International Journal of Scientific & Engineering Research, Volume 10, Issue 6, June-2019
ISSN 2229-5518

Mechanical behaviors of joining AL-Alloys based FSW parameters and welding tool design

Ahmed El-Keran1, Rania Mostafa2, Reham Al-Mahdy3*

Production Engineering and Mechanical Design Deptartment, Faculty of Engineering, Mansoura University, Mansoura, Egypt.
1Assoc. Professor, el_keran@mans.edu.eg
2Lecturer, ranmos75@mans.edu.eg
3 (corresponding author), rehamalmahdy18@gmail.com*

Abstract— Friction Stir Welding is a solid-state welding process with specially rotating tool design. The heat is generated due to the friction between the workpiece-surface and the tool shoulder. The core benefit of FSW joint is to weld the material without achieving the fusion temperature so it's allows to join almost types of aluminum alloys, even the ones categorized as non-weld able alloy by the traditional welding process such as fusion welding because of the hot cracking and unfortunate solidification microstructure in the welding zone. FSW is used in aerospace, automotive, marine industries, electronics etc. This paper introduces a literature review on FSW process and various researches in this field. The effect of the welding parameters such as tool rotation speed, welding speed, tool tilt angle and tool design are introduced. The article also reviews the FSW of similar and dissimilar aluminum alloys and the FSW benefits and applications.

Key Words — Friction Stir Welding, Al-Alloys, Welding parameters, FSW Tools, solid-state welding process, Rotional speed, Welding speed, Mechanical behaviors.

u

1 Introduction

In 1991, Wayne Thomas at The Welding Institute TWI invented a new welding process that is used to joint two pieces by soften the rejoin between them without melting. This process is called a Friction stir welding (FSW) [1]. FSW process has gone through stages of development and improvement along the last years. A non-consumable rotating tool consists of a pin with specially designed profile and shoulder is inserted into the join line of the two objective plates and is moved along the interface of the joint. This process is a solid-state joining process because the plastic deformation is produced by the frictional heating between the tool shoulder and the surface of the plates in the welding zone along the workpiece length. The two-metal plates are mechanically mix together at the place of the joint and by applying the mechanical pressure the softened metal can be joined. FSW is principally suitable for welding the high strength alloys such as Aluminum 5xxx series and dissimilar material [2].

FSW is defined as a green and environmentally friendly welding process. The welding operation is simple with a high energy efficient and eliminates the need for costly consumables. FSW process does not require filler wires and shielding gas, It's unnecessary to make special joint edge profiling or remov oxide immediately prior to welding. The benefits of FSW such as metallurgical, environments and energy benefits are summarized in [3].

Application of FSW includes various industries such as - Shipping and marine industries (aluminum plates extrusions, manufacturing of hulls, offshore housings, etc.), Aerospace industries (for welding Al alloys fuel tanks for aerospace vehicles, wings manufacturing, etc.), Railway industries (railway tankers, container bodies, etc.). Also, FSW is used in Land transports such as engine chassis, body frames, wheel rims, truck bodies, etc. [4]

2 Process principles

In FSW, a welding tool consists of a pin, shoulder, and shank and it is set in a milling machine chuck and rotated about its longitudinal axis. The plates are rigidity fixed to a backing plate, and clamps to prevent the work-piece from scattering or moving during welding. There are two welding sides; the advancing side is the location where the direction of rotation is the same welding direction and the solid material begains to be semi-solid material and the retreating side is the other side designated [5]. While the tool rotating and moving along the layer to be welded, the softened material is exactly stirred together forming a weld without reaching the melting point [6]. The welding tool is then withdrawn, commonly while the spindle keeps on turn. After the tool is withdrawn, a hole in the work-piece at the end of the weld leaved by the pin of the welding tool. The benefits of these welds are its require low energy input and no filler materials are used.

The principle parameters of FSW process is shown in Fig. 1. The factors which influence on the friction stir welding are Rotational Speed, Welding Speed, Down Force and Tool Tilt Angle.

International Journal of Scientific & Engineering Research, Volume 10, Issue 6, June-2019
ISSN 2229-5518

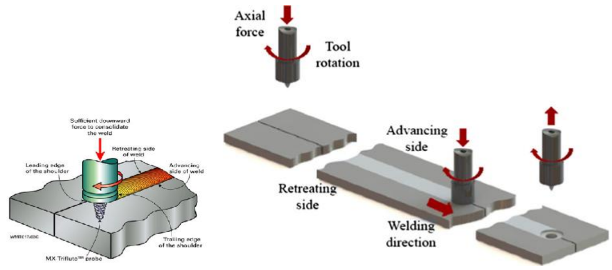

Fig.1 Process principle of friction stir welding

The almost process principles, microstructure and material properties were studied by R.S. Mishraa (2005) [7]. The tool geometry is founded that it is very important parameter for producing good welds and the welding parameters, including rotation speed, welding speed, tool-tilting angle, and tool pin penetration depth, are essential to produce defect-free weld. Compared to the traditional fusion welding, FSW exhibits a significant development in strength, fatigue, ductility and fracture toughness. Moreover, 80% of strength of the base material has been attained. The FSW parameters rotational speed, Tool depth and the shoulder dia. are very affected parameters on NiAl bronze to improve strength and ductility. M.W. Mahoney (2005) [8] studied these parameters and found that they had effectiveness on resistance to corrosion and fatigue, enhance formability, and improved the other properties.

Determine the selected rotational speeds depend on several parameters, such as material alloy type, welding speed, penetration depth, and joint type. (G. Çam et al.) (2008) [9] worked experimentally on FSW of Al-5086 H32 plates. A 3 mm plate thickness was studied with different welding speeds (175, 200, and 225 mm/min) at a constant tool rotational speed equal 1600 rpm. HSS conical tool was employed in FSW samples. The optimum combination of strength and ductility performances was obtained from the joint produced with W.S 200 mm/min and R.S 1600 rpm. The most defects were obtained at the samples welded with W.S 175 mm/min.

(Kumar K. et al.) (2008) [10] confirmed that higher tool rotation speeds produce higher temperature due to higher friction heat and cause of increasingly exceptional mixing and blending of material. Through welding, softened material from the main edge moves to the trailing edge because of the tool rotation and the tool movement during traverse, and this moved materials are joined in the trailing edge of the tool by the utilization of the requseted axial force.

(Fratini L. et al.) (2009) [11] studied the effect of tool rotation speed, welding speed and another important process parameter in FSW process which as a tool tilt angle. An appropriate tilt angle of the machine spindle in the direction of the welding confirms that the tool shoulder holds the mixed material by threaded pin and move material effectively from the front to the back of the pin. The tool is typically characterized by a small tool tilt angle, and as it is inserted into the plates, the gaps material undergoes to a local backward extrusion process up to the tool shoulder. Further, the penetration depth of pin into the work-pieces is effective parameter also to produce free defects welds with smooth surface.

The effect of FSW process parameters as; rotation speed and welding speed on the stirring act and friction heat during FSW experiments on dissimilar Al alloys AA5052-O and AA6061-T6 are studied by J. Park et al. (2010) [12]. By utilizing a range of parameters to study the mechanical properites of the welding experimentals such as strength of dissimilar materials weld nugget. They concluded that the optimum conditions were 61 mm/min as W.S and 1600 rpm as R.S. The inspection tests showed that the number of defects decreased when the welding speed was decreased.

(N. T. Kumbhar et al). (2012) [13] obtained that the optimum strength and ductility performances from the optimum combination of process parameters; high rotational speed and low welding speed with using the appropriate tool geometry.

(Abd Elnabi et al.) (2019) [14] considered the impact of FSW parameters on the mechanical properties of dissimilar AA5454-AA7075 aluminum alloys. The studied process parameters are tool rotational speed, welding speed, tool pin profile shoulder diameter (D) to pin diameter (d) ratio (D/d ratio), tool tilt angle, tool perntation depth, and weld location. The optimal parameters determined to attain the highest UTS using process condition are perntation depth 0.1 mm, rotational speed at 1225 rpm, tapered tool pin profile, welding speed at 21 mm/min, tilt angle 2°, D/d ratio 3, and AA5454 on the advancing side.

3 FSW Materials

FSW is mainly appropriate for aluminum alloys but can also used in welding other materials such as Copper and its alloys, Magnesium and its alloys, Titanium and its alloy, stainless steel, Lead, Zinc, Plastics and Mild steel. Plates sheets and heavy pipes can be welded by this method. The wide research and improvement at the last years reduced the limitations of FSW. Because of cost adequacy and capacity to weld dissimilar materials makes it a regularly utilized welding process in recent times. In any case, the material of the tool is dependent in the work piece material. The effect of the tool rotation speed on mechanical properties, microstructure and surface appearance of the FS-welded plates were studied and analysed by several mathematical methods and experimental technique [15]. Different series of dissimilar aluminum alloys have been successfully welded such as AA7xxx & AA6xxx [16-22], AA7xxx & AA5xxx [23,24], AA6xxx & AA5xxx [25,26] and AA6xxx & AA2xxx [27-29].

FSW is considered as the most effective way to joining of aluminum alloys especially high strength aluminum alloys which used in marine applications and aerospace which have problems in traditional welding joints because poor solidification microstructure and porosity defects in the fusion zone [30].

The dissimilar materials also can be welded using FSW process. The dissimilar alloys (AA2024-T351, AA7050-T7651, AA7075-T7651, and AA7075-T651) were welded and studied by J. B. Lumsden, M. W. Mahoney, and et al. (2002) [31]. the

International Journal of Scientific & Engineering Research, Volume 10, Issue 6, June-2019
ISSN 2229-5518

combination of FSW process parameters are experimentally considered to achieve high corrosion resistance and to develop their high strength.

(Paik) (2009) [32] studied the mechanical properties of friction stir welded dissimilar aluminum alloys 5083 and 5383 and compared between the FS-welded samples and fusion welded sample by observing the tensile test for both welding methods. FSW is considered to be more smart and simple, although its applications are some limited.

(Y. Kwon et al.) (2009) [33] considered FSW of AL5052 Alloy experimentally. The mechanical properties (Ultimate tensile strength and Hardness) and weld defects were studied in all chosen tool rotation speeds ranging from 500 to 3000 rpm while welding speed is constant at of 100 mm / min. The stirred zone (SZ) showed higher average hardness than the base metal, especially at 500 rpm, the average hardness of the SZ reached a level of 33% greater than that of the base metal. The UTS of some samples reached the value of the base material at the rotational speed 500, 1000, 2000 rpm. Under another conditions R.S 1120 rpm and W.S 100 mm / min at the same alloy, it was found that the UTS could be up to 90% of that of base material by N.T. Kumbhar and et al. (2011) [34].

(Yisong et al.) (2012) [35] studied friction stir welding on the large Aircraft Floor Structure using AA7050-T7451. The welding processing parameters which achieve tensile strength 90% of base metal are rotation 700rpm, welding speed 200mm / min, tool tilt angle 2.5°, welding force 7.7KN, and also observe perfect weld joint, which achieve the design requirements. In the case of welding 19m FSW floor structure, the force control technology and welding laser tracking technology are used to ensure the quality stability and standardization of the whole welding joint.

(Dinaharan et al.) (2013) [36] studied the process parameters of FSW on AA6061and observed that the process parameters such as rotational speed, welding speed, tool design and axial force are the main parameters to produce the FSW butt joint. A threaded pin profile tool with two different geometries has used and the tool material is H13. The maximum tensile strength obtained is 182Mpa at optimum welding conditions; Tool rotation speed 1400 rpm, welding speed 25mm / min and Pin length of the tool 5.7mm.

4 TOOLS-GEOMETRY

Welding Tool is a critical parameter in FSW process and optimizing tool geometry plays an important role to produce more heat or achieve more efficient offers two main benefits; Enhanced breaking and mixing of the surface oxide layers, and more effective heat generation and result higher welding speeds and improved quality. It consists of a shoulder and a pin. Pin profile has high effectiveness in material flow and in turn regulates the welding speed of the FSW process. The shoulder's main benefit is to generate most of the heat and to prevent the plasticized of the material from escaping from the workpiece surface, whereas both the tool shoulder and the tool pin affect the material flow rate [37].

Tool geometry such as pin length, pin profile and shoulder diameter are the key parameters because it would affect the heat generation and the plastic material flow. (Gopala et al.) (2011) [38] found that the tool design affects the heat generation, the power required, plastic material flow and the uniformity of the welded joint.

In FSW, there are many types of tool pin profile as shown in Fig.2. M. Venkateshkannan and et al. ,2014 [39] compared the FSW results of dissimilar AA5052 and AA2024 using five different tool pin profiles (Cylindrical, threaded, squared, tapered and stepped pin profiles). The stepped profile pin gave the highest UTS and the cylindrical threaded pin has produced defect-free welding with good UTS at R.S 100 rpm and W.S 40 mm / min.

Fig.2 Different type of FSW tools

(Rajkumar et al.) (2014) [40] studied the effect of tool design and welding parameters experimentally of dissimilar aluminum alloys AA 5052–AA 6061. Cylindrical threaded pin was used in this work under conditions; rotational speed 710rpm and two different welding speed 28 and 20 mm / min.

(Kumar et al.) (2014) [41] studied the effect of the FSW process parameters – tool rotational speed, tool welding speed and tool pin profiles – on Macro and microsstructure of dissimillar aluminum alloys AA7075-T651 and AA6061-T651. Taper cylinderical threaded pin profile tool obtained the maximum tensile strength at process parameters R.S 900rpm and W.S 100mm / min. The optical and ESM graphs observied that there is irregular distribition of two alloys in the nugget zone for the optimum combination.

(Ilangovan et al.) (2015) [42] considered the effect of tool pin profile on tensile properties and material microstructure of dissimilar Aluminum alloys 6061–AA 5086 joints using three different tool pin profiles; taper cylindrical, threaded cylindrical and straight cylindrical pin profile. The use of threaded pin profile tool improved the materials flow between the dissimilar alloys and generate a defect free samples in the stir zone. Compared to other two pin profiles, it is also showed higher hardness results in the stir zone and higher tensile strength.

(Patel et al.) (2016) [43] discussed the influence of Tool Pin Profile and Welding Parameter on Tensile Strength of Magnesium Alloy AZ91 during FSW process while The three pin profiles were used. The tapered cylindrical pin profile is not suitable with shoulder diameter 18 mm for welding the plates.

International Journal of Scientific & Engineering Research, Volume 10, Issue 6, June-2019
ISSN 2229-5518

The Straight one with rotational speed of 1000 rpm and welding speed of 28 mm / min gave a small defect in the weld zone surface. And the threaded straight cylindrical pin profile obtained high tensile strength at process parameters 710 rpm rotational speed and 28 mm / min welding speed.

(Saravanan et al.) (2016) [44] focused on the influence of shoulder diameter (D) to pin diameter (d) ratio of the tool on mechanical behaviour and microstructure measurements of dissimilar FS-Welded AA2024-T6 and AA7075-T6 Joints. This study obtained that the D / d ratio play an important rule in the FSW process, in case of D / d ratios of 3 and 3.5, the macrostructure in the stir zone clearly observed onion ring formation. In case of D / d ratio of 2, pin hole defect realized at the top surface because of fewer heat generation and inadequate material mixing. In case of D / d ratio equal 4 and because of friction between the work-piece surface and the tool shoulder extra heat generated so as a result of this the material softens and material flows at a faster rate from the bottom to the top surface generating a space at the bottom surface.

(Mehta et al.) (2016) [45] considered that tool pin design was an important parameter in Friction stir welding process and has effects on creation of defects in dissimilar welding. FSW was done on dissimilar aluminum - copper materials using 9 different tool pin profiles; triangular, cylindrical, square and hexagonal were utilized in this experimental study by keeping other parameters constant. The copper elements separated to large and irregular compared to the base material when the polygonal pin profiles was used. Triangular pin profiles were observed maximum unequal and large copper particles when use it. The defects such as cracks and voids produced when use polygonal pin profiles. The defects decreased when the polygonal edges increases. Defect free macro joint was described when use cylindrical tool pin profile.

4.1 tool materials

To select the suitable tool material involves knowing which material characteristics are significant for each friction stir application. A wide range of material characteristics could be considered in selecting FSW tool material such as Thermal Expansion Coefficient, Strength, Wear Resistance, Stability of the Temperature, Tool Reactivity, Machinability, Fracture Toughness, Uniformity in Microstructure and Density and Availability of Materials [46].Woke-piece materials such as aluminum or magnesium alloys, and aluminum matrix composites (AMCs) are regularly welded using steel tools such as HSS and steel12. Tool steel is the widely used tool material in FSW. This is because a common of the published FSW literature is on aluminum alloys, which are simply friction stirred with tool steels. The availability of tool steel material maked it a majority friction stir tooling material [47]. Table 1 illustrates the various types of FSW tools and its manufacturing temperature using forging process.

Table1 Summary of Current Friction Stir Welding Tool Materials with Their Forging Temperature [47].

(Bozkurt et al.) (2018) [48] experimentally concentrated on the effect of Tool material on the FSW of AA2124-T4 butt joint.

Alloys	Tool materials	Forging temperature in oc
Aluminum alloys	Tool steel, WC-Co	440-560
Magnesium alloys	Tool steel, WC	250-340
Copper and copper alloys	Nickel alloys, PCBN(a),tungsten alloys, Tool steel	600-910
Titanium alloys	Tungsten alloys	700-360
Stainless steels	PCBN, tungsten alloys	860-1030
Low-alloy steel	WC, PCBN	650-810

Coated tool with AlTiN, coated tool with a CrN and uncoated tool were used to join aluminum MMC plates. In microstructural inspection, no visible seeming porosity has been obtained in AA2124-T4 alloy matrix MMC joints, but some neglected macroscopic defects have been observed. The maximum UTS values of samples were achieved when the AlTiN coated tool was used. The welded samples showed two distinctive fracture modes. Both a blended brittle-ductile fracture and the relatively ductile fracture mode were obtained for both types of welds in UTS tensile tests. The welding samples presented low UTS values fractured with a blended brittle-ductile fracture, where as a ductile fracture mode was displayed by the joints showing higher UTS values.

5 The Mechanical Properties of Welded Material

There are three microstructural zones involve of FSW joints: (1) the nugget zone (NZ): gereated by the strong plastic deformation and large heat input, (2) the heat affected zone (HAZ): Is the region that is affected only by heat and no plastic deformation. and (3) the thermos-mechanically affected zone (TMAZ): Is the region surrounds the NZ Surrounds the nugget and it involvements lower temperatures and less deformation. It is discovered that mechanical properties and microstructure of FSW joints depords on many process parameters [49]. Microstructural characterization of the base and welding was done using optical microscope (OM) and scanning electron microscopy (SEM) prepared with an energy dispersive spectrometry (EDS) [50].

(Cole et al.) (2014)[51] studied the nominal FSW process parameters to join disimillar aluminum alloys 6061-T6 and 7075-T6 and to increase the welding quality by programmed tool offsets. Also, dynamic tool work-piece boundary temperatures are measured through the welding and used to clarify the effects of alloy location and weld tool offset from the joint. The strength measurment of joint is presented to improve with a decreasing quantity of power input to the weld, the alloy

International Journal of Scientific & Engineering Research, Volume 10, Issue 6, June-2019
ISSN 2229-5518

sensitive to heat input and weld temperature. It tends to be inferred that not exclusively should the material with the least solidus temperature be on the "cool" side of the weld (retreating side) yet additionally the material most vulnerable to debilitating at raised temperatures should encounter minimal measure of intensity input attainable amid the weld procedure.

(D. Urso et al.) (2017) [52] studied the influense of FSW process parameters on mechanical and corrosion behaviors in FSW of aluminum alloys, the process parameters experimentally studied on similar and dissimilar alloys AA7075 and AA2024. Tensile tests, Micro-Vickers tests and local corrosion potential measurements were assessed. The correlation between process parameters and welds properties permitted to determine the optimum welding conditions. The attacks morphology relies on the properties of the alloy; in AA2024 a serious crack and pitting attack happened while the AA7075 indicates peeling corrosion along the rolling direction. Join the dissimillar alloys, a serious galvanic assault happens on the AA7075, in the lower hardness regions. The decreasing of hardness and the different electrochemical performance in the joint line of the welding lead to the microstructural modification of the alloys during the FSW.

(Singh et al.)(2018)[53] studied the microstructure and mechanical behavior experimentally of FS-welded AZ61 magnesium alloy. The free defect joint produced at parameters conditions: rotational speed at 1400 rpm and welding speed at 25 mm/s. This samples shows tensile strength220 MPa, yield strength175 MPa, efficiency of weld about 82% and elongation about 7.2%. The development in hardness of the weld generate finer grains in the stir rigion. The micro-hardness values of base material are higher than thermo-mechanically affected region values but lower than stir region values.

(S. KUNDU et al.) (2017) [54] analyized the microstructure and the mechanical properites on FS-Welded joints of dissimillar 304 stainless steel and commercially pure aluminum under the welding conditions of rotational speed 1000 rpm, welding speed 60 mm/min and tool tilt angle 2°. Microstructural inspection was done by using optical microscope, scanning electron microscope (SEM). Optical images displayed that the microstructural change is very smallest in stainless steel side compared to aluminium side due to the difference in mechanical and thermal properties of the both material. Also the hardness measurements achived the maximum value at the stir zone as a result of the mixing of the materials.

(Zhang et al.) (2019)[55] studied the similar and dissimilar FSW joints of Aluminum alloys AA7075-T651 and AA2024-T351 to measure the effect of rotational speeds (600, 950, 1300 and 1650 rpm) on the mechanical properties, microstructure inspection and materials flow rate and specifications of the welding joints. Its concluded that the rotational speed has considerable effect on the mixing amounts of dissimilar materials in AA7075-2024 joints. When using low rotational speed, the mixing of materials decreases, while the usual onion ring form can be attained at the high tool rotational speed. Increasing rotational speed decrease hardness measurments in the nugget zone.

References

[1] W. M. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Temple-Smith and C. J. Dawes: International Patent Application PCT/GB92/02203 and GB Patent Application 9125978.8, UK Patent Office, London, (1991).

[2] S. Omar, et al., "A Review of Friction Stir Welding of Aluminium Matrix Composites", *Materials & Design. JMADE*, vol. 86, 2015, pp. 61–71.

[3] S. Mandeep, S. Sukhpal, "Friction Stir Welding – Process and its Variables: A Review", *International Journal of Emerging Technology and Advanced Engineering*, vol.2, 2012, pp. 275-279.

[4] Gabrielli, Filippo, et al. "Mechanical Properties and Formability of Cold Rolled Friction Stir Welded Sheets in AA5754 for Automotive Applications", *Procedia Engineering*, vol. 183, 2017, pp. 245–50.

[5] R. Nandan, T. DebRoy, et al., "Recent advances in friction-stir welding – Process, weldment structure and properties '', *Progress in Materials Science*, 2008, vol.53, pp. 980-1023.

[6] C. Rowe and T. Wayne, "Advances in tooling materials for friction stir welding", *TWI and Cedar Metals Ltd*., pp.1-11.

[7] R.S. Mishra, Z.Y. Maba, "Friction stir welding and processing", *Materials Science and Engineering*, 2005, pp.1-78.

[8] M. Mahoney, W. Binget and R. Mishra, "Microstructural Modification and Resultant Properties of Friction Stir Processed Cast NiAl Bronze", *Material Science Forum*, 2005, Vol. 426, pp. 2843-2853.

[9] G. Çam, S. Güçlüer, et al., "Mechanical properties of friction stir butt-welded Al-5086 H32 plate", *Journal of Achievements in Materials and Manufacturing Engineering*, 2008, vol.30, pp. 151-156.

[10] K. Kumar, V. Kailas Satish, "On the role of axial load and the effect of interface position on the tensile strength of a friction stir welded aluminium alloy*", Materials and Design*, 2008, vol.29, pp.791–797.

[11] L. Fratini, G. Buffa and R. Shivpuri, "In process heat treatments to improve FS-welded butt joints", Int J Adv. Manuf Technol ,2009, vol.43, pp. 664–670.

[12] J. Park and S. Kim, "The Effect of Traveling and Rotation Speeds on Mechanical Properties During Friction Stir Welding of Dissimilar Al Alloys", *Defect and Diffusion Forum*, 2010, pp. 590-595.

[13] N. Kumbhar and K. Bhanumurthy, "Friction Stir Welding of Al 5052 with Al 6061 Alloys", Hindawi Publishing Corporation, *Journal of Metallurgy*, 2012, pp.1-7.

[14] Abd Elnabi, Mohamed M., et al., "Influence of Friction Stir Welding Parameters On metallurgical and Mechanical Properties of dissimilar AA5454-AA7075 Aluminum Alloys", *Journal of Materials Research and Technology*Brazilian Metallurgical, Materials and Mining Association, 2019, pp. 1–10.

[15] R. Gupta, et al., "Friction Stir Welding: A Review", *Journal of Engineering, Computers & Applied Sciences*, 2013, vol.2, pp.172-176.

[16] J. Guo, H. Chen, et al., "Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters", *Material Design*, 2014.

[17] E. Cole, A. Fehrenbacher, et al., "Weld temperature effects during friction stir welding of dissimilar aluminum alloys 6061-t6 and 7075-t6". *International Journal Advanced Manufacturing Technolgy*, 2014.

[18] R. Rodriguez, J. Jordon et al., "Microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminum alloys" *Material Design*, 2015.

[19] H. Aval, "Influences of pin profile on the mechanical and microstructural behaviors in dissimilar friction stir welded AA6082–AA7075 butt joint", *Material Design*, 2015.

[20] L. Giraud, H. Robe, et al., "Investigation into the dissimilar friction

International Journal of Scientific & Engineering Research, Volume 10, Issue 6, June-2019
ISSN 2229-5518

stir welding of AA7020-T651 and AA6060-T6", *Journal of Material Process Technology*, 2016.

[21] K. Bijanrostami, R. Barenji, et al., "Effect of traverse and rotational speeds on the tensile behavior of the underwater dissimilar friction stir welded aluminum alloys", *J Mater Eng Perform*,2017.

[22] M. Hasan, M. Ishak, et al., "Effect of backing material and clamping system on the tensile strength of dissimilar AA7075-AA2024 friction stir welds", *Int. J Adv Manuf Tech*, 2017.

[23] V. Tran, J. Pan, et al., "Effects of processing time on strengths and failure modes of dissimilar spot friction welds between aluminum 5754-O and 7075-T6 sheets", *J Mater Process Technol*, 2009.

[24] Y. Chen, H. Ding, et al., "Microstructural and mechanical characteriza- tion of a dissimilar friction stir-welded AA5083-AA7B04 butt joint", *J Mater Eng Perform*, 2017.

[25] A. Steuwer, M. Peel et al., "Dissimilar friction stir welds in AA5083–AA6082: the effect of process parameters on residual stress", *Mater Sci Eng A*, 2006.

[26] M. Peel, A. Steuwer et al., "Dissimilar friction stir welds in AA5083-AA6082. Part I: process parameter effects on thermal history and weld properties", *Metall Mater Trans A*, 2006.

[27] P. Cavaliere, A. Santis, et al., "Effect of welding parameters on mechanical and microstructural properties of dissimilar AA6082–AA2024 joints produced by friction stir welding", *Mater Des*, 2009.

[28] C. Jonckheere, A. Denquin et al., "Torque, temperature and hardening precipitation evolution in dissimilar friction stir welds between 6061-T6 and 2014-T6 aluminum alloys", *J Mater Process Technol*, 2013.

[29] M. Moradi, H. Aval, et al., "Microstructure and texture evolution of friction stir welded dissimilar aluminum alloys: AA2024 and AA6061", *J Manuf Process*, 2018.

[30] G. Pouget, A. Reynolds, "Residual stress and microstructure effects on fatigue crack growth in AA2050 friction stir welds", *International Journal of Fatigue*, 2008, vol. 30, pp.463–472.

[31] J. Lumsden, M. Mahoney, and et al. "Corrosion Behavior of Friction-Stir-Welded AA7050-T7651", *NACE International; National Association of Corrosion Engineers*, 2003.

[32] Paik, K. Jeom, "Mechanical Properties of Friction Stir Welded Aluminum Alloys 5083 and 5383." *International Journal of Naval Architecture and Ocean Engineering*, vol. 1, 2009, pp. 39–49.

[33] Y. KWON, S. SHIM, and et al., "Friction stir welding of 5052 aluminum alloy plates", *Transactions of Nonferrous Metals Society of China*, 2009, vol.19, pp.23-27.

[34] N.T. Kumbhar, G.K. Dey and K. Bhanumurthy, "Friction Stir Welding of Aluminum Alloys" *BARC NEWSLETTER*, 2011, pp. 11-17.

[35] Yisong, Wang, et al. "Application of Friction Stir Welding on the Large Aircraft Floor Structure." *9th International Friction Stir Welding Symposium*, 2012.

[36] Dinaharan, I., et al. "A Study of Process Parameters of Friction Stir Welded Aa 6061 Aluminum Alloy" *International Journal of Innovative Research in Science, Engineering and Technology*, 2013, vol. 38, pp. 105–110.

[37] Rai, R., et al. "Review: Friction Stir Welding Tools." *Science and Technology of Welding and Joining*, 2011, vol. 16, no. 4, pp. 325–342.

[38] Gopalakrishnan S., Murugan N., "Prediction of tensile strength of friction stir welded aluminium matrix TiCp particulate reinforced composite", *Materials and Design*, 2011, vol. 32, pp.462–467.

[39] V. kannan, R. kumar, and et al. "Influences of tool geometry on metallurgical and mechanical properties of friction stir welded dissimilar AA2024 and AA5052", *Science Direct*, 2014, vol. 75, pp. 154-158.

[40] R. Kumar., V. Kannan, P. Sadeesh, and et al., "Studies on effect of tool design and welding parameters on the friction stir welding of dissimilar aluminium alloys AA 5052 – AA 6061", *Science Direct*, 2014, vol. 75, pp. 93-97.

[41] Kumar, S. Ravi, et al. "Effect of Welding Parameters on Macro and Microstructure of Friction Stir Welded Dissimilar Butt Joints between AA7075-T651 and AA6061-T651 Alloys." *Procedia Materials Science*, 2014, vol. 5, pp. 1726–1735.

[42] Ilangovan, M., et al. "Effect of Tool Pin Profile on Microstructure and Tensile Properties of Friction Stir Welded Dissimilar AA 6061–AA 5086 Aluminium Alloy Joints." *Defence Technology*, 2015, vol. 11, no. 2, Elsevier Ltd, pp. 174–184.

[43] Patel, Nikul, et al. "Influence of Tool Pin Profile and Welding Parameter on Tensile Strength of Magnesium Alloy AZ91 During FSW." *Procedia Technology*, Elsevier B.V., 2016, vol. 23, pp. 558–565.

[44] Saravanan, V., et al. "Effect of Shoulder Diameter to Pin Diameter Ratio on Microstructure and Mechanical Properties of Dissimilar Friction Stir Welded AA2024-T6 and AA7075-T6 Aluminum Alloy Joints." The *International Journal of Advanced Manufacturing Technology*, no. January 2019, 2016.

[45] Mehta, Kush P., and Vishvesh J. Badheka. "Effects of Tool Pin Design on Formation of Defects in Dissimilar Friction Stir Welding." *Procedia Technology*, Elsevier B.V., vol. 23, 2016, pp. 513–518.

[46] R. A. Prado, L. E. Murr, K. F. Soto and J. C. McClure: 'Self optimization in tool wear for friction-stir welding of Al 6061z20% Al2O3 MMC', *Mater. Sci. Eng. A*, 2003, pp.156–165.

[47] R. A. Prado, L. E. Murr, D. J. Shindo and K. F. Soto: 'Tool wear in the friction-stir welding of aluminum alloy 6061z20% Al2O3: a preliminary study", *Scr. Mater.*, 2001, vol. 45, no. 1, pp.75–80.

[48] Bozkurt, Yahya, and Zakaria Boumerzoug. "Tool Material Effect on the Friction Stir Butt Welding of AA2124-T4 Alloy Matrix MMC." *Journal of Materials Research and Technology*, Brazilian Metallurgical, Materials and Mining Association, 2018, vol. 7, no. 1, pp. 29–38.

[49] Singh, Kulwant, et al. "Review on Friction Stir Welding of Magnesium Alloys." *Journal of Magnesium and Alloys*, vol. 6, no. 4, Elsevier B.V., 2018, pp. 399–416.

[50] Luo, Quanshun. "Electron Microscopy and Spectroscopy in the Analysis of Friction and Wear Mechanisms", 2018, pp. 20–25.

[51] Cole, E. G., et al. "Weld Temperature Effects during Friction Stir Welding of Dissimilar Aluminum Alloys 6061-T6 and 7075-T6." *International Journal of Advanced Manufacturing Technology*, 2014, vol. 71, no. 1–4, pp. 643–652.

[52] Urso, D. "The Effects of Process Parameters on Mechanical Properties and Corrosion Behavior in Friction Stir Welding of Aluminum Alloys." *Procedia Engineering*, Elsevier B.V., 2017, vol. 183, pp. 270–276.

[53] Singh, Kulwant, et al. "Investigation of Microstructure and Mechanical Properties of Friction Stir Welded AZ61 Magnesium Alloy Joint." *Journal of Magnesium and Alloys*, Elsevier B.V., 2018, vol. 6, no. 3, pp. 292–298.

[54] S. Kundu, et al. "An analysis of microstructure ans mechanical properites on friction stir welded joint of dissimilar 304 stainless stell and commercially pure Aluminum" *Arch. Metall. Mater*, 2017, Vol. 62, pp. 1813–1817.

[55] Zhang, Chenghang, et al. "On the Microstructure and Mechanical Properties of Similar and Dissimilar AA7075 and AA2024 Friction Stir Welding Joints: Effect of Rotational Speed." *Journal of Manufacturing Processes*, vol. 37, Elsevier, 2019, no. October 2018, pp. 470–487.