# Optimization of Process Parameters of Friction Stir Welding by Using Doe

S. Rengaraj and V. Manivel Muralidaran

**Abstract**--- Friction stir welding (FSW) is solid state joining process. This technique is energy efficient, environment friendly and versatile. Welding is a multi input-output process in which quality of weld joint is depends upon a input parameter. Experiments are conducted here, with a tool having a cylindrical pin of 0.4mm clearance. The process parameters are optimized using the Taguchi technique based on Taguchi's L9 orthogonal array. Experiments have been conducted based on three process namely, the tool rotational speed, tool tilt angle and transverse speed. Tensile strength has been predicted for the Optimum welding parameters and their percentage of contribution in producing a better joint is calculated, by applying the effect of the signal-to-noise ratio and analysis of variance. Based on the study, the tool transverse speed is found to be the influencing factor over the other process parameters, and it enhances the quality of the weld on aluminium plate al(6061). The optimum tensile strength is predicted through taguchi technique. Confirmation tests have been performed for the resulting optimum parameter and the maximum tensile strength was found.

**Keywords**--- Friction Stir Welding, Taughchi, Anova, Tenstile Strength

## I. INTRODUCTION

The need for joining materials having higher hardness property and tensile strength. Friction stir welding (FSW) is a recent addition to the welding process and it is a solid state joining technique it was performed on Al and its alloys is now carried out on copper, magnesium and different material combinations. Different tool pin profiles have been used to weld aluminum alloys, and it has been found that the tapered pin gave defective welds when compared to other profiles. The cylindrical tool has been reported to give better joint strength because of the easy penetration of the pin inside the aluminium plate with reduced pin failures. The amount of friction heat produced for a better weld depends mainly on the process parameters, such as the tool rotational speed, plunge depth, plunge force, tool tilt angle and travel speed. Apart from the highest influencing process parameters, such as the rotating speed of the tool and traverse speed in FSW, the tool tilt angle is an added process parameter which could give better results in the FSW of aluminium. Tensile strength is the powerful mechanical property to optimize the process parameter of the weld to achieve a better joint.

The most efficient and simple way of designing an experiment can be achieved by the Taguchi method which helps to find out the most significant process parameter among the parameter combinations, by using the analysis of variance (ANOVA) and signal-to-noise ratio.L9 orthogonal array of the Taguchi design method has been used, because it is easy to use and solve complex problems more efficiently. The Calculation of the S/N ratio and mean response, by the ANOVA gives the most influential process parameter, while the mean effects of the plot for the S/N ratio and mean response predicts the optimum process parameter. The main objective is to estimate the contribution of the individual

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process parameters, and to determine the optimum combination of the process parameters for better possible strength. The Higher the better is used for maximization, while Smaller the better is used for minimization quality characteristics problem. In this studythe input energy and tensile strength of the welded joints are taken into consideration. Both has conflicting objective i.e., the tensile strength of the FSW has to be maximized while the input energy should be minimized.

Assignment of Weight method is used to solve the multiresponse problem (Jeyapaul et al. 2005). The individual loss function is integrated into overall loss function by assigning weights to each loss function. The value of the overall loss function is further transformed into signal to noise ratio. Based on the quality characteristics of the response intended the S/N ratio for each level of process parameter is calculated. Higher the S/N ratio implies better the quality, irrespective to maximization or minimization. Therefore, the highest S/N ratio corresponds to the optimal level of the parameter. ANOVA is performed to find the significant process parameter. A confirmation test is conducted to validate the predicted optimal levels found out from the analysis.

The welded plate is in rectangular shape with a size of 150mm×100mm×6mm. The used welding parameters are tool rotational speed, welding speed and tool tilt angle. The weld plates are suitably clamped in the suitable fixture for hold the plates in such a manner that both the plates cannot move from its position during the welding process. The fixture provides a base to place the plates for ensuring the proper flat position for the welding process. Many conditions are seen during the welding process when tool rotational speed is low, then welding become hard and welding process produce noise due to the improper heating and mixing of the material. The heat is also effect the type of chips produced during the welding process.

## II. MATERIALS AND EXPERIMENTAL SETUP

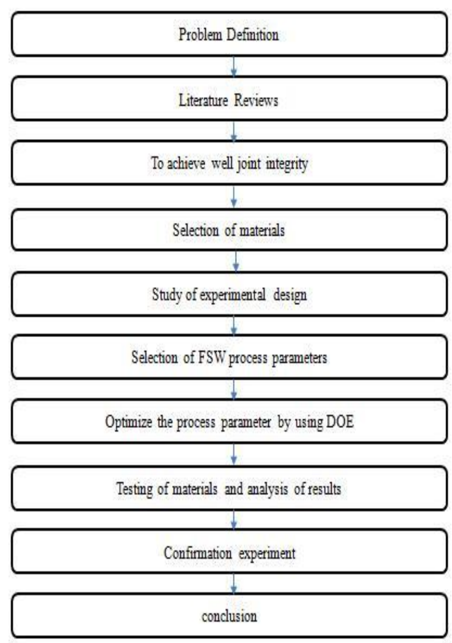
Table 1: Materials Selection

| | |
|---|---|
| Material | Al 6061 |
| Welding tool | HC HCr Tool steel |
| Shoulder dia of tool | 18mm |
| Pin dia of tool | 6mm |
| Welding machine | Vertical milling machine |

Figure 1: Tool Selection

1) SHSS tool
2) W – Alloy tool
3) H13Tool
4) HC HCr Tool
5) APST Tool
6) HSS Tool
7) EN 24 Tool

## III. METHODOLOGY



# IV. TAGUCHI METHOD

The Taguchi method is very effective, because it is simple to carry on the experimental design and its approach is very systematic to provide good quality and low cost in manufacturing (Demirci et al., 2011). The main aim of the Taguchi method is to analyze the statistical data, which has been given as an input function to produce an optimum result. The effect of the combination of the input functions as a result is produced by the S/N ratio and mean response (Wu et al., 2002). The strength of the weld is varied by the parameters such as the tool rotating speed, tool tilt angle, depth of tool penetration, dwell time and travel speed. Among these input parameters, rotating speed, tool tilt angle and travel speed are taken and the other parameters are maintained constant. The input parameters are entered in the array table with the output characteristics as the average tensile strength. The shorter conical pin with a concave shoulder should be optimized to have a better weld, with a suitable process parameter, and hence, the Taguchi technique is applied to a self analysis of the high strength material based on the tensile strength.

MINITAB Release 17 is the software that gives the statistical analysis of how to form a combination of input parameters and to find out the most significant combination (MINITAB TM 2008). Process parameters are control factors, and the factors which initiate variability in the process are the noise factors. In a Taguchi designed experiment, the noise factors are manipulated for the variability to occur, and from the results optimal control factors that make the process robust, can be identified. The Signal to Noise ratio (S/N) indicates the control factors settings that minimize the effects of the noise factors. The Taguchi experiments are carried out in a two step optimization process.

Step 1: use the S/N ratio to identify those control factors that reduce variability.

Step 2: identify the control factors that bring the mean to target and have little or no effect on the S/N ratio.

***The Larger the Better***

The Larger the better criterion is applied to the problems, when the maximization of the response is required for the output characteristics data. The data of the target value is positive. Here the optimized result needed is higher tensile strength, and hence this criterion is selected to find out the optimum process parameter, which can give better strength. The following formula is used to find the optimum result,

$$\text{S/N ratio } (\eta) = -10 \log10 \left(\left(1/n\right) \Sigma \left(1/ (y_{ij})^{2}\right)\right)$$

# V. EXPERIMENTAL WORK

According to the L9 orthogonal array, three experiments in each set of process parameters have been performed on Al 6061 aluminium plates. The three factors used in this experiment are the rotating speed, tool tilt angle and travel speed. The factors and the levels of the process parameters are presented in Table and these parameters are taken based on the trials to weld the FSW of aluminium plates. The experiment’s notation is also included in the L9 orthogonal array which results in an additional column, in order to represent the parameters,. The experiments are performed on a vertical milling machine which serves to perform the FSW operation. Beyond the tool tilt angle thickness of 6mm plate , 1̊,1°5 and 2° tool tilt angles were taken. The FSW butt joint weld being performed. and hence the tool is plunged slowly into the work piece till the tool shoulder comes in contact with the surface of the work piece.

When the tool is inserted, the stirring action starts to occur, and only the pin penetrates deep into the work piece while the tool shoulder touches the top surface. Frictional heat occurs along with the stirring action. The tensile failure has occurred in between the regions of HAZ and base metal. FSW joints of low alloy steel have been welded, and the average tensile strength of the three tensile specimens from the same sample was obtained It reveals that the FSW parameters do not lead to a significant variation, and hence, the ANOVA is used to find the optimum process parameter.

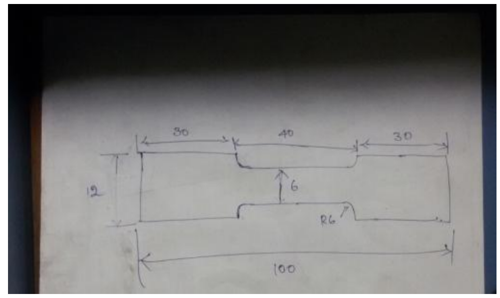
Table 2: Experimental Layout of L9 Orthogonal Array

| Sl.NO | EXPT.NO | A ROTATIONAL SPEED(rpm) | B TRANSVERSE SPEED (mm/min) | C TILT ANGLE(deg) |
|---|---|---|---|---|
| 1 | A1 | 1 | 1 | 1 |
| 2 | A2 | 1 | 2 | 2 |
| 3 | A3 | 1 | 3 | 3 |
| 4 | B1 | 2 | 1 | 2 |
| 5 | B2 | 2 | 2 | 3 |
| 6 | B3 | 2 | 3 | 1 |
| 7 | C1 | 3 | 1 | 3 |
| 8 | C2 | 3 | 2 | 1 |
| 9 | C3 | 3 | 3 | 2 |

(a)

(b)


(c)




(d)

Figure 2: (a)Tensile Specimen before Failure(b) Tensile Specimen after Failure(c) Tested with Universal testing Machine(d) ASTM E8 Sub Size Specimen

Table 3: The Table Shows the Input Parameter of or Thogonal Array and the Output Characteristics

| EXPERIMENTAL NUMBER | INPUT Rotational speed (rpm) | INPUT Transverse Speed (m/min) | INPUT Tilt angle (°) | OUTPUT Tensile Strngth (Mpa) |
|---|---|---|---|---|
| 1 | 700 | 45 | 1 | 79.85 |
| 2 | 700 | 35 | 1.5 | 75.79 |
| 3 | 700 | 40 | 2 | 74.79 |
| 4 | 1200 | 45 | 1.5 | 92.53 |
| 5 | 1200 | 35 | 2 | 76.56 |
| 6 | 1200 | 40 | 1 | 89.56 |
| 7 | 1400 | 45 | 2 | 82.86 |
| 8 | 1400 | 35 | 1 | 74.98 |
| 9 | 1400 | 40 | 1.5 | 91.50 |

## VI. MEAN AND SIGNAL TO NOISE RATIO

The Mean and signal to noise ratio are the two effects which influence the response of the factors. The influencing level of each selected welding parameter can be identified. The tensile strength of the FSW weld is taken as the output characteristic. The response table for the S/N ratio shows that the transverse speed ranks first in the contribution of good joint strength, while rotating speed and tool tilt angle take the second and third ranks. The same trend has been observed in the response table of the mean. The responses for the plot of the S/N ratio and Mean. The tensile strength is estimated to be the maximum at 1200 rpm rotation speed, 1.5° tool tilt angle and 40 mm/min travel feed;

which is optimal from the plots obtained.

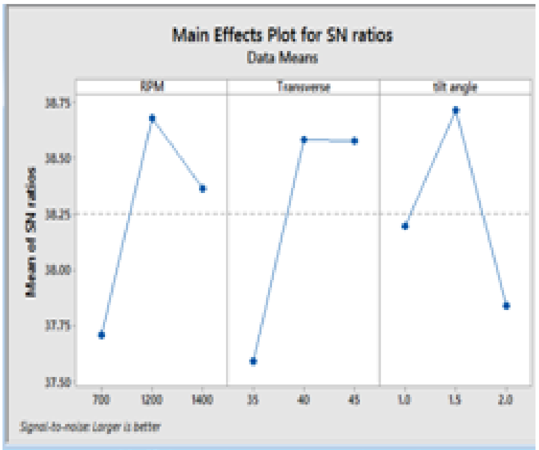



Figure 3: Main Effect Plot for SN Ratios

Table 4

**Response table for signal to noise ratio**

| level | rotating speed | Transverse speed | Tilt angle |
|---|---|---|---|
| 1 | 62.32 | 58.10 | 58.24 |
| 2 | 56.67 | 58.37 | 58.41 |
| 3 | 56.07 | 58.64 | 58.41 |
| delta | 6.26 | 0.54 | 0.17 |
| rank | 2 | 1 | 3 |

## VII. Analysis of Variance

ANOVA is done on MINITAB software. The main aim of the analysis is to estimate the percentage of the individual contribution of the welding parameter on the tensile strength of the weld, and also give accurately the combination of the process parameters. Individual optimal values for the process parameters and their specified performance characteristics can be obtained. The analysis of variance for tensile result shows that the transverse speed is the most influential parameter with a percentage of 40.848%, followed by the rotational speed of 31.77% and tilt angle of 25.655%.

Table 5: Analysis of Variance (ANOVA)

| source | DF | Seq ss | Adj ss | Adj ms | F | P |
|---|---|---|---|---|---|---|
| Rotating speed | 2 | 137.977 | 137.977 | 68.988 | 18.50 | 0.051 |
| Tool tilt angle | 2 | 177.359 | 177.359 | 88.680 | 23.78 | 0.040 |
| Travel feed | 2 | 111.391 | 111.391 | 55.696 | 14.93 | 0.063 |
| Error | 2 | 7.459 | 7.459 | 3.730 | | |
| total | 8 | 434.187 | | | | |

**Note:** DF- Degrees of Freedom, Seq SS – Sequential Sum of Squares, Adj SS – Adjusted Sum of Squares, Adj MS – Adjusted Mean Square, F test of hypothesis, P value of hypothesis.

## VIII. Result

Table 6: Optimized Result Obtained from ANOVA Minitab

| ROTATIONAL SPEED (rpm) | TRANSVERSE SPEED(mm/min) | TOOL TILT ANGLE($^0$) | TENSILE STRENGTH (Mpa) |
|---|---|---|---|
| 1200 | 40 | 1.5 | 94 |

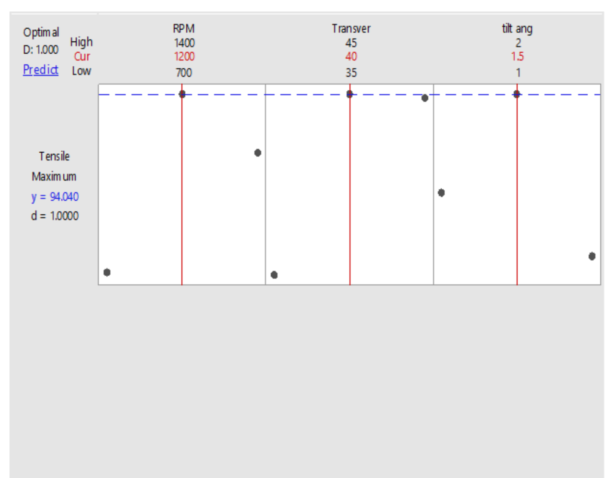



Figure 4: Graph Shows Optimum Value of Given Parameters

# IX. CONCLUSION

1. Hence the maximum tensile strength is obtained by using Taguchi technique and graph was plotted.
2. By using ANOVA table factors which influence tensile strength is obtained.

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