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# Friction Stir Welding as a Joining Process through Modified Conventional Milling Machine: A Review

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***Abstract:***
*Through this paper an attempt is made to review some techniques for modifying vertical milling machine to achieve special welding technology of friction stir welding (FSW) which is a solid-state joining process. As this process of joining is achieving success daily at the level of research but its excess to workshops having lesser capital is limited because of costlier machines. This problem inspired to review techniques so that FSW can be achieved in workshops with little modifications in the conventional machine like vertical milling. Modification of tool design and redesign of clamping system are discussed so that conventional milling machine can be used for friction stir welding. The major applications of FSW in the field of aerospace, shipbuilding and automotive are also reported.*

***Keywords****: Friction stir welding, modified milling machine, tool design, clamp design*

## 1. Introduction

Friction stir welding (FSW) is comparatively recent welding technique, invented by The Welding Institute (TWI), Cambridge, UK as a solid-state joining technique in the year 1991. Initially this technology was applied to aluminum alloys [1]. But now it is gaining importance for welding materials like steel and other alloys. Friction stir welding is based upon the simple concept of heat generation due to friction. The heat generated results in plastic diffusion of the material at the edges. In this case a non-consumable rotating tool with a pin and shoulder is inserted into the abutting edges of plates to be joined and traversed along the line of joint which is shown in Figure 1.

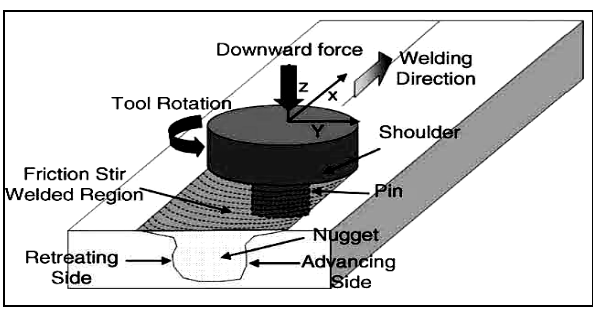


*Figure 1: Friction stir welding process by using a rotating tool which moves in the direction of joined edges of plates adopted from [1]*

The tool serves two primary functions including heating of workpiece as well as the movement of material to produce the joint. The heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece. The localized heating

softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state'.
Because of various geometrical features of the tool, the material movement around the pin can be complex [1]. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equaled recrystallized grains which results in good mechanical properties [1]. 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. As compared to the conventional welding methods, FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environment friendly.

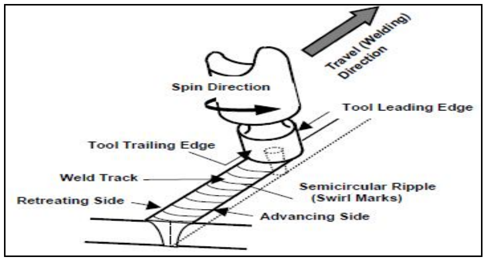


*Figure 2: Terminologies related to friction stir welding [5]*

**2. Friction Stir Welding Process Parameters**
Friction stir welding includes typical material movement and plastic deformation. Welding parameters, tool geometry and joint design has significant effect on the material flow pattern and temperature distribution, which also influencing the micro structural evolution of material. Some of the major factors affecting friction stir welding process are tool geometry, welding parameters and joint design.

*2.1. Tool geometry*
Tool geometry is one of the significant parameter of process development. The tool geometry plays a critical role in material flow and in turn governs the traverse rate at which the friction stir welding can be conducted. The tool consists of a shoulder and a pin as shown in Fig. 1. The tool is inserted till the shoulder touches the workpiece. The friction between the shoulder and workpiece results in the large component of heat generation. From heat generation point of view, the relative size of pin and shoulder is an important design aspects. The shoulder also provides confinement for the heated volume of material. The uniformity of microstructure and properties as well as process loads is governed by the tool design. In general, a concave shoulder and threaded cylindrical pins are used.

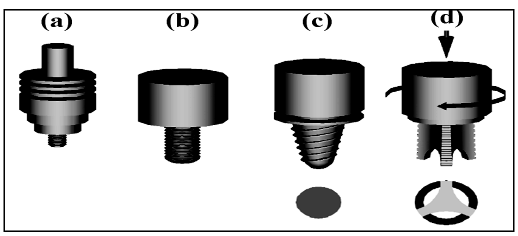


*Figure 3: Different Friction stir welding tool shapes (a) stepped shoulder with cylindrical threaded pin (b) Cylindrical threaded pin (c) tapered pin (d) flared-triflute pin as reported in [7]*

*2.2. Joint Design*
As far as friction stir welding is concerned, the most convenient joint configurations are butt and lap joints. A simple square butt joint is shown in Fig. 4a. Two plates or sheets with same thickness are placed on a backing plate and clamped firmly to prevent the butting joint faces from being forced apart. During the initial plunge of the tool, the forces are fairly large and extra care is required to ensure that plates in butt configuration do not separate. A rotating tool is plunged into the joint line and traversed along this line when the shoulder of the tool is in intimate contact with the surface of the plates, producing a weld along abutting line. On the other hand, for a simple lap joint, two lapped plates or sheets are clamped on a backing plate. A rotating tool is vertically plunged through the upper plate and into the lower plate and traversed along desired direction, joining the two plates (Fig. 4d). Many other configurations can be produced by combination of butt and lap joints. Apart from butt and lap joint configurations, other types of joint designs, such as fillet joints (Fig. 4g), are also possible as needed for some engineering applications[**1**]. It is important to note that no special preparation is needed for FSW of butt and lap joints. Two clean metal plates can be easily joined together in the form of butt or lap joints without any major concern about the surface conditions of the plates [**7**].

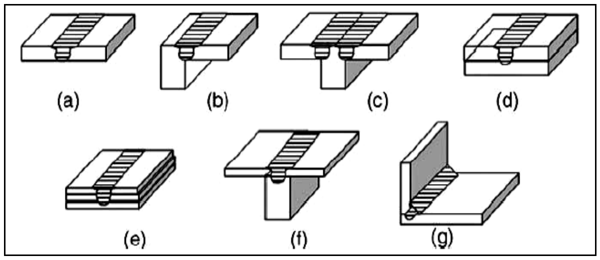


*Figure 4: Joint configurations for friction stir welding: (a) square butt, (b) edge butt, (c) T butt joint, (d) lap joint, (e) multiple lap joint, (f) T lap joint, and (g) fillet joint reported in [7].*

*2.3. Welding Parameters*

In case of friction stir welding, there are some welding parameters which are responsible for the performance and quality of the welded joint. These parameters are shown with the help of diagrammatic representation for each parameter [2,5].

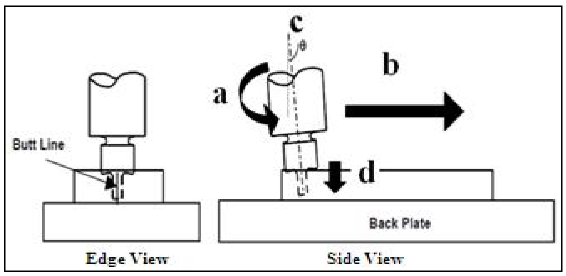


*Figure 5: Explanation of different welding parameters adopted from [5]*

- Tool rotation rate (v, rpm) in clockwise or counter clockwise direction.
- Tool traverse speed (n, mm/min) along the line of joint.
- Angle θ of spindle or tool tilt with respect to the work piece surface.
- Target depth i.e. insertion depth of pin into the work pieces.

**3. Utilization of Conventional Vertical Milling Machine for Friction Stir Welding**

Through the above discussion it is being realized that in order to achieve FSW through a machine the design of back plate is very important. Because when tool plunges initially large forces are exerted and try to separate two plates that to be welded. In such a situation to hold the plates at proper position back plate should be rigidly fixed to plates to be welded as well as a rigid machine bed. Secondly large forces are exerted on the tool that why tool should also be held in such a way that accurate welding can be achieved without much vibration. Also tool can be easily change during application. All such features are available with conventional vertical milling machine i.e. a strong bed to accommodate base plate with proper fixing arrangement; tool can also be secure with ease of changing in this machine. Many researchers work in this area of modifying vertical milling machine for achieving FSW as discussed below.

*3.1. Modification in Tool Design* [3]

T. Minton and D.J. Mynors. [3] described the procedures of using conventional manual milling machine whose operating ranges and speed values are shown below in table I and table II respectively for Friction Stir Weld (FSW) butt joints. Parkson Vertical Mill Type A was employed for trials on 6.3mm and 4.6mm thick aluminium 6082-T6 sheet, table III shows weld trial conditions. At the initial level it was unknown about the capability of milling machine for FSW, for this a single generic tool was designed for the 6.3mm sheet and used for the 4.6mmsheet.

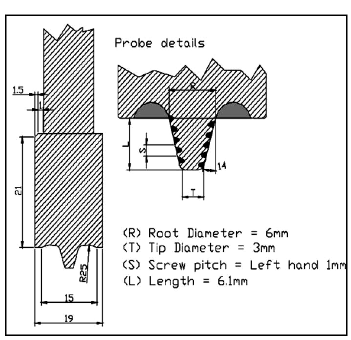


*Figure 6: Tool used for 6.3 mm sheet [3]*

The tools were manufactured from 19mm diameter silver steel [3]. The pieces to be welded were placed in butt position, bolted to a steel backing plate which was bolted directly to the machine's feed table.

| Spindle speed (rpm) | Feed speed (mm/s) |
|---|---|
| 1550 (maximum) | 3.175 (maximum) |
| 1160 | 2.12 |
| 930 | 1.49 |
| 620 | 0.95 |
| 464 | 0.50 |
| 372 | 0.42 |
| 125 | 0.26 |
| 93 | 0.1 (minimum) |
| 74 | |
| 50 | Spindle pitch (tool tilt angle) (°) |
| 38 | |
| 29 (minimum) | −90° to +90° |

*Table I: Parkson milling machine operating ranges [3]*

| | $V_s$ (rpm) | $V_f$ (mm/s) |
|---|---|---|
| Maximum (1) | 1550 | 3.175 |
| Mid-point (3) | 1160 | 1.49 |
| Minimum (4) | 620 | 0.26 |

*Table II: Speed Values [3]*

| Condition | $V_s$ (rpm) | $V_f$ (mm/s) |
|---|---|---|
| 1 | 1550 | 3.175 |
| 2 | 1550 | 0.26 |
| 3 | 1160 | 1.49 |
| 4 | 620 | 0.26 |
| 5 | 620 | 3.175 |

*Table III: Weld trial conditions [3]*

They found that the quality of weld with lesser thickness is not as good as for thicker plate i.e. 6.3 mm . They further suggested to access the effect of change of tool geometry for imprving weld quality of 4.6 mm plates for future work. But through this work FSW was successfully achieved for aluminium plate with the help of milling machine.

*3.2. Modification of A Clamping and Support System* [4]

Esther T. Akinlabi et.al. [4] designed and modified a clamping and support system in a reconfigured milling machine to produce friction stir welding joints. The re-designing of a milling was done to produce friction stir welds. The objective of this design was to develop a clamping and support system for a reconfigured milling machine to be utilized for producing friction stir welds with lesser vibration. They suggested that different thickness plates can be clamped and welded with proposed design.

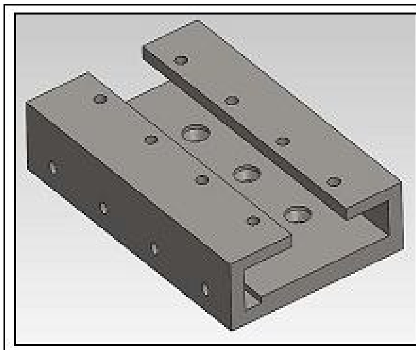
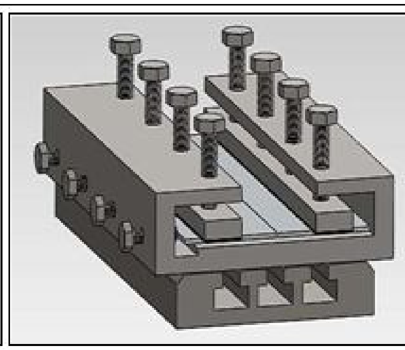
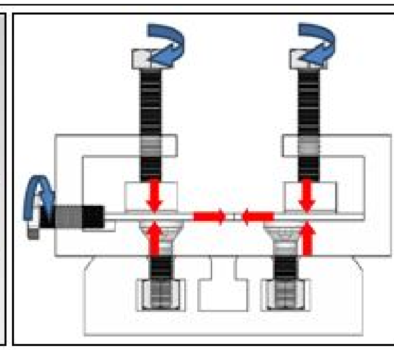

*Figure 7: The backing plate adopted from [4]*
*Figure 8: Assembly drawing showing the backing plate fastened to the XY table of the milling machine and the clamping system adopted from [4]*
*Figure 9: Major forces involved in a supporting system [4]*

The performance analysis showed that the concept can be used for friction stir welding to be performed by using a typical milling machine. The inexpensive milling machine adaptations allow for the conversion of any milling machine into a specialized Friction Stir Welding machine which is suitable for research purposes [4].

**4. Applications Of Friction Stir Welding**

*4.1. Aerospace industries*

Manufacture of aerospace components is weight savings, which translate directly into cost savings. Reducing weight enables higher speeds and/or reduced fuel consumption. Friction Stir Welding not only eliminates rivets and fasteners, but the need for an overlap sheet configuration. The fact that FSW offers the means to join previously unweldable Al-Li (e.g. AA2195) alloys **[6]** has attracted growing interest from the civil aeronautics and aerospace industries.

*4.2. Shipbuilding*

FSW represents a first step towards this type of construction approach in shipbuilding. The low heat input during joining assures less residual stress, resulting in precisely welded components that require minimal fit-up work. The resulting savings, both in time and money, are obvious. This offers users of FSW a clear competitive advantage, although documented data on actual savings is seldom reported.

*4.3. Automotive applications*

In larger road transport vehicles, the scope for applications is wider and easier to adapt – long, straight or curved welds: trailer beams, cabins and doors, spoilers, front walls, closed body or curtains, frames, rear doors and tail lifts, floors, sides, front and rear bumpers, chassis fuel and air containers, tool boxes, wheels, engine parts, etc. The ESAB Super Stir unit shown in Fig.10 was delivered to Tower Automotive in 2009[6].

*Figure 10: ESAB Super Stir unit at Tower automotive [6]*

**5. Conclusion**

As we know that friction stir welding (FSW) is a solid-state joining process based on the simple concept of heat generation due to friction but the cost of machine is huge and supplier are less. This leads to researchers to modify conventional vertical milling machine for the same purpose. As friction stir welding is used for joining of two plates which by applying compressive force that requires fixtures over the work table. Process parameter includes tool geometry, joint design and welding parameters which are to be kept in mind while performing FSW. Review of previous work based on tool design and redesign of clamping support system shown successful utilization of conventional milling machine for friction stir welding. This leads to achieve cheaper FSW process in the workshops. Further the load on suppliers to give machines will also reduce, unless very precise measurements are involved specially for research purposes. Some of the major applications of FSW in the field of aerospace, shipbuilding and automotive applications are also discussed along with their advantages. Lastly this review paper will open new doors of research for design of different clamping systems for different materials of different thicknesses so that conventional milling machines can be utilized in FSW of different materials with less investment.

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