Joining of Various Metals and Alloys via Friction Stir Welding Process: A Review

Ravi Prakash[1], S.K. Sharma[1]
[1]*Yamuna Institute of Engineering and Technology, Yamunanagar, Haryana, India*

Abstract- **Aluminium alloys are promptly replacing others conventional material for fabrication of automotive parts & structural components. Welding of Aluminium alloys have always been a challenge due to their poor weldability. Conventional fusion welding techniques have limitation of joining Aluminium alloys due to defects like depletion of alloying elements, porosity, blow holes, pin holes etc. Friction stir welding has become a alternative to the fusion welding as weld produce is free from all defects present in fusion welding. This study reviews the fabrication of various Aluminium alloys via Friction stir welding. An attempt has been made to study the effects of various friction stir welding parameters like tool geometry, tool rotational speed, welding speed , axial force, tool tilt angle, tool plunged depth etc. on the mechanical and microstructural properties of friction stir welding joints.**

Keywords: **Friction Stir Welding, Mechanical Characterization, Micro-Structural Evaluation, Tool Geometry.**

I. INTRODUCTION

TWI (The Welding Institute) invented a new welding technique in Cambridge, England, in 1991 which is called as Friction Stir Welding. The first research on friction stir welding was patented by TWI in 1991. It is not a fusion type welding process in which melting of workpiece takes place; it is a solid-state welding process means that the objects are joined without reaching melting point. It is a combined action of frictional heating and mechanical deformation due to a rotating tool. In FSW process, cylindrical tools are used which consisted of two concentric parts namely as tool shoulder and tool probe. The tool shoulder is the larger diameter part while tool probe is smaller diameter part. In this process, basically heat is generated primarily by friction between a rotating tool and the work piece. The pin is forced into the plates/workpiece at the joint until the shoulder contacts the plate surface. A downward forging pressure from the shoulder helps to prevent the expulsion of softened material. It helps to plasticize a cylindrical metal column around the pin and the immediate material under the shoulder. When the tool is moved forward, material is forced to flow from the leading edge to the trailing edge of the tool. The material that flows around the tool undergoes extreme level of plastic deformation. On cooling, a solid phase bond is created between the work pieces. The parts have to be securely clamped to prevent the joint faces from being forced apart. Figure-1 shows the schematic diagram of the friction stir welding.

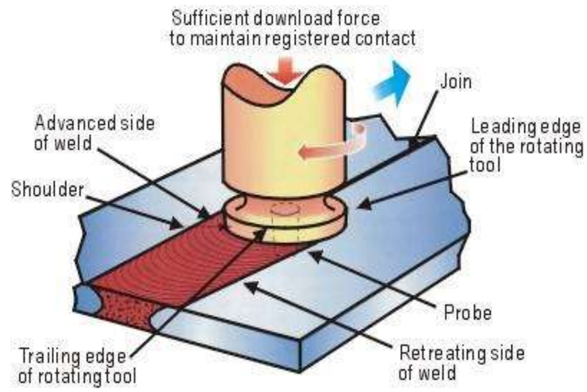

Figure-1: Schematic diagram of Friction Stir Welding

Friction stir welding has a wide range of application in aerospace industries, railway and ship building industries especially in the fabrication field of aluminium alloy. Friction stir welding is an exciting process for joining workpieces together as it requires little or no weld preparation, operates at relatively low temperatures so gives off no fumes, is environmentally friendly and can be used by semi-skilled personnel to produce a satisfactory weld. The big difference between FSW and fusion welding (other than the lack of melting) is the ability to manipulate peak temperatures by choice of different welding parameters. The microstructure of the welding zone in the friction stir welded was divided into four zones are base material, heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) and weld nugget. Friction Stir Welding results in a dynamically re-crystallized grain structure in the weld nugget [9].

II. FSW OF VARIOUS METALS AND ALLOYS

Mechanical properties of aluminium-based dissimilar Alloy A1050-H24 pure aluminum, A2017-T3 Al-Cu alloy, A5083-O Al-Mg alloy, A6061-T6 Al-Mg-Si alloy and A7075-T651 Al-Zn-Mg alloy plates of dimensions 105mm x 100mm x 3mm have been investigated by Power Beams, Arc and FSW Process and concluded that FSW was the most effective way to obtain the highest tensile strength of A2017/A7075 age-hardening aluminum alloy joint; LBW yielded a similar tensile strength in comparison with the other fusion welding processes [1]. The Friction Stir Welding of Al 6060 Alloy condition T6 plates of dimensions 150mm x 100mm x 5mm has been carried out successfully. In this research, the effects of process parameters and tool geometry on mechanical properties have been studied. Process parameters (rotational speed, feed rate) resulted to have a significant effect on UTS. The threaded tool design has proved more effective in friction stir welding of AA6060 T6 than standard tool [3]. A comparative study has accomplished on GMAW and FSW of AA 2024-T4 aluminium alloy plates of dimensions 150mm x 75mm x 3.8mm and concluded that better tensile strength was obtained with FSW welded joints; the width of the heat affected zone of FSW was narrower than GMAW welded joints [4]. The interface microstructure, surface morphology and mechanical properties has been studied by the successfully welding of plates having size 100mm x 50mm x 4mm of AA6063 aluminium alloy and commercially pure copper using FSW and shown that relatively better joints could be obtained when the hard Cu plates was fixed at the advancing side; the mechanical properties of the FSW Al-Cu joints were related closely to the interface microstructure between the Al matrix and Cu bulk [5]. A study has been carried out on microstructure and corrosion properties with friction stir welded 7075- Al Alloy and concluded that the weld nugget has a re-crystallized, fine equi -axed grain structure; Corrosion resistance of weld metal has been found to be better than that of thermo- mechanical affected zone [6]. An attempt was made to study the effect of tool pin profiles (square, circle, threaded) on tensile strength of AA6351 Aluminium Alloy of size100mm x 50mm x 6mm using friction stir welding process [7]. A research has completed on micro-structural and mechanical properties of 2219 aluminium alloy plates of sizes 140mm x 70mm x 4.5mm with double friction stir welding process and revealed that double friction stir zone was smaller than that of a single stir zone; the grain structure of the double FSW joints was found to be more unstable than that of single FSW joints [8]. After investigating the mechanical properties of AA6013-T6 plates of dimension 200mm x 20mm x 3.5mm, resulted that the base material exhibits average hardness value of 130 HV while the weld nugget has an average hardness of 100 HV; The average hardness values in the TMAZ are slightly lower than in the weld nugget [9]. The joining of 7049 aluminium alloy plates of sizes 1950mm x 45mm x 5mm on the basis of the adopted multifactoral orthogonal plan, was carried out under laboratory condition and stated that the adopted welding procedure with the use of optimal parameters of welding, welded joints with good characteristics can be obtained [10]. The Friction Stir Welding of dissimilar aluminium alloy AA 6262-T6 and AA 7075-T6 of 6mm thick plates has been accomplished successfully in [13] and observed that the weld parameters have a significant effect on mechanical and micro structural properties of the weld. A study was attempted to find out the effect of welding parameters on weld formation and mechanical properties in dissimilar al alloy 5052 and 5J32 with a thickness of 1.5mm rolled sheets and concluded that when the 5J32 aluminum alloy was placed on the advancing side, zigzag shapes were observed in the weld zone under all welding conditions; these phenomena were attributed to the difficulty of the plastic flow, so the material flow of 5052 on the retreating side was restricted by 5J32 which is harder than 5052 as in [14]. The parameters of FSW of cast LM6 aluminium alloy of size 175mm x 75mm x 6mm have evaluated and revealed to get defect free joints; the heat input must be optimized by optimizing FSW process parameters such as the rotation speed, welding speed and axial force [15].

III. FSW TOOLS AND SPECITIONS

Friction stir welding of 6060 aluminium alloy has been carried out in two cases. Case I: using Standard tool and Case II: Threaded tool. Both tools were made of AISI 1040 steel with 15mm shoulder diameter. The standard tool was very simple with a cylindrical diameter of 5mm and the threaded tool which contained a flat shoulder and a threaded probe obtaining using a commercial M5 thread forming tap, 2^o angle of tool tilt and 0.2mm clearance was taken. During mechanical tests, the threaded tool showed some robustness limits, related to speed variation. No significant problems, related to the durability of the standard tool, took place during the friction stir welding process [3]. In another study, there was used a conventional tool with a pin of 6mm diameter and 20mm shoulder diameter for successful friction stir welding of 2024-T4 aluminium alloy and observed that Increasing tool rotation speed from (450 to 710) rpm with fixed other parameter causes increasing in mechanical properties of the welds joint [4]. The FSW tool manufactured from AISIH13 tool steel and high speed steel (HSS) with the shoulder of 18mm and 15mm in diameter and the tool pin is 7mm in diameter and 3.7mm in length was used In the study on FSW of AA6063 aluminium alloy. It was also suggested that the tool material should be selected on the basis of hard material; the tool should be able to withhold the high temperature [5]. During the experiment on FSW of AA6351, it was revealed that the tensile strength of the FS welded was affected by the tool pin profile. Out of three pin profiles (Circle, threaded, square), straight square tool at (900rpm) give more tensile strength & Vickers hardness when compared to other tools [7]. The thermal stability of double-FSW zone of 2219 aluminium alloy with a common tool having13mm shoulder diameter and 4mm pin diameter has been studied [8]. FSW has completed to find out the mechanical properties ofAA6013-T6 with a FSW tool contained 6mm pin diameter and 18 mm shoulder diameter and it showed that in the T6 condition of AA6063, fracture always occurred in the HAZ [9]. Friction stir welding has been accomplished on AA5754 with a tool which was made from a hot work steel material, type 1.2344. The tool consisted of a concave shoulder 15 mm in diameter and a conical pin 5 mm in major diameter (root), 2 mm in minor diameter (tip), and 3 mm in length; the pin has a right-hand 0.9-mm pitch thread and a thread depth of 0.6 mm.

After FSW, a sound and defect-free weld was achieved with a tool rotation speed of 1100 rev/min and tool tilt angle of 2 deg, when the tool was rotated counterclockwise; the maximum tensile strength of the joint fabricated with FSW parameters was 217 MPa, which is 14% lower than that of the Al 5754 base metal [11]. The mechanical properties of the FSW composites (aluminium AA6351-T6 alloy and AA5083-H111 alloy) were compared and revealed that out of five pin profiles (Straight Square (SS), Tapered Square (TS), Straight Hexagon (SH), Straight Octagon (SO) and Tapered Octagon), the joints fabricated by square pin profiled tool produced a better tensile strength then the other tool pin profiles [12]. The joining of 6mm thick plates of AA6262-T6 to AA7075-T6 aluminium alloys has been performed using a cylindrical non-threaded FSW tool made of H13 tool steel during the study on FSW. The tool shoulder was 18mm in diameter and the probe was 1.7mm in diameter and a pin height of 5.8mm. The obtained joints shown no porosity or other defects in both top and root weld surface in all the welding conditions [13]. For dissimilar friction stir welding of 5052-5J32 aluminium alloy, the tool with threaded probe has successfully used with 3^o tilt angle and a shoulder with 12mm diameter; the probe diameter was3.8mm and length was 1.45mm [14]. FSW has been successfully completed on cast LM6 aluminium alloy using high carbon steel tool with 18mm shoulder diameter, 6mm pin diameter and 5.7mm probe height and suggested that the shoulder diameter should be usually taken as double the pin diameter and fabricated many joints successfully [15].

IV. FSW PARAMETERS AND MECHANICAL PROPERTIES

A research carried has been carried out by on the mechanical properties of aluminium-based dissimilar Alloy A1050-H24 pure aluminum, A2017-T3 Al-Cu alloy, A5083-O Al-Mg alloy, A6061-T6 Al-Mg-Si alloy and A7075-T651 Al-Zn-Mg alloy by different welding techniques such as selected processes such as YAG laser beam welding (LBW) by the optical energy, electron beam welding (EBW) by the electronic energy and MIG, TIG welding by the arc energy and FSW; the LBW was used with an output of 3.5kW and a welding speed of 3.3×10-2m/s; EBW was performed with an accelerating voltage of 120kV, and a welding speed of 1.7×10-2 m/s. The atmosphere for EBW is 5.0×10-2Pa. MIG welding was performed with a welding current of 130A and filler wire used was A5356-WY of 1.6 mm in diameter; TIG welding was used with a welding current of 100A. In case of TIG welding, no filler material was used in order to evaluate a melting behavior; Optimum FSW condition was selected for each dissimilar alloy joint, but the joining speed was kept constant as 6.7×10-3m/s. By using these parameters it was stated that A5083/A6061 aluminum alloy joint by FSW showed the highest hardness value in stir zone though the weld metal as compared with the other fusion welding processes that showed a tendency of becoming softer than base metals [1].A relationship has been established between welding parameters and mechanical properties in welding of aluminium alloy 2014 using FSW by analyzing variance (ANOVA); AA 2014 was welded by varying input parameters such as tool rotation speed and weld speed and it was proposed that weld speed was the main input parameter that contained the highest statical influence on mechanical properties [2]. The weldability, microstructure evolution and mechanical properties of AA6060-T6 have been studied by varying process parameters (namely tool rotational speed and feed rate) and tool geometry (two different tools were adopted for this purpose) during friction stir welding. In this study a universal testing machine Galdabini with a load cell of 50 kN was employed to evaluate tensile properties of the friction stir welded joints as a function of the different process parameters for both the adopted tools. After FSW both rotational speed and feed rate resulted to have a significant effect on UTS [3]. The mechanical properties of welded joints of AA2024-T4 aluminium alloy using FSW with four rotation speed (450,560,710 and 900 rpm) and GMAW has compared with each other to understand the advantages and disadvantages of the processes for welding applications of the Al alloy and concluded that in the weld nugget zone, fine equi-axed grains of size ranging are transformed from the parent metal gain structure; the heat –affected zone of FSW process is narrower than that of the GMAW process [4]. An experiment on FSW of AA6063 alloy has been carried out; A milling machine of BATLIBOI with a clock-wisely rotating pin at rotation rates of 1000-1400 rpm and traverse speeds ranging from 40mm/min - 80mm/min was operated. During this experiment, micro-structural characterization and analyses were carried out by optical microscopy [5]. The microstructures of the base metal, bore metal, thermo-mechanically affected zone (TMAZ) and weld region of aluminium alloy 7075 were characterized by optical microscopy and transmission electron microscopy in FSW technique; Micro-hardness profile was obtained across the weld and the pitting corrosion properties of the weldments were studied in 3.5% NaCl solution. Under Friction stir welding of this alloy resulted in fine recrystallized grains in weld nugget which has been attributed to frictional heating and plastic flow. An attempt was made to study the effect of tool pin profile on mechanical properties of AA6351 with friction stir welding with rotation speed 900rpm and1350rpm, welding speed 7.5 mm/min, axial force 10 kN and revealed that For AA6351aluminium alloy High speed welding will affect the welding strength [7]. In the welding of AA2219 aluminium alloy, the micro-structural and mechanical properties with tool rotation speed at 800 rpm and 1250rpm and at a feed rate of 87 mm/min have been studied and the PWHT experiment was performed at the two temperatures (470_C and 510_C) for 1 hr to evaluate the thermal stability in the weld. In the study, it was concluded that after PWHT, a faster abnormal grain growth was observed in the double-FSW joints, because of the smaller grain size, higher fraction of the low angle grain boundaries and lower particle density

[8]. A research on FSW of AA6013-T6 alloy with rotational speed of 1200 rpm and feed rates of 1000 mm/min have been accomplished. After FSW, tensile tests have been performed by computer controlled Instron 8500 Servo Hydraulic Universal Test Machine which has 200 KN static and 100 KN dynamic load capacity [9].

V. CONCLUSIONS

In this paper, we studied friction stir welding process on similar and dissimilar aluminium alloy using different process parameters (tool rotation speed, transverse speed, tool tilt angle, tool geometry) and its effect on different mechanical properties (including tensile strength, hardness etc.) and micro-structural behavior. The friction stir welding process improved mechanical properties and structural characterization of aluminium alloys. FSW was the most effective way to obtain the highest tensile strength of age-hardening aluminum alloy joint. The weld nugget was characterized by fine and equiaxed recrystalized grains. A variety of similar and dissimilar metals and alloys have been successfully joined using friction stir welding including 2000, 5000, 6000 and 7000 series of aluminium alloys, cast aluminium alloys, copper. As GTAW and GMAW welding processes replaced most of the original stick welding operations in the past, it is envisaged that FSW will displace many of the current GTAW and GMAW welding applications with reduced costs and superior weld quality. In short we can say that Friction stir welding is a very good and efficient process in manufacturing.

For further studies, good experimental conditions and information base to evaluate the microstructure which is highly hi-tech, are to be made. In future the relationship between bending strength, compressive strength and FSW parameters is to be established. Studies are to be conducted to evaluate effect of FSW on mechanical properties and structural characterization on titanium and their alloys.

REFERENCES

[1]. M. OKUBO, T. KON and N. ABE, *Mechanical Properties of Aluminum-Based Dissimilar Alloy Joints by Power Beams, Arc and FSW Process;* Journal of High Temp. Society, Vol. 133 No. 4, 2007, pp. 208-213.

[2]. N. Rajamanickam, V. Balusamy, *Effect of process parameters on mechanical properties of friction stir welds using design of experiments;* INDIAN Journal of Engineering & Material Science, Vol. 15, August 2008, pp. 293-299.

[3]. G. D'Urso, E. Ceretti, C. Giardini and G. Maccarini, *The Effect of Process Parameters and Tool Geometry on Mechanical properties of Friction Stir Welded Aluminum,* In: Proceedings of 10th International Conference on Technology of Plasticity (ICTP 2011). Aachen (Germany), September 25th-30th, 2011.

[4]. H. K. Mohammed, *A Comparative Study Between Friction Stir Welding and Metal Inert Gas Welding of 2024-T4 Aluminum Alloy*; ARPN Journal of Engineering and Applied Sciences, ISSN: 1819-6608, Vol. 6 No. 11, 2011, pp. 36-40.

[5]. P Agarwal S, Pr. Nageswaran, N. Arivazhagan & K. Dev. Ramkumar, *Development of Friction Stir Welded Butt Joints of AA 6063 Aluminium Alloy and Pure Copper*; International Conference on Advanced Research in Mechanical Engineering, , ISBN : 978-93-81693-59-9, May, 2012.

[6]. T. Venugopal, K. Srinivasa Rao and K. Prasad Rao, *Studies on Friction Stir Welded AA 7075 Aluminum Alloy;* Journal of Transactions of Indian Institute of Metals, Vol.57, No. 6, December 2004, pp. 659-663.

[7]. M. Karthikeyan and A.K.Shaik Dawood, *Influence of Tool Design on the Mechanical Properties and Microstructure in Friction Stir Welding of AA6351 Aluminium Alloy*; Engineering Science and Technology: An International journal, ISSN:2250-3498, Vol. 2 No. 2, April 2012, pp. 233-237.

[8]. Chang-Yong Lee, Don-Hyun Choi, Won-Bae Lee and Yun-Mo Yeon, *Microstructures and Mechanical Properties of Double-Friction Stir Welded 2219 Al Alloy*; Materials Transaction, The Japan Institute of Metals, Vol. 49 No.4, 2008, pp. 885-888.

[9]. H.Kafli and Nuran AY, *Mechanical Properties of 6013-T6 Aluminium Alloy Friction Stir Welded Plate*; International Conference on Aerospace Sciences & Aviation Technology, ASAT-13, 2009.

[10]. Nik.Sibalic,Mil. Vukcevic, Mileta Janjic, *Research Of Friction Stir Welded 7049 Aluminum Alloy*,International Research/Expert Conference,Trends in the Development of Machinery and Associated Technology, September 2012.

[11]. Z. Barlas and U. Ozsarac, *Effects of FSW Parameters on Joint Properties of AlMg3 Alloy*; Welding Journal, Vol. 91, January 2012, pp. 16-22.

[12]. R. Palanivel and P. Koshy Mathews, *The Tensile Behaviour of Friction-Stirwelded Dissimilar Aluminium Alloys*; Materials and Technology, professional article, ISSN 1580-2949, 2011, PP. 623-626.

[13]. R.Madhusudhan, M.M.M.Sarcar, N.Ramanaiah and K. Pra. Rao, *An Experimental Study on the Effect of Weld Parameters on Mechanical and Micro structural Properties of Dissimilar Aluminium*;International Journal of Modern Engineering Research, ISSN: 2249-6445, Vol. 2 No. 4, 2012, pp. 1459-1463.

[14]. Sang-Woo Song, Byung-Chul Kim and Tae-Jin Yoon, *Effect of Welding Parameters on Weld Formation and Mechanical Properties in Dissimilar Al Alloy Joints by FSW*; Material Transaction, The Japan Institute of Metals, Vol. 51 No.7, 2010, pp. 1319-1325.

[15]. M.Jayaraman, R.Sivasubramanian and V.Balusamy,*Effect of Process on Tensile Strength of Welded of Friction Stir Welded Cast LM6 Aluminium Alloy Joints*; Japan Material Science and Technology, Vol.25 No.5, 2009, pp. 655-664.