International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Evaluation of Joint Properties of Aluminium Alloy After Friction Stir Welding

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Abstract: ***Friction Stir Welding is a solid state joining process capable of joining similar or dissimilar materials. In Friction stir welding joining of work pieces takes place without melting the work piece. In this work the effects of tool rotation and feed on the properties of the weld joint is studied. The material used for the weld joint is Aluminium 6061 T6 alloy. This alloy is extensively used in aerospace industry and for marine fittings. Joints were made by using different combination of the tool rotation speeds and feed. The parameters used for the fabrication of the joint were 700rpm, 800rpm and 900rpm and the feeds used are 22mm/min, 30mm/min and 40mm/min. Tensile, hardness, bending tests were conducted. Microstructure and Macrostructure of the weld specimen was studied. These properties were evaluated and the variation of the same with the changing parameters was studied.***

Keywords: Friction stir welding; Aluminum alloy 6061-T6; Welding speed and feed rate; Mechanical properties; Macrostructure; Microstructure.

1. Introduction

Friction stir welding is advanced solid state joining process to join the work pieces without melting the work piece. It was invented in the year 1991 by The Welding Institute in UK by W Thomas and his colleagues. It mainly finds application in ship building aerospace automotive and rolling stock. FSW eliminates the weld defects like porosity, solute redistribution, solidification cracking, and liquation cracking and enable effective welding of Aluminium alloys which are otherwise difficult to weld by fusion welding.

The advantages include using of non-consumable tool, low environmental impact hence being also termed as “green technology”, good weld appearance. FSW allows joining dissimilar metal effectively. The non-consumable rotating tool is made to transverse along the entire length of the work piece which has been clamped to the backing plate. As it traverses the relative cyclic movement of the tool and the base plate results in generation of the frictional heat which changes the material to a plastic form thus gives an effective weld.

2. Methodology

The basic need for project is the selection and procurement of material Aluminium 6061 T6 which is further machined to desired dimension. Then the tool material is selected and machined to desired dimensions. The FSW machine is setup and specimens are placed on the fixture and welded according to different welding parameters. After welding is done, the destructive and non-destructive test is done on weld joints and studied.

2.1 Tool Design

The tool is made up of High speed steel material. The fabricated tool for the FSW process consists of three distinct part shank, shoulder and pin. Shank is used for holding purpose and shoulder and pin generate frictional heat on work piece. The pin diameter is 7mm.The shoulder diameter is at least 3 to 3.5 times the pin diameter. The pin penetration is designed on the thickness of the work piece. The diameter of the pin of the tool is 7mm. Shoulder diameter is around 25mm.The pin depth is selected around 5.8mm

Figure 1: Tool Geometry

Figure 2: Machined Tool (HSS)

Table 1: Tool Configuration

Pin Length	5.8mm
Pin Diameter	7mm
Shoulder Diameter	25mm
Shoulder length	10mm

2.2 Experimental Study

Eighteen Al6061-T6 Aluminium alloys with dimension 170x100x6 mm were used to get nine square butt joint. The weld parameter that is the tool rotation speed and its feed rate is varied for the 9 samples. The parameters of the weld are specified in table 1. The Chemical Composition of Al 6061-T6 is given in table 2. The properties of Al 6061-T6 is given in table 3. Friction Stir Welding governed by various independent parameters.

Experiments are conducted by changing the two parameters for the given 9 weld samples and investigate their properties. The feed rate is varied in three levels (22, 30, 40 mm/min) and the speed is varied as 700rpm, 800rpm, and 900rpm. For 40mm/min for all the 3 samples weld is done on both sides. Both destructive and non-destructive testing is performed on the 9 samples. Dye penetration test, tensile test, hardness, bending test performed. Further the macrostructure and microstructure of the weld is investigated.

Tensile test is conducted on Universal Testing Machine (UTV 40PC-M). 3-point bending test is performed on the double weld samples on universal testing machine based on ASTM standard. The test is conducted in UTM- (UTV 40PC-M) machine. Vickers Hardness test was carried out on (VM 50) testing machine with diamond square pyramid indenter. The load applied is 10kgf in hardness test.

Microstructure and macrostructure was carried out on the samples according to ASTM E3 standards. Macrostructure analysis was done on a stereomicroscope under 7X magnification

Table 2: The weld parameters

Sample No	*Welding Speed In rpm*	*Welding feed In mm/min*
1	700	22
2	800	22
3	900	22
4	700	30
5	800	30
6	900	30
7	700	40
8	800	40
9	900	40

Table 3: The Chemical Composition of AA6061-T6

Alloy	Si	Fe	Ti	Mn	Mg	Cu	Zn	Cr	Al
Al 6061 T6	0.4 - 0.8	0.70	0.15	0.15	0.8 - 1.2	0.15 - 0.40	0.25	0.04 - 0.35	Bal

Table 4: The properties of Al 6061-T6

Alloy	Ultimate tensile strength, MPa	Hardness HV	% Elongation on 50mm
AA6061-T6	280	105	7

2.3 Surface Appearance of Weld Joint

Figure 3: Top Surface of weld joint

Figure 4: Bottom Surface of weld joint

3. Results and Discussions

3.1 Dye Penetration Test

Dye Penetration Test is a type of non-destructive testing. It gives the details about the surface defects. It mainly gives details about surface cracks. The test surface is firstly cleaned using solvent. Penetrant is then applied to the surface and allowed to stay for some time. Now the excess penetrate is removed from the surface and developer is applied to the samples. After applying developer if any area bleeds the dye defect is indicated. It gives a fast indication of the defect and is low cost. The sample is shown in fig 5 & 6.

Figure 5: Penetrant is applied on weld surface

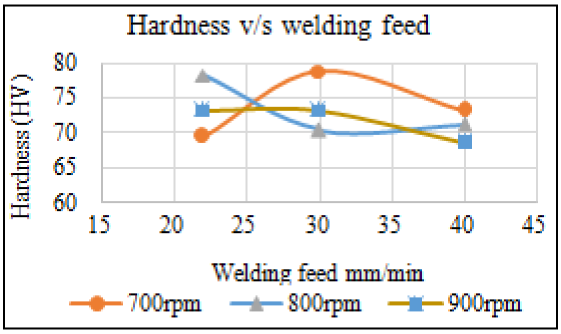
Figure 6: Developer is applied no crack were observed

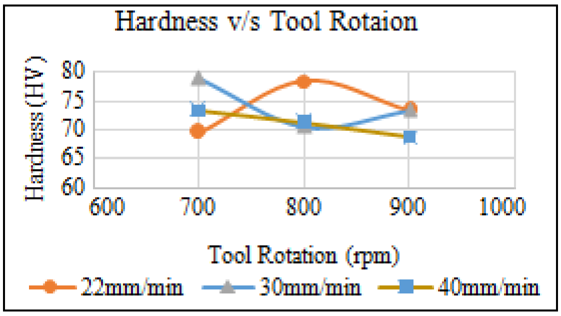
3.2 Hardness Test

Vickers Hardness test is performed on the 9 samples. Hardness on welding spot is calculated and average of three is taken. Hardness profiles are important as it helps to understand the mechanical properties. Highest hardness is obtained for the weld with 700 rpm and 30mm/min single weld in stir zone.

Table 5: Vickers hardness values

Sample No	Tool rotation in rpm	Welding feed In mm/min	Average HV
1	700	22	69.47
2	800	22	78.31
3	900	22	73.21
4	700	30	78.82
5	800	30	70.44
6	900	30	73.2
7	700	40	73.21
8	800	40	71.26
9	900	40	68.62





3.3 Tensile Test

Tensile test is performed on the samples at room temperature on universal testing machine based on ASTM E8-15. In this study it is observed that highest tensile strength is obtained for the sample with feed rate 22mm/min and speed of 800rpm for single weld. For double weld highest tensile strength was obtained for the weld with weld parameters 40mm/min and 700 rpm. Tensile test specimen is shown in fig 7.

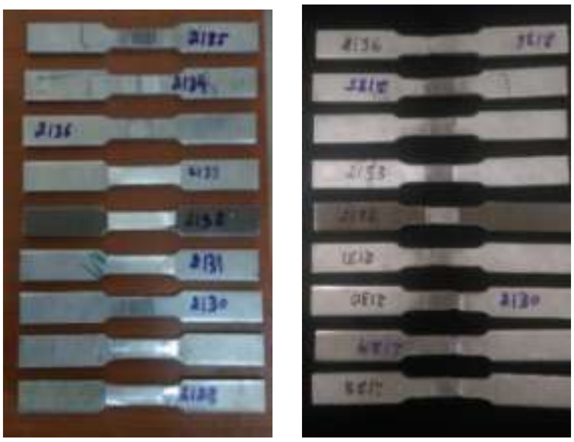
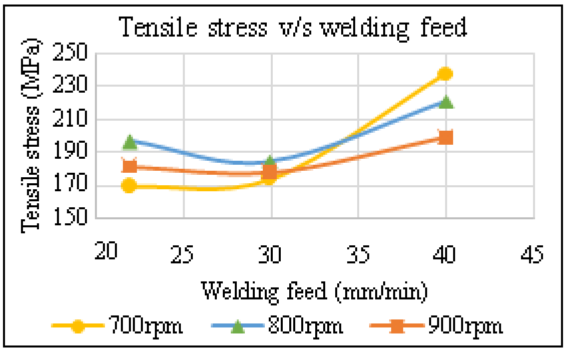


Figure 7: Tensile specimens before test and after test

Table 6: Tensile stress values

Sample No	Tool Rotation rpm	Welding Feed, mm/min	Ultimate tensile Strength, MPa
1	700	22	168.5
2	800	22	196
3	900	22	180.8
4	700	30	173.3
5	800	30	184
6	900	30	177.4
7	700	40	237.87
8	800	40	220.8
9	900	40	198.4



3.4 Bending Test

3-point bending test is performed on the double pass weld samples on universal testing machine based on ASTM standard. The highest bending stress is obtained is for 40mm/min and 800rpm.

Figure 8: Bending test samples

Figure 9: Bending sample after test

Table 7: Bending stress values

Sample No	Tool Rotation rpm	Welding Feed, mm/min	Bending stress MPa
7	700	40	733.33
8	800	40	1000
9	900	40	933.33

3.5 Microstructure and Macrostructure Analysis

All the joints of specimen are machined and the sample was polished with a series of emery papers down to 800grit size and subsequently lapped with diamond paste of 0.5microns size. It was etched with 0.5% solution of HF molded by cold mounting. Cold mounting using epoxy resin and hardener.

Macrostructure investigation were analysed at low magnification (7X) by optical microscope to analyse the weld structure. Microstructure is studied under 100X magnification.

Table 8: Macrostructure of weld

Sample	Macrostructure Image	Inference
1		Fusion & Penetration found complete. No cracks & porosities observed(7X)
2		Fusion & Penetration found complete. No cracks & porosities observed(7X)
3		Fusion & Penetration found complete. No cracks & porosities observed(7X)
4		Fusion & Penetration found complete. No cracks & porosities observed(7X)
5		Penetration found complete. No cracks/porosities observed. Slight gap observed(7X)
6		Penetration found complete. No cracks/porosities observed. Slight gap observed(7X)
7		Penetration found complete. No cracks/porosities observed. Slight gap observed(7X)
8		Fusion & Penetration found complete. No cracks & porosities observed(7X)
9		Penetration found complete. No cracks/porosities observed. Slight gap observed(7X)

Macrostructure indicates the large-scale structure of the weld. Cracks, penetration of the weld can be assessed using the macrostructure test. It was observed fusion and penetration of the weld was found complete for all the 9 samples. None of the samples showed any signs of porosities and cracks.

Microstructure of the weld of the samples revealed cast dendritic structure with silicon precipitates in aluminum solid solution. The base metal Al 6061 – T6 microstructure reveals elongated aluminum particles

Figure10: Macrostructure and Microstructure specimen

Microstructure of base metal of 9 samples


1

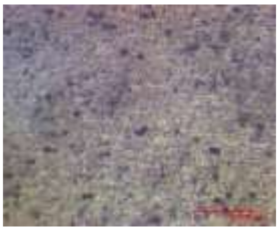

2


3


4


5


6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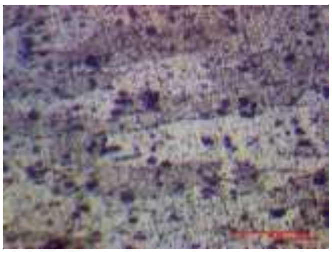
8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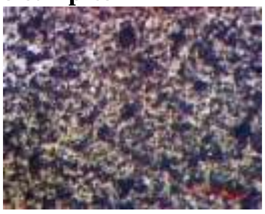
Microstructure of weld Zone of 9 samples


1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9

4. Conclusion

1) Dye penetration test indicated that no surface cracks were present on the weld.
2) Highest hardness was obtained for the sample with 700rpm and 30mm/min which is around 78.8 HV.
3) Highest hardness of the weld obtained is 24.9% lower than the base material hardness.
4) Tensile test was performed on both single and double weld. For single weld highest tensile strength was obtained for the 800rpm and 22mm/min which was 196MPa. For double weld highest tensile strength was obtained for 40mm/min and 700 rpm which was around 237.87MPa.
5) For single weld tensile strength of the weld is 68.66 % of the base material strength. Whereas for double weld tensile strength of the weld is 83.15% of the base material tensile strength.
6) The Maximum bending stress is obtained is 1000MPa for 800rpm and 40mm/min.
7) Macrostructure test revealed absence of cracks and porosities in the weld. Complete penetration was obtained for all friction stir welded samples.
8) Microstructure of the weld of the test samples indicated a cast dendritic structure with silicon precipitates in aluminium solid solution while that of base metal showed elongated aluminium grains.

5. Future Scope

- Altering the tool geometry concerning with the tool pin diameter, pin shape, pin length to the same of that of the thickness of the plate, variation with the shoulder diameter and effect of different materials (HSS) with varying hardness can be studied to generate more uniform grain size.
- Study of Variation of the temperature acting on the surface of the plate with varying tool rotational speed and feed rate can be worked on.
- Welding of dissimilar material can be achieved FSW. Thus welding of different aluminium alloy and evaluation of weld joint can be done.
- Optimization of tool rotation and welding feed at maximum rpm and feed can be studied joint properties can be obtained by non-destructive and destructive test.
- For different aluminium grades the FSW process can be done and comparative results with change in their respective properties can be evaluated based on their applications.

6. Acknowledgment

The authors gratefully acknowledge the support of our college PESIT Bangalore South Campus and the Department of Mechanical Engineering, CORI PES University, our guide Mr. Chandru A, the HOD of the Department Mr. Subramanian S Katte to give us the opportunity to carry out this research.

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