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Optimization of Process Parameters of Friction Stir Welding– Critical Review

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Abstract: Friction stir welding (FSW) is a recent and effective solid state joining technique for joining similar and dissimilar metals. It is being used mostly in aerospace, rail, automotive and marine industries applications. Many researchers are currently working with different perspectives of this friction stir welding process for different combinations of materials. The general input process parameters are tool design, tool rotational speed, traverse speed, tilt angle, flow of material and axial force. And the output parameters are joint hardness, tensile strength, and yield strength. This paper compiles the optimization of input parameters tried by different researchers with different perspective. And suggest the best use and practice to be followed in this welding process.

Key word: Friction stir welding, process parameters, tool rotational speed, traverse speed, tilt angle, flow of material optimization.

I. INTRODUCTION

Few of the metals such as aluminum and some alloy materials are known as non weldable material materials because traditional methods of welding are unable to provide required strength due to problems like porosity in fusion zone. But recent advancement in welding process and efforts of researchers leads to development of new welding technique known as Friction stir welding (FSW). It was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys.[1, 4-9] The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and moved along the line of joint. Friction stir welding is the solid state metal joining process in this process two metals are joined together using a third body which is also in a solid state. The FSW tool is the solid state heat treated hard metal, having special shape or geometry, which is passed through the two edge of the base metal to be joined together at a specific rotational speed, traverse speed, axial force and tilt angle. This process of welding is able to join variety of dissimilar metals with good quality of welding.[12] As the rotating tool is in contact with joining materials, it heat up the joint which further leads to plastic deformation of the joint. Also, rotary motion of the tool transfers the material to produce joint. This process comes under solid state welding category as there is no weld pool formation at the joint. The different tool geometries lead to the formation of different crystallization structure of grains which finally results into different strength of weld joint according to the type of geometry.[8,11]

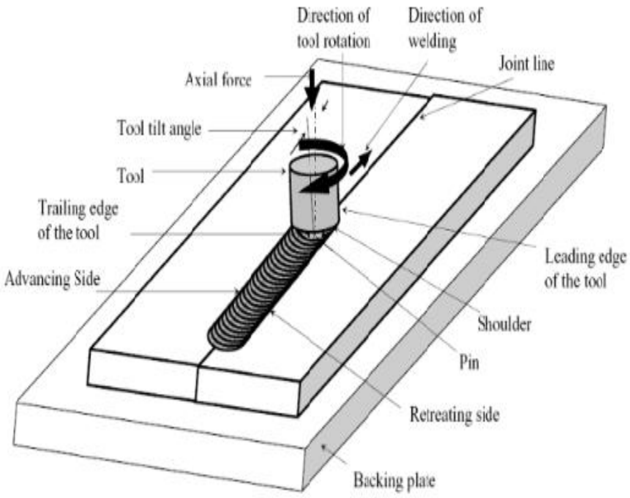

Fig.1 Basic Working Diagram of Friction Stir Welding[17]

Like this, change in different welding parameters lead to different advantages or disadvantages in the welding process as well as at the joint.

II. MAJOR ADVANTAGES OF FRICTION STIR WELDING

Friction Stir Welding has various advantageous corners viz.

a. **Mechanical Advantages:** Friction stir welding gives various mechanical advantages over the traditional welding technique. As it is a solid state welding, there is no metallurgical change in the material which avoids the distortion and weaknesses caused by metallurgical reaction during traditional welding method. Also, as there is no fusion, it gives better dimensional stability and repeatability. Further, no loss of material and no need to use filler material. It gives fine microstructure without cracking. These mechanical advantages yield a better mechanical bonding between joining materials.

b. **Environmental Advantages:** This process is a solid state welding process, which does not require melting of the base material. As no melting of material, no need of shielding gases, no problem of surface oxidation is there. Also, no need of surface cleaning, no need of consumable or filler material like wires, rugs or any other gases hence there is material saving and indirectly cost the saving. This process is environmental friendly as there is no escape of fumes, noise, ultraviolet light etc.

c. **Energy Advantages:** As with this method one can join different thickness plates, there is material saving which allows reduction in weight. To reduce weight by keeping adequate strength in aerospace applications is a vital issue which gets solved with this welding method. As no melting of material required, leads decrease energy consumptions.

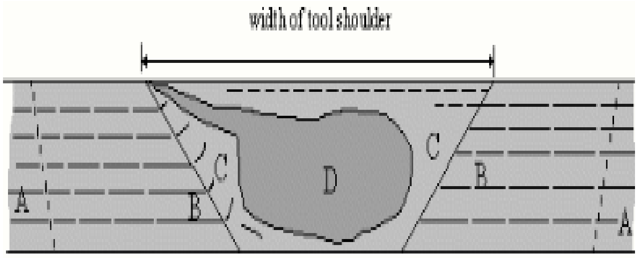

Fig.2 Friction stir welding microstructure[9]

a. Unaffected material,
b. Heat-affected zone(HAZ),
c. Thermo-mechanically affected zone (TMAZ),
d. Weld nugget (Part of TMAZ)

The microstructure of the weld nugget is characterized by a dynamically recrystallized region of the base material due to the conjoint influence of heavy plastic deformation and locally high temperature. The phenomenon of recrystallization in FSW weld nuggets is reported to be a continuous-dynamic- recrystallization. TMAZ is a region that undergoes plastic deformation at the “local” level coupled with a temperature rise that is lower than that of the weld nugget. HAZ is the region in which the material is affected by the heat generated during the process.[9]

III. PROCESS PARAMETERS OF FRICTION STIR WELDING:

The various welding process parameters which are generally considered in friction Stir Welding are as follows:

1. **Tool tilt and plunge depth :** It is defined as depth of the lowest point of the shoulder below the surface of the welding plate and plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2 to 4 degrees, such that the rear face of the tool is lower than the front face, will assist this forging process. It will gives the necessary downward force hence tool fully penetrates the weld addressing defects such as pin rubbing on the backing plate surface or a significant under-match of the weld thickness.[9]

2. **Tool rotation and traverse speeds :** These two parameters have more importance and must be chosen with care to ensure a successful and efficient welding cycle. Increasing the rotation speed or decreasing the traverse speed will result in a hotter weld also for good weld quality, and material surrounding the tool should be hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool leading to tool breakage. On the other hand excessively high heat input may be harm the final properties of the weld joint.[7,9]

3. **Welding forces :** To prevent tool fracture and to minimize excessive wear and tear on the tool and associated machinery, the welding cycle is to be modified by finding the best combination of welding parameters. The different forces will act on the tool during welding, a downward force to maintain the position of the tool, the traverse force acts parallel to the tool motion, and torque is required to rotate the tool.

4. Tool Design : Best tool design can improve both quality of the weld and possible welding speed. So the tool material must be sufficiently strong, tough, and hard wearing at the welding temperature along with good oxidation resistance and low thermal conductivity.

5. Flow of material: Mode of material flow through extrusion chamber and frozen pin technique will lead to better forging of material.[7,9]. The above discussed process parameters plays a vital role in friction stir welding process and we can found the importance of it with help of literature review.

IV. REVIEW OF LITERATURE

Chauhan, shaikh(2015)has described the joining of a heat treating aluminium with a non heat treating aluminium alloys. The input parameters considered for this work are Tool Rotational speed, traverse speed and tilt angle. The output parameters are hardness, tensile strength, and yield strength,they suggested that the dissimilar metal joining process using friction stir welding is very difficult to achieve because of different co-efficient of heat and the base metal chemical composition and their property make it difficult to choose a proper welding parameters. Srinivasulu et al. (2015) they haveoptimized the effect of the welding parameters on 5 mm thick AA 6082 aluminum plates. The process parameters are optimized by using ANOVA technique based as L8 orthogonal Array. The results indicate that the tool rotational speed, welding speed and plunge speed are the significant parameters in deciding the strengths and percentage elongation.

Ramanjaneyulu et al. (2015) In their literature theysuggested that FSW is an emerging solid state joining process, which is suitable for joining aluminum copper alloy AA2014 compared to fusion welding processes. This work presents the formulation of a mathematical model with process parameters and tool geometry to predict the responses of friction stir welds of AA 2014-T6 aluminum alloy, viz yield strength, tensile strength and ductility. Thete et al. (2015)In their research study they try to optimizethe process parameters to achieve high tensile strength. The study is related to effect of process parameters of friction stir welded joint for similar aluminium alloys H30. In their investigation, an effective approach has been developed to determine the optimum conditions leading to higher tensile strength. Experiments were conducted on varying rotational speed, transverse speed, and axial force using L9 orthogonal array of Taguchi method.

Manikkavasaganet al. (2015) has done work on effect of welding parameter evaluated in different mechanical properties of hardness distribution and tensile properties for axial weld zone. The significant optimal transverse feed is achieved with high weld quality and excellent joint properties with help of square tool. In this transverse feed the excellent result was obtained both tensile strength as well as hardness in order to improve productivity. Lokeshet al. (2015)they have used aAA 6063 alloy for friction stir welding 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. Theyemployed (ANOVA) and signal to noise ratio analyses to investigate the influence of different welding parameters on the hardness and to obtain the optimum parameters. According to his investigation, AA6063 alloy was successfully welded under submerged FSW.

Jambhale et al. (2015)has done work on finding the effect of various welding variables like tool rotation, transverse speed, dwell time, tool tilt, plunge depth and tool design on mechanical properties in the welding of aluminium alloys or various dissimilar alloys. Tool geometry, such as shoulder diameter and shape, pin shape, length, diameter and feature is a key parameter to affect heat generation and material flow. However theyindicates that there is need to identify the effect of different process parameters on Mechanical properties in FSSW. Madhusudhan et al. (2014)has work about the optimal process parameters like Tool rotational speed, Traverse feed and axial force of Friction Stir Welding (FSW) of dissimilar aluminum alloys AA 6262 and AA7075 using gray relational analysis by simultaneously considering multiple output parameters tensile strength (UTS) and hardness (VHN). They obtained the optimum process parameter combination of the FSW of dissimilar aluminum alloys via gray relational analysis. The optimal process parameters were identified in order to find the quality of the welded specimens. Theye suggested that tool rotational speed was the strongest factor among the other FSW process parameters.

Jadhavet al. (2014)has done work on Friction Stir Welding area but most of the initial work has been done on low temperature softening materials like aluminium alloys. The process uses a spinning non-consumable tool to generate frictional heat in the work piece. They have focus on friction stir welding process, various welding variables like tool rotation, transverse speed, tool tilt, plunge depth and tool design, for the welding of aluminium alloys or various dissimilar alloys.

Ramana et al. (2014)they suggested that this is an attractive technology for solid state material joining, contrary to conventional welding methods, having ability to produce welds with higher integrity and minimum induced distortion

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and residual stresses,their paper highlights the principle of FSW and vital factors that influence the quality of weld and the critical analysis realize the possible research works on other than aluminum alloys such as mild steel (work piece) and cubic boron nitride (tool), with same process parameters. Prashantet al. (2013) their research shows that, in Friction Stir Welding no cover gas or flux is used, thereby making the process environmentally friendly, energy efficiency and versatility or it is a "green technology." The joining does not involve any use of filler metal and therefore any aluminum alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding. They suggested Friction stir welding (FSW) as energy efficient, environment friendly, and versatile. The paper focuses on process parameters that in required for producing effective friction stir welding joint.

Jawdatet al. (2013) In their work they shows that in FSW process heat generated by friction between the surface of the plates and the contact surface of a special tool, composed of two main parts: shoulder and pin. Shoulder is responsible for the generation of heat and for containing the plasticized material in the weld zone, while pin mixes the material of the components to be welded, thus creating a joint. This allows for producing defect-free welds characterized by good mechanical and corrosion properties. The friction stir welding process (FSW) is a variant of the linear friction stir welding process in which the material is being welded without bulk melting. Rohilla et al. (2013)Intheir research study AA 6061 has gathered wide acceptance in the fabrication of the light structures required to high strength. In their experimental work, an extensive investigation has been carried out on FSW butt joint. Welded joints were made with the help of tool made of high speed steel (HSS) alloy steel. Cylindrical tool pin profile exhibited superior tensile properties compared to other joints, irrespective of tool rotational speed in double pass. The single pass joints have shown lower tensile strength and percentage of elongation compared to the joints double pass joints. AkosMeilinger et al. (2013)has done work on friction stir welding which is a dynamically developing version of pressure welding processes. High-quality weld can be created by this process with help of a milling machine by using special tools. Basically other tool design is needed because the goal isn't the material removing but the material mixing and heating by frictional heat. The significant dynamic stress occurs with high heat load and abrasive wear depending on the material. The tool has evolved reasonably in point of geometry, material and coating in the past two decades. I would like to show the importance of tools of friction stir welding in this article.

Mohanty et al. (2012)Intheir paper they discusses the modeling of tool geometry effects on the friction stir aluminiumwelds using response surface methodology. The effects of tool shoulder and probe geometries on friction stirred aluminum welds were experimentally investigated with respect to weld strength, weld cross section area, grain size of weld and grain size of thermo-mechanically affected zone. These effects were modeled using multiple and response surface regression analysis. The response surface regression modeling were found to be appropriate for defining the friction stir weldment characteristics. Ghaffarpour et al. (2012)studied that the most efficient methods for production of tailored welded blank sheets with the friction stir welding process. In their present article, they studied the effect of friction stir welding parameters on the microstructure and mechanical properties of heterogeneous tailored welded blank sheets made from aluminium alloys of types 5083-H12 and 6061- T6 with the similar thickness of 1.5mm is studied. Data variance analysis showed that rotational speed and diameter tool have the most and the least effect on tensile strength, respectively. Also they have suggested that rotational and linear speed are more effective than pin and shoulder diameter. Kumar et al. (2008)were worked on the influence of tool geometry on friction stir welding (FSW) of an aluminum alloy with specific reference to microstructural development, defect formation, and mechanical response. For a shoulder diameter of 20mm and a pin diameter of 6mm, the severity of defects in the weld was found to be the least and the resultant tensile strength of the weld was high. For the welds that were made using a tool having a shoulder diameter of 10mm and a pin diameter of 3mm the tensile strength of the weld was the least since the degree of defects observed were higher. Indira Rani et al. (2011) The paper focuses on optimization of FSW parameters in different conditions of base material and the microstructures of the welded condition are compared with the post weld heat treated microstructures welded in annealed and T6 condition.Author concluded 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. Hussain et al. (2010) Friction Stir welding method depends on the direct conversion of mechanical energy to thermal energy to form the weld without the application of heat from conventional source. The welding parameters are adjusted so that the interface is heated into the plastic temperature range (plastic state) where welding can take place. The functional behaviour of the weldments is substantially determined by the nature of the weld strength characterized by the tensile strength, metallurgical behavior, surface roughness, weld hardness and micro hardness. In this project results show strong relation and robust comparison between the weldment strength and process parameters. Chionopoulos et al. (2008)has workedon the welding parameters and tool pin profile play a major role in defining weld quality. In their investigation an attempt has been made to understand the influence of rotational and travel speed on friction stir processed (FSP) zone formation in AA5083 aluminum alloy plates. Theyexamined welded samples by using optical microscopy in order to define the different joined zones and to identify possible defects.

V. CONCLUSION

Significant research and developments in the field of FSW process has occurred around the world. With its ability to join lightweight, high strength aluminum alloys, this process has established itself as a viable joining option for the automotive and aerospace and all over in the industrial field. FSW process can provide a technical and economical edge over traditional welding processes.

1. FSW is a robust process, with capability to generate welds of good strength over a wide range of welding parameters.
2. In most of the research papers, three levels of welding parameters were selected
3. Tool rotational speed, Tool traverse speed and Tool plunge depth were effective on joint strength.

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