Effect of tool pin profile on mechanical properties of aluminium AA6351 alloy using friction stir welding

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Abstract

Friction stir welding (FSW) is a novel solid-state joining technique. FSW is gaining more popularity and more extensive application in the manufacturing sector. The heat generation, proper mixing of joint line material and properties of welds depends on the profiles of friction stir tools. This process was, in first time, develop to join the similar aluminum plates but now the technology can be used to weld a large area of materials similar or dissimilar. The present work investigates the effect of tool rotational speed on tensile strength of friction stir welded AA6351 material .Two different tool pin profiles, such as Square and Threaded Tri flute, with four different tool rotational speeds (750,1000,1250 and 1500 rpm) have been used to weld the joints. The effect of the pin profiles and the tool rotational speed on the tensile properties are analyzed. The joint exhibited maximum tensile strength at tool rotational speed of 1250 rpm. Tri flute tool provide the better tensile strength when compare to straight square tool at all tool rotational speeds.

1. Introduction

Friction stir welding (FSW) technology which was invented at The Welding Institute (TWI), UK in 1991 has revolutionized the welding industry. Successful works have been performed to investigate various aspects of this process, and it is established that heat generation and material flow in the weld nugget during welding as well as weld quality are strongly dependent on the pin and shoulder parameters of the FSW tool. Aluminum alloys are widely used in automotive, aerospace and ship industries due to the combination of mass reduction and high strength. A non-consumable rotating tool which has a shoulder and pin is plunged into the joint line. The frictional heat generated by the rubbing of shoulder and pin plasticized the materials to be joined. Since the material subjected to FSW does not melt and recast, the resultant weld offers advantages over conventional fusion welds. Conventional fusion welding of aluminum alloys results in numerous welding defects which includes voids, hot cracking, distortion, precipitates dissolution, loss of work hardening and lack of penetration in the joints.Therefore, solid state welding technique is highly recommended to solve those problems.

Bazani Shaik et al investigate that the effects of process parameters i.e. tool rotational speed, weld speed and tilt angle on the responses i.e tensile strength, impact strength & elongation in dissimilar welding of Aluminum alloys of different grades using the solid state welding technique Friction Stir Welding process. In view of the costlier process, Taguchi L9 is used for carrying out the research. As it is a complex process, to identify the significant variables, initial trial experiments are done on the same parent materials. Based on them ranges are also found out for each input process parameter. A total of three input process parameters (tool rotational speed, weld speed & tilt angle) are chosen for study and the output responses measured are tensile strength, impact strength and elongation. ASTM standards are used in preparing the work pieces. After measuring its output responses, main effects are studied between the input process parameters vs output responses. This analysis can be further used in predicting the empirical equations with which the process can be automated based on the optimal values. Lingraju Dumpala et al investigate that the study has been carried out on FSW on 6mm thick plates of 6063 Aluminium alloy using high chromium (H13) alloy steel tool. This 6063 Aluminium alloy is commonly used in marine applications due to weight-saving, corrosion resistance, extrusion requirements and structural applications. In this work, two types of tool pin profiles have been used to join the Aluminium alloy sheets. Two different tool pin profiles namely; 3 slots horizontal and 6 slots vertical cylindrical threaded have been used to fabricate. The weld joint at different tool rotational speeds of 760, 1130, 1340 rpm and traverse speeds of 11 and 25mm/min. Aluminium alloy of grade 6063 has been selected for this project report that covers the detailed study of FSW 6063 of Aluminium alloy of weld characteristics, i.e. tensile properties like Ultimate Tensile Strength (UTS), Yield Strength and % of elongation. Besides, it vividly covers the metallographic properties of the weldments like microstructure at various zones, as well.

2.Experimental work

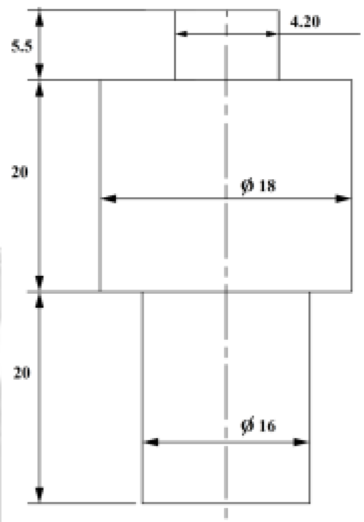

Figure 1. Square tool pin profile design

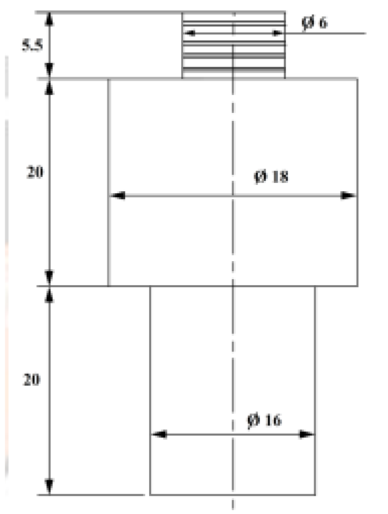

Figure 2.Threaded Triflute tool pin profile design

The above mentioned fig-1 is the design of Square tool pin profile for friction stir welding.
The above mentioned fig-2 is the design of Threaded Triflute tool pin profile for friction stir welding.This tools has been used to weld the plates at various rotational speed to find the ultimate tensile strength.

Tool Pin Profile	**Speed 1**	**Speed 2**	**Speed 3**	**Speed 4**
Square tool pin profile	750	1000	1250	1500

Table 1. Square tool pin profile rotational speed

We have conducted the experiment in various rotational speed by using square tool pin profile to find out the ultimate tensile strength. The above mentioned table.1 is the rotational speed variations of square tool pin profile .The rotational speed 3 which is 1250 rpm got the maximum tensile strength.

Tool Pin Profile	**Speed 1**	**Speed 2**	**Speed 3**	**Speed 4**
Threaded triflute tool pin profile	750	1000	1250	1500

Table 2. Threaded triflute tool pin profile rotational speed

We have conducted the experiment in various rotational speed by using Threaded Triflute tool pin profile to find out the ultimate tensile strength. The above mentioned table.2 is the rotational speed variations of Threaded Triflute tool pin profile . The rotational speed 3 which is 1250 rpm got the maximum tensile strength.

Figure.3 Welded plate using the rotational speed of 750 rpm

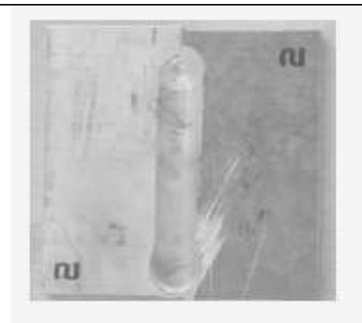

Figure.4 Welded plate using the rotational speed of 1000 rpm

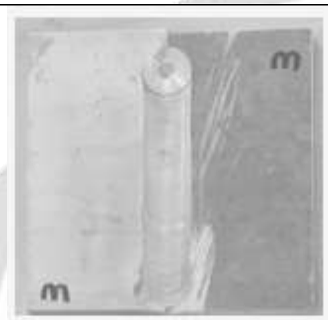

Figure.5 Welded plate using the rotational speed of 1250 rpm

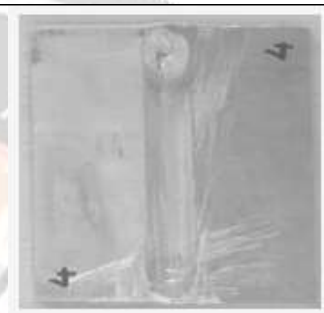

Figure.6 Welded plate using the rotational speed of 1500 rpm

The welded plate 1, fig.3 shows the welded plate using the rotational speed of 750 rpm.
The welded plate 2, fig.4 shows the welded plate using the rotational speed of 1000 rpm.
The welded plate 3, fig.5 shows the welded plate using the rotational speed of 1250 rpm.
The welded plate 4, fig.6 shows the welded plate using the rotational speed of 1500 rpm.

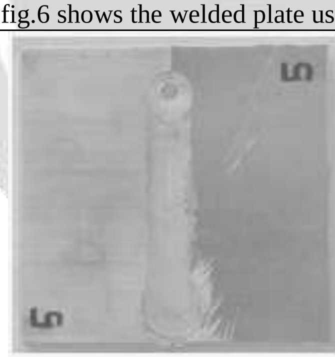

Figure.7 Welded plate using the rotational speed of 750 rpm

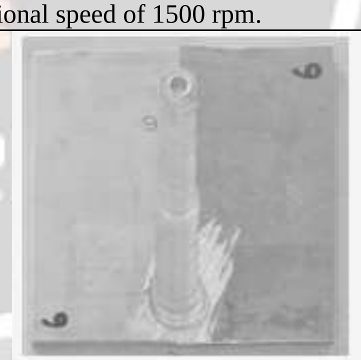

Figure.8 Welded plate using the rotational speed of 1000 rpm

Figure.9 Welded plate using the rotational speed of 1250 rpm

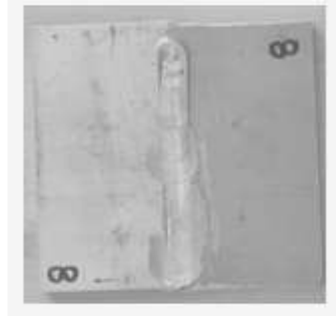

Figure.10 Welded plate using the rotational speed of 1500 rpm

The welded plate 5, fig.7 shows the welded plate using the rotational speed of 750 rpm.
The welded plate 6, fig.8 shows the welded plate using the rotational speed of 1000 rpm.
The welded plate 7, fig.9 shows the welded plate using the rotational speed of 1250 rpm.
The welded plate 8, fig.10 shows the welded plate using the rotational speed of 1500 rpm.

Figure.11 Square Tool Pin Profile

Figure.12 Threaded Triflute Tool Pin Profile

We conducted the experiment by the square tool pin profile which is in the above fig.11. We conducted the experiment by the threaded triflute tool pin profile which is in the above fig.12.These tools had been used to weld the plates at various rotational speed to find the ultimate tensile strength.

3.Result and Discussion

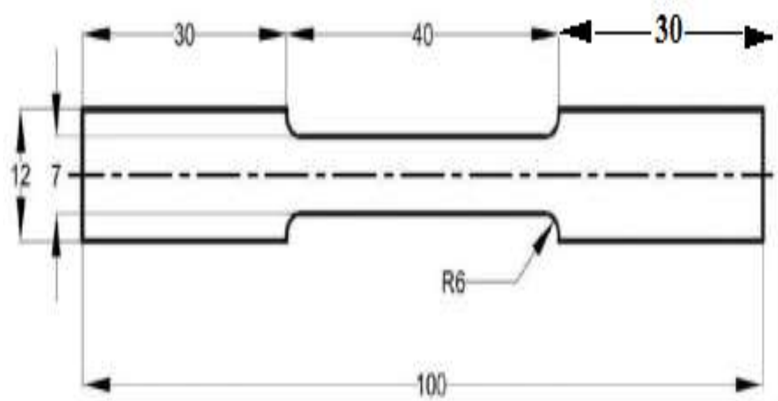

Figure.13 Tensile Specimen

Figure.14 Tensile Specimen before fracture

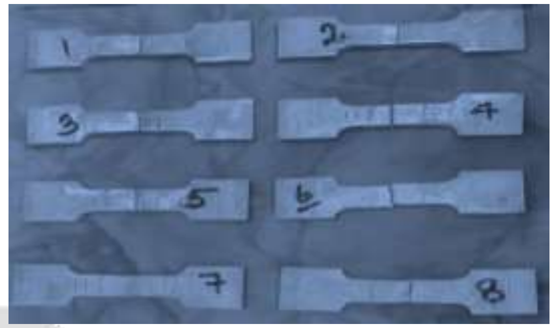

Figure.15 Tensile Specimen after fracture

TOOL ROTATIONAL SPEED (RPM)	TENSILE STRENGTH (MPa)
750	213
1000	232
1250	248
1500	223

Table.3 Square Tool Pin Profile Tensile Strength

The above table.3 shows that the square tool pin profile rotational speed and its equivalent tensile strength.

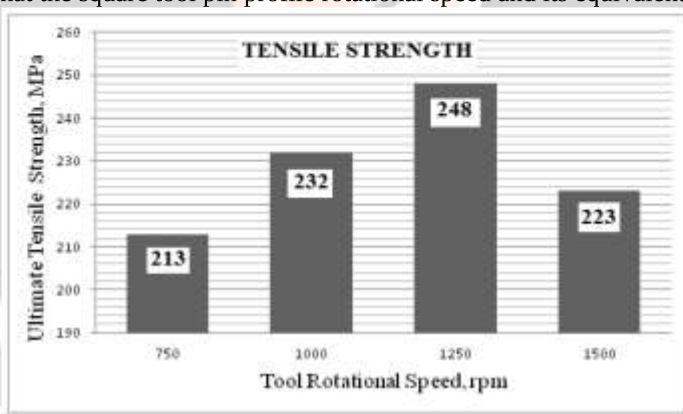

Figure.16 Graph of Square Tool Pin Profile Tensile strength

The above mentioned graph fig.16 is the Ultimate Tensile strength for our experimental work by varying rotational speed in the range of 750 to 1500 rpm by using square tool pin profile.The graph shows that whenever we increase the rotational speed of the tool, the tensile strength of the joint gradually increases upto certain extend (1250 rpm).If we further increase the rotational speed of the tool the tensile strength gradually reduces.

Distance from the center (mm)	Microhardness (HV)			
-5	61	61	59	61
-4	60	61	63	60
-3	60	59	61	63
-2	63	66	68	67
-1	70	70	70	70
0	83	87	92	87
1	72	72	72	72
2	64	68	67	63

3	59	61	62	61
4	60	60	61	63
5	62	63	61	63

Table.4 Micro hardness distribution across the joint when AA6351 of Square Tool pin profile

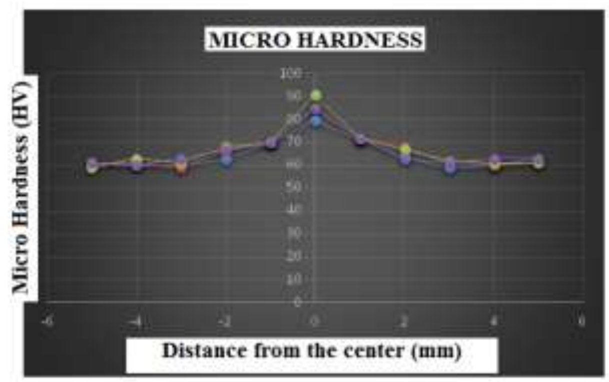

Figure.17 Graph of Micro hardness distribution across the joint when AA6351 of Square tool pin profile

TOOL ROTATIONAL SPEED (RPM)	**TENSILE STRENGTH (MPa)**
750	235
1000	252
1250	268
1500	236

Table.5 Threaded triflute Tool Pin Profile Tensile Strength

The above table.5 shows that the threaded triflute tool pin profile rotational speed and its equivalent tensile strength.

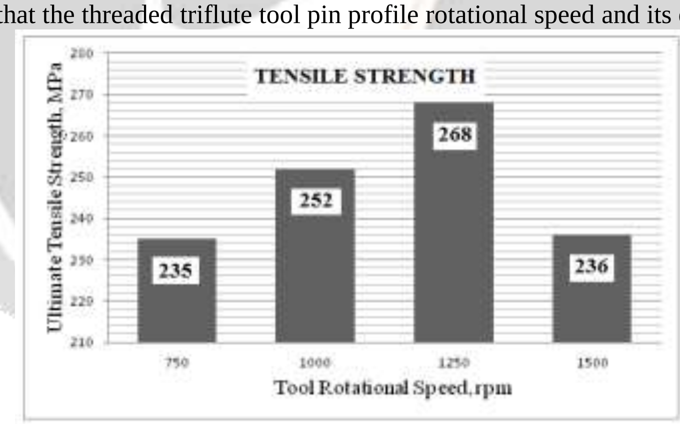

Figure.18 Graph of Threaded Triflute Tool Pin Profile Tensile strength

The above mentioned graph fig.18 is the Ultimate Tensile strength for our experimental work by varying the rotational speed in the range of 750 to 1500 rpm using threaded triflute tool pin profile.The graph shows that whenever we increase the rotational speed of the tool , the tensile strength of the joint gradually increases upto certain extend (1250 rpm).If we further increase the rotational speed of the tool the tensile strength gradually reduces.

Distance from the center (mm)	**Microhardness (HV)**			
-5	61	61	59	61
-4	60	61	63	60
-3	60	59	61	63
-2	63	66	68	67

-1	70	70	70	70
0	82	87	96	87
1	72	72	72	72
2	64	68	67	63
3	59	61	62	61
4	60	60	61	63
5	62	63	61	63

Table.6 Micro hardness distribution across the joint when AA6351 of Threaded Triflute Tool pin profile

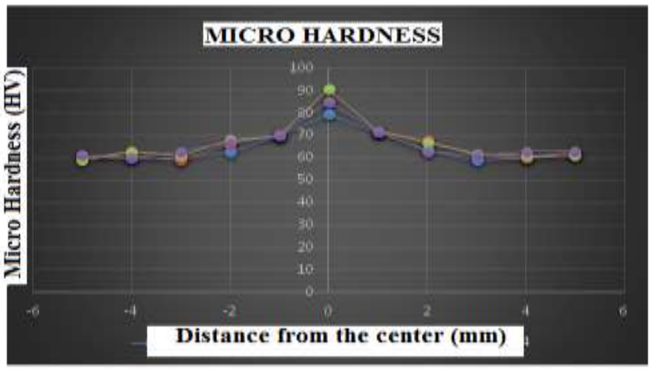

Figure.19 Graph of Micro hardness distribution across the joint when AA6351 of Threaded Triflute tool pin profile

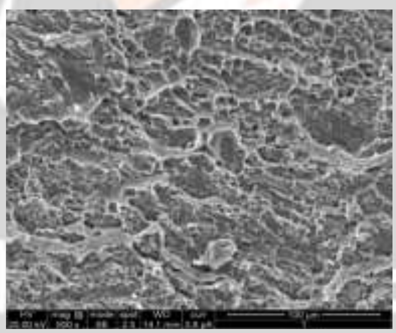

Figure.20 SEM Photomicrograph of fracture surface of Square Tool Pin Profile FS welded aluminum alloy

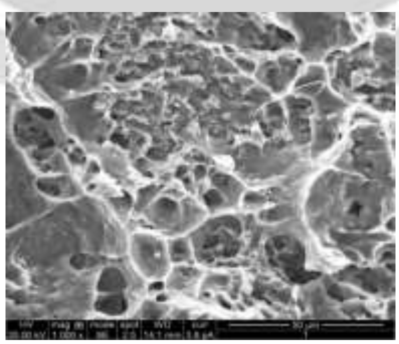

Figure.21 SEM Photomicrograph of fracture surface of Threaded Triflute Tool Pin Profile FS welded aluminum alloy

Conclusion

The micro hardness of some portion of weld zone was higher compared to base metal. Threaded Triflute tool pin profile got the maximum tensile strength 268 MPa at the rotational speed of 1250 rpm and the Square tool pin profile got the maximum tensile strength 248 MPa at the rotational speed of 1250 rpm. Thus here we concluded that the Threaded Triflute tool pin profile provide the better tensile strength when compared to Square tool pin profile tensile strength.

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