Influence of Cooling Media on Mechanical Properties of Friction Stir Welded 1060 Aluminium Alloy

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Abstract- Aluminium alloys generally present low weld ability by traditional fusion welding process. The development of the friction stir welding has provided an alternative improved way of satisfactorily producing aluminium joints, in a faster and reliable manner. Friction stir welding is a solid state welding process although frictional heating during welding degrades the mechanical properties of aluminium alloys. For reduction of heat input during welding other cooling media like compressed air, water etc is used. In this present work, the influence of process parameters and cooling media (Air and Water) on mechanical properties of Al 1060-O joints produced by friction stir welding were evaluated. Butt joints were fabricated by varying process parameters and cooling media.

Keywords: Friction stir welding, Aluminum alloy, Cooling Media, Mechanical Properties

I. INTRODUCTION

Al 1060 is generally considered difficult to weld due to its crack sensitivity problem. FSW is a solid state joining technology that has become well established for producing high quality welds of aluminum alloys. FSW helps to eliminate the problems associated with fusion welding processes like porosity, slag inclusion, solidification cracks, distortion etc. Al 1060 can be successfully welded with FSW and better weld quality and mechanical properties can be achieved.

II. DESIGN OF EXPERIMENTS

A two level factorial design of (2^3 =8) eight trials was selected to determine the effect of three independent direct welding parameters. Tool rotation speed, welding speed and pin diameter were identified as critical variables for carrying out the experimental work and to find out their effect on mechanical properties (tensile strength and impact strength). All remaining variables were kept constant. Table 1 shows the welding parameters and their limits.

III. EXPERIMENTATION

3.1 Friction stir welding equipment

Conventional vertical milling machine with mechanized feed can be adopted for FSW. The tool used is specially designed one with pin and shoulder. The rotational speed of tool and transverse speed of work piece determine the pitch between the ripples.

3.2 Material specification

Aluminum alloy Al 1060-O base plate of 6 mm thickness was used. The length and width are 250 mm and 100 mm respectively.

Friction stir welding (FSW) trials were carried out using Vertical Milling Machine fitted with specially designed high chromium high carbon tool. The material taken for investigation is Al 1060-O alloy having dimensions of 250 x 100 x 6 mm. A friction stir welding tool with a pin diameter (d) 8 mm and 10 mm, 5.6 mm pin length (h) and shoulder diameter (25 mm and 22 mm) is used.

Table 1: Welding parameters and their limits

Parameter	Units	Symbols	Designation	Upper limit	Lower limit
Tool rotation speed	rpm	R	X1	750	355
Welding speed	mm/min	F	X2	130	80
Pin Diameter	mm	d	X3	10	8

The welding was carried out by using a properly designed clamping fixture that allows fixing the two plates. To eliminate the effects of uncontrollable factors and noise, welding and testing sequences were randomized. The three welding parameters are considered i.e., tool rotation speed, welding speed and pin diameter. The main objective is to optimize the parameters on weld characteristics. To understand the role of each variable and the interaction of the factors in affecting the measurements, experiments were conducted using design of experiments (DOE).The complete set of eight trials was repeated thrice for the sake of determining the 'variance of optimization parameter' and 'Variance of adequacy' for this model. The experiments were performed in a random order in order to avoid any systematic error. First the experiments were carried out in air, optimum parameter were decided and then with same parameters welding was done in water.

IV. RESULTS AND DISCUSSION

4.1 Tensile Test

The tensile specimen was prepared according to ASTM standards and tensile test was carried out Table 3 shows the resultant values of tensile strength of test specimen. The values used for model development.

Table 3 Observed values of tensile strength

S NO	R (rpm)	F (mm/min)	d (mm)	T_1 (Mpa)	T_2(Mpa)	T_3(Mpa)
1	750	130	10	70	71	67.5
2	355	130	10	80	78	75
3	750	80	10	66	67	65
4	355	80	10	66	64	74.5
5	750	130	8	73	71	75
6	355	130	8	87	86	84
7	750	80	8	77	72	75
8	355	80	8	81	86	82

4.1.1 Model development for Tensile

After neglecting the factors that do not significantly affect the tensile strength we get the following model:

$T = 74.6 - 3.8R + 2.3F - 4.4d - 1.9RF + 2Rd + 2.1Fd$ (1)

4. 2 Impact test

Impact test was carried out at room temperature. The specimen for impact test was taken out of each plate. Impact values recorded are shown in table 4.

4.2.1Model for Impact strength

After neglecting the insignificant coefficients, the model developed for Impact strength with the help of values found by experiments

$I= 52.37 - 2R + 0.75RF - 3.62Rd$ (2)

V. ANALYSES OF RESULTS

5.1 Influence of tool rotation speed (rpm) on tensile strength

The relationship between tensile strength and tool rotation speed (rpm) for the given model of tensile strength has been displayed by Figure 1. It could be concluded from this figure that with increase in tool rotation speed (rpm) from 355 to 750 rpm, there is significant decrease in tensile strength from 77 MPa to 71.5 MPa. The high input rate and relatively low cooling rate results in coarse grained structure. This results in decrease in tensile strength with increase in tool rotation speed.

Table 4 Observed values of Impact strength

S NO	R (rpm)	F (mm/min)	d (mm)	I_1 (J)	I_2 (J)	I_3 (J)
1	750	130	10	48	46	50
2	355	130	10	58	56	54
3	750	80	10	46	42	48
4	355	80	10	58	55	54
5	750	130	8	58	53	52
6	355	130	8	50	51	55
7	750	80	8	56	54	52
8	355	80	8	52	55	55

5.2 Influence of pin diameter on tensile strength

The relationship between tensile strength and pin diameter for the given model of tensile strength has been displayed by Figure 2. It could be concluded from this figure that as pin diameter increases from 8mm to 10mm, there is decrease in tensile strength from 78 MPa to 71 MPa. By increasing the pin diameter, the surface contact area increases which results in high friction and high heat generation. The high input rate and relatively low cooling rates generate a coarse grained structure. This results in decrease in tensile strength.

5.3 Influence of welding speed on tensile strength

With the increase in welding speed from 80 to 130 mm/min, tensile strength increases from 72.5 MPa to 81 MPa. It is because by increasing the welding speed, there is low heat input. The low heat input rate gives relatively high cooling rate which generates a fine grained microstructure. This results in increased tensile strength.

5.4 Influence of tool rotation speed (rpm) on impact strength

With increase in tool rotation speed (rpm) from 355 to 750 rpm, impact strength decreases from 57 J to 48 J. The decrease of impact strength with increase in Tool rotation speed (rpm) is due to the reason that when a specimen is welded at a high rpm, then there is a rise in temperature due to high heat generation. High heat input rate and relatively low cooling rate which produces coarse grained structure. This results in decrease in impact strength.

5.5 Optimum Parameters

From the results it was observed that the highest tensile and impact strength has been achieved in specimen with the tool rotation speed 355 rpm, welding speed130 mm/min and pin diameter 8 mm. It was further observed that the surface finish of weld was good and free from visual defects.

6. Underwater welding

Welding was carried out at the above determined parameters in water as cooling media. Running flow of water at room temperature was used during welding. Specimens for tensile and impact test were taken from the weldament. Following are the values of tensile and impact strength at the above found optimium parameters.

Table 5 Observed values of tensile strength in underwater welding

R (rpm)	F (mm/min)	d (mm)	T_1 (Mpa)	T_2(Mpa)	T_3(Mpa)
355	130	8	93	87	107

Table 6 Observed values of impact strength in underwater welding

R (rpm)	F (mm/min)	d (mm)	I_1 (J)	I_2 (J)	I_3 (J)
355	130	8	66	73	81

Figure 1: Influence of tool speed (rpm) on tensile strength.

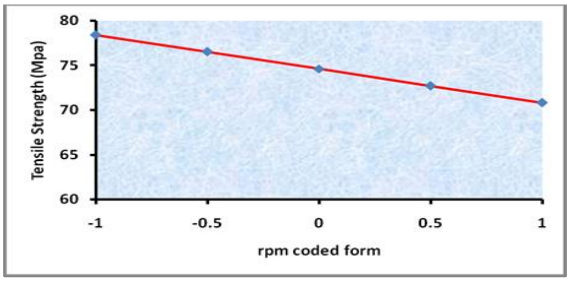


Figure 2 Influence of pin diameter on tensile strength.

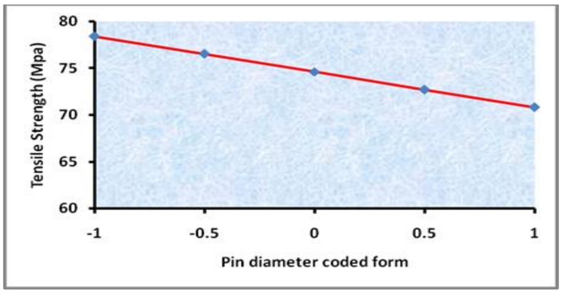


Figure 3: Influence of welding speed on tensile strength

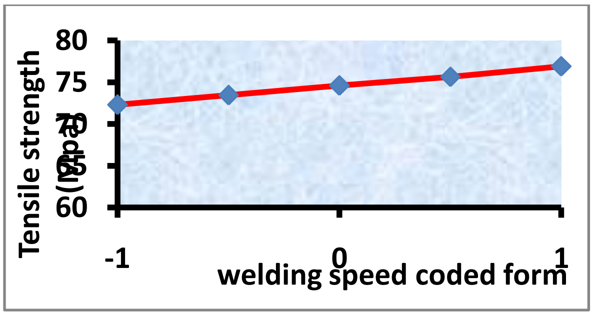


Figure 4: Influence of tool rotation speed (rpm) on impact strength.

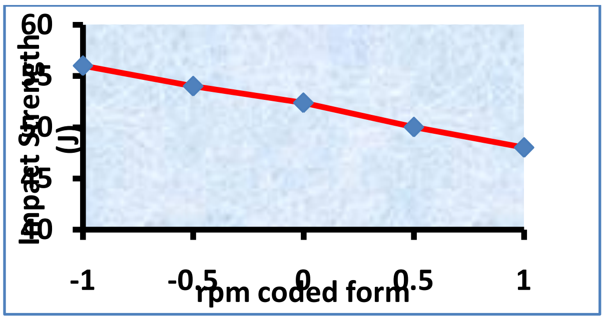


Figure 5: Influence of interaction of tool rotation speed and welding speed on tensile strength.

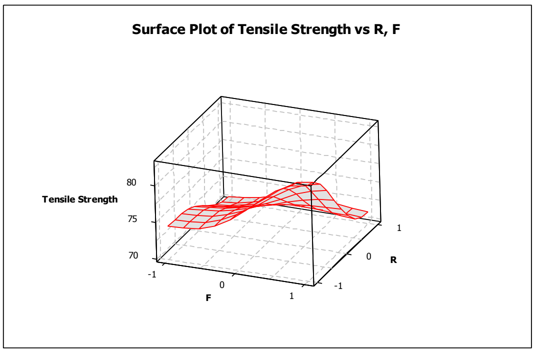


Figure 6: Influence of interaction of tool rotation speed and pin diameter on tensile strength.

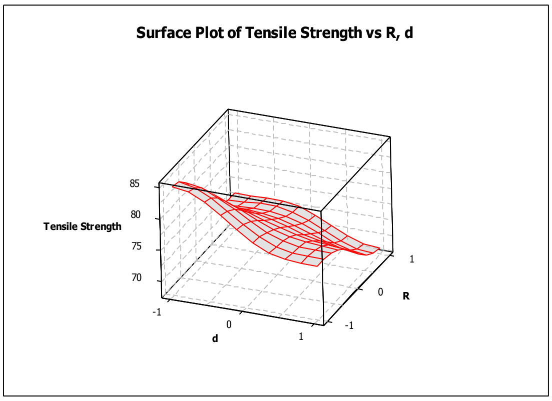


Figure 7: Influence of interaction of welding speed and pin diameter on tensile strength.

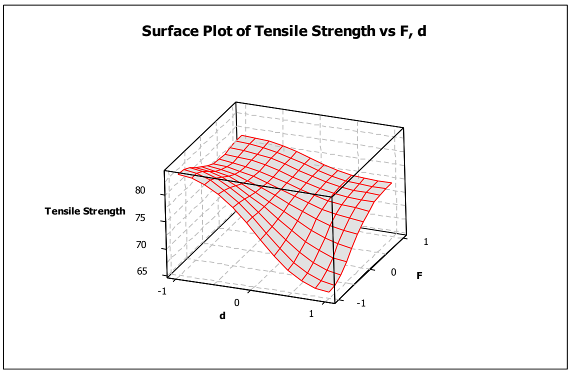


Figure 8: Influence of interaction of tool rotation speed speed and welding speed on impact strength.

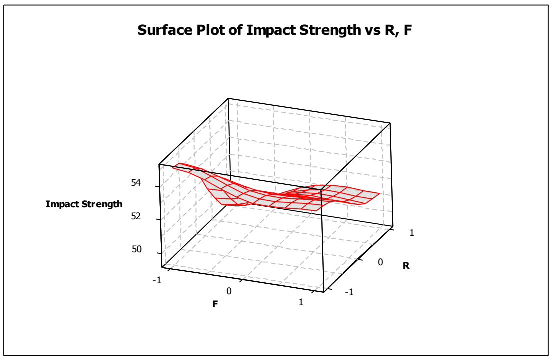
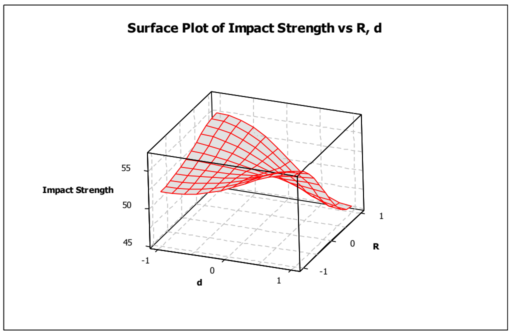


Figure 9: Influence of interaction of tool rotation speed speed and pin diameter on impact strength.



VI. CONCLUSIONS

1. Tensile strength decreases significantly with increase in tool rotation speed (rpm) and pin diameter and increases with increase in welding speed.

2. Impact strength decreases with increase in tool rotation speed (rpm) and pin diameter and increases with increase in welding speed.

3. Good surface finish with evenly distributed ripples was achieved.

4. From the results it was observed that the highest tensile and impact strength has been achieved with the tool rotation speed 355 rpm, welding speed 130 mm/min and pin diameter 8mm.

5. Underwater welding at the optimum parameters for air gives enhanced tensile and impact strength. This can be attributed the narrow HAZ.

REFERENCES

[1] K. Elangovan, V. Balasubramanian, "Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA6061 aluminium alloy" Materials and Design 29 (2008) 362–373.

[2] Weifeng Xu, Jinhe Liu, Hongqiang Zhu, Li Fu"Influence of welding parameters and tool pin profile on microstructure and mechanical properties along the thickness in a friction stir welded aluminum alloy," Materials and Design 47 (2013) 599–606.

[3] M.A. Mofid, A. Abdollah-zadeh ⇑, F. Malek Ghaini, "The effect of water cooling during dissimilar friction stir welding of Al alloy to Mg alloy," Materials and Design 36 (2012) 161–167.

[4] Shigeki Hirasawaa, Harsha Badarinarayanb, Kazutaka Okamotoc, Toshio Tomimurad, Tsuyoshi Kawanami, "Analysis of effect of tool geometry on plastic flow during friction stir spot welding using particle method" Journal of Materials Processing Technology 210 (2010) 1455–1463.

[5] W. Yuana, R.S. Mishraa,S. Webba, Y.L. Chenb, B. Carlsonb, D.R. Herlingc, G.J. Grantc, "Effect of tool design and process parameters on properties of Al alloy 6016 friction stir spot welds," Journal of Materials Processing Technology 211 (2011) 972–977.

[6] M. Dehghani, S. A. A. AkbarI Mousavi, A. Amadeh, "Effects of welding parameters and tool geometry on properties of 3003-H18 aluminum alloy to mild steel friction stir weld," Trans. Nonferrous Met. Soc. China 23(2013) 1957−1965.

[7] Y.G. Kima, H. Fujii b, T. Tsumura b, T. Komazaki c, K. Nakata, "Three defect types in friction stir welding of aluminum die casting alloy," Materials Science and Engineering A 415 (2006) 250–254.

[8] H. Badarinarayan, Y.Shi, X.Li, K.Okamoto, "Effect of tool geometry on hook formation and static strength of friction stir spot welded aluminum 5754-O sheets," International Journal of Machine Tools & Manufacture 49 (2009) 814–823.

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