Influence of Tool Pin Offset on the Weld Properties of Dissimilar 5083-H111 and 6082-T6 Aluminium Alloys by Friction Stir Welding

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Abstract— Friction Stir Welding (FSW) is a solid state joining process that is most widely used for joining of aluminium alloys due to low cost. In the present work, dissimilar aluminium alloys AA5083 and AA6082 are joined by Friction Stir Welding. Both the alloys are used in shipbuilding, automotive and construction industries. The Parameters like Tool rotational speed, Travel speed and Tool tilt angle are kept constant, whereas Tool pin is set to be offset for 1mm in both advancing side and retreating side on dissimilar aluminium alloys. The effect of Tool pin offset on the weld properties of chosen dissimilar aluminum alloys are studied. The welds are characterized by hardness testing, transverse tensile testing, macro examination & microstructural observation. The results showed that the Tool offset in the advancing side of AA6082 has better weld properties.

Keywords: Friction Stir Welding, Tool Pin Offset, Travel Speed, Tilt Angle, Rotational Speed, Advancing Side, Retreating Side

I. INTRODUCTION

A. Friction Stir Welding (FSW)

It is a solid-state joining process that uses a non-consumable tool to join two facing work pieces without melting the work piece material. Heat is generated by friction between the rotating tool and the work piece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. It is primarily used on wrought or extruded aluminium and particularly for structures which need very high weld strength. FSW is also found in modern shipbuilding, trains, and aerospace applications.

1) Advancing Side:

The side of the weld for which the rotating tool moves in the same direction as the traversing direction.

2) Retreating Side:

The other side where tool rotation opposes the traversing direction.

B. Aluminium Alloys:

AA5083 alloys are non-heat treatable. It has high strength, high corrosion resistance and are lightweight aluminum with high ductility and toughness. Meanwhile, AA6082 is a heat treatable alloy it exhibits high strength and high corrosion resistance. The combination of these two alloys has been used extensively in ship building components, highly stressed applications and automobile components.

Here the experiments is tool pin offset with dissimilar aluminium alloys by changing its advancing and retreating sides. 6 samples are welded at constant rotational speed, travel speed and tilt angle. From The welded sample we do the ultimate tensile test, bend test, micro hardness. The microstructure is observed by using metallurgical microscope at 100x and the macro examination is observed by naked eye & lens at 15x.

II. EXPERIMENTAL WORK

A. Material and Sample Preparation

From the given aluminum plate material was cut into the required dimension of 100X50X6mm to get the required optimized sample. The Samples are welded by using HSS (High Speed Steel). As per the standards the chemical composition of AA5083 and AA6082 were given in Table 1 and Table 2.

Zn %	Fe %	Cu %	Mn %	Mg %	Cr %	Si %	Ti %	Al %
0.09	0.37	0.07	0.59	4.7	0.09	0.28	0.04	Bal.

Table 1: Chemical composition of AA5083-H111

Zn %	Fe %	Cu %	Mn %	Mg %	Cr %	Si %	Ti %	Al %
0.03	0.21	0.02	0.56	0.98	0.12	1.01	0.03	Bal.

Table 2: Chemical composition of AA6082-T6

B. Process parameters

In this FSW method the process parameters are given below

- Tool rotational speed = 900rpm
- Welding speed = 90mm/min
- Tilt angle = 2º

Trial No.	Tool pin offset (mm)		Advancing Side	Retreating Side
	Right Side	Left Side		
1	0	0	AA5083	AA6082
2	0	0	AA6082	AA5083
3	1	0	AA5083	AA6082
4	0	1	AA6082	AA5083
5	0	1	AA5083	AA6082
6	1	0	AA6082	AA5083

Table 3: Tool pin offset and its sides

C. Welded samples:

Samples are welded by using friction stir welding at 0mm and 1mm offset by changing advancing side and retreating side (fig.1). The welding order given in the table 3,

Fig. 1: welded samples by FSW

III. Results and Discussion

A. Macro examination

Macro examination of all the welded aluminium alloys are cross sectioned and then examined by naked eye (or) using 10x lens. Cross section of the aluminium alloys shown in fig.2 and it shows complete fusion and free from defects. The following zones are observed in welded aluminium alloys such as 1) 6082 Base metal 2) Stir Zone 3)5083 Base Metal.

Fig. 2: Macro sample of cross sectioned specimen

B. Microstructure

The welded aluminium specimen cut across Transverse to the welding direction has been polished in the emery paper such as 180,220,320,400,600&800 and followed by disc polishing. Then the welded specimen is etched with freshly prepared keller's reagent and the reagent contains 190ml water+ 2ml HF+ 5ml HNO3+ 3ml HCl to reveal microstructure. Microstructure of aluminium alloys observed by optical Metallurgical microscope at 200X.

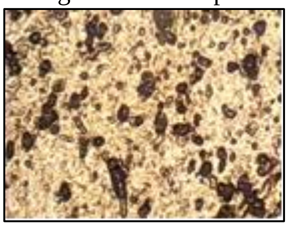

Fig. 3: 6082 base

Fig. 4: 5083 base

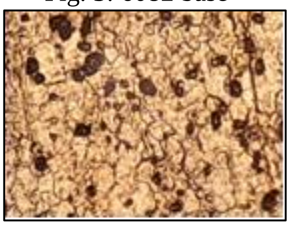

Fig. 5: 6082(TMAZ)

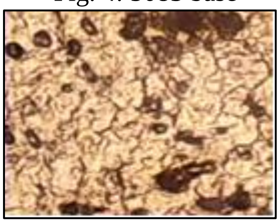

Fig. 6: 6082(HAZ)

Fig. 7: 5083(TMAZ)

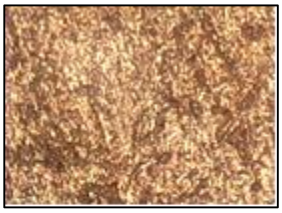

Fig. 8: Stir zone

From above figure microstructure analysis are given as follows,

Alloy AA6082-T6 (fig.3) contains Al matrix and intermetallics Mg5Al8.

Alloy AA5083-H111 (fig.4) contains Al matrix and intermetallics Mg5Al8.

In HAZ of 6082 alloy (fig.6) shows large grains and the precipitates which dissolved due to heat, reprecipitated as large cluster particles.

The stir zone (fig.8) shows fine fragmented particles of eutectic constituents in primary alpha aluminium solid solution. Fine grain size is due to recrystallization

In both 6082 & 5083 TMAZ (fig.5 & 7) shows small grains.

C. Vicker's Microhardness

Micro hardness across the welded joint, have been carried out in polished and etched sections, as per the standard ASTM E 384-99. A square base pyramid shaped diamond is used for testing in the Vickers scale. The hardness was carried out with MMTX3 Micro hardness tester using 200gf weight for aluminium 5083and 6082 with dwell time of 10s.

From the table 5 it is observed that high hardness in stir zone due to fine grain structure and also strengthening effect will occurs. The lowest hardness in TMAZ due to the hardening precipitates fully dissolved at 6082 TMAZ and non-hardening precipitates will be formed in 5083 TMAZ. In HAZ precipitates does not dissolve but become coarser precipitates, so hardness is higher than TMAZ.

Trial No.	5083 BASE METAL	5083 TMAZ	STIR ZONE	6082 TMAZ	6082 HAZ	6082 BASE METAL
1	44.8	33.2	39.9	36.3	41.4	52.5
2	44.8	34.5	42.0	38.1	40.6	52.5
3	44.8	36.0	43.7	38.9	39.8	52.5
4	44.8	33.1	42.8	37.4	38.9	52.5
5	44.8	35.8	41.4	38.3	40.0	52.5
6	44.8	36.9	41.9	35.2	39.3	52.5

Table 4: Micro hardness value

D. Ultimate Tensile Strength

Then tensile testing has been done on UTM machine as per the standard ASTM E8/E8M-09 and calculates the ultimate tensile strength, percentage of elongation, gauge width, gauge thickness, yield strength, and also fracture location for all specimens.

Trial No.	Ultimate Tensile Strength (N/mm2)	Location of failure
1	183	TMAZ(5083)
2	167	TMAZ(5083)
3	184	Stir zone
4	167	Stir zone

5	172	TMAZ(5083)
6	186	TMAZ(6082)

Table 5: Ultimate tensile strength value

In tensile test the high ultimate tensile strength was observed in three conditions, 1). 5083 on advancing side with 1mm offset [trial 3], 2). 6082 on retreating side with 1mm offset [trial 5], 3). 6082 on advancing side with 1mm offset [trial 6].

Comparing trial 1 &2 we observe high tensile strength in trial 2 by placing 6082 on advancing side and 5083 on retreating side without offset. Comparing trial 3&4 we observe high tensile strength in trial 3 by placing 5083 on advancing side & 6082 on retreating side with 1 mm offset towards advancing side. Comparing trial 5&6 we observe high tensile strength in trial 6 by placing 6082 on advancing side & 5083 on retreating side with 1 mm offset towards advancing side. The result showed that the Tool offset in the advancing side of AA6082 enhance the weld properties.

Fig. 9: tensile samples

E. Rockwell Hardness Test

Rockwell hardness testing is an indentation testing method. The indenter is 1/16 inch steel ball is used. The load applied is 100kg and scale is red scale. The indenter position is measured using an analog dial indicator or an electronic device with digital readout. Rockwell hardness test value is given in table 6.

Trial No.	5083 BASE METAL	5083 TMAZ	STIR ZONE	6082 TMAZ	6082 HAZ	6082 BASE METAL
1	72	52	68	59	63	85
2	73	50	67	57	62	86
3	72	54	69	60	64	89
4	71	53	70	59	65	82
5	74	54	68	61	62	85
6	73	57	66	55	64	83

Table 6: Rockwell hardness value

F. Corrosion Testing

Corrosion test carried out by linear polarization method in the NaCl environment at pH value 11. It is corrosion rate determination based on the stern-gray equation. It takes place in the absence of diffusion resistance.

Corrosion Rate α 1/Polarization resistance

It is also defined as the electrochemical method of corrosion testing equation and the Tafel –Extrapolation. The corrosion test values are given in table 5.4

Serial no.	Location of testing	Area (Cm2)	Corrosion rate(miles/year)
1	5083 base metal	1	9.951 e-002
2	6082 base metal	1	3.371 e+000
3	Weld zone (trial 1)	1	1.652 e+000
4	Weld zone (trial 2)	1	1.567 e+000
5	Weld zone (trial 3)	1	1.239 e+000
6	Weld zone (trial 4)	1	1.012 e-001
7	Weld zone (trial 5)	1	1.925 e+000
8	Weld zone (trial 6)	1	1.750 e+000

Table 7: Corrosion test values

The corrosion resistance in 5083 base material is high due to intermetallic compounds but in 6082 base material highly subjected IGC due to presence of non-crystallized grains. Comparing trial 1 and trail 2 weld zone, the trail 2 weld zone corrosion resistance is due more mixing of 5083 base. Comparing trial 3 and 4 weld zones, the trial 4 weld zone have high corrosion resistance due to pin offsetting in 5083 towards retreating side. Comparing trial 5 and 6 weld zones, the trial 6 weld zone have high corrosion resistance due to pin offsetting in 6082 towards advancing side. From table 7 it is concluded that corrosion resistance is high when pin offsetting towards 5083 compare to other trials.

IV. CONCLUSIONS

In the present study AA5083-H111 and AA6082-T6 aluminium alloys are joined by Friction Stir Welding and the welds were characterized. Based on the test results the following conclusions are drawn:

In tensile test, the maximum ultimate strength of 186MPa was obtained when the Tool pin was at an offset of 1mm in 6082 at advancing side because of proper mixing between two base materials.

In Vickers micro hardness test, it is observed that high hardness values in stir zone. It was due to fine grain size and intermetallic inclusion. Because intermetallic inclusion have double effect i.e. strengthening effect in thin layer and brittle behavior in thick layer.

The Macro examination and Microstructural analysis of welded samples showed defect free weld joints and good mixing of 6082 and 5083.

High tensile properties were observed offset towards 6082 advancing side. Low tensile properties were observed towards 5083 on retreating side without offset and with 1mm offset.

High corrosion resistance were observed when the Tool pin offset towards 5083 side. But offset towards 6082 resulted in high corrosion rate due to presence of non-crystalized grains.

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