

# “Review paper on optimization of friction stir welding process parameters”

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## **Abstract**

**AA 7075** is an aluminium alloy, with zinc as the main alloying constituent. It has high strength, with similar to many steels, have good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. AA7075 are frequently used in transport applications such as marine, aviation and automotive due to their high strength-to-density ratio. Strength and light weight also desirable in fields such as Rock climbing equipment, bicycle components and airframes are commonly made from 7075 aluminium alloy. AA 7075 has low weldability due to reduced solidification microstructure, and when welded by fusion welding techniques go down its mechanical properties. Friction stir welding (FSW) is solid state, reliable joining techniques to retain the properties of the alloy as there is no melting of metal takes place, welding takes place due to the forging effect. Current work deals with experimental investigation of optimization of friction stir welding process (FSW) to arrive at desirable mechanical properties of aluminum 7075 and C11000 plates. Main factors of process are tool pin profile, tool rotary speed, welding speed, and welding axial force and main responses are tensile strength, yield strength, and hardness of weld zone.

**Keywords:** Friction Stir Welding, Axial Force, Rotational Speed

## **Introduction**

Friction stir welding is a solid state joining technique, invented by The Welding Institute (TWI) United Kingdom in 1991. Although initially developed for Al-alloys, shortly it was applied effectively to many other metals and materials, specially to metals hard to weld by using the given fusion welding techniques. It is a solid state welding process in which the relative motion between the work piece and tool produces heat which makes the material of two ends being united by plastic atomic diffusion. This method (FSW) relies on the direct conversion of mechanical energy to thermal energy to create the weld with no application of heat from external sources. The rotational speed of the tools, welding speed, axial pressure, and the tool profile are the main principal variables that are to be controlled in order to provide the necessary combination of heat and pressure to form the

weld. These parameters are adjusted so that the interface of joining metals is heated into the plastic temperature range (plastic state) where welding can take place. The functional behavior of the welded joints was determined by the weld strength that is tensile strength, weld hardness and micro hardness. In this project an attempt will be made to determine and evaluate the influence of the process parameters of FSW on the welded joint.

Friction stir welding (FSW) is a developed solid state welding process to conquer the problems raised in fusion welding. This process uses a non-consumable tool. Rotational speed and frictional force generate heat. The welding parameters, such as tool pin profile, rotational speed, welding speed and axial force, play major role in determining the mechanical properties of welded joint.

## **Survey of work done in research area**

A number of research papers have been published on the optimization of friction stir welding. A brief review of some selected references on this topic is presented.

Sadeesh P *et al.* [1] used material i.e. 5mm thick plate of AA 2024-T4 (Al-Cu alloy) and AA 6061-T4 (Al-Mg-Si alloy). The plates were cut into rectangular shapes of 100 × 50 mm and the welding had been carried out. Tool used in his study was AISI H13 tool steel, which has high thermal fatigue resistance. The different shape pin profiles used in this work were cylindrical pin, threaded pin, tapered pin, squared pin and stepped pin. The process parameters used were tool shape, rotational speed, traverse speed, tilting angle. AA2024 were placed on the advancing side due to its higher mechanical strength and the tool pin was positioned at center of joint line. Optical microscope, scanning electron microscope and energy dispersive spectroscope were used to study microstructure of welded joint. Samples were prepared according to the ASTM E8 standards for tensile test and the tests were carried out at a strain rate of 0.5 mm/min. Micro hardness were carried out at a load of 100 gf with dwell time of 10 seconds and distance of 0.25 mm interval across the welded joint. It was found by studying literature that the rotational speed of 710 rpm, traverse speed of 28 mm/min and D/d ratio of 3, for cylindrical pin, were most efficient.

Sahu and Pal [2] were carried out experiments by using

Taguchi's L18 factorial design of experiment. Grey rational analysis was used for optimizing processes parameters. Percentage effect of individual process parameter on the weld quality was measured. They used AM20 Magnesium alloy to form square butt joint. Process parameters were used tool rotation speed, welding speed, shoulder diameter and plunge depth. After welding tensile test were calculated to find out ultimate tensile strength and yield strength. They found optimized process parameters were plunge depth at 0.12 mm, welding speed at 98 mm/min, rotational speed at 1100 rev/min and shoulder diameter at 24 mm.

PankajNeog *et al.* [3] were conducted welding on 6.35 mm thick plate of AA7075-T6 alloy using friction stir welding technique. He used square butt joint in the experiments as it found better result. Process parameters were rotational speed, welding speed and axial load, output variable as tensile strength. There was a positive relationship between the load and tensile strength. If axial load increases tensile strength also increases.

E. Fereidun *et al.* [4] used Al-5083 and steel alloy St-12 alloy sheets with the thicknesses of 3 and 1 mm as a material for friction stir welding. Temperature variation at the joint interface was measured. Rotational speeds of 900 and 1100 rpm were used with the dwell times of 5, 7, 10, 12 and 15 seconds to weld material. Then tensile and shear test are carried out on three specimens for each processing condition and the average values were recorded. They found that as dwell time increases joint strength increases up to certain limit and then start declining.

Joon-Tae Yoo *et al.* [5] tested mechanical properties and macro structure of friction stir welded joint using Radiography test for Al-Li alloy. Rotation speed and travel speed were selected as process parameters to compare the results. Tensile test was conducted to verify the strength and elongation of welded joint using defect free specimens. After welding, nondestructive tests by x-ray and macro observations of stir zone are conducted to verify the soundness of welding area. Increasing travel speed cause irregular boundary shape in advancing side boundary little defect start formation between advancing side and stir zone. From 300 mm/min, unstable boundary shape may be started. Increasing rotation speed also cause unstable boundary in advancing side. Defects were started when it doesn't have enough time for mixing the material in high travel speed zone.

RazaMoshwanet *et al.* [6] used 3 mm thick AA 5052-O aluminum alloy plates in his experiment. Specimens were welded using constant tool traverse speed of 120 mm/min and by changing rotating speeds from 800 to 3000 rpm. Then welded joints studied for its appearances, microstructural and mechanical properties. It was observed that joint produced at 1000 rpm gain a maximum tensile strength which was 74% of the base material strength. The stir zone produced finer grain compare to base material. The average micro hardness of the nugget zone was lower than the base material hardness. The heating and extreme deformation due to tool rotation and axial pressure during friction stir welding process leads to diffusion of magnesium atom from the grain interiors to the grain boundaries to form more b-phase (Mg<sub>2</sub>Al<sub>3</sub>) particles.

Shaikh and Dabade [7] conducted experiments on Al 6061-T6

and Electrolytic tough pitch Copper ETPC11000, effect of friction stir welding process parameters such as welding speed tool, rotational speed and axial load on tensile strength of friction stir welding were studied. They found that, rotational speed of 675 rpm, welding speed of 40 mm/min and axial force of 1500 N produce superior tensile strength in scope of experiments. But the use of combination of welding speed 30 mm/min, rotational speed of 510 rpm, axial force 1000 N produce lesser tensile strength.

Yadav and Bhatwadekar [8] conducted experiment on AA6101 Aluminium and pure Copper plates of 5mm thickness in butt joint configuration. Welding was done at speed of 700 rpm and at 11mm/min tool traverse speed and tool with cylindrical configuration. Welded joint shows onion ring structure in stir zone. They found that AA6101 and copper joint was brittle in nature, more downward force, higher welding speed and rotational speed produces strong butt joint.

S. Jambulingam [9] selected material were AA7075 and AA3014 and joined by friction stir welding, 9 experiments were conducted at different speed, feed, and axial force. Taguchi method was used for design of experiments. He found optimum parameters were 1200 rpm speed, 10 mm/min feed with cylindrical tool profile.

Shaikh and Chouhan [10] used material were AA6061 T6 and AA2024 T0. For design of experiment Taguchi method based on L9 orthogonal array were used. Hardness measure in Vickers hardness tester and tensile stress and yield stress are measured. Optimization analysis was done using MINITAB. Dissimilar metal joining process using friction stir welding is difficult to achieve because of different co-efficient of heat and the base metal chemical composition. Welding parameters like rotational speed, traverse speed, axial force and tilt angle which plays a very important role for increasing the weld quality.

Pradeep and Muthukumaran [11] used tool having a conical pin of 0.4 mm clearance. Process parameters were optimized by using the Taguchi technique. Experiments designed based on three process parameters, tool rotational speed, tool tilt angle and travel speed. Tensile strength was used as response. A conical shorter pin tool was better strength of weld at a lower travel speed, and it helps in the reduction of tool wear, by lesser usage of the tool material.

Fei Zhang *et al.* [12] in his study samples were made of super high strength aluminum alloy with high Zn content. Friction stir welding conducted with rotation rates of 350–950 rpm and welding speeds of 50–150 mm/min. It is observed that the grain size of the nugget zones decreased with the increasing welding speed. The ultimate tensile strength and elongation decreases when rotation rate increased from 350 to 950 rpm at a constant welding speed of 100 mm/min.

G. Rambabu *et al.* [13] conducted experiments for improved corrosion resistance of AA2219 aluminum alloy joints. Material used was AA2219-T87 and tool pin profile was conical, square, triangle, pentagon and Hexagon. He used software based GillAC electrochemical system for potentiodynamic polarization tests to study the pitting corrosion performance of the metal. Saturated calomel electrode and Platinum was used as reference electrodes and auxiliary electrodes respectively. All experiments were conducted in

aerated 3.5% NaCl solutions with pH adjusted to 10. The potential scan was carried out at 0.166. The exposure area for these experiments was 1 cm<sup>2</sup>. They found that the hexagon tool profile gives best results.

A. Pradeep and S. Muthukumaran [14] worked to optimize the process parameters of friction stir welding for low alloy steel plates. The tool used for the FSW process is a tungsten alloy, with a concave shoulder 25 mm in diameter and the pin is tapered, and cylindrical in shape as shown in Figure 14.1

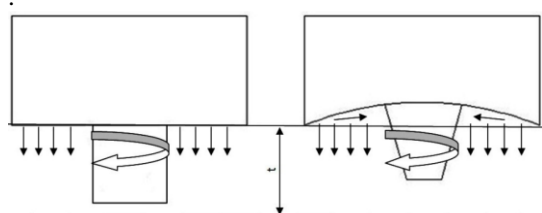


Figure 14.1: - Concave shoulder tool

Tool tilt angle is the most important parameter with a percentage of 63.46%, then the travel feed of 32.83% and then rotation speed of 2.81%. The optimal parameters obtained were 1120rpm rotational speed, 1° tool tilt angle and 8mm/min traverse speed, and the tensile strength was predicted as 472 MPa. Two distinct regions of HAZ are present and their hardness values given in the range of 205HV- 272 HV and 180HV- 210HV. The tool tilt angle of 1° is good to weld low alloy steels with good mechanical, metallurgical properties. A conical shorter pin profile had better strength at a lower travel speed, and the pin length indirectly aids in the minimizing tool wear.

Jawdat A. and Al-Jarrah [15] Worked for optimization of FSW Parameters for Joining Aluminum Alloys Using RSM. He used aluminum alloy sheets with thicknesses of 4, 5, 6, 7 and 8 mm were Butt jointed. High carbon steel used as tool material with flat cylindrical shoulder diameters of 18, 21, 24, 27 and 30 mm. rotational speed range used were 400, 700, 1000, 1300 and 1600 rpm. And welding speed range used 0.5, 1.0, 1.5, 2.0 and 2.5 mm/sec. it was found that a general result for a plate thickness of 6 mm, the best combination to have maximum yield strength is 1000 rpm rotational speed with 1.5 mm/sec welding speed and a shoulder diameter of 24 mm. This experiment results defect free joints. Though, the superiority of welded joints depends on controlling the rotation speed with welding speed to fill up the cavity behind the pin when moving forward.

Xun Liu *et al.* [16] worked on analysis of process parameters effects on friction stir welding of dissimilar aluminum alloy to advanced high strength steel. Tool material used was tungsten carbide with 10% cobalt content. 1200 rpm and 1800 rpm were used as rotational speed and three levels of welding speed and two levels of tool offset. Welding speed had a minor effect on mechanical welding force, temperature distribution and material strain rate and therefore the IMC layer composition. Though, higher welding speed shorten high temperature period and hence reduce the interlayer thickness. Higher rotational speed and larger tool offset can elevate the overall temperature in the weld and decrease the required vertical and lateral force for moving forward the tool along joint line.

A.F. Hasan *et al.* [17] studied flow behavior in Friction Stir

Welding using unworn and worn tool geometries. A validated 3D model of the FSW process was developed using the CFD software FLUENT. This model was used to compare the material flow behavior around an unworn and worn tool during welding. The geometry of the computational domain of the model was a rectangular cuboid. Model was used to conduct a mesh study using a threaded tool and used to compare the flow behavior of the unworn and worn tools.

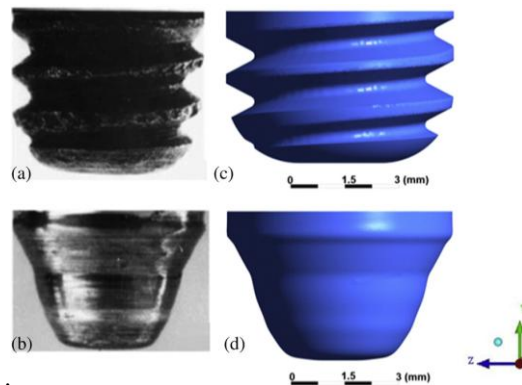


Figure 17.1:- Worn and unworn tool geometries.

They found that a hybrid is more computationally efficient for achieving a correct solution for the FSW and for modeling difficult tool geometry. The results of the strain rate and velocity distribution shows a low stirring action for the worn tool, mostly near the nugget zone, possibly leads to defective weld. Results show the weld penetration does not reach up to the bottom of the plate when tool becomes worn, which affect the quality of the weld joint.

D. Trimble *et al.* [18] worked for characterization of tool shape and rotational speed for increased speed during friction stir welding of AA2024-T3. A 3-piece tooling system was used for interchangeable shoulder and pin components. Fig. 2 shows the different shoulder and pin shapes used. Two different shoulder designs with a diameter of 18 mm were used. Concave shoulder with a 7° recess angle and a scroll shoulder of height 1 mm, thickness 0.5 mm, pitch 2 mm and revolutions 1.75. Three different pin shapes cylindrical, square and triflute was used.

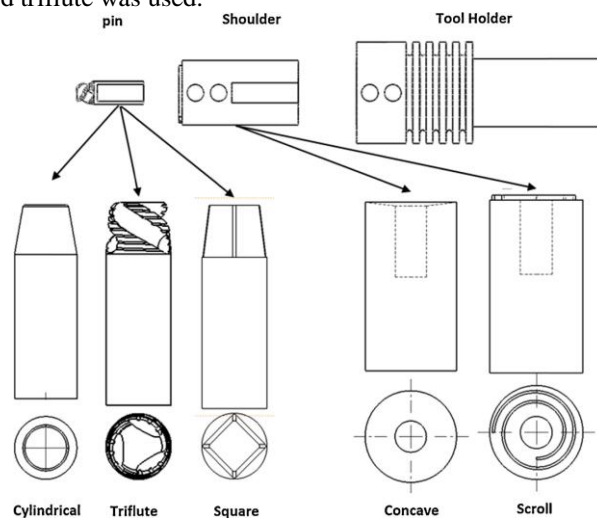


Figure 18.1:- Different types of tool and shoulder

Results show due to decrease in tool lift, enhanced deformation and frictional heat at the surface, scroll shoulder design enabled higher welding speeds in comparison to a

concave shoulder design. The triflute gives best result for welding at high speeds. Welds produced at 450 rpm provide the optimal amount of plastic deformation and frictional heating at high welding speeds. Welding at rotational speed below this value leads to insufficient material deformation to form a fully consolidated weld. Whereas welding at rotational speeds above this optimal value leads excessive plastic deformation and stirring leading to the occurring of small voids in the workpiece. Results confirm that increased welding speeds cannot be simply achieved by increasing the tool rotational speed.

Qingzhao Wang *et al.* [19] studied corrosion behavior of spray formed 7055 aluminum alloy joint welded by underwater friction stir welding. Spray formed 7055 aluminum alloy was used as base metal. Sheets were welded through traditional and underwater friction stir welding. Tool was made of H13 steel had a concave 10 mm diameter shoulder and a 4 mm diameter pin with pin length of 3.75 mm and tool tilt angle of 2.5. Welding speed was 100 mm/min and rotation speed of tool was 1000 rpm. Under water environment was provided by water tank. IGC corrosive solution consists of 0.97 mol NaCl + 0.3 mol H<sub>2</sub>O<sub>2</sub> + 1 L distilled water. He observed that the tensile strength of underwater joint had improved 15% compared with traditional joint and elongation reached 7.2%.

Shayan Eslami *et al.* [20] studied effect of newly developed tool on friction stir welding parameters for lap joint of dissimilar polymers. Polymers buckle easier under pressure hence they requires more complex clamping system. A thermocouple has used inside the bottom part of static shoulder. Rotational speed, traverse speed and tool geometry was taken as process parameters. They found that the stationary shoulder allowed stronger welds with good surface finish. Most important welding parameters in the new tool were the traversing speed after that rotational speed. Unlike metallic material, the defect for lap joining the polymeric materials occurs on the retreating side of the weld. With low traversing speed (20mm/min), material degrades maybe due to excessive heat generation.

Fei Zhang *et al.* [21] worked on Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of a super high strength Al–Zn–Mg–Cu aluminum alloy.

6 mm thick aluminum alloy plates were used as base metal. The plates were butt welded. A constant plunged depth of 0.25mm was used in all experiments. After welding, all FSW joints were tested by X-ray technique, stereoscopy, Scanning Electron Microscope, optical microscopy, tensile test and Vickers hardness measurements. They found after FSW, NZs of all joints had fine equiaxed grains. The grain size at the centre of the NZ reduced with the increasing welding, and increased with the increasing tool rotation speed. The lowermost hardness exists in the transition zone between the advancing sides of TMAZ and HAZ. At a constant welding speed of 100 mm/min, increasing tool rotation speed from 350 to 950 rpm, UTS decreased from 484 to 373 MPa. The maximum elongation of 9.4% was attained at 350 rpm. 50 mm/min, a 96% improvement over the base metal samples, and the fracture of this sample was ductile.

Raza Moshwan *et al.* [22] studied Effect of tool rotational

speed on force generation, microstructure and mechanical properties of friction stir welded Al–Mg–Cr–Mn (AA 5052-O) alloy. Base metal selected was 100×50 ×3 mm and hardened mild steel as tool material with rotational speeds of 800, 1000, 1500, 2000, and 3000 whereas the traverse speed was constant at 120 mm/min. Standard metallographic techniques such as Scanning electron microscope, energy dispersive spectroscopy (EDS) and field emission scanning was used for studying microstructure, mechanical tests such as tensile tests and hardness measurements conducted.

They found the weld produced at 1000 rpm had a maximum tensile strength of 132 MPa which was 76% of the base material. In all experiments the ultimate/yield strength of the welded joints was lower than the base material. stir zone had finer grain compare to base material also micro hardness of the nugget zone was lower compared to base material hardness.

H.B. Chen *et al.* [23] worked on effects of initial oxide on microstructural and mechanical properties of friction stir welded AA2219 alloy. Heat treatable AA2219 aluminum alloy plate used as a base metal. For studying material flow of the initial surface oxide film on the plate, four pairs of plates were anodized up to thickness range from 39 to 40 μm. Tool material used high-speed steel W9, threaded pin of 5.7 mm diameter and 4.0 mm length and shoulder of 12 mm diameter was used. The tool tilt angle was 2.5°. At the time of plunge the rotation speed of 1500 rpm used which ensure adequate pre-heat. On completion of welding tests carried out such as X-ray radiography inspection, tensile test, optical microscopy, energy-dispersive spectroscopy (EDS). They found the initial surface oxide film remaining had different microstructure characterizations of joint line remnant in the upper, central, and root regions. Tensile strength of FSW joints with JLR inside the stir zone is far lesser than that of the good FSW joint. Tensile fracture examination exposes a series of severe “scalloping” appearance in the joint with continuous JLR flaw, while the sound weld exhibits fine dimples.

Xun Liu *et al.* [24] developed electrically assisted friction stir welding system, which enables a local electrical current field moving with the FSW tool without requiring the tool to be one of the electrodes. Material softening phenomenon occurs during due to induced high density current. Axial welding force reduced with application of current and with lower rotating speed and a smaller tool offset into aluminum. Microstructure analysis shows greater creation of thin layer of intermetallic compounds and micro inter lock features at the Al–Fe interface. Axial welding force can be reduced by using both electro-plastic effect and Joule heating. The electrical current can help promote formation of a thin layer of inter metallic compound for the plunge section of the joint, which is possibly due to a combined effect of accelerated atom diffusion and reduced activation energy for chemical reaction. Mohamadreza Nourani *et al.* [25] worked on Taguchi Optimization of Process Parameters in Friction Stir Welding of 6061 Aluminum Alloy: A Review and Case Study. His study intended to present computationally efficient method for optimizing the process parameters of friction stir welding of 6061 aluminum alloy. ANOVA analysis on the L9 orthogonal array with three factors is done and results shows that among the parameters considered (*i.e.*, the tool rotational speed,

transverse speed, and the axial force), the most important parameter on the weld quality is the rotational speed, followed by the axial force and transverse speed. Results indicate the tool rotational speed was the highest significance, followed by the normal force and the welding speed. Variation of the rotational speed of the tool leads to 51% contribution on the HAZ distance to the weld line. The minimized peak temperature of 458.90°C in the case study indicated a 91°C temperature reduction from the nominal (initial) value of 550°C. The ANOVA method of the Taguchi L9 design and the full factorial analysis yielded similar parameter contributions.

U. Donatus *et al.* [26] studied the flow patterns in dissimilar friction stir welds of AA5083-O and AA6082-T6 alloys. It was observed that material flows more from the advancing side into the retreating side. Material flow from the retreating side to the advancing side only occurs in the tool shoulder domain, and the pull is max at the transition region in between the tool pin domain and the tool shoulder domain. It was also observed that materials tend to extrude out only in the TMAZ of the retreating side, which was influenced by rotation tool shoulder and the tool pin. The finest grains were present near to the tool edge in the retreating side. The volume fraction of recrystallized grains grows into the deeper portion of the nugget from the flow arm region. Lowest hardness was present at nugget zone and the heat affected zone of the AA6082-T6 alloy side. Material pull from the RS to the AS is highest in the transition region between the tool shoulder domain and the tool pin domain. Materials tend to extrude out of the weld zone in the thermo mechanically affected zone of the retreating side only, and it is caused by action of the tool shoulder and the tool pin. Mixing of materials frequently occurs in the top surface in the tool shoulder domain, the nugget stem and in the nugget. The slower traverse welding speed gives a better mixture of materials in the weld zones compared with the increased traverse welding speed.

Banglong Fu *et al.* [27] conducted FSW on 6061-T6 aluminum alloy to AZ31B magnesium alloy with the rotation speed of (600–800 rpm) and traverse speed (30–60 mm/min) when Mg was on advancing side with tool offset of 0.3mm towards Mg. Intermetallic compound consisted of Al<sub>12</sub>Mg<sub>17</sub> and Al<sub>3</sub>Mg<sub>2</sub>. The tensile strength obtained reach up to 70% of that of the Mg base metal. The NZ at Mg side was divided into three regions, shoulder affected zone, banded zone and severe intercalated zone, the last two zones showed Al–Mg intercalated structures. Heat input in Al–Mg FSW could be calculated from tool rotational speed and x-axis torque. By placing Al on advancing side and tool offsetting to Al, the heat input increased, and it decreased with the increase of rotation speed and traverse speed. Variations in friction coefficient, liquation tendency and deformability between Al and Mg, as well as the extent of mixing were related to the variation of heat input.

Ming-Jer Hsieh *et al.* [28] studied Friction stir spot welding of low-carbon steel using an assembly-embedded rod tool Friction stir spot welding (FSSW) has been conducted on a low carbon steel (SS400) plate with different thicknesses with downward force of 8 kN, a rotating speed of 1200 rpm with dwell time of 100 s. The temperature at 2 mm below the center of the stir surface quickly rises to about 900 °C using

the AER tool, but it increases to about 510 °C using the plain tool in primary dwell time. The rate of the increase in temperature using the AER tool is 1.7 times than that of plain tool. The depth of TMAZ using the AER tool is about 6 mm it is 2 times that using the plain tool. When the thickness of the upper plate is lesser than 3 mm, the failure load using the AER tool is about 35 kN. This load is about 1.7 times larger than that using plain tool. The failure load for a 4 mm thick upper plate using the AER tool is still greater than that for a thinner plate using the plain tool.

S. Sabooni *et al.* [29] worked on Friction-stir welding of ultrafine grained austenitic 304L. After FSW, dissimilar grain structures in different regions of the weld nugget were detected due to the variations in the heat generation during the welding process. Grain growth was predominant in the region just ahead of the rotating tool during the thermal cycle of FSW. The grain structure in the weld nugget region is not homogenous due to the variations in the heat generation between the AS and RS of the rotating tool during FSW. Substantial grain growth was observed during the thermal cycle of the FSW, with the grain size of the region ahead of the welding tool grown to a large value of about 3 μm for the high heat input condition. Increasing the welding speed can reduce the amount of grain growth.

Jian Luo *et al.* [30] worked on electrical current aided friction stir welding (EFSW) which is based on increasing heat generation during welding with aid of a resistant heat source. For the AZ31B joints, the resistant heat source leads to major grain refinement and hardness enhancement of nugget zone. It also increased plastic deformation during welding. For the Al7075 joints, the grain size in the NZ and heat affected zone (HAZ) increased slightly with the increase in electric current intensity. EFSW was proven to be suitable for joining high-strength alloys. The tool was made of T12 carbon tool steel, which had a pin of 5 mm in diameter, 4.7 mm in length, and a shoulder with a diameter of 14 mm. Results shows higher electric current intensity refined the welding's arc-shaped features. For AZ31B Mg alloy, the WNZ grains were considerably refined in EFSW joints. High micro hardness values were found in the WNZ of AZ31B EFSW joints.

Omar S. Salih *et al.* [31] given reviewed of friction stir welding of aluminium matrix composites and the mechanical properties of AMCs joined by FSW were mainly dependent on the combined effect of the composition of AMCs and the FSW processing conditions. Macro structural analysis revealed the formation of tunnel defects caused by incorrect flow of plasticized metal. Microstructural evaluation shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with changed amount of heat input by varying the welding parameters. Using new tool designs which have frustum shapes surface coating of pin by suitable material, and surface heat treatment techniques could be possible solutions to improve tool life and joint efficiency.

Pardeep Sharma *et al.* [32] studied on microstructure of aluminium matrix composites. Their work focuses on the effect of graphite particles addition on the microstructure of Al6082 metal matrix composites manufactured by conventional stir casting process. There is a non-uniform distribution of Gr particles in the matrix. The hardness of

composites decreased by 11.1% with respect to addition of weight percentage of Gr (0–12%).

Divya Deep Dhancholia *et al.* [33] worked on Optimization of Friction Stir Welding Parameters for AA 6061 and AA 7039 Aluminium Alloys by Response Surface Methodology (RSM). They found that Rotational speed and welding speed contributes much in producing the necessary frictional heat and has significant impact on the mechanical properties. The mechanical properties increases as the parameters varied from low to high but up to a definite limit then they start declining. Bandari Vijendra and Abhay Sharma [34] worked on Induction heated tool assisted friction-stir welding (i-FSW). In this process the friction-stir is heated during welding by induction and the temperature is accurately controlled. They found induction heated tool welds plates with a least amount of flash. Induction heating of tool enabled the plastic material to soften in a short time and to be easily stirred. As the tool-pin temperature rises, the hardness at the stir zone decreases due to plasticity nature of joint. At high tool pin temperatures the strength of the joint is governed by the ductile behavior material that joined. Turbulence of the material, caused by the stirring action of the tool, was the main factor that governed the strength of the welds at low tool temperature. The optimum conditions for the good mechanical properties of the joints were a tool pin temperature of 45°C and a rotational speed of 2000 rpm.

Dongxiao Li *et al.* [35] investigated the stationary shoulder friction stir welding of aluminum alloy 7075-T651. The narrow TMAZ and HAZ surrounding the NZ and were fairly symmetrical in the transverse section. The NZ and the TMAZ consist of fine equiaxed and banded grains respectively, though there is no change in the grain structure in the HAZ and BM. Constituent particles are homogeneously distributed in the NZ. In the HAZ and the TMAZ, the spacing and distribution of constituent particles was same as in BM. Precipitates dissolved in the NZ during the welding process. High tool rotational speed or high welding speed results in stronger joints.

Jingqing Zhang *et al.* [36] investigated dissimilar underwater friction stir lap welding of 6061-T6 aluminum alloy to pure copper. In aluminum/copper (Al/Cu) metallic couple formation of the Al–Cu intermetallic compounds is the major problem. Underwater FSW (underwater weld) was analyzed via comparing with the weld obtained under same parameters by classical FSW (classical weld). Results show that the external water could decrease the peak temperature and shorten the hot working time also oxidization. For the classical FSW an obvious Al–Cu diffusion interlayer appeared thick at the weld interface, while for the underwater FSW this interlayer was much thinner.

M Jayaraman *et al.* [37] worked on optimization of process parameters for friction stir welding of cast aluminium alloy A319 by Taguchi method. To correlate process parameters and tensile strength, a mathematical model had developed by nonlinear regression analysis. Tool rotation speed has been found dominant parameter for tensile strength followed by welding speed. Axial force shows less effect on tensile strength compared to other parameters. A maximum tensile strength (147 Mpa) found by FSW joints with optimal process parameters (tool rotation speed, 1200 rpm; welding

speed, 40 mm/min, and axial force, 4 kN).

F. Simoes and D.M. Rodrigues [38] studied material flow and thermo-mechanical conditions during Friction Stir Welding of polymers. The differences in thermo-mechanical conditions are explained based on the strong differences in weld morphology and defect location. Meanwhile for metals the welds result from the confluence of the pin and shoulder driven flow volumes in the thermally affected zone, for polymers, only the pin driven flow volume enters the thermally affected zone, since the shoulder driven material, melted during welding, is squeezed from the joint. Discontinuities forms at the retreating side of the welds.

Kirk A. Fraser *et al.* [39] worked for optimization of Friction Stir Welding Tool Advance Speed via Monte-Carlo Simulation of the Friction Stir Welding Process. Results show the exterior penalty optimization method lends itself well to this simplified two parameter model. With the exterior penalty method Extension to a higher number of parameters is possible. Though the simplified numerical model only consider the evolution of the temperature field during the FSW process, the microstructure change in the joint is very closely related to the temperature field. An estimate of the optimal FSW process parameters can be obtained from a simplified numerical model that approximates the microstructure and joint strength by using the temperature field. The proposed optimization approach is in close contract with experimental optimization work.

X.C. Liu and C.S. Wu [40] investigated material flow in ultrasonic vibration enhanced friction stir welding. Ultrasonic waves were transmitted directly into the local area of the workpiece near and ahead of the rotating tool by sonotrode. The ultrasonic waves enhance the volume of the deformed material around the pin, improve the stability of the continuous material flow and the material strain of the non-continuous flow obviously, and weakened the degree of vertical material transfer. This leads to improvement of weld joint quality. Results show the transverse cross-section of welds can be divided into three different material flow zones, shoulder affected zone, pin affected zone and weld bottom zone. In shoulder affected zone, the material in leading edge is transferred along the retreating side of the pin to the trailing edge. During this process, the material in front of pin does not touch the pin surface and keeps a certain distance from the pin side all the time. It is a continuous material flow, presenting obvious laminar flow feature in shoulder affected zone. In pin affected zone, the material in front of the pin touches the pin shortly after it begins to deform. The ultrasonic vibration enhances the laminar flow stability. For non-continuous material flow in pin affected zone, the ultrasonic vibration increases the material strain and leads to the weakening of the vertical material transfer.

B. R. Rana *et al.* [41] studied the effect of welding speed on mechanical properties of friction stir welding of Aluminum alloy. The tensile test result indicating that with increase in welding speed there is increase in tensile strength of weldments but fracture surface reveal that there was present of some micro cracks and voids which is further indicating the improper agglomeration of weld. The hardness profile measurement indicated that there was an average 57% decrease in hardness compared to Base metal.

R. I. Rodriguez *et al.* [42] studied microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminum alloys. Microstructure analysis of the stir zone shows the presence of bands of mixed and unmixed material that demonstrated the degree of material intermixing, as the tool rotational speed were changed. Material intermixing and joint strength were increases with the increasing tool rotational speed. In tensile loading weld failed through the heat-affected zone corresponding to the 6061 Al alloy side. However, for the low tool rotational speed, failure occurred in the stir zone due to poor material intermixing.

Hamed Jamshidi Aval [43] worked on microstructure and residual stress distributions in friction stir welding of dissimilar aluminium alloys. He used triangular frustum pin tool. Results show Zinc distribution across the weld shows that with increasing welding heat input, improves the mixing of the material in the weld nugget, and due to severe plastic deformation of the material and high peak temperature in the weld nugget causes atomic diffusion at the interface of the materials. In all welding heat input, the grain size in the AA7075 side is finer than that in the AA6082 side. The peak temperature effect on the SZ grain size is dominant on deformation rate. An increase in welding heat input resulted in decreased maximum tensile residual stress and increased size of the tensile residual stress region on both sides of the weld line.

C. Devanathan *et al.* [44] worked on optimization of process parameters in friction stir welding of AL 6063. Optimal process parameters were spindle speed at 1400 rpm, traverse feed at 1.2 mm/ sec and axial load at 7 KN. The maximum of 70% joint efficiency was achieved for optimum process parameters. It was found that the welding speed had maximum contribution of 81%. Spindle speed and axial force showed minimum effect on tensile strength when compared to the traverse feed.

Mouloud Aissani *et al.* [45] worked on Design and Optimization of Friction Stir Welding Tool. Their results show to improve the efficiency of the obtained joint and the nugget integrity of aluminium alloys optimal tool geometry, the advancing and rotational speeds, and the axial pressure is very important. Vertical excessive load during the welding and avoids premature damages. Tri-flute type pin tool with a conical threaded geometry manufactured in this framework allows produces a good weld. At very slow travel rate, relatively high pressure, and high rotation speed, we can obtain a better weld appearance without void, cracking, or distortion. Recrystallization phenomena observed in the NZ. Tool geometries and suitable FSW parameters contribute to obtain a smallest equiaxed grain size on the stirred zone. Inhomogeneous diminution of the micro hardness values is obtained in the advancing and retreating sides.

Z. Shen *et al.* [46] investigated role of welding parameters on interfacial bonding in dissimilar steel/aluminum friction stir welds. Results shows higher penetration depth leads to less intermetallic compounds at the interface. Penetration depth into the steel substrate decides the weld strength. Micro-hardness in the joint interface is greater than the base materials. Intermetallic compound of Fe<sub>4</sub>Al<sub>13</sub> was detected at the fracture surface, which are responsible for the deteriorated weld strength at lower penetration depth.

Binbin Kuang *et al.* [47] worked on the dissimilar friction stir lap welding of 1A99 Al to pure Cu using Zn as filler metal with “pinless” tool configuration. FSW of 1A99 Al plate to pure Cu plate of 2 mm in thickness each, using 0.2 mm-thick Zn foil as filler metal is an advanced process. The thickness of interlayer decreases with the increase in heat input; also increase of the rotating speed and the decrease of the traverse speed. The rotating speed plays a more important role in the thickness of the interlayer. The peak temperature and the existence time of the peak temperature at the weld center part increases with the increasing of the rotating speed and the decreasing of the traverse speed, which is consistent with the thickness of the interlayer.

L. Shi *et al.* [48] studied the effect of the welding parameters and tool size on the thermal process and tool torque in reverse dual-rotation friction stir welding. The heat generation rate at the shoulder work piece contact interfaces is non-axisymmetrical. For the points with the same distance away from the tool axis, in front of the tool the heat generation rate is higher than that of behind it. The reverse rotation of the tool pin and the assisted shoulder has little effect on the heat generation. Though, the change in rotation direction changes the material flow pattern, which has great effect on the temperature distribution, and leads to more homogeneous temperature distribution in the RDR-FSW process.

Shude Ji *et al.* [49] worked on vertical compensation friction stir welding assisted by external stationary shoulder. A gap may be present at the interface between two workpieces to be welded and that affects the quality of FSW joint. In order to solve this problem, VCFSW by the self-designed stationary shoulder tool system was used. The stationary shoulder tool system is better than the traditional tool. Lower welding speed and higher rotational velocity are beneficial to break up the compensation strip to make the strip and BM sufficiently mix, which causes the formation of two vortex-like structures with white and black bands in WZ of VCFSW joint.

Huijie Zhang *et al.* [50] worked on microstructure-property characteristics of a novel non-weld-thinning friction stir welding process of aluminum alloys. Results show a novel NWT FSW process, during which a zero shoulder plunge depth is applied and high quality NWT-FSW joints were produced by using the novel process, checking the viability of the process on solving the weld thinning problem occurring in C-FSW. Compared with C-FSW joints, the NWT-FSW joints show a size decrease in the shoulder-affected zone, and the weld nugget of NWT-FSW joints presents with finer grain structures, and the grains exhibit a more uniformly distributed feature along the weld thickness direction.

## Concluding Remarks

For friction stir welding number of process parameters affects weld mechanical properties. Which are tool rotational speeds, welding speed, axial force, tool geometry and tool angle. Rotational speed produces the frictional heat required to plasticize the material. The weld produced at low speed have fine mechanical properties than weld produced at higher speed. The mechanical property increases with the rotational speed and welding speed but up to a certain level then they starts declining. There is a positive relationship between the

axial load and tensile strength. If axial load increases tensile strength also increases. Also as dwell time increases joint strength increases up to certain limit and then start declining. Increasing rotation speed cause unstable boundary defect in advancing side. Aluminium and copper joint is brittle in nature, more downward force, higher welding speed and rotational speed produces strong joint. Performance of AA7075 and C11100 friction stir welding detailed experimentation and testing procedure is not yet carried out. AA 7075 has low weldability due to the poor solidification after fusion weld and in friction stir welding no melting of metals takes place, welding takes place by forging effect. Friction stir welding has very much importance for joining of nonferrous metals. There is need to study the effect of process parameters on the performance of AA7075 and C11000 friction stir welded joints. Detailed experimentation and testing procedure is not yet carried out on AA7075 and C11000.

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