Effect of Process Parameters on Friction Stir Welded Al Alloys: A Review

Prashant Kumar Pandey[1], Vishaldeep Singh[1]

[1] Mechanical Engineering Department, Lovely Professional University, Punjab, India

Abstract

An effort has been made to summarise most of the aspects of FSW (friction stir welding) process and the effect of process parameters of this welding technique on mechanical as well as microstructural behaviour of aluminium alloys. The variations in the process parameters discussed in this review paper are: variation of the downward force, variation of the probe angle, length of probe, shape of shoulder, rotational speed of the tool, pin profile, traverse speed and working conditions. The setups used in majority of places consist of vertical milling machines. It has been observed that the joint strength is increased between the dissimilar materials on introducing a third foil of roughly one-tenth thickness, between the two sheets of dissimilar material to be joined, in case of lap joint. The value of thermal co-efficient of expansion for the filler metal sheet must lie between the values of the thermal expansion coefficients of the materials of the sheets to be joined.

***Keywords*:** Aluminium Alloys, Friction stir welding, The effect of FSW process parameters, Tool pin profile, Traverse speed

1. Introduction

The integration of friction stir welding in automobile industries and aviation industries is truly doing wonder by reducing the weight of the components without compromising the strength. In addition to high strength, the friction-stir welding process also eliminated the need of any filler material. The research and the development team in "The Welding Institute (TWI)", situated in United Kingdom, has been carrying out extensive researches in the field of friction welding. Apart from studying the effect of varying rotation speed and torque parameters in friction welding, the researchers also showed interest in the properties of various materials in the plastic state [1]. The need of eliminating the geometric restrictions was already being felt by the team. It was not long after when in 1991 on a very fine day, Wayne Thomas struck an idea of using a probe of a harder material than those materials to be joined and with the correct rotational speed and torque, using it to fuse the specimens together. This led to the invention of process named as Friction Stir Welding. In 1991, Wayne Thomas and his colleagues at TWI patented this technology [2].

The significance of the word "stir" in friction stir welding is that the probe of a harder material than the specimens to be joined causes a stirring action in the material at the joint and thus highly plasticising the material to a point at which the complete joint is created. In comparison to laser beam welding, the FSW costs less and its equipment accommodates part variety much better than that accommodated by the laser beam welding setup [3].

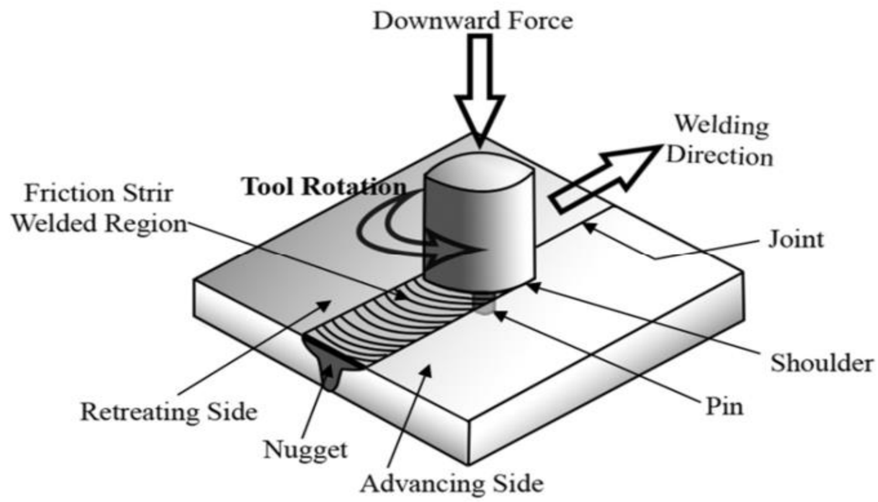

Figure 1: Schematic diagram of FSW process

2.Literature Review

P. Karthikeyan et al.[4] studied the relation between welding and the hardening parameters of friction stir welded aluminium. It has been discussed that how varying the parameters in friction stir welding, the different values of hardness for the joint could be achieved. The verification has been done by universal tensile strength (UTS) testing and the Izod impact testing. A model of least square hardening has been compared with corresponding welding parameters. Further, the relationship has been derived during their investigation. Statistical software named "Minitab 16" had been employed to accomplish the same. The methodology followed throughout the research work was "Box Behnken design of response surface".

R.K. Kesharwani et al.[5] have researched on the multi-objective optimisation of FSW parameters for joining of the two dissimilar thin aluminium sheets. The research had been conducted to obtain the optimised parameters which would further fulfil the various pre-decided objectives, the main objective being then improvement of the weld quality. The FSW process was carried out to butt weld dissimilar AA5052-H32 and AA5754-H22 metallic sheets of thickness 2 mm each. The methodology followed throughout the research was Taguchi grey based approach. The use of L9 orthogonal array has been made for the design of experiments. Utilising the grey relation grade, optimum level of the parameters was identified. The application of this research involves the development of the light weight automobiles using tailor welded blanks (TWB) in the body in white (BIW). This ensured that no compromise in the strength would have to be made to obtain a lighter structure. The process involves the welding of dissimilar metallic sheets of different thicknesses.

M. Felix Xavier Muthu et al.[6] deliberated the consequences of the pin profile and the process parameters on the mechanical properties and the microstructure of the friction stir welded aluminium-copper joints. For dissimilar metals with different values of yield strengths, the pin profile plays a very important role. The superior joint properties as desired, shows the attributes such as dispersion strengthening and formation of friction stir zone without any defect.

Cabibbo et al.[7] have done their research on the effect of welding motion, and pre-annealing and post-annealing of friction stir welded AA5754 joints. In this research, an innovative approach has been followed in the friction stir welding of AA5754 sheets. As per the definition given by the researchers involved in this work, they followed RT-type configuration. In RT-configuration, two different motions of pin are clubbed together. The pin with 0.5 mm radius on deviation from the welding centre-line, in post-welded annealed condition illustrated better tensile strength in comparison to the conventional (T-type) welding.

V.C. Sinha et al.[8] made an attempt to compare the microstructure as well as the mechanical characteristics of the friction stir welded joints between the two cases. The first case being the joint created between the two samples of similar metal and the other one being the joint created between the two dissimilar metals. The three pairs of joints created by the combination of Aluminium Alloy (AlA) and the pure copper (Cu) are AlA-AlA, AlA-Cu and Cu-Cu. The rotation speeds were varied between 150 rpm to 900 rpm and in the steps of 150 rpm at 60 mm/min travel speed at a constant angle of 2°, in order to obtain enough experimental results. Through SEM, the microstructure was determined. The following were the intermetallic compounds created at the interface of Aluminium Alloy and pure copper at the friction stir welded joints of these two materials: Al4Cu9, AlCu, Al2Cu & Al2Cu3. Also, the corresponding values of grain size were obtained against the different step-values of heat input.

Prakash Kumar Sahu et al.[9] discussed various parameters for the AL/CU FSW such as tool offset position, tool rotational speed and more significantly the influence of the plate position on the microstructure as well as the macrostructure of the joint. The important results obtained by their quest were that the copper must be placed at the advancing side of the tool if finer microstructure is intended. Moreover, it has also been observed that joint prepared with these dissimilar materials displays the tensile strength to be 95 % of that of aluminium and the bending angle as 65°.

Hui Shi et al.[10] experimented and made report on the friction stir welding of dissimilar Al/Mg joint. The area of significance in this study was the banded structure zone (BSZ). In BSZ, the formation of the intermetallic compounds was specifically analysed. The intermetallic compounds have been known to affect the properties of the joint, say it, microstructural properties or the macro-structural ones. The morphology of the bands as well as the quantity and distribution of IMCs was based upon the TRS (Tool Rotation Speed). Throughout the experimentation, the team made sure that the traverse speed was constant. The end result suggested that the BSZ should be tailored in order to improve the properties of the AL/Mg friction welded joint.

Landry Giraud et al.[11] studied the dissimilar welding of two heat treatable aluminium alloys namely AA6060-T6 and AA7020-T651 by using FSW process. As with all the friction stir welding processes, even here it was observed that the intermixing of the intermetallic compounds had occurred at the interface very prominently. The advance speed was kept between 300 mm/min and 1100 mm/min while the tool rotation speed was kept between 1000 rpm and 2000 rpm. It was nowhere observed that the dissimilar FSW process induced hotter side but the efforts that were made throughout the practical research were very much dependant on the process parameters. The end result of the experimentation left the researchers with the quasi-static tensile values of the specimens. Venkateshkanan M et al. [12] considered the dissimilar weld joint of AA2024 and AA5052. The two dissimilar aluminium alloys were friction stir welded and the joint was analysed for the microstructural and macro-structural properties. The main parameter considered in their experimentation was the tool geometry. As discussed in the paper, newly developed steeped tool pin profile makes better joint than the other commonly used tool profiles for friction stir welding. Minute discontinuities could be observed in the cylindrical and tapered tool profiles while in the other tool profiles, there was no such thing.

3. Materials and Methods

As per the end application of the finished product, the materials are chosen to be joined by friction stir welding. Generally those metals which have lower carbon content are readily weldable. Also, as per the size and assembly of the end product, we choose the suitable equipment. The types of joint also play a significant role in the methods that follow.

3.1. Types of FSW Joints

One of the most beneficial factors that can be noticed in FSW is that it doesn't add any mass to the joint since there is no involvement of the filler material in the general use. For the very same reason, it has found industrial applications in the space equipment industry and the automobile industry where the volume to weight ratio matters a lot. Another advantage that the concerned process carries is that it can effectively join the sum up thickness of up-to 5 mm, depending upon the properties of material and the temperature conditions. Also, high accuracy can be achieved while welding the sum up thickness of plates of 0.2 mm.

The types of joints that can be formed by friction stir welding are the lap joint and the butt joint. For a fixed setup it is not convenient to make any other kind of joints in the specimens, however, with the advancement in the technical field where robotic arms are being employed to achieve various tasks in space with higher degrees of freedom, there is no limit in possibilities.

3.1.1. The types of joints discussed in this review paper

Not all the types of joints are possible through friction stir welding process. However among the joints that can be created using this process, we have emphasised more on the lap joint and the butt joint. Moreover, there have been discussions involving multi-lap joint.

3.2. The Material for Friction Stir Welded Sheets

Joints of various grades of aluminium and steel have been tested for macro-structural and micro-structural properties after friction stir welding. Furthermore, friction stir welding of copper and aluminium has also been discussed.

3.3. Testing Of Specimens

3.3.1. Macro-structure testing

The tensile testing has been carried out by using UTM (Universal Testing Machine) under the ASTM (American Society for Testing & Materials) specifications.

3.3.2. Micro-structure testing

The micro-structures of the specimens have been tested by the following devices: optical microscope, scanning electron microscope, X-ray diffraction and EDS (Energy-dispersive X-ray spectroscopy).

4. Discussion

4.1. Effect of traverse speed

For the welding of aluminium Al 5083-H321 and stainless steel 316L, the traverse speed of 160 mm/min was much defect free and had higher strength in comparison to the traverse speed of 200 mm/min at 280 rpm constant rotation.

4.2. Effect of pin offset

The zero or negative pin offset showed reduced tensile strength in comparison to the positive pin offset at 280 rpm and 160 mm/min traverse speed.

4.3. Effect of tool rotation direction

The welding with minimum defects took place only in case of the clockwise tool rotation whereas there was no proper welding observed when the tool rotation was in the counter-clockwise direction and there were many defects.

4. Conclusion

During the course of friction stir welding, if any IMCs (Inter-Metallic Compounds) are created, then they reduce the tensile strength of joint, thereby weakening the joint. The lap joints between aluminium alloy and Cu alloy showed better strength when pure zinc foil was used as the filler metal. Macro-interlocks, the mixed layer of aluminium and zinc, and the mixed layer of zinc and Cu were found out to strengthen the joint.

References:

[1] Çam G. Friction stir welded structural materials: beyond Al-alloys. International Materials Reviews. 2011;56:1-48.

[2] Farrokhi H, Heidarzadeh A, Saeid T. Frictions stir welding of copper under different welding parameters and media. Science and Technology of Welding and Joining. 2013;18:697-702.

[3] Motalleb-nejad P, Saeid T, Heidarzadeh A, Darzi K, Ashjari M. Effect of tool pin profile on microstructure and mechanical properties of friction stir welded AZ31B magnesium alloy. Materials & Design. 2014;59:221-6.

[4] P. Karthikeyan, D.Thiagarajan, K.Mahadevan. Study of relation between welding and hardening parameters of friction stir welded Aluminium 2024 alloy. Procedia Engineering 97 (2014) 505 – 512

[5] R. K. Kesharwani, S. K. Panda, S. K. Pal. Multi Objective Optimization of Friction Stir Welding Parameters for Joining of Two Dissimilar Thin Aluminum Sheets. Procedia Materials Science 6 (2014) 178 – 187.

[6] M. Felix Xavier Muthu, V. Jayabalan. Effect of pin profile and process parameters on microstructure and mechanical properties of friction stir welded Al−Cu joints. Trans. Nonferrous Met. Soc. China 26(2016) 984−993.

[7] Cabibbo, M., A. Forcellese, M. Simoncini, M. Pieralisi, and D. Ciccarelli. "Effect of welding motion and pre-/post-annealing of friction stir welded AA5754 joints." *Materials & Design* 93 (2016): 146-159.

[8] V.C. Sinha, S. Kundu, S. Chatterjee. Microstructure and mechanical properties of similar and dissimilar joints of aluminium alloy and pure copper by friction stir welding. Perspectives in Science (2016) 8, 543—546.

[9] Sahu, Prakash Kumar, Pal, Sukhomay, Pal, Surjya K., Jain, Rahul, Influence of Plate Position, Tool Offset and Tool Rotational Speed on Mechanical Properties and Microstructures of Dissimilar Al/Cu Friction Stir Welding Joints. Journal of Materials Processing Technology.

[10] Hui Shi, Ke Chen, Zhiyuan Liang, Fengbo Dong, Taiwu Yu, Xianping Dong, Lanting Zhang, Aidang Shan. Intermetallic Compounds in the Banded Structure and Their Effect on Mechanical Properties of Al/Mg Dissimilar Friction StirWelding Joints. Journal of Materials Science & Technology (2016).

[11] Giraud, Landry, Hugo Robe, Christophe Claudin, Christophe Desrayaud, Philippe Bocher, and Eric Feulvarch. "Investigation into the dissimilar friction stir welding of AA7020-T651 and AA6060-T6." *Journal of Materials Processing Technology* 235 (2016): 220-230.

[12] Venkateshkanan M, Rajkumar V, Sadeesh P, Arivazhagan N, Narayanan S, Devendranath Ramkumar K. Influences of tool geometry on metallurgical and mechanical properties of friction stir welded dissimilar AA 2024 and AA 5052. Procedia Engineering 75 (2014) 154 - 158.

[13] Gao, Y., K. Nakata, K. Nagatsuka, T. Matsuyama, Y. Shibata, and M. Amano. "Microstructures and mechanical properties of friction stir welded brass/steel dissimilar lap joints at various welding speeds." *Materials & Design* 90 (2016): 1018-1025.