Friction Stir Welding: A Review

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ABSTRACT
Friction stir welding (FSW) is a solid state joining process in which a rotating tool is used to join the two metal parts. The rotating tool is inserted in between two metal parts and the frictional energy is used to join the metal. In this research paper a review has been presented on FSW. The previous literature has been discussed along with the future aspects included in the field of FSW.

Keywords: FSW, microstructure, modelling, review, strength

1. INTRODUCTION
The difficulties arising in joining of the aluminium alloy and dissimilar metals by commonly used technologies such as fusion welding, a new welding technology friction stir welding (FSW), invented and patented in 1991 by Wayne Thomas at TWI (The welding institute) Ltd. Friction stir welding (FSW) is a solid state joining process in which specially designed rotating tool, which is inserted into the adjoining edges of the sheets to be welded and the tool moved across the length of the joint. The frictional heating and plastic deformation heating produces by the tool in the welding zone along the joining of the work piece length basis for the welding. The friction stir welding is solid state joining process mean no melting of the material take place during the process. The tool moves and rotates along the welding line and forced the material to flow around the welding line in an intricate pattern.

Firstly research on friction stir welding (FSW) for the examination of the process mechanics and the influence of the most relevant process parameters on the mechanical properties of the welded joints. A few geometrical and technological parameters strongly control the process: the tool geometry affects both the metal flow and the heat generation due to the friction forces work, while the tool rotating speed and feed rate combination determines the heat flux conferred to the joint during the process. Effect of tool design, tool rotation speed and tool travel speed on mechanical property is to be analyzed by various experiment techniques [1-2].

The various parameters are welding speed, tool rotation speed, tool shoulder diameter, tool pin length and tool pin diameter. The various type of the tool structure such as tool with cylindrical pin, threaded pin and square pin are used.

The FSW (Friction stir welding) process is particularly applicable for aluminum alloys but can be extended to other products such as stainless steel, Copper and its alloys, Lead, Titanium and its alloy, Magnesium and its alloys, Zinc, Plastics and Mild steel. Plates, sheets and hollow pipes can be welded by this method. The limitations of FSW are reduced by serious research and improvement. Due to cost effectiveness and ability to weld dissimilar metals makes it a commonly used welding process in recent times. However the material of the tool is depends upon the work piece material. The influence of the tool rotation speed on microstructure, surface appearance, and mechanical properties of the friction stir welded plates were investigated and analysis by various mathematical model and experimental technique.

The schematic diagram for FSW is shown in figure 1. The non-consumable tool has a circular section except at the end where there is a threaded probe or more complicated flute; the junction between the cylindrical portion and the probe is known as the shoulder. The probe penetrates the work piece whereas the shoulder rubs with the top surface. Friction stir welding (FSW) has the advantages such as increased strength, Improved sealing, completely void-free, leak proof joints with greater strength than fusion-welded joints, reduced heat distortion, improved repeatability, quality and environmental aspects.
The research work of various researchers has been divided into various group viz. strength of weld, microstructure of weld, numerical or mathematical modeling and defects removal along with the future aspects of friction stir welding on novel materials.

2. STRENGTH OF WELD

A lot of research has been carried on friction stir welded joints. When the two pieces are joined then the strength of the joint must be measured for a basic knowledge of deformation. Various researchers envisaged the different types of strength (viz. tensile strength, shear strength and yield strength etc.) of FSW joints.

In 2003 Ericsson and Sandstrom [4] compared the fatigue strength of Friction Stir Welding (FSW) with the conventional arc-welding methods: MIG-pulse and TIG. The Al–Mg–Si alloy 6082 was FS welded in the T6 and T4 temper conditions, and MIG-pulse and TIG welded in T6. The T4-welded material was subjected to a post-weld ageing treatment. The parts were joined with a welding speed of 700 or 1400 mm/min. The probe diameter of the tool measured 6 mm, and the shoulder diameter was 14 mm. The penetration depth was adapted to fully penetrated butt joint in a material of 4 mm thickness. The rotation speed of the tool (spindle speed) was 2500 rpm for the high speed and 2200 rpm for the low speed tests. The MIG-pulse and TIG welds showed lower static and dynamic strength than the FS welds. The TIG welds had better fatigue performance than the MIG pulse welds. The welds in the alloy with the T4 condition were further post-weld aged (PWAT). This enhances yield and tensile properties to a level corresponding to that of the T6 temper. The fatigue strength of FS welded Al–Mg–Si alloy 6082 is higher than that of MIG-pulse and TIG welds of the same material. The TIG welds had better fatigue performance than MIG. Zhang & Zhang (2007) joined two plates butt weld made of Al 6061-T6. The radii of the pin and the shoulder are 5 mm and 22.7 mm, respectively. The dimensions of the two plates are 100 mm in length, 40 mm in width and 8 mm in thickness. The tool pin rotates with a certain angular velocity and the translational velocity is applied on the boundaries of plates in the numerical modeling. Three dimensional finite element simulations based on solid mechanics have been carried out to understand the material flow, the deformations of material, and the formations of weld zones in the friction stir welding process. Increasing the angular velocity of the pin, the material in the nugget zone can be more fully mixed, which improves the joining quality of the two welding plates. The increase of speeds, including the rotational speed and the translational speed, can both accelerate the material flow, especially in front of the pin on the retreating side where the fastest material flow occurs. The contact pressure on the pin-plate interface is decreased with the increase of the angular velocity. The equivalent plastic strain is increased with the increase of the angular velocity, but is decreased with the increase of the translational velocity. The material in the nugget zone can be more fully stirred with the increase of the angular velocity [5].

Kulkei et al. (2008) made lap joints by FSW of AA 5754 plates by means of a conventional semi-automatic milling machine. The thickness of these aluminium alloy plates was 3 mm and machined out in 200 mm lengths and 100 mm width. The three tools with shoulder diameter and threaded pin height of 15 and 5 mm, respectively, were chosen. The diameters of the threaded pins were 3 mm, 4 mm and 5 mm (threads m3, m4 and m5) with 2 degrees tilt angle. Increasing tool rotation for a fixed tool pin diameter reduces fatigue strength of joints. Increasing tool pin diameter for a fixed tool rotation, decreases fatigue strength of joints [6]. Kumbhar and Bhanumurthy (2008) joined Al alloy 6061 with dimensions 300 mm x 50 mm x 5 mm using FSW.
A high-speed steel tool was used having the shoulder diameter of 25 mm with pin height of 4.8 mm and a 5 mm pin diameter. The tool rotation speeds 710, 1120 and 1400 rpm and the tool traverse speeds of 63, 80 and 100 mm/min were used. The tool tilt in all the trials was kept constant at 2°. The resultant microstructure was characterized using electron probe microanalysis (EPMA), secondary electron microscopy (SEM) and orientation imaging microscopy (OIM). It is useful to friction stir weld of Al 6061-O condition at lower tool rotation speeds and at a higher welding speeds, thus enhancing the productivity. Friction stir welding of Al 6061- O condition increases the strength of the weld joint as compared to that of the parent material in O-condition at the cost of the ductility, for all welding trials. But the ductility is equal to or better than that of the parent material in T6 condition. PWHT substantially reduces inhomogenities. Orientation imaging microscopy results suggest that the base material is more textured than the nugget region. Mechanical properties substantially improve during PWHT and at an optimized heat treatment schedule [7].

Sahin (2009) studied the FSW on austenitic stainless steel (AISI 304) and aluminium materials for the statistical analysis, tensile testing, micro structural observation, EDS measurements, and hardness testing. Statistical analysis is an economical and reliable method for optimizing welding parameters. Tensile strengths for austenitic stainless steel and aluminium parts yielded a positive result when compared to those of base metals. The joint strength increased and then decreased after reaching a maximum value, with increasing friction time. The presence of contaminants at the interface of the metals reduces the joint quality. No significant effect was observed on welding properties with respect to the surface finish operations. In the micro photos, the broken up aluminium oxide film resulted in increased deformation at the interface. Formation of an oxide in the joints causes a barrier that prevents diffusion. The difference in weight of alloying elements can be clearly seen by analyzing spectrum of elements. EDX measurements clearly show that St-Al joints consist of some inter metallic compounds. Hardness of both materials in the vicinity of the weld interface was higher than that of the base metals [8].

In 2009 Lakshminarayanan et al. reported on their research that the friction stir welding (FSW) on aluminium alloy 6061 showed better mechanical properties compared with gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) joints. This was due to the formation of fine and equi-axed grains which was uniformly distributed. The aluminium alloy AA 4043 used as a filler rod for GTA and GMA welding process. The FSW joint has more strength and hardness as compared to gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) joints [9]. Arora et al. (2010) founded that forging force to be dependent on shoulder diameter and rotational speed where as welding force dependent on welding speed and pin diameter, when friction stir welding on AA 2219 using vertical milling machine. Tensile strength of welds was significantly affected by welding speed and shoulder diameter whereas welding speed strongly affected percentage elongation. Tensile strength, Vickers hardness, percentage elongation and microstructure of the welded joint studied. TEM studies indicated coarsening and/or dissolving of precipitates in nugget. For the gas metal arc weld, SEM investigations revealed segregation of copper at grain boundaries in partially melted zone. In order to measure the process forces, a fixture with load cells, was designed, developed, and then interfaced to a computer through a DAQ card using Lab VIEW. Final experimentation was done according to Taguchi L9 orthogonal array. [10]

Lorrain et.al (2010) studied the friction stir welding on 4mm thick aluminium alloy 7020-T6 using an ESAB friction stir welding. Two tools, made of high carbon steel has a straight cylindrical pin (SC) whereas the second tool has a tapered cylindrical pin (TC3F) with three flats been used to produce the joints and the both tool were unthreaded pin. Material flow with unthreaded pin was found to have the same features as material flow using classical threaded pins: material is deposited in the advancing side (AS) in the upper part of the weld and in the retreating side (RS) in the lower part of the weld; a rotating layer appears around the tool. However, the analysis revealed a too low vertical motion towards the bottom of the weld, attributed to the lack of threads. The product of the plunge force and the rotational speed was found to affect the size of the shoulder dominated zone. This effect is reduced using the cylindrical tapered pin with flats. The three flat faces change the material flow generated by the shoulder and create more variation of the material velocity than the straight cylindrical pin [11].

In 2011 Bitondo et al. investigated the friction-stir welded butt joint of AA 2198 T3 aluminium alloy with varying rotational and welding speeds. Two sets of empirical models based on regression analysis are developed, the first one predicts the downwards forging welding forces and the second one predicts yield and tensile strength. Non-consumable tools, made of Cr-Mo steel, were used to fabricate the joints. Tool geometry is characterized by a shoulder radius of 12 mm and by an unthreaded cylindrical pin of 4 mm in diameter and 3 mm long. The forging action of the tool
shoulder was enhanced by a forwards tool tilt angle of 2°. The plates were butt welded using a five axes DMG CNC universal milling machine with a 0°×600×600 (x/y/z) workspace. Welding forces demonstrate a simple and analogous dependence upon process parameters under concern: they decrease increasing the rotational speed and slightly rise with the welding speed, however following dissimilar laws. On the contrary, yield and tensile strengths show a very different dependence on rotational and welding speeds [12].

Deplus et al. (2011) measured the longitudinal residual stress performed by the slitting method on friction stir welds in 2024-T3, 6082-T6 and 5754-H111 aluminum alloys and compared. In friction stir welding of aluminium alloys, the level of the maximum residual stresses is most of the time significantly lower than the base material yield strength [13].

In 2012 Bahemmat et al. worked on the friction stir welding (FSW) on dissimilar AA2024-T4 and AA7075-O to obtain high-quality welds by adjusting the rotational and welding speeds. The threaded cylindrical tool with notch and the threaded taper tool are used and compare which produce the better result or no effect. Threaded taper and threaded 4-flute tools are utilized to perform the welding process. The mechanical properties of the welds are studied through micro hardness distribution and tensile tests. It was clarified that increasing the rotational speed and reducing the welding speed culminated in a decrease in the overall hardness value in the SZ. Macro structural analysis was performed to check to identify the weld ability. The extra defects were founded in 4-flute tool in AA 7075-O at AS, as compared to the taper tool. From the micro hardness test average hardness value in 4-flute tool case was lower [14]. Jonckheere et al. (2012) studied the friction stir welding (FSW) on AA 6063- T6 alloy performed on a CNC milling machine. The work pieces were 90 mm long and 30-mm-wide × 3-mm-thick. Two cylindrical tools with a threaded pin and a flat scrolled shoulder with pin and the shoulder diameters were equal to 4 and 10 mm, and 5 and 15 mm respectively. The tool rotation speed is equal to 1,000, 1,500, or 2,000 rpm, clockwise. The influence of the tool dimensions and of the welding parameters on the fracture and lap shear properties of friction stir spot welds is investigated. Fracture initiating at the triangular cavity and following the thermo mechanically affected zone [15].

Cole et al. (2012) investigated the friction stir welding on 5-mm-thick aluminum alloy 5083-H111 to explore common process variations encountered in friction stir welding (FSW) using robotic FSW system. Part fit-up and mating variations are common in manufacturing. The effects on joint strength and mechanical properties of several of the most common mating variations (i.e., faying surface gap, misalignment, mismatch, etc.) are experimentally determined as individual effects as well as among common welding parameters. The work also indicates that of all the mating variations tested in this study, tool misalignment, followed by travel angle, has the most significant effect on the measured joint strength [16]. Borino et al. (2009) investigated the friction stir welding (FSW) on AA6082- T6, 3 mm thick specimens, welded on a milling machine. Tool was made in H13 steel quenched at 1020°C, characterized by 52HRc hardness; a cylindrical pin with pin diameter of 4.00 mm, pin height of 2.90 mm and the shoulder diameter of 10 mm were used. Tool rotation speed of 1040 rpm, a tool feed rate of 100 mm/min, a tilt angle of 2° and a tool sinking of 2.9 mm were used. The finite element method was used to analyze mechanical response. The conventional tensile tests and local indentation tests were to investigate mechanical properties of dissimilar zones of FSW welded joint [17].

Fratini et al. (2009) calculated the possibility to enhance the joint performances through in process heat treatments on FSW of AA7075-T6 aluminum alloy on traditional milling machine. Welded joints were developed under three different conditions, namely, free air, forced air, and with water flowing on the surface of the joint itself. The tool material was H13 steel quenched at 1020°C with cylindrical HSS steel pin was inserted in the tool with the following geometrical characteristics: pin diameter equal to 4.00 mm and total pin height (h) equal to 2.70 mm; the tool shoulder was 12 mm. Using an external cooling during the FSW process an improvement is observed in the mechanical resistance, in terms of UTS of the developed joints [18].

The strength of weld is enhanced by increasing the angular velocity of the pin. The effect of other parameters like welding speed, shoulder diameter, pin structure (Shape) and pin diameters can be considered for future investigations.

3. MODELLING

The mathematical or numerical modeling was one of famous method for investigation of effect of process parameters on response variable with the help of model. These models were made with the help of finite element modeling or response surface methodology. The research of various researchers has been explored into the following paragraphs. Zhang et al. (2007) worked on Al 6061-T6 plate. The radii of the pin and the shoulder are 3 and 7.5 mm, respectively. The dimensions of the two
welding plates are 100mm in length (along the welding line), 30mm in width and 3mm in thickness. Material flow in friction stir welding (FSW) under different process parameters is simulated by using the finite element technique based on the nonlinear continuum mechanics. Results indicate that the distribution of the equivalent plastic strain correlates well with the distribution of the microstructure zones in the weld. It seems that there is a quasi-linear relation between the change of the axial load on the shoulder and the variation of the equivalent plastic strain. The material flow can be accelerated with the increase of the translational velocity and the angular velocity of the pin. There exists a swirl on the advancing side and the material flow in the swirl on the advancing side becomes faster with the increase of the translational velocity [19].

Fratini et al. (2009) analyzed the FSW of butt joints by using finite element analysis (FEA) to investigate the actual material flow occurring in the FSW of T-joints. A thin foil of brass as marker, placed at the interface of the two blanks to be welded. Two different tools were utilized as cylindrical tool: a 15-mm shoulder was made in C40 steel, while a conical pin, made in tungsten carbide, was characterized by a diameter equal to 4.00 mm and a height equal to 4.00 mm conical tool: shoulder of 18 mm, conical pin characterized by a major diameter equal to 6.00 mm, a minor diameter of 1.90 mm, and a pin height equal to 4.80 mm (cone angle 20°); the tool was made in tempered C40 steel. The cylindrical determines some flow defects due to its geometrical discontinuities. In turn, the conical pin determines a stronger vertical movement of the flowing material which makes the bonding easier and also improves the forging action [20].

In 2010 Karthikeyan and Balasubramanian predicted the tensile shear fracture load of friction stir spot-welded AA 2024. The response surface methodology (RSM) was applied to optimize the FSSW parameters. A non consumable tool made of high-carbon steel with a flat cylindrical shoulder diameter of 16.2 mm, 0.8-mm pitch metric, left hand threaded pin of 5.4-mm diameter, was used. An indigenously designed and developed computer numerical controlled friction stir spot welding machine (4,000 rpm, 22 kW, 6 t) was used. A maximum tensile shear fracture load of 9.39 kN could be attained under the welding conditions of 1,000 rpm of tool rotational speed, 13.56 mm/min of plunge rate, 5.178 mm of plunge depth [21]. Aval et al. (2011) observed the relationship between the microstructures of thermo mechanically affected zone (TMAZ) and heat input in friction stir welding (FSW) of 5086 aluminum alloy. A three-dimensional finite element analysis was used to predict the welding heat input. The aluminum plate with 5-mm thickness welded with a tool of shoulder diameter 20-mm consisting conical pin. The grain size within the TMAZ decreases with decreasing heat input per unit length during FSW. Heat flow parameter (Q/t/S) may be considered as an important factor in the stir zone affecting grain size and recrystallization kinetics. The predicted peak temperatures are higher on the advancing side than the retreating side [22].

S. Rajakumar et al. (2011) investigated friction-stir-welded joint of AA6061 aluminum and develop empirical relationships to predict grain size and hardness of weld nugget. At varying welding speed, rotational speed, pin diameter, tool hardness and shoulder diameter showed the defect on weld joint which occur with probable reasons. The empirical relationships are developed by response surface methodology incorporating FSW tool and process parameters. A linear regression relationship was also established between grain size and hardness of the weld nugget of FSW joints [23]. Aval et al. (2012) analyzed the thermo mechanical responses of friction stir welding on AA5086-O and AA6061-T6 aluminum alloys by using three-dimensional model and the finite element software ABAQUS. It is found that tool rotational speed significantly affects the amount of maximum tensile residual stress while traverse speed mainly changes the distribution of transverse residual stresses [24].

Arora et.al (2012) modelled the friction stir welding by using three-dimensional heat transfer and viscoplastic model to compute the influence of pin length and diameter on traverse force. It is investigated that a tool pin with smaller length and larger diameter will be able to sustain more stress than a longer pin with smaller diameter. The proposed methodology is used to explain the failure and deformation of the tool pin in independent experiments for the welding of both L80 steel and AA7075 alloy. The computed values of maximum shear stress on tool pin increases with either the increase in pin length or the decrease in pin diameter [25].

4. MICROSTRUCTURE

The investigation of surface of an object by some enlarged scale is known as microstructure analysis. The macro and micro-structure analysis carried by different researchers given below.

In 2005 Uzun et al. has joined the dissimilar materials, Al 6013-T4 alloy and X5CrNi18-10 stainless steel was carried out using friction stir welding (FSW) technique. The 4 mm thick plates of 6013-T4 aluminium alloy and X5CrNi18-10 stainless steel were friction stir welded using an FSW adapted milling machine at DLR. The tool rotational speed and travel speed were 800 rpm and
80 mm/min, respectively. The microstructure, hardness and fatigue properties of friction stir welded 6013 aluminium alloy to stainless steel have been investigated. Optical microscopy was used to characterize the microstructures of the weld nugget, the heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) and the base materials. Fatigue properties of Al 6013-T4/X5CrNi18-10 stainless steel joints were found to be approximately 30% lower than that of the Al 6013-T6 alloy base metal. The hardness value slightly decreases in the TMAZ at the advancing side (Al 6013-T4 alloy side). The minimum hardness indicated to the HAZ in the Al 6013-T4 alloy is located around 6 to 11 mm from the weld centre at the retreating side [26].

Zhang et al. [27] optimized the welding parameters of AZ31 magnesium alloy by friction stir welded to get the best conditions for defect-free weld. The base metal used in this study was the hot rolled magnesium alloy AZ31, 5 mm in thickness, 100 mm in width and 200 mm in length. Two plates were friction stir welded at different welding speed (from 40 to 600 mm/min) and at the same rotation speed 1000 r/min. The experimental results showed that there was pore produced in friction stir weld when the welding speed increased to 200 mm/min with the constant rotation speed 1000 r/min. The pore firstly occurred near the welding line at relatively low welding speed, but move into advancing side and up part of the weld when continues to increase the welding speed. Faster the welding speed is, larger the pore is. When kept welding speed and rotation speed constant, pore occurred at small welding pressure. Based on experimental results, a simple mathematic model was brought forward to simplify the process for choosing suitable welding parameters. The defect-free model consists well with the friction stir welding procedure and provides a simple method for defect-free weld.

Sakthivel et al. (2009) found that two aluminum plates of 300×150×6 mm (length, width, and thickness, respectively) were used for FSW. At a constant rotational speed of 1,000 rpm with various translation speeds, welding was carried out. The tool had dimensions of 15-mm-diameter shoulder with a threaded cylindrical pin size of standard metric M6 (6-mm diameter, 1-mm pitch) and 5.75-mm pin length. The microstructure of the weld nugget consists of fine equiaxed grains. These grains are more homogeneous at lower welding speed than at higher welding speed. Weld zone hardness is decreasing as compared to the parent metal, but the hardness slightly increases with the increase of welding speed. The ultimate tensile strength is observed to increase when decreasing the traverse speed. Fig. 2 exhibits the microstructure of FSP region of all the joints manufactured at an axial force of 7 kg. The highest hardness value of 88 VHN has been achieved using square pin and minimum hardness (57 VHN) has been noted Out Of the five joints, the highest hardness value of 88 VHN has been recorded in the joint made by straight cylindrical profile pin tool. The FSP region of the joint made using square pin profile contains very fine equiaxed microstructure (Fig. 2d) compared to other joints [28].
Sarsılmaz & Çaydaş (2009) studied the effect of stirrer geometry on mechanical properties of AA 1050/AA 5083 alloy couples. The alloys were machined to 120×65×6 mm dimensions by a vertical CNC milling center. The tilt angle was kept at 2.5°. The relative effect of each factor and combination of factors on responses was obtained by analysis of variance (ANOVA). The welding parameters were optimized by using the S/N ratio approach. The welding zone and fracture surfaces were also studied by using optic and scanning electron microscopes (SEM), respectively. The UTS and nugget hardness increase with traverse speed. The UTS and nugget hardness decrease with tool rotational speed. ANOVA results shows that the most important factor on UTS was found as traverse speed (71.62%), while the rotational speed was the second ranking factor (10.59%) and stirrer geometry was the least (7.03%). According to the ANOVA results, the most important factor on nugget hardness was found as traverse speed (72.57%), while the rotational speed was second ranking factor (21.19%) and stirrer geometry was the least (0.89%) [29].

Padmanaban & Balasubramanian (2010) investigated the effect of friction stir welding process parameters such as tool rotational speed, welding speed, and axial force on AZ31B magnesium alloy. Tensile properties of the welded joints were evaluated and correlated with the weld zone microstructure and hardness. The joint fabricated with the rotational speed of 1,600 rpm, welding speed of 0.67 mm/s, and axial force of 3 kN showed higher tensile properties, compared to their counterparts. Fatigue properties of FSW joints were slightly lower than the base metal. Non consumable tool made of high carbon steel with threaded pin profile was used to fabricate the joints [30]. Das et al. (2012) considered the Friction stir welding on aluminum sheet (AA6063) and zinc-coated steel (HIF-GA) sheet to evaluate joint strength of lap joint between under different combination of rotational speed and traverse speed. The shear strength decreases significantly when rotational speed increases from 700 to 1,500 rpm at a traverse speed of 30 mm/min. At traverse speed of 50 mm/min, increasing rotational speed from 700 to 1,500 rpm, shear strength remains more or less the same. However, at a traverse speed of 100 mm/min, the shear strength increases significantly with increasing rotational speed from 700 to 1,500 rpm. The results have been correlated with the microstructural characteristics at the bond interface using energy dispersive X-ray spectroscopy, electron probe micro analyzer, and X-ray diffraction [31].

Better morphological properties were obtained by a square threaded profiled pin tool. The region of friction stir welding contains fine and equi-axed microstructure.

5. DEFECTS REMOVAL

During the friction stir welding some defects are observed. For the production of defect free weld some research has been carried by researchers. Elangovan et al. (2008) fabricated the specimens of AA6061 into the required sizes (300×150×6 mm) by power hacksaw cutting and grinding. Non-consumable tools made of high carbon steel were used to fabricate the joints. The tool Rotational speed 1200 RPM, welding speed 1.25 mm/sec, axial force 6.0, 7.0 and 8.0 KN, pin length 5.5 mm, tool shoulder diameter 18 mm, pin diameter 6 mm were used for welding. Five different tool pin profiles (straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square) have been used to fabricate the joints at three different axial force levels (6kN, 7kN, 8kN). From this investigation it is found that the square tool pin profile produces mechanically sound and metallurgically defect free welds compared to other tool pin profiles. An axial force of 7 KN produces a defect-free FSP region, irrespective of tool pin profiles [32].

Zhang et al. (2009) reported that the maximum temperature can be increased with the increase of the shoulder size. The temperature distribution under the shoulder becomes more uniform with the increase of the shoulder size. The increase of the shoulder diameter can lead to the increase of the efficient power for FSW process. The material used as the work-piece Al 6061 T-6 of round plate of 80 mm diameter. The weld thickness is 3 mm. When the welding speed is not properly selected, weld defects can be found. So, a velocity of 2 mm/s is used. The diameter of the pin is 8 mm, and the diameters of three shoulders are 16, 20, and 24 mm, respectively, cylindrical pin without thread is adopted for the current study. All the three welding tools rotate with angular velocity of 290 rpm around their axes, and the axial pressure applied to the shoulder is 90 MPa. Preheating time is selected to be 2.5 s and then the welding tool translates for 12 s [33]. Zimmerman et al. (2010) optimized the FSW process parameters for the forces and torque generated on 6-mm thick 6082-T651 aluminum alloy series. The analysis of their research showed that the maximum axial force and torque can be influenced by both spindle rotational speed and tool plunge velocity. Their research gives a way to reduce the maximum amplitude without drilling a hole before starting the plunging stage. As, the dissipated heat energy was too small, the material...
applied more resistance on the tool, generating greater forces and torque [34].

6. CONCLUSIONS
Based on the review of friction stir welding it has been found that a lot of materials can be processed on friction stir welding. With the increase of angular velocity a greater strength has been obtained. Square profiled pin tool gives the better results for morphological characteristics. Some future scope of work can also be considered like
1. Novel materials, composites and dissimilar materials can be considered for future investigation.
2. A little research has been carried for the defect removals.
3. Heat affected zone investigation and minimization is another thrust area for future work.
4. Friction stir welding still requires a database for the processing of materials, so researches can work in this area for creating a database for the industries. In this database the industry select the optimum results for a material specific.


REFERENCES


