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Research Article

Effect of Different Parameters on Heat Generation and Tensile Strength of FSW AA5083 Joint

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Abstract

Friction stir welding (FSW) is an advanced and upgraded version of friction welding. It has been systematically developed for joining non-weldable aluminium alloys. This joining process is a more robust process for aluminium. In the joining of aluminium based alloys with FSW, different parameters such as tool rotational speed, welding speed, tool tilt angle influence the quality of the weld. In the present article these effects have been identified through one factor at a time approach. Tool rotational speed has been the major influencing parameter for generating frictional heat. Tool rotational speed with frictional heat makes the material to reach at re-crystallization temperature at which two plates were welded. Other parameters also have significant impact on the friction stir welded joint quality. Microstructure also changes at different level of parameters.

Keywords: *FSW, welding, aluminium alloy, tool rotational speed, tool tilt angle.*

1. Introduction

FSW (FSW) process was invented at The Welding Institute (TWI) in 1991 and inventor W. M. Thomas applied for a patent on November 25, 1991. This invention of joining material has been found quite useful in the past two decades.

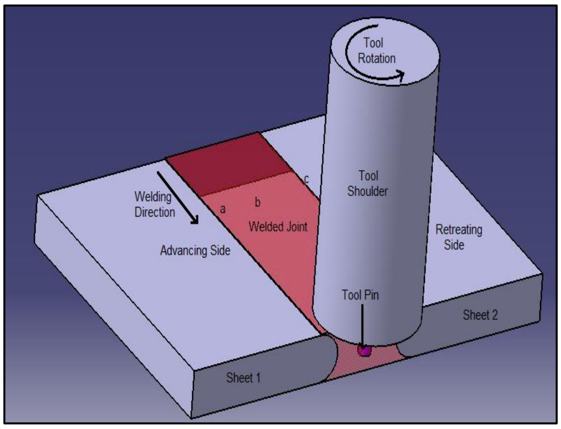

Figure 1: FSW set-up

The FSW joining process was initially used for welding of aluminium and its alloys in the lab research program but it has gradually been used for the welding of relatively harder metals including composites and plastics. The process has attracted the attention of researchers due to its abundant advantages over conventional welding processes. The main components of FSW are given in figure 1 (Kundu & Singh 2017).

2. Heat Generation in FSW

Conventional joining processes provide heat from the external specific power source but in FSW heat is generated by joining process itself. Basically, heat generation in FSW is derived by two mechanisms named friction and plastic deformation. The essential attentiveness of heat generation, heat transfer, and material flow delivers a defect free quality friction stir welded joint. As given in figure 2, the heat flux changes as the heat dissipation from the system through conduction (backing plate and welding plates), convection (welding plates, tools to the environment), and radiation (welding plates, tools to the environment) will change.

Generated frictional heat is very complex to measure because it depends on different process variables like rotational speed, traverse speed, and downward force which are the function of tool design and base material to be joined. As we focus more precisely, the tool design and dimensions e.g. size, surface angle, tool tilt angle, pin geometry etc. influence the heat generation and heat transfer

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mechanism as well as material flow design. Sliding and sticking of material generate a larger part of the heat. Movements of the material under the tool shoulder are caused by sticking phenomenon of the material. In FSW tool shoulder surface is taken flat, concave or convex, and the weld quality significantly changes as the shape is changed. The beat results have been recorded through the convex surface tool shoulder. Tool pin geometry also plays a vital role for the flow and mixing of the materials and then finally the properties of the welded joint are affected (Kundu & Singh 2016). The tool shoulder makes the smooth flow of the material in bulk but tool pin geometry produces material flow layer-by-layer. Therefore flow of material in triangular pin geometry is more as compared to the cylindrical tool pin geometry.

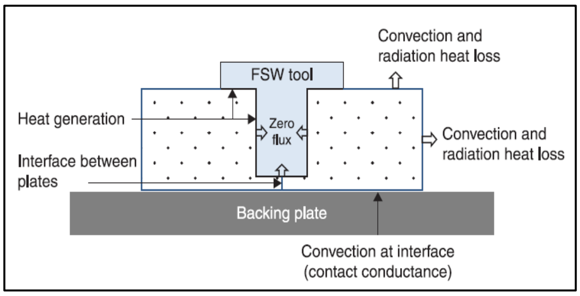

Figure 2: Schematic heat generation and heat dissipation diagram (Givi 2014)

The square geometry of tool pin produces more homogeneous flow pattern of the material. Threads cut on the tool pin also affect the flow of material and heat generation. The threaded pin profile and flutes on the tool pin produce more heat rate due to the larger interfacial area. High heat generation confirms the smooth material flow and it affects the axial as well as transverse force due to the phase change of the material, it starts flow at higher temperature. The circular tool encounters less wear as compared to the flat-faced tool. In joining of dissimilar materials through FSW, preheating has also been used for better welded joint properties.

3. Literature Study

The influences of tool rotational speed and various parameters on macrostructure, microstructure and tensile strength of FSW of aluminium alloy AA5456 was studied by Salari *et al.* (2014). Four types of tool pin profiles were employed for the effect investigation of different input process parameters with two rotational speeds of 600 and 800 rpm. The results showed that tool rotational speed and tool geometry influences significantly the material flow in the stir zone and it accordingly controls the weld mechanical properties like tensile strength and hardness.

In the FSW process, the rotation of the tool generate fractional heat and movement of material under the tool shoulder results in the stirring and mixing of material around the rotating pin while the traverse speed of the tool transports the stirred material from the front side to the back side of the pin (Mishra & Ma 2005; Akinlabi 2012). Higher tool rotational speed produces higher temperature because of the increased frictional heating and this result in more intense stirring and mixing of the material (Indira *et al*. 2011). The choice of feed rate and rotational speed are significant for heat generation in producing good material flow around the tool while minimizing the forces on the tool during the welding procedure. Therefore, rotational speed and pin profile were taken as process variables and process was analysed for the weld appearance, yield strength and elongation of the weld in relation to process variables. Elongvan & Balasubramanian (2007) investigated the formation of friction stir processed (FSP) zone with different tool pin profiles and rotational speeds. They have also explored the relationship between FSP zone formation and the tensile strength properties of the friction stir welded AA2219 aluminium alloy joints. *Muhsin et al.* (2012) performed the experiments on 5 mm thick plate of AA 7020-T53 to determine the variation of transient temperature in a FSWed joint. Experimental records specify some location of transient temperature which were compared with thermocouple records and verified through a numerical simulation study. Kundu & Singh (2016)a discussed the effects of process parameters on joint strength. They analyzed that during the FSW, re-crystallization occurs at nugget zone and transformation of grains is seen at thermo-mechanical heat affected zone (TMAZ) and heat affected zone (HAZ). In this advance joining process, two materials are intermixed through the stir action of the pin. Onion rings are formed at the surface at the nugget zone proper mixing of two materials and re crystallization make strong bonding but at heat affected zone can lose the base material properties. Barlas & Ozsarac (2012) optimized the process parameters of FSW such as tool tilt angle, tool rotation speed and tool rotation direction for microstructure, mechanical properties and macrostructure of the joint. The material used for experimentation was AA 5754. Rai *et al*. (2011) used the varying tool speed, tool feed and maintaining a constant depth of penetration for determining the influence of these process parameters of FSW on the weldment properties. Qualitative tests are performed on welded AA 6351 aluminium alloy. The output factors are measured on UTM, Vickers hardness tester, and Radiography equipment. Results have shown a good relationship between process parameters and weld strength which will surely help in finding the optimal combination of process parameters for an efficient joint. Reddy *et al.* (2011) is measured the effect of tool tilt angle for FSW of aluminium alloy AA5052. In this study, two alloy plates of different thickness have been welded and the tilt angle has been calculated with the relative thickness of two welded plates. Mehta & Badheka (2016) discussed the effect of tool tilt angle on mechanical properties of FSWed joints. With tool tilt angle 1° defective welded joints have been obtained but 2°, 3°, and 4° are having excellent tensile strength. Ghosh et al. (2010) were got excellent welded joints at a parameter of tool tilt angle of 3°. Barlas & Ozsarac (2012) were evaluated the influence of tool tilt angle and direction of tool rotation for the joining of Al-Mg alloy. A tool tilt angle of 2° gives the best results of joint strength which was 86% of the base metal tensile strength (Kundu & Singh 2016)b.

4. Materials and Methodology

For the current research study and experimentation aluminium alloy 5083 has been used. AA5083 has wide applications in marine and aerospace industry due to its high strength to weight ratio and resistance to corrosion in moisture conditions which is due to magnesium as a major alloying element. The chemical composition of AA5083 is given in table 1. For the experimentation each plate of AA5083 with dimensions 140 mm×75 mm×6 mm is used.

Table 1: Chemical composition of AA 5083

Mg	Mn	Fe	Si	Cr	Zn	**Al**
4.3	0.63	0.13	0.076	0.06	0.03	**Reminder**

The higher tensile strength for the base material has been varied from 320-335 MPa. One factor at a time approach has been used for finding out the range and effects of parameters on tensile strength of FSWed joints. With OFAT approach one factor was varied and other factors were kept at average or mean value. Here tool rotational speed and tool tilt angle were varied from minimum to maximum according to facility available.

Traverse speed or feed rate is taken 28mm/min and square pin profile has been employed for all experiments. The diameter of tool shoulder is 18 mm with square pin of side 4.24 mm. The initial heating time or dwell time is taken 12 seconds. All the experiments have been conducted on vertical milling machine with a fabricated fixture mounted on working table. The range and variations of parameters tool rotational speed and tool tilt angle has been given in table 2.

Table 2: Range/ Levels of parameters used

Level No.	Tool Rotational Speed	Tool Tilt Angle
1	355	0
2	710	2
3	1000	4
4	1400	6
5	2000	8

All the ranges have been decided through literature study and experimental facility available. The experiments have been conducted and the testing sample or coupon has been cut out from the welded joints as per ASTM standard for tensile testing.

The figure 3 displays the important arrangement of plates as well as welding conditions.

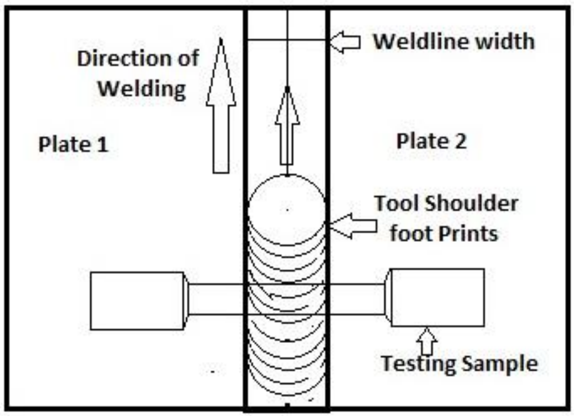

Figure 3: Arrangement of FSW Process

Some of the welded joints have been shown in figure 4. Out of ten friction stir welded joints 2 joints are very poor in strength and visualization.

Figure 4: Best FSW welded joints

Six welded joints are shown in below figure which is best in quality and the tensile strength. The joining of aluminium alloy plates has significant strength as compared with the base material.

4. Result and Discussion

The approach one factor at a time has been employed for experiments. All the joints produced by FSW are almost good albeit three joints having tunnel defects due to poor heat generation. The experimental data has been given in table 3. Universal testing machine at National Institute of Technology Kurukshetra has been used for tensile test testing of all the welded joints. Some of the welded joints are satisfactorily having high strength.

Table 3: Experimental data for FSW Joints

Sr. no.	Tool Rotational speed (rpm)	Tool tilt angle (degree)	Tool pin profile	Tensile strength (MPa)
1	355	3	Square	195.5
2	710	3	Square	213.3
3	1000	3	Square	274.4
4	1400	3	Square	155.5
5	2000	3	Square	205.5
6	1000	0	Square	210.2
7	1000	2	Square	203.3
8	1000	4	Square	207.8
9	1000	6	Square	176.7
10	1000	8	Square	140

The variation of tensile strength with other parameters has been shown in figure 5 and figure 6.

The parameter tool rotational speed has been varied from 355 rpm to 2000 rpm. At a low tool rotational speed the tensile strength value is 195.5 MPa which is quite low. Some defects like tunnel defect, short weld and kiss bond have been found on first experiment.

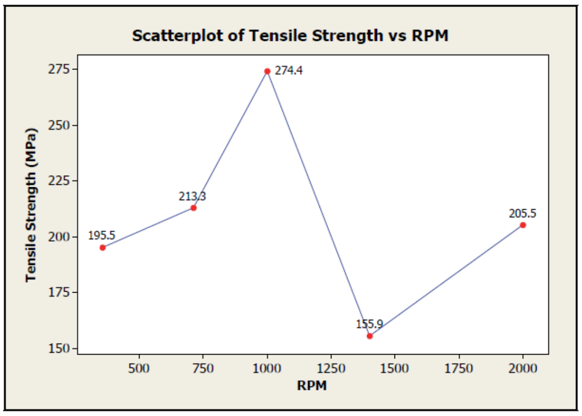

Figure 5: Scatter plot of Tensile Strength vs Tool Rotational Speed (RPM)

As the tool rotational speed increased to 1000 rpm, the tensile strength increased to maximum. High heat generation is the reason for the increase in tensile strength. But further increase in tool rotational speed also has adverse effect on joint strength. A proper combination of parameters is necessary for the best FSWed joint.

Tool tilt angle is also an important parameter in FSW process. In the present article it has been varied from 0° to 8°. A scatter plot between tensile strength and tool tilt angle has been given which convey the effect of TTA on FSW joint strength. From the figure 5, it has been estimated that at zero degree of tool tilt angle tensile strength is highest. But the finishing of the welded joint is poor an extra material has been erode from the weld line. As the TTA increased from 4° angle, the tensile strength is sharply decrease and poor weld bead occurred at the finish line of the welded joint.

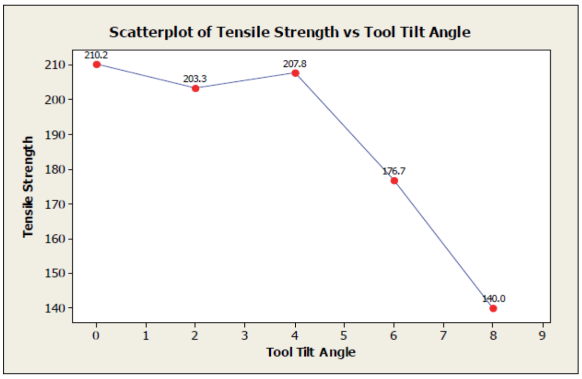

Figure 6: Scatter plot of Tensile Strength vs Tool Tilt Angle

As the tool shoulder is provided angle its forward part moves the material to be transformed in plastic like semi solid material. The trailing or backward part of tool shoulder works as a impact loading press which make plastic deformed material to settle down in the weld line properly without any vacant space or non-mixing of material. This purpose of the tool shoulder has not been employed as the TTA increase beyond the four degree. Surface finish is also not good in higher setting of tool tilt angle of FSW process.

Conclusions

Through the literature study following conclusions have been estimated:

1) Tool rotational speed has large influence on FSW joint. High tool rotational speed produce smooth welding as compared to low tool rotational speed.
2) Though the maximum rpm also responsible for higher frictional heat which also affect the heat affected area and weaken the base material aluminium alloy 5083.
3) Tool tilt angle of 1°- 4° produce good friction stir welded joint. At higher tool tilt angle welded joint is not good it shows poor tensile strength as compared to base material.
4) A proper combination of input process parameters is necessary as an adequate amount of frictional heat produces higher strength welded joint. A low as well as high frictional heat has adverse effects on welding joints.

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