EXPERIMENTAL STUDY OF WELD CHARACTERISTICS DURING FRICTION STIR WELDING (FSW) OF ALUMINUM ALLOY (AA6061-T6)

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Abstract

In this study the weld characteristics of AA6061-T6 Aluminum alloy during Friction Stir Welding (FSW) has been studied experimentally. The work has been carried out to study the tensile properties of the weldments like tensile strength, hardness and measurements of temperature at various distances along the weld zone on the weldments. The exp erimental work has been carried out with different tool shapes like taper threaded tool and half grooved tool at various weld parameters.

Index Terms: *Friction Stir Welding (FSW), AA6061-T6 Aluminum alloy, Taper threaded tool, Half grooved tool.*

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1. INTRODUCTION

The demand is increasing for aluminum alloy welded structure and product where a high standard of quality is required such as in aerospace applications. The aluminum alloy easily welded by welding methods like metal inert gas(MIG), tungsten inert gas(TIG) and friction stir welding(FSW). Among these three the friction stir welding (FSW) process has proved for many years to be suitable for welding the 6061-T6 aluminum alloy since it gives best quality of welds. Two different geometry tools (Taper threaded tool, Half grooved tool) are used to study the weld characteristics of friction stir welding (FSW). Friction stir welding (FSW) process was invented and patented by The Welding Institute (TWI) U.K in 1991[1]. Friction stir welding is a continuous, hot shear, auto geneous process involving non-consumable rotating tool of harder material than the substrate material. Defect free welds with good mechanical properties have been made in a variety of aluminum alloys[2]. A British research and technology organization, the process is applicable to aerospace, shipbuilding, aircraft and automotive industries. One of the key benefits of this new technology is that it allows welds to be made on aluminum alloys that cannot be readily fusion arc welded, the traditional method of welding. Due to the absence of parent metal melting, the FSW process is observed to offer several advantages over fusion welding [3].

A significant benefit of friction stir welding is that it has significantly fewer process elements to control. In a fusion weld there are many process factors that must be controlled such as purge gas, voltage, amperage, wire feed, travel speed, shield gas and arc gap. However in friction stir weld there are only three process variables to control: rotational speed, travel speed and pressure, all of which are easily controlled. The increase in joint strength combined with the reduction in process variability provides for an increased safety margin and high degree of reliability. The present investigation is aim to study the weld characteristics of AA6061-T6 aluminum alloy.

2. EXPERIMENTAL PROCEDURE

The Friction stir welding (FSW) was carried out on 3-axis CIMTRIX make computer numerical controlled milling machine with FANUC controller. The figures 1&2 shows the experimental process of friction stir welding of AA6061-T6 Aluminum alloy plates. The chemical composition of AA6061 aluminum alloy is given in Table 1[4].

Table 1: Chemical composition of AA6061 Aluminum alloy

Chemical composition (wt %)							
Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
0.66	0.25	0.31	0.08	0.99	0.16	0.01	balance

Figure 1. CNC milling machine with tool and fixture

Figure2. Tools used in Friction Stir Welding (Half grooved tool & taper threaded tool)

During the experimental process eight work pieces of dimension (200X60X6mm) are taken for joining process. Four joints are obtained from eight work pieces. The experimental plane is given in the Table 2.

Table 2: Experimental plan

Joint No	Rotation al Speed (rpm)	Feed (mm/ min)	Welding Position	Tool geometry
1	900	16	Forward Welding	Taper threaded tool
2	900	16	Reverse Welding	Taper threaded tool
3	900	16	Forward Welding	Half grooved tool
4	900	16	Reverse Welding	Half grooved tool

A milling machine was used for friction stir welding (FSW) of Aluminum alloy. The machine was a maximum speed of 6000 rpm and 10-horse power. The experiments were conducted on the Aluminum alloy 6061. Before the friction welding, the weld surface of the base material was cleaned. Undesired the rotating pin was inserted into an initially predrilled hole of 4.5mm long Tool tilt angle was 2^o.Welding was initiated Processing began at spindle speed of 900rpm and travel rate of 16mm/min.

In the present work temperature distribution in work piece are measured by using Resistance Temperature Detector (Figure 3.). RTD sensing element consists of a wire coil or deposited film of pure metal. The element's resistance increases with temperature in a known and repeatable manner. RTD's exhibit excellent accuracy over a wide temperature range and represent the fastest growing segment among industrial temperature sensor. RTD's can measure temperatures from -200°C to 650°C.

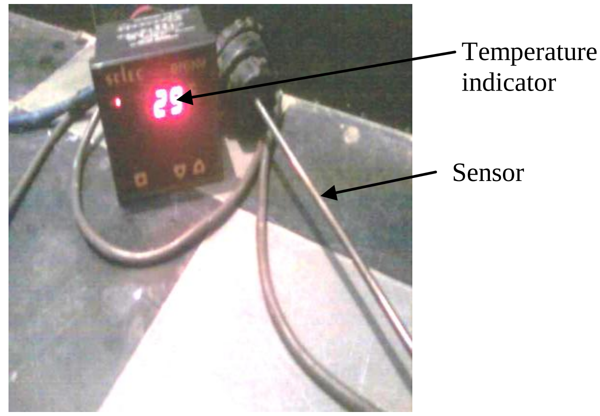

Figure3. Resistance Temperature Detector

Figure4. Universal Testing Machine (UTM)

The Tensile test has been conducted on the AA6061 friction stir elements in a Universal Testing Machine (figure 4) as per the ASTM standards to determine the tensile strength of the weldment.

3. RESULTS AND ANALYSIS

3.1 Temperature results

In the first experiment the temperature values for the first joint and third joint along the direction of weld line at rotational speed of 900 rpm and feed of 16mm/min. with the Taper threaded tool (T1) and Half grooved tool (T2) in clockwise direction (CW). These results are given in the table 3.

In the second experiment the Temperature values for the second joint and fourth joint along the direction of weld line at rotational speed of 900 rpm and feed of 16mm/min. with the Taper threaded tool (T1) and Half grooved tool (T2) in counter clockwise direction (CCW). These results are given in the table 4.

Table 3: Temperature values of first & third joint

SI. No	Distance(cm)	Temperature(^oC)	
		T1	T2
1	3	45	55
2	6	80	90
3	9	260	280
4	12	410	430
5	15	240	255
6	18	210	218

Table 4: Temperature values of second & fourth joint

SI. No	Distance(cm)	Temperature(^oC)	
		T1	T2
1	3	50	58
2	6	85	93
3	9	270	290
4	12	420	445
5	15	244	270
6	18	212	220

3.2 Tensile Test Results

During the tensile test with, we find the tensile strength values of the weldments for first , second , third and fourth joint along the weld zone using taper threaded and half grooved tool in clock wise (CW) and counter clock wise direction (CCW) and the test results are given in tables 5-8.

Table 5: Tensile strength values of the first joint

Work Piece Number	Distance from reference end(mm)	Width x Thick (mm)	Tensile strength (N/mm^2)
1	20	19.03x6.20	50
2	100	19.03x6.20	78
3	140	19.04x6.20	70

Table 6: Tensile strength values of the second joint

Work Piece Number	Distance from reference end(mm)	Width x Thick (mm)	Tensile strength (N/mm^2)
1	20	19.02x6.20	68
2	100	19.07x6.20	85
3	140	19.09x6.20	71

Table 7: Tensile strength values of the third joint

Work Piece Number	Distance from reference end(mm)	Width x Thick (mm)	Tensile strength (N/mm^2)
1	20	19.05x6.16	44
2	100	19.02x6.17	89
3	140	19.06x6.16	80

Table 8: Tensile strength values of the fourth joint

Work Piece Number	Distance from reference end(mm)	Width x Thick (mm)	Tensile strength (N/mm^2)
1	20	19.02x6.20	75
2	100	19.02x6.20	94
3	140	19.01x6.20	84

3.3 Brinell's Hardness Test Results

Hardness values for the first joint and third joint along the direction of weld line using Taper threaded tool (T1) and Half grooved tool (T2) in clockwise direction (CW). These results are given in the table 9.

Hardness values for the second joint and fourth joint along the direction of weld line using Taper threaded tool (T1) and Half grooved tool (T2) in counter clockwise direction (CCW). These results are given in the table 10.

Table 9: Hardness values of first & third joint

SI. No	Distance on weld zone(mm)	BHN	
		T1	T2
1	40	43.5	45.5
2	80	51.6	51.6
3	120	63.5	66.3
4	160	59.5	62.5

Table 10: Hardness values of second & fourth joint

SI. No	Distance on weld zone(mm)	BHN	
		T1	T2
1	40	44.6	50.5
2	80	50.5	55.3
3	120	65.5	69.5
4	160	60.3	65.0

Figure5 shows the variation in temperature with distance along the top surface for four joints in forward direction and reverse direction of the weld. The peak temperature obtained was 4450C in fourth joint (half grooved tool) in reverse direction of weld. The maximum temperature obtained during FSW process by taper threaded tool is 420oc. After comparison the welded joints by using two tools, it has been observed that half threaded tool has developed maximum temperature than the taper threaded tool due to more frictional area of contact between tool and work piece. And also the maximum temperature is obtained during FSW process by using half threaded is 75% of the melting temperature of AA 6061-T6 which gives better quality of the weld[5].

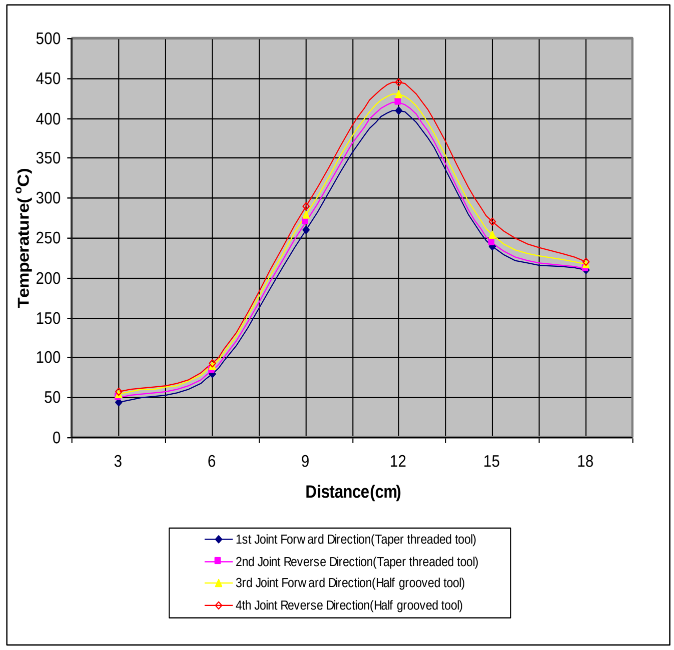

Figure5. Variation in Temperature with distance along the weld line on the top surface

Figure 6 shows the variation of tensile strength along the weld zone. The Tensile test is conducted on the AA 6061 friction stir elements in a Universal Testing Machine as per ASTM standards to determine the breaking load and yield strength of the weldment. It is observed that the maximum tensile strength is 94 N/mm2 using half grooved tool and 85N/mm2 using taper threaded tool at which maximum temperature occurs. After comparing the two values, the half grooved tool gives the maximum due to grain refinement.

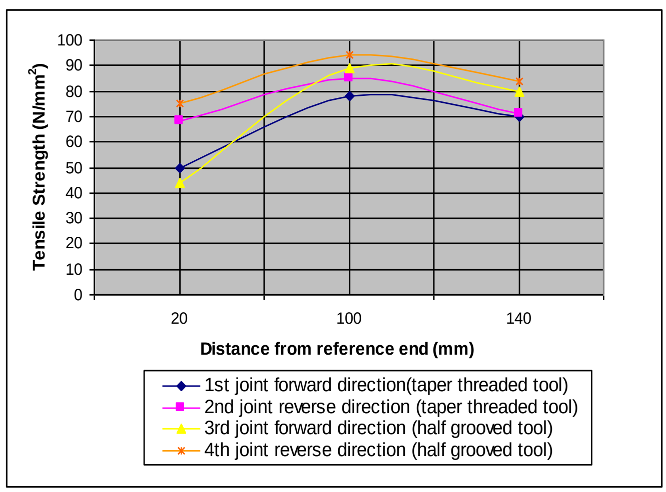

Figure 6 Variation of Tensile strength with distance along the weld zone.

Figure 7 shows the Variation of Brinell's hardness number along the weld zone. From this figure it can be observed that the Brinell's hardness number first increases and then decreases along the weld zone. The hardness variation on the material surface is inherent and influenced by a number of metallurgical parameters during solidification of the material. Higher hardness value occurred at maximum temperature point due to the formation of new grains.

The Brinell's Hardness has been conducted on FSW welded joint for determine the hardness along welded zone. It is observed that the maximum Brinell's hardness number is 69.5 BHN using half grooved tool and 66.5 BHN using taper threaded tool at which maximum temperature occurs. After comparing the two hardness values, the half grooved tool gives the maximum due to influenced by a number of metallurgical parameters like grain refinement, heat treatment during solidification of the material.

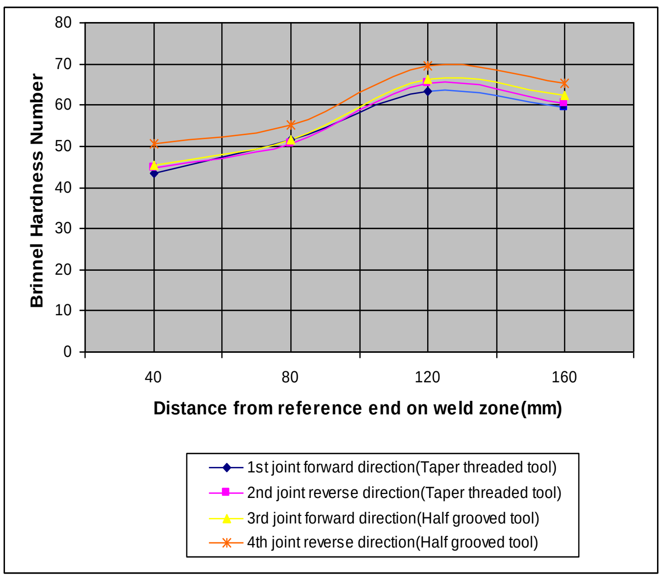

Figure 7. Variation of Brinell's Hardness Number with distance along the weld zone

CONCLUSIONS

The following observations can be made during this experimental study

- The variation in peak temperature perpendicular to the weld line at constant rotational speed and constant welding speed.
- Variation of the nugget–zone temperature with respect to time.
- Experimentally the maximum temperature is obtained during FSW process by using half grooved tool is 445^0 C and 420^0 C by using taper threaded tool.
- The maximum tensile strength is 94 N/mm^2 by using half grooved tool and 85 N/mm^2 by using taper threaded tool.
- The maximum Brinell's hardness number is 69.5BHN using half threaded tool and 66.5BHN using taper threaded tool at which maximum temperature occurs.
- From the above results it is concluded that half grooved tool gives good quality of weld than the taper threaded tool.

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