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A Review on Progress of Different Types of Friction Stir Welding Tool Geometry Design

[1]P. Madhan Kumar, [2] Dr. V. Anbumalar and [3]K.R. Ramesh Babu

[1]*Assistant Professor, Dept. of Mechanical Engineering, Fatima Michael College of Engineering & Technology, Madurai*
[2]*Professor, Dept. of Mechanical Engineering, Velammal College of Engineering & Technology, Madurai*
[3]*Assistant Professor, Dept. of Mechanical Engineering, SACS MAVMM Engineering College, Madurai*

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ABSTRACT
The friction stir welding (FSW) is a dynamically developing version of pressure welding processes. It is possible to create high quality welding by using FSW process. The performance of the FSW is mainly based on the tool design, process parameters and welding material. In this tool is most important part, which is used to create good quality of weldment. Basically tool design is needed because the goal is not the material removing but the material mixing and heating by frictional heat. The tool must be meet several important requirements. On the one hand in the course of mixing the material flow conditions specifically affect the quality of the weld, so the tool geometry is very important. Thus, At most care should be taken in design of tool. Therefore, this paper presents an overview of the FSW tool, tool material, tool geometry, design of tool pins and welding variables.

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INTRODUCTION

The technique of Friction Stir Welding (FSW) was developed at The Welding Institute (TWI) in 1991 as a method to join non-ferrous materials like aluminium and magnesium etc. The process uses the non consumable specially designed rotating tool which is inserted in to the material by giving the axial force and then translated along the joint line to make the weld (Don-Hyun Choi, 2011). The basic principle of the process is shown in the fig. 1.

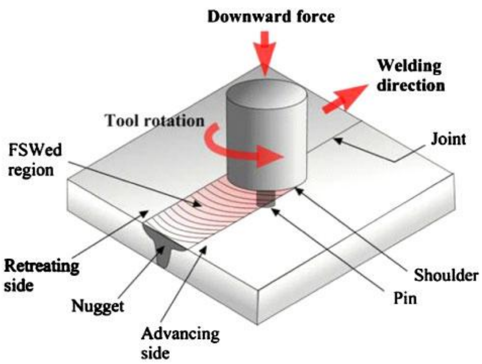

Fig. 1: Principle of Friction Stir Welding.

Due to difficulties of high temperature involved in joining of steel which has an effect of rapid softening and wearing of the tool, this process was not so popular in joining of steel and other hard materials like titanium. Later, it has been discovered that if FSW is applied to steels, the mechanical properties were close to the base materials (Choi *et al*.2011).There have been a discovery of suitable tool material such as Tungsten Carbide (WC) and Polycrystalline cubic boron nitride (PCBN) for FSW tools which can join hard alloys such as steels and Ti alloys. Because of such discoveries, the joining of steels became increasingly popular (Rai.R *et al.*

Corresponding Author: Dr. V. Anbumalar Professor, Dept. of Mechanical Engineering, Velammal College of Engineering & Technology, Madurai
E-mail: dranbumalarv@gmail.com

2011).(Hidetoshi Fujii *et al*. 2006, noted that the use of FSW process had the advantage that material is not melted and hence grain growth cannot occur when this method is applied thus it has been shown that the process of FSW is a solid state process which does not involve the melting of the materials being joined. The residual stresses and distortion in FSW welds are generally lower than those found in fusion welds. The associated lower energy input in FSW tends to minimize grain growth in the Heat Affected Zone (HAZ) and there by limiting distortion and residual stresses. FSW being a solid state process eliminates the problems associated with hydrogen cracking in steels (Lienert *et al*. 2003). In FSW process, a shouldered tool with a probe is rotated and traversed along the joint line of the two materials being joined. It is that rotation which cause frictional heating that softens and plasticize the work material resulting in joining.(Yousif *et al*.2008) made a remarkable statement when he said that FSW is rather a combined effect of forging and extrusion and not a true welding process in actual fact. The Mechanical fastening is the most familiar to aerospace structures because high strength. The Aluminum martial difficult to join by convectional fusion welding techniques. (Pouget *et al*.2008). Due to hot cracking and poor solidification microstructure in fusion zone (Zimmer Sandra *et al*.2010). FSW process is most significant improvement of joining decade technology of efficiency and so environment friendliness.

Fsw Processes:

FSW process in a new and unique thermo mechanical processing techniques, the process developed by (mishra *et al*.2005) used by basic concept of FSW this process is the rotating tool of desired a pin and shoulder plunged in a single material for properties enhancement the work piece is plunged until top surface of the shoulder contact with the plate surface. The action first develops the heat and then the plate is moved relative to a rotating tool which lead to grain refinement by a dynamic re crystallization the application of friction stir processing is also super plastic forming is net shape technique. The technique also used for preparing the surface composite & micro structural refinement are cast aluminium alloy this process have been applied aluminium ,copper , nickel, alloy. The cast nickel aluminium bronzes are the strength and ductility of Al Alloy A356 was increased at 5 times and also increase the fatigue life is used by the FSW process. AH feng *et al* has been choose three friction steel process namely single pass, single pass with a pre-solution treatment and two pass and also study micro structural and mechanical properties Pin is fixed in a milling machine chuck is rotated about longitudinal axis with rigid to backing plate. The back plate prevent work piece from spreading or lifting during welding. The rotary welding tool is slowly plunged into work piece until the shoulder of the welding tool forcibly contacts the upper surface of the material. As tool moving along butting surface heat is produce the work piece when at pin /work piece contact as surface as a result of friction dissipation (Grujicic M. *et al*.2011). A welding tool comprised of a shank, shoulder, and pin is fixed in a milling machine chuck and is rotated about its longitudinal axis. The work piece, with square mating edges, is fixed to a rigid backing plate, and a clamp or anvil prevents the work piece from spreading or lifting during welding. The half-plate where the direction of rotation is the same as that of welding is called the advancing side, with the other side designated as being the retreating side (Nandan R. *et al*., 2008). The rotating welding tool is slowly plunged into the work piece until the shoulder of the welding tool forcibly contacts the upper surface of the material. By keeping the tool rotating and moving it along the seam to be joined, the softened material is literally stirred together forming a weld without melting (Rowe C.E.D. *et al*., 2005). The welding speed depends upon all several factors then produce high friction is produce to heating more intense stirring and mixing of material. Tool is applied into axial force on the work piece (Kumar K. *et al*.2008) plasticized martial around it and forging same in place.

Fsw Tool:

FSW tool is a heart of the FSW process, then they consists of two primary parts namely shoulder & pin shoulder part. The tool is frictionally heats the portion of the work piece & they induced the axial download force of welding consolidation. They shoulder end surface are consist normally. Flat, convex, concave, & they features are such that scrolls, rigid, knurling, grooves & concentric circle, these features of to be improve the weld quality. They the probe is a one of the FSW tool. The probe tools are inserted with work piece by axial force which shears of material in front & move the same at behind the tool. Probe consist different shapes such as refer fig .2 FSW tool are three types fixed, adjusting, self reacting. The fixed tool is made by single piece & is used to weld the entire work piece with constant thickness.

The probe length was adjustable by during welding. Te shoulder & pin is made us the two independent pieces such us self reciprocating tool (or) bobbing. This type of tool is made up three pieces namely to shoulder probe & bottom shoulder diagram of tool shape.

The Function Of Tool:

(Rajiv S *et al*.2007) Investigate the friction stirring tool consists of a pin, or probe, and a shoulder. Contact of the pin with the work piece creates frictional and deformational heating and softens the work piece material, contacting the shoulder to the work piece increases the work piece heating, expands the zone of softened material, and constrains the deformed material . Figure 2 shows the most important tool parts.

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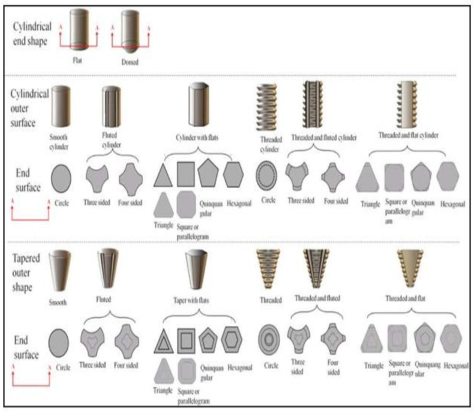

Fig. 2: Different Shapes of Probe.

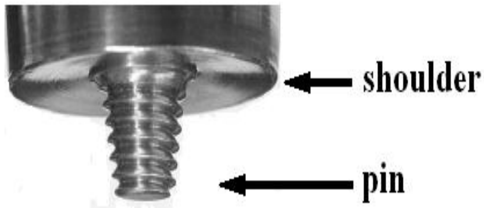

Fig. 3: Parts of friction stir welding tool.

Naturally, there are important effects to the tool during welding: abrasive wear, high temperature and dynamic effects. Therefore, the good tool materials will have the following properties:

- good wear resistance,
- high temperature strength, temper resistance,
- Good toughness.

So as we can see there are two important fields of friction stir welding tool design: tool material and geometry.

Tool Material:

Friction stirring is a thermo mechanical deformation process where the tool temperature approaches the solidus temperature of base metal. Production of a quality friction stir weld requires the proper tool material selection for the desired application. Thus, it is undesirable to have a tool that loses dimensional stability, the designed features, or worse, fractures.The following characteristics have to be considered for material choice:

- ambient and elevated temperature strength,
- elevated temperature stability,
- wear resistance,
- tool reactivity,
- fracture toughness,
- coefficient of thermal expansion,
- machinability.

There are several tool materials used depending upon the base material:

- Hot-work tool steels: the most commonly used material, easy availability and machinability, thermal fatigue resistance, wear resistance, especially for aluminium and copper.
- Nickel- and cobalt base alloys: high strength, excellent ductility, hardness stability, creep resistance. These alloys derive their strength from precipitates, so the operational temperature must be kept below the precipitation temperature (typically 600 – 800 °C).
- Refractory metals (W, Mo): high temperature strength, strongest alloys between 1000 –1500 °C, expensive, difficult machining, brittle because of powder processing.
- tungsten-base alloys: good strength, high operational temperature, high cost (W-Re)
- carbide particle reinforced metal composites (WC, WC-Co, Tic): superior wear resistance, reasonable fracture toughness. Steels with polycrystalline cubic boron nitride PCBN) coating: high operational temperature,

excellent wear resistance, low fracture toughness, expensive tool.Table 1 shows the most commonly used tool materials for different base materials and thicknesses.

Table 1: Summary of tool materials.

Sl.No	Alloys to be welded	Thickness (mm)	Tool material
1	Aluminium alloys	3 – 50	Tool steels, Co-WC composite
2	Magnesium alloys	3 – 10	Tool steel, WC composite
3	Copper alloys	3 – 50	Ni-alloys, W-alloys, PCBN, Tool steels
4	Titanium alloys	3 – 10	W-alloys
5	Stainless steels	3 – 10	PCBN, W-alloys
6	Low-alloy steels	3 – 10	WC composite, PCBN
7	Nickel alloys	3 - 10	PCBN

Tool Geometry:

Each of the friction tool parts (pin and shoulder) has a different function. Therefore, the best tool design may consist of the shoulder and pin constructed with different materials. The work piece and tool materials, joint configuration (butt or lap, plate or extrusion), tool parameters (tool rotation and travel speeds), and the user's own experiences and preferences are factors to consider when selecting the shoulder and pin designs. It is Very important factor of the tool design that the material flow has adequate direction and quantity during welding. Generally, the greater volume of material to stir better weld quality is obtained, but it has strong correlation with other technological parameters (rotational speed, welding speed). Horizontal material flow certainly occur during welding, but if some oxide occurs on the base material surface, the vertical material flow will be very significant and this is especially true at lap joint welding. If vertical flow doesn't occur during welding, the surface oxide will remains in the joint line and remains the creation of the joint. Figure 4.a shows the horizontal material flow, figure 4. b shows the vertical material.

Flow around the tool:

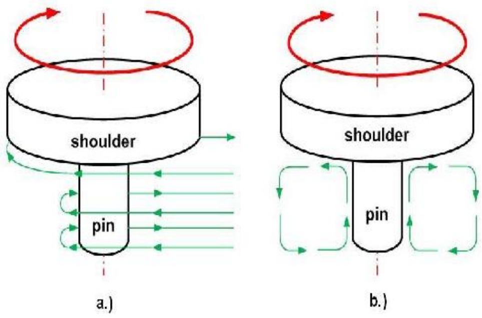

Fig. 4: a Horizontal material flow, b.vertical material flow.

Tool Design:

(Gopala Krishnan S. *et al*.,). Investigate the tool design influences heat generation, plastic flow, the power required, and the uniformity of the welded joint. Tool geometry such as probe length, probe shape and shoulder size are the key parameters because it would affect the heat generation and the plastic material flow The tool is an important part of this welding process. It consists of a shoulder and a pin. Pin profile plays a crucial role in material flow and in turn regulates the welding speed of the FSW process. The shoulder generates most of the heat and prevents the plasticized material from escaping from the work-piece, while both the shoulder and the tool pin affect the material flow. Friction stir welds are characterized by well-defined weld nugget and flow contours, almost spherical in shape, these contours are dependent on the tool design and welding parameters and process conditions. The tools design is determine the optimum tool geometry . That comments of the torque are used for various diameter, Mt increases reaches a maximum and the decreases. A three dimensional heat transfer and viscous – plastidel is used to compute the influence of pin length during FSW.

The commonly used five pin profiles i.e., straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square pins to fabricate the joints, in FSW are shown schematically in Fig.5(Elangovan K. *et al*)

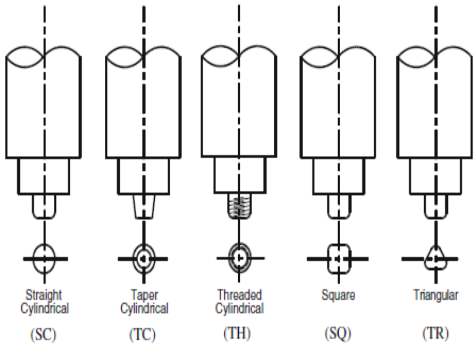

Fig. 5: Schematic drawing of the FSW tool.

Design of tool shoulders:

M. Mehta and A. Arora et. al. investigate that tool shoulders are designed to produce heat to the surface and subsurface regions of the work piece. The tool shoulder produces a majority of the deformational and frictional heating in thin sheet, while the pin produces a majority of the heating in thick work pieces. The most important parameter of the shoulder is the diameter because it has significant effect to the amount of frictional heat. Figure 5. Shows the relation between the shoulder diameter and peak temperature at different rotational speeds during aluminium welding.

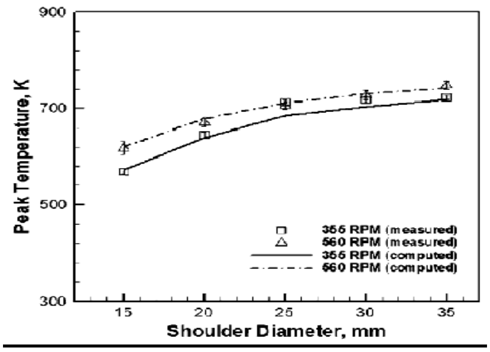

Fig. 5: The effect of shoulder diameter to the peak temperature.

Design of tool pins:

Friction stirring pins produce deformational and frictional heating to the joint surfaces. The pin is designed to disrupt the faying, or contacting surfaces of the work piece, shear material in front of the tool, and move material behind the tool. In addition, the depth of deformation and tool travel speed are governed by the pin design. Commonly used pin

Designs are as follows:

- Round-bottom cylindrical pin (Figure 6.a.): A round end to the pin tool reduces the tool wear upon plunging and improves the quality of the weld root directly underneath the bottom of the pin. The best dome radius was specified as 75% of the pin diameter. It was claimed that as the dome radius decreased, a higher probability of poor-quality weld was encountered, especially directly below the pin. Machining a radius at the bottom of the threads will increase tool life by eliminating stress concentrations at the root of the threads.
- Flat-bottom cylindrical pin (Figure 6.b.): The friction velocity of a rotating cylinder increases from zero at the center of the cylinder to a maximum value at the edge of the the importance of friction stir welding tool cylinder. The local velocity coupled with the friction coefficient between the pin and the metal dictates the deformation during friction stirring. The lowest point of the flat bottom pin tilted to a small angle to the normal axis is the edge of the pin, where the velocity is the highest.
- Truncated cone pin (Figure 3.): Cylindrical pins are found to be sufficient for aluminum plate up to 12 mm thick, but researchers wanted to friction stir weld thicker plates at faster travel speeds. A simple modification of a cylindrical pin is a truncated cone. Truncated cone pins have lower transverse loads (when compared to a cylindrical pin), and the largest moment load on a truncated cone is at the base of the cone, where it is the strongest.

After the described basic pin geometries the development of tools were continuing and appeared unusual pin geometries:

- MX triflute pin (Figure 6.c.): it contains three flutes cut into the helical ridge. The flutes reduce the displaced volume of a cylindrical pin by approximately 70% and supply additional deformation at the weld line in addition it increases the tool travel speed. It can be used advantageously to welding thick-section aluminium alloys.
- A-skewTM (Figure 6.d): The effect of this pin geometry is similar than MX triflute.It increases travel speed, improves the tensile properties of the weld, and reduces the weld asymmetry.
- Trivex pin (Figure 6.e.): It produced an 18 to 25% reduction of traversing forces and a 12% reduction in forging (normal) forces in comparison to an MX triflute pin of comparable dimensions.
- Thread less pins (Figure 6.f.): These are useful in specific FSW applications where thread features would not survive without fracture or severe wear. Tools operating under aggressive environments can't retain threaded tool features without excessive pin wear. Pins for these conditions typically consist of simple designs with robust features.

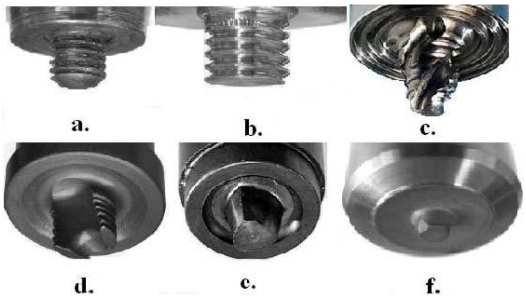

Fig. 7: Different pin geometries a. round-bottom, b. flat-bottom, c. MX triflute, d. A-skewTM, e. Trivex, f. threadless.

Micro-Structural:

The equaled fine grain structure is attained in the welded joints due to the high temperature and severe plastic deformation during welding in that zone. The different shapes of nugget zones are observed which is shown in the fig.7

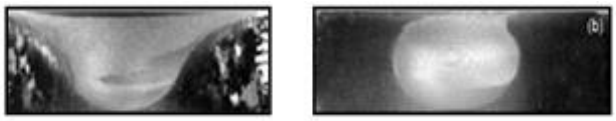

Fig. 7: (a) Basin Shape (b) Elliptical Shaped.

The most common shapes of the nugget zone are basin shaped nugget (a) and elliptical nugget (b). In basin shaped nugget, the widening neat the upper surface. The shapes of the nugget are decided by the various parameters such as, tool geometry, temperature of the work piece, thermal conductivity of the work piece. The nugget zone is slightly larger than the pin diameter. R.S Mishra *et al*) observed that the basin shaped nugget zone and elliptical nugget is attained in both low rotational and high rotation tool speed respectively. P.L.Thread gill was made the first in classifying the micro structural of the welding joints for butt joints the generalized profile proposal by TWI was an inverted trapethoidal structure with four zone which is shown is the fig 8.

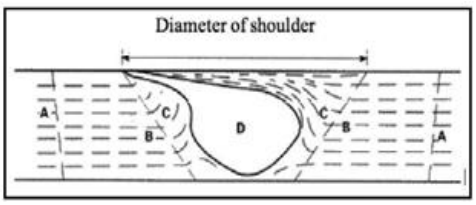

Fig. 8: Microstructure of the FSW Weldment.

In [A]zone there is no change in properties and micro structural of the BM this zone is far away from the welding zone it is unaffected by heat and deformation. In zone [B], materials is influenced by heat (thermal cycle) and lead to changing of micro structure in BM, Heat in this zone does not affect any plastic deformation in B zone the [c]zone which is unique in FSW the region experience both deformation and temperature which are not to induce the re crystallisation of material the portion where the actual stirring takes place which bads to deformation and change in micro structural and experience the high strain is referred as dynamically[D] recrystallised zone (DRZ) (or) nuggel zone[D].

Welding variables:

FSW involves complex martial movement and plastic deformation. Welding parameters, tool geometry and joint design exert significant effect on the martial flow pattern and temperature distribution, thereby influencing the micro structural evolution of material (Mishra R.S. *et al*., 2005). 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. The tool towards moving is the pattern material so heat spread in to the pattern materials micro – structure deformation .Therefore they tool parameters is also main independent variable are used to control FSW process. The main process parameters and there effects in friction stir welding are given below Table :2 (FSW-Technical-Handbook).

Table 2: Main process and parameter in friction stir welding.

Sl.No	Parameter	Effect
1	Rotation Speed	Frictional heat, oxide layer Breaking and mixing of metrial.
2.	Tilting angle	The appearance of the Weld, thinning
3.	Welding Speed	Heat control
4.	Axial load(Down force)	Frictional heat maintaining contact conditions

Tool rotation, Transverse speed, Tool tilt angle and plunge:

In addition to the tool rotation rate and transverse speed another important process parameters are tool tilt with respect to the work piece surface plunge depth. The tool is usually characterized by a small tilt angle (ϴ) and as it inserted into sheets the materially was undergoes to a local backward extrusion (Frantini. L *et al*) For FSW, two parameters are very important: tool rotation rate (v, rpm) in clockwise direction and tool transverse or counter clockwise direction and tool traverse speed (n, mm/min) along the line of joint. The motion of the tool generates frictional. Tool rotation rate and travel speed, another process parameter is angle of spherical tool respect to the work piece surface . Tool tilt direction ensures holds the stirred material from the front to the back direction pin . Material to a load extrusion process up to the tool is used further , the plunge depth of pin of work piece.

Tool Used In FSW Process:

lienert *et al* found that a partial solution can be found by the slow plunge rate, preheating the plunge area, partial penetration and artia diameter of the hole. Wc (tungsten carbide) materials are used in the joining of high carbon steels Eni *et al*. Wc based tools are strong and with stand at elevated temperatures. This tool materials has good toughness and excellent thermal conductivity at temperatures below Al, Chung *et al*. The joining of materials such as steels requires tools which can operate at high temperatures and also maintain high strength and hardness of the tools. The PCBN tools are used to join the stools of FSW process Rai *et al*. The PCBN material can weld very had alloys such as Titanium, and it was a low coefficient of friction.

Conclusion:

This paper is overview the performance of the FSW tool design. It is concluded that, FSW tool is a heart of the FSW process. It shows the performance of the FSW is based on the tool geometry, tool material, shoulder design, pin design. It may conclude as tool design is strongly affect the quality of the weldment. There are numerous works are carried out in the FSW. However, further research is required to achieve the better weldment with reduced cost. Thus, the scope for the further research in FSW is given below.

1. Effect of other process parameters like tilt angle, tool material etc may be investigated.
2. Different design of the tool could be used to investigate the effect of the tool design. The study could be extended to lap joints and investigated in the same way. Development of better tool profile, which is economical, may deliver better results.
3. Thermocouple may be used to measure the temperature at different zones- HAZ and base metal.
4. Alloy elements in the form of powder may be added in the stir zone.

In addition, further study into welding of unequal gauge materials or dissimilar alloys would provide a more thorough understanding of the capabilities of friction stir welding and possible applications for use. The temperature needs for each different material will be important to consider while welding dissimilar alloys. Research needs to be done in the area of FSP as it has proved to be a viable method that could be used to improve mechanical and metallurgical properties of various aluminium alloys. Aluminium alloys and Steel are normally grouped according to their applications in industry and the introduction of FSP tends to improve an otherwise good alloy by introducing super plastic properties and grain refinement of the parent material. The research could be taken further by applying the same technique to other Aluminum alloys which are used in the utomotive industry. This could help the increase of use of the friction stir welding in the automotive industry.

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