Experimental and Numerical Investigation on Process Parameters of Friction Stir Welding on Weldment of Dissimilar Aluminium Alloys

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Abstract- Study on effect of process parameters like tool rotational speed, transverse speed and tilting angle of tool for friction stir welding on dissimilar aluminium alloys. Fabrication of dissimilar aluminium alloys AA5052 and AA7075 on friction stir welding machine. To observe the mechanical properties such as tensile strength, strain energy and hardness of weld joints of specimen by tensile test, hardness test and impact test. Design the specimens for Tensile and Impact test in CATIA and analysis are done in ANSYS WORKBENCH. Compare the experimental and analytical test results and determine the percentage error between them. With an increase in tool rotational speed mechanical properties of weldments increases. Determine and Plot the Prediction of strain energy values by using the MATLAB. Image analysis software is used to get the microstructure of the weld bead of samples and at the base material of AA7075 and AA5052. Grain size is affected by the tool rotational speed such as by increase the tool speed then grain refinement increases.

KEYWORDS: Aluminium alloys, Friction stir welding, Microstructure,

1. INTRODUCTION

Friction Stir Welding (FSW) which could join metals with minimum defects and better properties. The present work deals with the research that is pertaining to Preparation of the aluminium alloy and Study of the welding characteristics of the alloy using Friction Stir Welding process. Al-Mg alloys of 5xxx series can be strain hardened and have moderately high strength. These alloys have very good corrosion resistance in marine environment and very high toughness even at low temperatures to near absolute zero.

Material Properties of AA5052

- Elastic (Young's, Tensile) Modulus : 70 GPa 10 x 10^6 psi
- Poisson's Ratio : 0.33
- Shear Modulus : 26 GPa or 3.8 x 10^6 psi
- Tensile Strength: Ultimate (UTS) : 190 to 310 MPa 28 to 45 x 10^3 psi
- Tensile Strength Yield (Proof) : 76 to 260 MPa 11 to 38 x 10^3 psi
- Brinell Hardness : 46 to 83
- Density : 2.7 g/cm^{3}170 lb/ft^3

High-strength, precipitation-hardening 7000 series aluminium alloys such as alloy 7075 are used extensively in aircraft primary structures. In recent years, there have been proposals to use high strength aluminium alloys from 7000 series, particularly the alloy AA7075, in the fabrication of heavy vehicle hulls.

Material properties of AA7075

- Density : 3.1 g/cm3 (190 lb/ft3)

- Elastic (Young's, Tensile) Modulus : 73 GPa (10 x 10^6 psi)
- Poisson's ratio : 0.32
- Tensile Strength: Ultimate (UTS) : 230 to 590 MPa (33 to 86 x 103 psi)
- Tensile Strength: Yield (Proof) : 120 to 520 MPa (17 to 75 x 103 psi)

Friction stir welding (FSW) is a welding process invented in 1991 at The Welding Institute. This is a solid-state welding the material will not be subjected to its melting temperature. This process is used specially in joining of high strength aluminium alloys.

2. FABRICATION OF ALUMINIUM PLATES BY FSW

Samples prepared for welding are cut into the required plate sizes (150mm x 75mm x 5mm) by power hacksaw. Good surface finish was obtained on the plates by milling machine. Then these plates were grinded and polished for good dimensional accuracy. The specimens prepared and hold the specimen between two firmly holding jaws which are tightened by hand levers and wrenches. For Rough Finishing maintaining speed must be at 450 RPM in Gear mechanism.

The vertical milling machine used for the welding has different speeds and feeds ranging from 250 to 1800 rpm and 10 to 150 mm/min respectively. The parameters which were considered for the conduction of experiment are shown in the Table 2.1

Table 2.1 Input parameter combinations for conducting the experiments

Sl.no.	Tool rotation speed in rpm	Tool traverse speed in mm/min	Tool tilt angle in degrees
1	710	40	1
2	900	40	1
3	1120	40	1

The depth of penetration of the tool for all the combinations is constant at 5mm. The cylindrical shouldered tool used is of H13 Tool steel material and with a cylindrical tool pin profile is as shown in figure 2.1 and chang of the tool rotational speed by the gear mechanism is as shown in figure 2.2

Fig 2.1 Tapered profiled H13 Tool Steel

Fig.2.2 Gear Mechanism

3. EXPERIMENTAL INVESTIGATIONS ON FRICTION STIR WELDED SPECIMENS

3.1 Experimentation for welding characteristics investigation

To study the welding characteristics of the welded specimens the following tests were conducted.

1. Tensile testing
2. Impact testing
3. Hardness testing
4. Micro structural study

3.2 Tensile test of the welded specimens

The weld joint functionality will depend on the strength characteristics of the weld joint to evaluate the strength of the weld specimens the UTM is used. The specimen diagram with all the specified dimensions is shown in Fig. 3.1.

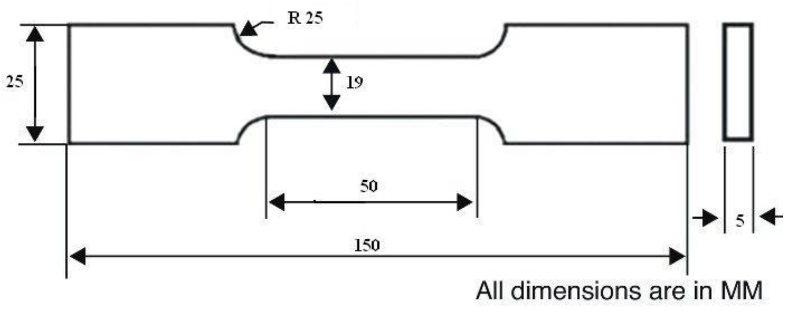


Fig.3.1 Tensile test specimen dimensions

Specimens which are arranged below are related to specimen 1 ,2 and 3 corresponding to machining at Speeds 710, 900 and 1120RPM respectively are shown in Fig. 3.2.

Fig 3.2 Tensile test specimen after testing

3.3Charpy Impact test of the welded specimens

The impact strength of the welded specimens was determined by Charpy impact test on v-notch specimen for the impact energy. Specimen dimensions have taken 10mm x 55mm specimen as the plate thickness is 5mm. The test specimen with the standard dimensions is shown in the Fig. 3.3. The specimens are shown after testing as in Fig 3.4.

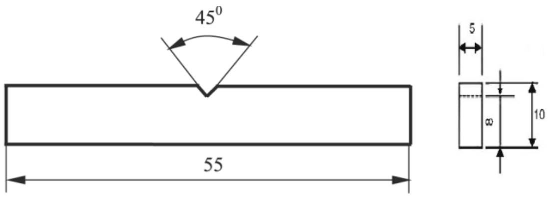


Fig 3.3 Charpy impact test specimen dimensions

Fig. 3.4 Specimens after testing

3.4 Brinell Hardness testing

The Brinell Hardness Testing machines are designed to measure hardness of castings, forgings, other metals and alloys of all kinds, hard or soft, whether flat, round or irregular in shape.

$$\mathrm{BHN} = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

Where

BHN = BrinellHardness Number (kgf/mm^2)

P = applied load in kilogram-force (kgf)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

Fig.3.5 Specimens after Hardness Test

Specimens which are arranged below are specimen 1, 2 and 3 correspondingly and are machining at Speeds 710, 900 and 1120RPM respectively.

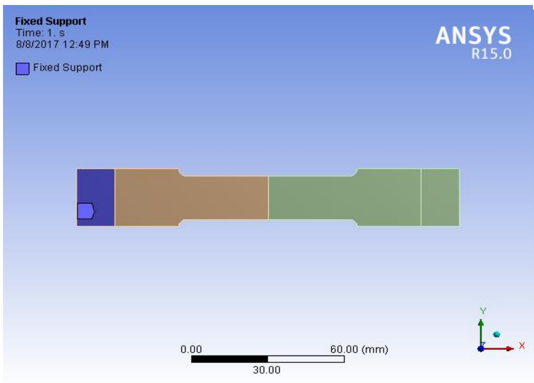
3.5 Micro structural study

After the grinding process, test specimens are grounded on progressively finer SiC waterproof emery papers from 120, 220, 320, 400, 4.0, 5.0 to produce a reasonably flat surface.Etching enhances the features of the microstructure such as grain size and phase features optically. This process used selectively to know changes of microstructural features based on composition, stress, or crystal structure. 2% Nital solution is used for etching. The weld bead is observed in the inverted metallurgical microscope with 500x magnification, connected to image analyser software.

4. DESIGN AND ANALYIS OF FRICTION STIR WELDING TEST SPECIMENS

4.1 Tensile Analysis

Design the tensile specimen in CATIA V5R20 by using sketching, part and assembly. Save the Catia file in igs format and import into ANSYS WORKBENCH. Applying Loads (14360, 15040 and 19280 N for specimen 1, 2, 3 respectively) at Right end of specimen for Tensile Testing.



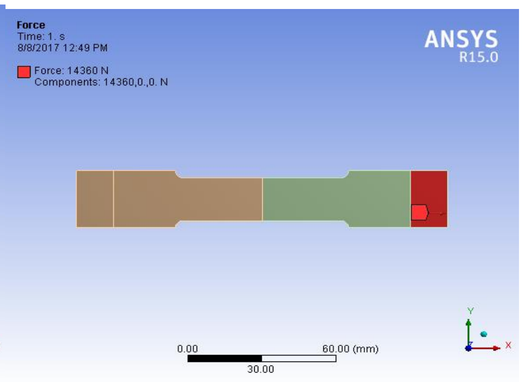


Fig 4.1 Fixed support at left end Fig.4.2 Force or load applied at right end

After applying the loads, select the von-Mises stress and click on solve for obtaining the results of tensile test specimens

4.2 Charpy impact test analysis

Design the impact test specimen in CATIA V5R20 by using sketching, part and assembly. Save the Catia file in igs format and import into ANSYS WORKBENCH. Input data is given to the specimen, supports and punch or hammer such as material properties on either side of the specimen. Boundary conditions are given as fixed support condition for bottom supports and velocity 5.35m/s are given in y – direction.

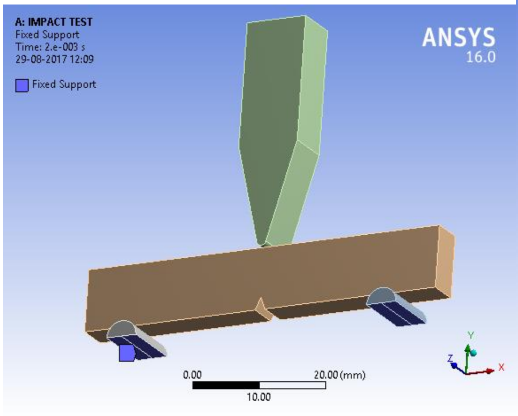


Fig 4.3 Fixed support condition

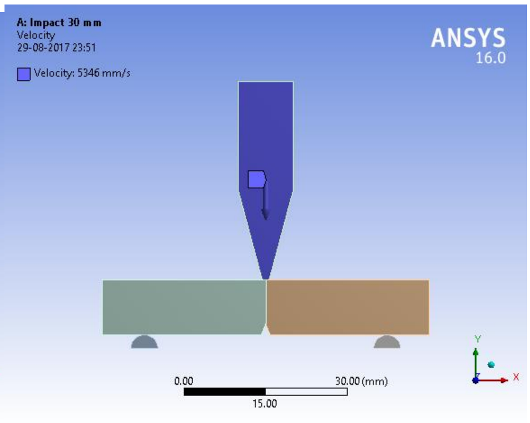


Fig 4.4 Velocity applied to Hammer

By changing the input parameters velocity and material properties of specimens to various parts of the assembled impact testing equipment. Tensile strength, young's modulus and poison's ratio values which are obtained from the tensile testing are taken and will give as input parameters of impact testing. Hence obtain the various strain energy values.

5. RESULTS AND DISCUSSION

At the outset, the data obtained on the welding characteristics of aluminium alloys 7075 and 5052 which are fabricated by friction stir welding machine is presented and discussed. It is followed by the laboratory study of the influence of input parameters on friction stir weldment.

5.1 Tensile Test properties

The tensile properties of the welded specimens were determined by Universal Testing Machine of 40 Ton capacity. These properties of the weld specimens are increased with increase in the tool traverse speed and the tool rotation speed. Among the 3 different combinations which are taken for the welding of the specimens, the best properties are achieved at 1120 rpm.

Table 5.1: Tensile Test Experimental Results

Speed (Rpm)	Ultimate Load (KN)	Ultimate Tensile Strength(MPa)	Elongation %	0.2% Proof Stress (Mpa)	0.2% Proof Load(KN)
710	14.36	138.476	3.86	116.347	12.065
900	15.04	147.047	2.16	116.773	11.944
1120	19.28	193.574	5.4	145.526	14.494

By observing the experimental and numerical analysis the value of directional deformation is increases by the increase in load in x – direction of tensile test specimen comparison between the experimental and numerical values deformation of tensile test is shown in Table 5.2.

Table 5.2 Tensile Test Results Comparison for directional deformation at various speeds or specimens

Specimen No	Load (N)	Directional Deformation (X-Axis) (mm)	
		Experimental	ANSYS
1	14360	1.93	1.7236
2	15040	1.08	1.0514
3	19280	2.7	2.5854

5.2 Hardness Test properties

The hardness at different welding zones is increasing with increase in tool traverse speed and the tool rotation speed. The hardness at the heat affected zone and the stir zone are decreased compared to the parent metal in all the combinations chose for the welding of the specimens. At tool rotation speed 1120 rpm, best hardness properties are achieved.

rpm, best hardness properties are achieved.

Table 5.3 Hardness Test Results

Specimen No	Observed values in BHN			
	Impression On Advancing Side(AA7075)	Impression at middle of weld ment	Impression on retreating side (AA5052)	Average value
1	76.3	75.5	73.9	75.23
2	77.1	76.3	75.3	76.23
3	78.7	77.1	76.8	77.53

5.3 Charpy impact test results

The Charpy impact test is done to measure the impact energy of the weldments. The results show that there is considerable affect of the tool traverse speed and the tool rotation speed on the impact energy of the weldment. tool rotation speed of 1120 rpm the best impact energy is observed.

Table 5.4 Impact Test Results comparison at various speeds or samples

Specimen No	Strain Energy (Joules)		% Error
	Experimental	ANSYS	
1	14	12.704	13.75
2	30	27.474	8.42
3	20	17.583	12.08

5.4 Micro structural study

From the micrographs it can be seen that the weld metal has fine grain size which is progressively changes by the changing from sample 1 to sample 3. The captured microstructure of the sample with image analyser presented. Table 6.6 representing the measured values of the grain area.

Table 5.5 Grain area

Position of microstructure	Grain area (mm^2) * 10^{-5}
Base metal on AA5052 Side	9.568
Base metal on AA7075 Side	8.616
Specimen 1 weld region	6.682
Specimen 2 weld region	6.257
Specimen 3 weld region	6.179

6. CONCLUSION

Dissimilar AA7075 and AA5052 alloys have been friction stir welded with a variety of different process parameters. At a variant tool rotation speeds, the effects of materials position and welding speed on materials flow, hardness and tensile properties of the joints were investigated. Based on the above results and discussion, the following conclusions are discussed

1. Highest Tensile strength of 193.574MPa is obtained at highest cutting tool speed 1120RPM.
2. Deformation of the specimens increases by the increase in speed of the cutting tool. Maximum deformation 2.7mm occurs at the 1120RPM. But rate of deformation is fluctuating by the increase in tool rotational speed.
3. Whatever the positioning of the base materials, the fracture is always obtained on the minimum hardness or tensile strength side (i.e. AA5052 or retreating side).
4. By the transforming of the material from advancing side to retreating side or vice versa, individual hardness of base metal increased from BHN60 to BHN73.
5. Strain energy value is fluctuating by the increase in speed and maximum strain energy value 30.46 Joules obtained at 940RPM. Maximum strain energy value was obtained by the prediction of strain energy values at various cutting tool speeds (710, 900 and 1120 RPM).
6. Grain size is affected by the tool rotational speed such as by increase the tool speed then grain refinement increases. Grain size area decreases by increase in tool rotational speed of the friction stir welding machine.Minimum Grain size area 6.179×10^{-5} mm^2 found at weldment of Specimen 3.

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