcom Flex 50A Mobile Surface Measuring Instrument surface profilometer (Tokyo Seimitsu Co. LTD, Japan). At a speed of 0.6 mm/sec, the surface roughness is measured in the steady-state region using a cut-off length of 0.25 mm. Six locations—labeled as locations 1 through 6 on the friction stir welded surface—were measured for surface roughness of both the base metal and the friction stir welded surface for each sample. These locations were taken along different paths along the length of the weld, with equal spacing from right to left at intervals of 1.25 mm.

3 Results

3.1 Aluminum Alloy 6063's Chemical Composition (wt %)

With weight percentages shown, the inductively coupled plasma (ICP) analysis of the aluminum alloy AA6063 T6 reveals the elements' chemical makeup. It is important to note that the exact chemical composition of alloy 6063 can vary slightly depending on the supplier, manufacturing method, and specific alloy standards or specifications (e.g., ASTM, EN, and JIS). The obtained ICP-OES result of AA6063 T6 aluminum alloy is closely matching with the standard composition in accordance with UNS standard no. A96063. The weight percentage of various elements is Al- 98.66 %, Mg- 0.549 %, Si- 0.376 % and trace element.

3.2. RSM

Jawdat A. Al-Jarrah focused on the central composite rotatable design with four factors and five levels was chosen to minimize the number of experimental conditions. Empirical relationships were established to predict the yield tensile strength and the hardness of friction stir welded aluminum alloys by incorporating independently controllable FSW process parameters. Response surface methodology (RSM) was applied to optimize the FSW parameters to attain maximum yield strength of the welded joints [15].

The present work involved to optimize the weld strength by adjusting welding parameters. The response variable was ultimate strength, and a Box Behnken design of experiments with 28 inputs was used to suggest statically designed combinations. Three variables were experimentally found to be correlated with ultimate strength, and the minimum and maximum values of strength were 72.5 N/mm^2 and

133.576 N/mm^2 respectively. With a desirability factor of 1, the highest ultimate strength was obtained with a tapered threaded cylindrical tool profile, 1000 rpm spindle speed, and 30 mm/min Y-axis feed. These findings are summarized. In this work, the highest weld strength is achieved by optimizing the welding parameters, such as feed, weld speed, and tool profile, using RSM. Twenty-seven samples were examined, and the results showed that the tensile strength was optimized.

3.3. Micro Tensile Test

Tensile testing is done on the base material (175.61 N/mm^2) and on each of the 27 weld samples on their nugget zone. Peak load, peak stress, displacement at peak load, and strains at peak stress are all measured during this test. Figure 7 illustrates how the tensile strength of different samples varies in response to feed changes. When compared to other welds, the base material has a higher tensile strength. Tensile strength variation is displayed on the graph for spindle speeds of 800, 1000, and 1200 rpm with feed rates of 20, 25, and 30 mm/min. The findings were displayed for various tool profiles, including hexagonal (HEX), square cylindrical (SQC), and tapered threaded (TTH).

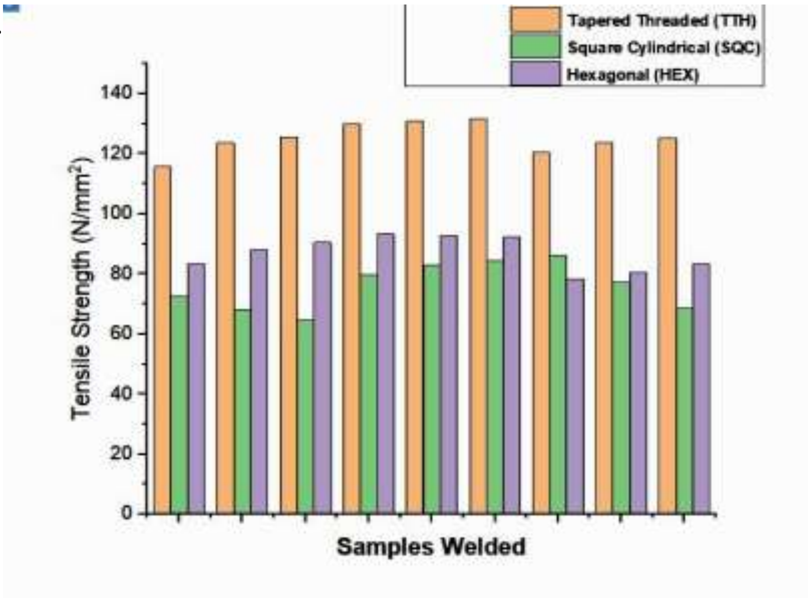


Figure 3. Tensile strength vs Samples welded.

As can be seen from the above findings, different tool profiles, spindle speeds, and table feed rates all had an impact on the tensile strength. The tapered threaded profile with a feed rate of 30 mm/min and a spindle speed of 1000 rpm corresponds to the highest value of tensile strength, which was measured at 131.66 N/mm^2. For more research to examine the impact of feed rate and spindle speed on tensile test, the tapered threaded profile with the highest tensile strength is selected. In order to examine the weld penetration of a chosen sample and its impact on tensile strength, a radiography test was also performed. In fact, tool profiles can be impacted by the tensile strength of friction stir welded (FSW) aluminum 6063 alloy, especially with regard to wear and deformation.

The tool experiences considerable mechanical loads as a result of material flow and heat cycling during FSW. The tapered threaded tool profile yields the best welds with the highest tensile strength out of the three tool profiles employed in this application: hexagonal, square cylindrical and tapered threaded. ***Daniel F.O. Braga***[1] concentrated on identifying the most significant FSW parameters on UTS for all joints and how they interacted with one another[16].The Box Behnken design of studies suggests that the ultimate strength (response) for the statically determined combinations (28 inputs) matches to the three variables that were also established through experimentation. With a spindle speed of 1000 rpm and a Y axis feed of 20 mm/min, the sample characteristics of a tapered threaded cylindrical tool profile yielded the maximum ultimate strength value of 133.576 N/mm^2. It was discovered that every single variable affected the final strength differently. The final strength rises to a significant range when the table feed value, which matches the tapered threaded profile, climbs from 20 mm/min to 30 mm/min. As a result, the tool with the tapered threaded profile is the more important one and has a greater weld strength value.

54.27% represents the difference between the weld strength and the minimum and maximum range. Furthermore, 74.85% is the joint efficiency.

3.3.1 Effect of Tensile Strength on Feed Rate and spindle speed

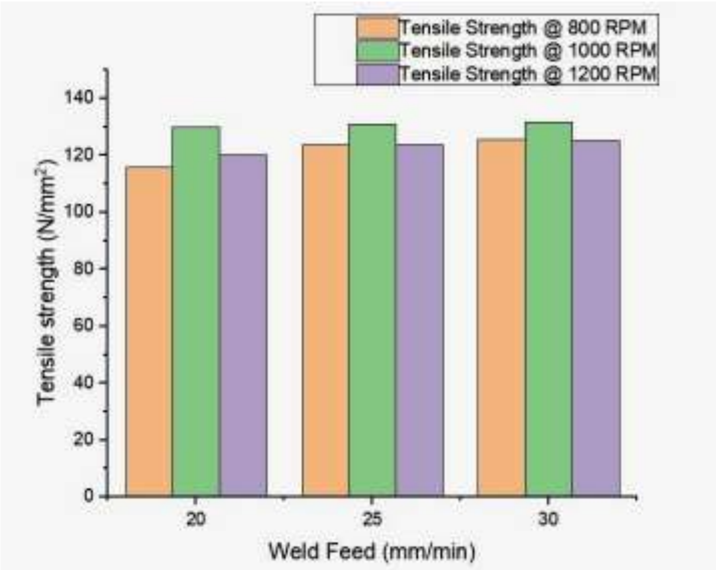


Figure 4. Tensile strength vs Table Feed corresponds (800 -1200 rpm) with TTH tool profile

Figure 8 illustrates how feed rate and spindle speed affect the tapered threaded sample's tensile strength. Table feed was shown to be impacted by tensile strength, with a little increase in spindle speed at lower feed rates. Tensile strength was shown to have an effect on spindle speed; it rose somewhat for each tool profile variation and as feed rate dropped. In this case, the highest value is 131.66 N/mm^2, which is consistent with a 20 mm/min feed rate, a 1000 rpm spindle speed, and a tapered threaded tool profile (TTH). Through its effects on material properties, residual stresses, tool wear, surface finish requirements, and machining technique, weld quality indirectly influences spindle speed.

3.4. Surface Roughness measurement:

Satish Chinchanikar, Swaroop Gharde , Mahendra Gadge focused on the mechanical behaviour of Aluminium 6063 alloy (AA6063) FSW joints in terms of tool forces, weld bead micro-hardness and surface roughness was investigated varying the welding parameters, namely the welding speed and feed which were varied in the range of 385–960 rpm and 18–45 mm/min, respectively. It has been observed that tool forces and hence, the surface roughness decreases with increase in welding speed and feed. Lower tool forces at higher values of welding speed and feed can be attributed to increase in temperature at weld bead resulted in softening of the material at higher welding parameters. [17]

In order to support the consistency of the data collected, roughness data were gathered for a single set of samples with varying table feed and the results were compared between spindle speeds, as shown in figure 5. The optimized profile of the FSP tool (TTH) from RSM used, along with all ranges of rotational speed and feed, are represented by the arithmetic roughness, Ra, data for six locations of various feed combinations.

The results of surface roughness are shown in table 3. These results suggest that feed rate is a more important factor than spindle speed in determining surface roughness for the tapered threaded tool used in this experiment. As with any experimental result, it's important to consider the specific material, tool, and operating conditions used in these experiments.

The tool displays a reasonably consistent roughness pattern along with measured location, according to the graphical analysis of roughness for TTH. The friction stirred surfaces provided by TTH tool have consistently lower Ra values, which makes them smoother and better suited for certain applications. Ra was consistently recorded at 0.822μm for the TTH tool at a feed rate of 20 mm/min and 1000 rpm, while at other feed rates, it was 2.315μm (25 mm/min) and 3.752μm (30 mm/min).

FSP Parameters		Taper Threaded Tool (TTH)		
Rotational Speed	Feed Rate	Max. Ra	Max. Rsk	Max. Rz
(RPM)	(mm/min)	(μm)	(μm)	(μm)
800	20	2.307	76.025	11.021
800	25	4.021	86.147	13.712
800	30	4.752	96.323	16.231
1000	20	0.822	8.163	4.363
1000	25	1.616	9.621	13.712
1000	30	1.723	10.221	16.231
1200	20	2.315	10.682	7.125
1200	25	3.752	9.621	4.983
1200	30	2.452	10.221	5.528

Table 3. Maximum values for Skewness (Rsk), Average Peak-Valley (Rz), and Arithmetic Roughness (Ra)

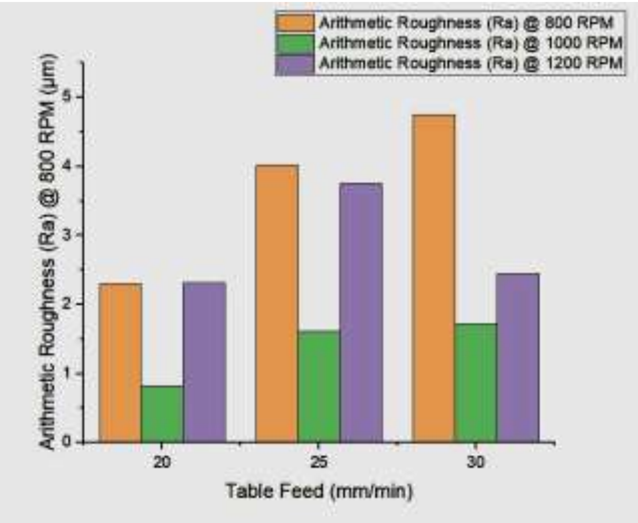


Figure 5. Comparison of Ra value using TTH tool at, (a) 800 rpm, 20 mm/min, (b) 1000 rpm, 20 mm/min, and (c) 1200 rpm, 20 mm/min.

Table 4: Tapered Threaded Tool Profile at 800 RPM

Welding Feed **(mm/min)**	Surface Roughness, **Ra (µm) Xi**	Deviation from Mean (**Xi - X̄**) **X̄ =3.69**	**(Xi - X̄)²**
20	2.307	-1.386	1.921
25	4.021	0.331	0.109
30	4.752	1.062	1.127
Standard deviation = √[3.157/3]= 0.888 µm			

Table 5: Tapered Threaded Tool Profile at 1000 RPM

Welding Feed **(mm/min)**	Surface Roughness, **Ra (µm) Xi**	Deviation from Mean (**Xi - X̄**) **X̄ = 1.387**	**(Xi - X̄)²**
20	0.822	-0.565	0.319
25	1.616	0.229	0.052
30	1.723	0.336	0.1128
Standard deviation = √[0.4838/3]= 0.1612 µm			

Table 6: Tapered Threaded Tool Profile at 1200 RPM

Welding Feed **(mm/min)**	Surface Roughness, **Ra (µm) Xi**	Deviation from Mean (**Xi - X̄**) **X̄ =2.839**	**(Xi - X̄)²**
20	2.315	-0.524	0.274
25	3.752	0.913	0.833
30	2.452	-0.387	0.149
Standard deviation = √[1.256/3]= 0.418 µm			

Rajesh Kumar Bhushan[1] and Deepak Sharma. Shows the attainment of the maximum tensile strength, micro hardness, and minimum surface roughness during FSW is a desired method to improve the service life and suitability of AA6061-T651 [18].

The present results obtained from table 4-6, indicates that the standard deviation value of 0.1612 µm surface roughness value be the least one. As the spindle speed is directly proportional up to an optimal speed, beyond which the surface roughness will raises. Hence weld surface with tapered threaded tool profile, weld speed of 1000 rpm, with 20 mm/min of table feed be the optimal result.

4 Discussions

4.1 Chemical Composition:

AA6063 is a popular aluminum alloy known for its good extrudability and high corrosion resistance. The T6 temper indicates that the alloy has undergone heat treatment to achieve a solution heat-treated condition, followed by artificial aging to improve its mechanical properties.

4.2 *RSM*

Doude H, J. Schneider, B. Patton, reported the series of welds were completed at various processing parameters for a threaded tool in butt friction stir welded (FSWed) panels of AA 2219-T87 to determine the optimal welding parameters. The panels were sectioned transversely along the entire panel and characterized by tensile tests, hardness, and macrostructure imaging. An optimal parameter window was chosen based on the UTS, hardness, changes in the weld forces, and the presence of volumetric defects [19-22]

In the present work, there are the statistical parameters obtained from the generated model for ultimate tensile strength in the FSW process: R-Squared: 0.9785, which indicates a high degree of fitness between the actual and predicted values of UTS. The adjusted R-squared, or R-squared adjusted for the number of predictor variables in the model, is 0.9526. It implies that the independent variables account for roughly 95% of the variability in UTS. Based on the validation data set, the model's predicted R-Squared, or ability to predict, is 0.8253. It implies that the model can predict UTS with a reasonable degree of accuracy.

The score of 15.934 indicates that the model's ability to navigate the design space is adequate. It suggests that the model can separate out noise from important effects of process parameters on UTS. These parameters collectively imply that the generated model can reasonably be used to predict UTS and is a good fit for representing the process parameter conditions in FSW.It is suggested that the generated model is statistically significant by the Model F-value of 34.51. Merely 0.01% of the F-value obtained could have been caused by noise, suggesting that the model terms exert a substantial influence on the response variable. A (tool profile), A^2 (square of tool profile), and B^2 (square of spindle speed) are the only significant terms in the model, according to the p-values for the individual terms. This implies that the tensile strength is most significantly influenced by these variables.

With a friction stir welded tool profile of tapered threaded (TTH), the best combination of process parameters was found to be a spindle speed of 1000 rpm and a table feed of 20 mm/min. With a percentage error of 1.455%, this combination produced the highest tensile strength of 133.576 N/mm^2. The optimal value of the results is made easier to see with the help of the desirability graph below.

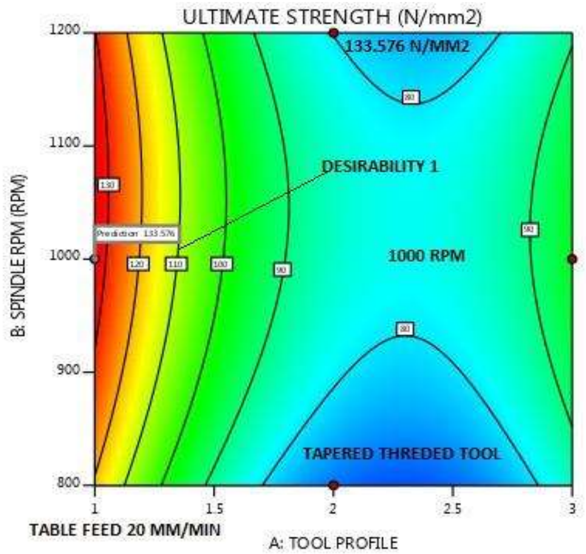


Figure. 7: Desirability Graph

Jinewen Qian, Jinglong Li, Fu Sun focused on an analytical model which is proposed and tested for optimizing rotation speed and travel speed for defect-free joints. The model is based on the principle of exactly balancing the material flowing from the region ahead of the pin to the rear with an optimum temperature [23-25].In cases where there are many insignificant model terms; model reduction may improve the model by eliminating noise and improving its accuracy.

4.2.1 Effect of variables

Mohamed Mohamed Abd Elnabi , developes a statistical optimization based on experimental work was conducted to consider ultimate tensile strength (UTS) and elongation of dissimilar joints between AA5454 and AA7075 by friction stir weld (FSW). The goal of this work is to develop a comparative study of the optimization of FSW parameters using different orthogonal arrays [26-27].

In the present analysis the desirability graph shown in Figure 11 illustrates the effect of individual variables on the ultimate strength of the welds when all other variables are kept at their optimum level. It was found that each variable had its own effect on the ultimate strength. Specifically, when the table feed was increased from 20 mm/min to 30 mm/min, corresponding to the tapered threaded tool profile, the ultimate strength increased significantly. This suggests that the tool with the tapered threaded profile is the more significant variable that contributes to higher weld strength.

Overall, these results highlight the importance of carefully selecting the appropriate process parameters in friction stir welding to achieve the desired weld strength. The desirability graph can be a useful tool for identifying the optimal combination of process parameters for a given application.

4.3 Micro Tensile Test

It's worth noting that this result is consistent with the other experiments mentioned, which also found that the tapered threaded tool profile produced the highest tensile strength values, at different spindle speeds and feed rates. This suggests that the geometry of the tapered threaded tool profile is particularly well-suited for maximizing tensile strength under the conditions tested.

As with any experimental result, it's important to consider the specific material, tool, and operating conditions used in these experiments, and to evaluate the results in the context of other relevant research and industry standards. Nonetheless, these results provide valuable insights into how different machining parameters can affect material properties such as tensile strength.

4.4 Surface Roughness measurement:

The least value of roughness was stipulated Ra as 0.822 corresponds to 20mm/min feed rate with 1000 rpm. The Ra values vary 1.616 corresponds to 1200 rpm, the percentage rise of Ra has been recorded as 96.59%, the surface roughness value raises due to gas entrapping during the welding process as the speed increases beyond an optimum speed. Similarly The Ra values vary 2.307 corresponds to 800 rpm, the percentage rise of Ra has been recorded as 42.75%. So the average percentage rise of Ra varies from 1200 rpm to 800 rpm has recorded 69.67% corresponds to 20mm/min feed rate. Similarly, the average percentage rise of Ra varies from 1200 rpm to 800 rpm has recorded 34.12% corresponds to 25mm/min feed rate. So the average percentage rise of Ra varies from 1200 rpm to 800 rpm has recorded 39.83% corresponds to 20mm/min feed rate. The weld with table feed rate of 20 mm/min exhibits more surface finish or least value of Ra, vice versa irrespective of spindle rpm.

5. Summary and Conclusions

In summary, it can be observed that FSW is capable of enhancing the micro tensile strength properties of AA 6063similar joints. The results showed that FSW improved the micro tensile strength properties of the joints, and that the tapered threaded tool produced higher mechanical and surface properties than the other two tool profiles. In particular, the optimal micro tensile strength was obtained at 1000 rpm and 20 mm/min. The results indicates that the standard deviation value of 0.1612 µm surface roughness value be the least one. As the spindle speed is directly proportional up to an optimal speed, beyond which the surface roughness will raise. Hence weld surface with tapered threaded tool profile, weld speed of 1000 rpm, with 20 mm/min of table feed be the optimal result The TTH tool yielded the smoothest surface with consistently lower Ra values, which makes it perfect for structural applications. Additionally, the study discovered that the feed rate had a greater impact on surface roughness than spindle speed and that raising the feed rate could further improve Ra values because higher temperatures soften the material that comes into contact with the tool shoulder. On the other hand, the material flow was inadequate with the square cylindrical tool, and the surface roughness increased with increased rotational speed.

Overall, the results indicate that the TTH tool outperforms the SQC tool in terms of micro tensile strength and surface roughness, and that the optimal results are obtained when the feed rate is 20 mm/min and the spindle speed is 1000rpm. . It has been concluded that tool forces directly affects the surface roughness, decreases with increase in welding speed and feed. As the welding speed increase the surface roughness will reduces and beyond a particular spindle speed the surface quality will decrease due to gas entrappement during welding. Hence the spindle speed with 1000rpm is the optimal rpm for tapered threaded tool profile. Lower tool forces at higher values of welding speed and feed can be attributed to increase in temperature at weld bead resulted in softening of the material at higher welding parameters.

Conflict of Interest

This version of the article has been reviewed and approved by all authors, and great care has been taken to maintain the integrity of the work. The authors declare that none of the work reported in this paper could have been influenced by any known competing financial interests or personal relationships. This paper has not been submitted for review to any other journal; it is our original, unpublished work.

Author’s contribution statement

The authors confirm contribution to the paper as follows: Study conception and design: Pramod Ramakrishnan[1], M.R Radhakrishna Panicker [2]. Data collection: Pramod Ramakrishnan[1]. Experimental analysis and interpretation of results: Pramod Ramakrishnan[1], M.R Radhakrishna Panicker[2], Ajin C Sajeevan[3], Biju N [4]. Draft manuscript preparation: Pramod Ramakrishnan[1], M.R Radhakrishna Panicker[2], Ajin C Sajeevan[3] and Biju N [4]. All authors reviewed the results and approved the final version of the manuscript.

Statement of Data Availability

Upon request, the corresponding author Pramod Ramakrishnan[1] will provide the data supporting the study's findings.

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