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Friction Stir Welding Process & Parameters: A Review

Prashant Pratap Mall[1],
[1]Research Scholar,
Modern Institute of Engineering & Technology,
Kurukshetra, Haryana (India)

Jitender Panchal[2]
[2]Assistant Professor,
Mechanical Engineering Department,
Modern Institute of Engineering & Technology,
Kurukshetra, Haryana (India)

***Abstract*-In Friction Stir Welding (FSW) Tensile strength of welds was significantly affected by welding speed and shoulder diameter whereas welding speed strongly affected percentage elongation. Friction stir welding (FSW) modeling with a special focus on the heat generation due to the contact conditions between the FSW tool and the work piece. The thermo-mechanical conditions during FSW are very different from that registered during welding of metals, leading to completely different material flow mechanisms and weld defect morphologies**.

I. INTRODUCTION

A new welding process named "Friction Stir Welding **(**FSW)"was invented by Wayne Thomas in 1991 at The Welding Institute. It overtakes many of the problems accompanied with conventional joining processes.FSW input 'slow energy is also capable of producing very high strength welds in wide range of materials at quite low cost. Friction Stir Welding process occurs in the solid phase below the melting point of the joining material.

WORKING PRINCIPLE OF FSW

Friction stir welding process uses a cylindrical tool which is shouldered with a profile & is rotated and slowly moves into the joint between two pieces joined together with the help of butt joint which results in the generation of frictional heat between the work piece material and the welding tool which is wear resistant. This heat allows traversing of the tool along the weld line without reaching the melting point. The plasticized material is shifted from the front edge of the tool to back edge of the tool probe and it's forged by the contact of the shouldered tool and pin profile. Friction Stir Welding is used to join following materials

- Lead
- Copper and its alloys
- Titanium and its alloys
- Magnesium alloys
- Zinc
- Plastics
- Mild steel
- Stainless steel
- Nickel alloys

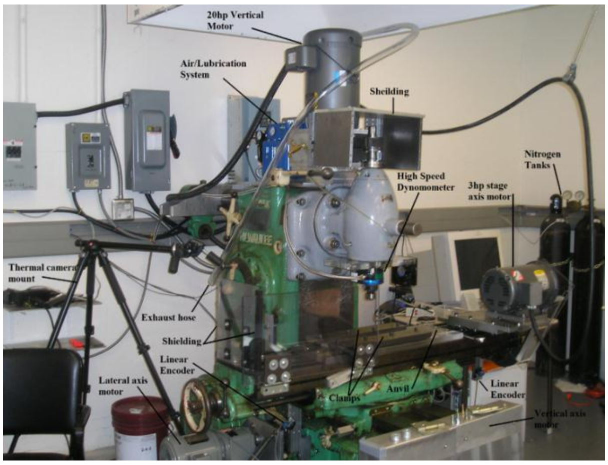

Fig 1 Schematic diagram of friction stir welding.

PROCESS PARAMETERS

TOOL DESIGN-This is an important factor as this can improve the quality of the weld as well as the maximum attainable welding speed. It is pre-requisite to have a tool material having sufficiently strong, tough and hard wearing, at the welding temperature.

TOOL ROTATIONAL SPEED-Friction stir welding is a solid state joining process, in this process welding is done by producing friction between tool pin profile and plate. Friction generation depends on Rotational speed. When rotational speed of the tool is increased or decrease dweld quality will likely to increase or decrease accordingly.

WELDING FEED SPEED- Temperature decreases when there is an increase in welding speed the temperature at local position. Whereas, when there is slow feed speed the temperature will increase.

AXIAL FORCE- There is an increase in axial force if the thickness of the material is increased.

There are different weld zone into distinct regions as explained below:

Unaffected material
Heat affected zone (HAZ)

Thermo-mechanically affected zone (TMAZ)

Weld nugget (Part of thermo-mechanically affected zone)

A. Unaffected material or parent metal

This is material remote from the weld, which has not been deformed, and which although it may have experienced a thermal cycle from the weld is not affected by the heat in terms of microstructure or mechanical properties.

B. Heat affected zone

In this region, which clearly will lie closer to the weld centre, the material has experienced a thermal cycle, which has modified the microstructure and/or the mechanical properties. However, there is no plastic deformation occurring in this area. In the previous system, this was referred to as the "thermally affected zone". The term heat affected zone is now preferred, as this is a direct parallel with the heat affected zone in other thermal processes, and there is little justification for a separate name.

C. Thermo-mechanically affected zone

In this region, the material has been plastically deformed by the friction stir welding tool, and the heat from the process will also have exerted some influence on the material. In the case of aluminium, it is possible to get significant plastic strain without re-crystallization in this region, and there is generally a distinct boundary between the re-crystallized zone and the deformed zones of the TMAZ. In the earlier classification, these two sub-zones were treated as distinct micro structural regions. However, subsequent work on other materials has shown that aluminium behaves in a different manner to most other materials, in that it can be extensively deformed at high temperature without re-crystallization. In other materials, the distinct re-crystallized region (the nugget) is absent, and the whole of the TMAZ appears to be re-crystallized

D. Weld nugget

The re-crystallized area in the TMAZ in aluminium alloys has traditionally been called the nugget. Although this term is descriptive, it is not very scientific. However, its use has become widespread, and as there is no word which is equally simple with greater scientific merit, this term has been adopted. A schematic diagram is shown in the above Figure which clearly identifies the various regions. It has been suggested that the area immediately below the tool shoulder (which is clearly part of the TMAZ) should be given a separate category, as the grain structure is often different here. The microstructure here is determined by rubbing by the rear face of the shoulder, and the material may have cooled below its maximum. It is suggested that this area is treated as a separate sub-zone of the TMAZ.

APPLICATIONS

1. Shipping and Marine: The shipbuilding and marine industries are the first industry sectors which have adopted the process for commercial applications. The process is suitable for the following applications: deck panels, sides, floors Aluminium extrusions Hulls and superstructures Marine and transport structures Masts and booms, e.g. for sailing boats

2. Aerospace Industry: At present the aerospace industry is welding prototype and production parts by friction stir welding. Opportunities exist to weld skins to spars, ribs, and stringers for use in military and civilian aircraft. Longitudinal butt welds in Al alloy fuel tanks for space vehicles have been friction stir welded and successfully used. The friction stir welding process can therefore be considered forewings, fuselages, empennages. Cryogenic fuel tanks for space vehicles. Aviation fuel tanks. Military and scientific rockets. Various primary and secondary structural components.

3. Railway Industry: The commercial production of high speed trains made from aluminium extrusions which may be joined by friction stir welding has been published. Applications include: High speed trains. Rolling stock of railways, underground carriages, trams. Railway tankers and goods wagons. Container bodies.

4. Other Industry Sectors: Friction stir welding can also be considered for: Electric motor housings (in production),Refrigeration panels,Cooking equipment and kitchens, Gas tanks and gas cylinders, Connecting of aluminium or copper coils in rolling mills.

ADVANTAGES OF FRICTION STIR WELDING:-

- It increases strength
- This process improves sealing. Completely void-free, leak proof joints with greater strength than fusion-welded joints the weld is in principle flush with the parent material
- It reduces heat distortion
- It improves repeatability. The FSW operation comprises a small number of variables which it is easy to monitor: tools, feed rate, rpm, and position of tool. This also permits close tolerances.

ENVIRONMENTAL ASPECTS OF FRICTION STIR WELDING

Today, there is a need to check new industrial process with respect to its impact on the environment. Careful consideration of HSE (Health, Safety and Environment) issues at the workplace is of prime important to any industry. It is quite common for manufacturers to monitor the environmental impact of any product throughout its life cycle. Friction Stir Welding offers numerous environmental advantages compared to other joining methods.

Moreover, “green thinking” is cutting edge in the industrial sector and of considerable marketing value

Less weld-seam preparation

Butt, overlap and blind welds are the main weld applications for the FSW process. To prepare the right bead configuration, work pieces featuring greater wall thicknesses often require a special cutting or milling process.

Fewer resources

The FSW Process needs no shielding gas therefore no investment such as pressure tanks, pipe fittings and gas regulators, as long as it is applied to low melting temperature materials such as aluminium. No need for consumables, eliminating the need for their storage and transport inside the production area, and avoiding the need for their production.

Noise, an underestimated health threat

The commonly used welding processes for aluminium are the MIG-pulse or TIG square-wave techniques. When used for work pieces of medium thickness, both require a lot of energy. Moreover, the pulse or square-wave frequencies make noise protection for the worker a must, although this is mostly ignored.

Because of electric spindle drive and hydraulic unit for axial pressure, an FSW unit generates consistently less noise when compared to a standard milling machine.

Energy saving FSW process

When considering energy consumption, three factors must be assessed: how much energy is required to perform the weld, what is the total energy required to operate the machinery and ancillary equipment, and how much energy is required for post treatment (grinding and cleaning). Generally, FSW demands less energy input to the weld than MIG and TIG, but more than laser welding. Total energy input depends on the size of the equipment being used and the thickness of the joint, depending on whether single-pass or multi pass welding is used. FSW is always single pass, offering the greatest energy savings at higher wall thicknesses.

Less post-treatment and impact on the environment

With most other welding processes, the weld requires weld and root reinforcement. In the latter case, this means grinding, with a negative impact on the workplace environment, as well as increased energy consumption and additional investment in equipment.

II LITERATURE SURVEY

Kumaran et al.(2011) In this research numerous advancements have been occurring in the field of materials processing. Friction welding is an important solid-state joining technique. In this research project, friction welding of tube-to-tube plate using an external tool (FWTPET) has been performed, and the process parameters have been prioritized using Taguchi's L27 orthogonal array. Genetic algorithm (GA) is used to optimize the welding process parameters. The practical significance of applying GA to FWTPET process has been validated by means of computing the deviation between predicted and experimentally obtained welding process parameters.

*Elangovan et al.(2012)*The researchers in this paper focuses on the development of an effective methodology to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding using response surface methodology (RSM) coupled with genetic algorithm (GA). RSM is utilized to create an efficient analytical model for welding strength in terms of welding parameters namely pressure, weld time, and amplitude. Experiments were conducted as per central composite design of experiments for spot and seam welding of 0.3- and 0.4-mm-thick Al specimens. An effective second-order response surface model is developed utilizing experimental measurements. Response surface model is further interfaced with GA to optimize the welding conditions for desired weld strength. Optimum welding conditions produced from GA are verified with experimental results and are found to be in good agreement.

Mariano et al. (2012) presents a literature review on friction stir welding (FSW) modelling with a special focus on the heat generation due to the contact conditions between the FSW tool and the work piece. The physical process is described and the main process parameters that are relevant to its modelling are highlighted. The contact conditions (sliding/sticking) are presented as well as an analytical model that allows estimating the associated heat generation. The modelling of the FSW process requires the knowledge of the heat loss mechanisms, which are discussed mainly considering the more commonly adopted formulations. Different approaches that have been used to investigate the material flow are presented and their advantages/drawbacks are discussed. A reliable FSW process modelling depends on the fine tuning of some process and material parameters. Usually, these parameters are achieved with base on experimental data. The numerical modelling of the FSW process can help to achieve such parameters with less effort and with economic advantages.

ZHANG (2012) studied that, the thermal modelling of underwater friction stir welding (FSW) was conducted with a three-dimensional heat transfer model. The vaporizing characteristics of water were analyzed to illuminate the boundary conditions of underwater FSW. Temperature dependent properties of the material were considered for the modelling. FSW experiments were carried out to validate the calculated results, and the calculated results showed good agreement with the experimental results. The results indicate that the maximum peak temperature of underwater joint is significantly lower than that of normal joint, although the surface heat flux of shoulder during then underwater FSW is higher than that during normal FSW. For underwater joint, the high-temperature distributing area is dramatically narrowed and the welding thermal cycles in different zones are effectively controlled in contrast to the normal joint.

Liu a (2013) In their research, the 4 mm thick 6061-T6 aluminium alloy was self-reacting friction stir welded at a constant tool rotation speed of 600 r/min. The specially designed self-reacting tool was characterized by the two different shoulder diameters. The effect of welding speed on microstructure and mechanical properties of the joints was investigated. As the welding speed increased from 50 to 200 mm/min, the grain size of the stir nugget zone increased, but the grain size of the heat affected zone was almost not changed. So-called band patterns from the advancing side to the weld centre were detected in the stir nugget zone. The strengthening meta-stable precipitates were all diminished in the stir nugget zone and the thermal mechanically affected zone of the joints. However, considerable amount of b0 phases, tending to reduce with increasing welding speed, were retained in the heat affected zone. The results of transverse tensile test indicated that the elongation and tensile strength of joints increased with increasing welding speed. The defect-free joints were obtained at lower welding speeds and the tensile fracture was located at the heat affected zone adjacent to the thermal mechanically affected zone on the advancing side.

Simoes a, (2013) their work describes the thermo-mechanical conditions during Friction Stir Welding (FSW) of metals have already been subject of extensive analysis and thoroughly discussed in literature, in which concerns the FSW of polymers, the information regarding this subject is still very scarce. In this work, an analysis of the material flow and thermo-mechanical phenomena taking place during FSW of polymers is performed. The analysis is based on a literature review and on the examination of friction stir welds, produced under varied FSW conditions, on polymethyl methacrylate (PMMA). Due to the high transparency of this polymer,
it was possible to analyse easily the morphological changes induced by the welding process on it. Results of the weld morphologic analysis, of the residual stress fields in the different weld zones and of temperature measurements during welding are shown, and its relation with welding conditions is discussed. From the study it was possible to conclude that, due to the polymers rheological and physical properties, the thermo-mechanical conditions during FSW are very different from that registered during welding of metals, leading to completely different material flow mechanisms and weld defect morphologies.

Ni (2014) observed that the Thin sheets of aluminium alloy 6061-T6 and one type of Advanced high strength steel, transformation induced plasticity (TRIP) steel have been successfully butt joined using friction stir welding (FSW) technique. The maximum ultimate tensile strength can reach 85% of the base aluminium alloy. Inter-metallic compound (IMC) layer of FeAl or Fe3Al with thickness of less than 1 lm was formed at the Al–Fe interface in the advancing side, which can actually contribute to the joint strength. Tensile tests and scanning electron microscopy (SEM) results indicate that the weld nugget can be considered as aluminium matrix composite, which is enhanced by dispersed sheared-off steel fragments encompassed by a thin inter-metallic layer or simply inter-metallic particles. Effects of process parameters on the joint microstructure evolution were analyzed based on mechanical welding force and temperature that have been measured during the welding process.

III. CONCLUSIONS

This paper is aimed to explain the Principle of Friction stir welding process & also tells the various parameters associated with it. It also helps in explaining the various Zones apart from it, helps in explaining the environmental aspects of Friction Stir Welding (FSW) & the various advantages of friction stir welding. Some research papers of FSW have also been considered to through enough light on this topic.

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