Experimental Investigations of Friction Stir Welding (FSW) on Al 6061 : A Case study

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Abstract - *Friction Stir Welding (FSW) is a state-of-the art welding technique in which a specially designed rotating tool consists of a shoulder and a pin that applies the frictional force. Friction causes to produce heat on the work piece to weld two work pieces clamped together on fixture. Studies have shown that FSW has been successfully applied on many smart materials like AA2219Al-T6, AA6061-T6, 7075Al-T6, 7010Al-T7651 etc. that are being used in high end applications like aerospace, biomedical, marine, defense etc. This article provides an overview of experimental studies on FSW. Some potential research areas in this regard are explored.*

INTRODUCTION

Welding is one of the most commonly used processes in the industry for joining of different materials. High quality joining of materials is need of time for industries and it is goal of many researchers to achieve it through different techniques. Welding of common materials used by small to large industries like aluminium, copper, nickel, titanium and its alloys still seem to be less efficient due to its high thermal conductivity and relatively low melting temperature. Friction stir welding (FSW) was invented by The Welding Institute (TWI) in 1991 [1]. FSW is a state-of-the art-technique in which a specially designed rotating tool consists of a shoulder and a pin which applies the downward force and friction produced causes to produce heat on the work piece to weld two work pieces clamped together on fixture and as illustrated in Figure 1. The friction causes the temperature of the work piece to increase to an extent where the material goes into plastic deformation phase but still not molten. After that, the rotation of the tool stirs the material and causes it to flow plastically; this is considered a deformation at a temperature under the melting temperature of the material causing various improvements in its properties and microstructure [3, 4].

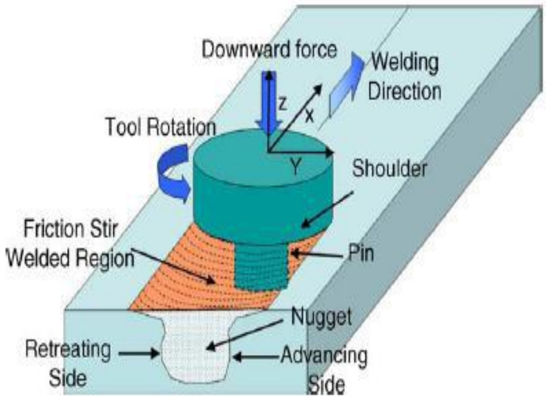


Fig. 1 FSW Process [15]

Studies have shown that FSW have been successfully applied on many smart materials like AA2219Al-T6, AA6061-T6, 7075Al-T6, 7010Al-T7651 etc. and being used in high end applications like aerospace, biomedical, marine, defence etc. So far limited focus has been observed on common materials like aluminium-copper alloys being used with FSW technology. Thus studies on common applications of FSW with common materials are very limited and are being applied to small scale and rural industries. Use of FSW on composite materials such as MMCs is also very limited. In present research work, an attempt is made to investigate the effect of various welding conditions on the quality of the FSW joint of similar and dissimilar aluminium, copper alloys and low carbon steels that are used for common applications like Automotive, Home appliances, Roofing for Buildings, Heat Exchangers, Tubing and Piping, Packaging etc.

LITERATURE REVIEW

Elangovan et al [1] studied effect of axial force and tool pin profile on friction stir processing zone formation in AA6061 aluminium alloy. Five different tool pin profiles straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square have been used at three different axial force levels. Joints fabricated with square and triangular pin profile tool showed superior tensile properties irrespective of axial load whereas joints fabricated with straight cylindrical pin profile tool showed inferior tensile properties. Biswas et al. [2] studied effect of geometry of tool

pin and effect of tool rotation and welding speed on the mechanical properties of friction stir welding of commercial grade aluminium alloy. Tool geometries viz trapezoidal, hexagonal and threaded tool pins with tapered cylindrical and simple cylindrical were used for the study. It was observed that strain rate of the plasticized material was increased with increase in tool rotation at given weld speed thus affecting the resulting microstructure of stirred zone. Koilraj et al. [3] carried out joining of dissimilar Al-cu alloy AA2219-T87 and Al-Mg alloy AA5083-H321 with taguchi L16 orthogonal design of experiments. He found that fusion welding of dissimilar aluminium alloys was very challenging due to formation of low melting eutectic by constituent element resulting in cracking. Four parameters rotational speed, traverse speed, tool geometry and shoulder diameter to pin diameter were taken into consideration. Significant drop in hardness from AA2219 unaffected base material to weld nugget on advancing side have been observed. Rambabu et al. [4] conducted study on aluminium alloy AA2219 (Al-Cu-Mg alloy) which has high strength to weight ratio and good corrosion resistance properties. Mathematical model was presented to predict corrosion resistance of friction stir welded AA2219 al alloy. Kadaganchi et al.[5] formulated a mathematical model with spindle speed, welding speed, and tilt angle and tool geometry to predict the yield strength, tensile strength, % elongation of friction stir welds of AA2014-T6 aluminium alloy. Hexagonal tool profile produces higher pulsating effect and smooth material flow which resulted in improved mechanical properties, whereas conical tool profile produced the lowest mechanical properties. Lokesh et al. [6] carried out friction stir welding of AA 6063 alloy under the submerged condition to obtain the optimum welding condition for maximum hardness. Rotational speed, welding speed and tool pin profiles (cylindrical, threaded and tapered) were taken as process parameters. Fuji et al.[7] Performed butt welding of 1050-H24, 5083-O and 6061-T6 aluminium alloys. Tools with columnar probe with threads and without threads, triangular prism were used during the experiment. Wei et al.[8] conducted experiments on 2mm thick 01420 Al-Li alloy plates with different welding parameters pin rotation, welding speed, welding pressure. It was found that hardness value was high in stir zone than base metal. Hardness tended to decrease with an increase in heat input due to different thermal effects with welding conditions. Very fine equaxed recrystalised grain structure was obtained in stir zone after dynamic recryastalization. Heat input had little influence on joint strength.Zhang et al. [9] carried experiments in underwater conditions of AA2219 alloy. Tensile strength of the joint was found to be improved from axial load of 324 MPa by external water cooling action in normal to 341 MPa with deterioration of plasticity of weld nugget. Underwater joint was found to be fractured at the interface between NZ and TMAZ on advancing side during tensile test. Underwater FSW joint exhibits lower hardness in NZ and Higher Hardness in TMAZ and HAZ when compared with normal FSW. Zhang et al. [10] has studied effect of water cooling on the performance weld quality in heat affected zone. Heat affected zone is generally intrinsic weakest location of normal friction stir welded precipitate hardened aluminum alloy. Patil et al. [11] investigated effects of different welding speed and tool pin profiles on the weld quality of AA6082-O aluminum where tool rotation was kept constant. Elatharasan et al. [12] investigated effect of rpm, weld speed and axial force on tensile strength, yield strength and displacement during welding of AA6061 -T6 and AA7075-T6.It was observed that ultimate tensile strength is less than base metal. Increase in rpm and weld speed showed increase in ultimate tensile strength upto a point which thereafter decreased. Tutar et al. [13]conducted study on non heat treatable AA3003-H12 aluminum alloy sheets to find optimum welding conditions using taguchi orthogonal array with due consideration of tensile shear load. Three different parameters rotational speed, plunge depth and dwell time were considered during the study. Kumar et al. [14] investigated effect of rotational speed, weld speed, axial load, on tensile strength and % elongation during welding of dissimilar aluminum AA5083-O and 6061-T6.Cylindrical profile tool with shoulder diameter 18 mm with probe length 4.7 mm was used for the welding. It was observed that increase in tool rotation and axial force resulted in increase in percentage elongation whereas increase in welding speed resulted in decrease of percentage elongation.
All the above literature review has revealed many potential thrust listed below.
Literature review reveals that many studies reported on FSW Technology are being applied to high-tech machines such as CNC Machines. No studies have been reported till date regarding application of FSW to common machine tools. Hence, this technology needs to focus upon; so that it can be also applied on general machine tools such as drilling, milling in future, so that this technology could be transferred and transformed to small scale and rural industries in particular i.e. Transferring technology from Lab to Land.

Experimental Setup:

The experimental set up is designed and developed for Friction Stir Welding (FSW) of common materials such as aluminium. Special arrangement will be done to hold the FSW tool and workpiece holding fixture is designed and developed suitably for this purpose. The vertical tool head can be moved along the vertical guide way (Z axis), the horizontal bed can be moved along X and Y axis. The weld specimens are properly aligned with the centre line of the FSW tool with the help of mechanical clamps on back plate and a special designed fixture. The main components of FSW tool are pin and shoulder. Non-consumable tool made of hardened steel (D2- tool steel) is used to form the joints.

Fig.3. Friction Stir Welding Experimental Set up

Materials and Welding Conditions:

In present project work, an attempt is made to investigate the effect of welding parameters on the quality of the FSW joint on aluminium alloy that are used for common applications like Automotive, Home appliances, Roofing for Buildings, Heat Exchangers, Tubing and Piping, Packaging etc. Experiments are carried out with various combinations of process parameters i.e. rotational speed, travel speed and axial force with tool with different pin profile.

Table 1: Alluminium alloy 6061

	Si	Iron	Copper	Mg	Cr	Zinc
AA6061	0.4	0.7	0.15	0.15	0.04	0.025

Workpiece dimension: 200x75x12mm Aluminium alloy plate

Machine selection:

Fig.4 Milling machine

From literature review it is found that, many researchers have used VMC for FSW testing. This research is aim to conduct FSW on conventional machine tool. Hence small scale industries can adopt this process on their machines.fig 4 . shows the milling machine used for trials.

FSW tool

Hardened steel material is taken as tool material and three pin profiles are selected. Cylindrical, conical and diamond shaped pin profiles are selected, shown in figure 5.

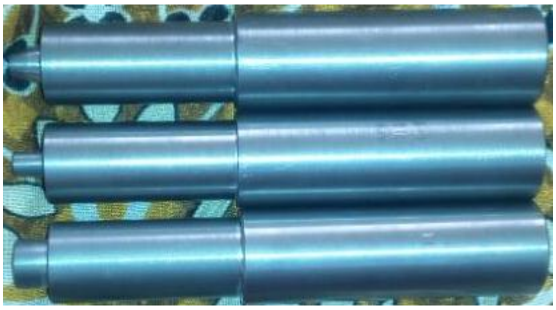


Fig. 5 FSW tools with tapered, cylindrical & diamond shaped pins

RESULT AND DISCUSSION

Failure Mode Analysis

After trials, it is found that welding process is not done upto mark. In zone 1 & 2, cylindrical and diamond pin profile tool get broken. And zone 3 very poor quality of weld is observed, shown in figure 6.

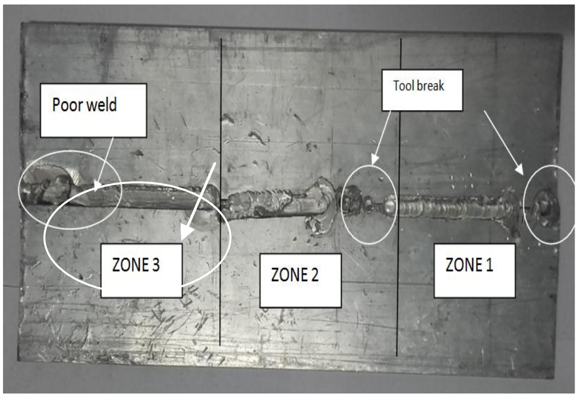
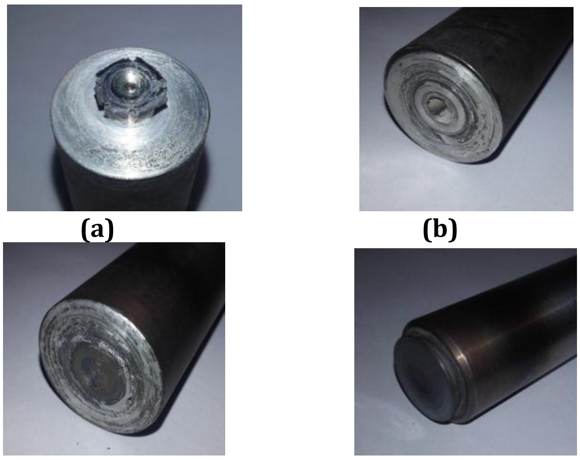


Fig. 6 FSW failure locations in workpiece

Tool Pin damages:



(a) (b) (c) (d)

Fig. 7 (a) Cylindrical tool break (b) diamond tool wear (C) Taper tool failure (d) cylindrical tools shoulder without pin.

Tool profiles gets fail during experimentation as shown in figure 7. The parameters affecting the failure of the process are

- Tool material
- Tool rpm
- Tool profile
- Tool vibrations due to length.

Cause& Effect Diagram:

Hence to optimize FSW conditions, Quality control technique is used to reach the root cause for tool failure. Fishbone diagram is drawn to analyze the root cause of tool failure.

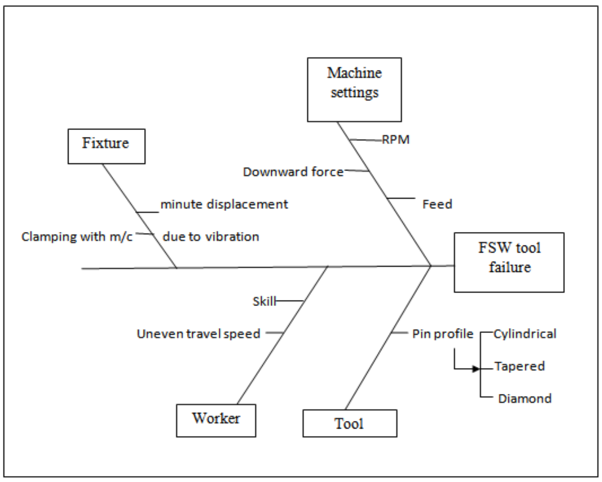


Fig. 8. Fish bone diagram to understand failure analysis

From the fishbone diagram analysis, it is understood that there is need to change the tool pin profile and rpm has to keep at high level. So, tapered with threaded pin is given to tool. The height of tool is also reduced to avoid vibration shown in following figure 9.

Fig. 9 Tapered and threaded pin tool

Fig.10 Improved weld after modification

After modification of tool geometry, FSW trial is conducted with tool rpm 1200rpm and tool travel speed 0.03mm/sec. Trial is successfully conducted, where tensile strength of the weld found is 66MPa.

CONCLUSION

- Friction stir welding can be possible on conventional milling machine.
- FSW tool which can produce optimum weld quality for aluminum AA6061 is observed. Tensile strength of weld joint is observed 66MPa.
- Optimum pin profile for FSW could be assessed. Conical with threaded pin gave good results.

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