Friction Stir Welded Joints Using Grey Relational Analysis

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Abstract

This paper investigates the effect of the tool pin profile and friction stir welding parameters on the microstructure and mechanical properties of the 6061 aluminum alloy welded joints prepared by friction stir welding. It has been found that a fine grain microstructure obtained by hexagonal pin profile. But using a square pin profile produced a higher strength welded joints. FSW process offers a potential advantage in manufacturing industries to eliminate mechanical fastening such as riveted or bolted joints. The maximum tensile strength achieved was 29.65MPa while welding at 1600rpm with 40 mm/min feed using the hexagonal tool. The analysis of variance for the tensile result concludes that the tool profile is the most significant parameter with a percentage of 36.45 %, followed by the feed of 8.62 % and spindle speed 10.22 %. Friction stir welding is applied successfully for AA6061 T6 grade aluminum alloy by milling machine.

Key words: Friction Stir welding, Aluminum Alloy, Pin profile, Tensile

I. Introduction

Friction stir welding is a solid state welding process developed by Wayne Thomas at The Welding Institute (TWI) in 1991. The research was funded in part by the National Aeronautics and Space Administration (NASA) in an effort to find a welding method that would not add weight to orbital spacecraft. A major advantage of friction stir welding is that it is a solid state weld where the base material does not reach the melting point. Therefore, it does not exhibit the same deficiencies as fusion welding, which is associated with cooling from the liquid phase. Other benefits of friction stir welding include the ability to make welds in “hard-to-weld” materials and in dissimilar metals. It also eliminates toxic fumes which makes it much more environmentally friendly than fusion welds [1]. Friction stir welding is extensively used by NASA to join large portions of aluminum for their space shuttle external fuel tank at the Michoud research facility. It is the preferred NASA welding technique for their moon rocket. As friction stir welding advances and is used in more applications, tool materials will need to be selected for optimal weld efficiency. This thesis will determine the significance a tool material has on the mechanical properties of a friction stir weld in 5083-H131 aluminum[2].

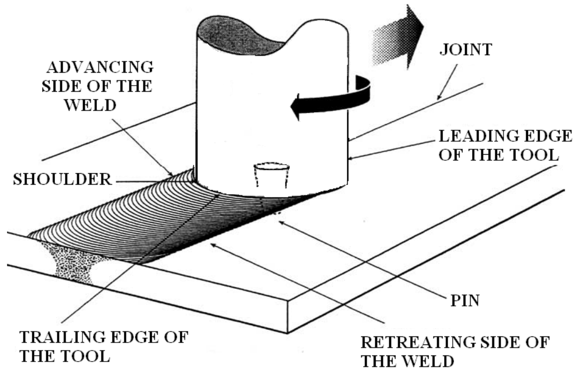

Figure 1 Friction Stir Welding Process [2]

The difference in the friction stir welds will be compared directly to both MIG welds and the parent material.

A fixture was developed which allowed welds to be performed in a vertical CNC machine. Test samples were cut from the work piece for visual evaluation, tensile, bend, and hardness testing. Welds produced by three different tool materials were compared: H13 tool steel, 420 stainless steel, and A2 tool steel. The system developed at Auburn University, with support from Anniston Army Depot and NASA's Marshal Space Flight Center, uses a threaded pin and scrolled shouldered tool to perform welds as detailed in Figure 1 [2]

The following research paper is designed as follows. Section II describes friction stir welding procedure whereas Section III gives idea of problem formulation. Performance parameter defines in section IV and last but not the least Section V concludes the paper.

II. Friction Stir Welding Procedure

9 experiments had been performed on AA6061 T6 grade aluminium alloy plates. The three factors used in this experiment are the rotating speed, feed and tool pin profile. The elements and the levels of the process parameters are presented in table 1. The experiments are completed on a vertical milling machine.

A rotating device is plunge as much as the shoulder within the abutting edges of aluminium plates having dimensions are 100 mm x 50mm x 5mm (L x b x t) respectively. Those plates have been placed on fixture in a manner that the displacement of plates in the course of welding and fasten them along the travel line of welding tool. The velocity difference among the rotating tool and the stationary work piece, heat is produced through frictional work and deformation of aluminium. This deformed material fused as a single piece creates a joint. To perform the welding, the rotating tool is traversed alongside the line, at the same time as the shoulder of the tool is maintained in intimate contact with the plate surface. Shoulder confirms the underlying material so void formation and porosity behind the probe are averted. As the heat dissipated into the surrounding material, the temperature rises and material softens without reaching the melting point (for this reason known as solid state process). as the pin is moved within the path of the welding leading face of pin, assisted with the aid of a precise pin profile, forces plasticized material to the again of the pin while making use of a large forging pressure to consolidate the weld steel. While the weld distance is protected, the tool is pulled out of the work piece leaving in the back of a hole as a foot print of the device. The following figure 2 contains the sample prepared by friction stir welding.

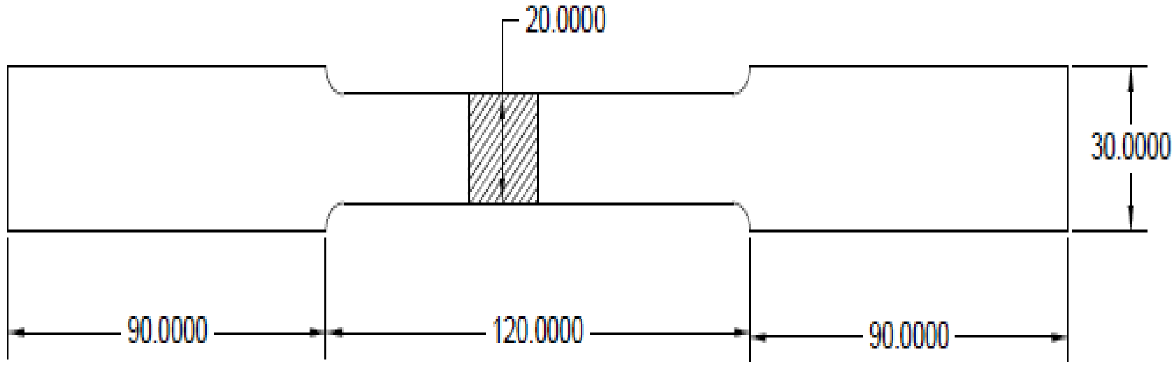

Figure 2 Sample dimension for FSW (all dimensions in mm)

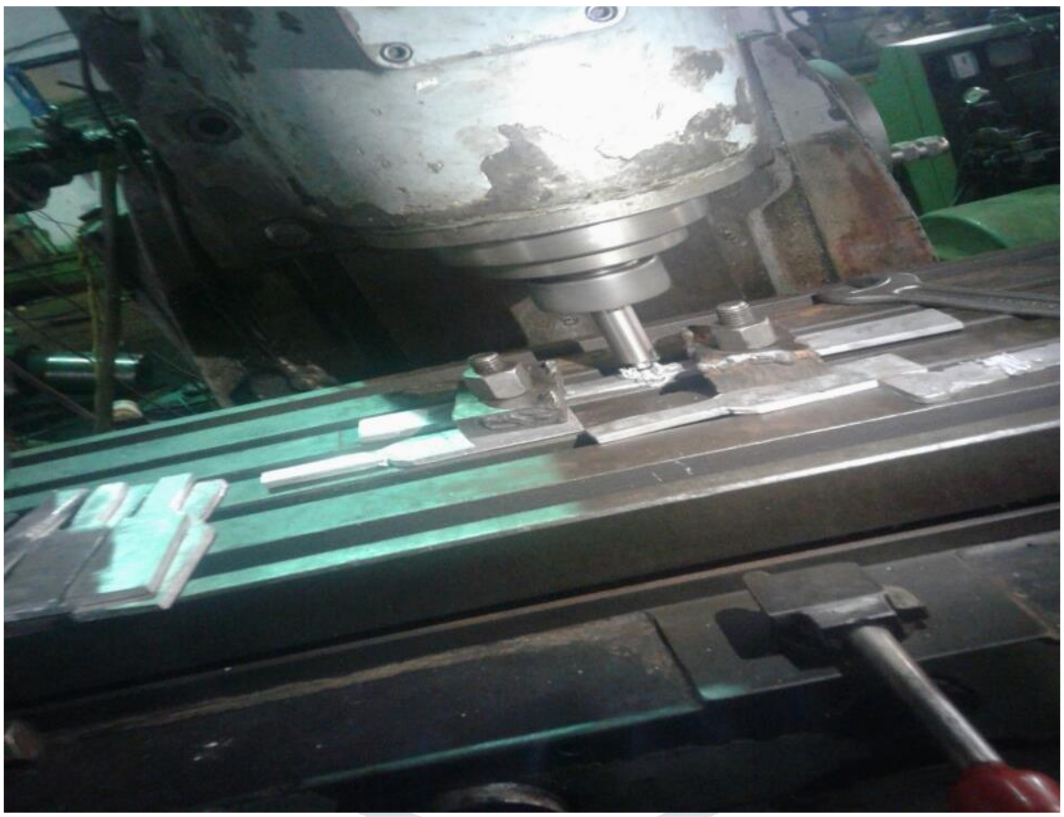

Figure 3 Rotating tool is ready for friction welding

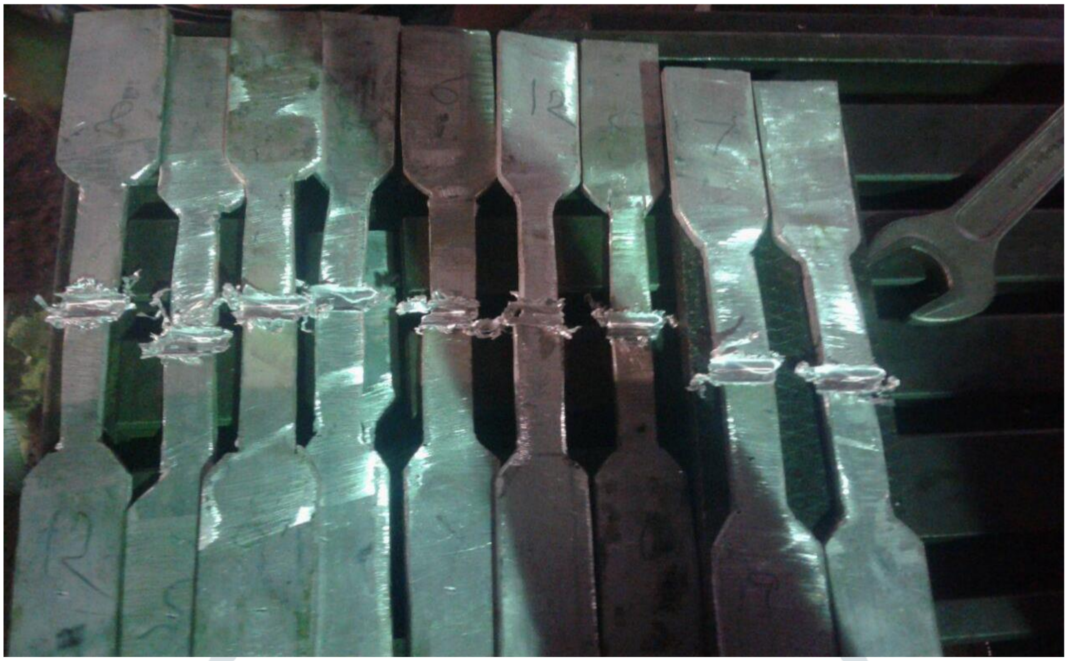

Figure 4 Friction stir weld samples

III. Weld Testing Procedure

After friction stir welding, tensile test is performed on universal testing machine. If A is the cross sectional area and F is the maximum force and tensile strength calculated by: Tensile strength=F/A

Figure 5 Process setup for tensile test

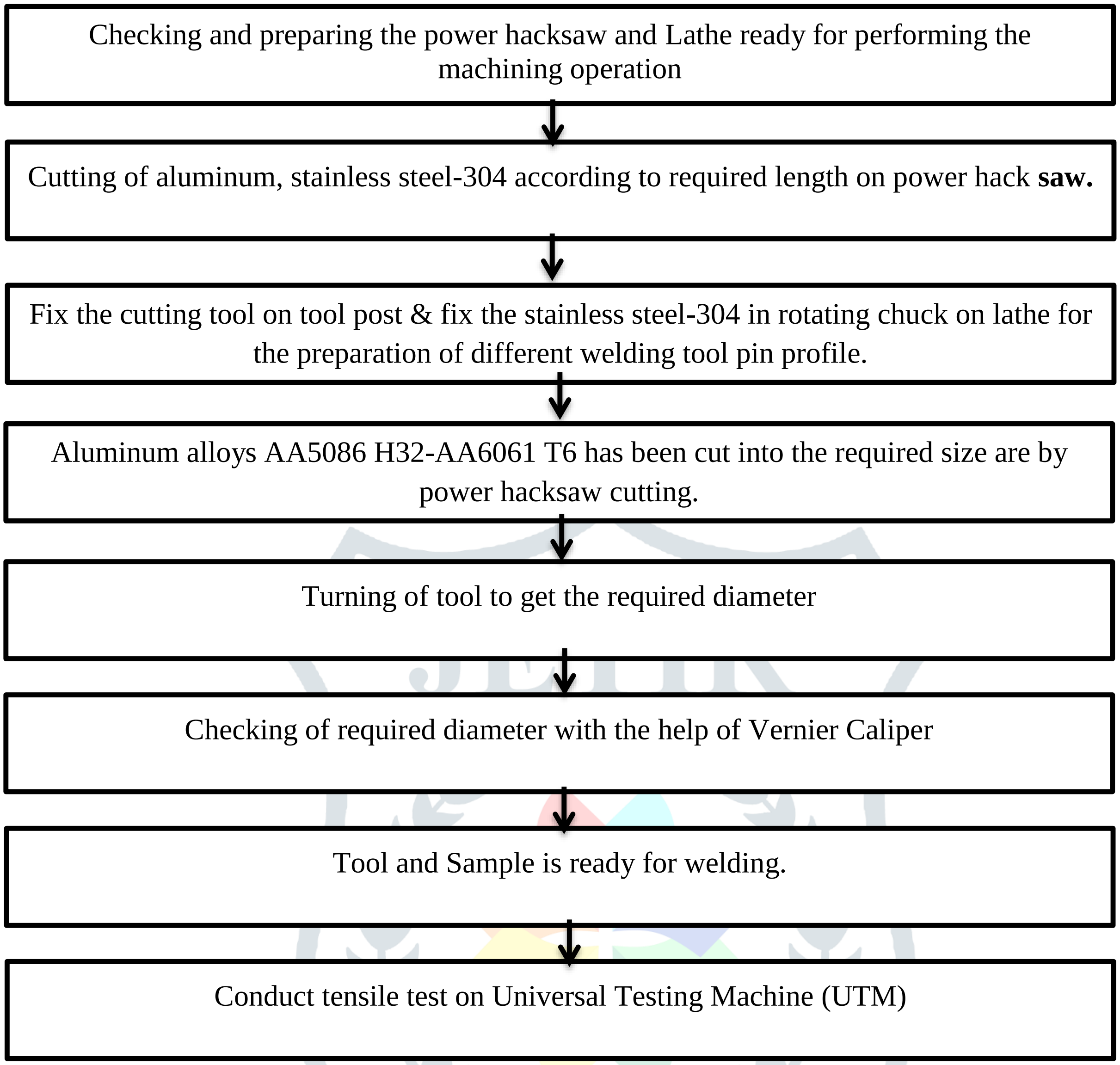

Figure 6 Process flow of the experiment

IV. MATERIAL USED

The current experimental research is a try to discover the feasibility of using FSW method in joining AA6061 T6 grade aluminum alloy sheets of 5 mm thickness. Two work pieces of size 300 mm x 30mm x 5mm are joined collectively to make butt joint. The composition and material properties of aluminum alloys are given in table:

Table 1 Chemical Composition by wt%

Material	Mg	Mn	Si	Fe	Cu	Zn	Cr	Ti	Al
AA6061-T6	0.91	0.09	0.52	0.32	0.21	0.095	0.11	0.04	Balance

Table 2 Mechanical Properties of AA6061-T6

Material	UTS (MPa)	Yield Strength (MPa)	% Elongation	Hardness (HV)
AA6061-T6	312	240	26	107

Welding Tool Material

The tool geometry plays an important role in FSW process. Localized heating and material flow are the two basic functions of FSW tool. Tool is used in this study is made of high-speed tool steel. This is the most commonly used material due to easy availability, thermal fatigue resistance, wear resistance, especially for aluminum and copper.

The selected tool geometries and the fabricated tool for FSW of 5 mm thick aluminum alloy is manufactured using lathe.

In the current study, the three types of tool profiles were designed and applied; namely,

- Hexagonal tool profile
- Triangular tool profile
- Square tool profile

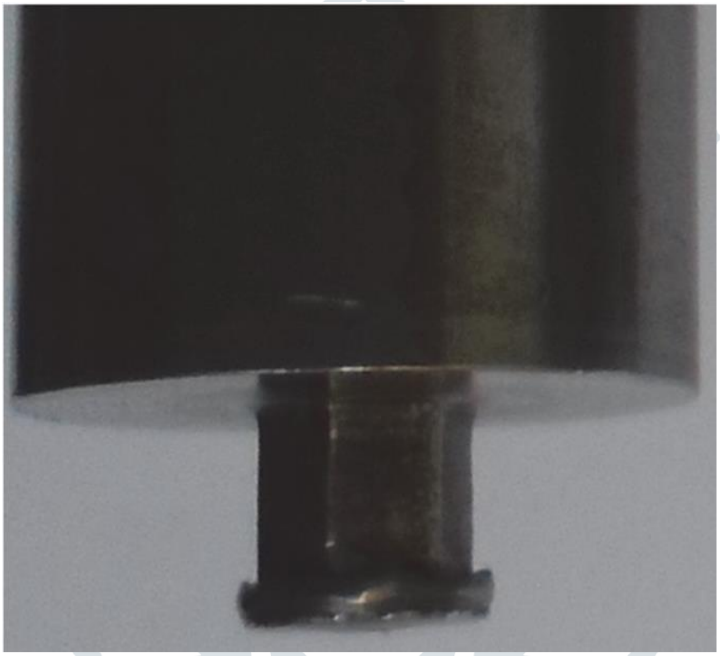

Figure 7 Pin profile setup

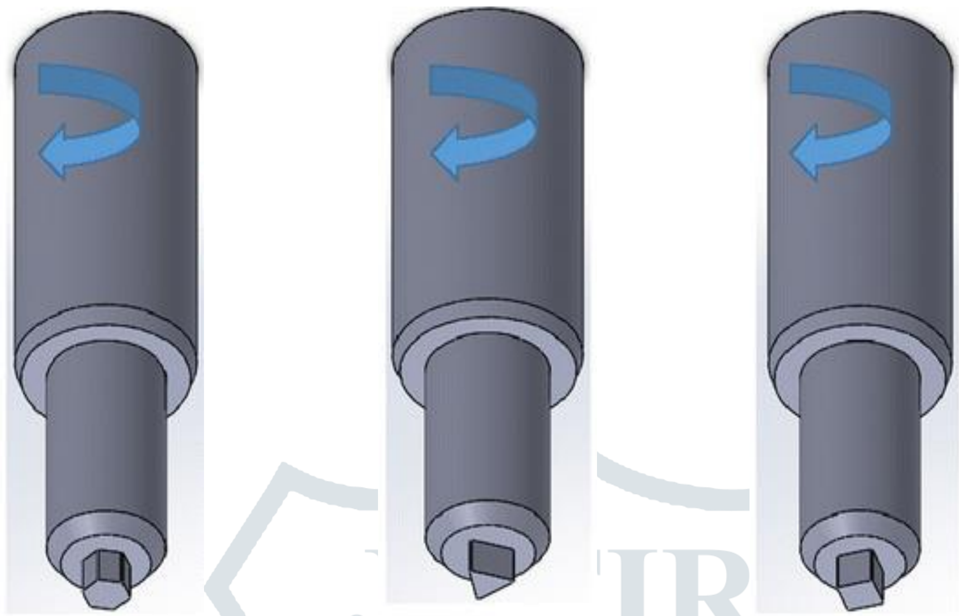

Figure 8 Different cases of pin profiles hexagonal, triangular and square shaped

V. EXPERIMENTAL SET-UP

To set off the FSW experiment a vertical milling machine is used. The tool is fix inside the vertical arbour using the perfect collates. The plates to be connected are clamped to the horizontal bed with nil root gaps. The clamping of the check pieces are executed such that the strength of the plates is definitely constrained beneath each plunging and translational forces of the FSW tool.

Table 3 Specification of Milling Machine

Manufacturer	(PACMILL) Simple milling machine
Spindle position	Vertical position
Max. rpm	4800
Diameter of Tool Holder	18mm
Motor	4 Horse Power(hp), 1400 rpm
Longitudinal Transverse speed Range	15-900 /min

Figure 9 Rotating tool loading in milling machine

VI. Result Analysis

The results for tensile strength were obtained from the 9 experiments performed of Taguchi. The experimental results analyzed with ANOVA are shown in the Table 4. The F value calculated through MINITAB 15 software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%). The results show that only spindle speed is the most significant factor. In the Table 5 ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor.

Table 4 Analysis of Variance for Means of tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Spindle Speed (rpm)	2	1.1088	1.1088	0.5863	0.22	0.805	10.18%
Feed rate (mm/rev)	2	0.9534	0.9534	0.4549	0.20	0.819	9.23%
Tool Profile	2	3.9828	3.9828	1.8715	0.81	0.81	82.12%
Error	2	4.6308	4.6308	2.4721			
Total	8	10.6758					
S = 1.5612 R-Sq = 56.48% R-Sq (adj) = 0.35%							

Table 5 Response table for means for tensile strength

Level	Spindle speed (rpm)	Feed rate (mm/min)	Tool profile
1	25.75	25.47	25.72
2	26.20	25.72	25.20
3	25.25	26.06	26.54
Delta	0.83	0.7	1.45
Rank	2	3	1

A. Main Effect Plots For Tensile Strength

Main effect plots for tensile strength are shown in the figure 10. Main effect plot shows the variation of tensile strength with respect to spindle speed, feed rate and tool profile. X axis represents change in level of the variable and y axis represents the change in the resultant response.

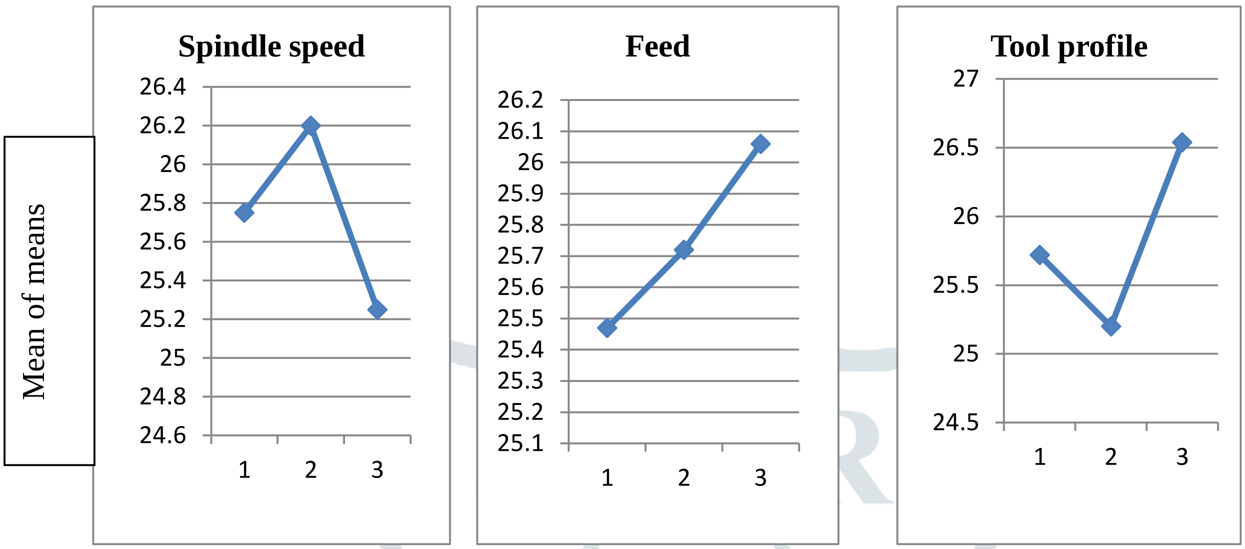

Figure 10 Main effects plot for means for tensile strength

B. Analysis of S/N Ratio For Tensile Strength

The signal to noise ratios tells us about the deviations present in the process. The values of all the results according to Taguchi array parameter design layout are presented in this section. The S/N ratios have been calculated to identify the major contributing factors for variation of values. In this design situation, bigger-the-better is used.

Table 5.3 shows the ANOVA calculations for the S/N ratio. The analysis was carried out at a significance of α=0.05. Table 5.4 shows the response table for S/N for tensile strength. Ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor. It was found that only spindle speed is a significant factor with F value of 11.12.

Table 6 Analysis of Variance for S/N ratio for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Spindle Speed (rpm)	2	0.12466	0.8652	0.4176	1.28	0.458	10.21%
Feed rate (mm/rev)	2	0.08965	0.8286	0.4264	1.23	0.462	8.54%
Tool Profile	2	0.42396	0.3228	0.1751	0.57	0.678	36.50%
Error	2	0.51754	0.6745	0.3576			
Total	8	1.15581					
S = 0.5983 R-Sq = 74.83% R-Sq (adj) = 0.23%							

Table 7 Response table for S/N ratio for tensile strength

Level	Spindle speed (rpm)	Feed rate (mm/min)	Tool profile
1	28.43	28.41	28.50
2	28.56	28.43	28.22
3	28.21	28.75	28.74
Delta	0.30	0.33	0.65
Rank	2	3	1

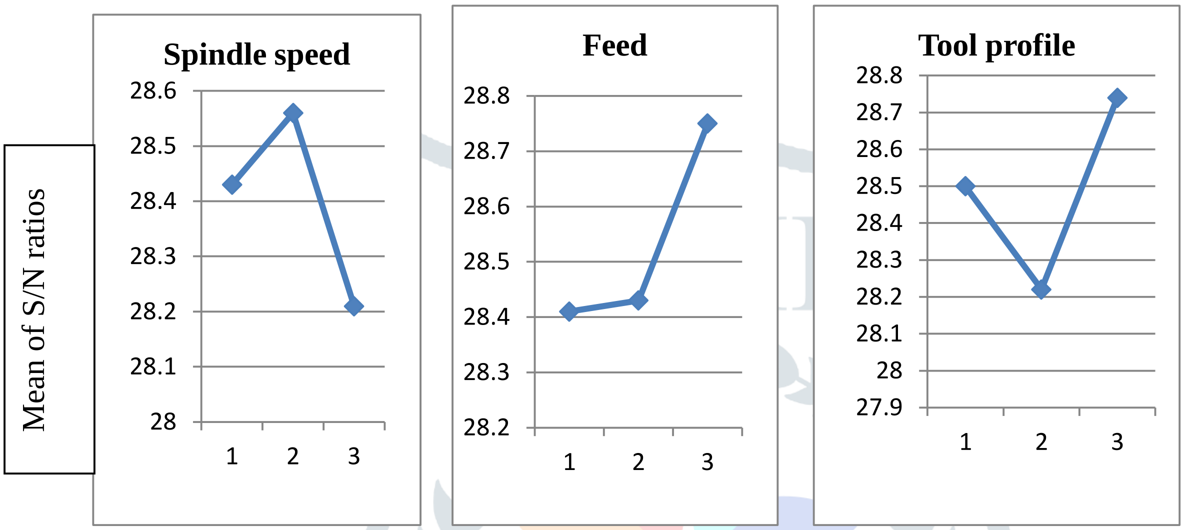

Figure 11 Main effects plot for S/N ratio for tensile strength

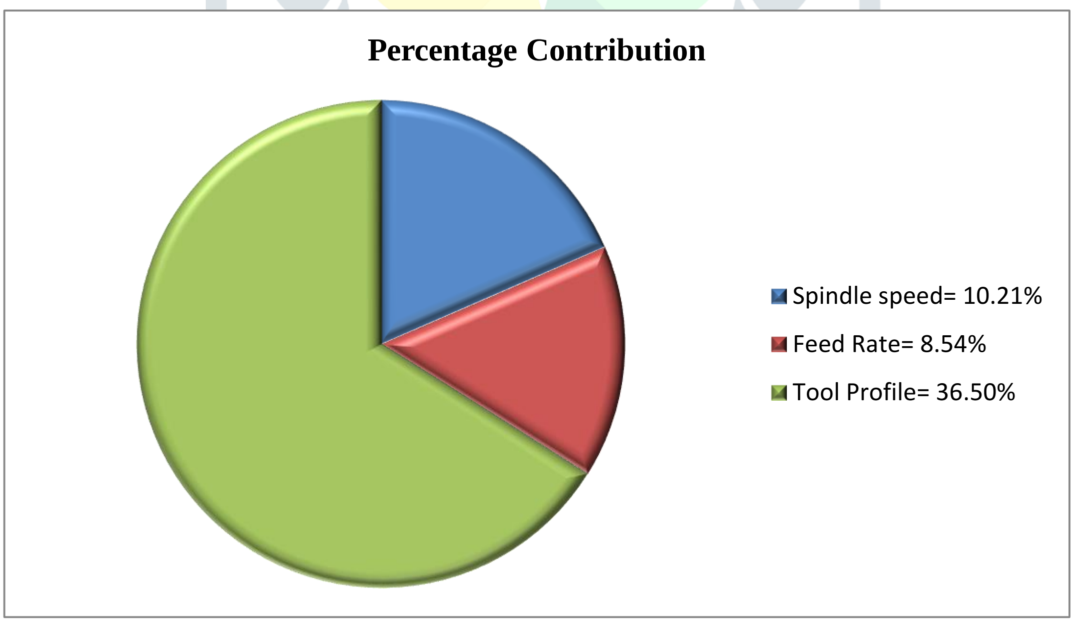

Figure 12 Percentage contributions of process parameters on tensile strength

C. Pie-chart

Pie- chart is used to describe the percentage contribution in a graphical manner to clearly distinguish the contribution of parameters- spindle speed, feed rate, tool profile including error. This is described below.

1. Spindle speed- It is denoted by dark blue colour, it contributes only 10.21 % which is the minimum.
2. Feed rate- It is denoted by red colour, it contributes 8.54 % which is the maximum contribution.
3. Tool profile - It is denoted by green colour, it contributes only 36.50 % which is the maximum contribution. It is mainly responsible to affect the tensile strength of work piece.

VII. Conclusion

It can hence be concluded that use of round tool profiles yield better results than that of the square tool and round with thread tool profiles. The tensile strength increases with increase in the tool feed. The optimum value of process parameters such as spindle speed, feed rate and tool profile are found to be 1300 rpm (level 2), 60 mm/min (level 3) and square tool pin (level 3) respectively. The maximum tensile strength achieved was 29.65MPa while welding at 1600rpm with 40 mm/min feed using the hexagonal tool. The analysis of variance for the tensile result concludes that the tool profile is the most significant parameter with a percentage of 36.45 %, followed by the feed of 8.62 % and spindle speed 10.22 %. Friction stir welding is applied successfully for AA6061 T6 grade aluminum alloy by milling machine.

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