Applicability of Friction Stir Welding and Friction Stir Processing: A Review Paper

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Abstract— Friction stir attachment (FSW) could be a solid-state change of integrity method within which a non-consumable rotating tool is employed to affix two facing surfaces. It's widely used for joining aluminum alloys in the region, ship manufacturing, and industry. This joining technique is energy-efficient, environment-friendly, and versatile. Especially, it is wont to be a part of high-strength region atomic number 13 alloys and different metallic alloys that are exhausting to weld by conventional fusion welding. Within the gift study friction stir attachment of aluminum alloy 6061 and 6063 is carried out on vertical milling machine. The tool material used was an H13 alloy steel. The plates were joined as a butt joint. In this paper literature review additionally thought-about for all previous research work done. Based on the author's view, additionally, describe the previous work is completed and therefore the future scope of this technology. I will be able to execute my research on FSW, FSP using review of various rising technology which gives me actual future work for obtaining result accuracy.

Keywords— Friction stir welding, friction stir processing, Heat affected zone, Stir zone etc.

I. INTRODUCTION

Friction stir welding (FSW) may be a relatively new solid-state joining method. This joining technique is energy-efficient, environment-friendly, and versatile. in particular, it can be used to join high-strength part aluminum alloys and other metallic alloys that are hard to weld by typical fusion welding. FSW is considered to be the most important development in metal joining in a decade. Recently, this processing (FSP) was developed for microstructural modification of metallic materials [1].

It was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and initially, it was applied to aluminum alloys. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder are inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. This tool serves two primary functions: (i) heating of work piece, and (ii) movement of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of the work piece. The localized heating softens the material around the pin and combination of tool rotation and translation results in movement of material from the front of the pin to the rear of the pin. As a result of this method, a joint is made in 'solid-state'. Due to various geometrical options of the tool, the material movement around the pin can be quite complex. Throughout the FSW method, the material undergoes intense plastic deformation at elevated temperature, resulting in the generation of fine and equated recrystallized grains. The fine microstructure in friction stir welds produces good mechanical properties [2].
The solid-state nature of FSW results in several benefits over fusion welding methods as issues associated with cooling from the liquid part is avoided. Defects such as porosity, solute redistribution, solidification cracking do not arise in friction stir welding. In general, FSW has been found to produce a low concentration of defects and is very tolerant of variations in process parameters and materials. The alloys of aluminum and magnesium are generally classified as non-wieldable because of the poor solidification, microstructure, and porosity in the fusion zone. FSW could overcome the problems associated with the welding of these alloys [3].

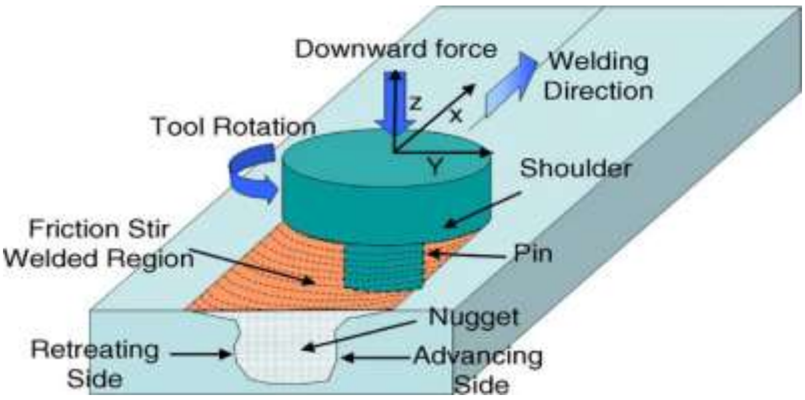

Figure 1. Schematic illustration of Friction Stir Weldin

FSW is taken into account to be the most important development in metal joining in a decade and maybe a ''green'' technology because of its energy efficiency, atmosphere friendliness, and versatility. As compared to the conventional welding methods, FSW consumes significantly less energy. No cover gas or flux is employed, thereby creating the method environmentally friendly. The joining doesn't involve any use of filler metal and thus any aluminum alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding. When fascinating, dissimilar aluminum alloys and composites can be joined with equal ease. In contrast to the standard friction welding, that is usually performed on tiny axisymmetric elements which will be revolved and pushed against one another to create a joint, friction stir welding may be applied to varied types of joints like butt joints, lap joints, T butt joints, and fillet joints [6].

FSW involves complex material movement and plastic deformation. Welding parameters, tool geometry, and Joint design exert a significant effect on the material flow pattern and temperature distribution, thereby influencing the microstructural evolution of the material. In this paper discussed based on the literature review, a few major factors affecting the FSW process, such as tool geometry, welding parameters, joint design are addressed.

This review paper explains the basic principle and methodology of FSW. It covers all the technical aspects which affect the process and quality of FSW joints. Effect on all the kinds of joint configuration is studied. All the technical aspects of FSW tool geometry and material of tool is roofed. Effect on welding quality of basic parameters like tool rpm, tool feed, tool tilt angle, downward force and tool indentation time has been studied. Finally, the area on which furthermore research can be carried out is identified

II LIMITATION

The limitations of the FSW method are: Exit hole left once the tool is withdrawn. Massive down forces needed with heavy-duty clamping necessary to carry the plates along. Less versatile than manual and arc processes (difficulties with thickness variations and non-linear welds). Usually slower traverse rate than some fusion welding techniques, though this could be offset if fewer welding passes are needed [8].

III LITERATURE SURVEY

The objective of this literature review is to quantify the relationship between various welding parameters like tool rotational speed, tool traverse speed, tool geometry, target depth for friction stir welding (FSW). Previously reported the study of various aluminium alloys is included. Forty research papers are taken chronologically for the literature review and concluding remarks, the methodology adopted and findings are studied.

Akinlabi et al. (2012) studied Friction Stir Welds of 5754 aluminium alloy (AA) and C11000 copper in butt joint configurations. Statistical analysis was conducted on the weld data obtained from friction stir welding of aluminium and copper. The welds were produced by varying the process parameters, the rotational speed was varied between 600 to 1200 rpm and the welding speed varied between 50 and 300 mm/min. The Statistical (version 9.0) analysis software package was used to generate the scatter and surface plots relative to the experimental results obtained from the tensile testing and the FSW data. Multivariate analysis was also done on weld data. It was found that the downward vertical force has a significant effect on the Ultimate Tensile Strength of the weld and a strong relationship exist between the heat input into the welds and the measured electrical resistivity of the welds. Based on the statistical analysis, the optimal weld setting concerning the UTS was weld produced at 950 rpm and 150 mm/min [12].

enkateswaran et al. (2012) carried out the study of factors affecting the properties of Friction Stir Welds between aluminum and magnesium alloys. Al–0.5Mg–0.3Si (6063) aluminum and rolled Mg–3Al–1Zn (AZ31B) magnesium alloy sheets were joined by Friction Stir Welding. The nugget grain size on both the Al and Mg sides monotonically increased as the tool rotational speed increased. The midplane micro hardness traverses showed fluctuating hardness peaks due to the presence of different microstructural phases in the nugget zone. The maximum tensile strength of the dissimilar weld joint was 68% of the 6063-T5 base metal with a maximum elongation of 1%. The low ductility was attributed to the formation of brittle intermetallic phases at the Al-Mg interface in the weld joint. The micro hardness distribution of the weld joints is mainly influenced by the local microstructural constituents such as the Al-Mg type intermetallic compounds, strengthening precipitates on the Al sides and grain size on the Mg sides of the weld joints. The formation of Al_3Mg_2 and $Al_{12}Mg_{17}$ intermetallic compounds are inevitable in the dissimilar Al-Mg weld joints under all conditions of the welding. The tensile failure of the weld joints occurred by two mechanisms; fracture along the intermetallic layer, where the continuous layer was observed, and through the aluminum base metal in the IPF (interpenetrating feature) regions [13].

Gheisari et al. (2013) explored the formation of weld defects in FSWed copper metals via both numerical and experimental approaches. The 4 mm-thick copper sheets were friction stir welded at a tool rotational speed of 710 rpm and tool translational speed of 40 mm/min. Microstructural evaluations were performed on the welded specimens. Also, a 3D arbitrary Lagrangian-Eulerian numerical model was developed to get temperature and material rate profiles. To this aim, DEFORM-3D was implemented for developing the numerical simulation. Numerical results for temperature values showed good agreement with the recorded experimental data. They also suggest that on the advancing side (AS) of the trailing side, the pin velocity has the minimum amount (zero), and this is the main reason for the formation of tunneling cavity. Experimental results show that a force is formed between the reminder of material at the joint and the rim of AS. This force causes a prong of surface material from the AS rim to penetrate lower parts of a weld. The inadequate pressure (low values of the plunge depth), inadequate surface materials, and the trapped air were the main causes for the formation of the weld defects [14].

Muruganandam et al. (2013) did the experimental investigation of the effects of geometrical parameters of friction stir welding of dissimilar Aluminium alloys and analysis of output responses such as tensile strength in the friction stir welding. friction stir welding. An interaction result of one input parameter over another parameter is studied to grasp their influences on output performance characteristics. Analysis of Variance (ANOVA) is also performed to study the contribution of an individual parameter on the output quality characteristics based on the Signal-to-Noise ratio. The welding parameters like rotational and transverse speed, plunge depth, tool tilt, initial heating time and tool down speed are important input during the welding process. Rotational speed and transverse speed used are 600 rpm to 1200 rpm and 60 mm/min to 75 mm/min. The analysis was carried out for taper threaded and straight threaded tool for joining two dissimilar materials. The results obtained were, for taper threaded, the optimum condition was rotational speed of 600 rpm, axial force of 3 KN and weld speed of 65 mm/min and for straight thread, the optimum conditions being rotational speed of 1200 rpm, axial force of 3 KN and weld speed of 65 mm/min. The most influencing parameter for both tapers threaded and straight threaded weld components was rotational speed followed by axial force and weld speed [15].

Li et al. (2013) analyzed the microstructural evolution and mechanical properties of dissimilar Al–Cu joints produced by friction stir welding in this research work. Pure copper and 5A02 aluminum alloy were joined by friction stir welding (FSW). A defect-free joint was obtained when one of the process parameters, i.e. the traverse speed was lowered from 40 mm/min to 20 mm/min. Sensible mixture of Al and Cu was discovered within the weld lump zone (WNZ). A large number of fine Cu particles were dispersed in the upper part of the WNZ produced a composite-like structure. In the lower part, nano-scaled intercalations were observed and identified by transmission electron microscopy (TEM). These layered structures were subsequently confirmed as Al4Cu9, Al2Cu3. Formation of these microstructures caused a heterogeneous hardness profile. Particularly, a definite rise in hardness was noticed at the Al/Cu interface. Excellent metallurgic bonding between Al and Cu gave rise to sensible behaviors within the tensile and bending strength. Enduringness may reach a hundred thirty MPa, representing joint potency of 75 .6% of the Al alloy base metal. No crack was discovered on the looks when the bending check [16].

Table -1: FSW PARAMETERS FOR MECHANIZED WELDING

Sr No.	Parameters	Effect of parameters
1	Rotational Speed	Frictional heat, stirring, oxide layer breaking and mixing of material
2	Welding Speed	Appearance, heat control.
3	Pressure on tool (Down Force)	Frictional heat, maintaining contact conditions
4	Tilting Angle	The appearance of the weld, thinning

Materials

Tool materials scheduled for friction stir welding and processing. The scheduled tool materials should not be viewed as an extensive list, because many papers do not specify the tool material or right the tool materials are proprietary. Table 2 is a summary of the current tool materials used to friction stir the indicated materials and thicknesses. These data are assembled from the indicated literature sources. [5]

Table 2 Summary of Current Friction Stir Welding Tool Materials with Their Forging Temperature.

Alloys	Tool materials	Forging temperature in 0c
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

TABLE.3 COMPLEX MOTION TOOL

Sr. no.	Type of Tool	Description of the type of tool
1.	Skew-Stir Tool	increase the volume of material swept by pin-to pin volume ratio by offsetting the axis of the pin from the axis of the spindle
2.	Com-Stir tools	Combine rotary motion (tool shoulder) with orbital motion (tool pin) to maximize the volume of material swept by pin-to-pin volume ratio
3.	Dual- Rotation Tool	the pin and shoulder rotate Separately at different speeds and/or in different directions
4.	Re-Stir Tool	1. Avoids the inherent asymmetry Produced during friction stirring by alternating the tool rotation, Either by angular reciprocation (direction reversal during one revolution) or rotary reverse (direction reversal every one or more revolutions) 2. Alternating the tool rotation produces alternating regions of Advancing and retreating side material through the length of the wed weld, thus eliminating the asymmetry issues

III LITERATURE REVIEW

Table 1. Literature Review on FSW

Sr. No.	Researchers	Journal and year	Materials	Problem Discussed & Outcome
1	S. Verma, Meenu, J. P. Mishra	Materials Today: Proceedings (2017)	AA6082	• Studied temperature distribution during FSW of AA6082. • Thermocouples were placed at equally distance to measure the Resulting temperature. • The results shows that temperature on advancing side is higher compared to retreating side.[2]
2	YahyaBozkurt, ZakariaBoumerzo ug	Journals of Material Research and Technology (2017)	AA2124 MMC	• In this study the effect of material properties of tool on friction stir welding of AA2124-T4 alloy matrix MMC. • Uncoated tool, coated tool with a CrN, and coated tool with AlTiN were used to weld aluminum MMC plates. • Results showed that the good welded joints could be obtained when a tool is coated with AlTiN. [3]
3	Gurmeet Singh,	Materials	AA6082	• The experimental comparison of friction stir welding process

	Amardeep S.	Today:		and TIG welding process for 6082 – T6 aluminium alloy
4	Yinfei Yan, YifuShen, Bing Lan, JichengGao	Journal of Manufacturing Processes (2017)	HDPE	In this paper double-pin tool is adopted in the FSW of high density polyethylene sheets. Effects of welding parameters on weld morphology and tensile strength are investigated. • Results shows that tensile strength of the weld joint increases with the increase of rotational Speed and the decrease of welding speed. [5]
5	D.K. Yaduwanshi, S. Bag, S. Pal	Materials and Design (2016)	AA1100 & Copper	In this study the effect of preheating by plasma source is analyzed by microstructural phenomena. Result shows that preheat is beneficial to increase the temperature of the harder work piece in front of the tool pin during dissimilar material joint, making the material easy to be welded. [6]
6	Prasad Rao, JavedAkram, Mano Misra, DamodaramRama chandr, Janaki Ram	Defense Technology (2016)	P91 Steel	FSW were made on P91 alloy with low and high rotational speeds to study their effects on weld micro-structural changes. The results suggest that the microstructural degradation in P91 welds can be controlled by low temperature friction stir welding technique.[7]
7	S. Malarvizhi V. Balasubramanian G. Madusudhan Reddy	S. SreeSabari, Defence Technology (2016)	AA2519	In this investigation, an attempt has been made to evaluate the mechanical properties and microstructural characteristics of AA2519-T87 joints made by FSW and UWFSW processes. Results shows that UWFSW joint exhibited higher tensile strength of 271 MPa and higher joint efficiency of 60% than conventional FSW. [8]
8	Sanghoon Noh, Masami Ando, Hiroyasu Tanigawa, Hidetoshi Fujii, Akihiko Kimura	A Journal of Nuclear Materials (2016)	F82H Steel	In this study, friction stir welding was employed to join F82H steels. The microstructures and mechanical properties on the joint region were investigated to evaluate the applicability of friction stir welding. • Based on the results, friction stir welding is considered to be a potential welding method to maintain a comparable property between weld zone and base metal of F82H steels without PWHT. [9]
9	Nikul Patel, K.D. Bhatt, Vishal Mehta	Procedia Technology (2016)	Magnesium Alloy AZ91	Researchers studied 6 mm thick plates of the Magnesium alloy joined at welding speed of 28 mm/min to 56 mm/min with tool rotation speed ranging from 710 rpm to 1400 rpm. Result shows shoulder diameter of 18 mm using threaded straight cylindrical pin profile used at the rotational speed of 710 rpm and welding speed of 28 mm/min is suitable for good
10	Chinmay Shah, BhupeshGoyal, Vijay Patel	Materials Today: Proceedings (2015)	AlSiCp PRMMC	In this research work, stir casting method is used for uniform distribution of the reinforcement material (SiC) in Aluminium as a matrix material. Friction stir welding (FSW) is performed to join this metal. ANOVA is performed for the optimization of the process parameters. Results shows that UTS of Friction Stir Weld is highly influenced by Wt% of SiC. As the Wt% of SiC increases, UTS increases. [11]

11	S. M. Bayazid, H. Farhangi, A. Ghahramani	Procedia Materials Science (2015)	AA 6063 & AA7075	• In this work, effect of some welding parameters of Friction Stir Welded joint of 6063 and 7075 alloys was predicted via Taguchi method. • Results of S/N analysis indicated that the optimal condition for dissimilar 6063-7075 joint is achieved when values of rotational speed and travel speed were 1600 rpm and 120 mm/min respectively. In such condition, tensile strength of joint was 143.59 MPa. [12]
12	Z. Shen, Y. Chen, M. Haghshenas, A.P. Gerlich	Engineering Science and Technology (2015)	AA5754 & DP600 Steel	• Lap welds between AA5754 to DP600 steel were manufactured by friction stir welding. • The results show that intermetallic compound of Fe_4Al_{13} was detected at the Al/Fe interface. The weld strength increases significantly by increasing the penetration depth into the lower steel substrate at all travel speeds. [13]
13	R.I. Rodriguez, J.B. Jordon, P.G. Allison, T. Rushing, L. Garcia	Materials & Design (2015)	AA6061 & AA7050	• In this work, the microstructure and mechanical properties of AA 6061 to 7050 were evaluated for FSW Process. • Microstructure analysis of the stir zone revealed the presence of bands of mixed and unmixed material. • Under tensile loading, an increase in the joint strength was observed with the increase in the tool rotational speed. [14]
14	Jaiganesh. V, Maruthu. B, Gopinath. E	Procedia Engineering (2014)	Polypropylene	• In this study polypropylene plates were successfully welded by using Friction stir welding by selecting the suitable optimal Conditions. • The yield strength of welded material was found to be 45% of the parent materials strength and characteristic. • With the optimum spindle speed of 950 to 1000 RPM and feed rate of 9 to 12 mm/min and tilt angle of 10, a superior weld was obtained. [15]
15	Sadeesh P, VenkateshKannan M, Rajkumar V, Avinash P, Arivazhagan N, DevendranathRamkumar K, Narayanan S.	Procedia Engineering (2014)	AA2024 & AA6061	• The joining of dissimilar AA2024 and AA6061 aluminium plates of 5mm thickness was carried out by friction stir welding (FSW) technique. • From the result the cylindrical threaded and squared pin tool profile are found to be the best among other tool profiles that were considered. [16]

RESEARCH GAPS AND CRITICAL PARAMETERS:

The gaps identified in literature review includes limited study on tool geometry. Most of the time cylindrical profile is used. Limited study on friction stir welding of aluminum alloy 6061 and aluminum alloy 6063. The critical research issues are listed below.

1. The effect of area of different tool geometries is not studied on tensile strength.
2. Fewer research has been reported on the effect of higher RPM ranges like 1000-2000 rpm on tensile strength.
3. Fewer researches has been reported on the effect of higher RPM ranges and traverse speed ranges like 20-50 mm/min on stir zone and heat affected zone micro hardness.
4. Tool rotation and traverse speeds, to be considered in FS.
5. Tool tilt and plunge depth, plunge depth is defined as depth of the lowest point of the shoulder below the surface of the welded plate and plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool.
6. Tool Design, good tool can improve both quality of the weld and the maximum possible welding speed.

CONCLUSION

Based on the literature survey performed, leading fact is that research has been conducted to obtain the optimum value of friction welding parameters that gives best value for welding of materials. We can conclude that process parameters of friction stir welding i.e. pin profile, rotating speed and translator feed rate of tool are higher influencing factors affecting on weld quality. From the literature review, it can be observed that friction stir welding process has been successfully applied for joining similar as well as dissimilar materials. Different optimization techniques can be used to optimize welding process parameters. We can conclude that preheating of material can improve the quality of weld.so I conclude my research work on the basis of this review paper in further research work done.

The friction stir welding is very recent trends in the manufacturing technology of metal joining processes especially for aluminum alloys. It is found that many research works are done on the aluminum alloys. Moreover, various engineering

Industries will not only give importance for aluminum and aluminum based alloys but also for mild steel and its alloys. This paper highlights the principle of FSW and vital factors that influence the quality of weld and the critical analysis realize the possible research works on other than aluminum alloys such as mild steel (work piece) and cubic boron nitride (tool), with same process parameters.

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