Review on Different Trends in Friction Stir Welding

B. Supraja Reddy
Assistant Professor
Department of Mechanical Engineering
VRSiddhartha Engineering college, Vijayawada, A.P, India

DR. B.Ram Gopal Reddy
Associate Professor
Department of Mechanical Engineering
RVR&JC College of Engineering, Guntur, A.P, India

Abstract- Friction stir welding was introduced by Wayne Thomas at The Welding Institute in December 1991. Friction stir welding was a major welding process in Ship building, Aerospace, Automotive and Railway industries especially in Aluminium Alloys and also Recently Applicable for copper, magnesium, Steel, Titanium, Nickel based Alloys, Metal Matrix Composites and Dissimilar Metals. This review discuss on evaluation of mechanical properties and micro structure characteristics of different material welded joints using different weld parameters made by Friction Stir Welding (FSW), Friction Stir Spot Welding (FSSW) and Underwater Friction Stir Welding (UWFSW). This review also discuss on machine and control systems applied in friction stir welding with a special focus on new trends (Robots and force controls).

Keywords –FSW, FSSW, UWFSW, Process Parameters, Microstructure, Mechanical Properties, Machine and Control Systems.

I. INTRODUCTION

FSW is a major manufacturing technology for aerospace, civil structures, Automotive and ship building. The FSW was a solid phase process takes place at temperatures below the melting point of the material. As a result, the weld seams produced by this method are defect free from defects such as shrinkage, cracking, porosity, and embrittlement. Minimize the welding temperature during FSW process makes possible lower distortion and residual stresses, enabling improved mechanical properties. FSW is also energy efficient process that requires no filler rods and in most cases, does not require the use of shielding gas. Furthermore, the process lacks fumes, arc flash, spatter, and pollution which are associated with more fusion welding techniques. This makes FSW a very attractive welding process. FSW is a continuous process that involves the plunging of a portion of a specially shaped rotating tool between the welding faces of the joint. FSW can be applied to most geometrical shapes and to different types of joints, those are lap, butt, T-butt, and fillet shapes. The most convenient joint configurations for FSW are butt and lap joints. The Schematic diagram of FSW process is presented in Figure 1. The relative motion between the tool and the work piece generates frictional heat that creates a plasticized region around the contact portion of the tool. In that the shoulder prevents the plasticized material from being expelled from the weld. Therefore, the tool is moved relatively along the joint line, forcing the plasticized material to coalesce behind the tool to form a solid-state joint. The resulting microstructure of FSWelds are divided into three different regions [Threadgill PL(2007)], the heat affected zone (HAZ), which is closer to the weld-center where the material has experienced a thermal cycle that has modified the microstructure, the thermo-mechanically affected zone(TMAZ), a region where the FSW tool has plastically deformed the material and the Weld Nugget(WN) sometimes referred to as the stir zone(SZ) a fully recrystallized area, which is refer to the zone previously occupied by the tool pin. Although, FSW gives high quality welds, proper use of the process and the control of process parameters are needed to achieve the desired quality of weld [Record JH (2004)]. Process parameters such as the tool design, input welding parameters, joint configurations, tool displacements and forces acting on the tool during the friction stir welding process and the heat input during the process, are found to influence the material flow and temperature distribution during the welding process [BlignaultC(2002), Zorc TB(1993)] thereby influencing the microstructure evolution and the mechanical properties of the joints. The benefits of this FSW process include low distortion, greater weld strength compared to the fusion welding process, improved corrosion resistance and lower cost in production applications [O' Brien A(2007)].

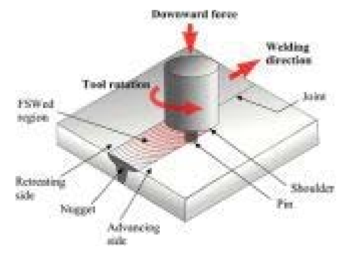


Figure 1: Friction stir welding Process

Friction stir spot welding (FSSW) was introduced based on the basic principle of the Friction stir welding. FSSW (fig2) has consists three basic steps plunging, stirring, and drawing out [H. Zhang (2015), M. Merzoug (2010)]. A rotating tool with a projecting pin slowly penetrates the overlapped sheets until the tool shoulder contacts the top surface of the upper sheet and reaches the desired depth. In the stirring step, the material from the two work pieces is mixed together. The downward force and the tool rotational speed are keep for an appropriate time to generate frictional heat. Then heated and softened material maintain to the tool deforms plastically, and a solid state bond is made between the surfaces of the upper and lower sheet surfaces. In the last step once the bonding is achieved the tool is drawn out. FSSW can be considered as a transient process due to its short cycle time. FSSW has been used effectively to spot weld several materials including aluminum, magnesium, polymers and steel.

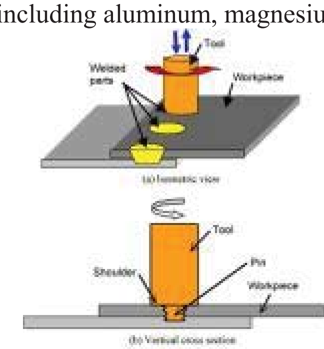


Figure 2: Friction stir spot welding process

Researchers confirmed that FSW can produce sound welded joints in aluminium alloys [Mehta M,(2015)]. However, the thermal cycles exerted during FSW resulted in the reduction of mechanical properties of the welded joints due to coarsening and dissolution of strengthening precipitates in the TMAZ and HAZ of the welded joints [Liang XP,(2012)]. In most of the age hardenable aluminium alloys, TMAZ and HAZ are identified as the weak regions [Sivaraj P,(2014)]. The strength of the parent metal and weld joints of aluminium alloys depend on the presence of the precipitates. The thermal conditions prevailed during heating and cooling cycle of welding affect the precipitation behavior. In FSW, the heat generated in the stir zone and heat conducted to TMAZ and HAZ causes the precipitates to be either solutionized or coarsened. The loss of precipitates during solutionizing and coarsening of precipitates resulted in poor welded joint properties [Lee WB,(2003)]. In addition the high thermal conductivity of aluminium creates variation in the thermal gradient and heat generated along the longitudinal direction, particularly in joining of thick plates. It results in non uniformity along the weld region. In order to overcome the heat related problems created in TMAZ and HAZ and to improve the strength of FSW welded joints, the heat should be dissipated readily using a cooling method. The water cooling method is more efficient than the other cooling method in terms of uniform cooling and heat coefficient. From the literature it is understood that the mechanical properties of the FSW welded joints could be improved by the water cooling.

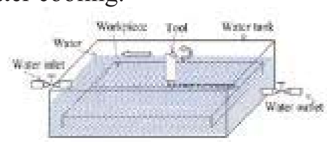


Figure 3: Schematic diagram of UWFSW process

A quality weld produced by a robot depends on the fine tuning of some process parameters and force/ motion control abilities. Therefore, Control systems can deal with these limitations. The different ways to the control systems applied in Friction Stir Welding are discuses and also discussed their advantages, drawbacks. In this review, discuss about evaluation of mechanical properties and microstructure characteristics of different material welded joints using different weld parameters made by Friction Stir Welding (FSW), Friction Stir Spot Welding (FSSW) and Under Water Friction Stir Welding (UWFSW) and also focus on new trends (Robots and force controls).

II. EFFECT OF PROCESS PARAMETERS ON MICRO STRUCTURE EVOLUTION AND MECHANICAL PROPERTIES OF DISSIMILAR METALS BY USING FRICTION STIR WELDING

A joining criteria of dissimilar Aluminium and stainless steel has been achieved for lap welds [K.Kimapong, (2004)]. Successful welding of Aluminium and copper with good joint integrities have been achieved [I.Galvao]. Other successful dissimilar materials include Aluminium and Magnesium [V.Firouzdor, (2009)], Steel and Titanium[GAO Yefei,(2012)], Aluminium and Titanium [Yuhua Chen,(2011)], and Mild steel and copper Bronze [A.Kurt, (2011)] welded joints using FSW. Micro structure preparation of steels will be affected by both temperature and composition. Two major problems encountered during Friction stir welding of high melting point alloys are tool wear and plastic deformation (L80 steels) [A.N. Jiten(2014)]. The tool wear is due to mechanical damage of the tool and work piece; however the plastic deformation is associated with the variation strain rate, stress and temperature during friction stir welding. Therefore the tool must withstand high resultant and frictional forces experienced by the pin during initial plunge stage [Jiye Wang, (2014)]. [C.Rajendran,(2015)] et.al were discussed about the effect of tool tilting angle on strength of friction stir welded lap joints of AA2014-T6 Aluminium Alloy joints. They were maintain 3^0 tilt angle registered a maximum tensile shear fracture load and showed a joint efficiency of 84% and also observed formation of closely spaced onion rings, formation of finer grains in stir zone and higher hardness of stir zone are the reason of superior performance of the joint fabricated by maintaining 3^0 tool tilt angle than other joints. [K.K.Ramachandran,(2015)] et.al were discussed about dissimilar Aluminium alloy AA5052 H32 and HSLA steel IRS M-42-97 butt welded using FSW technique. They observed that the tensile strength of joint is sensitive to the change in tool tilting angle and highest joint strength obtained is about 90% of the ultimate tensile strength of the base Al alloy at 1.5^0 tool tilt angle under constant tool rotation and observed that formation of intermetallic compounds at the joint interface and it is inferred that the strength of the joint greatly depends on the thickness of the IMC layer formed at the interface.

The key features of friction stir welding are selection of tool material and its configuration to avoid interaction gap between consecutive cycles, which prevent defects like pin hole, tunnel defects and warm holes at the advancing side [K.Kumar, (2008)]. More number of tool failures are occur during plunge depth, in poor stirring and non uniform grains of the parent metal in stir zone and there by violating the primary advantage of friction stir welding process itself and tool pin is responsible for plasticizing the stir zone from advancing side to retreating side [D.K.Kim, (1998)]. [Hidetoshi Fujiia,(2016)] et.al were observed micro structural evolution cold-rolled commercial 3N copper sheets during friction stir welding, the plastic deformation stage and the post-annealing stage of the FSW were separated by a stop action technique associated with liquid CO2 cooling and a subsequent annealing treatment. They were discussed during plastic deformation stage, initially large grains in the base metal were subdivided with the increasing strained temperature, and the SZ showed ultra fined grains with a large quantity of low angle boundaries and a symmetrical simple texture and during the subsequent annealing stage, static recrystallization occurred, which led to the selected grain growth and absence of dislocations, that produced the simple shear texture change. Also observed in stir zone a recrystallised structure in appearance caused by the static continuous and discontinuous recrystallization and the static restoration caused by the post-annealing reason can significantly affect the microstructure, which produced by the plastic deformation and it should not be ignored, when discussing the microstructure evolution of the FSW. [Yifu Shen, (2016)] et.al were successfully conducted a computational Fluid Dynamics based modified 3D model was developed to advise the distribution of temperature during lap FSW of dissimilar aluminium alloys AA2024 and AA7075. They were discussed the reason for the symmetry is that the values of the resultant vector and the radiating surface area in the advancing side are relatively larger than the retreating side. They were observed the temperature change along the z direction was not continuous and in the interface of upper and lower plates the temperature changes have saltation. This is mainly due to the different kinds of materials with specific heat capacity, viscosity and thermal conductivity, and the mutual control between temperature and material properties will also make the distribution of work piece temperature field shows a significant difference and also observed welding time had a great influence on welding temperature, the end of the welding increase and decrease of temperature was gentler than other observation points.

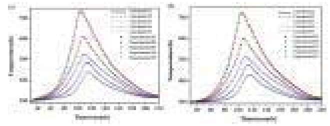
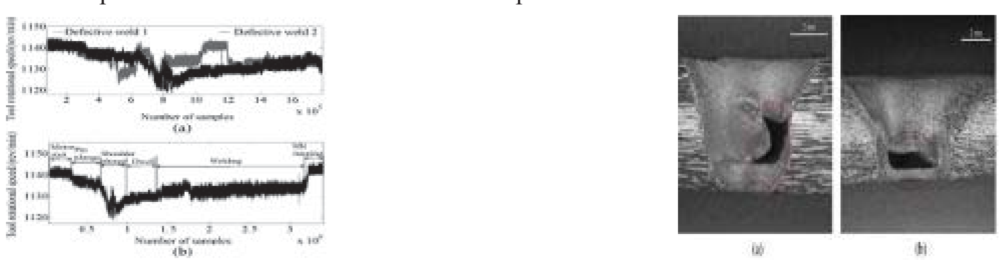


Figure 4: Variation of transient temperature at locations the work piece (a) Advancing side (b) Retreating side

[S. Ragu Nathan, (2016)] et.al were discussed the vital requirement of non-consumable tool for FSW of high melting point alloys are steel and titanium. In this investigation an attempt was made to understand the pre-weld and post-weld micro structural characteristics of three tungsten based alloy FSW tools viz 90%W, 95%W and 99%W. From this investigation, it is found that the tool made of 99%W doped with 1% La2O3 exhibited micro structural stability due to absence of Fe-Co-Ni phase formation at elevated temperatures during FSW process.

Figure 5: Optical Micrographs of Tungsten based alloy tools before and after FSW process

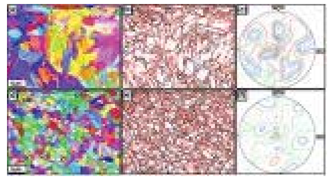
[Heena K Sharma, (2016)] et.al were investigated for weld strength of Aluminium alloy 6061 and Magnesium alloy AZ31 are welded in circular butt joint geometry by FSW, using CNC vertical milling machine. It consists of a cylindrical shoulder and a pin with different geometry, it is found that welded joints between Al 6061 and Mg AZ31 can be formed using FSW by selecting proper tool pin profile and welding parameters. It was suggested that FSW of Aluminium alloy and Magnesium alloy circular butt joint geometry would be useful in the future for automobile applications by getting the benefits from each material in a functional way. [S. Bag, (2015)] et.al discussed AA1100 aluminium alloy about the possibility of quantifying the dynamic spectrum of signals in FSW process using the concept of fractional dimension. They were using Higuchi's method from tool rotational speed signal shows promising direction to identifying the formation of defects in FSW process and found the defect free weld produced consistent fractal dimension within the tolerance limit of ±0.025 for all segmented data. This methodology is limited to identify the special position and size of the defect and with modification can be adopted for online monitoring of the weld quality in FSW process. The analysis reveals the fact that fractal dimensions can be an independent indicator for the prediction of defect formation in FSW process.



(a) Defective welding cases (welding period data only) Tunnel defect (a) Defective weld1
(b) Defect free case in different stages (b) Defective weld2

Figure 6: Tool rotational speed signals and tunnel defect

[G.Buffa, (2016)] et.al successfully conducted a numerical and experimental study was carried out to highlight the effect of distance d between the weld seam and reinforcement on the residual stress distribution in Friction stir welded L-shaped AA6082-T6 structures. They were using Cut Compliance method was used to determine the resulting longitudinal residual stresses and found that compressive residual stress away from the weld seam while relatively large tensile stress is found in correspondence of the weld seam itself and Residual stress only slightly increases both with tool rotation, i.e; with the heat input to the joint and distance d. This analysis allowed the identification of a few design guidelines in order to reduce the detrimental effect of the residual stresses. [Suk Hoon Kanga,(2016)] et.al were discussed joining of oxide dispersion strengthened (ODS) steel plug and F/M steel tube by using Friction stir welding. They were designed a special jig of curvature and smaller thickness tubes for stabilization and slow rotation of tube during FSW and also observed considerable hardening occurs in the joint because the cooling rate is sufficient to reproduce a martensitic microstructure and measures hoop strength of the FSWed joint was 70-90 MPa, the value was at around 70% of the tube.



(a) EBSD grain map, (b) Grain and sub grain boundary distribution, (c) 100 pole figure of the tube, (d) EBSD grain map, (e) Grain and sub grain boundary distribution, (f) 100 pole figure of FSWed joint

Figure 7: EBSD analysis of FSWed tube

[C.S. Wu, (2016)] et.al were investigated on the constitutive equation shows that it can describe the effect of ultrasonic vibration on FSW of Al 6061 – T6 plates reasonably. It reveals that the ultrasonic vibration energy density reduces the activation energy for deformation, results in a decrease of the flow stress during hot plastic deformation with superimposed ultrasonic vibration. Finally they were observed that through lowering the flow stress and viscosity of the plastic material near the tool, the ultrasonic vibration leads to an enlargement of the flow region and deformation region in UVeFSW process. [Priya yaganti, (2015)] et.al were discussed tool rotation upon the base materials which are fitted under high pressure forms a sound metallurgical bond between steel and Aluminium using Friction stir spot welding. This joining process is adopted in front sub frame of Honda Accord (2013) 25% weight reduction is achieved compared to whole steel car through this technology and also enables 20% increment in rigidity of the mounting point and therefore enhanced the vehicles dynamic performance. [M.Mahadeva Swamy,(2015)] et.al were successfully controlled to much extent by using the newly developed improved friction stir spot welding process and the mechanical properties of the Al – steel joint has been improved to a great extent. This has been accomplished by incorporating the surfacing as an interlayer before the welding operation. The modification made in respect of the base materials provides more advantages. They were observed specimens show high shear tensile strength, which fracture through plug in mode and takes place at a certain distance away from the interface which indirectly concluded the process involves controlling intermetalic compound formation and by using the pin less tool in this process provides the advantages in terms of low tool wear and indirectly reduce the welding cost. [S. Jambulingam,(2015)] has been successfully carried out on AA7075 and AA3104 dissimilar Aluminium welded joint using Friction stir welding. He was concluded that speed is the major factor influencing the mechanical properties like tensile strength and hardness. [R.Kamal Jaya Raj,(2015)] et.al were applied Micro arc oxidation (MAO) coatings on friction stir welds of aluminium alloys to improve their corrosion resistance. In this study revealed severe corrosion in uncoated welds, particularly in their stir zones and MAO- coated welds showed no signs of corrosion. Finally they suggested that the corrosion resistance of friction stir welded aluminium alloys can be substantially improved by applying MAO coatings. [S.Raghunathan,(2015)] et.al were investigated the effect of tool shoulder diameter by evaluating the weld metal microstructure of naval grade high strength low alloy steel joints. They were concluded that the joint fabricated using a tool with the shoulder diameter five times plate thickness yielded defect free joint with improved metallurgical features compared to other joints and axial thrust Is most affected by tool shoulder diameter, X-force is most affected by welding speed, pin diameter and the interaction of tool diameter and rotational speed. Hence, the shoulder diameter may be the key for proper material flow during FSW process. [S.Sree Sabari,(2015)] et.al were investigated the contribution of texture evolution and precipitation on the mechanical properties of FS welded AA2519-T87 aluminium alloy joint. They were concluded that the micro hardness plot shows fluctuations in stir zone and the lowest micro hardness in the TMAZ and also observed mechanical properties of joint cannot be correlated with the EBSD results like grain misorientation, boundary angle, grain size and grain strain. [S.V.Satish,(2015)] et.al were investigated the characteristics on fracture surface of friction stir butt welded Austempered ductile iron joints are compared with ductile iron FSW joints. They were observed both in case of ductile iron and austempered ductile iron with E7018 deposition, the strength values higher than the minimum specified tensile strength of base metal and also observed micro structure in the bond region indicated more highly deformed grain structure at the friction stir welded zone along with the martensite with some amount of retained austenite without any micro-cracks. [M.Ilangovan, (2015)] et.al were investigated to evaluate the fatigue performance of the similar and dissimilar joints made of heat treatable (AA6061) and non-heated treatable (AA5086) aluminium alloys by FSW process. They were observed that S66 joint exhibited higher fatigue strength compared to D65 joint because of high yield strength and elongation and preferred microstructure such as very fine, uniformly distributed strengthening precipitates in the stir zone. [Bipul Das, (2015)] et.al were demonstrated a different avenue of fractal theory for the prediction of weld quality combines with artificial intelligence in FSW. They were model an artificial neutral network is develops using the process parameters and computes fractal dimensions in input space of the network for the prediction of ultimate tensile strength and developed model yields appreciable average absolute percentage prediction error which leads to impression that can be implemented for online monitoring of weld quality in friction stir welding. [Sabitha Jannet,(2015)] et.al were investigated effect of process parameters on mechanical properties of dissimilar AA6061 T6-AA50830 joints by using Friction stir welding. They were understanding the relation between the dependent and independent variables of the system using artificial neural networks. The aim is to train the network so that it will be able to predict with reasonable accuracy and to use the network for prediction, it must show the least possible root mean square error during validation.

III. EFFECT OF PROCESS PARAMETERS ON MICRO STRUCTURE EVOLUTION AND MECHANICAL PROPERTIES OF DISSIMILAR METALS BY USING FRICTION STIR SPOT WELDING

[Shin,(2010)] et.al first successfully applied friction stir spot welding for joining of 1mm thick Zr-based Bulk metallic glass plates and also to join Bulk metallic glass to Aluminium alloy. Shin has revealed the temperature at stirred zone around the probe pin was in super cooled liquid region which represents a super plastic deformation behavior of Newtonian viscous flow in that region. [Sun, (2013)] et.al applied spot FSW to join a Bulk metallic glass to copper. Titanium based Bulk metallic glasses hold a promising spot in engineering application since they possess good mechanical properties, good anti-corrosion, low density and low elastic modulus [P.Gong, (2012)]. Recently [Gong (2013)] et.al has reported the effect of copper addition on the glass forming ability and mechanical properties of quaternary TiZrFeBe glass alloy. It was revealed that the studied glassy alloy 93Cu7 Bulk metallic glass with high super cooling liquid region and good glass forming ability with critical diameter is good for engineering applications. [I.M.Hodge,(1996)] shoul be noted that 93Cu7 Bulk metallic glass is a strong glass former with an m factor of 24 according to Hodge's equation. [Mohsen Haddad-Sabzevar,(2016)] et.al were studied effect of process parameters on the microstructure and mechanical properties of the TiZrFeBeCu bulk metallic glass plates have been welded together by using the FSSW method. They were shown that the tensile/shear strength and fracture toughness would increase with increasing the tool rotational speed and then decrease because of the crystallization effects under the tool shoulder and holding time also has a similar effect as the tool rotation speed on fracture load and fracture strength. They were also observed plunge depth effect is an important factor on the fracture mode and fracture strength. The highest tensile/shear fracture load was obtained at the plunge depth >95% of combined plate thickness and at small plunge depths the interface fracture mode is observed that to show the lowest fracture load and fracture toughness whereas at large plunge depths the upper sheet fracture mode is responsible for the shear fracture. Also observed three kinds of zone effects, stirring zone under the tool shoulder shows a higher micro hardness than the base metal owing to the formation of nanocrystals. The stirring zone under the tool tip has a lower hardness is comparison with the base metal due to the residual tensile stress formed during the holding process. The TMAZ locates at a narrow region between the SZ and the base metal has a Vickers hardness value smaller than base metal. The shear bands observed around the indent within different zones are different. Finally the results show that the FSSW method is an effective way to weld the strong glass former BMGs together, which would significantly promotes the application of the bulk metallic glasses through overcoming the limitation of their critical size by joining them together.

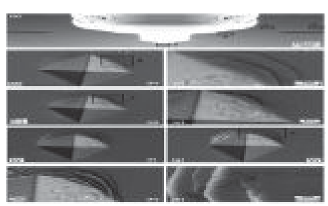
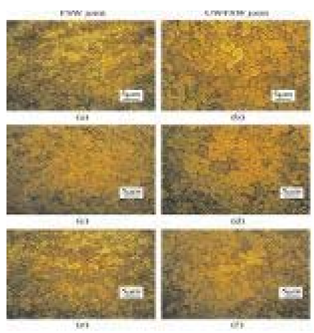


Figure 8: (a) Cross-section of weld spot, (b-c) BM, (d-e) SSZ, (f) TMAZ, (g-k) TSZ

[I. Dinaharan,(2015)] et.al were successfully conducted pure copper Friction stir spot welding and analyzed influence of the key processing parameter tool rotational speed on micro structure and tensile shear load. They were observed increase in tool rotational speed increased the bond width and coarsened the grains in stir zone, TMAZ, and HAZ and also improved tensile shear load.

IV. EFFECT OF PROCESS PARAMETERS ON MICRO STRUCTURE EVOLUTION AND MECHANICAL PROPERTIES OF DISSIMILAR METALS BY USING UNDERWATER FRICTION STIR WELDING

[Liu,(2011)] et.al were investigated on under water friction stir welding of AA2219-T6 Aluminium alloy and in that the underwater friction stir welding improved the strength of the joint by restricting the coarsening and dissolution of strengthening precipitates. [Fu,(2011)] et.al observed that the improvement in the tensile strength of underwater friction stir welding joints of AA7075-T87 Aluminium alloy by reducing the width of Heat Affected Zone. [Fratini,(2010)] et.al were analyzed temperature histories of underwater friction stir welding process and finds that the water cooling resulted in reduction of thermal flow adjacent to the tool. [Huijie,(2011)] et.al developed mathematical model and optimization procedures for UWFSW of a heat treatable aluminium alloy and concluded that a maximum tensile strength can be obtained through UWFSW, which is 6% higher than FSW. [Qingzhao Wang,(2016)] et.al were successfully produced defect free butt joints of spray forming Al-Zn-Mg-Cu alloy has been welded by underwater FSW (UFSW). They were observed in microstructure of underwater joint has been improved in the hard-etched area is eliminated compared with traditional joint. The results shows water cooling method has improved to thermal cycle of welding and also observed joint is defect free and gets an increase of ~30% in strength and twice the elongation compared with traditional joint. The results shows underwater joint has eliminated the hard-etched zone with “W” shape distribution of hardness. Finally Underwater FSW process provide a relative balance thermal cycle for joint and restricts the exsolution $MgZn_2$ and ensures strengthening phases disperse in the matrix with semi-coherent structure. So the joint gets coherency strengthening and improvement on the properties. [V. Balasubramanian,(2016)] et.al were investigated to evaluate the mechanical properties and micro structural characteristics of AA2519-T87 aluminium alloy joints was made by FSW and UWFSW process and also Finite element analysis has been used to estimate the temperature distribution and width of TMAZ region in both the joints. Finally they were observed UWFSW joint exhibited higher tensile strength and higher joint efficiency of 60% than conventional FSW joint and also observed controlling of thermal histories and its subsequent effect on precipitation behavior are found to be the main reason for the enhancement in the strength of UWFSW joint.



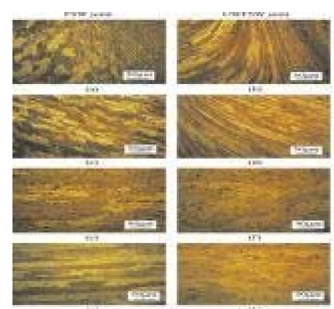


Figure 9: Optical micrographs of SZ, TMAZ and HAZ

(a-b) Shoulder influenced region
(c-d) Mid thickness region
(e-f) pin influence region

(a-b) Advancing side TMAZ
(c-d) Retreating side TMAZ
(e-f) Advancing side HAZ (g-h) Retreating side HAZ

[K.Tejonadha Babu,(2015)] et.al were investigated under water friction stir welding of 5052 aluminium alloy was carried out in order to future improve the joint performances and creating fine grained welds by varying welding parameters. Their result indicated that the tensile strength of the joint can be improved in underwater friction stir welding and the grain size in the underwater welding is finer than that in the conventional welding and the formability of underwater welding has been improved by the refinement of grain size.

V. NEW TRENDS IN FRICTION STIR WELDING (ROBOTS AND FORCE SYSTEMS)

Three kinds of machines reported in this review; Conventional machine tools, Dedicated FSW machines and industrial robots. Conventional machine tool, such as milling machine, can be used to perform FSW process [T.Minton,(2006)]. The loads involving in FSW are higher than loads generates in the milling process [W.R.Longhurst,(2010), B.J.De,(2012)]. For this reason the conventional machine tools having to be strengthened in order to increase their load and stiffness capabilities. Dedicated FSW machines having the highest load capability, stiffness, accuracy and availability [Y.Okawa, (2006)]. They assume different configurations presenting distinct level of flexibility. The next generation of machines that has been introduced in FSW of metals concerns to robotic machines. The advantages of robotic machines are flexibility and process automation which allows for significant productivity improvements. In this survey FSW of thermoplastics as well as metals that the amount of heat provided to welding joint is a key point to achieve quality welds. This achieved by changing the other welding parameters such as rotational speed, transverse speed, etc [N.Mendes, (2014)]. The main conclusion of this the deflection in the robot can be significantly reduced by welding at high rotational speed and lower axial force. However, the friction coefficient between tool and material is a limiting factor for the rotational speed. [Crawford,(2006)] et.al have shown by simulation of the robotic FSW that axial force and torque decrease as rotational speed is increased. [Zimmer,(2010)] et.al concluded that the plunging stage is feasible to decrease axial force and torque by increasing generated energy and/or using control force instead motion control. [Fleming, (2008)] et.al investigated that automatic fault detection in robotic friction stir lap welds and observed that to overcome faults as worm holes, real time analysis of axial force through a methodology based on principal component analysis were proposed. Robot force control plays an important role in the performance of some robotic task not only used tasks where it is sufficient to maintain the contact force and torques within certain limits but on tasks where the deflexion of the robot is a major factor. In the current state, there are four ways to control the robotic FSW. Adjust the plunge depth according to a given set force, torque for robot motors, and torque for tool and adjust the traverse speed according to a given set force. [Nuno Mendes,(2016)] et.al discussed successfully on the machine and control systems applied in FSW with a special focus on the new trends using robots and force controls. They were studied in detail role of different parameters are force, stiffness, accuracy, sensing, decision-making and flexibility capabilities and also discussed comparison of different machines, namely the conventional machine tools, dedicates FSW machines, parallel kinematic robots and articulated robots and discussed about different approaches to the control systems applied in FSW are presented and their advantages/drawbacks.

Figure 10: Robotic FSW Machine

Figure 11: Articulated arm Robot

[Mario Guillo,(2016)] et.al discussed about the use of an industrial robot to reduce the investment cost and to increase the process flexibility of FSW and also discussed characterizes the impact of pin axis position on Friction stir weld (AA 5754-H22 Sheets) quality and shows a method to compensate the lateral pin deviation in real-time during Robot FSW. They were show firstly, FSW trials on CNC system show that the pin could be located into an offset of about 1.25 and 0.7mm around the seam without impacting the weld quality and secondly, in RFSW, important forces result in a lateral pin deviation of about 7mm between the programmed path and real path.

Figure 12 Real time compensation of the lateral tool deviation

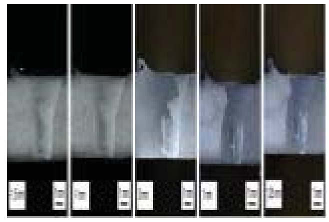


Figure 13 Metallurgical cross sections of welds with pin positions

Considering the result on CNC system, a good weld quality could not be achieved. Finally the robot with the embedded algorithm can compensate the lateral pin deviation in real-time.

VI.CONCLUSION

In this review, discussed about dissimilar welded joints made by FSW, FSSW, UWFSW and Robots and force systems. This paper presents effect of microstructure evolution and mechanical properties on dissimilar metals using different process parameters. From the literature survey understood that mechanical properties of FSW joints could be improved by water cooling (UWFSW) and also observed that the FSSW method is an efficient way to weld the strong glass formers BMGs together, which would significantly promotes the application of bulk metallic glasses through overcoming the limitation of their critical size by joining them together. Industrial Robots having great potential in the FSW of soft metals and polymers and in the short time expectable that this one will be the most used machine in the welding of soft metals.

REFERENCES

[1] Nan Xua,b, Rintaro Uejia, Hidetoshi Fujiia*, “Dynamic and static change of grain size and texture of copper during friction stir welding”, Journal of Materials Processing Technology 232 (2016) 90–99.

[2] Jingming Tang , Yifu Shen *, " Numerical simulation and experimental investigation of friction stir lap welding between aluminum alloys AA2024 and AA7075," Journal of Alloys and Compounds 666 (2016) 493e500

[3] S. Ragu Nathan*, S. Malarvizhi , V. Balasubramanian , A.G. Rao, " Failure analysis of tungsten based tool materials used in friction stir welding of high strength low alloy steels," Engineering Failure Analysis 66 (2016) 88–98.

[4] Heena K Sharma*, Kamlesh Bhatt, Krunal Shah Unnati Joshi, " Experimental Analysis of Friction Stir Welding of Dissimilar Alloys AA6061 and Mg AZ31 Using Circular Butt Joint Geometry ", Procedia Technology 23 (2016) 566 – 572

[5] G. Buffa *, L.Fratini, G.Marannano, A.Pasta, " Effect of the mutual position between weld seam and reinforcement on the residual stress distribution in Friction Stir Welding of AA6082 skin and stringer structures ", ScienceDirect ,Thin-WalledStructures103(2016)62–71

[6] Suk Hoon Kang*, M. Vasudevan, Sanghoon Noh, Hyun Ju Jin, Jinsung Jang,,Tae Kyu Kim” Friction stir welding of F/M ODS steel plug and F/M steel tube ", Fusion Engineering and Design (2016).

[7] L. Shi, C.S. Wu*, S. Gao, G.K. Padhy., “Modified constitutive equation for use in modeling the ultrasonic vibration enhanced friction stir welding process,” Scripta Materialia 119 (2016) 21–26.

[8] Qingzhao Wang*, Zhixia Zhao, Yong Zhao, Keng Yan, Chuan Liu, Hao Zhang.,” The strengthening mechanism of spray forming Al-Zn-Mg-Cu alloy by underwater friction stir welding”, Materials and Design 102 (2016) 91–99.

[9] S. Sree Sabari , S. Malarvizhi , V. Balasubramanian*, G. Madusudhan reddy, “Experimental and numerical investigation on under-water friction stir welding of armour grade AA2519-T87 aluminium alloy,” Defence Technology (2016), doi: 10.1016/j.dt.2016.02.003

[10] Nuno Mendes *, Pedro Neto , Altino Loureiro , António Paulo Moreira, “Machines and control systems for friction stir welding: A review”, Materials and Design 90 (2016) 256–265.

[11] Mario Guillo*, LaurentDubourg, " Impact & improvement of tool deviation in friction stir welding: Weld quality & real-time compensation on an industrial robot ", Robotics and Computer-Integrated Manufacturing 39 (2016) 22–31.

[12] B. Das, S. Bag*, S. Pal, " Defect detection in friction stir welding process through characterization of signals by fractal dimension ", Society of Manufacturing Engineers (SME). Published by Elsevier Ltd 21 November 2015.

[13] Krishna priya yaganti , G.Padmanabham, " Joining of Aluminium alloys to steels using fusion and Non-Fusion processes ", 2nd international conference on Advances in Cutting, welding and surfacing, CWS 2015

[14] M.Mahadeva Swamy, S. Muthukumaran, Vinayaka Jaigude, " Development of an improved Friction stir welding to join Aluminium and Steel Sheets ", 2nd international conference on Advances in Cutting, welding and surfacing, CWS 2015.

[15] S. Jambulingam, " Experimental analysis of FSW of Dissimilar Aluminium alloys AA7075 and AA3014 using CNC VMC ", 2nd international conference on Advances in Cutting, welding and surfacing, CWS 2015.

[16] R.Kamal JayaRaj, S.Malarvizhi, V.Balasubramanian, " Improving corrosion Resistance of Friction stir welded AA6061-T6 Aluminium Alloy using Micro- Arc oxidation coatings ", 2nd international conference on Advances in Cutting, welding and surfacing, CWS 2015.

[17] C.Rajendran, K.Srinivasan, V.Balasubramanian , H.Balaji, " Effect of Tool Tilt Angle on Strength of Friction stir welded lap joints of AA2014-T6 Aluminium Alloy joints ", 2nd international conference on Advances in Cutting, welding and surfacing, CWS 2015.