

STUDY OF TOOL GEOMETRY FOR FRICTION STIR WELDING – A REVIEW

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ABSTRACT: - Friction Stir Welding (FSW) is solid state joining process. It is widely used for joining dissimilar material welding like steel with aluminum alloy which are very difficult to join by fusion welding. FSW weld quality is mainly influenced by shoulder & pin geometry, diameter, tool material, rotation speed and feed rate. It is observed that the effect of pin geometry and tool material selection should be based on welding materials. FSW can be used for joining many types of materials and different material combinations. This review paper suggests about the various tool geometries and tool materials with different coatings that are used in FSW to conduct several experiments, thereby increasing the weldability of FSW.

Keywords: FSW tool geometry, tool coating, weldability, fusion welding

INTRODUCTION:

The conventional welding process involves the melting and fusion of the metal that is to be joined. The conventional welding processes involve the use of filler material and the possibility of occurrence of defects like slag inclusion, porosity, cracks and surface damage is more. Also these processes cannot be used to join dissimilar metals. Hence a new welding process called Friction Stir Welding was developed to join dissimilar metals. Friction Stir Welding is a solid-state process in which metal parts are joined without reaching the melting point. FSW process involves a rotating tool consisting of a pin and a shoulder. The pin is fixed on the shoulder. Pin is inserted between adjoining metal pieces and then the shoulder is placed at top surface of the joint. The rotating tool generates heat between the interfaces of the adjoining metal pieces due to friction and brings the metal to a viscos plastic state. There is a flow of this plasticised metal as the tool is translated along the welding direction and thus forms a weld joint. This weld joint will have a fine microstructure and it exhibits good mechanical properties. The stirring of the tool produces negligible local inclusions at the weld joint and thus makes the weld joint void-free structure.

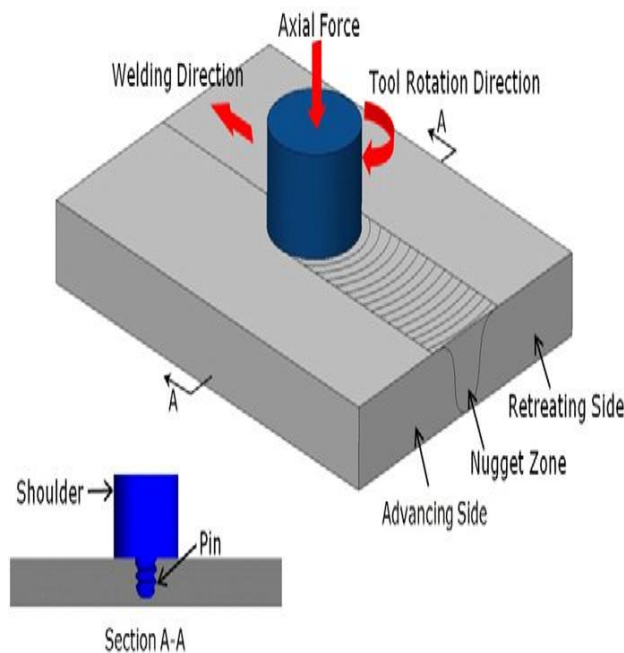


Fig 1 Schematic Drawing of FSW[7]

Process parameters of FSW:

The process parameters in friction stir welding are listed below

- Tool rotational speed
- Shoulder diameter
- Axial force
- Welding speed
- Pin diameter and profile
- Shoulder and pin material
- Work piece material
- Tilt angle

Tool Materials:

The characteristics that are to be considered for material choice are ambient and elevated temperature stability, elevated temperature strength, fracture toughness, wear resistance tool reactivity, machinability, coefficient of thermal expansion. The commonly used tool materials are WC-Co based alloys, TiC, TiC–Ni–W, Ti–Ni–Mo, PCBN, AISI H13, AISI 4340, Wear resistant steel Ni/Co based alloys.

Tool Geometry:

Tool geometry is an important factor that determines the mechanical properties of the weld joint. The tool geometry has to be properly selected depending upon the material that is to be welded. The following are the various tool geometries that are generally used: Round-bottom tool, Flat-bottom tool, MX triflute tool, A-skew TM shaped tool, Trivex tool, Thread less tool.

Advantages of FSW:

- Friction welding is eco-friendly process as it does not generate fumes, gases or smoke.
- It reduces machining labor, which in turn increases capacity and reduces perishable tooling cost.
- It creates a narrow heat affected zone.
- It reduces maintenance cost.
- Friction welding is consistent and repetitive process
- As friction welding is a solid state process, possibility of porosity and slag inclusions are very less when compared to conventional welding process.
- Dissimilar materials which are normally not compatible for welding can be friction welded.
- It consumes low energy and low welding stress.
- It reduces cost for complex forgings or castings.

LITERATURE REVIEW:

Atul Suri [1] in his research work in the improvement of FSW tool for joining commercial aluminum plates have discussed about the newly developed flat pin tool with side radius and with standard straight threaded pin tool with flat collar made of hardened steel. He has studied the effect of FSW on toughness, strength, microstructure and hardness with different tool rotational speed from 400 rpm to 1400 rpm, at a constant feed rate i.e., at 30 mm/min. In his research, he conclude the followings,

- It is observed that surface appearance and the accumulation of material on the advancing side increases with the decrease of tool rotational speed at a constant feed rate
- The hardness reduces with increase of tool speed. Improved flat pin tool indicates better hardness of weld zone.
- Increasing the tool rotation speed at 1200 rpm and 1400 rpm surface defects on weld specimen result in poor mechanical strength at the weld zone.
- Increased modulus of toughness is observed for the specimen produced by improved tool
- The elongation of FS- welded specimen is less than uniform plate virgin specimen.

Yuang-Cherng Chiou et al [2] in their research paper of FSW of aluminium alloy using pinless embedded tool and plain tool proposed to achieve high butt tensile strength in aluminium alloy sheets. In their experiment, they have used hollow cylindrical tool with cylindrical insert rod made of aluminium alloy. They have discussed about the mechanism of weld formation, effects of rod diameter, weld structure and failure load of FSW. They have concluded that failure load of the weld increases along with the diameter of the embedded rod due to the higher friction and adhesive action. The failure load of embedded tool was found to be about 1.46 kN and the failure load is about 0.72 kN for the plain tool.

Kush P.Mehta et al [3] in their study on effects of tool pin design on formation of defects in dissimilar friction stir welding carried out FSW on dissimilar copper to aluminium materials by nine different tool designs. Various tool profiles such as cylindrical, triangular, square and hexagonal tool profiles were used in their experiments and the following conclusions were made from their investigation:

- Using polygonal pin designs, large particles of copper were detached from the base material.

- Maximum irregular and large copper particles were reported in welds that are made by triangular pin profiles.
- Polygonal pin profiles caused defects such as, cracks, fragmental defects and voids irrespective of its static and dynamic constant areas.
- The defects were decreased, with increase in polygonal edges.
- Defect free macro joint was reported for cylindrical tool pin profile.
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C.Devanathan et al [4] in their research work on FSW of metal matrix composites using coated tool conducted experiments on FSW of aluminium alloy reinforced with Silicon Carbide as the parent material and high speed steel as the tool material. The tool material was coated with TiAlN upto 4 microns by Physical Vapour Deposition technique. They have concluded

- After welding no physical wear was observed and aluminium particles were deposited over tool pin.
- The optimal process parameters were observed to be at spindle speed of 1500 rpm, traverse speed of 40mm/min and axial load of 8 KN.
- The axial force contributed upto 35% of the FSW process parameters while the traverse speed and spindle speed contributed upto 25% and 12% respectively.
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Giuseppe Casalino et al [5] in their study on Influence of Shoulder Geometry and Coating of the Tool on the Friction Stir Welding(FSW) of Aluminium Alloy Plates investigated on the effects of geometry and surface coating of the tool shoulder on the defectiveness, microstructure and the micro hardness of a 3 mm thick aluminium alloy butt weld. They have conducted experiments on various tool geometries such as tools with conical small shoulder, flat small shoulder, carbide large shoulder, carbide large flat shoulder with coating at tool speed ranging from 500-1700 rpm. They have discussed about weld appearance, cross section, micro hardness and grain size of the samples and the following conclusions were obtained:

- Conical tool produced smooth surface at the joint
- The carbide coated tool with large shoulder produced almost defect free weld
- The hardness profile and the size of the microstructural zones were dependent on the shoulder size.
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Y.Gao et al [6] in their investigation on optimizing tool diameter for Friction stir welded brass/steel lap joint used brass plate as the top plate and structural steel as the bottom plate in the FSW process. In their study, they used five kinds of WC-Co based tools with different probe diameters ranging from 6-10 mm and shoulder diameters ranging from 15-20 mm.in this paper they have discussed about microstructures and macrostructures of FSW joints, hardness in joints, tensile properties of joints. They have concluded that increase in probe diameter and decrease in shoulder diameter improved the tensile shear fracture load of the lap joints. But the tensile shear strength decrease with the increase in probe and shoulder diameters.

Omar S. Salih et al [7] in their research work of FSW of aluminium matrix composites have reviewed with specific attention and critical assessment given to macrostructure and microstructure of AMC joints, evaluation of mechanical properties of joints, and wear of FSW tools due to the presence of reinforcement materials in aluminium matrices. In their paper they have discussed the

Mechanical properties of FSW joints in AMCs such as Micro hardness of AMC joints, Tensile strength of AMC joints, Effect of tool design, Effect of welding parameters, Fatigue strength of AMC joints. They have concluded that, severe wear of FSW tool occurs in the pin when steel is used as tool material for joining AMCs. Tool wear resistance can be improved by changing the design and the pin material. Suitable coating material compatible with the substrate tool materials that can improve wear resistance.

Rong-Tsong Lee et al [8] in their study on the effect of nickel coating on the shear strength of Friction Stir Welding lap joint between Ni-Cu alloy and steel investigated about the interface temperature, downward force at various rotating speeds of the tool .They have also discussed about the effect on Ni coating thickness and the various welding parameters with Cu-Ni alloy and low carbon steels as the base material and High Speed steel as the tool material. The conclusions revealed that the shear strength is about 2.9 times as high as that of joints without Ni coating. Maximum shear strength was obtained at the rotating speeds of 800-1400 rpm and feed rate of 10mm/min. Due to the presence of Ni coating micro-voids were reduced in size.

M.Karthikeyan et al [9] in their research paper on influence of tool design on mechanical properties and microstructure in Friction Stir Welding(FSW) of AA6351 aluminium alloy made an investigation to study the effect of tool pin profiles on weld and the tensile properties of the weld structure. They proposed three different tool pin profiles (square, circle, threaded) made of High Speed Steel. The tensile strength test and Vickers hardness test revealed that tool pin profile straight square tool at (900rpm) gives more tensile strength & Vickers hardness when compared to other tools. The square tool results in the formation of very fine grain microstructure and higher stir zone hardness at 900 rpm.

R. Karimdadashi et al [10] in their research paper on the tool shape effect on mechanical properties of FSW joints of 2024- T4 aluminum alloy investigated the effect of tool shape on microstructure and mechanical properties of the weld zone in 2024 aluminium alloy. They used tools with threaded profile and square profile with a rotational speed of 1200 rpm and feed rate of 25, 50, 75, 150 and 200 millimetres per minute. The experiments on both the tool profiles revealed that the tool with a square pin have better mechanical properties, especially better tensile strength than the threaded profile pin. The yield strength of both square and threaded tool increases with the increase in feed rate. At the feed rate of 200mm/min the vicker's hardness value for both the tool profiles is almost equal.

Venugopal.S et al [11] in their research work studied the impact on Hss Tool Pin Profile in FSW Welded Joints on Mechanical Properties of Aa7075-T6 Aluminium Alloy. In this paper they have analysed about the microstructure of aluminium AA 7075-T6 alloy with three different tool profiles (Taper Threaded, cylindrical and square) to construct the joints in particular rotational speed. The tensile, Impact, micro hardness of mechanical properties of the joints have also been evaluated. From the research it was found that the threaded cylindrical profile produces highly defined Strength in the welds. The Taper threaded cylindrical pin profile exhibits the better tensile strength at 800 rpm, higher quality for this alloy. From the effect of axial load it has been concluded that the impact strength of threaded pin tool is higher than the square pin tool.

Moslem Paidar et al [12] in their research paper on the Shoulder Geometry and Effect of Pin on Stir Zone and Mechanical Properties of Friction Stir Spot-Welded aluminium Alloy 2024-T3 Sheets worked on Aluminium 2024-T3 sheets as their samples with H13 Steel in the form of cylindrical and triangular profiles as their tool material. In their paper, they have studied about the mechanical properties and the stir zone characteristics of the samples. From their experiments, the following conclusions are listed below:

- At low rotational speeds, triangular pins resulted in finer grains than the cylindrical pins.
- The change in cross section of the pin will result in the reduction of the stir zone.
- The shape of the hook at the joints was dependent on the shoulder geometry.
- Hardness decreased from the stir zone to heat affected zones at all tool rotational speeds.

M. Shamsujjoha et al [13] in their research paper on Friction Stir Lap Welding of Aluminum to Steel using Refractory Metal Pin Tools investigated about the effects of plunge depth, microstructure and mechanical properties of the weld joint. In their experiments, Aluminium and Steel were friction stir lap welded using two different Tungsten-Rhenium HfC pin tools having two different pin lengths and pin diameters. The conclusion showed that joint efficiency of 58% was achieved when lap welds were made using the pin tool with longer pin length and also W-Re-HfC tools are capable of producing lap joints with good mechanical properties.

Heena K Sharma et al [14] in their experiment on the Analysis of Friction Stir Welding(FSW) of Dissimilar Alloys AA6061 and Mg AZ31 using Circular Butt Joint Geometry carried out friction stir welding process on aluminium and magnesium alloy plates of 6 mm thickness. Different tool materials like HSS, Tool steel-H13 and HCHCr with different tool profiles with rotational speed ranging 800-1200 rpm and feed rate 10-40 mm/min were used in the process to assess the mechanical properties of weld joints. The following conclusions were obtained: (a) Aluminium and Magnesium plates can be welded FSW if proper tool profile and process parameters are selected (b) Mechanical properties of weld joint is more influential at a rotational speed of 1200 rpm and welding speed of 10 mm/min when HCHCr tool with cylindrical threaded profile is used.

G. Rambabu et al [15] in their investigation on Optimization of friction stir welding (FSW) parameters for improved corrosion resistance of AA2219 aluminium alloy joints have discussed about the improvement in corrosion resistance in the weld joint of Al-Cu-Mg alloy. They have discussed about the effects of welding parameters like tool pin profile, rotational speed, welding speed and axial force and their influence in the microstructure and corrosion resistance of the alloy. Five different tool geometries like square, hexagon, triangle, pentagon and conical were considered in their experiment and the following conclusions were made (a) Hexagonal tool profile produced the best quality weld and that shape pin plays a significant role in the structure of the joint and its resistance to corrosion (b) Mathematical models were developed to determine the optimised friction stir welding parameters for each material.

Conclusion:

This review paper has made an attempt to present the recent works carried out by different researchers working in FSW. The review clearly indicates us the importance of tool geometry and

process parameters for the better mechanical properties of the welded materials. Also coatings of the tool can improve the tool life and weldability. For research work is in process to improve the tool efficiency.

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