Volume : 5 | Issue : 4 | April 2016 • ISSN No 2277 - 8179 | IF : 3.508 | IC Value : 69.48

Research Paper

Analytical Study of Influencing Parameters in Fsw And Their Impact on Weld Strength

Engineering

KEYWORDS :Friction Stir Welding, Yield Strength, Aluminium Alloy, Parameter Optimization, Weightage Allocation.

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ABSTRACT

Friction Stir Welding is the process used for joining softer material using a non-consumable tool. The flow of material in Friction Stir Welding is governed by the base metal or alloy properties such as yield strength, ductility and hardness. The present work deals with identification of optimal range of welding parameters in Friction Stir Welding for Aluminium Alloy (Al-6061), considering maximum temperature generated in the weld material as the main constraint. The parameters considered for study are tool rotational speed, welding speed, axial force and tool pin diameter. After finding the optimal range of all these parameters, the effects of these on yield strength of the weld are studied separately and an attempt has been made to find an empirical relationship between yield strength of the weld and all the considered parameters, considering appropriate weightage of each parameter in contributing to the weld strength.

INTRODUCTION

Aluminium alloy Al-6061 has 95-98% of Al and finds numerous applications [1].This alloy can be welded by most fusion and solid-state welding processes as well as by brazing and soldering but it loses its alloying materials during melting in these processes [5]. Also, it tends to exhibit cracking during brazing and soldering which resulted to the invention of Friction Stir Welding Process. FSW was first invented and validated experimentally by TWI (The Welding institute)-UK in December1991 [8]. In FSW, two surfaces are joined by first creating a very softer region by generating heat between them and then inter-mixing these surfaces by using mechanical pressure [2]. Severe plastic deformation and flow of the plasticized metal occurs, as the tool is translated along the welding direction. Many researchers have presented various advancements in this process since its invention depending upon the weld material being used, tool profiles or design parameters, welding parameters and so on [11].

Various defects occur due to material positioning and varying the process parameters. These parameters can be optimized considering different constraints. A microstructural analysis helps to identify the defects produced due to variation in range of parameters [4]. The combined material position and welding speed have a combined effect on the dissimilar metal welding[8] and thebehavior of different zones (HAZ - Heat Affected Zone, TMAZ - Thermo-mechanically Affected Zone and NZ - Nugget Zone) of the weld is highly affected by the tool rotational speed variation[3]. There can be various approaches to optimize the FSW process parameters [11].

The tool geometry, process parameters, and different approaches or setups affect the weld strength of the material. All these factors have different effect on the weld strength which can be analysed by using Taguchi Approach [2] or Response Surface Methodology [9].The contribution of all the influencing parameters can be analysed with Taguchi or RSM by first identifying the optimal values of these parameters [12]. RSM is also used to simulate the FSW process and to identify the defects like fine cracks, lack of fusion and holes developed due to improper process parameters such as tilt angle, traverse speed, tool rotation and probe length [10].

There had been developed separate empirical relationships between different parameters with yield strength and hardness of the weld joint [7],which formed the basis of the work presented in this paper.

The solidus temperature of material taken for study, i.e. Al-6061 is found to be 582ºC, hence the maximum temperature achieved during welding process cannot be more than that. A mathematical relationship is established between heat generated and welding parameters. The next step is to find an optimal range of all these parameters which is done by varying the value of each parameter keeping others constant and evaluating the maximum heat generated for each variation. The range out of which the maximum temperature exceeds the limit or solidus temperature is the required optimal range.

METHODOLOGY

3.1 Identify all the influencing parameters of FSW

The parameters which can influence the process include tilt angle, rotational speed, traverse speed or welding speed, pin diameter, pin profile, shoulder diameter, probe length, probe design, axial force, backup plate etc. Out of these parameters, a few are considered for being most influential and taken for study in this paper. These parameters are:

3.1.1 Rotational speed

The temperature increases with the increase in rotational speed; so a reasonable range is essential to be identified.

3.1.2 Welding speed

Also termed as traverse speed, this parameter affects inversely the temperature in welding zone and hence considered as an influential parameter.

3.1.3 Axial force

The higher the force, higher will be the flow of material and subsequently, higher will be the weld strength. It also affects directly the temperature generated in TMAZ of a weld joint.

3.1.4 Pin diameter

In comparison to other factors, pin diameter is less influential for temperature generation but it is considered in this study because of its great influence on the weld strength.

3.2 Select the objective function and main constraint for analysis

The objective function considered in this study is the yield strength of the weld and the objective is to maximize this yield strength keeping maximum heat generated as a constraint. The maximum heat generated must be such that the temperature does not exceed the value of solidus temperature of weld material. If temperature exceeds, it will cause the weld material to melt and that will go against the objective of FSW.

3.3 Find the optimal range of all parameters with respect to temperature

A mathematical relation is used among the heat generated in weld material and all four parameters considered in this study. This relation is given by the following equation.

$$q = \left(\frac{2\pi}{S}\right)\mu NFR\eta \qquad (1)$$

Using the above equation, we can calculate the maximum heat generated at different values of each parameter, keeping the others as constant. The heat generated can be used to calculate the maximum temperature by the following equation:

$$q = mC_v\Delta T \qquad (2)$$

The range of each parameter which gives the value of maximum temperature less than solidus temperature (582°C) and high enough to be considered as weldable temperature will be the optimal range for that parameter.

This step will be repeated for each parameter so that an optimal range of each of these parameters is found.

3.4 Analysis of parameters' effect on yield strength of weld material

Each parameter affects the yield strength of the weld in some or the other way. Literature[7] provides mathematical relationships between yield strength and each parameter separately. These equations are mentioned as follows:

3.4.1 Yield Strength and Rotational Speed

More rotational speed will give more heat generation which makes intermixing better.The relation used between these two quantities is given as:

$$N = 31.60 \times (Y.S)^{0.66} \qquad (3)$$

3.4.2 Yield Strength and Welding Speed

Lower welding speed will provide more time for the material to get welded and thus makes intermixing better. The relation used is given as:

$$S = 1116.8 \times (Y.S.)^{-0.458} \qquad (4)$$

3.4.3 Yield Strength and Axial Force

Insufficient downward force causes no vertical flow of material and when axial force was increased beyond the limit large mass of flash and excessive thinning were observed due to higher heat input. The relation is given as:

$$\mathrm{F} = 0.627 \times (\mathrm{Y.S.})^{0.707} \qquad (5)$$

3.4.4 Yield Strength and Pin Radius

The relation between yield strength and pin radius has been established similar to the other relationships and can be expressed as:

$$R = (8.67 \times 10^{-6}) \times (Y.S.)^{1.108} \qquad (6)$$

3.5 Evaluate an optimal set of parameters values

These equations define the effect of each parameter on yield strength. However, our objective is to find out an optimal set of values for each parameter which will maximize the yield strength of weld joint. Hence the value of each parameter from its respective range which gives maximum value of yield strength is considered as the best or optimal value.

3.6 Analysis of the weightage of all parameters on yield strength

This weightage is found on the basis of sensitivity of each criterion. The parameter which has highest sensitivity will be assigned the highest weightage and vice versa. Here, sensitivity means that what amount of change in the parameter gives significant change in the yield strength.

3.7 Formation of a single relationship between parameters and yield strength

After finding the weightage of each criterion, a linear mathematical relation is formed among all criteria and the yield strength. The equation is found to be as follows:

$$Y.S. = w_1 \times Y.S_N. + w_2 \times Y.S_S + w_3 \times Y.S_F + w_4 \times Y.S_R \qquad (7)$$

where;

$Y.S_N$ is the yield strength at optimal value of N

$Y.S_S$ is the yield strength at optimal value of S

$Y.S_F$ is the yield strength at optimal value of F

$Y.S_R$ is the yield strength at optimal value of R

ANALYSIS

Three levels of each parameter are decided and using these values, different combinations of all parameters are made.

Table 1: Levels of Parameters

S. No.	Parameter	Level 1	Level 2	Level 3
1	Rotational Speed	550	650	750
2	Welding Speed	90	100	110
3	Axial Force	20	25	30
4	Pin Radius	0.002	0.003	0.004

Calculation of maximum temperature at each combination of parameters is done.

Table 2: Temperature Variation with Pin Radius at First Levels of Axial Force and Welding Speed

N	F	S	R	D	Q	T
550	20	90	0.002	20	3.892	165.083
550	20	90	0.003	20	5.839	232.125
550	20	90	0.004	20	7.785	299.166

Similarly, all the other temperatures are evaluated and the variation of temperature along with pin radius at different levels of rotational speed, welding speed and axial force are analysed; one example is shown in **Figure 1**.

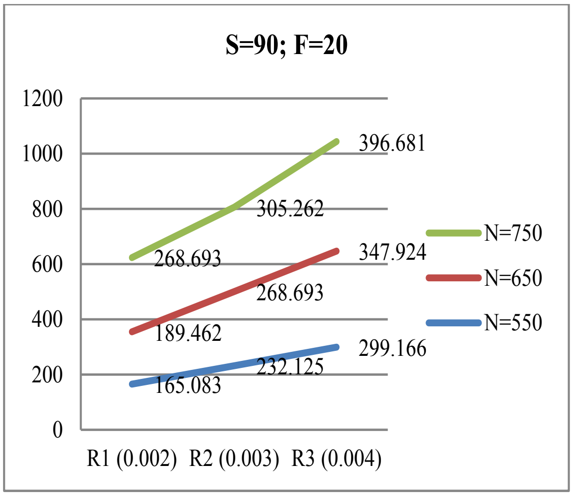

Figure 1: Temperature variation at first levels of welding speed and axial force

The effects of each parameter on yield strength of weld material are analysed with the help of line graphs using the equations as described in methodology.

N	YS	S	YS	F	YS	R	YS
550	75.8	90	244	20	134	0	74.1
650	97.7	100	194	25	184	0	111
750	121	110	158	30	238	0	148

Table 3: Yield strength at different values of parameters

The variation of yield strength along with parameters using **Table 3** are shown in **Figure 2-Figure 5.**

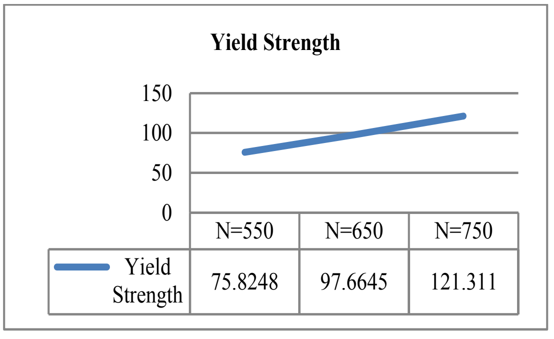

Figure 2: Rotational Speed v/s Yield Strength

Volume : 5 | Issue : 4 | April 2016 • ISSN No 2277 - 8179 | IF : 3.508 | IC Value : 69.48

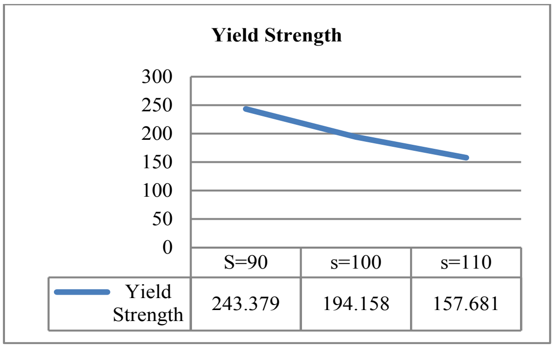

Figure 3: Welding speed v/s Yield Strength

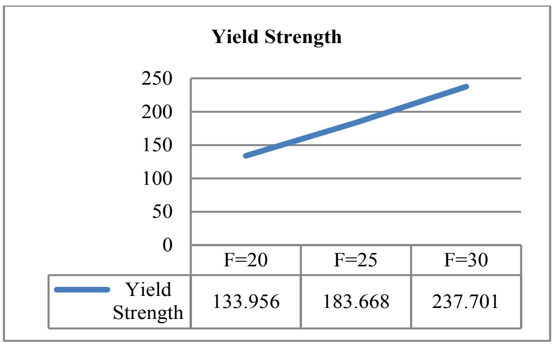

Figure 4: Axial force v/s Yield Strength

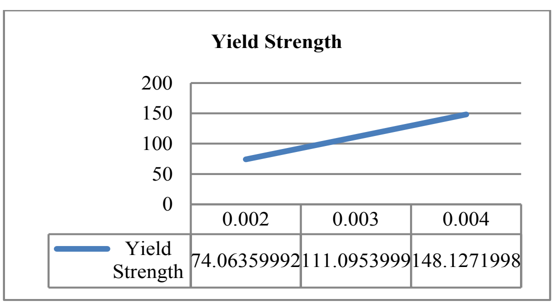

Figure 5: Pin radius v/s Yield Strength

As it is clear from **Table 3**, that a slightest variation in tool pin radius (as low as 0.001m) shows drastic change in yield strength of weld joint numerically. Hence its weightage is assumed to be 50% as compared to the other parameters. This assumption can be favoured by the fact that slopes of each graph from **Figure 2 - Figure 5** give the sensitivity of each parameter with respect to the yield strength. The higher the sensitivity of the parameter, the higher will be the assigned weightage for that parameter in yield strength calculation. The sensitivities are calculated as follows:

$$\mathrm{S}_1 = 0.218$$

This value of sensitivity is normalized by adding 1 to it as all the sensitivities need to be between 1 and 10 so that weightage of each parameter can be calculated easily. Hence, the modified sensitivity of rotational speed is:

$$\mathrm{S}_1 = 1.218$$

Similarly;

$$\mathrm{S}_2 = -5.022$$

Here, negative sign in slope shows that welding speed affects the yield strength inversely and but its weightage will be taken as positive while establishing a single relationship among all these parameters and yield strength, as it shows the importance of parameter which cannot be negative. Also;

$$\mathrm{S}_3 = 9.942$$

$$S_4 = 37039.39$$

The weightage of each parameter is calculated as follows:

$$W_i = \frac{S_i}{\sum_{i=1}^{3} S_i} \times 0.5$$

0.5 is multiplied to the ratio of sensitivity and sum of sensitivities because of the fact that only 50% of weightage is left for parameters apart from the tool pin radius. Using the above equation, the weightage of rotational speed, welding speed and axial force are found to be:

$$W_1 = \frac{1.218}{16.182} \times 0.5 = 0.0375$$

$$W_2 = \frac{5.022}{16.182} \times 0.5 = 0.155$$

$$W_3 = \frac{9.942}{16.182} \times 0.5 = 0.307$$

Hence, the relationship between all four parameters and yield strength is developed as follows:

$$Y.S. = 0.0375 \times \mathrm{Y.S_N} + 0.155 \times \mathrm{Y.S_S} + 0.307 \times \mathrm{Y.S_F} + 0.5 \times \mathrm{Y.S_R}$$

CONCLUSION

All these parameters and their effects on yield strength are studied simultaneously and the weightage of each parameter on this yield strength is found. It is also found in the result that the optimal set of parameters i.e. N=750, S=90mm/min, F=30KN & R=0.004mm when used simultaneously gives the strength of the weld equals to 242.7 MPa which is near to the tensile strength of base material. This similar result is found by the experiment in the literature which proves the authenticity of the empirical relation developed in this paper. However. The future scope has room for its validation by experimenting on different alloys and metals.

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