

## INVESTIGATION ON INDUCTION HEATING ASSISTED FRICTION STIR WELDING

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### ABSTRACT

The method of joining metal to metal through melting had remain mostly the same for decades, that is until 1991, when a new kind of welding was invented instead of melting metals to connect them using high temperature this new method called Friction stir welding, uses friction just like when you rub your hands together on a cold day. Friction stir welding (FSW) is limited to use in metals having high melting point due to the inadequate tool life. Tool life is decreasing due to high wear rate. Welding high melting point metal reduces the tool life. The alternative changing of tool may cost too high. The best way to increase the tool life for friction stir welding of high melting point metal is to preheat the metal. Preheating reduces the tool wear rate and increase the tool life. One of the best methods to heat high melting point metal is induction heating process. This project aims to review on induction heating process parameters and its effects on friction stir welding process and to determine the microstructure analysis and tensile strength of the metal.

### 1. INTRODUCTION

Friction stir welding is a solid-state joining process that uses a non-consumable tool to join two facing work pieces without melting the work piece material. Heat is generated by friction between rotating tool and work piece material, which leads to a softened region near FSW tool. For almost 20 years, FSW has been used in high technology applications such as aerospace, automotive, marine, and boilers. FSW does not produce flames or sparks. The FSW makes it possible to join lightweight materials such as aluminium alloy, copper and titanium alloys which are very difficult to weld by conventional welding. The one of the main drawbacks of FSW was it is not able to weld very hard metals. It is a solid state hot shear joining process in which a rotating tool with a shoulder and a pin traverses along the weld. Kilorad et al.,(2012 ) in their work, optimization of process parameters of friction stir welding of dissimilar aluminium alloys (copper, magnesium, and aluminium alloys) using Taguchi technique (Taguchi L16 orthogonal design of experiments), considered parameters rotational speed, traverse speed, tool geometry and ratio between tool and shoulder diameter and pin diameter for optimization to investigate tensile strength of the joint. The results were analyzed with the help of analysis of variance (ANOVA) and concluded that optimum levels of tool rotational speed of 700 rpm, traverse speed is 15mm/min, ratio between tool shoulder diameter and pin diameter is 3.00, pin tool profile is cylindrical threaded and finally friction stir welding produces satisfactory butt welds. Yahya Bozkurt (2012) has done work on optimization of friction stir welding process parameters to achieve maximum tensile strength in the polyethylene slab. Three process parameters, to tool rotational speeds, tool traverse speed and tilt angle of the tool were identified for optimization. The material taken for the study is a high-density polyethylene sheet which is the thermoplastic to determine welding process parameters on the ultimate tensile strength of the weld for good joint efficiency. The optimization technique applied is Touch's L9 orthogonal array, signal to noise ratio and ANOVA. They have adopted response surface methodology (RSM) and ANOVA for the optimization of process parameters. The out come of the experiments is ultimate tensile strength, yield strength increased with increase in tool rotational speed, welding speed and tool axial force. The percentage of total elongation increased with increase in rotational speed and axial force but decreased when there is increase in welding speed continuously. The results documented as maximum tensile strength is 197.50Mpa , yield strength is 175.25Mpa, percentage of total elongation is 6.96 was exhibited by the friction stir welding joints fabricated with optimized para meters of 1199rpm rotational speed, 30mm/min welding speed and 9 KN axial force. Further authors like

Luijendijk T, Bala Srinivasan p, Dietzel W, Zettler R, dos Santos Sivan V, Amancio-Filho ST, Sheikhi S and Cavaliere P, De Santis A, Panella F, Squillace A, have contributed towards this friction stir welding applications by selecting different parameters, dissimilar metal alloys, joints, and their micro structures, mechanical properties were analyzed in terms stress, corrosion cracking, fatigue strength, apart from the influence of process parameters. So, it can be understood that many research works are aimed towards parameters like microstructure behavior, tool traverse, tool profile etc, and aluminium based metal alloys and there is every scope to analyze with other metal alloys depending on the need. Ex., Advance Tool steels, Mildsteel alloys (as workpiece) with cubic boron nitride (as tool). Therefore, suitable research works can be extended in this area.

## 2. TOOL DESIGN PROCEDURE

The following procedure is followed to utilize the designer's time to best advantage, to prevent mistakes and to bring forth the best and correct design. The first step in the design procedure is to define the problem in a clear and simple statement of the functional needs. The need analysis, sometimes called the pre design analysis, pinpoints the problem in terms of functional need, all information supplied by the manufacturing engineer is examined, and all questions that arise or listed on paper to provide a permanent record. A considerable amount of time should be spent on the need analysis. Many tool designers have developed a checklist of need-analysis questions to make sure no important points are overlooked. Often tool drawings are used only once, when the tool is constructed, they are brought back to use only when necessary.

### 2.1 Operations Involved in Tool Design

There are several parameters that are involved in tool design. They are:

**Facing** – Facing on the lathe uses a facing tool to cut a flat surface perpendicular to the work piece's rotational axis. A facing tool is mounted into a tool holder that rests on the carriage of the lathe. The tool will then feed perpendicularly across the part's rotational axis as it spins in the jaws of the chuck. A user will have the option to hand feed the machine while facing or use the power feed option. For a smoother surface, using the power feed option is optimal due to a constant feed rate. Facing will take the work piece down to its finished length very accurately. Depending on how much material needs to be taken off, a machinist can choose to take roughing or finishing cuts. Factors that affect the quality and effectiveness of facing operations on the lathe are speeds and feeds, material hardness, cutter size, and how the part is being clamped down.

**Turning** The general process of turning involves rotating a part while a single-point cutting tool is moved parallel to the axis of rotation. Turning can be done on the external surface of the part as well as the internal surface (the process known as boring). The starting material is generally a work piece generated by other processes such as casting, forging, extrusion, or drawing.

**Taper turning** Tapered turning produces a cylindrical shape that gradually decreases in diameter from one end to the other. This can be achieved a) from the compound slide b) from taper turning attachment c) using a hydraulic copy attachment d) using a C.N.C. lathe e) using a form tool f) by the offsetting of the tailstock - this method more suited for shallow tapers.

### 2.2 The Finished Design

The finished design may not be the actual finished product, for even the final stages of drawing changes and additions may be required. However, an accurate drawing must be completed before the tool maker is able to begin construction. The drawing must be completed before the tool maker is able to begin construction. The drawing will probably consist of three-view (or more) orthographic drawing, which will be drawn to scale according to the tool-drawing procedures established.



Figure 1 : High carbon high chromium steel tool

### 3. EXPERIMENTAL METHOD

#### 3.1 Friction Stir Welding Without Induction Heating

A constantly rotated non-consumable cylindrical tool with a profiled probe is transversely at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth requires, with the tool shoulder riding at top the work surface. Frictional heat is generated between the rear resistant welding components and the work pieces. This heat, along with that heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld.

#### 3.2. Principle of FSW

Friction stir welding is a solid state welding process that gained much consideration in research areas as well as manufacturing industry since its prologue in 1991. For almost 20 years FSW has been used in high technology application such as aerospace, automotive, marine and boilers. The main feature of a solid-state welding process is the work material is only converted to semi-solidus state, which allows a lower temperature and lower heat input welding process.

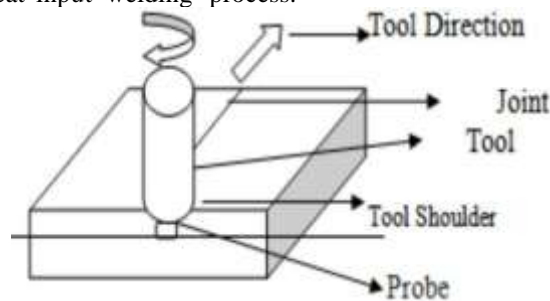


Figure 2: Diagram of Friction stir welding process

FSW does not produce sparks or flames. Thus, safety and environmental issues are not of major concern. FSW provides proven good quality and strong weldment with smaller expense and lesser number of equipment eliminates the use of filler material and improves weldability. FSW continues to propagate in many applications such as oil type welding and boiler welding. Friction stir welding makes it possible to join lightweight materials such as aluminium alloy, magnesium alloy, copper and titanium alloys which are very difficult to weld by conventional welding. One of the major drawbacks of FSW was it was not able to weld hard metals. Now by providing additional heating sources like induction heating.



Figure 3: Friction stir welding

### 3.3 Friction Stir Welding with Induction Heating

The successful application of FSW in aluminum and its alloys, during recent years and FSW technique has been extended to many other metallic materials. Nowadays, the main problem found in FSW was the difficulty to weld high melting point metals or its alloys are the tool material cost, appropriate design and the scarcity of high melting point material welding tools. It is well known that friction stir welding can provide strong and reliable welded joints; it can apply to a variety of materials including those which are difficult to weld.



Figure 4: Induction assisted FSW

When the FSW for higher melting point alloys such as steels, Ti or Ni alloys, much larger heat input is required to plasticize the materials so that the plastic stirring can proceed. The tool shoulder can reach temperature above 8600c and the weld seam behind the tool stays around this temperature for up to 25mm behind the tool when FSW is applied to steels. On the other hand, although the rotation tool has been developed and can be made of high durable materials like PCBN, WC alloy, Si3N4, etc., the wear of the rotation tool is still very severe. The tool surface was damaged rigorously, and the tool became greatly deformed and would worsen the weld quality if it is used for further welding process. Preheating the metals before welding starts on the metals is one of the best and economical methods for gaining better welding strength and increasing tool life. Induction and laser assisted FSW carried out on marine steel plate grade A successfully welded. A decreasing forge force has been observed and it helps to enhance the tool life. The preheating treatment slightly increases the hardness of the stir zone and it does not have an effect on travel speed.

When the seam throughout the welding process or the melting point or work piece is high, then the tool can travel too rapidly along the welding. The frictional heat generated between the shoulder and the structural members may not be sufficient to plasticize the structural members. The main consequence is the formation of the tool is generally restricted by the rate at which frictional heat is generated between the tool and the workpiece. For the low melting point metals like aluminum, magnesium alloys, the frictional heat is high enough to soften the materials and sound weld can be obtained after the FSW process.



**Figure: 5 .** Welded butt joint of aluminum and copper

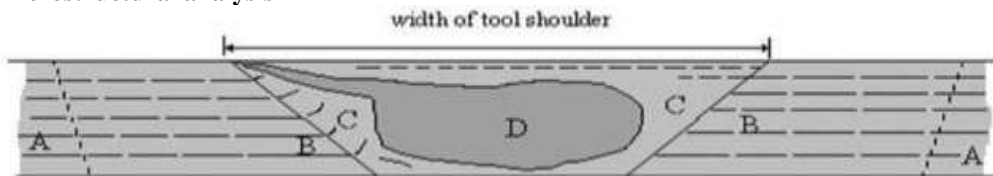
In this process, the workpiece we have used is a combination of aluminum (black) and copper with different speeds. And the tool we have used is High Carbon High Chromium Steel. In traditional friction welding process, where the metals are joined without melting the workpiece. Heat is generated by friction between the rotating tool and the workpiece material.

But the use of FSW in high melting point materials like aluminum is restricted due to its limited tool life. Due to high wear involved in the process, the tool is short. In such cases we will use Induction heating assisted FSW to increase the tool life. The tool life is increased by heating the workpiece with a preheating technique called Induction Heating.

### 3.4 Post Weld Analysis

To investigate the micro structural cross-section of a weld, the sample must first be prepared properly. The first step is to cut a small cross-section out of the middle of the weld; the spot is carefully chosen to make sure the cross section is from the steady state portion. A diamond saw is used to cut the face of the cross-section to ensure the smooth surface. The cross-section face is then polished using a polishing wheel with successively finer grades of silicon paper. At this point the cross-section surface is mirror like without any scratches or abrasions. To help really bring out the microstructure features the sample is etched by covering with Keller's reagent, a solution of 5% hydrofluoric acid, and 85% water. After etching an optical microscope and computer were used to capture the macrograph images as well as investigate the grain structure of the weld.

### 3.5 Microstructural analysis



**Figure 6.** Microstructural analysis

According to the figure 6, A - Unaffected zone, B - Heat affected zone, C – Thermo Mechanically affected zone, D – Weld nugget (part of thermo mechanically affected zone)

## 4. RESULT

For testing of tensile strength and microstructure analysis, a combination of both aluminum (thickness 6mm) and copper (thickness 5mm) with speeds (700rpm, 900rpm, 1000rpm) is used. The specimen is polished by a drum polisher by using a 200 to 1000 grade sanding sheet. Before dipping into the etchant solution, the specimen is buffed. Kalling's number -2, is the etchant solution taken for AISI 410SS. The solution is prepared by blending CuC12- 5g, HCL 100ml, respectively. The specimen dipped into the etchant having a temperature of 25-degree celsius for 10 seconds.



Figure 7 Materials after breaking



Figure 8 (a) Material after testing (speed 700 rpm)



Figure 8 (b) and 8 (c) Material after testing (900,1000rpm)

Table 1. Analysis of Tensile Stress by varying speed for given Specimen.

| S.No | Parameter                                      | Specimen I | Specimen II | Specimen III |
|------|--|------------|-------------|--------------|
| 1.   | Speed (RPM)                                    | 700        | 900         | 1000         |
| 2.   | Ultimate Tensile (kN)                          | 3          | 0.740       | 1.760        |
| 3.   | Ultimate Tensile Strength (N/mm <sup>2</sup> ) | 42.831     | 10.894      | 23.797       |
| 4.   | Yield Load (kN)                                | 1.960      | 0.710       | 1.680        |
| 5.   | Yield Stress (N/mm <sup>2</sup> )              | 27.256     | 10.452      | 22.715       |

## CONCLUSIONS

The present work presents an attempt where friction stir welding is done by using a preheating technique called induction heating. The investigation also seeks to assess the efficacy of the proposed process through examination of joint efficiency, weld microstructure, tensile stress. The Induction assisted friction stir welding is very recent trends in the manufacturing technology of metal joining processes especially for aluminium alloys. It is found many research works are done on the aluminium alloys. Moreover, various engineering industries will not only give importance for aluminium and aluminium based alloys but also for mild steel and its alloys. This induction heating enhances the tool life, increases the weld speed and it can decrease the grain size while plasticizing, Induction heating assisted friction stir welding can be adopted in all ferromagnetic materials and by comparing to other heating sources, it provides a quick heating. It requires considerable further development for avoiding the hardening in the stir zone and produces much more welded joints

It has been shown that to come up with good weld quality it is necessary to have knowledge of tool material selection. The type of material being welded as well as the weld parameters such as traverse speed and rotational speed as well as the material characteristics determines the best tool material that is selected. If the tool material is not hard enough to offer sufficient wear resistance to the materials being joined. In general, soft materials can be joined with relatively harder tool materials while hard materials also need very hard tool materials for successful joints to be made.

It is evident that Induction assisted friction stir welding has more potential in the fabrication of similar and dissimilar aluminium alloys when compared with other conventional welding methods. It creates high strength weld in hard materials and it is alternative to fusion welding. Although it is only 26 years since FSW technology was invented, quite a few successful industrial applications have been demonstrated. The process has demonstrated its capabilities and been approved as a novel method for joining aluminum and other metals. Induction assisted FSW opening totally new areas of welding daily. The welding improves existing structural properties and leaves "cold". In some cases, if proper care is taken, weld properties become equal to those of the base material. Anyone currently working with aluminum can use FSW. Although currently not widely used, it is within everyone's reach and it promises the elimination of smoke and spatter typical of arc welding. It is concluded that this review on induction assisted friction stir welding shows how preheating helps to apply FSW on harder metals.

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