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Effect of process parameters on mechanical properties of friction stir welded AL6063 & AL7075

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ABSTRACT

Applications of dissimilar alloys are finding good scope in the present industry. One of the reasons may be ease of welding with dissimilar alloys. To increase the strength of friction stir welded Al 6063, fractional experimental design was used and the process was discussed here. Friction Stir Welding (FSW) is an effective method for joining dissimilar alloys. During this process a joint is made between contacting sheets by traversing a rotating tool comprising a pin and shoulder between the mating surfaces. A material which is formed dynamically adjacent to the periphery of the rotating tool creates a weld between contacting work pieces. Optimum rotational speed to be maintained to avoid increase of temperature. The focus of this project is on the variation of ultimate tensile strength and Vickers hardness due to variations in axial force.

KEY WORDS: Al 6063 And 7075 Alloy, Cylindrical Profile Tool, Axial Force, Tool Rotation Speed, Feed Rate, Ultimate Tensile Strength, Vickers Harness.

1. INTRODUCTION

A novel technique available in joining two dissimilar alloys is Friction Stir Welding and this process is a solid state joining technique. Friction stir process does not join the metals together but it is used to modify the local microstructure of the alloys.

2. MATERIALS

Chosen materials for FSW technique are a commercial 6063 Aluminium alloy and 7075 Aluminium alloy was used as starting material for friction stir welding technique.

Table.1. Types of work material used in present study

Item	Specifications
Sheet metal Al 6063	100 mm (length) × 50 mm (width) × 6 mm (thick)
Sheet metal Al 7075	100 mm (length) × 50 mm (width) × 6 mm (thick)

Table.2. Chemical Composition of 6063 Aluminium Alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt (%)	0.548	0.346	0.152	0.083	0.488	0.02	0.098	0.023	Balance

Table.3. Chemical Composition of 7075Aluminium Alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
wt (%)	0.009	0.172	1.049	0.013	2.002	0.19	6.323	0.05	Balance

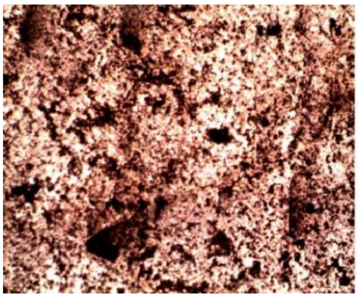

Figure.1. Microstructure of the Al 6063

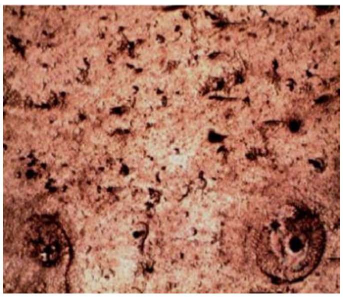

Figure.2. Microstructure of the Al 707

Table.4. Process variables

Tool design Variables	Machine Variables	Other Variables
Shoulder and pin materials	Welding speed	Anvil material
Shoulder diameter	Spindle speed	Anvil size
Pin diameter	Plunge force or depth	Workpiece size
Pin length		
Thread pitch	Tool tilt angle	Workpiece properties
Feature geometry		

Tool geometry: Welding tool geometry development led to the first sound welds made in aluminium alloys and this has led to higher weld production speeds, higher workpiece thickness, improved joint properties, new materials and new welding equipment.

Factorial Method: A full factorial design may also be called a fully crossed design. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. If more than two factors are present a 2^k factorial experiment can be designed from a 2^{k-1} factorial experiment. We can assign first replicate to the first (or low) level of the new factor and the second replicate as second (or high) level.

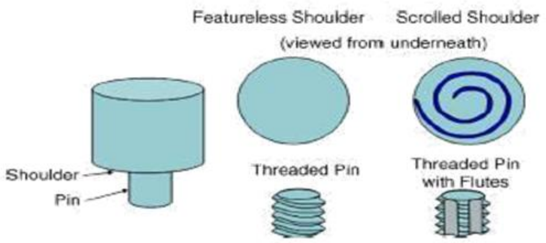

Fig.3. Tool Geometry

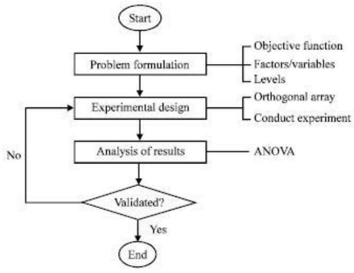

Figure.4. Flowchart for DoE

Welding process: The thickness of the both aluminium alloy plates is 6 mm. Chemical compositions and the mechanical properties of Al 6063 and Al 7075 are given below. The plates are placed in a butt configuration of 100 mm length; 50 mm width and the FSW process is carried out normal to the direction of the plates. The side where the tool rotation is in the same direction of translation of the tool referred to as advancing side whereas when this two tool motion counters referred as retreating side. Dissimilar friction stir welding process is carried out by placing the high strength aluminium alloy Al 7075 at the retreating side (RS), and by placing the aluminium alloy Al 6063 at the advancing side (AS); since if the weaker alloy is located at the RS, the fabricated weld will become weaker than when the weaker alloy is at the RS. The process parameters which have the greater influence on the tensile strength of dissimilar FSW joints are identified as Tool rotational speed, Feed Rate and Axial Force.

ASTM Standard Tensile Testing Specimen: The specimens were cut from the weld sample using wire cutting EDM Machine according to the required dimensions. The tensile test for calculating the ultimate tensile strength was conducted on the specimen.

Figure.5.Tensile Test specimens before and after testing

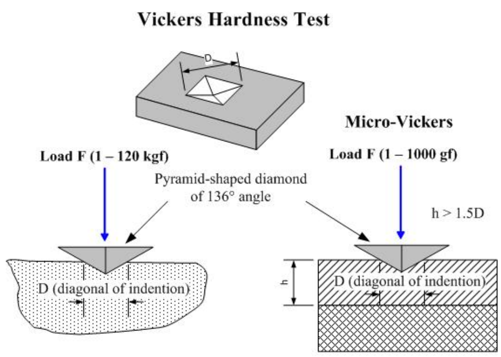

Figure.6.Vickers Hardness testing process

3. RESULTS

Table.5. Tensile test readings

Sample no	Thickness (mm)	Width (mm)	Area (mm^2)	Failure Load (N)	Tensile Strength (N/mm^2)
1	5.22	7	36.54	4672	127.86
2	5.3	7.01	37.15	4648	125.1
3	5.27	7.04	37.1	4950	133.42
4	5.22	7	36.54	4964	135.85
5	5.24	6.99	36.63	4914	134.16
6	4.62	7.06	32.62	4490	137.66
7	5.2	6.99	36.35	4552	125.23
8	5.2	7.01	36.45	4964	136.18
9	5.12	7	35.84	4716	131.58

Hardness test: HV number can be determined by the ratio F/A, where F is the force applied and A is the surface area in millimeters. A can be determined by the formula.

$$A = \frac{d^2}{2\sin(136°/2)},$$

This can be approximated by evaluating the sine term to give

$$A \approx \frac{d^2}{1.8544},$$

Where d is the average length of the diagonal left by the indenter

Table.6. Hardness Test Readings

Sample no	d' Value	Hardness(HV)
1	0.368	68.5
2	0.336	82.1
3	0.348	76.6
4	0.305	99.7
5	0.311	95.9
6	0.330	85.2
7	0.329	85.7
8	0.315	93.4
9	0.304	100

Microstructure analysis: The accurate of these rings was not established even though particle number variation and grain density were accurately established.

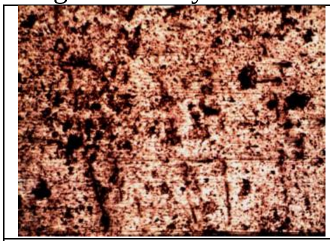

Figure.7. Microstructure of the weld zone

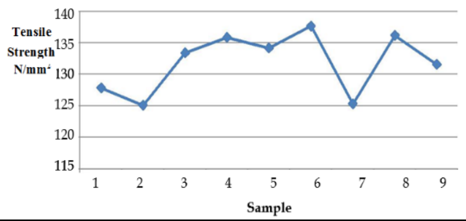

Figure.8. Graph showing the variation of Tensile Strength

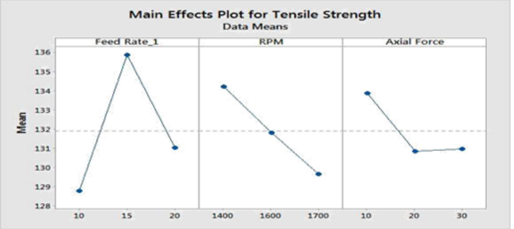

Figure.9. Main effects plot at a speed of 1400 rpm

Effect of process parameters on tensile strength: The feed rate obtains the rank 1 in the response table. This implies that Feed rate affects the Tensile strength to a larger extent.

Main Effects Plot: The main effects plot is most useful when you have several categorical variables. You can then compare the changes in the level means to see which categorical variable influences the response the most. A main effect is present when different levels of a categorical variable affect the response differently. For a variable with two levels, one level can increase the mean compared to the other level. This difference is a main effect. This implies that Maximum Tensile Strength is obtained when feed rate was 15 mm/min at a tool rotation speed of 1400 rpm when the axial force was 10kN.

Table.7. Response table for Tensile Strength

Level	Feed Rate	RPM	Axial Force
1	128.8	134.2	133.9
2	135.9	131.8	130.8
3	131	129.7	131
Delta	7.1	4.5	3.1
Rank	1	2	3

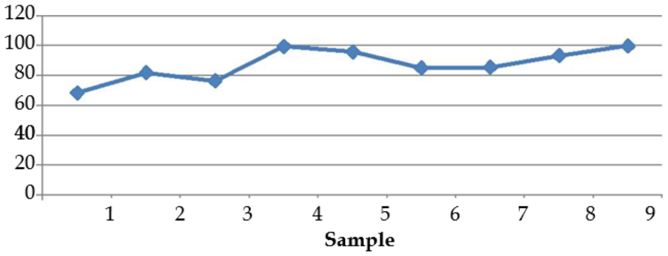

Figure.10. Graph showing the variation of Hardness value

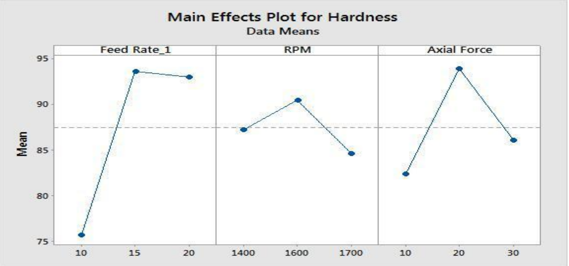

Figure.11. Main plot effect at a speed of 1600rpm

Main Plot Effect: This implies Maximum Hardness could be obtained when the Feed rate was 15mm/min at a tool rotation speed of 1600 rpm when applied with an axial force of 20kN.

Table.8. Response table for Hardness

Level	Feed Rate	RPM	Axial Force
1	75.73	87.27	82.37
2	93.6	90.47	93.93
3	93.03	84.63	86.07
Delta	17.87	5.83	11.57
Rank	1	3	2

The feed rate obtains the rank 1 in the response table. This implies that Feed rate affects the Hardness to a larger extent.

S/N ratio calculation: Since we have obtained different settings (input factors) for obtaining maximum tensile strength and hardness it becomes necessary to know which parameter produces the ideal condition i.e., the input parameters which provide the maximum tensile strength and hardness value. S/N ratio helps us to find this. The product of ideal quality should always respond in exactly the same manner to the signals provided by the user.

For example, due to such uncontrollable factors as extreme cold, humidity, engine wear, etc. the engine may sometimes start only after turning over 20 times and finally not start at all. This example illustrates the key principle in measuring quality according to Taguchi. Noise factors are those that are not under the control of the operator of a product. In the car example, those factors include temperature changes, different qualities of gasoline, engine wear, etc. Signal factors are those factors that are set or controlled by the operator of the product to make use of its intended functions (turning the ignition key to start the car). Finally, the goal of your quality improvement effort is to find the best settings of factors under your control that are involved in the production process, in order to maximize the S/N ratio; thus, the factors in the experiment represent control factors.

S/N ratios: The conclusion of the previous paragraph is that quality can be quantified in terms of the respective product's response to noise factors and signal factors. The ideal product will only respond to the operator's signals and will be unaffected by random noise factors (weather, temperature, humidity, etc.). Therefore, the goal of your quality improvement effort can be stated as attempting to maximize the signal-to-noise (S/N) ratio for the respective product.

$$S/N\ ratio=-10\ Log_{10}\ [\text{mean of sum squares of reciprocal of measured data}]$$

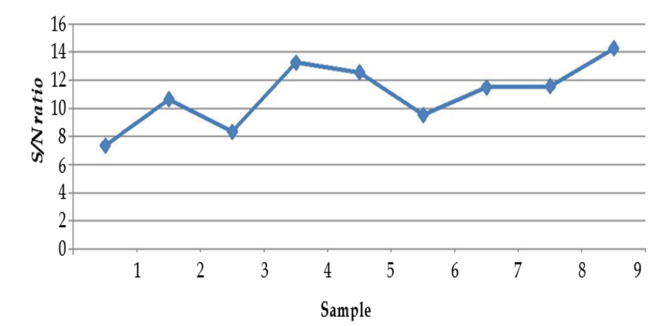

Figure.12. S/N ratio

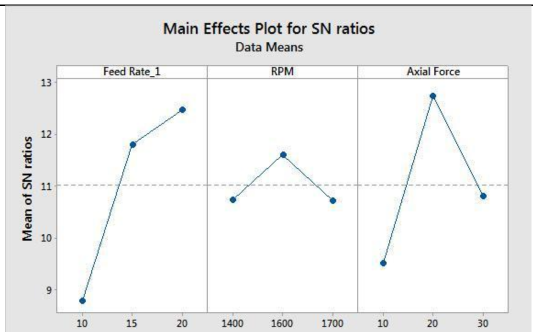

Figure.13. Main effects plot for S/N ratios

Sample 9 shows the highest S/N ratio. This signifies that the input factors of sample 9 produces a weld having both increased tensile strength and hardness value.

Main Effects Plot: Maximum S/N ratio is obtained at 20mm/min feed rate having 1600 rpm as tool rotational speed at an axial force of 20 kN as the input factors.

Table.9. Response Table for S/N ratios

Level	Feed Rate	RPM	Axial Force
1	8.791	10.731	9.506
2	11.798	11.601	12.738
3	12.465	10.722	10.811
Delta	3.674	0.879	3.232
Rank	1	3	2

The feed rate obtains the rank 1 in the response table. This implies that Feed rate affects the S/N ratios to a larger extent, i.e., Feed Rate is an important input factor for obtaining a weld with high tensile strength and hardness.

4. CONCLUSION

Feed Rate affects the Tensile strength of the weld more than any other factors. As the feed rate in-creases the tensile strength tends to decrease. Maximum tensile strength of 137.66 N/mm2 (Sample 6) was obtained when the tool rotational speed was 1400 rpm at the feed rate of 15 mm/min when the axial force applied is 10KN.

Feed Rate affects the Hardness of the weld more than any other factors. The maximum hardness of 100 VHN (Sample 9) was obtained when the feed rate was 20mm/min and axial force of 20 KN with a spindle speed of 1400 rpm. However by the main effects plot we can predict that the maximum hardness could have been obtained when the feed rate was 15 mm/min at a spindle speed of 1600 rpm when the axial force applied was 20 kN. The reason for obtaining a weld with properties better than base metal 6063(56.5 VHN & 129.11N/mm^2), is because of the fine grains formed due to the dynamic recrystallization process.

The specimen with the maximum S/N ratio was obtained for a tool rotational speed of 1400 rpm, at 20mm/min feed rate, and when the axial force applied was 20 KN. (100 VHN and 131.58N/mm^2 for Sample 9). This is termed as the best weld.

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