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Review of Friction Stir Welding Tools

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ABSTRACT

Friction Stir Welding is a solid state welding process that can be applied to non ferrous materials like aluminium, magnesium, copper, brass and zinc and different joint designs such as butt joint, T-butt joint, corner joint and lap joint. Focus of this review paper is to analyze and discuss the outlines of tool pin and shoulder geometry, tool material and influence of tool on mechanical and metallurgical properties. Tool design, material and welding parameters play vital role on mechanical and metallurgical properties of weld joints, defect free weld, better material flow, friction heat and finer grain size. H13 is used more than any other tool steel in tooling applications due to excellent combination of high toughness and fatigue resistance. Higher mechanical properties and better intermixing were obtained by tapered threaded pin. The scrolled shoulder and triflute pin was most effective shape for welding at high speed with increased amount of plastic deformation and stirring of the workpiece. The microstructural zone, hardness profile and tensile strength are depending upon shoulder size and pin profile.

Keywords – Friction stir welding, Rotating tools, Tool materials, Pin profiles

1. INTRODUCTION

Friction Stir Welding (FSW) was invented by The Welding Institute (TWI) in 1991 especially for aluminum alloys. The process requires lower energy than conventional fusion welding processes and no consumables such as electrodes and protecting gases are needed and have been successfully applied to the aerospace, automobile, shipbuilding industries, etc. In this process a rotating tool is inserted into the butt of the work piece due to the action of the axial pressure it produces a highly plastically deformed zone through the associated stirring action. Studies report that temperature in the material being welded is usually less than 80% of its melting temperature.

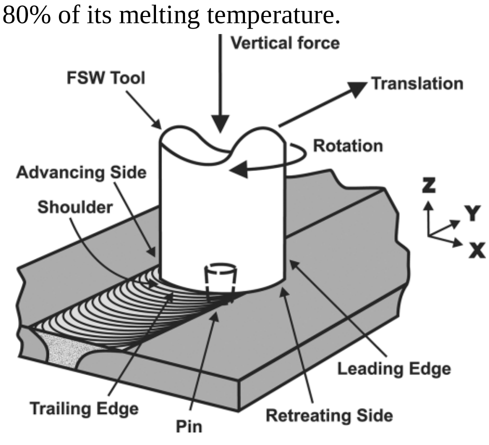

Fig.1 Basic principle of friction stir welding process.

Bahrami et al., [8] used threaded tapered, triangular, square, four-flute square, and four-flute cylindrical pin profiles with 5.7mm. Bahrami et al., [8] examined the role of pin geometry in mechanical properties using H13 steel and heat treated to 58HRC. Ramachandran et al., [28] investigated effect of tool axis offset and geometry of tool pin profile on the characteristics of aluminum alloy AA5052 and HSLA steel using carbide pin and shoulder and oil hardened EN31 steel shank to reduce the cost of the tool. Luis Trueba Jr et al., [32] studied the effect of tool shoulder features on defects and tensile properties of aluminum 6061-T6 with pins such as non threaded, flat bottom and cylindrical were pressed fit into the tools. In addition to that a wiper feature was included around the outer diameter of the shoulder of tool which improves the surface finish of welds.

2. TOOL SHOULDER AND PIN GEOMETRY

Li et al., [1] used bobbin-tool to conduct the friction stir welding for Mg AZ31 alloy shown in figure 2. Tarasov et al., [2] investigated diffusion controlled wear mechanism of alloy steel tools to weld aluminum alloy using tool with shoulder diameter of 19 mm and pin diameter of 6 mm. Binbin Kuang et al., [3] friction stir welded of 1A99 Al to pure copper using 0.2 mm zinc foil as filler metal with pinless tool configuration. Metha et al., [6] prepared the numerical model for friction stir welding in associated with polygonal pin length of 4.7 mm and shoulder diameter of 12 mm shown in figure 2.

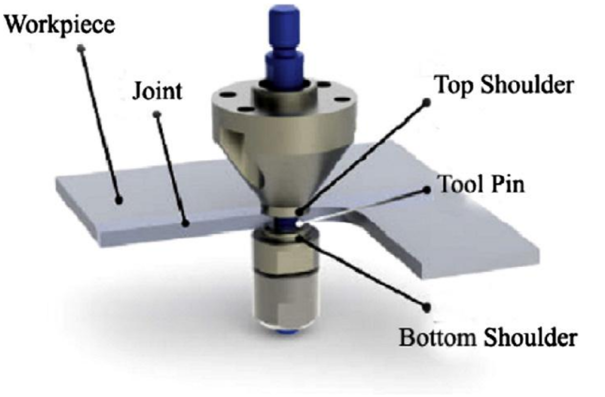

Fig. 2 Schematic of BT-FSW.

Weifeng Xu et al., [7] investigated the influence tool pin profile on microstructure and mechanical properties of aluminium alloy with application of shoulder diameter of 26 mm and two tools pin profiles threaded and tapered with three spiral flutes, second tool is threaded and tapered with triangle. Bahrami et al., [8] examined the role of pin geometry in mechanical properties by five tools with different pin geometries namely threaded tapered, triangular, square, four-flute square, and four-flute cylindrical with 5.7 mm long pin shown in figure 3. Sued et al., [9] designed the bobbin tool for friction stir welding with scrolled shoulder and threaded pin. Emad Salari et al., [10] analysed the influence of tool geometry on mechanical properties 5456 aluminum alloy using four different tool pin profiles namely conical thread pin, cylindrical conical thread pin, stepped conical thread pin and flared triflute pin tool.

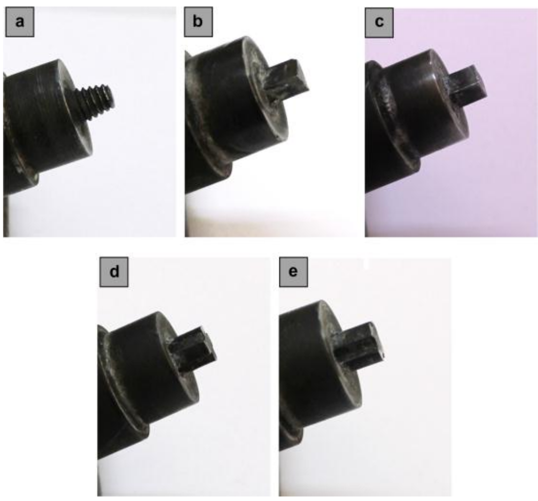

Fig. 3. Designed pin geometries: (a) TT, (b) T, (c) S, (d) FFS, and (e) FFC pin tool.

Salari et al., [10] analysed the influence of tool geometry on mechanical properties with applications of shoulder diameter of 20 mm and the pin length of 7 mm. Anand Kumar et al., [11] studied influence of tool geometries on welding of metal matrix composites with 7 mm diameter titanium probe of having anticlockwise thread of 1 mm pitch, moreover the threaded probes were further hardened by oxyacetylene gas flame followed by oil quench for improving the wear resistance of the probe. Ji et al., [12] fabricated stationary shoulder tool for welding of AA6005-T6 aluminum alloy associated with pin diameter is tapered from 5 mm at pin bottom to 3 mm at pin tip and the rotational pin with right screws rotates clockwise. Mao Yuqing et al., [13] investigated effect of tool pin eccentricity on mechanical properties using shoulder diameter of 28 mm and tapered threaded pin diameter of 10 mm and 5 mm at the head and pin length of 9.7 mm.

Mohammadi et al., [18] examined effect of tool geometry on the properties of magnesium/aluminum alloy with applications of concave shoulder with a diameter of 18 mm and tapered threaded and tapered pin profiles with an increasing diameter from 5 to 6 mm, and length of 4.5 mm. Juan Chen et al., [19] welded magnesium alloy by double sided friction stir welding with concave and convex tools the upper tool has threaded probe with a cylindrical shape the lower tool has a concave shape with a hole, which is shown in figure 4.

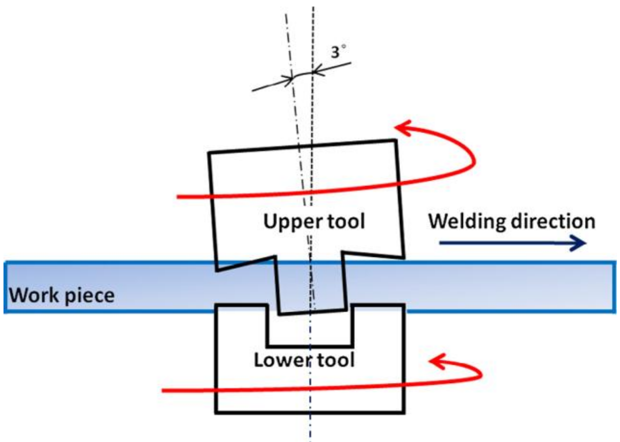

Fig. 4. Schematic illustration of the DFSW with a concave lower tool.

Hao Su et al., [20] used numerical modeling to study the effect of pin profiles on thermal and material flow characteristics by conical and triflat tool pins and the diameter of tool shoulder was 15 mm, the top and bottom diameter of pin was 6 mm and 4 mm and the length of the pin was 5.75 mm. Costa et al., [23] investigated influence of material properties and tool geometry on weld strength for AA 5754-H22/AA 6082-T6 aluminium alloys, the weld was performed with a 12 mm diameter conical shoulder and 1.3 mm long cylindrical and conical pins. Zhengwei Li et al., [24] studied Joint features and mechanical properties 2024 aluminum alloy assisted by external stationary shoulder. Mario Guillo et al., [25] investigated the improvement of tool deviation in friction stir welding with the application of conical left-hand threaded pin of 3mm diameter and 2.8mm long and shoulder is a scroll shape with a diameter of 8.5 mm. Kumari et al., [27] studied the role of tool on material flow and weld formation using 4.2mm long frustum shaped pin of 6mm top and 4mm bottom diameter with 20mm flat shoulder diameter.

Ramachandran et al., [28] investigated effect of tool axis offset and geometry of tool pin profile on the characteristics of aluminum alloy AA5052 and HSLA steel by three different taper cylindrical and one straight cylindrical tool pin profiles with length 2.7mm and diameter 4mm. Elangovan et al., [29] examined the influences of tool pin profile on the formation weld zone in AA2219 aluminium alloy using straight cylindrical, taper cylindrical, threaded cylindrical, square and triangle pin profiles. Galvao et al., [30] analyzed influence of tool shoulder geometry on thin copper sheets in associated with 3 mm diameter and 0.9 mm length right hand threaded cylindrical pin and three shoulder geometries such as flat, 6◦ conical concave and scrolled shoulder with13 mm diameters. Luis Trueba Jr et al., [32] studied the effect of tool shoulder features on defects and tensile properties of aluminum 6061-T6 associated with pins such as non threaded, flat bottom and cylindrical were pressed fit into the tools. In addition to that a wiper feature was included around the outer diameter of the shoulder of tool which improves the surface finish of welds.

Cost et al., [34] analysed influence of pin geometry and process parameters on lap joint of AA5754-H22 thin sheets along with shoulder diameter of 12mm cylindrical and conical pins of 6mm diameter. Gaoa et al., [35] used concave shoulder of 15 and 20 mm in diameter, different probe diameters of 6, 8 and 10 mm but the constant probe length of 2.9 mm shown in figure 5. Dehghani et al., [37] investigated the effect of welding parameters and tool geometry on properties of AA3003-H18 mild steel by two tools like first tool consisted a shoulder diameter of 24 mm and a cylindrical non threaded pin with a diameter of 6 mm and second tool diameter of 18 mm with non threaded conical pin. Dawood et al., [39] analysed the effect of small tool pin profiles on microstructures and mechanical properties of 6061 aluminum alloy using threaded tapered cylindrical pin, triangular pin and square pin profiles diameter of 2 mm and length of 3.7 mm with tool shoulder diameter of 9 mm. Arora et al., [41] optimized the tool shoulder diameter with respect to rotational speed as 18mm diameter at 1200rpm rotational speed resulted superior tensile properties.

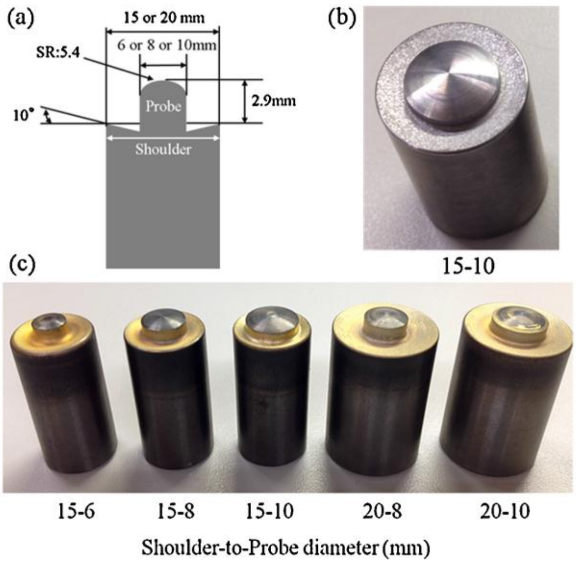

Fig. 5 The pictures of FSW tools. (a) Schematic diagram of tool, (b) the appearance of tool before FSW (SD:15 mm, PD:10 mm), (c) the appearances of five kinds of tools after FSW.

Trimble et al., [42] investigated characteristics of tool shape and rotational speed for AA2024-T3 alloy using concave and scroll shoulders with a diameter of 18 mm and three different pin shapes square, cylindrical and triflute with diameter of 6.5 mm and length of 4.5 mm. Bandari Vijendra et al., [43] used induction heated tool for his study along with shoulder diameter of 10 mm and the taper threaded pin with major and minor diameter of 6 and 5 mm with length of 3.83 mm. RajKumar et al [44] studied the effect of tool design and welding parameters on dissimilar aluminium alloys AA 5052 – AA 6061associated with shoulder diameter of 16mm and cylindrical pin of diameter 6mm. Giuseppe Casalino et al., [45] used cylindrical threaded pin for excellent bondage between AA 5052 and AA 6061 alloys along with three types of tools such as the first tool had a 10 mm shoulder and 7° conical edge cylindrical pin with a 4 mm flat bottom and a 2.8 mm height, second tool was made up of the conic shoulder but had a different shoulder size which was flat with

10.32 mm and third tool made up of shoulder diameter of 25 mm with a 7° concavity and pin was trunk conic with a flat bottom of 2.8mm height.

Vinayak Malik et al., [46] investigated the effect of various tool pin profiles using finite element simulations with six pin profile tool such as cylindrical, square, triangular, rectangular, polygon and hexagonal pins. Shayan Eslami et al., [47] studied the effect of parameters using newly developed tool for polymers, the newly developed tool consisted static shoulder made by teflon with a highly conductive bronze sleeve around the rotating pin profiles like flat and triangle diameter of 6mm. Ugender et al., [49] investigated tool geometry on mechanical properties for AA2014 Aluminium alloy with application of shoulder diameter of 18mm and tapered cylindrical and straight cylindrical pin profiles with diameter of 6mm and length of 4.8mm. Bayazid et al., [50] analyzed the effect of pin profile on AA7075 aluminum alloy associated with pin profiles like cylindrical, square and triangle tool. Ch Venkata rao et al [53] studied effect of tool profile on microstructure and pitting corrosion resistance of AA2219 alloy using conical and triangle pin profiles. Additionally pitting corrosion resistance of weldment was better for triangle pin profile compared to conical pin. Ilangovan et al., [54] studied effect of tool pin profile on microstructure and tensile properties of AA 6061-AA 5086 aluminium alloy with application of straight cylindrical, threaded cylindrical, and tapered cylindrical pin profiles length of 5.7 mm and shoulder diameter of 18mm. Ch. Venkata rao et al., [55] analysed influence of tool pin profile on microstructure and corrosion behavior of AA2219 Al-Cu alloy weld nuggets with shoulder diameter of 30 mm and conical, triangular, square, pentagon and hexagon pin profiles diameter of 10 mm and height of 7.5 mm shown in figure 6. Venkateshkanan et al., [56] investigated influence of tool geometry on metallurgical and mechanical properties for AA2024 and AA5052 alloy using cylindrical, cylindrical threaded, squared, tapered and stepped pin profile tools.

3. TOOL MATERIAL OF FSW TOOL

Tarasov et al., [2] used hot work tool steel as the tool material to conduct friction stir welding. Devanathan et al., [5] friction stir welded of metal matrix composite using high speed steel as the tool material and then tool was coated by TiAlN on the tool material to the thickness of 4 microns. Mehta et al., [6] used the EN40 tool for tool material and polygon pin. Weifeng Xu et al., [7] investigated the influence tool pin profile on microstructure and mechanical properties of aluminium alloy by using H13 steel as the tool material. Bahrami et al., [8] examined the role of pin geometry in mechanical properties using H13 steel and heat treated to have 58HRC. Emad Salari et al., [10] analysed the influence of tool geometry on mechanical properties of 5456 aluminum alloy with tool material H13 steel tool. Mao Yuqing et al [13] investigated effect of tool pin eccentricity on mechanical properties for AA7075 aluminium alloy with GH4169 steel. Charles et al. [14] used stationary shoulder for welding of steel and tool had chemical composition of 70% pcBN/30%. Christopher Tingey et al. [16] welded DH36 steel by friction stir welding with hybrid composite WRe-PCBN tool as a tool material.

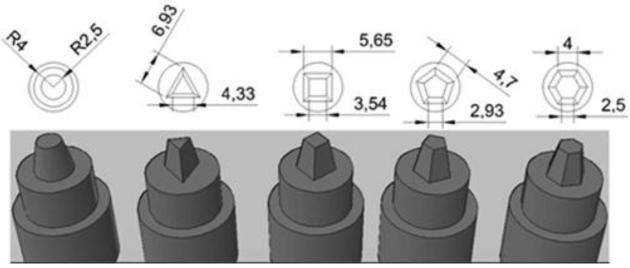

Fig. 6 Geometries of five tool profiles and weld joints made with five tools.

Mohammadi et al., [18] examined effect of tool geometry on the properties of magnesium/aluminum alloy using H13 tool steel. Juan Chen et al., [19] welded magnesium alloy by double sided friction stir welding with concave and convex tools made by tool steel. Ragu Nathan et al., [21] investigated metallurgical characteristics of friction stir welding of high strength low alloy steels using tungsten as tool materials. Mario Guillo et al., [25] investigated the improvement of tool deviation in friction stir welding with application of H13 tool steel as tool material. Kumar et al., [27] studied the role of tool on material flow and weld formation, they used H13 tool steel and hardened to 55HRC. Ramachandran et al., [28] investigated effect of tool axis offset and geometry of tool pin profile on the characteristics of aluminum alloy AA5052 and HSLA steel associated with carbide pin and shoulder and oil hardened EN31 steel shank to reduce the cost of the tool. Elangovan et al., [29] examined the influences of tool pin profile on the formation weld zone in AA2219 aluminium alloy using high carbon steel as tool material.

Luis Trueba Jr et al., [32] studied the effect of tool shoulder features on defects and tensile properties of aluminum 6061-T6 alloy by using AISI 1090 steel pins.

Cost et al., [34] analyzed influence of pin geometry and process parameters on lap joint of AA5754-H22 thin sheets with application of CN8 tool as tool material. Gaoa et al., [35] optimized tool diameter for brass/steel lap joint with WC-Co tools. Dawood et al., [39] analyzed the effect of small tool pin profiles on microstructures and mechanical properties of 6061 aluminum alloy by using medium carbon steel as a tool material and heat treated to 58 HRC. Trimble et al [42] investigated characteristics of tool shape and rotational speed for AA2024-T3 alloy using AISI H 13tool steel. Bandari Vijendra et al., [43] used induction heated tool for his study and H13 tool steel as the tool material with heat treated to 53HRC. RajKumar.V et al., [44] studied the effect of tool design and welding parameters on dissimilar aluminium alloys AA 5052 – AA 6061 associated with AISI H13 tool steel. Relationship between base material and tool material is shown table 1.

Table 1 Relationship between base metal and tool material.

Base Metal	Tool Material
AA7075/SiC nano-composite	H13 tool steel
AA5456 aluminum alloy	H13 tool steel
AZ31 Magnesium alloy and 6061 aluminium alloy	H13 tool steel
AA 5754-H22 aluminium alloy	H13 tool steel
AA7020-T6 aluminium alloy	H13 tool steel
AA5052 aluminium alloy and HSLA steel	Carbide
AA5754-H22 aluminium alloy	CN8 tool
Brass and Steel	WC-Co
Austenitic stainless steel	Polycrystalline cubic boron nitride
AA 6061 and AA 5086 aluminium alloy	High speed steel
AA2219 aluminium alloy	EN24 tool steel
AA2024 and AA5052 aluminium alloy	H13 tool steel
Titanium	WC 411

Giuseppe Casalino et al., [45] used cylindrical threaded pin for excellent bondage between AA 5052 and AA 6061 alloys with tungsten carbide tool material. Manish Meshram et al., [48] friction stir welded austenitic stainless steel by PCBN tool and analyzed the joint using polycrystalline cubic boron nitride with tungsten rhenium composite tool material. Ugender Singarapu et al., [51] investigated the influence of tool material and rotational speed on mechanical properties for AZ31B magnesium alloy using three tool materials stainless steel, high speed steel and H13 tool steel. Lakshminarayanan et al., [52] investigated feasibility of surface coated tools to join AISI 304 grade austenitic stainless steel the refractory ceramic composite such as tungsten carbide, chromium carbide, boron carbide, titanium carbide and boron nitride used to coating on the inconel 738 alloy with atmospheric plasma spray and plasma transferred arc hardfacing processes. Ilangovan et al., [54] studied effect of tool pin profile on microstructure and tensile properties of AA 6061-AA 5086 aluminium alloy by using high speed steel as the tool material. Ch. Venkata rao et al., [55] analyzed influence of tool pin profile on microstructure and corrosion behavior of AA2219 Al-Cu alloy weld nuggets associated with EN24 tool steel as the pin material. Venkateshkanan et al., [56] investigated influence of tool geometry on metallurgical and mechanical properties for AA2024 and AA5052 alloy with application of H13 tool steel as the tool material. Jiye Wang et al., [4] studied tool wear mechanisms on Ti–6Al–4V alloy with three tool materials such as W–La, CY16 and WC411.

4. INFLUENCE OF TOOL ON MECHANICAL AND METALLURGICAL PROPERTIES

Binbin Kuang et al., [3] joined 2mm copper and aluminium plates the results showed that when the tool rotating speed increased and traverse speed decreased the thickness of the interlayer is decreased. Devanathan et al., [5] used TiAlN coated tool to weld metal matrix composite they showed that no noticeable tool wear and only aluminum particles were deposited on the tool pin. Mehta et al., [6] used the polygon pin for his investigation, it was found that the mechanical strength of weld joint is improved than the tools with circular pins, Furthermore they noticed that the hexagonal pins experienced the less resultant maximum shear stress than the triangular pin. Weifeng Xu et al., [7] analyzed the influence of tool pin profile on mechanical strength and microstructure for aluminium alloy, the results indicated that hardness decreased slightly using the pin with threaded and tapered with triangle furthermore strength and ductility increase with the increase of traverse speed to 100 mm/min or the decrease of rotational speed from to 300 rpm.

Mohsen Bahrami et al., [8] examined the role of pin geometry in mechanical and microstructure properties of AA7075 -SiC nano composite, it was shown that most uniform particles distributed uniformly while using threaded tapered pin tool. Moreover threaded tapered specimens showed highest microhardness and four flute cylindrical specimens showed the lowest microhardness. In Addition the highest ultimate tensile strength was recorded for the specimen with triangular pin tool. Relationship between base metal thickness and pin profile is shown in table 2.

Table 2 Relationship between base metal thickness and pin.

Thickness of base metal	Pin Profile
1 mm	Threaded cylindrical
1.5 mm	Cylindrical and conical
2.5mm	Tapered cylindrical
3 mm	Conical threaded pin
4mm	Threaded tapered, cylindrical, triangular and square
5 mm	Polygon
6 mm	Threaded tapered, triangular, square, four flute square, and four flute cylindrical
7 mm	Conical thread, cylindrical conical thread, stepped conical thread and flared triflute
8 mm	Square frustum, Square frustum probe, and Conical probe
10 mm	Tapered threaded

Sued et al., [9] designed the bobbin tool for friction stir welding the results revealed that the best joint was produced by four flats tool pin. Emad Salari et al., [10] analysed the influence of tool geometry on mechanical properties of 5456 aluminum alloy, they found that optimum microstructure and mechanical properties were obtained for the joints produced with the stepped conical thread pin profile furthermore the highest joint performances were obtained with the stepped conical thread. Mao Yuqing et al., [13] investigated effect of tool pin eccentricity on mechanical properties in friction stir welded 7075 aluminum alloy, the nugget area increases firstly and then decreases with increasing the pin eccentricity furthermore the joints produced by the pin with 0.2 mm eccentricity perform the highest tensile strength and elongation.

Huijie Zhang et al., [15] friction stir welded 2A14-T6 aluminum alloy and studied the influence of bobbin tool on mechanical properties, it was revealed that the grains in the upper layer of weld nugget zone are smaller than those in the lower layer of weld nugget zone furthermore the insufficient material plastic deformation caused by the flat feature of tool pin. Hamed Jamshidi Aval et al., [17] analysed influences of pin profile on the mechanical and microstructural behaviors for AA6082–AA7075 alloy they noted that the highest temperature in the welded joints made by the tool with a conical probe with three grooves than those made by the tools with square frustum probes. Furthermore mixing of materials in the weld nugget of samples welded using the tool with a square frustum probe was more uniform than that in the other samples. Mohammadi et al., [18] examined effect of tool geometry on the properties of magnesium/aluminum alloy their results clearly showed that higher mechanical properties and better intermixing between Al and Mg alloys were obtained when pin tool with the tool geometry of tapered threaded pin was used in comparison with the tapered pin tool. X -ray diffraction pattern for stir zone

Juan Chen et al., [19] welded magnesium alloy by double sided friction stir welding with concave and convex tools the results showed that mean grain size of the stir zone of the concave double sided friction stir welding increases with the decreasing rotation rate of the lower tool. Furthermore observed the joint made by the concave double sided friction stir welding has a more preferable ductility. Hao Su et al., [20] used numerical modeling to study the effect of pin profiles on thermal and material flow characteristics, it was found that the stiring action of triflat tool is better than conical tool. Ragu Nathan et al., [21] investigated metallurgical characteristics of friction stir welding of high strength low alloy steels using tungsten as tool materials. They found that the tool made of 99% W and 1% La_2 O_3 withstood high strain rate, temperature and flow stresses generated. Hasan et al., [22] numerically compared flow behavior using unworn and worn tool geometries, the size and shape of the mechanical effected zone with the worn tool is shorter and about 2.5 mm smaller than that associated with the unworn tool. Additionally strain rate and velocity distribution showed a low stirring action for the worn tool, especially near the weld root resulted in defective weld joints.

Costa et al., [23] investigated influence of material properties and tool geometry on weld strength for AA 5754-H22/AA 6082-T6 aluminium alloys they suggested that excellent quality weld was obtained by placing the AA 6082-T6 alloy in the top of the lap joints and welding with conical pin. Zhengwei Li et al., [24] studied Joint features and mechanical properties 2024 aluminum alloy assisted by external stationary shoulder the results showed that joints assisted by external stationary shoulder own smaller effective sheet thickness of cold lap and bigger effective lapwidth. Shi et al., [26] analyzed the effect of the welding parameters and tool size on the thermal process and tool torque in reverse dual rotation, they concluded that the separated and reverse rotate of the tool pin and the assisted shoulder lower the total net torque exerted on the specimen in addition to that the different rotation direction changes the material flow pattern, which has great effect on the temperature distribution.

Kumar et al., [27] studied the role of tool on material flow and weld formation, the result indicated that material flows occurred two ways namely shoulder and pin driven material flows the pin transfers the material layer by layer, while the shoulder transfers the material by bulk. Ramachandran et al., [28] investigated effect of tool axis offset and geometry of tool pin profile on the characteristics of aluminum alloy AA5052 and HSLA steel, the study revealed that tool with taper cylindrical pin profile having 10° taper angle produced the best joint with tensile strength of 188MPa. Elangovan et al., [29] examined the influences of tool pin profile on the formation weld zone in AA2219 aluminium alloy the results exhibited that joint fabricated with square pin profile tool at a welding speed 0.76mm/s showed maximum tensile strength, higher hardness and finer grains in the weld zone. Galvao et al., [30] analyzed influence of tool shoulder geometry on thin copper sheets they noticed that scrolled shoulder provides the better material flow and the flat shoulder the worst material flow and producing only defective welds and scrolled shoulder provides greater grain refinement in the nugget of the welds than the conical or flat shoulders, this refinement is responsible for the increased hardness and mechanical strength of the weld.

Kumari et al., [31] investigated influences of mechanical properties on counter rotating twin tool, they results showed that at 1800 rpm welds made with twin tool had higher hardness profile under all values of welding speed. Dongxiao Li et al., [33] investigated stationary shoulder friction stir welding of 7075-T651 aluminum alloy it was observed that the stationary shoulder of friction stir welding slides over the weld surface during the welding process and creates a smooth surface which is beneficial to the fatigue property of the weld. Moreover the limited material flow under the stationary shoulder results in much homogenous heat input and microstructure in the thickness direction of the weld. Gaoa et al., [35] optimized tool diameter for brass/steel lap joint it was identified that tensile shear strength of the lap joints was improved by the increase of probe diameter and slightly decreased with the increase of shoulder diameter. Ji et al., [36] numerically simulated the influence of rotational tool geometry on material flow, they found that flow velocity of material inside weldment is increased by decreasing the cone angle of pin or decreasing the width of screw groove. Furthermore material flow, the concentric circles flute shoulder produced better material flow than the inner concave flute shoulder.

Dehghani et al., [37] investigated the effect of welding parameters and tool geometry on properties of AA3003-H18 mild steel, the result indicated that conical pins are not suitable for welding aluminum to steel due to producing no interaction between steel faying surface and conical pin at the bottom region of the weld. Zhao Zhang et al., [38] studied numerically effect of tool sizes and pin shapes on AA2024-T3 aluminium alloy, they suggested that shoulder plate contact surface takes the main contribution to the frictional dissipations and heat generations. Furthermore variation of the shoulder diameter is more important to the energy inputs than the variation of the pin diameter and energy ratio converted to heat is increased with the decrease of the shoulder diameter. Dawood et al., [39] analyzed the effect of small tool pin profiles on microstructures and mechanical properties of 6061 aluminum alloy the best mechanical properties are obtained for the joint by a triangular tool pin and the less pulsating action experienced in the nugget zone of triangular tool pin profile with fine grains. In addition addition lowest tensile strength and microhardness were recorded for the specimen joined with square tool pin.

Li et al., [40] investigated the effects of the reversely rotating assisted shoulder on microstructures they found that the decrease of plastic flow of material because the deformation of material were constrained in a thin layer near the weld top surface. Furthermore the degree of plastic flow of material was reduced when sub size concave shoulder and the flat assisted shoulder were used. Trimble et al., [42] investigated characteristics of tool shape and rotational speed for AA2024-T3 alloy the scrolled shoulder and triflute pin was most effective shape for welding at high speed with increased the amount of plastic deformation and stirring of the workpiece. Bandari Vijendra et al., [43] used induction heated tool for his study the heated tool improved plasticizing the material. Moreover high strength values of joints achieved by induction assisted heated pin attributed to good material mixing and the high level of crystallization at weld seam. RajKumar et al., studied the effect of tool design and welding parameters on dissimilar aluminium alloys AA 5052 – AA 6061 it was showed that the excellent mixing due to proper stirring of cylindrical tool pin with lower feed rate.

Giuseppe Casalino et al., used cylindrical threaded pin for excellent bondage between AA 5052 and AA 6061 alloys the results revealed that the microstructural zone and the hardness profile were depend upon shoulder size. Additionally large shoulder produced the defect free weld. Vinayak Malik et al., [46] investigated the effect of various tool pin profiles using finite element simulations they results suggested that less welding power was consumed by square profile pin without affecting temperature generation. In addition compared to straight pins the defect diminished for frustum type pins. Ugender et al., [49] investigated tool geometry on mechanical properties for AA2014 Aluminium alloy when shoulder and pin diameter increased flow velocity of material also increased. Moreover Flow direction of material near the tool is the same as rotational direction of the tool. Bayazid et al., [50] analyzed the effect of pin profile on AA7075 aluminum alloy the results indicated that tunnel, kissing bond and zigzag line defects were observed in weld zone welded with cylindrical pin, tunnel and crack defects were observed in weld zone welded with triangle pin but not any defects in weld zone welded with square pin. Lakshminarayanan et al., [52] investigated feasibility of surface coated tools to join AISI 304 grade austenitic stainless steel the results revealed that the joints made using plasma transferred arc hard faced self fluxing with boron nitride tool produced less reduction in toughness value. Ch Venkata rao et al., [53] studied effect of tool profile on microstructure and pitting corrosion resistance of AA2219 alloy they showed that the triangle pin produced high temperature than conical pin.

Ilangovan et al., [54] studied effect of tool pin profile on microstructure and tensile properties of AA 6061-AA 5086 aluminium alloy the results revealed that defect free joints were fabricated by threaded and tapered cylindrical pin profile tools and threaded cylindrical pin profile tool produced defect free weld, finer, uniformly distributed precipitates, circular onion rings and smaller grain joints than tapered cylindrical pin profile tool. Ch. Venkata rao et al., [55] analysed influence of tool pin profile on microstructure and corrosion behavior of AA2219 alloy they concluded that heat generation, peak temperature and fine grain structure obtained for hexagon tool pin profile. Venkateshkanan et al., [56] investigated influence of tool geometry on metallurgical and mechanical properties for AA2024 and AA5052 alloy the results showed that cylindrical and tapered pins showed minute discontinuities and defect free weld was produced with new stepped pin tool. Wang et al., [4] studied tool wear mechanisms on Ti–6Al–4V alloy CY16 tool produced the fracture failure and WC411 produced the micro crack in the weld with improved fracture toughness.

5. CONCLUSION

1. Selection of tool profile is most important to achieving the optimum microstructure, mechanical properties, heat generation, material flow and fine grain size of the friction stir weld.H13 is used more than any other tool steel in tooling applications due to excellent combination of high toughness and fatigue resistance.

2. Threaded tapered specimens showed highest microhardness and four flute cylindrical specimens showed the lowest microhardness. Higher mechanical properties and better intermixing were obtained by tapered threaded pin than tapered pin tool.

3. The material flows is occurred in two ways namely shoulder and pin driven material flows. Pin transfers the material layer by layer and shoulder transfers the material by bulk.The joint fabricated with square pin profile tool at a welding speed 0.76mm/s showed maximum tensile strength, higher hardness and finer grains in the weld zone.

4. Scrolled shoulder provides greater grain refinement in the nugget of the welds than the conical or flat shoulders, this refinement increased hardness and mechanical strength of the weld. Flow velocity of material inside weldment is increased by decreasing the cone angle of pin or decreasing the width of thread groove.

5. The shoulder plate contact surface takes the main contribution to the frictional dissipations and heat

generations. Furthermore variation of the shoulder diameter is more important to the energy inputs than the variation of the pin diameter.

6. The scrolled shoulder and triflute pin was most effective shape for welding at high speed with increased the amount of plastic deformation and stirring of the workpiece. The induction heated tool improved plasticizing the material.

7. The microstructural zone and the hardness profile are depend upon shoulder size and large shoulder produced the defect free weld. The cylindrical pin produces tunnel, kissing bond and zigzag line defects and square pin produces tunnel and crack defects were observed in weld zone.

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