Friction Stir Welding Processing, Materials and its Applications.

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Abstract. Friction stir welding (FSW) is solid state welding process for joining the two similar or dissimilar materials. Friction stir welding process is alternative joining process for thin plates and pipes. In this process non consumable tool is used to join two work faces by friction. FSW process is energy efficient and environment friendly process. In this paper summary of research work done by researchers for Friction stir welding process is presented. The aftermath of this work is to elaborate the overview of numerical analysis and overview of process parameters like tool tip angle, Tool geometry; Tool and joint Materials and Joint design. FSW process can be used for joining different materials. In current research the materials used for experimentation by different researches and its applications are summarized. All the vital factors are covered here for making the process for improvement of effectiveness/ cost reduction. After refining all the process, researcher has found a scope in joining the different / alternative joining process, in different sectors.

Keywords: FSW, FSWoP, Tool tip angle, Tool Geometry.

1. Introduction
The friction stir welding (FSW) is solid state welding process for joining the wide range of materials like copper, bronze, aluminum, polymer, magnesium and steel materials which are widely used in many industrial applications. The FSW process was invented by The Welding Institute (TWI) of Cambridge, England in 1991 [1]. FSW process is simple in construction, pollution free, cost efficient and becomes very popular in automobile, aircraft, marine and aerospace industries. In FSW process the weight of the joint is minimum as compare to conventional welding processes and in this process no liquid state for weld pool, the welding joint takes place in the solid phase below the melting point of the materials. Thus the problems related to the fused material eliminated by FSW process. [2] FSW has many advantages over traditional welding techniques. FSW process has ability to weld dissimilar metals especially in automobile industry where there is need of joining steel to aluminum [3]. FSW is performed at temperature under the base metal's dissolving point. Along these lines, all issues identifying with re-cementing of welded material, similar to, fragility, split age and porosity. [4]
2. LITERATURE REVIEW

The FSW procedure includes a perplexing wonder identified with plastic deformation and material development during the welding procedure. The main elements disturbing FSW process are Welding parameters, tool geometry, numerical analysis and Joint shape. These elements show vital part in the material temperature distribution and flow configuration.

Analysis of friction stir welding process by using simulation one of the complicated process. Simulation is related with “heat transfer” and “mechanics”. Also great distortions and strain proportions around the tool probe within stir area forms on the basis of simulation. Analysis of effect of several parameters like tool ‘rotational speed’, ‘tool design’, ‘tool transverse speed’ and ‘tool angle’ are easily possible by using numerical analysis. Growth of temperatures during FSW process can be predicted by using numerical modelling process. Temperature evaluation can also possible by using Computational fluid dynamics (CFD). It has observed that finite element method is best for identification and assessment of faults in FSW joints and experimental investigation also carried out by Mohammad Ali Fakih et al. He has done the detailed group of weld junctions in connotation through "CT scanning" for destruction indices (DI) [5].

Impact of FEW on residuary worries notwithstanding distortion estimation for planned airplane structure get together examination has analysed by R. W. McCune et al and he expressed that it is essential to decisively structure and mimic the FSW procedure, as the powers associated with the procedure visibly affect level of "leftover burdens",[6]. Mir Zahedul H. Khandkar et al. [7], was performed FEA for guessed the residual "Thermal stresses" inside the metal work pieces combined with FSW process. A. Murphy et al. [8], spoke to the effect of FSW process on stiffened panel for buckling potential by actualizing FEA. D.G. Richards et al. [9], used numerical investigation to break down and trial the idea of "Worldwide mechanical tensioning" to control the residual stresses created through FSW process inside the weld intersections. J.W. Yoon et al. [10], dissected the impact of FSW if there should be an occurrence of a “inherently solidified panel (ISP) structure" on its "fastening performance" by actualizing FEA. E. Feulvarch [11] was proposed a basic yet powerful moving cross section method dependent on Eulerian formalism for the numerical modelling of the FSW procedure.
In FSW strategy process parameters are assumes significant job. Some significant procedure parameters are ‘‘Tool crosswise speed’’, ‘‘axial force’’, ‘‘Tool rotating speed’’ and ‘‘Tilt angle of tool’’.

Shultz EF et al. [12], broke down the impact produced on the weld pattern viability because of the FSW device probe tilt point alongside the contraption quiet submission, though smearing FSW on "5083-H111 Al composite". Francesco Lambiase et al. [13], though actualizing FSW on AA5053 Al composite moved sheets and (PVC) plate, saw that "joint quality" just as effectiveness of the vitality consumed in the proper method of welding procedure improved, with the utilization of securing casing obligating lesser thermal conductivity. It continued in this way surmised, a more prominent estimation of "joint quality" having moderately littler "heating time" and synchronous decrease in "immersed energy" is conceivable adequately with a subsequent utilization of timber in place of the affixing outline material. Krishnan M et al. [14], saw that with a resulting ascend in "tool revolving speed" and "axial load", improved the components, for example, elasticity just as hardness up to a specific point, yet thus gets decreased as most extreme point is accomplished; while utilizing "Response Surface Methodology (RSM)" and "Artificial Neural Networks (ANN)" strategy to assess the ideal joining variables of Al amalgams AA6063 and A319 implied for FSW. Nonetheless, an unfortunate impact on reactions was distinguished because of ascend in "tool traverse speed".

In FSW procedure apparatus geometry is one of significant parameter for delivering the ideal joint. It is valuable for age of warmth during procedure and it is likewise useful for material stream as the apparatus is moving consistent in transverse way. The heat produces essentially by uprightness of grinding in the focus of the tool pin shape and tool substantial, at the primary period of the tool climb. Yanni Wei et al. [15], executed friction stir segment welding for joining of Al and Ti amalgam with cutting pin has made of tungsten carbide. It has been seen that segment joints with greater quality. Shanavas Shamsudeen et al [16] researched the impact of various profiles of tool pin for joining AA 5052 H32 aluminium combination by FSW procedure utilizing reaction surface philosophy and dark social examination. The nature of the welded joint is estimated dependent on the higher estimation of rigidity and hardness of the joint got by experimentation.
one another by dropping a FSW device symmetrically hooked on the base plate over the main one and navigating it lengthwise the welding course by Rajiv S et al [17]. done FSW methodology device point playing key part to joining two materials. A. Arici et al. [18] investigated those impacts from claiming device around point for FSW for joining polyethylene. Butt joint might have been produces throughout methodology what’s more it might have been found that the welding parameters required noteworthy impacts around ductile properties and crack areas of the welds. The rigidity diminished with expanding device around tilt point. Kush P. Mehta et al. [19] presented the work on dissimilar material such as electrolytic hard field copper, and aluminum 6061-T651. In this experimentation effect of slope approach on the mechanical and metallurgical things were calculated. Different tests were carried out for checking the quality. It was found that fault free different copper–aluminum friction stir welding was reached by tilt angles 2°, 3°, and 4°. The supreme strength of weld was obtained at 4° tilt angle. Devaiah D. et al. [20] also examined the effect of tilt angle on mechanical properties in FSW process. it was found that 0 to 2° has effective tilt angle during FSW process. The contribution of tilt angle also evaluated for strength of welded joints and elongation of welded joint. It was found that tool tilt angle has 33% contribution to % of elongation of welded joint.

Shuai Zhang et al.[21] has created CFD prototypical in which a geometrical prototypical and a fragmented contact limit situation are planned, to examine the impacts of hardware tilt edge continuously the in-process heat move and mass exchange during FSW. Creator has discovered three promising outcome initial, a greater temperature has produced by the slope welding instrument on the propelling crosswise, which is credited to the fragmented interaction at the shoulder/work piece boundary. Second, the slope welding instrument creates a greater frictional power on the device/work piece interface, which altogether recovers the interfacial material stream speed after the device. Third, the slope welding apparatus produces a more grounded blending activity toward the substantial in the region of the fusing instrument, which is useful for the blending of materials and the development of grating mix welds.

Lemos G.V.B [22] has done experimental work on nickel-chromium alloy 625 by using FSW process. The outcomes of investigation were the rotational speed badly affected on residual stresses in weld zone. Leite A.M.S. [23] were done experimental investigation on duplex stainless steel, grade UNS S82441 and polycrystalline cubic boron nitride used as a tool material. It has been found that TMAZ was the zone most susceptible to pitting. R.F. Hamade [24] were investigated the position and volume of the present defects.by using CT apparatus by using FSW technique on aluminium alloy. Yasui [25] were formulated the dissimilar metal joint by using FSW process and it was observed that Welding force and temp increases with rotating angle and fracture strength, weld strength were low as compare
to base metal strength. da Cunha [26] were studied the effect FSW parameters like Rotational speed, welding speed, Torque, Axial force, Heat input on GL E36 shipbuilding steel. It has been found that high gradient was occurred within a stirred zone. Wang [27] has investigated the performance of FSW joint for material used in aerospace tanks and rocket tanks. It was observed that high quality of longitudinal straight joint can be obtained by FSW. This process can further extended for joining domes to body of the tank in rocket. V. S. Gadakh [28] has performed experimental work on aluminum alloy by using FSW process and it has observed that tool rotational speed played vital role in FSW process and the author stated that Increasing the rotational speed and tilt angle of the tool at constant weld speed resulted in decrease in mechanical properties and hardness values. The author investigated the multi objective optimization of FSW process. It has been observed that tool rotation speed and welding speed shows significant influence on mechanical properties of welded joint and composite profile with conical base are improved the performance characteristics of the Friction stir welding process stated by Wakchaure [29].

Baffari D. [30] presented the effect of FSW process on composite material. It has been observed new exploratory apparatuses and opening plans were researched so as to improve the mechanical opposition of the joints and a numerical model was set up to investigation the procedure mechanics. Shujun Chen [31] investigated the effect of microstructure on the mechanical properties of friction stir welded 5A06 Al alloy. It has been found that grain orientation does not affect the tensile strength of the welded joints. At higher temperatures both the yield pressure and a definitive pliable pressure decline with temperature, while the all out extension increments and increase in hardness observed with increasing traverse speed has investigated by H. Dawson [32]. Rao et al. [33] done the experimentation for joining aluminium alloy by using different pin profile by using FSW process and predicted tool pin profiles mostly influenced the tensile properties of joint. Cylindrical profile of pin found out the most suitable profile which has no defect found during experimentation. Thermal and CFD models revealed that higher viscosity was observed in the SS side and different height levels of the weld section have different flow behaviour. Sadeghian [34] done simulation of FSW and it was observed that thermal and CFD models revealed that higher viscosity at SS side and different height levels of the weld section have different flow behavior. Bevilacqua [35] invented the effect of environmental impact on FSW process on butt joint for aluminum alloy. The outcomes given by the existence cycle appraisal examination has demonstrated that the ecological effect of rubbing mix welding is unequivocally influenced by rotational and welding speed. Ahmed, M.M [36] performed dissimilar weld joint by using FSW process. It was found that a noteworthy grain refining was happened in the NG zones of both similar and dissimilar FSW of AA7075 and AA5083. Frictions stir welding conducted by Sidhar [37] for joining of aluminum and magnesium alloy. It was resulted that dissolution of precipitates in WN and HAZ. Leitao [38] invented the utilization of a multi pass welding system for improving the attachment area in the dissimilar friction stir lap welding to reduce tool wear. Gite R.et. al. [40] was done review of FSW process. In the paper author has reported many important parameters and methodology for friction stir welding process. Javadi Y. [41] Invented optimization of residual stresses produced by friction stir welding (FSW) of 5086 aluminum plates. It has been inferred that the most critical impact on the longitudinal remaining pressure top is identified with the feed rate while the stick and shoulder breadth have no predominant impact. Shultz, E.F et. al [42] suggested the different tool tip angle for effective FSW joining process. It has been observed that as the tool tip angle increases the gap width reduces. Leitao, C et. al [43] presented the categorization of the constitutive behavior of welds by using digital image processing techniques. Elatharasan et. al. [44] was listed the important process parameters for the friction stir welding process. It has been observed that as the tool rotational speed, welding speed and tool axial force increases UTS and YS also increased. Gibson, B.T et al. [45] has also reported the important parameters of FSW process and automation. The latest application has also discussed. Lakshminarayanan et al [46] done the experimentation on ferritic stainless steel by using FSW process and microstructure as well as mechanical characterization has presented. It has been observed that the coarse ferrite grains in the base material are changed to extremely fine grains comprising duplex
structure of ferrite and martensitic because of the quick cooling rate and high strain actuated by extreme plastic twisting brought about by frictional mixing. Sun, Y et al. [47] has demonstrated Hydrogen-induced destruction and cracking in friction stir welded low carbon steel by the cathodic hydrogen charging method. It has been observed that cracking made along the thermo-mechanically affected zone boundary.

3. GAPS IN LITERATURE REVIEW
After study the existing literature review on FSW process a number of gaps have been observed
- FSW Tool probe tilt angle is also dominant parameter and very few literature is availed hence work can be extended to study the effect of tool profile by changing the tool probe angle on the mechanical properties.
- Most of the researcher investigated influence of limited process parameters for joining the Aluminium matrix composites (AMC) and Sandwich Aluminium matrix composites (SAMC).
- Very few literatures are available on the effect of post weld heat treatment on weld joint.
- AMC and SAMC sheets can be satisfactorily welded by using threaded cylindrical FSW tool. Similar joint can be produce by using another profile of tool and work can be extended to study the effect of tool profile on the mechanical properties.
- Very few literatures is available on Friction stir welding of pipes (FSWoP) as compare to friction stir welding (FSW) for plates.

All the summary of Friction stir welding important parameters, workpiece material s and tool materials are listed in table no.1.

Table 1. Experimental Process parameters. Workpiece material, Tool material and application of FSW

| Author) (Year) | Input variables/parameters considered with their ranges | Response & quality characteristics | Material (s), machine, Tool material etc. |
|----------------|---------------------------------------------------------|------------------------------------|------------------------------------------|
| Lemos et.al. [22] | - Welding speed - Axial force - Rotational speed | -Weld surface Quality -Welded depth | -Nickel-chromium alloy 625 Rigid clad pipes for transporting oil. |
| dos Santos Leite et.al. [23] | -Rotational speed -Welding speed - Axial force | -Microstructure -Localized corrosion resistance e | -Duplex stainless steel, grade UNS S82441 Oil, gas and Chemical transportation pipes |
| Hamade R.F et.al. [42] | -Feed mm/min | -Position and volume of the present defects by using CT apparatus | -Aluminium AA6061-T6 and AA1050 Automotive industry |
| Yasui T. et.al. [25] | -Tool tilt angle | -HAZ -Microstructure -Fracture strength -weld strength | -AA6063 and S45C High speed train, Ship & rocket Structures |
| da Cunha [26] | -Rotational speed (rpm) -Welding speed (mm/s) -Torque (Nm) -Axial force (kN) -Heat input (kJ/mm) | -Microstructure -UTS -YS -Elongation -Hardness | -GL E36 shipbuilding steel Shipbuilding |
| Author(s) | Parameters | Materials | Application |
|-----------|------------|-----------|-------------|
| Krishnan et al [14] | Rotational speed, Welding speed, Axial force | UTS, YS, Elongation, Hardness | Al-Si-Mg, AA6063 and A319 dissimilar alloys |
| Devaiah D. et al [20] | Tool rotational speed, Welding speed, Tool tilt angle | UTS, YS, Elongation, Hardness | AA5083 and AA6061 Aluminum alloys |
| Wang G. et al [27] | Rotation speed, Traverse speed, Tool tilt angle, Pin Length | UTS, YS, Elongation, Hardness | Aluminium alloy AA2219 |
| Devaiah D. et al [20] | Process parameters are constant. | Temp, Fracture zone, Weld zone, Microstructure, Grain size. | Aluminium alloy AA6061 of |
| Kumar, T.P. et al [43] | Tool Rotational Speed, Weld Speed, Tilt Angle | Microstructure, Micro hardness | AA2014 is a heat treatable aluminium alloy |
| Gadakh V. S. et al [28] | Tool Rotation (TR) (RPM), Tilt Angle (degrees), Welding Speed (WS) (Inch/sec) | UTS, YS, Elongation, Hardness | AA6082-T6 aluminium alloy |
| Wakchaure K. N. et al [29] | Rotation speed, Traverse speed, Tilt angle, Shoulder diameter, Pin diameter, Pin height | UTS, YS, Elongation, Hardness | DP700 steel |
| Mahdi M. et al [44] | Tool rotation, Feed rate, Tilt angle, Tool force, Dwell time | Elongation, Hardness, YS | Aluminium alloy AA6082-T6 |
| Baffari D. et al [30] | Rotation speed, Tilt angle, Traverse speed | Hardness, Microstructure, Tensile test | 5A06 Aluminum alloy Light weight hybrid structures for automotive, aeronautics and shipbuilding |
| Chen S. et al. [31] | Tool rotational speed, Tool tilt angle, Traverse speed | Hardness, Microstructure, Tensile test | 5A06 Aluminum alloy, Pressure vessels, ships, and automobiles, aerospace. |
| Name          | Parameters                        | Materials                                      | Industries                                      |
|---------------|-----------------------------------|------------------------------------------------|------------------------------------------------|
| Dawson H. et.al. [32] | Rotation speed, Traverse speed, Micro hardness, Temperature dependent mechanical Behavior, Tensile testing of base material at room temp to 750 c, Weld joint test by tensile test at room temp to 500 c | Fully ferrite MA956 ODS steel | Nuclear fission and fusion reactors |
| Rao M.S.S. et.al. [33] | Rotational speed, Welding speed, Tool pin, Tensile strength, Weld joint, 5mm thick IS:65032 aluminium alloys |  | Automobile and aircraft industries |
| Sadeghian B. et al [34] | Tool rotational speed, Tensile flow, Weld morphology, 304 SS AA-5083 |  | Aerospace and chemical industry |
| Lambiase F. | -Plunging Load, Dwell time, Joining forces, Thermal analysis, Morphology of the joints, Mechanical behavior of the joints, | AA5053 sheets with polyvinyl chloride (PVC) | Automotive, aerospace, biomedical, civil constructions |
| Bevilacqua et al. [35] | Rotational speed, Welding speed, Tilt angle, Metering of electrical energy absorbed, Tensile test, Life cycle assessment, AA5754 aluminum alloy H13 tool steel |  | Shipbuilding and Vehicle bodies, Food processing, Chemical and nuclear structures |
| Ahmeda M.M.Z. et.al. [36] | Traverse speeds, Diameter of the pin, Tensile test, Microstructure, Hardness, Aluminum alloys AA7075-T6 and AA5083-H111 |  | Rail cars, Vehicle bodies, Tip truck bodies, Pressure vessels |
| Sidhar H. et.al. [37] | Two thermal conditions were made by using external cooling mediums, Weldability, 1424 aluminum alloy |  | Automotive and aerospace |
| Leitao C. [38] | Rotational speed, Welding speed, Minimize tool wear, Aluminium and Steel |  | Automotive parts |
| Evans, W. et.al. [39] | Friction Stir Extrusion process, Tensile test, Microstructure, Hardness, Aluminium and Steel |  | Automotive parts |
4. CONCLUSION.
In the current research researchers has found that friction stir welding is effective/cost efficient alternative method for joining the thin plates/hollow pipes. Hence same joining process can be used for joining the thin shell/tanks for many applications like automobiles, aerospace, shipbuilding etc. There is wide scope in joining thin dissimilar materials by using friction stir welding process. Friction stir process for joining of pipes (FSWOP) is also one of alternative efficient and cost effective method for joining the pipe as compare to friction stir welding of plates (FSW). There is limited research has been done in this areas. This method can be easily implemented/applied for joining the different parts/sectors

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