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Research Article

Analysis on Mechanical Behavior of Friction Stir Welding using different Tool pin Profiles

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Abstract

Friction stir welding (FSW) has a wide scope. Friction stir welding (FSW) process is a solid state joining process in which the material that is being welded does not melt and recast. An investigation has been carried out on the friction stir welding of Al Alloy (AA6061) grade aluminum alloy plates. Four different tool pin profiles (Square, Straight cylindrical, Threaded and Triangular) be used to fabricate joints in a single and sequential double sided. In this investigation, tool rotation and traverse speeds be kept constant i.e. 3080 rpm and 30mm/min. The joints fabricated by single pass have shown lower tensile strength and also percentage of elongation compared to the joints fabricated by double pass and this trend is common for all the tool profiles. The results of our work were shown by histogram graph.

Keywords: *FSW, Tool pin profiles, Tensile Strength, Percentage Elongation and Joint Efficiency.*

1. Introduction

The need for joining materials having higher hardness property and tensile strength has arisen with the present advancement in science and technology (A. Pradeep, S. Muthukumaran, 2013). FSW is a solid state welding process for joining aluminum alloys and has been employed in aerospace, rail, automotive and marine industries for joining aluminum, magnesium, zinc and copper alloys. The basic principle of friction welding involves the simultaneous application of pressure and relative motion, generally in a rotational mode, between the components to be joined. The frictional heat thus generated raises the interface temperature of the components to their melting points while the applied pressure perpendicular to the plane of motion serves to extrude the heated material including any dirt and oxide films from the interface, bringing the components to be joined into intimate contact. Friction stir welding (FSW), a solid-state welding process was invented and experimentally proven by Wayne Thomas and a team of his colleagues at the Welding Institute UK and patented by the TWI in 1991(L. John Baruch, R. Raju, V. Balasubramanian, 2012) and emerged as a welding technique to be used in high-strength alloys that were difficult to join with conventional technique. The process was developed initially for aluminum alloys, but since then FSW was found suitable for joining a large number of materials. In aeronautics, for instance, riveting is the preferred manufacturing process for aircraft fuselage structures; nevertheless, In FSW process, a non-consumable rotating tool (Lakshminarayanan A.K. *et al*, 2012) consisting of a shoulder and profiled probe or pin, is forced down into the joint line under conditions where the frictional heating is sufficient to raise the temperature of the material to the range where it is plastically deformed (W.M. Thomas, C.J.Dawes) as shown in Figure. 1

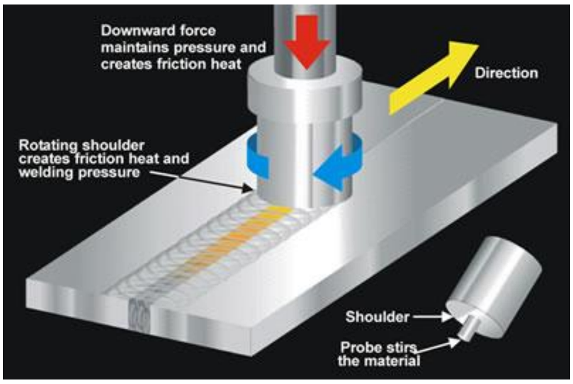

Fig.1 Friction Stir Welding

Single pass friction stir welding is not able to provide better results in case of thick work material plates which is mainly due to the difficulty in finding a suitable backing material. Obviously the thickness of plate that can be joined by FSW can be increased by passing the tool along both sides of the butted plates in sequence. The use of the sequential double pass weld can almost double the plate thickness (P Alanivel R *et al*, 2012) that can be joined, thereby significantly increasing the industrial utility of the FSW joining process for other materials like steels etc.

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Several previous studies reported the effects of the tool threads and probe profile on different aluminum alloys. In spite of these achievements, the effect of tool shape on mechanical properties in single and sequential double sided friction stir welds of aluminum alloy (Kevin Deplus et. al, 2011) has not yet been systematically classified. Additionally, in order to design effective tools of high carbon steel to precede FSW on aluminum alloys, new concept is necessary. A specially shaped tool made from material that have a hard and wear resistant relative to the material being welded, is rotated and plunged into the adjacent edges of the aluminum plates to be joined. Heat is generated by the rubbing action of tool shoulder as the tool translates along the joint.

2. Material and Methods

2.1 Work piece Material specification

Base Metal Used: AA6061 (Al Alloy).
Base Metal plate Dimensions: 100 x 50 x 6 mm.

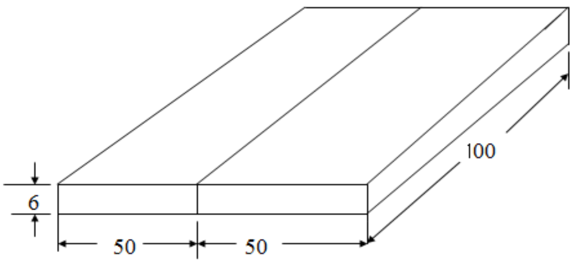


Fig.2 Work piece Dimensions

Table 1 Chemical composition (weight %)

Mg	Cu	Si	Fe	Cr	Al
0.8-1.2	0.15-0.4	0.4-0.8	0-0.7	0.04- 0.35	97.56

Table.2 Mechanical properties

Tensile Strength	Yield Strength	Elongation %	Hardness (BHN)
310	276	12	107

2.2 Tool Material Specification

Material: - High Carbon steel
Diameter of tool head used 17 mm.
Length of tool is used 50 mm.
For Single sided friction stir welding

1. Straight Cylindrical (SC) – Pin diameter-5mm and pin length – 5 mm.
2. Square (SQ) - Pin dimensions – (5x5) mm, diagonal 7 mm and pin length – 5 mm.
3. Cylindrical Threaded (TH) – pin diameter -6mm, pitch of thread- 0.7 mm, pin length- 5 mm.
4. Triangular (TR) – diagonal – 5mm, pin length- 5 mm.

Similarly four shapes of tools being used for double sided FSW dimensions are given below

1. Straight Cylindrical (SC) – pin diameter-5mm and pin length – 3 mm.
2. Square (SQ) - Pin dimensions – (5x5) mm, diagonal - 7 mm and pin length – 3 mm.
3. Cylindrical Threaded (TH) – pin diameter 6mm, pitch of thread- 0.7 mm, pin length- 3mm.
4. Triangular (TR) – diagonal – 5mm, pin length- 3 mm.

All tools were machined on the basis that the maximum shank diameter of tool should be 17 mm.

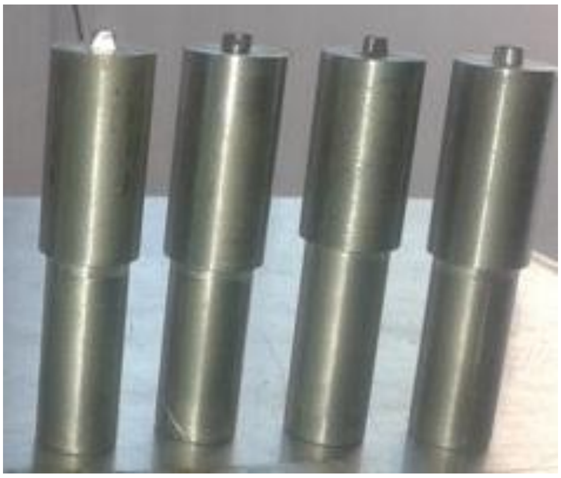


Fig.3 Different tool pin profiles for welding.

Properties of High Carbon Steel Tool

a) These steel have carbon percentage from 0.8 to 1.5%.
b) Because of their high hardness these are suitable for wear resistant parts.
c) These steels have easy to forge and simple to harden.
d) Its melting point is 1300°C

2.3 Machine Specification

Fig. 4 Vertical milling machine used for FSW operation

Table 3 Machine Specification

Specifications	Values
Make	PACMILL
Range	100-4650 rpm (50 Hz)
Type	Vertical
Longitudinal bed range	900mm
Cross bed range	600mm
Traverse feed range	12-90 mm/min.
Motor	3H.P, 1450 rpm
Tool holder diameter	50 mm

2.4 Procedure for Friction Stir Welding

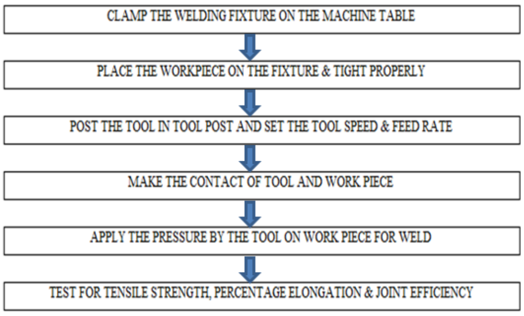


Fig. 5 Friction Stir Welding

2.5 Testing Equipment

Tensile Testing on Universal testing machine
Steps followed during the tensile test.

i. Record the maximum load.
ii. Conduct the test until fracture.

Fig. 6 Specimen under tensile testing in UTM

After the test Measure the final gage length and calculate Elongation. The length has been measured according to the gage marking. Mechanical properties which had been tested are

a) Ultimate tensile strength.
b) Percentage of elongation.
c) Joint efficiency of samples.

3. Result & Discussion

The results of tensile loading of the base metal and welded specimens in single and double pass are shown in Table 4, 5 & 6. In table 4 & 5 some shortcuts are used like SC - Straight Cylindrical, S - Square, CT - Cylindrical Threaded and T - Triangular. The variation of tensile strength, percentage elongation and joint efficiency are shown in Graphs 1, 2 & 3 respectively. In bar chart data for single pass is represented by blue color and data for double pass is represented by red color.

Formulae used for mechanical testing are given below

Stress: - Load/Area
Note- All load values we got from testing are in Kgf (1 Kgf: - 9.81 N/mm^2)
Percentage Elongation :- (Final length – Initial length)/100
Joint Efficiency: - UTS of welded specimen/UTS of base metal.

Table 4 Results of tensile loading of welded specimens in single pass.

Mechanical Properties	Single Pass			
	SC	**S**	**CT**	**T**
Load (kgf)	730	757	655	700
Area(mm)	84	84	84	84
Tensile Strength (N/mm^2)	85.25	88.31	76.4	81.75
Elongation (mm)	56.3	57.5	53.4	54.6
% Elongation	12.6	15	6.8	9.2
Joint Efficiency (%)	65.5	68	59	63

Here table 4 shows that tensile strength, percentage elongation and joint efficiency are more for square tool pin profile during single pass.

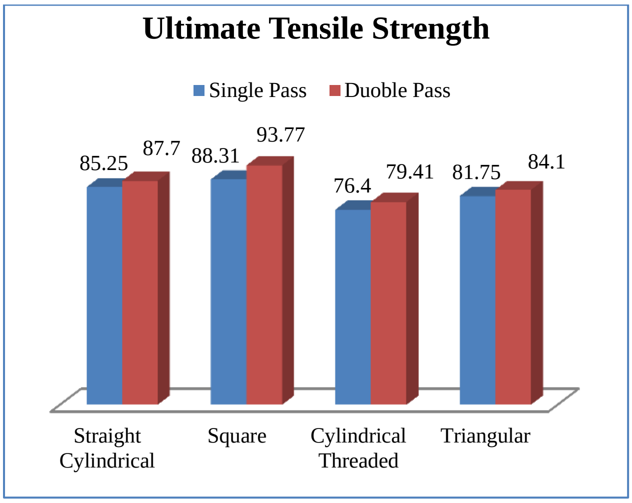
Table 5 Result of tensile loading of welded specimens in Double pass

Mechanical Properties	Double Pass			
	SC	**S**	**CT**	**T**
Load (kgf)	751	803	680	720
Area(mm)	84	84	84	84
Tensile Strength (N/mm^2)	87.7	93.77	79.41	84.1
Elongation (mm)	56.2	58.4	53.8	54.8
% Elongation	12.4	16.8	7.4	9.6
Joint Efficiency (%)	67.55	72.2	61	64.5

Here table 5 shows that tensile strength, percentage elongation and joint efficiency are more for square tool pin profile during double pass.

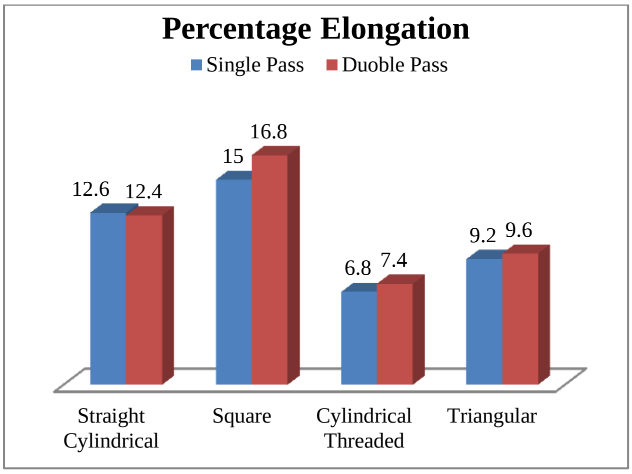
Table 6 Values for Base Metal.

Base metal	Load	Area	Tensile strength	% Elongation
Mechanical Properties	1113	84	130	18



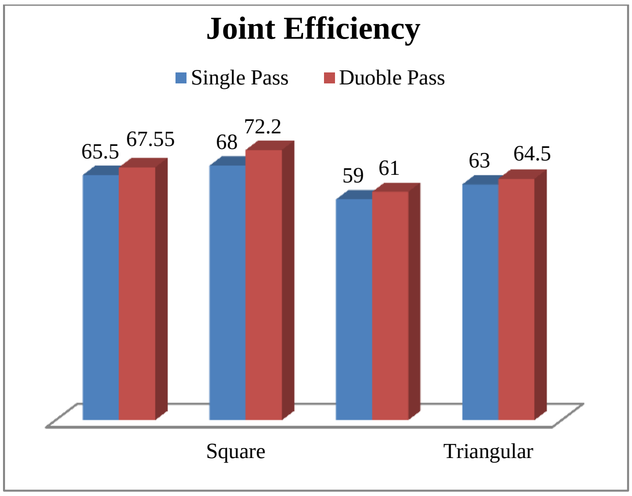
Graph 1 Variation of Ultimate Tensile Strength.

Graph shows that square tool pin profile have high tensile strength when tool pass twice on a specimen.



Graph 2 Variation of Percentage Elongation.

Graph shows that square tool pin profile have more elongation percentage when tool pass twice on a specimen.



Graph 3 Variation of Joint Efficiency.

Graph shows that square tool pin profile have more joint efficiency (%) when tool pass twice on a specimen.

Conclusions and Future Scope

Conclusions

The conclusions drawn from the present study are listed below: -

1. Tool pin profile is very much responsible for deciding the weld quality.
2. Square tool pin profile has more joint efficiency 72.2% during double side weld joint as compare to single side weld joint.
3. The ultimate tensile strength is maximum (93.77 N/mm^2) of double side weld joint for square tool pin profile as compare to other tool profiles (88.31 Square tool single pass, 87.7 Straight tool double pass).
4. Square tool profile double pass has more percentage elongation (16.8%) as compared to other tool profiles (15% square tool single pass, 12.6 % straight cylindrical tool double pass, 12.4% straight cylindrical tool single pass).

Further Scope

Very large number of parameters in any experimentation and it is not possible to check the effect of varying each and every parameter. So further work can be done on:

- To find the optimum tool rotation speed for sound welding.
- Temperatures at various points and heat input per unit volume can be calculated.
- Determine the fatigue behaviors of notched specimens of friction stir welded aluminum alloys.
- Welding can be done on high melting point alloys such as steels etc.
- Mathematical models can be developed to study various parameters.
- Variation in the tool material may be taken into consideration.

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