

EFFECT OF VARIOUS PROCESS PARAMETERS ON FRICTION STIR WELDED JOINT: A REVIEW

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Abstract

This paper is a review of research work in the last decade on friction stir welding. Research is going on to investigate the effect of various process parameters on quality of the welded joint. In this study, the investigation is made on the effect of various process parameters, such as tool rotational speed, traverse speed, axial force and tool geometry on the quality of the welded joint are reviewed. Yield strength, ultimate strength, elongation, toughness, microstructure of the joint are evaluated and correlated with received base material. To compare and validate experimental results, FEA model is the best way to study the quality of welded joint.

Keywords- Friction stir welding, tool rotation and transverse speed, axial force, tool geometry

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1. INTRODUCTION

Friction stir welding (FSW) is a material joining process. It is a highly important and recently developed joining technology that produces a solid phase bond. It is particularly appropriate for the welding of high strength alloys. Its main characteristic is to join material without reaching the fusion temperature. It enables to weld almost all types of aluminium alloys, even the one classified as non-weldable by fusion welding due to hot cracking and poor solidification microstructure in the fusion zone. FSW is considered to be the most significant development in metal joining in a decade and is a “green” technology due to its energy efficiency, environment friendliness, and versatility. The key benefits of FSW are summarized in Table 1[1].

Table 1 Key benefits of FSW are summarized below

Metallurgical benefits	Environmental benefits
<ul style="list-style-type: none"> • Solid phase process. • Low distortion of work piece. • Good dimensional stability & repeatability. • No loss of alloying elements. • Fine microstructure • Absence of cracking 	<ul style="list-style-type: none"> • No shielding gas required. • No surface cleaning required. • Eliminate grinding wastes. • Consumable materials saving.

Friction stir welding process parameters and welded joint are analysed by testing welded joint or modeling welding process using FEA software’s and simulating it. The FEA software, such as WELDSOFT, ABACUS, Altair Hyperworks, DEFORM-3D etc. are more user friendly to the designer such that modifications of any data is easily done on seeing preview of the simulated weld conditions. The accuracy of the result depends upon the assumption made in constructing the model. The results obtained from FEA simulation are verified by running a confirmatory experiment [20].

2. FSW PROCESS

The working principle of Friction Stir Welding process is shown in Fig. 1 The FSW process utilizes a rotating tool to perform the welding process. The rotating tool consist of small pin (probe) underneath a larger shoulder. The tool serves three primary functions, that is, heating of the workpiece, movement of material to produce the joint, and containment the hot metal beneath the tool shoulder. In FSW, rotating shouldered tool plunges into the joining point of plates and the heat is originally developed from the friction between the welding tool (including the shoulder and the probe) and the welded material, which causes the welded material to soften at a temperature less than its melting point. The tool shoulder restricts softened material underneath the shoulder is further leads to movement of material from the front of the pin to the back of the pin by the rotational and transverse movements of tool. It is expected that this process will inherently produce a weld with less residual stress and distortion as compared to the fusion welding methods, since no melting of the material occurs during the welding [19].

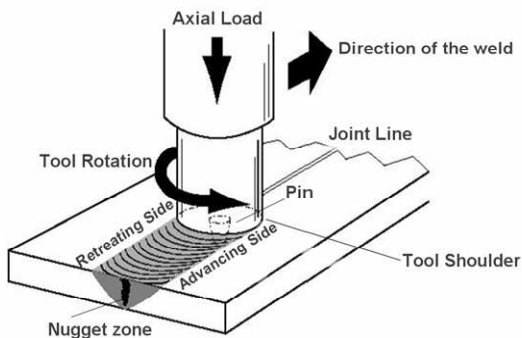


Fig. 1: Schematic of Friction Stir Welding.

3. WELDING PARAMETERS

FSW involves complex material movement and plastic deformation. Welding parameters, Tool geometry and joint design exert significant effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material [1]. Therefore, welding speed, the tool rotational speed, the tilt angle of the tool, tool material and the tool design are the main independent variables that are used to control the FSW process.

3.1 Tool Rotation

For FSW, two parameters are very important: tool rotation rate (v , rpm) in clockwise or counter clockwise direction. The motion of the tool generates frictional heat within the work pieces, extruding the softened plasticized material around it and forging the same in place so as to form a solid-state joint.

3.2 Transverse Speed

The welding speed depends on several factors, such as alloy type, rotational speed, penetration depth, and joint type. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. During traversing, softened material from the leading edge moves to the trailing edge due to the tool rotation and the traverse movement of the tool, and this transferred material, are solidify in the trailing edge of the tool by the application of an axial force [1].

3.3 Tool Tilt Angle

In addition to the tool rotation rate and traverse speed, another important process parameter is the angle of spindle or tool tilt with respect to the workpiece surface. A suitable tilt of the spindle towards trailing direction ensures that the shoulder of the tool holds the stirred material by threaded pin and move material efficiently from the front to the back of the pin. The tool is usually characterized by a small tilt angle (θ), and as it is inserted into the sheets, the blanks material undergoes to a local backward extrusion process up to the tool shoulder. Further, the plunge depth of pin into the work pieces (also

called target depth) is important for producing sound welds with smooth tool shoulders [1].

3.4 Tool Design

In order to determine the optimum tool geometry, the two components of the torque are used for various shoulder diameters. As the shoulder diameter increases, the sticking torque, MT , increases, reaches a maximum and then decreases. This behavior can be examined, which shows that two main factors affect the value of the sticking torque. First, the strength of the material is decreases with increasing temperature due to an increase in the shoulder diameter. Second, the area over which the torque is applied increases with shoulder diameter [2].

A three-dimensional heat transfer and visco-plastic model is used to compute the influence of pin length and diameter on traverse force during FSW. The total traverse force increases significantly with increase in pin length [3].

4. PARAMETRIC STUDY OF FSW

Many investigators have performed friction stir welding to study the effect of various parameters on quality of friction stir welded joint.

4.1 Aluminium

V. Balasubramanian, et al [4] investigates the effect of welding speed and tool pin profile on friction stir processing zone formation in AA2219 aluminium alloy. They found that the square pin profile tool at a welding speed 45.6mm/min, produced mechanically sound and metallurgically defect free welds with maximum tensile strength, higher hardness. Vivekanandan, P, et al [5] study microstructure and hardness of aluminium 6035 and 8011. At the rotating speed 550rpm and welding speed 60mm/min, the fine grain are formed at the center of the weld, due to dynamic recrystallization, which result in higher tensile strength of 50N/mm² with the maximum hardness of 91HV. M. Abbasi Gharacheh, et al [6]found that increase in the ratio of rotational speed / traverse speed results in formation of large weld nugget, because of increase in heat input easier material flow, therefore probability of formation of incomplete root penetration defect is reduced. A. C. S. Kumar, et al [7]focus on optimization of FSW parameters in different conditions of base material and the microstructures of the as-welded condition are compared with the post weld heat treated microstructures welded in annealed and T6 condition. The result show that in annealed condition tool rotation speed 800 rpm and welding speed 10 mm/min and 15 mm/min are the optimal parameters. The tool rotation speed 1000 rpm and welding speed 10 mm/min are the optimal parameters in 'T6' condition. P. Cavaliere, et al [8] study mechanical and microstructural properties of AA6082 joints. The material welded with the advancing speed of 115mm/min & fixed rotating speeds of 1600rpm exhibited

the best fatigue properties and the higher fatigue limit. A. Kumar, et al [9] find optimum mechanical properties of Al 6061-T6 alloy & Mg AZ31B alloy. The joint fabricated using rotational speed of 1120 rpm, a welding speed of 40 mm/min, taper thread pin profile, shoulder diameter of 18mm, (D/d)=3 shows higher tensile properties. S. Rajakumar, et al [10] study tensile strength properties of AA7075-T6 joints produced by friction stir welding. They found that the joint fabricated at a tool rotational speed of 1400 rpm, welding speed of 60 mm/min, axial force of 8 kN, using the tool with 15 mm shoulder diameter, 5 mm pin diameter, 45 HRC tool hardness yielded higher strength properties. Prashant Prakash, et al [11] found that at rotational speed 1400rpm, welding speed 25 mm/min & pin length 5.7mm maximum tensile strength obtained is 182MPa, gives 60% joint efficiency. Dr. Ayad M. Takhakh, et al [12] optimum result gained at 80 mm/min weld speed and 1500 rpm rotation speed, the efficiency reaches to 89% of the ultimate tensile strength of the alloy 3003 H13. P. Bahemmat, et al [13] found that the joint is fabricated by four-flute pin profile at rotational speed of 800rpm have demonstrated 90% ultimate and yield strength and the tapered screw thread joint fabricated at the rotational speed of 600rpm show 84% ultimate strength in AA2024 aluminium. Patil H S, et al [14] found that the joint fabricated using taper screw thread pin at welding speed of 70mm/min exhibits superior tensile strength of 92.30% of base metal ultimate strength and % elongation of 27.58% in AA6082-0 aluminium.

4.1 High Density Polyethylene

Mustafa Kemal Bilici, et al [15] study the effects of welding parameters on friction stir spot welding of HDPE sheets to analyse the strength of the welds of HDPE sheets by means of experimental techniques. Friction stir spot welding parameters such as the tool rotation speed, tool plunge depth, plunge rate, dwell time & tool geometry are found to affect significantly the weld strength & weld nugget formation. Fabrizio Quadrini et al [16] studied Friction stir welding of 3mm thick high density polyethylene (HDPE) sheet with single pass. At high rotational speeds, a higher amount of heat. Finally they concluded that welding strength is depends on the optimized temperature value in the range of 132-140°C. M. K. Bilici investigate the effect of tool geometry on friction stir spot welding of polyethylene sheets. They were obtained biggest tensile strength with threaded tool for 4mm thick sheets with 7.5mm pin diameter, 15° pin angle, 5.5mm pin length, 30mm shoulder diameter and 6° shoulder angle, pitch length 0.8mm [17]. Amir Mostafapour et al They conclude that by utilizing heat assisted friction stir welding, polyethylene sheets could be joined with ultimate tensile strength of higher than 95% of base material strength at welding speed of 25 mm/min [18].

5. THERMAL EFFECTS ON FSW

Many researchers have developed friction stir welding model in various analysis software for analyzing the thermal effect produced in the FSW. C.M. Chen, et al [19] study the thermal

history & thermomechanical process using 3D FEA model. Prediction & measurement shows that maximum temperature in longitudinal & lateral direction are beyond shoulder edge. Longitudinal residual stress is greater than lateral residual stress. Binnur Gören Kırıl et al [20] found that maximum temperature increases as tool holding time & rotational speed increases. Temperature decreases as welding speed increases in aluminum alloys Al6061. Muhsin J. J, et al [21] found that the maximum temperature measured during FSW at mid position 629K & numerically value from the simulation is 642K, which is significantly less than the melting temperature of 7020-T53 aluminum alloy at 916K. Numerical results ($T_{max} = 642K$) agreement with measured data ($T_{max} = 629K$) in 5mm workpiece (AA 7020-T53) thickness. Abdul Arif, et al [22] with dissimilar alloys (AA5086 & AA6061) they found that longitudinal residual stresses are about 30-45% transverse of the residual stresses. Values of temperature & residual stresses by FEM are close to real temperature distribution & residual stress in weld construction. N. Rajamanickam, et al [23] study the numerical simulation of thermal history & residual stresses in friction stir welding of Al 2014-T6. Difference of maximum temperature at same location is less than 120K (2% error). Selvamani S.T, et al [24] model is developed to study the temperature analysis of tool geometry & material properties. Rotational speed & axial force is constant & 0.75mm/sec welding speed yield strength, ultimate strength, elongation & hardness test of Al6061 alloy is more reliable on retreating side.

CONCLUSIONS

From the above review it is observed that –

- Tool rotation speed, traverse speed, axial force and tool design are the most significant process parameters in friction stir welding.
- Modeling of friction stir welded joint can be done with various FEA software's such as WELDSOFT, ABACUS, Altair Hyperworks, DEFORM-3D etc.
- Values of temperature and residual stresses by finite element modeling are close to real temperature distribution and residual stresses in experimental construction of friction stir welding.
- Yield strength, ultimate strength, elongation and hardness test are more reliable in both experimental and proposed model.

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