

Parametric Optimization Through Taguchi Approach for Tensile Stress in FSW of AA6101-T6

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Abstract—In this experimental study, mechanical and metallurgical properties of the friction stir welding of aluminium alloy (AA6101-T6) are observed. A cylindrical threaded tool of high-speed steel (H13) used for friction stir welding of AA6101-T6. The Taguchi method with three levels and three parameters selected at a time for the optimization of parameters in Friction stir welding. The design of the experiment and ANOVA statistical tool used for the optimization of parameters for the response of tensile strength of the weld. SEM analysis, the microstructure of the weld surface and fractography of the fractured weld surface are studied by Scanning electron microscope.

Keywords—FSW, ANOVA, SEM, Tensile strength, Taguchi.

I. INTRODUCTION

Friction Stir Welding is a new fabrication technique for aluminium alloys invented by the welding institute (TWI), in the United Kingdom in 1991 and patented by W.M Thomas. It is a new joining method generally known as a solid-state fabrication process [1]. It is environmentally friendly and single-phase process and suitable for the joining of almost all type of aluminium alloys which are widely applied in the aircraft industries. A specially designed rotating tool traversed along the line of the joint which inserted into the abutting edges of sheets [2]. The parts which clamped rigidly on fixture as a backing plate, to control the abutting joint surfaces from being forced apart. When the tool shoulder starts to touch the surface of the workpiece then stop plunging. Shoulder of the tool should be in touch with the working plates. The main aim of the rotating tool is heating and softening the work-piece and produce the joint due to the movement of material. Enough heat can be obtained which is used for welding of joint and the temperature of the pairing point can be raised to a level at which surfaces susceptible to friction can be welded together. Due to the rotational and transverse speed of the tool, localized plastic heating which softens the working material around the tool pin [3]. The tool is travel along the joint until it reaches the last of the weld and both plates are welded by frictional heat.

Numerous researches around the world investigated on FSW with different wide series of materials. **Mishra et al.** [2] published a series of books on FSW and FSP which provides informative and comprehensive of the process. **C. Elanchezian et al.** [4] carried out optimization of FSW parameters on aluminium alloys (AA8011 & AA 6062) by

using the Taguchi approach. The responses were manipulated with ANOVA statistical tools and Taguchi L9 orthogonal array. Evaluating the result such as tensile, impact, microhardness and these responses affected by different values of parameters. SEM was manipulated to test the quality of the surface texture. **G. Elatharasan et al.** [5] carried out the optimization of FSW parameters on AA6061-T6 by using RSM. In their investigation, build the relationship between the parameters and responses (elongation, yield stress, and tensile strength). A mathematical model of RSM with three different parameters and 3-levels selected. They performed 20 runs and analyzed the results with RSM methodology. **Sarsilmaz and Caydas** [6] performed FSW on dissimilar aluminium alloy (AA1050 & AA5083) by a full factorial design approach. In their investigation, to study the parametric effect on mechanical properties (UTS and Hardness) of the weld. ANOVA statistical tool used for this investigation and reported significant factor and predict the optimum result of the experiment. **Sergey M. et al.** [7] investigated on optimization of processing microstructural properties on weld of FSW 6061-T6. They considered parameters and analysed their effects. Reported the microhardness lower at stir zone from base metal and tool travel speed 760 mm/min had yield joint efficiency 93%, localization of strain in HAZ.

There is no study reported on statistical optimization of the FSW parameters with three levels and three parameters at a time for the selected aluminium alloy (6101-T6) and the parametric effect on the mechanical and metallurgical properties of FSW using the DOE (Taguchi approach) with three levels and three parameters at a time.

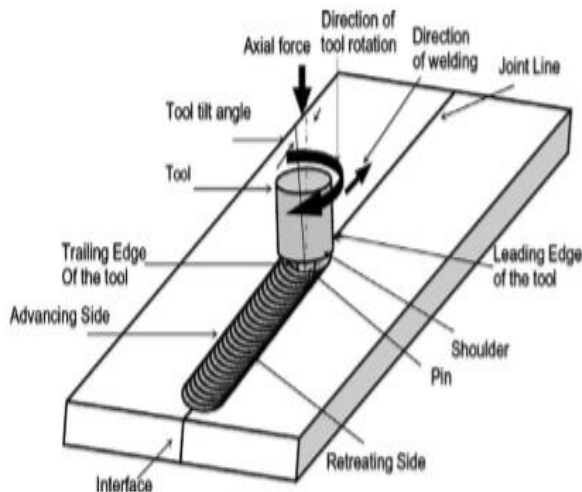


Fig. 1. A schematic diagram of the FSW process [8].

II. EXPERIMENTATION

A. Setup of Friction stir welding

We perform the experiment on a vertical milling machine with some modifications on the machine. According to the machine, we designed the fixture which it can easily fit on the bed of the machine. A threaded cylindrical tool of high-speed steel with a shank diameter of 20 mm to fix in to cullet. A schematic pictorial diagram of machine setup which is shown below in the figure.

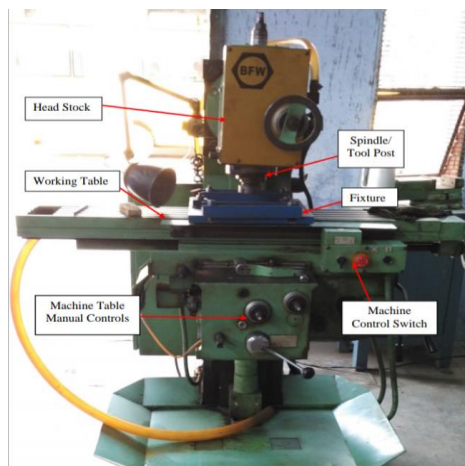


Fig. 2. FSW setup on a vertical milling machine

B. Material used

Aluminium alloy AA6101-T6 with 150×60×6 mm material is used for this investigation. Alloy 6101-T6 is an extruded product as a heat treatable alloy and offers good weldability, bendability, formability and electrical conductivity as well as thermal conductivity [9]. Temper - T6 means artificially aged and heat treated.

Table I. (%) Chemical composition of plate AA6101-T6 [9].

Chemical composition	Cu	Mg	Si	Fe	Mn	Others	Al
wt %	0-0.05	0.40 - 0.90	0.30-0.70	0.50	0.03	0.1	rest

Table II. Mechanical properties of AA6101-T6 [9].

Density gm/cc	Melting point	UTS MPa	Yield strength (MPa)	% Elongation	Young's modulus (GPa)
2.7	635	221	172	19	75

C. Tool used

The tool would be made from those type materials which can withstand in the process and offers enough generation of frictional heat. It must be sufficiently stronger, high melting temperature and high wear resistance from the base material [10]. We designed it by the CATIA software and then manufactures it by specific design. If the harness is less, then hardening required so we hardened the tool 60 HRC by tempering process.

Table III. Tool description

Material	H13
Shoulder Dia.	20 mm
Pin Length	5.8 mm
Pin Base Dia.	6.3 mm

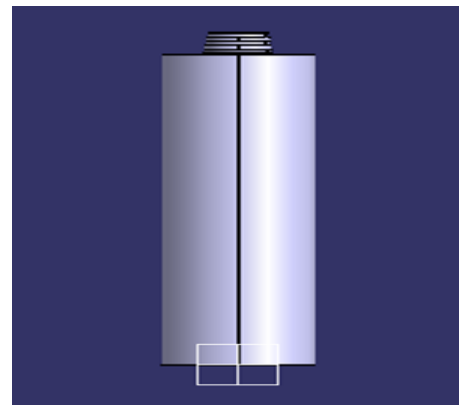


Fig. 3. Design of tool

D. Design of Experiment

In this investigation, the Taguchi approach applied for optimization of parameters in the FSW of AA6101-T6. It is more systematic and efficient approach and relates to inadequate knowledge of statistics. Now selected L9 orthogonal array for optimizing the parameters. DOE application: based on the Taguchi approach. Total all three parameters have $DOF = 6$, and total $DOF = N-1=8$; Where, N = no. of trials [11].

III. RESULTS

Friction stir welding conducted for investigation of parametric effect on responses as Tensile strength and microhardness which are tabulated below. Tensile test performed on digital UTM machine which gives a graph between stress v/s strain. In Microhardness test where indentation is the form used for calculation and we take an average of response values.

Table IV. Results of testing in L9 representations

Experiments	rpm (R)	Feed(S)	Tilt angle	Av. Tensile strength (MPa)
Exp-1	710	16	0	135
Exp-2	710	25	1	139
Exp-3	710	40	2	140
Exp-4	1000	16	1	141
Exp-5	1000	25	2	154
Exp-6	1000	40	0	144
Exp-7	1400	16	2	140
Exp-8	1400	25	0	147
Exp-9	1400	40	1	134

A. Effect on Tensile Strength

Values of tensile strength at levels of 1, 2 and 3 for each parameter are plotted which shows below in the figure. It shows that the tensile strength increases with the increase of rpm and but decreases after reaching a maximum value and similarly for feed, but it decreased with increases of tilt angle and reached to a minimum value after that tensile increase with the increases of the tilt angle.

Table V. ANOVA for tensile strength

Source	DOF	Adj SS	Adj MS	F-Value	P-Value
R	2	110.889	55.444	19.96	0.048
S	2	118.22	59.111	21.28	0.045
Θ	2	67.556	33.778	12.16	0.076
Error	2	5.556	2.778		
Total	8	302.22			

MS – mean of squares SS – squares sum, F- [Vs / Ve], P < 0.05 - 95% confidence level for significance

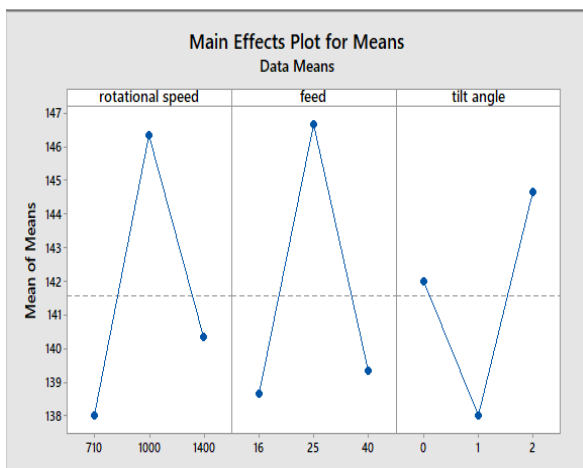


Fig. 4. Parametric effect on the response tensile strength

Table VI. Response for Means

Level	R	S	θ
1	138.0	138.7	142.0
2	146.3	146.7	138.0
3	140.3	139.3	144.7
Delta	8.3	8.0	6.7
Rank	1	2	3

B. Selection of optimum levels

Analysis of variance (ANOVA) performed and noticed that some factors are more effective for the response of tensile strength. Rank and delta assign the greatest effect on the response (tensile strength) indicates the importance of each factor in each response. Responses for (S/N and Means) for each level factor. MINITAB 17 uses for plotting Table and calculating the delta. For strength, Larger better type [11].

C. Estimation of optimum response (Tensile strength)

Significant variables are A2, B2.

$$\mu_T = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_2 - \bar{T})$$

The overall mean of tensile strength $\bar{T} = 141.556$ MPa

Predicted optimal value $\mu_T = 151.444$ MPa

CI_{CE} and CI_{POP} are calculated by the eqn (i), (ii) [11-12].

$$(i) CI_{POP} = \sqrt{\frac{F_{\alpha}(1, f_e) V_e}{n_{eff}}} \quad (ii) CI_{CE} = \sqrt{F_{\alpha}(1, f_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R} \right]}$$

$F_{\alpha}(1, f_e)$ = F-ratio level of confidence $(1-\alpha)$ aligned with DF 1 and error DOF (f_e)

$n_{eff} = N/1 + (DF \text{ estimated response}) = 1.2857$, $F_{0.05}(1, 2) = 18.5120$ (chart F-value) [12].

95 % confidence intervals of (CI_{CE}) and (CI_{POP}) are calculated from Equations [11-12].

$$CI_{POP} = \pm 6.324, \quad CI_{CE} = \pm 7.5591$$

The optimal values of parameters are: Rpm (A2) = 1000 rpm, Feed (B2) = 25mm/min,

D. Confirmation Experiment

The values of tensile strength and microhardness calculated from confirmation experiments.

Table VII. Predicted Optimal values, CI and Results of CE

Response	Predicted optimal value	Predicted interval with 95% confidence level	Av. of CE value
Tensile strength	151.444 MPa	$CI_{POP} = 145.44 < \mu_T < 157.768$ $CI_{CE} = 143.882 < \mu_T < 158.99$	149 MPa

E. Microstructural Analysis of surface Using Scanning Electron Microscopy (SEM)

A scanning electron microscope develops images of the surface by scanning it with a focused beam of electrons. A small sample was cut from the welded portion into 5×10 mm. It examines by SEM on the weld portion at a different-magnification at different point of the weld. It is observed that material flow in the weld zone of FSW (lump material deposits) in Fig 6a.

A careful attention required for analysis of fractography, firstly prepare a sample for which we select to study. The tensile tested sample which was fractured during the tensile test at UTM is selected for the study. In fig. 6(b) observed

partially plastic and partially ductile failure. Due to the presence of other particles, Transgranular in the fracture area observed that local plastic deformation brittle failure of weld during a tensile test on UTM machine.

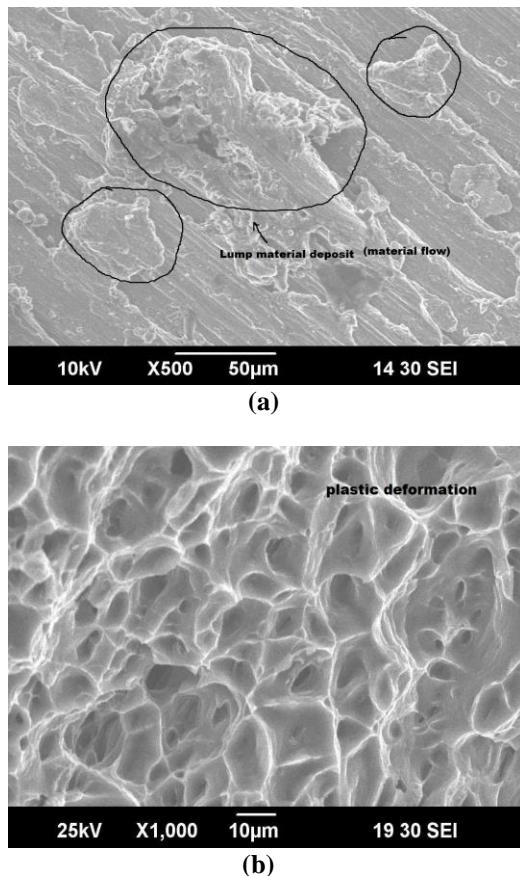


Fig. 5. The microstructure of the weld surface by SEM

IV. CONCLUSIONS

- Tool rotational speed is found to be the most significant parameter for tensile strength.
- The tensile strength of joints increases with an increase of rotational speed in the range of 710 – 1000 rpm and reached a maximum at 1000 rpm. After that, it decreases with the increase of rotational speed.
- Tilt angle has been found to be insignificant for tensile strength. However, it is found to be significant for the other response.
- The optimized value of tensile stress is 151.444 MPa which indicate a significant improvement in both

responses from the initial setting of the first experiment. Moreover, the optimized results have been validated through a confirmation experiment.

- From the microstructure analysis of the welded samples, localized as well as widespread plastic deformation is visible for few samples. Observed lumped material deposits, partially plastic and partially ductile failure of weld during a tensile test.

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