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Influence of FSW Process Parameters on Mechanical Properties of Dissimilar Aluminum Butt Welded

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Abstract. The Aluminium alloys have seen a tremendous growth in the last decade in its applications among all the industries owing to its accessibility and other desirable characteristics such a high strength-to-weight ratio, resistance to corrosion, heat conductance, and a durable nature etc. The Aluminium alloys will continue to be in demand in Aerospace, Automobile, ship building, Defence, Transportation, packaging and several other industries. When performing the similar and dissimilar friction stir welding process, the tool profile and specifications are crucial for enhancing the microstructure and mechanical characteristics of the joints. The present research work is about the Friction stir welding of dissimilar Aluminium alloys (AA 8011, AA 2024).The purpose of the project is to examine the mechanical properties of weld joint of aluminium alloys AA8011 and AA2024. In the present work the weld properties (like UTS, YS and weld strength) of AA2024 and AA8011 welded joints by changing the process parameters like Tool rotation speed (in rpm), welding speed or traverse speed and Tilt angle.

Keywords: AA 2024, AA 8011, Friction stir welding, Heat effected zone

1 Introduction

1. A Subsection Sample

FSW is a cutting-edge and environmentally friendly solid state joining technological advances used to connect lightweight materials such as aluminium alloys. During FSW, a non-consumable rotating tool with a shoulder and a pin at the end is set into the base material and twisted in the welding direction[1]-[4]. The FSW technique is regarded as a fumeless welding process that works well for joining soft materials like aluminium, copper, nickel, titanium, etc. that are challenging to join using conventional welding techniques[10]-[12].

The non-consumable spinning tool utilised advances across the joint, creating heat well below the melting temperature of the base metals[7]. The tool also has a pin and shoulder that are specifically designed to be inserted into the two plates edges being joined, and it moves along the joint line with the work piece. The materials are joined using at the temperature of the FSW process of recrystallization[14]. The components in the workpiece are stirred together by the tool's spinning, and as it travels over the welded joint, it produces enough heat from friction to liquefy the substance without

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melting it. Fig 1 shows FSW welding process and various heat zones that are formed during in FSW welding.

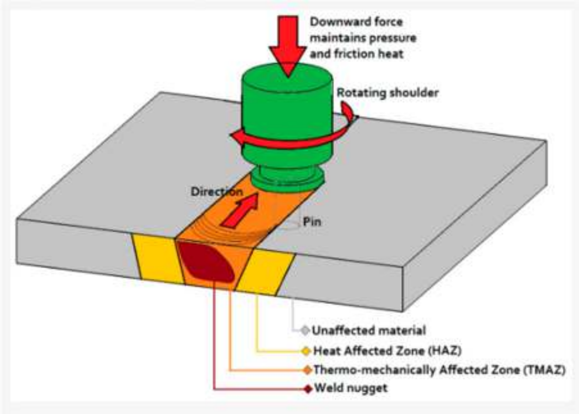


Fig. 1. FSW welding process and Heat zones

2 Methodology

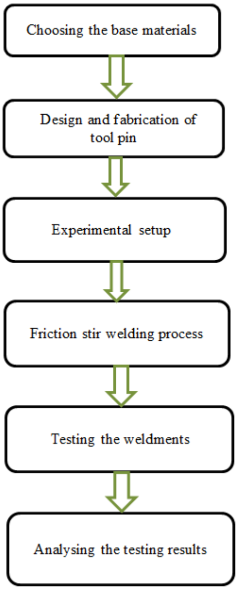


Fig. 2. Methodology flowchart

To obtain the above-mentioned objectives, a sequence of operations was followed as shown in the Fig. 2. In the initial stage, base materials and tool pin material were finalized and tool pin was designed using AutoCAD software. Fabrication of the tool pins was completed on the lathe machine[13]. FSW experimentation was performed as per the selected parameters. After the welding process the weldments are tested on universal testing machine and the results are analysed.

3 Workpiece and tool Material

The work piece material (base material) is the Aluminium alloys AA2024 and AA8011 both having the dimensions (specimen size) 150mm length, 100mm width and 5.5mm thickness. By placing AA8011 alloy on the retreating side and AA2024 on the advancing side, the FSW process is used to produce the butt joints of aluminium alloys.The tool that we are using is made of H13 tool steel and the tool pin cross-section is tapered cylindrical shape.Tool profile is shown in Fig 3[15] .On the basis of earlier literature on the welded joints, the practical working limits are chosen. The chemical compositions of the AA8011 and AA2024 aluminum alloys are shown in the Table 1 and Table 2 below. Work piece dimensions are shown in Table 3.

Table 1. AA2024 chemical composition

Sample AA 2024	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight (%)	0.03	0.23	3.95	0.40	1.70	0.022	0.020	0.040	Rem

Table 2. AA8011 chemical composition

Sample AA 8011	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight (%)	0.76	0.89	0.002	0.002	0.002	0.002	0.002	0.015	98.32

Table 3. Work material specification

S.No	Sheet Metal	Specifications
1	AA2024	150x100x5.5 mm
2	AA8011	150x100x5.5 mm

Table 4. Composition of Tool Material

Element	Cr	Mo	Si	V	C	Ni	Cu	Mn	P	S
Content (%)	4.75-5.5	1.10-1.75	0.80-1.2	0.80-1.2	0.32-0.45	0.3	0.25	0.20-0.5	0.03	0.03

Fig. 3. Tapered Cylindrical Tool Profile

4 Experimental Procedure

Using the three factors (the rotational speed, the transverse or welding speed and Tilt Angle) and three levels, we can apply the L9 Orthogonal rule or Taguchi method to weld the two dissimilar alloys for welding 9 different pairs and form joints by using the friction stir welding equipment. Table 5 below is called as the L9 Orthogonal array rule .To work out this rule we have to take 3 different values in each parameter. Then out of all the nine different values by changing the combinations we can get 3^3 i.e. 27 combinations. The graph drawn with the outcomes of these 9 weld joints is used to get the approximate outcome of other combinations.

Table 5. L9 Orthogonal array

EXPERIMENT NO	ROTATIONAL SPEED	TRAVEL SPEED	TILT ANGLE
1	1	1	1
2	1	2	2
3	1	3	3
4	2	2	1

5	2	3	2
6	2	1	3
7	3	3	1
8	3	1	2
9	3	2	3

The plates were clamped rigidly on the fixture and supported by stainless steel backing plates. These alloys should be very tight and should not move when the tool pin starts welding on the material. The movement of the equipment bed is possible in three directions, longitudinal for providing the feed, vertical for providing the depth and transverse direction. The tool should be in line to the joint where it is being made, 2 or 3mm tolerance is accepted as it can enhance the properties of the weld joint and heat generated in a great way depending on the material or alloy used. Experiment set up is shown in the fig 4. Fig 5 shows the work pieces after joining through FSW process.

Fig. 4. FSW Welding setup

Fig. 5. FSW Weldment

Table 6. L9 Design of Experiments

Experiment No.	Rotational speed (RPM)	Travel speed(mm/min)	Angle (Degrees)
1	710	20	0
2	710	30	1
3	710	40	2
4	900	30	0
5	900	40	1
6	900	20	2
7	1120	40	0
8	1120	20	1
9	1120	30	2

5 Testing and Microstructure

Fig. 6. Universal Testing Machine(TUE-C-600)

Fig. 7. Trinocular metallurgical microscope

After performing the friction stir welding on all the 9 different pairs of alloys, now we have to perform destructive testing and analyse the weld properties like the ultimate tensile strength, yield stress, weld strength etc., and analyse what are the best suitable levels(optimum values) for each factors among rotational speed, transverse speed and tilt angle so as to achieve the good weld quality and improved mechanical properties. Fig 6 shows the Computerized Universal Testing Machine (TUE-C-600).

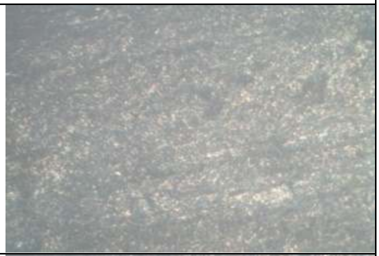
The weldments are machined to tensile specimen using the machining process to find out the mechanical properties by testing the specimen on a Universal testing machine. Tensile Specimen After Test are shown in Fig 8.

Fig. 8: Tensile Specimen After the Test

The specimen is disc polished and is soaked in water for 5 seconds and dried by using a dryer. After this process the specimen is dipped in kellers reagent for 16 seconds and is cleaned with cotton. Now the specimen is ready to observe the microstructure[6].

Fig.7 shows Trinocular metallurgical microscope which is widely used for metal structure observation and inspection [8]-[9]. The specimen is kept on the trinocular metallurgical microscope and the weld zone is focused and captured in the computer. Weld zone and Heat affected zones are observed for every specimen and the zones are captured. Table 7 shows Weld zone and Heat effected area for all the 9 specimens

Table 7 Weld zones and HAZ

Experi-ment	**Weld Zone**	**Heat Affected**
1		
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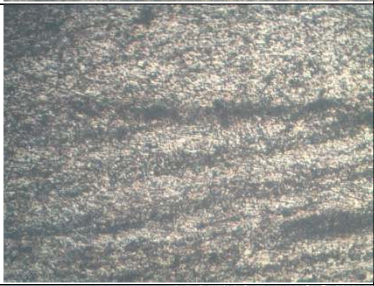
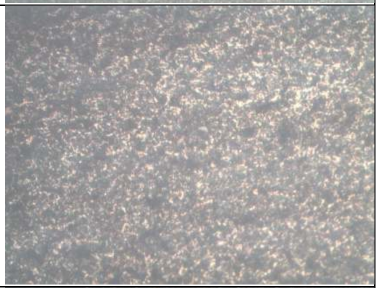
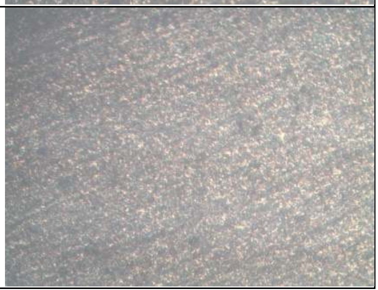
7		
8		
9		

5 Results and Discussion

5.1 Mechanical Properties:

This work mainly focuses on the impact of input parameters like tool rotational speed, traverse speed and tilt angle and the influence of tapered cylindrical tool pin in achieving a good weld joint as well as the better weldment strength. So in order to achieve the required results, a destructive analysis is performed on the weldment by machining them into tensile specimens on Computerized Universal Testing Machine (TUE-C-600) and the two ends of a specimen are placed on the fixtures called the "grips" which clamp the material and the tensile test is performed for all the nine weldments.

Table 8: Mechanical properties of weldments

Experiment No	**TRS (RPM)**	**TS (mm/min)**	**Tilt Angle (degrees)**	**UTS (Mpa)**	**YS (Mpa)**	**% Elongation**
1	710	20	0	58.633	58.172	3.20
2	710	30	1	93.985	68.227	8.52
3	710	40	2	81.029	69.711	8.14
4	900	30	0	90.292	69.792	7.50
5	900	40	1	70.712	58.665	6.92
6	900	20	2	89.031	63.270	10.86
7	1120	40	0	84.406	72.050	8.86
8	1120	20	1	95.494	72.499	7.00
9	1120	30	2	37.673	33.716	4.4

The various parameters like Ultimate tensile strength(UTS in Mpa), Yield stress(YS in Mpa) and percentage of elongation are observed and recorded in the Table 8.

5.2 Optimal Parameters

Using the above data we can find the optimal parameters by drawing the graphs of Tool Rotational speed vs Mean of UTS, Traverse speed vs Mean of UTS and Tilt Angle vs Mean of UTS. To draw these graphs the more comfortable would be Minitab software which generally is most user friendly[5]. The optimal parameters came out to be as follows.

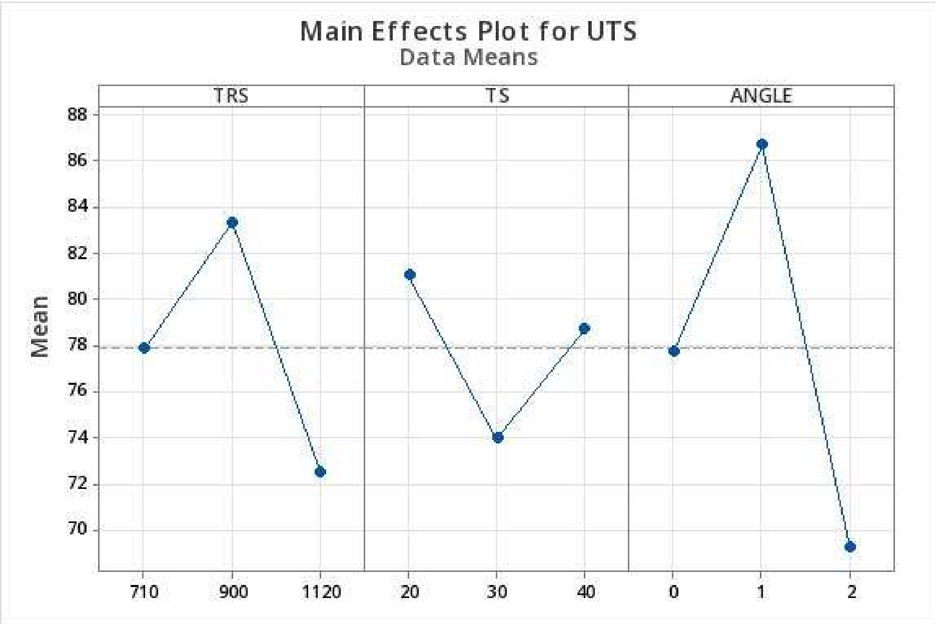


Fig. 9. Optimal parameters

From the above graph Fig 9 it is evident that the optimal parameters are 900RPM, 20mm/min and 1° Tilt angle. Also to generate the regression equation which can predict the ultimate tensile strength(UTS), the above data is sufficient and the equation is generated as below using the same Minitab software.

A Regression Equation is generated as follows:

Means = 98.4 - 0.0140 TRS - 0.117 TS - 4.27 ANGLE

By substituting the optimal parameters in the regression equation, we obtained the predicted UTS value as 79.19 MPa. The optimal parameters obtained by Minitab are listed in the below Table 9.

Table 9. Optimal Parameters by Minitab

Tool Rotation speed (RPM)	Traverse Speed (mm/min)	Angle (degrees)	Predicted UTS (Mpa)
900	20	1	79.19

5.3 Micro Vickers Hardness Testing

Table 10. Hardness Values

Experiment No	TRS (RPM)	TS (mm/min)	Tilt Angle (degrees)	Hardness (VICKERS)
1	710	20	0	96.4
2	710	30	1	71.6
3	710	40	2	114.8
4	900	30	0	77.8
5	900	40	1	142.9
6	900	20	2	117.8
7	1120	40	0	126.1
8	1120	20	1	96.4
9	1120	30	2	136.4

From the above Table 10 it is clear that the hardness is higher at the 900RPM, 40mm/min and 1° tilt angle. Also from the observations made from both tensile testing and micro-vicker hardness we can clearly say that the weld joint mechanical parameters mostly depend upon tool rotational speed and Tilt Angle with Traverse speed having a very little impact on the joint when the welding is carried out under constant axial load(5kN is applied).

6 Conclusion

The following conclusions are made after conducting the experimentation:

•The tensile specimens are tested on the computerized universal testing machine and the highest tensile strength is observed at 1120 RPM,20 mm/min and 1°tilt angle.

•The optimal parameters are 900 RPM,20 mm/min and 1° tilt angle obtained by using ANOVA technique in Minitab software.

•By using the Regression equation, the predicted tensile strength is 79.19 Mpa at the optimal parameters.

•The weld zone and the heat affected zone (HAZ) of the weldments are observed by using a trinocular metallurgical microscope.

•The micro-Vickers hardness testing is performed on the weldments to observe the hardness of pieces and came to know that the weldment done with 900 RPM, 40 mm/min and 1° tilt angle has the highest hardness value of 142.9.

From the above study we came to conclude that the tool rotational speed and tilt angle has the maximum impact on the welding with traverse speed having very minimal affect when the welding is performed under constant axial load of 5kN.

7 Future Scope

Friction stir welding can be performed to join metal alloys of all kinds and dissimilar metal alloys but only very few studies have been done out of which major studies have been done only on aluminium alloys and stainless-steel alloys. A very recent study has proven that the FSW can be used in welding of polymers. There is a lot of gaps between the applications and implementation of FSW technology into the real world which needs to be fulfilled. A lot of innovation can be helpful to weld the specimen of higher thicknesses.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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