Process Optimization of Aluminium 6061 and 5083 T6 Alloys using Friction Stir Welding

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ABSTRACT

There are several different types of welding processes, including friction stir welding (FWS), arc welding, and fusion welding. Here, we've used the FSW method to weld the aluminium alloys AA6061 and 5083 T6 together. This weld can be used in the aerospace industry to save weight, in ships to withstand corrosion, etc. In marines, 5083 T6 alloy is used inside for greater strength and AA6061 alloy is used outside for corrosion protection. Here, friction stir welding will be used to fuse these two aluminium alloys together. Due to the heat generated by friction, friction stir welding is a sort of welding procedure that joins two alloys, whether they are comparable or different. FSW is used to create super-strong, low-distortion welds. In this work, two different aluminium alloys, AA5083 and AA6061, were dissimilarly welded together at the butt joint using FSW. The fundamental idea behind FSW is the joining of two metal plates using a non-melting pin tool. Since aluminium alloys have a great strength to weight ratio compared to steel, there are many applications for them. In this study, we optimise the welding speed, the axial force, the rotating speed, the tilt angle, and the profiles of the tool pins. Utilising Minitab software, one can design the central composite, obtain the full factorial design analysis, and check the parameters and the welded section's strength and hardness.

Keywords: Aluminium alloy 6061 and 5083 T6 alloy, Friction stir welding (FSW), Tensile strength.

1 Introduction

The aerospace, automotive, and shipbuilding sectors place a high focus on reducing the weight of vehicles, equipment, and vessels in order to save fuel consumption and eliminate pollution. By adopting lightweight metal constructions, such as aluminium alloys, weight may be reduced. Aluminium alloys are extremely important in the automotive, marine, aerospace, and national defense industries due to their low density, outstanding mechanical qualities, simple machinability, and excellent corrosion resistance. Due to their excellent weldability, heat treatability, high specific strength, and good toughness, 5000 and 6000 series aluminium (AA) alloys are frequently used in structural parts for both aerospace and automobiles. Among these, AA6061 (AlMg-Si alloy) is used often in welded components for things like ship frames, railway cars, trucks, and pipelines because of its light weight, high specific strength, and outstanding corrosion resistance. Similar to AA5083, which has a moderate degree of strength, good readability, low heat cracking, and high ductility, it is utilized in a variety of structural components as well as by the maritime and automotive sectors [1]. To create welded constructions such composite I-beams and hollow or semi-hollow ducts, AA6061 and AA5083 are frequently coupled. There are several weld flaws when pieces composed of various aluminium alloys (such as AA6061 and AA5083) are welded using standard fusion welding. Friction stir welding, or FSW, is used to address this issue. FSW as in figure 1.1 is a popular solid state welding method for connecting metals and their alloys that are comparable and different. To attach sheet or plate components, FSW employs a non-abrasive rotary tool constructed of a substance that is tougher than the

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base material. When the FSW tool is rotated in the direction of the welding operation, substantial heat is generated between the base metal and the tool shoulder [10]. Extrusion of the plastic deformation material is reversed. The FSW rotary tool is shown from the front. The base metal is welded as a consequence.

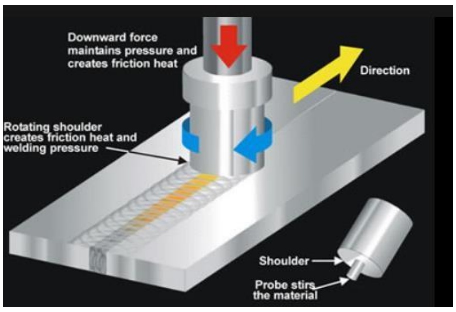

Figure 1.1: *FSW process*

2 Methodology

Set the settings first. Utilise the Minitab programme to create an RSM model. material testing for hardness and strength when welding. Using RSM, create a regression model for stiffness response and tensile strength and investigating the contact between the microstructure and the mechanical (tensile, hardness) properties of welds. One of the best mathematical methods for analysing issues when a large number of factors impact the answer is the response surface method (RSM) [2]. Finding the answer's highest value is the goal of the RSM search. To better understand degrees of impact, models describing the connection between responses and factors may be created. Additionally, contour and geometric charts are available. It is a visual tool to help assess interpersonal behaviour. In this investigation, a complete factorial-centred composite design (CCD) was employed. In total, two factors are taken into account: tool speed (A) and welding speed (B). Working range and fill level information is supplied to process parameters. Following the welding procedure, tensile testing is carried out using an electronic universal tension tester in accordance with ASTM E8M-04 [3]. The tensile test piece's dimensions are customarily machined on the wire EDM machine. Three samples of the same pipe weld are collected at different angles all throughout the weld. To confirm and guarantee the consistent pressure drop given by the created equipment throughout the weld, the tensile values of these three samples were averaged. Measurements are made of the yield strength (YS), ultimate tensile strength (UTS), and elongation (%E). An inverted metallurgical microscope was used to conduct microstructural analyses. The surfaces are prepared by cutting patterns along the weld, using various emery boards, and then using velvet cloth combined with diamond powder.

2.1 Influence of process parameters

FSW includes sophisticated material and plastic deformation. Welding settings, tool geometry, and joint design all have a significant impact on the material flow pattern and temperature distribution, as well as the microstructure development of the material [4]. This section discusses some of the important aspects influencing the FSW process, such as tool form, welding settings, and connection design.

2.1.1 Tool geometry

The most crucial element influencing the development process is tool form. The travel speed at which FSW may be done depends on tool shape and the flow of materials. Like before, this tool serves few major purposes. a) local heating b) material flow. The tool rotates at a set speed and enters the component in the first step. The friction between the pin and the component's shoulder causes heating to then occur. The material becomes more heated as a result of deformation [5]. Friction among the shoulder and the

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workpiece is the major cause of heating. The pins and shoulders comparative sizes are crucial for heating, while other design elements are not. The amount of material that may be heated is likewise constrained by the shoulder. Using the tool to "stir" and "move" the components is its second use. The weld zone features a sticky face and a return face since the instrument rotates during stirring. This time, the tool consists of shifting the hot plate's heated substance from one plate to another. The material must then be reunited once the substance solidifies. Tool geometry has changed a lot over time as a result of experience and a better knowledge of material flow. Add sophisticated functionality to change the process's offloading, mixing, and material flow. Tools such as concave pins, convex pins, cylindrical pins, triangular pins, square pins, and set screws must be used for welding [6], [7]. Due to a better material combination, convex gets the maximum tensile strength when compared to concave. Due of their unique forms, the square tools do produce superior outcomes. In situations where fatigue is a major concern, important factors taken into account for overlap welds are the width of the interface and the angle at which the notch touches the edge of the weld. Weld microstructure is also influenced by the kind of tool used and how it is shaped [8]. At conferences on friction stir welding, some companies highlight their in-house R&D initiatives, but no literature has been written about these initiatives and outcomes. It is crucial to understand that without instrument information, generalization about the evolution of microstructure and the effect of processing settings is challenging.

2.1.2 Welding parameter

Mainly two parameters are very critical in FSW:

Tool feed rate (rpm) and travel speed (mm/min) in a clockwise or anticlockwise direction along the brace line. After the material has been stirred and mingled around the rotating shaft by the tool's rotation, to finish welding, the tool forces the stirred material from the front to the rear of the spindle. We'll find later that the more thoroughly a substance is combined and agitated, the higher the rotating speed of the tool raises the temperature as a result of increased frictional heat. But bear in mind that friction between the tool surface and the workpiece controls the heating. As a result, don't assume that increasing tool speed would result in a continuous increase in heat [9]. Because of the coefficient of friction at the alliance, the tool actually travels faster. Along with tool speed and travel speed, the spindle angle, or inclination of the tool with regard to the workpiece, is a critical factor. The tool's shoulder may effectively transport material from the front of the spindle to the back by keeping it agitated through the set screw thanks to the proper spindle lead angle. Additionally, a strong weld with a smooth tool shoulder depends greatly on the pin's insertion depth into the workpiece (also known as the target depth). The pin height and depth are connected. Insufficient tool insertion depth will result in the shoulder of the tool not coincide with the workpiece, no friction in the welding region, and no welding action [11]. The weld plate will narrow locally and the weld edges will be strongly concaved if the tool is inserted too deeply, biting into the workpiece and producing excessive burrs. Note that his FSW has zero tool tilt thanks to the newly built "circular" tool shoulder. For arc joints, such tools are highly suited Some specific FSW processes may also benefit from preheating or cooling. The heat produced by friction and agitation may not be enough to soften and plasticize the surrounding material when it comes to materials with high melting points, like steel and titanium, or materials with high electrical conductivity, like copper [12]. As a result, it is difficult to produce a continuous and faultless weld. Preheating or a second external heat source can shorten the processing time while enhancing material flow in these conditions. On the other hand, for substances with low melting points, like magnesium and aluminium, cooling can be selected to minimize the development of recrystallized particles and the dissolution of hardened precipitates in and around the zone. In FSW, the axial force is crucial as well. Because of the limited axial force and low frictional force acting on the shoulder and component, very little heat is produced and no material mixing takes place. Because of the increased plunge force and deeper shoulder penetration caused by the higher axial force, the tool and component have a tapered form [13].

3 Influence of Tool Material and Geometry on Weld Quality

Given that different tool geometries produce welds with different microstructures and mechanical properties and that design influences both the heat generated and the flow of the material, the design of welding tools is more significant in the FSW process.

3.1 Tool material

The FSW tool is made up of an instrument body and a probe. Tool technology lies at the heart of the friction stir welding process. The geometry of the tool controls the heating, ductility, and forging patterns of the metal used in plastic welds. The shape of the tool has an impact on the size of the weld, welding speed, and tool resistance [14]. The tool's material has an impact on the frictional heating rate, the tool's resistance, and the operating temperature.

3.2 Tool geometry

The shape of the tool has an impact on its heat rate, cutting force, and torque. The flow of plasticizing material into the component is influenced by the geometry of the tool as well as by its linear and rotational motion [15]. Significant factors include shoulder diameter, tilt angle, pin geometry, including size and shape, and tool surface.

4 Result And Discussions

13 aluminuim alloys were welded using FSW machine at different parameters which have been obtained from the Minitab software and the welded specimen are tested for tensile and hardness using UTM and Rockwell hardness tester.

4.1 Welding process

First, clamp the two worktops together like a butt joint as shown in figure 4.1. The weldable surfaces of both of these plates are in contact with each other. A rotating tool pin is placed into the workpiece at the alliance till the shoulder of the tool come in contacts the workpiece. As a result, the material undergoes

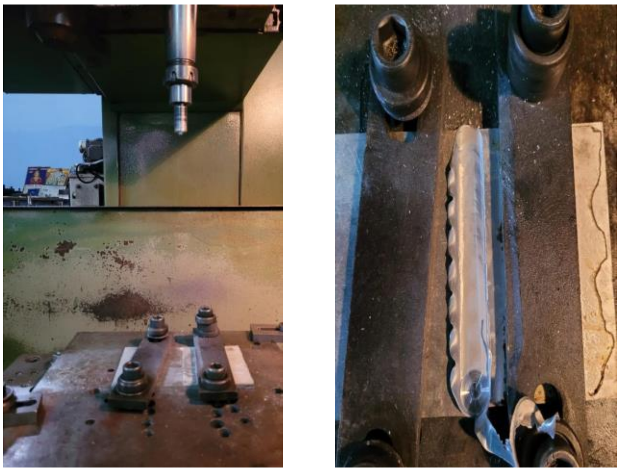

Figure 4.1: *Welding process*

plastic deformation due to heating by frictional forces. This is a state of the joining process where intermolecular diffusion plastically deforms the material due to frictional heating. Now the rotating tool moves towards the joint line. This will create a joint behind the tool. The tool moves continuously until the entire weld is formed. After the joining process the tool is separated from the workpiece. Holes created by tool pins remain in the weld plate.

4.2 Tensile test

For conducting tensile test, we use UTM and find out the ultimate strength, breaking point, yield strength and calculated the tensile strength of the specimens. After conducting the tensile test, we can find out that the specimen welded with the combination of (1500 rpm, 20mm/min, 6KN) have the high tensile strength. Here other combination gives moderate range of tensile strength because of variation in parameters and they have been shown in Table 1.

4.3 Hardness Test

The rectangular shaped test specimen is cut out from the welded specimen for conducting hardness test using ROCKWELL HARDNESS TESTING MACHINE. Using cone indenter and the results have been shows in Table 2. Out of the test result we can found that the specimen welded using combination of (1400rpm, 25mm/min, 6KN) have the highest hardness value.

Table 1: *Tensile Test Results*

Samples	Rpm	Traverse speed	Axial force (KN)	Yield strength (KN)	Ultimate strength (KN)	Breaking point
1	1400	25	6	6.7	7.4	6.8
2	1500	15	6	6.8	7.2	6
3	1400	30	6	6.6	7.2	6.7
4	1200	20	6	6.2	6.8	6.6
5	1400	20	6	5.8	6.2	6
6	1500	30	5	6.2	6.4	6.2
7	1200	25	6	6.2	8.6	7
8	1500	20	6	6.4	8.8	8.2
9	1400	20	6	5	7.2	5.8
10	1200	30	5	5.8	5.9	5.7
11	1400	15	6	7	7.8	6
12	1400	25	6	7	7.2	6.6
13	1500	25	6	8	6	5.8

Table 2: *Hardness Test Results*

Samples	Rpm	Traverse speed	Axial force (KN)	Hardness (RHN)
1	1400	25	6	53.5
2	1500	15	6	55
3	1400	30	6	51.5
4	1200	20	6	54
5	1400	20	6	49
6	1500	30	5	49.5
7	1200	25	6	49.25
8	1500	20	6	50
9	1400	20	6	51.5
10	1200	30	5	49.75
11	1400	15	6	49.5
12	1400	25	6	61.5
13	1500	25	6	53.5

4.4 MINITAB analysis

In a full factorial design, responses are assessed at every possible combination of factor levels. Two different full factorial designs are available in Minitab.

- A 2-level full factorial design using only 2-level components.
- Generally speaking, a full factorial design with three or more layers of elements

2K runs are needed for a 2-level full factorial design. K represents how many factors there are hardness and tensile strength are response variables, whereas process speed, welding speed, and axial force are design input parameters. In order to produce individual response factor residual plots, analyse these components in a full factorial design. paired fits, residual plots with histograms, and normal probability plots. Examining the residual plot will show you whether the ordinary least-squares assumption is valid. Ordinary least-squares regression generates unbiased coefficient estimates with little variance if these conditions are true. The residuals versus fit plot are the most typical plot generated when performing residual analysis. This scatter plot has the estimated responses on the x-axis and the residuals on the y-axis. Inconsistent error distributions, nonlinearities, and outliers are all found using charts. The residuals are displayed in the sequence of data collection in a residual vs. ordinal plot. To verify the notion that the residuals are independent, use the residuals vs. order plot. The residual plots of hardness and tensile strength are represented in figure 4.2 and figure 4.3 respectively. If independent residuals are analysed chronologically, no trends or patterns are apparent. The distribution of the points would suggest that correlated residuals

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are less likely to be independent than those that are near in space. The plot residuals should ideally be distributed randomly around the centerline. The dependent nature of the residuals may be deduced from the patterns below. A histogram is a presentation that presents neighboring bars on a chart to indicate the frequency of a range of continuous data values. The dataset's interval is the range of data. The number of frequencies included in a certain class interval is represented by a rectangle. Examine the histogram to see if a normal distribution is depicted. The design is effective because each response's residual plot includes the complete residual value. To forecast the ideal condition of the input parameters for healthy weld joints (quality response), main and interaction effects are also shown. The mean for each group within a categorical variable is displayed on a main effects plot. By charting the mean for each value of the categorical variables, Minitab develops a main effects graphic. Each variable's dots should have a line joining them. Check the rows to determine whether there are any main impacts for the category variables. Additionally, Minitab plots a reference line for the overall average. As an interpretation, consider the following:

• There is no primary impact if the line is horizontal (parallel to the x-axis). For all factor values, the average reaction is the same.

• There is a primary consequence if the line is not horizontal. For each factor level, the mean response variable differs. The amplitude of the major effect increases with the slope of the line.

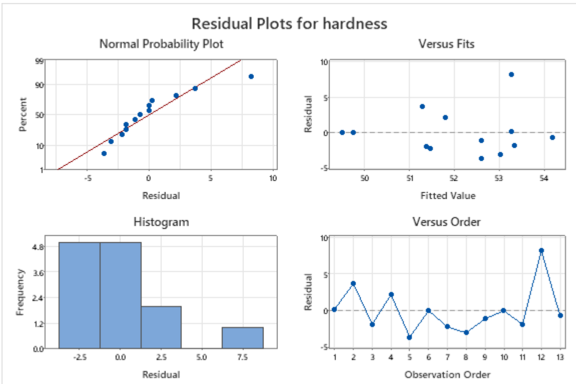

Figure 4.2: *Residual plots for hardness*

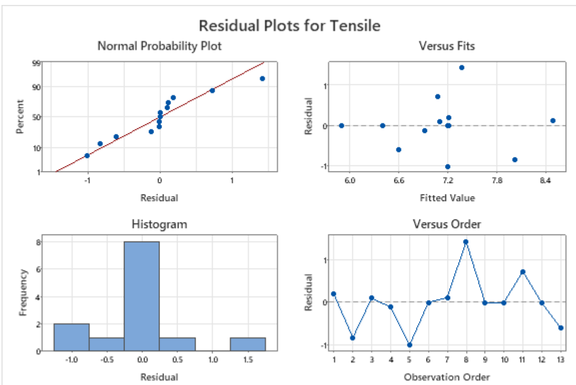

Figure 4.3: *Residual plots for tensile strength*

Use interaction plots to demonstrate how the values of a second categorical component affect the connection between one categorical factor and a continuous answer. On the x-axis of this graph is the mean level of one component, and there is a distinct line for each level of each additional element. To visualize how interactions impact the connection between variables and answers, use score lines. The interaction plots for hardness and tensile strength are represented by figure 4.3 and figure 4.4.

- parallel patterns

There hasn't been any interaction.

- Lines that aren't parallel

Interactions exist. The interaction will be stronger if the lines are more parallel.

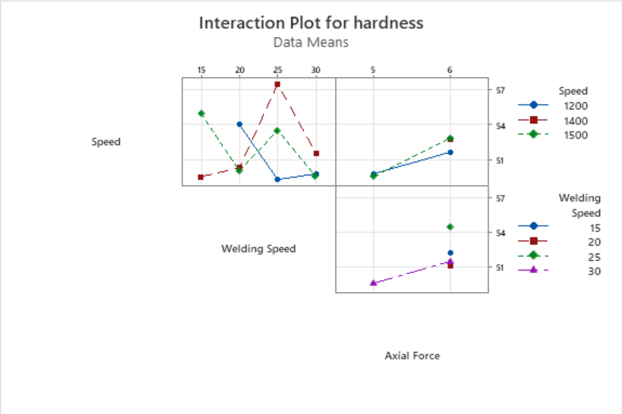

Figure 4.3: *Interaction plot for hardness*

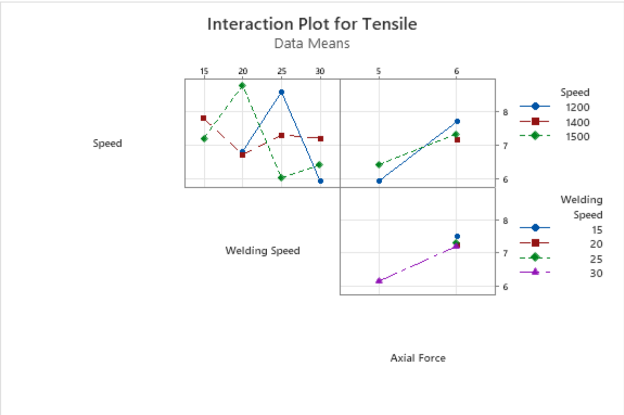

Figure 4.4: *Interaction plot for tensile strength*

5 Conclusions

While conducting tensile test using UTM machine we get the appropriate values regarding the specimens, the yield strength, breaking point and ultimate strength has been obtained. From that observation we come into the conclusion that the specimen welded using parameters 1500 rpm, 20 traverse speed, 6KN axial force will give maximum ultimate strength.

The specimen welded using parameter 1400rpm, 25 traverse speed, 6KN axial speed will give maximum hardness while testing.

After analyzing the parameters with the help of Minitab software interaction plots have been obtained from that we can observe that the interaction plot for hardness shows the maximum interaction were obtained in 26 mm/min traverse speed and 1400 welding speed.

While considering the interaction plot for tensile strength we can found out that the highest interaction was obtained at 20mm/min traverse speed and 1500 rpm.

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6 Declarations

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