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Optimization of Process Parameter on Friction Stir Welding on Aluminium Alloy 6061 Using Taguchi Method

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This research looks at the friction stir welding process and how it works on AA6061 plates, a material that is difficult to weld with traditional fusion welding. By using three different tool pin diameters with varying welding parameters, the objectives are to to determine the optimum process parameter of the friction stir welding on aluminum 6061 using Taguchi method. The Fiction Stir Welding (FSW) is the alternative method for joining two pieces of metal together without destroying the microstructure of the aluminum alloy 6061. The problem with this method is that there was not many research where it has found the optimum parameter for the Friction Stir Welding process for aluminum alloy 6061. It will take a great amount of material, time and work force to classify the optimum parameter. Tools with pin profile of cylindrical, squared, and triangular which were manufactured by using a normal lathe machine. The welding processes were carried out using a conventional milling machine. The triangular pin was identified as the most effective shape for welding at high speeds. This was attributed to its unique three side design which increases the amount of plastic deformation and stirring of the workpiece to process the workpiece material at an increased rate. The optimum process parameter of the friction stir welding on aluminum 6061 is triangular pin profile, 1583 rpm and 20.09 mm/min.

Keywords: Friction Stir Welding, Optimization, Taguchi Method

1. Introduction

Friction Stir Welding (FSW) is an alternative method in the joining process which has been invented in the 1991 at The Welding Institute (TWI) located in the United Kingdom, UK. FSW is a solid-state joining technique that we apply to material that has been classified as difficult to weld together by using the conventional fusion welding process. One of the materials that fall in this category is aluminum alloy because of factors such as the poor solidification microstructure and porosity in the

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fusion zone. The FSW can be stated as a fairly simple joining process concept where the process consists of applying friction between the two plates with the rotating tool pin. The friction will generate heat and cause plastic deformation to occur on the joining workpiece. The primary tools for the FSW are the tool pin and the shoulder. The tool is inserted between the two workpieces and it will be traversed along the joining line of the workpiece. There are two primary functions of the FSW tools which are to produce heat for the workpiece and the material to produce the joining zone.

There are many materials that have been classified as a material which is difficult to weld to their properties. When applying the conventional Tungsten Inert Gas (TIG) and the Metal Inert Gas (MIG) to the joining material, it will destroy the microstructure itself. Some aluminum falls in this category such as aluminum alloy 6061. Friction Stir Welding (FSW) is the alternative method for joining two pieces of metal together without destroying the microstructure of the aluminum alloy 6061. The problem with this method is that it will take a great amount of material, time, and workforce to classify the optimum parameter. To solve this, the Taguchi Method will be used it has the minimum factor and run for one process to obtain the optimum parameter. There will be various tool geometry of the tool pin used in this FSW process. This is due to a different type of tool geometry that will lead to different results in the surface quality of the welding process. The suitable welding parameters will have to be identified prior to applying the friction stir welding process in the AA6061 plates as if we select the unsuitable welding parameter for the process will result in the lowering performance of the welding process due to its poor quality of surface appearance and will cause defects on the surface of the welding zone. The objective of this study is to determine the optimum process parameter by using the Taguchi method. The outcome of this study is we able to determine the optimum process parameter for the FSW on the AA6061 and design the desired tooltip.

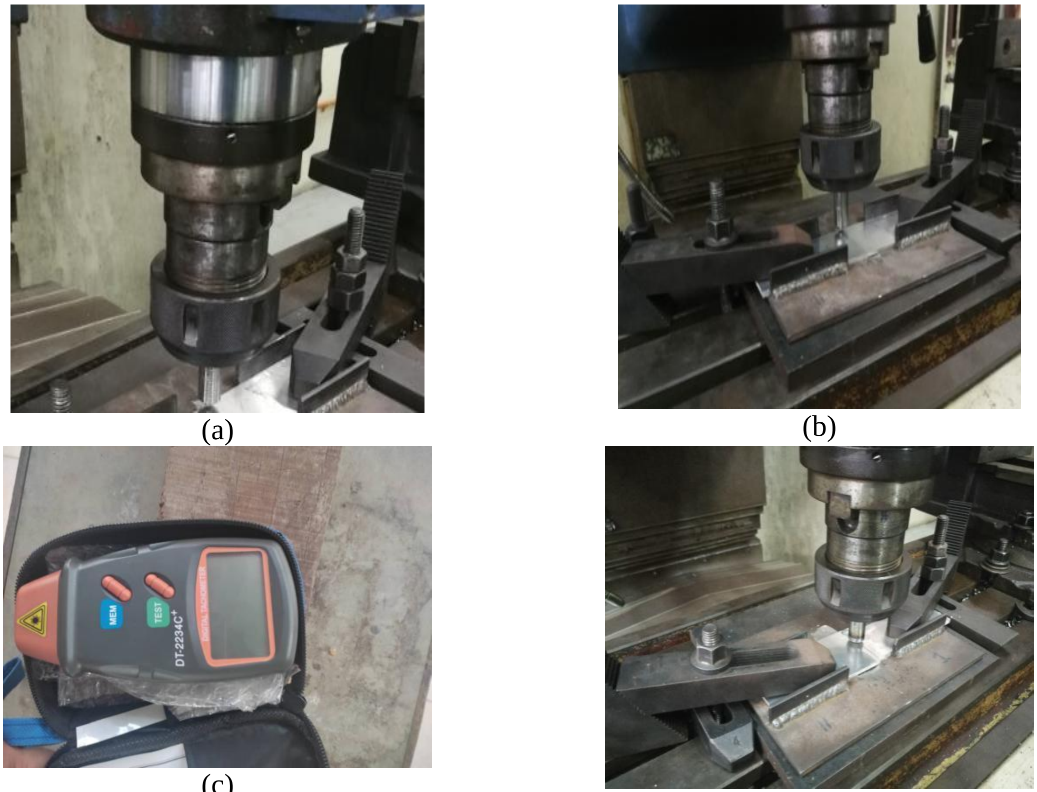
2. Materials and Methods

2.1 Materials

The material used in this study is aluminum alloy 6061 for the metal plate and mild steel for the tooltips. The dimension aluminum alloy plate is 50mm x 28mm x 3mm. The cylindrical mild steel is cut into 3 parts where the shoulder part is the same for all specimens which are 40mm long x 12mm diameter. The tip differs as the triangular tip is 4mm, the cylindrical tip is 5mm and the squared tip is 5mm.

2.2 Methodology

This welding procedure has been prepared as a guide to start the welding process and to avoid any failure that occurs during running the welding process. Procedures of the welding process in this experiment are shown below:



(a) (b) (c) (d)

Figure 1: Methodology

Figure 1(a) shows the FSW tool was plugged and tightened at the chuck of the milling machine. Figure 1(b) shows the workpiece is clamped tightly at the fixture table with square mating edges fixed on the rigid backing plate so that the workpiece will not move during the welding process. Figure 1(c) shows the spindle speed of the rotational tool and traverse speed were set on the control panel at 1583rpm and an average of 15.4mm/min on the machine by using the tachometer. Figure 1(d) shows the slowly plunging of the rotating tool into the joining workpiece until the tool shoulder forcibly contacts the upper surface of the workpiece.

2.3 Design of Experiment

The FSW process parameters such as pin profiles, rotational speed, and traverse speed have a significant influence on the process and have huge roles in its characteristics and its mechanical properties. The study uses the rotational speed of 719 - 1583 rpm and traverse speed set at 8 - 22 mm/min. Two three-level parameters (rotational speed and traverse speed) and one two-level parameter (pin profile). The main factor is taken into consideration. A total of 9 runs were conducted by using the combination of levels for each process parameter. The analysis was carried out by using the MINITAB statistical software.

Table 1: Design of experiment parameter

Pin Profile	Spindle Speed, (RPM)	Traverse Speed, (mm/min)
Cylindrical	719.0	20.09
Squared	795.2	9.82
Triangular	1583.0	15.45

The range of parameters of the pin profile selected is cylindrical, squared, and triangular. The pin profile was selected in account of the prior studies related to the experiment. The spindle speed and traverse speed selected are 719 rpm, 795.2 rpm, 1583 rpm, and 9.82mm/min, 15.45 mm/min, and 20.09mm/min respectively due to the conventional milling machine specification.

2.4 Taguchi Design Analyses

Taguchi experiments often use a 2-step optimization process. Step 1 uses the signal-to-noise ratio to identify those control factors that reduce variability. In step 2, identify control factors that move the mean to target and have a small or no effect on the signal-to-noise ratio.

The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different signal-to-noise ratios, depending on the goal of your experiment. In this experiment, the larger is better is chosen to maximize the response of the modulus young.

3. Results and Discussion

3.1 Tensile Strength Test Analysis

Table 2: Tensile Test Data Summary for the Welded Specimen

Item	Stress	Strain	Modulus Young
Cylindrical 1	138.681	0.0629	3265.29
Cylindrical 2	67.9861	0.0321	2117.95
Cylindrical 3	120.816	0.037	2204.79
Squared 1	84.3316	0.0423	1637.92
Squared 2	67.4913	0.0215	3139.13
Squared 3	84.3316	0.0423	1993.65
Triangular 1	65.1649	0.0198	2556.44
Triangular 2	56.8924	0.0231	3026.19
Triangular 3	59.0538	0.0231	3291.16

According to the result, the specimen Triangular 1 have the lowest strain which means it has smaller elongation compared to other which makes it stronger to withstand higher force. The specimen triangular 1 also has the highest stress which implies it can withstand higher force before breaking down. By calculating the modulus young, the specimen triangular 1 has the highest which makes it the strongest.

The Young's Modulus of a material is a fundamental property of every material that cannot be changed. It is dependent upon temperature and pressure, however. The Young's Modulus or Elastic Modulus is in essence the stiffness of a material. In other words, it is how easy it is bent or stretched.

The Modulus Young will be calculated by dividing the stress by the strain obtained from the tensile strength test. The formula is shown below;

$$E = \frac{\sigma}{\varepsilon} \qquad \text{Eq.1}$$

Where E = Modulus Young, σ = Stress, and ε = strain.

In table 2, the highest Modulus Young is 3291.6 which is the triangular 3. The triangular 3 has the highest stiffness which makes it stronger than the other welded specimen.

3.2 Taguchi Table

Table 3 shows FSW process parameters such as pin profiles, rotational speed and traverse speed have a significant influence on the process and have huge roles in characteristics and mechanical properties. The study uses the rotational speed of 719 - 1583 rpm and traverse speed set at 8 - 22 mm/min. Two three-level parameters (rotational speed and traverse speed) and one two-level parameter (pin profile). The main factor is taken into consideration. A total of 9 runs were conducted by using the combination of levels for each process parameter. The analysis was carried out by using the MINITAB statistical software.

Table 3: Design of experiment

↓	C1-T	C2	C3
	Pin Profile	Spindle Speed	Traverse Speed
1	Cylindrical	719.0	20.09
2	Cylindrical	795.2	9.82
3	Cylindrical	1583.0	15.45
4	Squared	719.0	9.82
5	Squared	795.2	15.45
6	Squared	1583.0	20.09
7	Triangular	719.0	15.45
8	Triangular	795.2	20.09
9	Triangular	1583.0	9.82

3.3 Minitab Generated Graph

The figures below show the generated graph from the Minitab software:

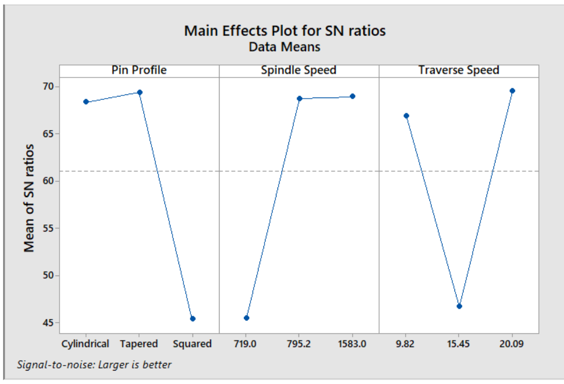


Figure 2: Main effects plot for SN ratios

The main effect plot of SN ratios for pin profile is shown in Figure 2, it was observed that a higher mean is generated for the triangular pin profile than for the cylindrical pin profile and the lowest is for the squared pin profile. The highest mean for the spindle speed is at 1583 rpm followed by 795.2 rpm and the lowest is at 719 rpm. The highest mean for the traverse speed is 20.09 mm/min followed by 9.82 mm/min and 15.45 mm/min.

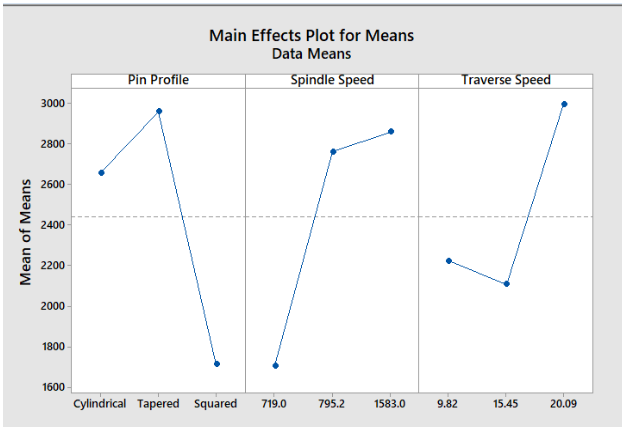


Figure 3: Main effects plot for means

Figure 3 depicts the main effect plot of the means for the pin profile and it was found that the squared pin profile has the lowest mean and the triangular pin profile generates a larger mean than the cylindrical pin profile. The mean spindle speed ranges from 719 rpm to 1583 rpm, with 795.2 rpm being the next highest and 719 rpm being the lowest. 20.09 mm/min is the highest mean traverse speed, followed by 9.82 mm/min and 15.45 mm/min.

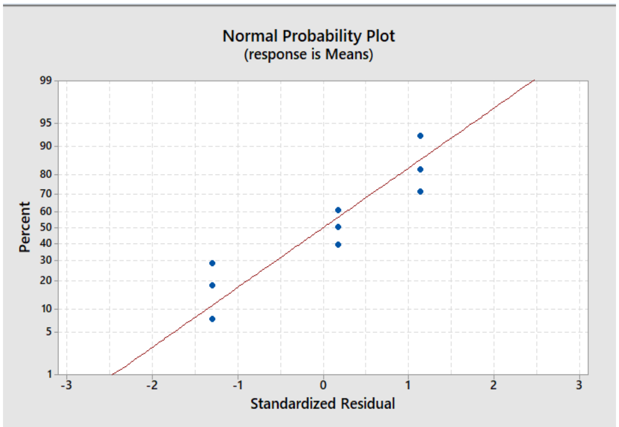


Figure 4: Minitab Graph

In Figure 4, the standardized residual can be seen to fall on an approximately straight line which indicates that the residual is fairly distributed were around 8 % to 30 % when the standardised residual is between -1 and -2, 40 % to 80 % when the standardized residual is between 0 and 1 and 70 % to 93 % when the standardized residual is between 1 and 2. Inactive main and interaction effects tend to fall roughly along a straight line, whereas active effects tend to appear as extreme points falling off each end of the straight line

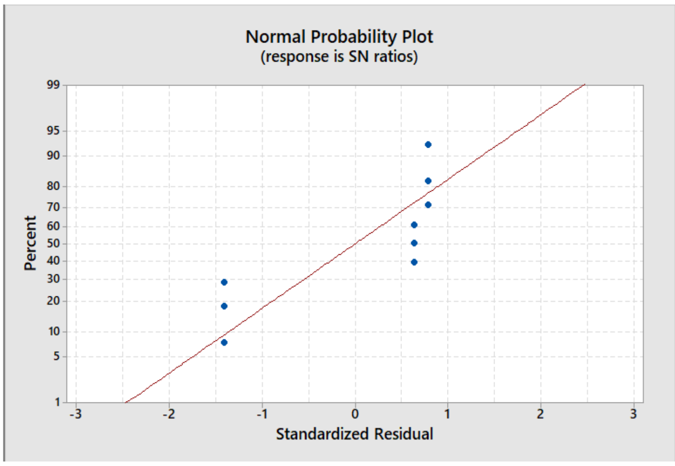


Figure 5: Minitab Graph

The standardised residual in Figure 5 appears to roughly follow a straight line around 5 % to 30 % when the standardised residual is between -1 and -2 and 40 % to 95 % when the standardised residual is between 0 and 1, indicating that the residual is evenly distributed. Active effects typically appear as extreme points falling off each end of the straight line, but inactive main and interaction effects typically fall roughly along a straight line.

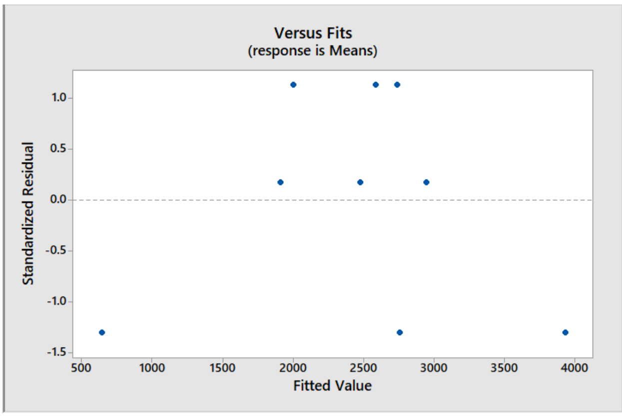


Figure 6: Minitab Graph

In Figure 6, the point appears to be an extreme point falling off each end of the straight lines. These active effects are judged to be statistically significant. The point can be seen distributed far from each other. Here the significance level is the risk of saying that a factor is significant when in fact it is not. In other words, it is the probability of the observed significant effect being due to pure chance.

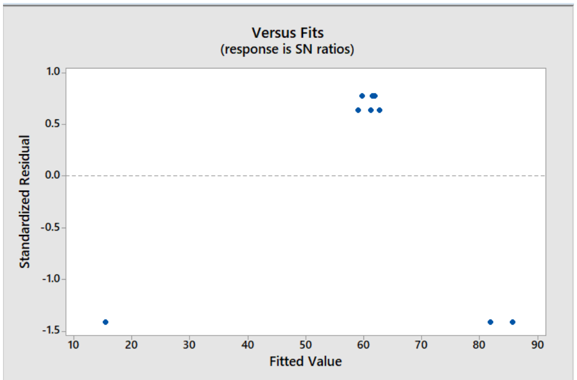


Figure 7: Minitab Graph

The point in Figure 7 seems to be an extreme point that falls off each end of the straight lines. It is determined that these active effects are statistically significant. The point can be seen distributed fairly close except for the point at the -1 to -1.5 standardized residual where it is distributed far away. Here, the risk of claiming that a factor is important when it is not being represented by the significance level. It is, in other words, the likelihood that the observed significant effect is the result of random chance.

4. Conclusion

The optimum process parameter of the friction stir welding on aluminium 6061 using the Taguchi method has been successfully achieved. The optimum parameter for the friction stir welding is the triangular pin profile, spindle speed of 1583 rpm, and traverse speed of 20.09 mm/min.

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