Friction Stir Welding of Thin Sheets - An Overview

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***Abstract*:** **Friction-stir welding (FSW) is a solid-state joining process that uses a third body tool to join two facing surfaces. FSW has been proven successful on numerous of alloys and materials, including high-strength steels, stainless steel and titanium. FSW produces welds of high quality in difficult to weld materials such as aluminium and is fast becoming the process of choice for manufacturing light weight transport structures such as boats, trains and aeroplanes. FSW is considered to offer advantages over fusion welding in terms of dissimilar jointing. Improvements on the existing methods and materials as well as new technological development, an expansion are expected. Research towards the further extension of the process to join thin sheet of similar and dissimilar metal combinations like aluminium alloys, aluminium to magnesium, steel and titanium is currently underway. In this paper an attempt has been made to review the current state of FSW in joining of thin sheets.**

Keywords: Friction Stir Welding, Thin sheet, Tool, Mechanical Properties

I. INTRODUCTION

Increasing in the need to design for lightweight structures in aircraft panels and vehicle body shells has lead invention of advanced joining technology which is an integral part of the manufacturing processes. Considerable effort has been expended to develop various joining processes and assess their suitability for use in light weight structures [1–2].

FSW is one of the solid-state joining techniques which was invented at The Welding Institute (TWI), UK, in 1991. The FSW has been found to be effective for joining hard-to-weld metals and for joining plates with different thicknesses and different materials [3].

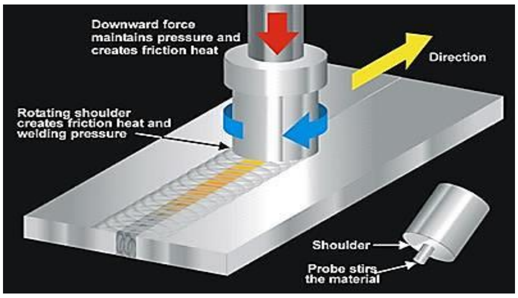

Fig.1. Schematic drawing of FSW process [4]

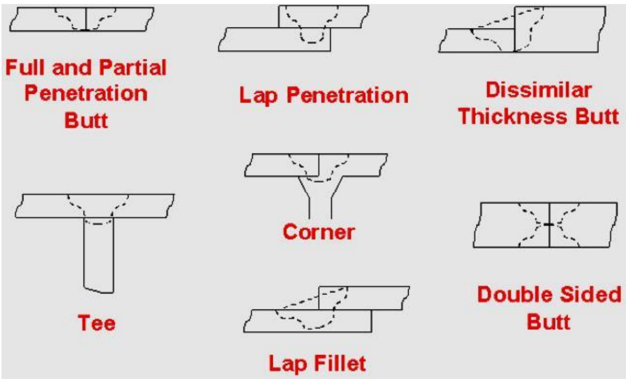

Fig.2. Joint configurations for FSW [5]

The working principle of FSW as shown in Fig 1. In FSW the parts intended for joining are usually arranged in a butt configuration. The rotating tool is then brought into contact with the work pieces. The tool has two basic components: the probe, which protrudes from the lower surface of the tool, and the shoulder, which is relatively large diameter. The length of the probe is typically designed to match closely the thickness of the work pieces. Welding is initiated by first plunging the rotating probe into the work pieces until the shoulder is in close contact with the component top surface. Friction heat is generated as the rotating shoulder rubs on the top surface under an applied force. Once sufficient heat is generated and conducted into the work piece, the rotating tool is propelled forward. Material is softened by the heating action of the shoulder, and transported by the probe across the bond line, facilitating the joint [4]. FSW can be used in a variety of joint configurations as shown in Fig 2. Including butt welds, dissimilar thickness butt welds, lap penetration, and lap fillet configurations. This can often require redesign of the product, to take full advantage of the FSW process [5].

The objective of this paper is to study the attempts that have been made by different researchers in the interest of joining thin sheets by FSW process.

II. THE REVIEW WORK IS CLASSIFIED INTO SIX MAJOR GROUPS FOR EASE OF UNDERSTANDING AND DISSEMINATION

A. FSW of thin sheets

P Staron et. al. studied the residual stress states of FSW joints of 3.2 mm thick AA2024 Al-sheets that have been welded under mechanical tensioning were analyzed, they found that large compressive stress can be induced in the weld by applying mechanical tensioning during welding [6].

A. Scialpi et. al. studied thin aluminium alloy 2024-T3 and 6082-T6 sheets of 0.8 mm thick, have been welded in the rolling direction by μFSW (FSW for ultra-thin sheets). Micro-hardness and residual stress measurements have been executed on welded sheets for each joint typology [7].

R.K. Kesharwani et. al. joined 2.0-mm thick AA5754-H22 and AA5052-H32 sheet metals with optimized tool design and process parameters to maximize the weld strength and total elongation reducing the surface roughness and energy consumption, they found that the formability was improved by 27% using the modified conical tractrix die [8].

Shuja Ahmed et. al. joined AA6XXX series aluminium alloys of thickness 0.44 mm have been welded together in both butt and lap fashion. They established the measure of joint's tensile strength (by conducting both transverse and longitudinal tension tests) and the micro-hardness [9].

A. Heidarzadeh et. al. a thermal model was developed and applied to simulate the friction stir welding of pure copper plates with the thickness of 2 mm. The different traverse speeds of 100, 200, 300, and 400 mm /min and rotational speeds of 400, 700, 900 rev min−1 were considered as welding parameters, they found that the peak temperature was the dominant factor controlling the grain size and mechanical properties, where the fine grains could be achieved at low rotational speed as well as high traverse speed [10].

B. FSW of special materials

High-strength of M190 steel sheets of 1.1 mm thickness were joined by friction-stir welded by Ghosh et. al [11]. It was found from the optical microstructure of the joints that, at the weld nugget depended on the cooling rate during welding. They observed the effect on joint efficiency were more than 50 pct of that of parent alloy [11].

AZ31B magnesium alloy of 2 mm thickness were joined by F SW with various welding parameters. By the three-point method experimentally studied that the transverse rigidities of the friction stir welded samples were lower of those of the base material. Furthermore, reduction of transverse rigidities was induced by the decrease of Young's moduli [12].

D.G. SANDERS et. al. joined two sheets of Ti-6Al-4V alloy of 2.54 mm thickness were butt welded by FSW to have an ultra-fine grain size. They conducted the experiments in accordance with industry standard testing specifications. It is reported that the macrostructures revealed a good quality weld joint with no inclusions, no voids, and complete fusion [13].

C. Tool geometry used for FSW of thin sheets

2-mm-thick of 7B04-T74 aluminum alloys were joined by Friction stir lap welding. Min Wang et. al. [14] investigated the effect of pin length on hook size and joint properties. They found that the process parameters, characteristics of pin length on joint properties are dependent on the heat input levels.

M. Simoncini et. al. [15] investigated the effect of tool geometry, tool configuration and process parameters on 1 mm thick of AA5754 Al alloy by FSW. They found that the joints welded by PIN tool exhibits more grain refinement and mechanical properties than joints welded by PINLESS tool.

The fracture behavior and intermetallic formation were investigated by joining of 2.8mm thickness of Al-Cu bi-layer sheets by FSW with help of tapered threaded pin. They found that the FSW of Al-Cu laminates demonstrate important role of contact condition on joint quality [16].

D. Process parameters in FSW of thin sheets

Ghosh et. al [11] joined high-strength of M190 steel sheets of 1.1 mm thickness by FSW under different tool rotational and traversing speeds. They concluded that adequate joint efficiency (›60 pct) can be obtained by FSW through controlling the tool rotational and traversing speed.

Tool material, configuration and geometry, which affects on macrostructure, microstructure, and mechanical properties of pure titanium weld joint were investigated by K. Reshad Seighalani et. al. [17]. They found that Ti can be joined by the FSW, using a tool with a shoulder made of tungsten (W) and simple pin made of tungsten carbide (WC). Furthermore, the tensile strength and the yield strength of the welded joint were similar to the corresponding strengths of the base metal.

FS welds of very thin plates of the AA 6016-T4 aluminium alloy has been done by D.M. Rodrigues et. al.[18] with two different tools to analyze the microstructure and mechanical properties. They concluded that the differences in tool geometry and welding parameters induced significant changes in the material flow path during welding as well as in the microstructure in the weld nugget.

E. Significant microstructures of FS Welded material

2 mm thick of AA2024-T3–Cu10100 dissimilar joints were made by FSW offsetting the tool probe and selected processing parameters. They analyzed that the Joint microstructure by conventional optic microscopy and scanning electron microscopy also found that microstructure variation significantly affects the micro-hardness distribution in the cross-section of the joint [19].

Amir Abbas Zadpoor et. al.[20] studied the FS welded joints with dissimilar aluminum alloys of 2024-T3 and 7075-T6 of 1.2 mm thicknesses were welded in different combinations of alloys and thicknesses. They found that the dissimilar alloys has no significant diffusion of alloying elements between the alloys and the fracture mechanism were mixture of ductile and brittle fractures and to qualify as ‘‘quasi-cleavage.

Investigated the internal features, defects and initial gap between the two parent sheets of AA2198-T851 of 3.1 mm thickness were joined by FSW. Based on the experimental data micro-structural, mechanical characterization of base material and Failure location is sensitive to the presence of some of the considered weld flaws [21].

F. *Challenges faced in FSW of thin sheets*

Jiye Wang et. al.[22] joined the Ti-6Al-4V alloy of rolled sheet with a thickness of 2.5 mm were welded with a position-controlled FSW machine. They found that the tool debris particles became the void nucleation sites, which significantly lowered the total ductility, although the particles had little effect on the uniform plastic strain.

Dissimilar lap joints of Ti-6Al-4 V titanium alloy sheet of 1.6 mm thick and an AISI 304 stainless steel sheet of 1 mm thickness were welded by FSW process. Based on the experimental and numerical analysis, both hooking defects and tunnels may occur with incorrect choice of process parameters. [23].

2-mm thick 2060 Al-Li alloy plates were FS welded, they investigated the effects of welding speed and rotation speed on formation quality, microstructure, phase particles ’ transformation, and mechanical properties of the joints. They found that the joints fails with a shear fracture due to welding parameters, where there exist f layered ledges and river patterns, joints welded using high heat input fracture from the heat-affected zones close to the thermo-mechanically affected zones [24].

Muthukrishnan et. al. studied the effects of process parameters in butt welded of Al-6082-T6 plates Of 3mm thickness plates by FSW method. They concluded that tensile strength of FSW welds is directly proportional to the travel / welding speed. Hardness drop were observed in the weld region [25].

FSW of 2024-T3and 6082-T6 Al rolled sheets of 0.8 mm thickness have been tried by Emanuela Cerri et. al. used a cylindrical, non-threaded probe. They found that the specimens fractured in the middle of the weld zone in a ductile mode due to the micro-void size distribution and coalescence of void nucleation mechanism [26].

III. CONCLUSIONS

This paper provides some useful insights into the use of friction stir welding for joining configuration of thin sheets. It reviews the latest developments in the study of the FSW process parameters, microstructures of FSWelded joints and the properties of FSWelded structures. Several important key problems and opportunities for further research are also observed. Also in this paper, the study on the effects of the tool shape and surface condition on the microstructure, micro hardness and grain size for thin aluminum alloy, magnesium alloy, titanium alloy, etc,. FSW were observed.

REFERENCES

[1] He X, Gu F, Ball A. Recent development in finite element analysis of self-piercing riveted joints. Int J AdvManufTechnol 2012;58:643–9.
[2] He X, Pearson I, Young K. Self-pierce riveting for sheet materials: state of the art. J Mater Process Technol 2008;199:27–36
[3] Thomas WM, Nicholas ED, Needham JC, Murch MG, Temple-Smith P, Dawes CJ. Friction stir butt welding. nternational Patent Application No. PCT/GB92/02203; 1991
[4] Xiaocong He, FengshouGu, Andrew Ball. A review of numerical analysis of friction stir welding, Progress in Materials Science 65 (2014) 1–66
[5] Mishra RS, Ma ZY. Friction stir welding and processing. Mater SciEng R: Rep 2005;50:1–78
[6] P Staron, M Koçak, S Williams, A Wescott, Residual stress in friction stir-welded Al sheets, Volume 350, Issues 1–3, Supplement, 15 July 2004, Pages E491–E493
[7] A. Scialpi, M. De Giorgi, L.A.C. De Filippis, R. Nobile, F.W. Panella, Mechanical analysis of ultra-thin friction stir welding joined sheets with dissimilar and similar materials, Volume 29, Issue 5, 2008, Pages 928–936
[8] R.K. Kesharwani, S.K. Panda, S.K. Pal, Experimental Investigations on Formability of Aluminum Tailor Friction Stir Welded Blanks in Deep Drawing Process, Volume 24(2) February 2015—1049
[9] Shuja Ahmed, Abhishek Shubhrant, Akash Deep and Probir Saha, Development and Analysis of Butt and Lap Welds in Micro-friction Stir Welding (μFSW), DOI 10.1007/978-81-322-2355-9_15
[10] A. Heidarzadeh, M. Jabbari, M. Esmaily, Prediction of grain size and mechanical properties in friction stir welded pure copper joints using a thermal model, DOI 10.1007/s00170-014-6543-7
[11] M. Ghosh, K. Kumar, R.S. Mishra, Process Optimization for Friction-Stir-Welded Martensitic Steel, DOI: 10.1007/s11661-012-1084-x
[12] Luo Zhi, Hao Zhiyong, Ni Dingrui, Zheng Xu, Friction Stir Welding Effect on Transverse Rigidity and Sound Transmission Characteristics of AZ31B Magnesium Alloy, DOI 10.1007/s12209-015-2370-7
[13] D.G. Sanders, P. Edwards, A.M. Cantrell, K. Gangwar, M. Ramulu, Friction Stir-Welded Titanium Alloy Ti-6Al-4V: Microstructure, Mechanical and Fracture Properties, DOI: 10.1007/s11837-015-1376-x
[14] Min Wang, Huijie Zang, Jingbao Zhang, Xiao Zhang, Lei Yang, Effect of Pin Length on Hook Size and Joint Properties in Friction Stir Lap Welding of 7B04 Aluminum Alloy, DOI: 10.1007/s11665-014-0936-5
[15] M. Simoncini, D. Cicearelli, A. Forcellese, M. Pieralisi, Micro and Macro-Mechanical properties of Pinless Friction Stir Welded Joints in AA5754 Aluminium Thin Sheets, DOI: 10.1016/j.procir.2014.06.099
[16] R. Beygi, M. Kazeminezhad, A.H. Kokabi, A. Loureiro, Friction Stir Welding of Al-Cu Bilayer Sheet by Tapered Threaded Pin: Microstructure, Material Flow, and Fracture Behavior, DOI: 10.1007/s11661-015-2859-7

[17] K. Reshad Seighalani, M.K. Besharati Givi, A.M. Nasiri, P. Bahemmat, Investigations on the Effects of the Tool Material, Geometry, and Tilt Angle on Friction Stir Welding of Pure Titanium, DOI: 10.1007/s11665-009-9582-8

[18] D.M. Rodrigues, A. Loureiro, C. Leitao, R.M. Leal, B.M. Chaparro, P. Vilaça, Influence of friction stir welding parameters on the microstructural and mechanical properties of AA 6016-T4 thin welds, Materials and Design 30 (2009) 1913–1921

[19] Pierpaolo Carlone, Antonello Astarita, Gaetano S. Palazzo, Valentino Paradiso, Antonino Squillace, Microstructural aspects in Al–Cu dissimilar joining by FSW, DOI 10.1007/s00170-015-6874-z

[20] Amir Abbas Zadpoor, Jos Sinke, Rinze Benedictus, Global and Local Mechanical Properties and Microstructure of Friction Stir Welds with Dissimilar Materials and/or Thicknesses, DOI: 10.1007/s11661-010-0403-3

[21] Thomas Le Jolu, Thilo f. Morgeneyer, Anne denquin, Mohamed sennour, Anne laurent, Jacques besson, Anne-francoise gourgues-lorenzon, Microstructural Characterization of Internal Welding Defects and Their Effect on the Tensile Behavior of FSW Joints of AA2198 Al-Cu-Li Alloy, DOI: 10.1007/s11661-014-2537-1

[22] Jiye Wang, Jianqing Su, Rajiv S. Mishra, Ray Xu, and John A. Baumann, A Preliminary Study of Deformation Behavior of Friction Stir Welded Ti-6Al-4V, DOI: 10.1007/s11665-014-1075-8

[23] Gianluca Buffa, Joining Ti6Al4Vand AISI 304 through friction stir welding of lap joints: experimental and numerical analysis, DOI 10.1007/s12289-014-1206-7

[24] Yuqing Mao, Liming Ke, Fencheng Liu, Chunping Huang, Yuhua Chen, Qiang Liu, Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of 2060 aluminum lithium alloy, DOI 10.1007/s00170-015-7191-2

[25] M. Muthukrishnan, K. Marimuthu, Some Studies on Mechanical Properties of Friction Stir Butt Welded Al-6082-T6 Plates, 978-1-4244-9082-0/10/$26.00 ©2010 IEEE

[26] Emanuela Cerri, Mechanical Properties and Microstructural Evolution of Friction-Stir-Welded Thin Sheet Aluminum Alloys, DOI: 10.1007/s11661-010-0524-8