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# Effect of Process Parameters on Weld-Strength in Friction Stir Welding of Dissimilar Aluminium Alloys

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**ABSTRACT**

*Friction stir welding is an efficient technique in joining of dissimilar materials. Aluminium alloys AA2014 and AA7075 were joined by Friction Stir Welding by varying parameters like tool rotational speed, transverse speed and tool pin profile. The optimum parameters are found out by Taguchi technique using Taguchi's L9 orthogonal array. Also the contribution of each parameter on the joint quality is found out with the help of signal to noise ratio and Analysis of Variance (ANOVA) studies and an experiment was carried out on optimized parameters. Also, the microstructure of the welding joints was studied using optical micrography.*

**Key words:** Friction stir welding, Dissimilar aluminium alloys, ANOVA, Taguchi Method

## INTRODUCTION

Aluminium alloys like AA2014 and AA7075 are used in aerospace and automotive industry due to their light weight and good mechanical properties. But joining dissimilar materials is often a difficult task than joining similar materials due to different properties and composition of the base materials[1-3].However dissimilar aluminium alloys can be joined by friction stir welding because it is operated well below the melting point of the base materials resulting in absence of secondary phase and results in satisfactory joint quality[4].Friction stir welding was invented at The Welding Institute, United Kingdom in 1991.It is a solid state joining process which uses a non consumable rotating tool having pin and shoulder. The tool is inserted between the abutting surfaces of the plates to be joined and is transverse along the line of joint. The heating is accomplished by the heat produced due to friction between tool and work piece. The heat softens the material around the pin and a combination of tool rotation and translation leads to the transfer of the material from the front to the back of the pin [5]. The process of FSW is shown in fig. 1.

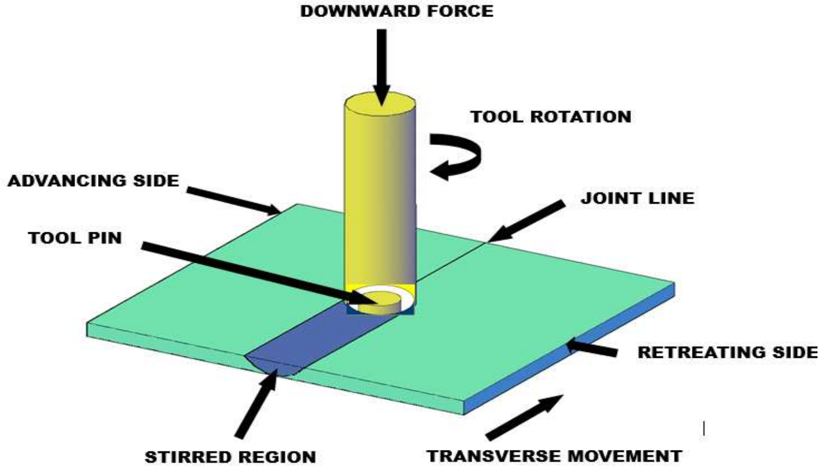



**Fig. 1 Friction Stir Welding Process**

There are many process parameters such as tool rotational speed, tool pin profile and tool transverse speed etc. that affect the joint strength. Tool pin profile has great influence on the tensile strength. Generally, tools with edges like a hexagonal pin profile gives maximum tensile strength which is due to the intense stirring of the material resulting in grain refinement[6].Other profiles like triangular, square and threaded has a very good stirring action from top to bottom of the weld[7].The tensile strength of the joint increases with increasing tool rotational speed, achieves a maximum value and then decrease [8].Previous studies shows that the maximum strength in case of aluminium alloy is obtained at medium rotational speeds of 800 to 1200 rpm[9]. The D/d ratio (shoulder diameter to pin diameter) plays a vital role and accounts for 60% to the overall contribution in Friction stir welding between AA2219-T87 and AA5083-H321 sheets [10].

## MATERIALS AND METHOD

### Materials

Aluminium alloy AA 2014 and AA7075 were used in this study. The rolled plates of 6.35 mm thickness were cut to a size of 100*70 with the help of a power bandsaw. The composition and mechanical properties of both materials is shown in the Table- (1-4).

### FSW Tool

Three different tool pin profiles were used for welding i.e. plain cylindrical, square and threaded triangular. Three pin profiles are shown in the fig. 2. The tools were made from M1 High Speed Steel having hardness of 54 HRC. All the tools have a common shoulder diameter of 18mm and pin length and diameter of 6 mm.

### Taguchi Method

Taguchi method is a very simple and effective method for experiment design. Main objective of Taguchi method is to analyse the input statistical data and determine the optimum results [11]. S-N ratio and mean response gives the results of effects of the combinations of the input data. Taguchi method was used with MATLAB 17 to calculate S/N ratio and perform ANOVA. ANOVA is used to find the effect of a parameter individually, in influencing the joint quality.

**Table- 1 Chemical Composition of AA 7075 Alloy**

| Element | Al | Si | Fe | Cu | Mn | Mg | Cr | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|
| % | 89.76 | 0.05 | 0.1 | 1.3 | 0.03 | 2.69 | 0.2 | 0.01 | 5.78 |

**Table- 2 Mechanical Properties of AA7075 alloy**

| Material | Ultimate Tensile Strength (MPa) | Hardness (VHN) | Elongation at Break |
|---|---|---|---|
| AA7075 T651 | 600 | 170 | 11% |

**Table- 3 Mechanical Properties of AA2014 Alloy**

| Material | Ultimate Tensile Strength (MPa) | Hardness (VHN) | Elongation At Break |
|---|---|---|---|
| AA2014 T651 | 569 | 134 | 13% |

**Table- 4 Chemical Composition of AA 2014 Alloy**

| Element | Cu | Si | Mn | Mg | Fe | Zn | Ti | Cr | Al |
|---|---|---|---|---|---|---|---|---|---|
| % | 3.90 | .50 | 0.40 | .20 | .70 | .25 | .15 | .10 | Balance |

**Fig. 2 Cylindrical, Square and Threaded Triangular pin profiles**

**Experimentation**

Three process parameters used in this study are tool pin profile, tool rotational speed and tool transverse speed. The three parameters have three different levels according to L9 orthogonal array and are shown in the Table-5.Experimental layout of L9 orthogonal array is shown in the Table- 6.During welding, the alloy with higher strength i.e. AA7075 is placed on the retreating side whereas lower strength alloy AA2014 is placed on the advancing side because good results are obtained with this arrangement [12]. Welding was performed on a vertical milling machine according to the design of experiments. After the welding, transverse tensile specimen were prepared confirming to ASTM-E8 standard [12] as shown in the Fig. 3.

**Table- 5 Factors and their Levels**

| Factors | Levels | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| X. Pin Profile | Squar | Cylindrica | Triangula |
| Y. Rotational | 1000 | 1400 | 2000 |
| D. Transverse | 28 | 56 | 80 |

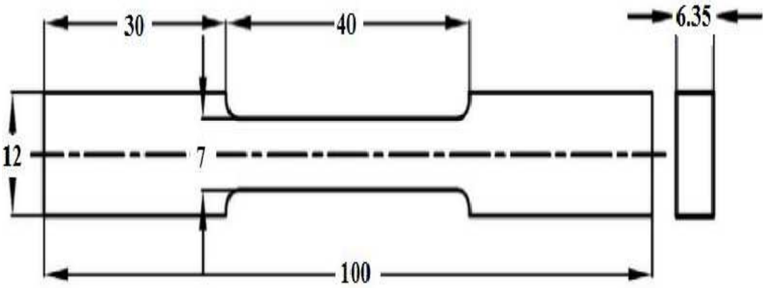



**Fig. 3 Specifications of the sample used for determining Tensile strength (All dimensions are in mm)**

**Table- 6 Experimental Layout**

| S.No | Experiment | FSW Parameters | | |
|---|---|---|---|---|
| | | Pin | Rotational | Transverse |
| 1 | X1 | 1 | 1 | 1 |
| 2 | X2 | 1 | 2 | 2 |
| 3 | X3 | 1 | 3 | 3 |
| 4 | Y1 | 2 | 1 | 2 |
| 5 | Y2 | 2 | 2 | 3 |
| 6 | Y3 | 2 | 3 | 1 |
| 7 | Z1 | 3 | 1 | 3 |
| 8 | Z2 | 3 | 2 | 1 |
| 9 | Z3 | 3 | 3 | 2 |

**Table- 6 Design of Experiments**

| Exp. No. | Tool Profile | RPM | Transverse Speed | Maximum Strength(MPa) |
|---|---|---|---|---|
| 1 | Square | 1000 | 28 | 237.57 |
| 2 | Square | 1400 | 56 | 257.81 |
| 3 | Square | 2000 | 80 | 319.25 |
| 4 | Cylinderical | 1000 | 56 | 97.18 |
| 5 | Cylinderical | 1400 | 80 | 190.32 |
| 6 | Cylinderical | 2000 | 28 | 117.43 |
| 7 | Threaded | 1000 | 80 | 109.33 |
| 8 | Threaded | 1400 | 28 | 207.37 |
| 9 | Threaded | 2000 | 56 | 143.53 |

## RESULTS AND DISCUSSION

### Signal to Noise Ratio and Mean

Main effect plots for S/N ratio and means are shown in the Fig.4 while Table- 8 presents the result of ANOVA. It can be observed from the plots that tool pin profile is the most influencing factor on the joint strength. Next, the rotational speed of the tool is the second most influencing factor followed by the transverse speed of the tool which is least influencing factor among three parameters.

As can be seen from Fig. 4, square pin profile is best suitable- to obtain better joint quality followed by the triangular pin profile and then cylindrical pin profile. The reason behind the suitability of square pin profile is that the square profile of the pin provides intense stirring of the material due to flat edged surfaces which in turn leads to finer grain structure and thus higher tensile strength. This hypothesis is also supported by Rama and Rani [13]. But in case of the cylindrical tool without any threads, the strength achieved is very low as compare to other tool profiles on all combinations of speed and RPM. Form ANOVA, it is clear that pin profile is the most influencing factor on the joint strength with a contribution of 64.9 % followed by the rotational speed as second most influencing parameter with contribution of 23.1%. The least influencing parameter in the present study is transverse speed of the tool with a total contribution of 4.91%. A confirmatory experiment was performed on the optimized process parameters found out from the S/N ratio plots. The optimized parameters are Square profile, 1400 RPM rotational speed and 80mm/min. transverse speed. The joint strength obtained with the optimized process parameters is 330 MPa which is clearly higher than the maximum strength achieved before optimization.

**Table- 8 Analysis of Variance (ANOVA) data**

| Source | DF | Seq SS | Adj SS | Adj MS | %Contribution |
|---|---|---|---|---|---|
| Pin Profile | 2 | 68.809 | 68.809 | 34.404 | 64.90 |
| Rotational Speed | 2 | 24.496 | 24.496 | 12.248 | 23.10 |
| Transverse Speed | 2 | 5.213 | 5.213 | 2.606 | 4.91 |
| Residual Error | 2 | 7.503 | 7.503 | 3.752 | |
| Total | 8 | 106.021 | | | |

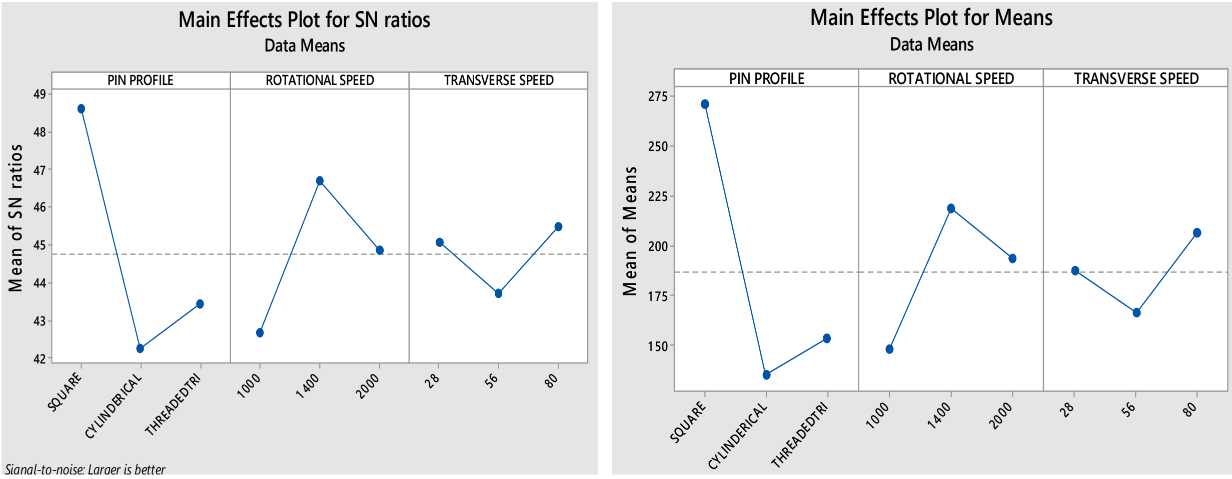
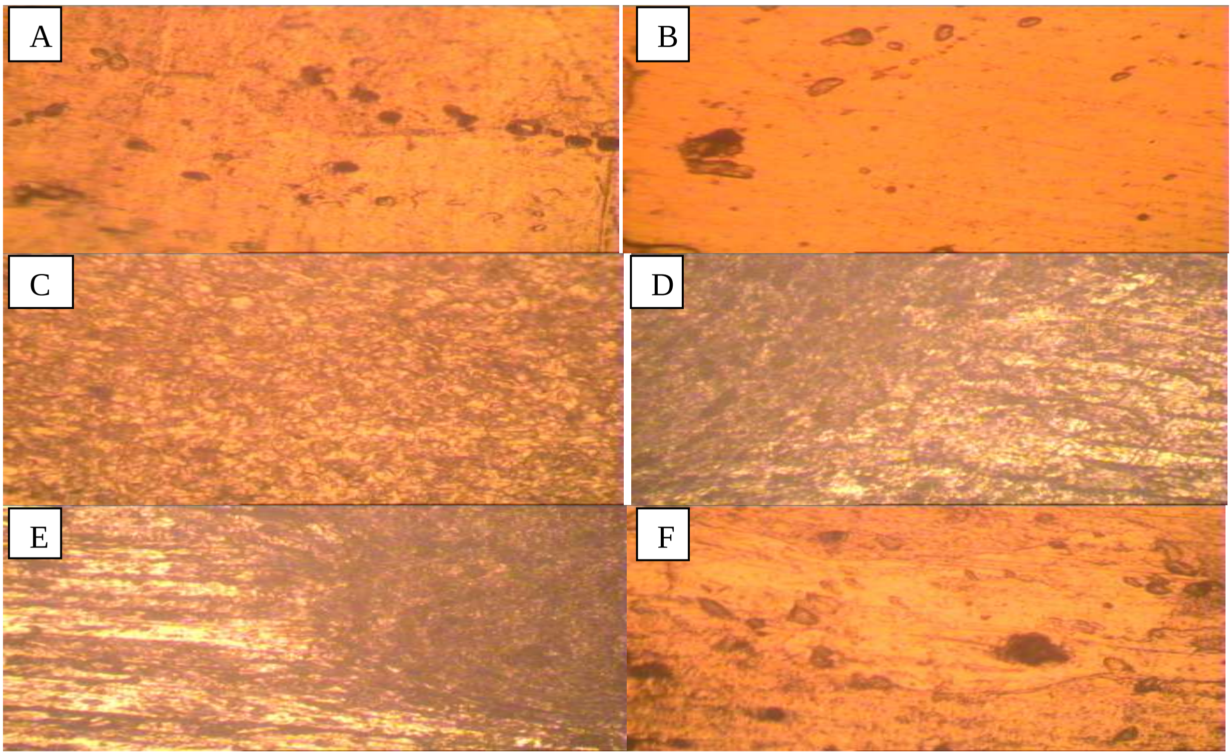



**Fig. 4 Main effect plots for S/N ratio and means**

## MICROSTRUCTURE ANALYSIS

Optical micrographs of the base materials of AA 2014 and AA 7075 at 400X are shown in Fig.6 (a) and (b) respectively. The eutectic particles are clearly visible in the aluminium matrix in both of the micrographs. Fig. (c-g) shows the micrographs of the joint obtained at 1400 RPM and 56 mm/min. with square tool. The fig. (c) is of the nugget zone of the weld showing the formation of the fine, recrystallized and equiaxed grains. The formation of the finer grain size is due to the intense plastic deformation of the material in the stirring zone during welding operation conforming to the general principles of the work hardening mechanisms. This hypothesis is also supported by [14]. Fig. (d) shows the interface between the nugget zone and the parent 2014 material whereas fig. (e) shows the interface between the nugget zone and the parent 7075 material with the darker portion showing the finer microstructure of the nugget zone in both micrographs. The zones adjacent to the nugget zones in the both micrographs is the thermomechanically affected zone. This zone undergoes both mechanical deformation and thermal cycles during the welding operation. But the grains are not recrystallized like the nugget zone owing to the inadequate deformation rate in the TMAZ. Fig. (f) and (g) shows the heat affected zone of the advancing side and retreating sides respectively. This zone is only thermally affected during the welding operation. There is not much variation of the microstructure of the HAZ from the parent metal but the precipitates are coarsened comparing to the base metals as it is evident from some bigger precipitate particles in both (f) and (g) as compared to (a) and (b) which shows the micrographs of the base materials. This hypothesis is also supported by [15], [16] and [17].



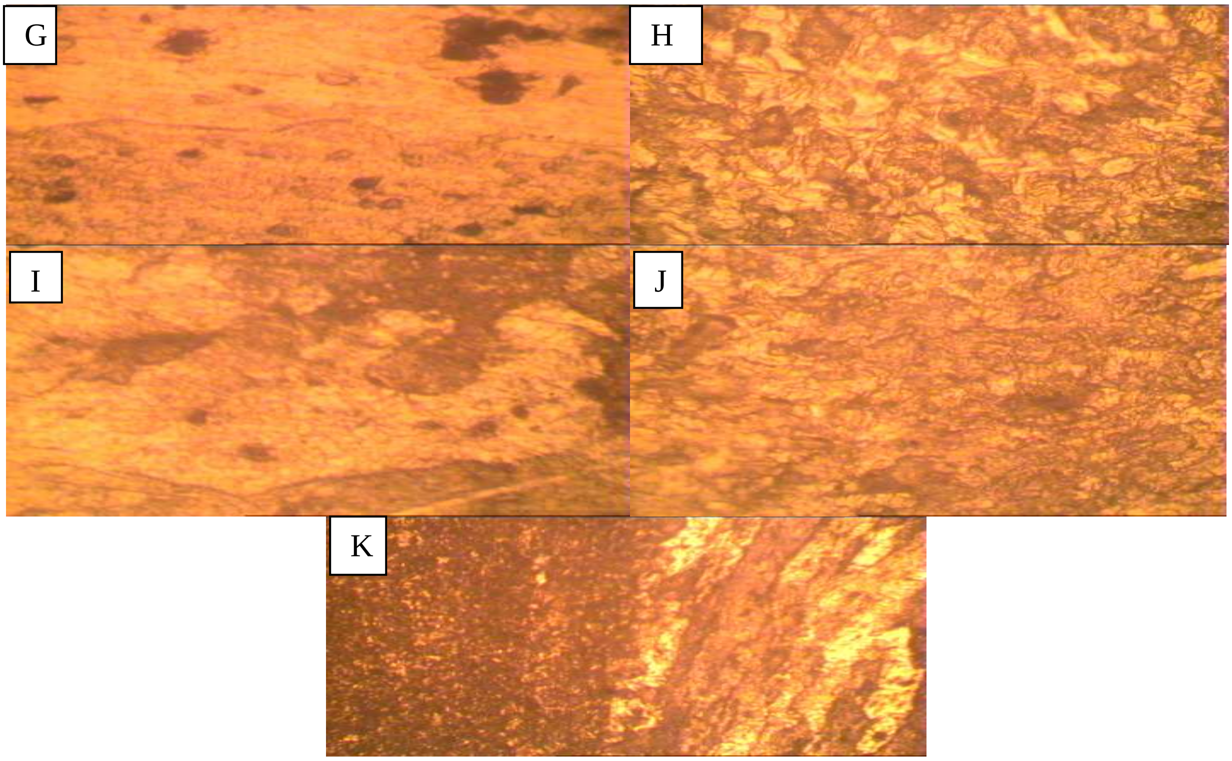



**Fig. 6 (a-f) Optical Micrograph of the weld obtained at 1400 RPM, 56mm/min and square tool and (g-k) 1400 rpm,80mm/min and cylindrical tool**

Fig. 6 (h-k) shows the micrographs of the weld obtained at 1400 RPM, 80mm/min with cylindrical tool. Fig. (h) shows the micrograph of the nugget zone of the weld. The grain size is not as much refined as it is in the (c) which is at 1400 RPM, 56mm/min with square tool although the favourable condition for the plastic deformation is high travel speed which is present in joint obtained at 80mm/min i.e. (h). Thus, it is evident that the square tool induces much more intense plastic deformation as compared to the cylindrical tool, refining the grain structure and resulting in greater joint strength as compared to the cylindrical tool. Fig. (i) and (j) shows the heat affected zone of the advancing side and retreating side respectively whereas the (k) shows the interface between the TMAZ of the advancing side and the nugget zone. It is clear from the micrographs that the nugget zone and the heat affected zone at the retreating side are more or less similar and also there is no clear distinction between the nugget and TMAZ of the retreating side. A similar conclusion of diffused interface between the nugget zone and the parent metal is also made by [18].

## CONCLUSION

Friction stir welding has been successfully applied to join dissimilar AA2014 and AA7075 aluminium alloys. The process parameters of the welding operation are optimized for strength and the post welding microstructure has been analyzed. Following conclusions can be drawn from the study -

- The optimized parameters for the FSW of AA2014 and AA7075 aluminium alloy are found to be 1400 RPM , 80mm/min travel speed with square tool.
- The tool profile has a contribution effect on the joint strength and the microstructure of the weld zone followed by rotational speed and transverse speed. Square pin is found to give the maximum strength due to the finest grain structure (as compared to other profiles) in the weld nugget resulting from the intense plastic deformation of the stirred material.
- The micrographs of the weld zone reveal three distinct zones, i.e. nugget zone. thermomechanically affected zone and the heat affected zone. The grain structure in the nugget zone is recrystallized and refined due to the heat and plastic deformation induced by the tool respectively.
- As it is evident from this study, tool pin profile is the most influential parameter affecting the weld strength. Thus, there is a wide scope for studying the weld quality produced by different and specially designed tool pin profiles.

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