Experimental Study on the Effect of Tool Pin Profiles on Dissimilar Aluminum Alloy Friction Stir Welding

B.L.N.Krishna Sai, M.S. Srinivasa Rao

Abstract— **The development of the Friction Stir Welding has provided an alternative improved way of producing aluminum joints, in a faster and reliable manner.fsw technology has been recognized to have many advantages for the construction of aluminum structures as it is a low cost welding process when compared to other processes.. In the present study, aluminum alloys AA5083 and AA6082 sheets are used for joining using friction stir welding process. This dissimilar AA5083 and AA6082 is commonly used in marine applications due to weight saving, corrosion resistance, extrusion requirements and structural applications. In this research project three types of tool pin profiles are used to join the dissimilar aluminum alloy sheets. The pin shapes are triangle, square, and pentagon shapes. In this project, study the influence of various tool pin profiles on the quality of the welding using three traverse speeds (mm/min) at constant spindle rotation speed (rpm). This project report covers the detailed study of friction stir welding of AA5083-AA6082 weld characteristics i.e., tensile properties like ultimate tensile strength, yield strength and %elongation. It also covers the metallographic properties of the weldments like microstructure and micro hardness at various zones.**

Index Terms— AA5083, AA6082, Ultimate Tensile Strength, Tool pin profiles, microstructure, micro hardness

I. Introduction

Aluminum alloys AA5083 and AA6082 is commonly used in marine applications due to weight saving, corrosion resistance, extrusion requirements and in structural applications. Aluminum alloy AA5083 is considered as non-heat treatable alloy and AA6082 is heat treatable alloy. Compared to the fusion welding processes that are routinely used for joining structural aluminum alloys. Friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. FSW process was developed by The Welding Institute (TWI) of Cambridge, England in 1991[1]. This joining technique is simple, environment friendly, energy efficient and becomes major attraction for automobile and aircraft industries. Due to the high strength of the FSW joints, it allows considerable weight savings in light weight construction compared to conventional joining technologies [2]. In contrast to conventional joining welding process, there is no liquid state for the weld pool during FSW, the welding takes place in the solid phase below the melting point of the materials to be joined. Thus, all the problems related to the solidification of a fused material are avoided. Materials which are difficult to fusion weld like the high strength aluminum alloys can be joined with minor loss in strength [3]. In friction stir welding a non consumable rotating tool with a specially profiled pin plunges into the two pieces of sheet or plate material and through frictional heat it locally plasticized the joint region. The tool then allowed to stir the joint surface along the joining direction [3]. During tool plunge, the rotating tool undergoes only rotational motion at only one place till the shoulder touches the surface of the work material; this is called the dwelling period of the tool. During this stage of tool plunge it produces lateral force orthogonal to welding or joining direction as shown in Fig 1.

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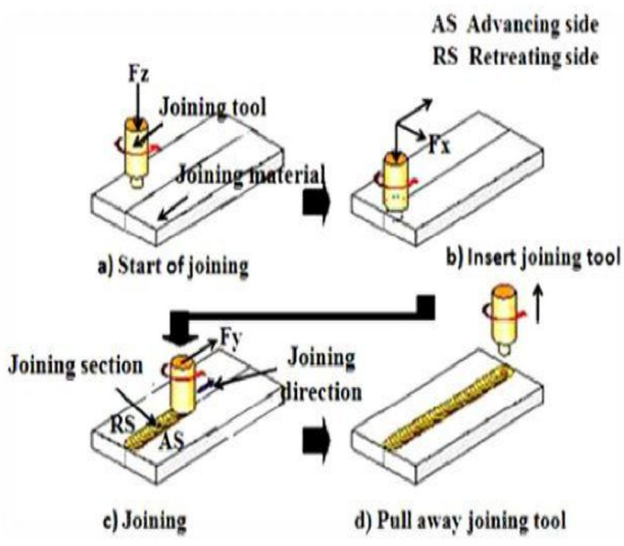

Fig 1. Over view of Friction stir welding process

The effects of welding parameters and tool profiles like triangle, square, and pentagon on tensile and metallographic properties in AA6082 and AA5083 aluminum alloys are not reported. Hence, in this investigation an attempt has been made to understand the effect of tool pin profiles and welding speed on FSW formation, tensile properties, microstructure and micro hardness.

II. Experimental Work

A. Material

The material used for this investigation are aluminum alloys AA5083 and AA6082 of size 150X100X4 mm. the base material used for this experiment chemical composition is listed in Table I. A conventional milling machine is converted into friction stir welding machine for welding process. Mechanical properties of aluminum alloy AA5083 and AA6082 are represented in Table II

Table. I Chemical compositions of AA 5083 and AA6082

%Wt	5083	6082
Silicon(Si)	0.4	0.7-1.3
Iron(Fe)	0.4	0.5
Manganese(Mn)	0.4-1.0	0.4-1.0
Magnesium(Mg)	4.0-4.9	0.6-1.2
Zink(Zn)	0.25	0.2
Titanium(Ti)	0.15	0.1
Chromium(Cr)	0.05-0.25	0.25
Copper(Cu)	0.1	0.1
Aluminum (Al)	balance	balance

Table.II mechanical properties of AA6082 and AA5083

Material	5083	6082
UTS(MPa)	300	360
0.2% Y.S(MPa)	145	322
Elongation (%)	15	16

B. Welding procedure

Aluminum alloys of AA5083 and AA6082 were chosen for this experiment work. Dissimilar combinations of AA5083 with AA6082 friction stir welded in this experiment. Specially designed tools were used in this friction stir welding process. The tool material used in this work was high speed steel (HSS) with different tool pin profiles like pentagon, Square and Triangular with tapered as shown in the Fig 2.

Fig 2. FSW tool pin profiles

The FSW tool was subjected to hest treatment process to improve hardness, the hardness of tool after heat treatment process is 50-55 HRC. The welding parameters and tool dimensions are shown in the Table III. The dimensions are same for all the three tool pin profiles.

Table.III welding parameters and tool dimension

Process parameters	values
Rotational speed(rpm)	1120
Welding speed(mm/min)	60,80,100
D/d ratio of tool	3
Pin length, L(mm)	3.7
Tool shoulder diameter, D(mm)	15
Pin diameter, d(mm)	5

A conventional milling machine is converted in to friction stir welding machine to carry out welding process. The two plates are partitioned in the fixture which is prepared for fabricating FSW joint by using mechanical clamps so that the plates will not separate during welding process. Two aluminum alloy plates of size 150X100X4 mm were perfectly clamped in milling machine bed on a back up plate. The FSW tool is inserted into the tool holder. Tool is plunged into the joint in the downward direction with the welding speed of 60, 80,100 mm/min simultaneously at constant rotational speed 1120 rpm. The experimental setup was shown in the Fig 3.

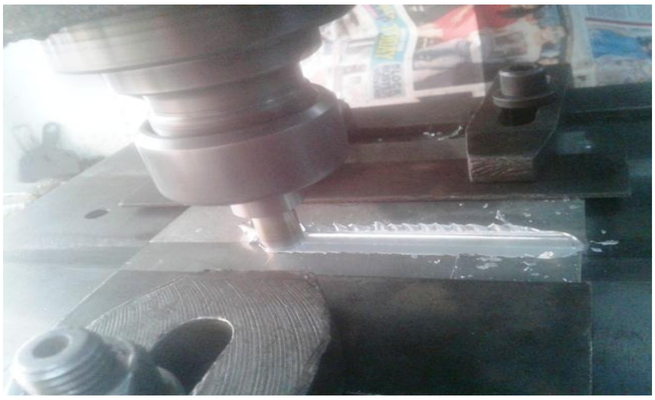

Fig 3. Friction stir welding Experimental Setup

Using each tool, three joints have been fabricated at three different welding speeds and in total 9 joints (3X3) have been fabricated. The weldments are shown in the Fig 4.

(a) Weld joints fabricated with pentagon tool pin profile

(b) Weld joints fabricated with Square tool pin profile

Fig 4.Weldments of AA5083 and AA6082

C. Tensile testing

To investigate the tensile properties of the weldments, as per ASTM E8M-04 standard the tensile specimens were prepared on CNC wire cut EDM as in the Fig 5. The prepared samples are shown in Fig 6. The finished specimens were tested to find the ultimate tensile strength (UTS) and %elongation using 40 ton Universal Testing Machine.

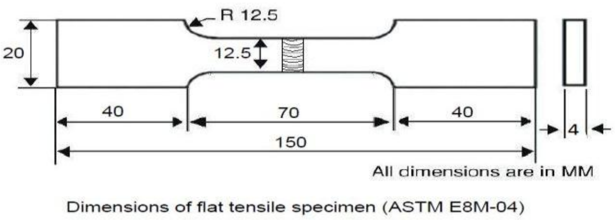

Fig 5. Tensile Test specimen

Fig 6. Prepared tensile specimens

D. Microstructure

Metallographic specimens were cut mechanically from the welds, embedded in resin and mechanically ground and polished using abrasive disks and cloths as shown in the Fig 7. The chemical etchant was the Keller's reagent(1 ml hydrofluoric acid, 1.5 ml hydrochloric acid, 2.5 ml nitric acid and 95 ml water) to reveal the microstructure of the weld region. The microstructures were observed on metallurgical microscope as shown in the Fig 8.

Fig 7. Moulds prepared for metallographic study

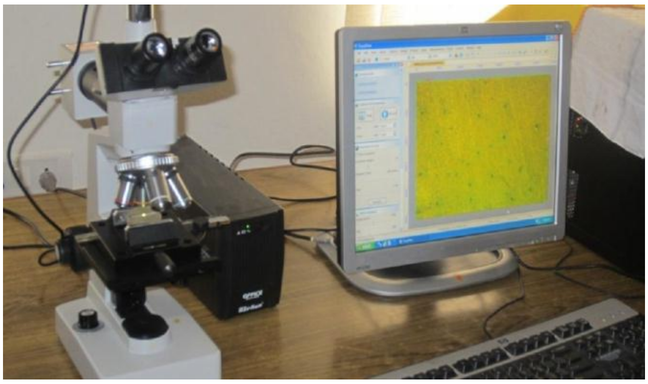

Fig 8. Metallurgical microscope

E. Micro hardness

Micro hardness of the welds was measured with the test load of 200g. The indentations were made at midsection of the thickness of the plates across the joint. The micro hardness values were measured on Vickers micro hardness tester as shown in the Fig 9.

Fig 9. Micro hardness tester

III. RESULTS AND DISCUSSIONS

A. Tensile Test

Tensile test were performed to determine the tensile properties (yield strength, tensile strength and percentage of elongation) of the aluminum alloy dissimilar combination of AA5083 and AA6082. For the tensile testing of the weldments, two samples from each weldment are made and tested. For results which ever sample has produced better strength is taken in to account. The tensile values of the weldments are shown in the Table IV. Fig 10 and Fig 11 shows the effect of tool pin profiles on UTS and % elongation of friction stir welded aluminum alloy AA5083 with AA6082. It seen from the figures that at pentagon tool pin profile (60 mm/min), higher tensile properties of the FSW welded joints were observed. When welding speed increased from 60mm/min onwards tensile properties were decreasing and the same repeating in remaining two tool pin profiles(square and triangular).

Table.IV Tensile Test values

Type of tool pin profile	Welding speed (mm/min)	Sample no	UTS (Mpa)	0.2% Y.S (Mpa)	% of elongation
Pentagon	60	1	169.3	162.1	4.6
		2	160.8	138.4	4.2
	80	1	153.9	113.2	3.8
		2	152	110	3.7
	100	1	127.2	100	3.4
		2	147.8	90	2.5
Square	60	1	110.7	105.1	4.0
		2	107.6	91.7	2.8
	80	1	103.5	103.5	2.6
		2	101.4	101.4	2
	100	1	131.2	116	2.4
		2	125.8	85.2	3
Triangular	60	1	81.6	73.6	1.8
		2	88.4	88.4	2.1
	80	1	90.6	87.4	2.1
		2	71.6	39	2.1
	100	1	60.6	43	2.1
		2	38.2	37.4	2.6

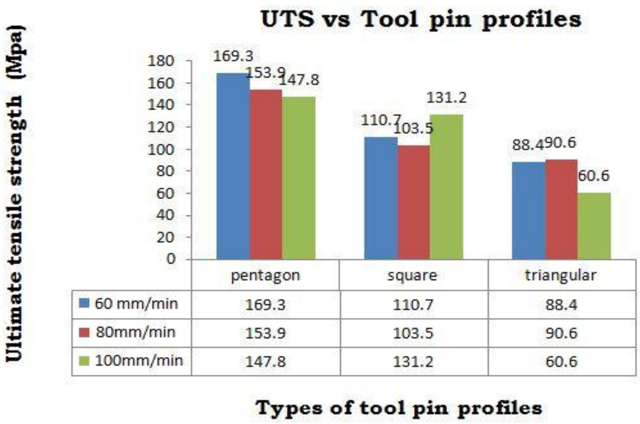

Fig 10. Effect of Tool pin profiles on UTS

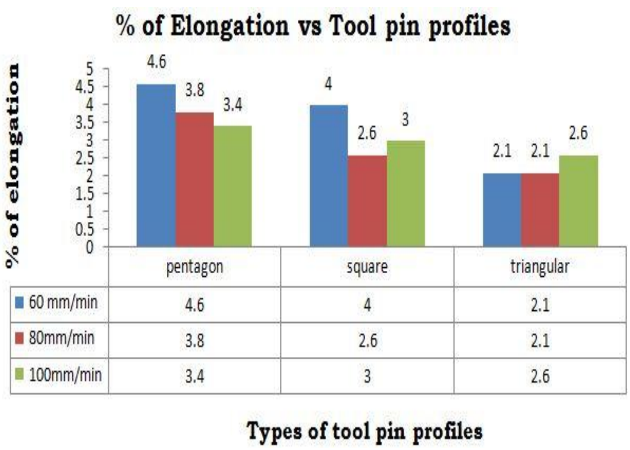

Fig 11. Effect of Tool pin profile on % of elongation

B. Microstructure

The micro structural behavior of aluminum alloys joined by FSW was studied by employing light optical microscope (LOM). Images of weld zones cross section are outlined in Fig 12.

In the weld nuggets of all the joints, grains haven been refined as a result of dynamic Recrystallization. Heterogeneous mixing of recrystallized fine grains of 5083 and pancake grains of 6082 had been clearly seen in weld nugget zones. Superior tensile properties for pentagon tool pin profile were observed, this is due to the formation of fine equiaxed grains and uniformly distributed very fine strengthening precipitates in the weld region.

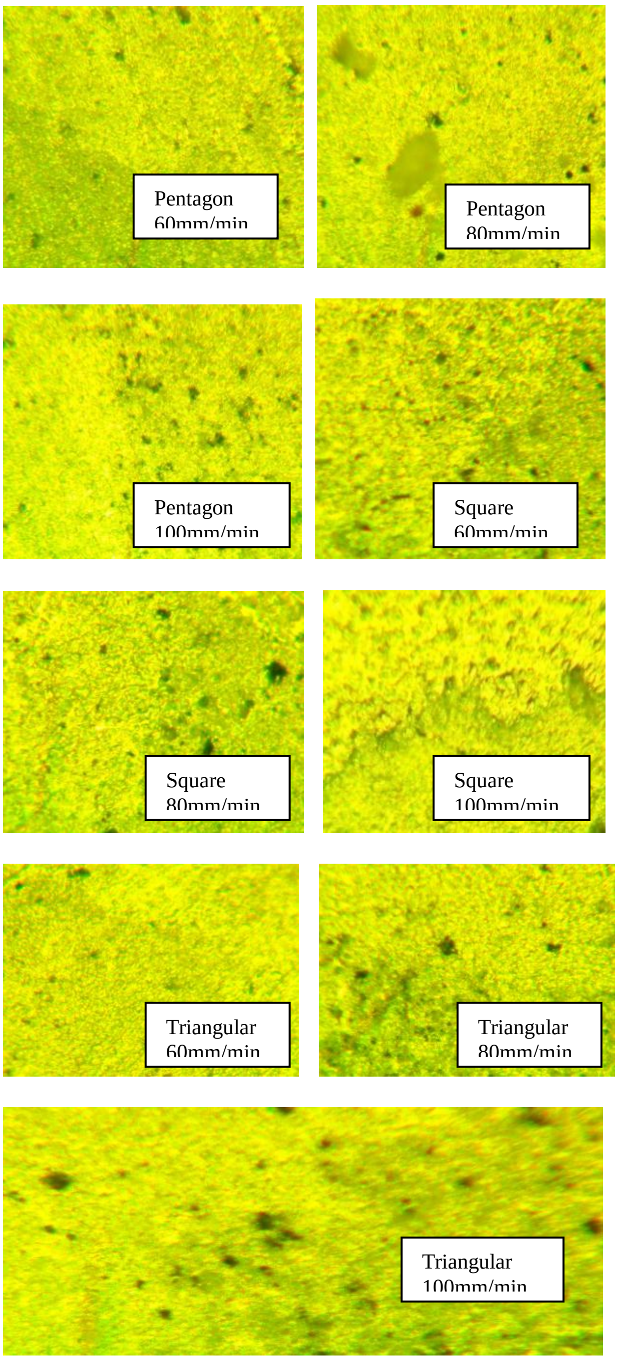

Fig 12. LOM images of weld zones cross sections

C. Micro hardness

The micro-hardness indentations of the weldments are shown in Fig 13. Micro hardness tests were performs to determine hardness number values of the aluminum dissimilar alloy combination AA5083 with AA6082 with various tool pin profiles and welding speeds. The hardness values are shown in the Table V. Fig 14 represents the hardness diagram of the joints FSW. The hardness of both the heat affected zone (HAZ) and the weld nugget (WN) is lower than that of base metal (BM) respectively in all the joints. The pentagon tool pin profile values shows so what higher values than the remaining two pin profiles i.e., square and triangular.

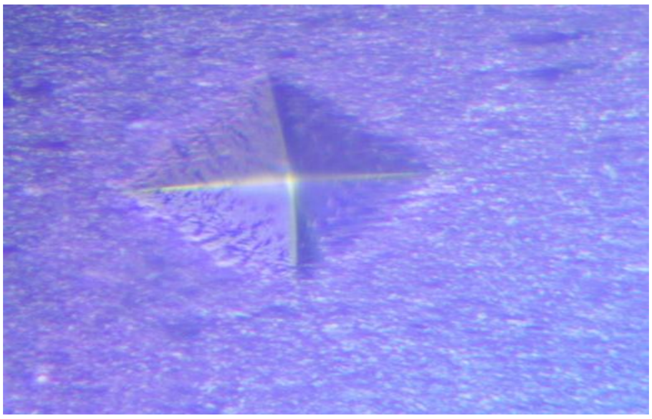

Fig 13. Micro hardness indentation of 5083AA And 6082AA

Table V: Vickers hardness values

S.no	Type of tool pin profile	Welding speed (mm/min)	HAZ ($HV_{0.2}$)	FZ ($HV_{0.2}$)	HAZ ($HV_{0.2}$)
1	Pentagon	60	70	60	73
2		80	69	54.5	63
3		100	65	52	64.5
4	Square	60	67.3	55.2	58
5		80	64.7	53.7	57.3
6		100	62.4	58.7	54
7	Triangular	60	63	57.6	59
8		80	59.7	54.1	56
9		100	58	53.8	57.6

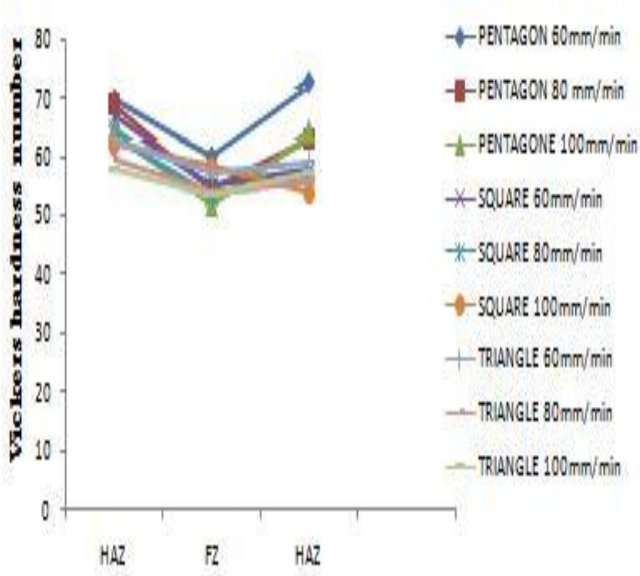

Fig 14. Micro Hardness profile of AA5083 and AA6082 weldments

IV. CONCLUSION

A. Tensile strength

- **Ultimate tensile strength**
  The pentagon tool pin profile produced maximum ultimate tensile strength i.e., 169.3 *MPa*. At 60mm/min welding speed this is due to as the welding speed increases the tensile strength decreases.
- **% of elongation**
  The pentagon tool pin profile at 60mm/min has maximum % of elongation i.e., 4.6 %.

B. Micro structure

The microstructures of dissimilar formed of Al 5083 and Al 6082 alloys joint showed the mixture structure of two materials. In pentagon tool pin profile superior tensile properties of FSW joints were observed, this is due to the formation of fine equiaxed grains and uniformly distributed very fine strengthening precipitates in the weld region. The rapid recrystallization is favored at the top of the weld, where contact with the tool shoulder occurred. This region experiences the highest deformation and most wear debris.

C. Micro hardness

The pentagon tool pin profile at 60 mm/min has produced high hardness (73 $HV_{0.2}$) .Recrystallization results in the weld zone having considerably lower hardness and yield stress than the parent base metals. During tensile testing, almost all the plastic flow occurs within the recrystallized weld zone.

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