Evaluation of Tensile Behavior of AA6082 Friction Stir Welded Joints

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Abstract— Friction stir welding joints are used to join aluminium alloys commonly in present industry. Use of aluminium was increased due to its high tensile strength to weight ratio. This article focuses the evaluation for tensile strength of friction stir welded joints of AA 6082 using full factorial design matrix. Tensile behaviour is an important factor to judge a welded joint in industry. Full factorial is used to get the best combination of parameters for higher tensile strength. Optimized combination of parameters are trying to be found using welding parameters i.e. rotational speed (1000-4000 rpm), travel speed (10-40 mm/min) and tool pin length (4-5mm). Results show that with higher rpm, lower travel speed and higher ping length gives the better results.

Key words: Friction stir welding, Aluminum alloy, Taguchi, full factorial, Tensile strength

I. INTRODUCTION

Friction stir welding is the latest invented metal joining technique which is employed to join metals like aluminum that are considered as non-weldable previously [1-3]. Friction stir welding was invented in 1991 by the welding institute. Presently friction stir welding is used majorly as a cleaner manufacturing technology for the present industry. Friction stir welding involves a solid tool having a pin at the leading edge that is to plunge in between the abutting edges of the metal pieces which is to be welded. For easy understanding the sychematic diagram of the welding process is shown in figure 1. Concept behind the friction stir welding is very commonly used physics that when two solid surface comes in contact with each other the heat generated at that contact point. Rotating pin produces heat in between the abutting edges of the aluminium plates. The rotating tool increases this heat generation with the continuous contact in between the tool and metal surface. Friction stir welding is a solid state welding procedure in which metal dose not undergone to the melting state but get the weld joint at plastic state only [4-5]. This uniqueness of friction stir welding makes it free from the oxidation, shrinkage, porosity and hydrogen solubility and low heat input to the weld metal successfully inhibit the intermetallic compound layer formation which helps to make sound metal joint. Friction stir welding is also a cleaner metal joining process because this joining process if free from any hazard gases or any harmful chemical fumes [6]. These harmful gases are responsible for bronchitis and other lungs disorders.

Recently some noble articles are published with international journals, which help and motivate us for research in this field. Uzun et al. [7] reported the joint strength of friction stir welded joint between 304 stainless steel and Al 6013-T4 with thickness of plates 4 mm can reach approximately 70% of the base aluminum alloy. Ghosh et al. [8] studied the FSW joint of pure Aluminium to 304 stainless steel and the ultimate tensile strength was recorded as 82% of base Aluminium. Presence of Fe_3Al was reported with finer grains exist in the stirring zone, which indicate the dynamic recrystallization of metal grains. Tanaka et al. [9] weld two dissimilar metal, Al7075-T6 to mild steel of the thickness of 3 mm. Tool rotational speed with in the range of 400 to 1200 rpm with tool travel speed of 100 mm/min. The highest tensile strength was observed as 333 MPa, which is about 60% of the base aluminium alloy. Moreover, the author found an exponentially increasing relation between the interface strength and the reducing thickness of IMC layer, which has the composition of $FeAl_3$. Lee et al. [10] conducting experiments on FW of Al6056-T4 to 304 stainless steel with thickness of 4 mm with the rotational speed of 800 rpm and welding speed of 80 mm/min. The thin intermetallic compound layer of 250 nm thickness was analysed through transmission electron microscopy (TEM) and identified as formation of $FeAl_4$. Chen and Kovacevic [11] joined Al6061 to AISI 1018 steel sheet with the thickness of 6 mm. Local melting of Aluminum was observed and shear-off steel platelets encompassed by IMC layers of Fe_4Al_{13} and Fe_2 Al_{15} existed in the weld nugget. Locally partial molten Aluminum was again reported by Jiang and Kovacevic [12] when they did study on the same pair of materials with the same thickness.in present article, aluminium alloy 6082 was used and effect of parameters on tensile strength was studied.

II. MATERIAL AND METHODOLOGY

A. *Aluminium Alloy 6082:*

Material used for friction stir welding was commercially available aluminium alloy 6082. Aluminium is widely used in the manufacturing industry that increases its acceptability as research material. The chemical composition and mechanical properties of AA6082 are shown in table 1 and table 2. These properties shows its versatility among the engineering material.

Si	Mg	Cu	Fe	Mn	Zn	Cr	Ti	Al
1.25	0.75	0.1	0.45	0.70	0.2	0.20	0.1	Balance

Table 1: Chemical composition of AA 6082(wt %)

Tensile strength	Yield strength	Elongation	Hardness(HV)
0.160 KN/mm^2	0.085 KN/mm^2	Up to 20%	38

Table 2: Mechanical properties of 6082 AA

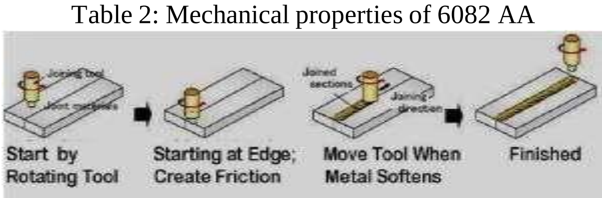

Fig. 1: Step wise procedure for Friction stir welding

B. *Tool Material:*

Tool used for friction stir welding is made of mild steel having a pin of desired length which is to be inserted to the abutting edges of metal pieces. Description of tool material shown in table 3. Figure 2 shows the drawing of tool used and figure 3 shows the tool used during the experimentation.

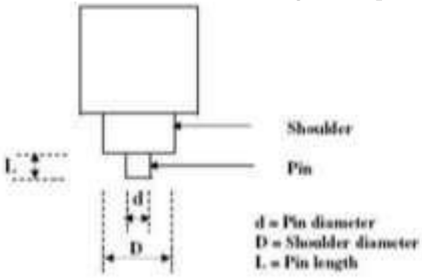

Fig. 2: Tool Geometry for FSW

C. Parameters Selection:

Process parameters are selected on the basis of pilot experimination. From litrature it was evident that rotational speed, travel speed and tool pin length are the major parameters in friction stir welding. These parameters shows the large percentage contributation in terems of tensile strength of friction stir welde joints. The range of parameters selction are shown in the following table 4.


Fig. 3: Tool prepared for FSW with different pin length

Element	C	SI	Mn	S	P	Ni	Cr
Wt%	0.44	0.4	1.65	0.01	0.017	0.09	0.152

Table 3: Chemical composition of mild steel used as tool

Sr No	Parameters	Units	Range	Level 1	Level 2	Level 3
1	Rotational speed (R)	RPM	1000 - 4000	1000	2500	4000
2	Traverse speed(T)	mm/min	10-50	10	25	40
3	Tool Pin length(P)	Mm	4-5	4	4.5	5

Table 4: Parameters and their levels selected through preliminary experimentation

III. METHODOLOGY

Full factorial orthogonal array was used to check the optimum combination of parameters for the tensile strength of welded joint. The design matrix of 3 parameters with 3 level each. No of experiments is calclucted by simple formula $=n^p$, where n= no of parameters and p= no of levels. So according to the formula 27 no of experiments is to be conducted under this full factorial design.

IV. EXPERIMENTATION

The following steps are followed for the welding process of AA6082:

Two AA 6082 plates with dimensions 150x50x6mm(Lxbxt) respectively were placed on fixture in a manner that prevents the displacement of plates during welding and fix them along the travel line of welding tool. Tool was fixed firmly in the tool collect of respective dimension and rotated at required rpm. Tool pin is plunged vertically into the joint line between the workpieces, while the tool is rotating. Due to velocity difference between the rotating tool and the stationary work piece, heat is produced by frictional work and material deformation is started. To accomplish the welding, the rotating tool is traversed along the line, while the shoulder of the tool is maintained in intimate contact with the plate surface. Shoulder confirms the underlying material so void formation and porosity behind the probe are prevented. As the heat dissipated into the surrounding material, the temperature rises and material softens without reaching the melting point (hence known as solid state process). As the pin is moved in the direction of the welding leading face of pin, assisted by a specified pin profile, forces plasticized material to the back of the pin whilst applying a substantial forging force to consolidate the weld metal. When the weld distance is covered, the tool is pulled out of the workpiece leaving behind an exit hole as a foot print of the tool. The following figure 4 contains the sample prepared by friction stir welding.

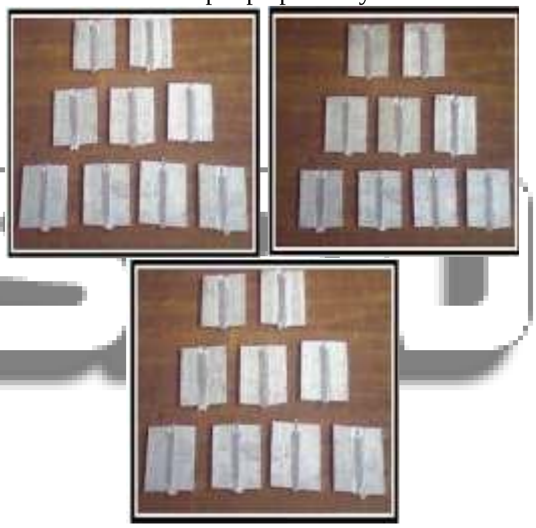
Fig. 4: Welded piece of aluminium by FSW

A. Sample Preparation:

Ultimate tensile strength (UTS), or tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking. Tensile strength is defined as a stress, which is measured as force per unit area. This test was performed on universal testing machine. Specimen for this testing shown in Figure 5 were cut from the welded plate on power hacksaw and prepared on vertical milling machine.

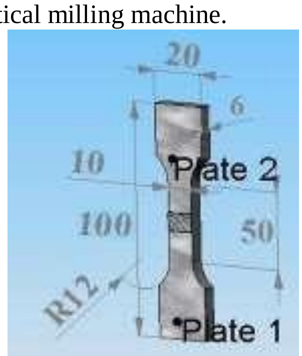

Fig. 5: Design for tensile specimen

Fig. 6: Sample prepared for tensile strength

V. RESULT AND DISCUSSION

Total 27 no of experiments are performed with all possible combination of selected parameters (rotational speed, traverse speed and pin length) according to combination of parameters by full factorial design matrix. Tensile strength at desired combination of parameters are shown below in table 5. The tensile strength of FSW specimens within the range of 0.112 to 0.157 KN/mm2. Which is almost 60 to 98 % of the base metal and shows the better tensile strength as compared to other welding process.

Sr. no	Rotational Speed(R)	Traverse Speed (T)	Tool Pin Length (P)	Tensile Strength (KN/mm^2)
1	1000	40	4.0	0.111
2	2500	40	4.0	0.124
3	2500	10	5.0	0.154
4	1000	10	4.5	0.122
5	4000	40	4.0	0.138
6	2500	25	5.0	0.150
7	4000	10	5.0	0.157
8	4000	40	4.5	0.141
9	4000	10	4.0	0.145
10	2500	40	4.5	0.128
11	1000	25	4.5	0.118
12	2500	10	4.5	0.134
13	4000	25	4.0	0.140
14	2500	10	4.0	0.130
15	4000	25	4.5	0.145
16	4000	10	4.5	0.150
17	1000	10	4.0	0.119
18	1000	25	4.0	0.115
19	1000	40	5.0	0.126
20	1000	40	4.5	0.112
21	2500	25	4.5	0.130
22	1000	25	5.0	0.132
23	4000	40	5.0	0.148
24	2500	25	4.0	0.128
25	1000	10	5.0	0.139
26	2500	40	5.0	0.145
27	4000	25	5.0	0.154

Table 5: Tensile Strength of FSW specimens welded at different set of parameters

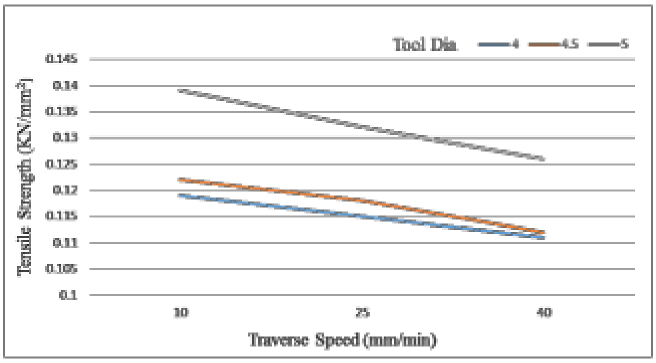

Fig. 7: Tensile behaviour of FSW joints for varying feed rate for 1000 RPM with different tools.

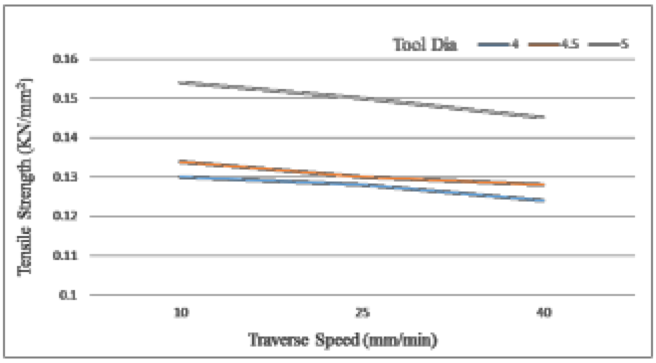

Fig. 8: Tensile behaviour of FSW joints for varying feed rate for 2500 RPM with different tools

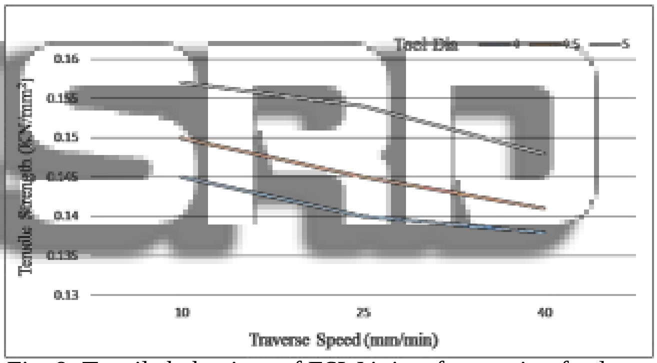

Fig. 9: Tensile behaviour of FSW joints for varying feed rate for 4000 RPM with different tools

From the above figure 7, 8 and 9 it is evident that the tensile strength has a significant effect with all above stated parameters and there effect can be seen from the graphs.

VI. CONCLUSION

Friction stir welding is the modern manufacturing process which can solved different welding defects easily. Parameters involved in friction stir welding shows there effect of mechanical properties and all involved parameters can be explained as follows:

- Rotational speed shows its effect very significantly higher rpm gives better tensile strength, as the average tensile strength with 4000 rpm is 0.146 KN/mm^2 which is higher than the tensile strength at 2500 and 100 rpm i.e. 0.135 and 0.121KN/mm^2 respectively. So the rotational speed should be kept high with in the range.
- Traverse speed shows its effect and it can be seen that increasing traverse speed gives lower tensile strength. With increasing traverse speed the contact

time decreases and less heat generated at that particular point and lowers the tensile strength.

– Pin length also shown its effect and increasing pin length gives better tensile strength with every rotational speed. Full length pin gives more surface contact area and produces more frictional heat which provide better tensile strength.

From full factorial design the optimum set of parameters is experiment no 7. Which is maximum rotational speed (4000 rpm), lower traverse speed (10mm/min) and longest pin length (5 mm).

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