A REVIEW ON FRICTION STIR WELDING OF SIMILAR AND DISSIMILAR ALUMINIUM ALLOYS

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ABSTRACT: *Aluminium alloy composites are the fastest developing materials for structural application due to their high specific weight, modulus, and resistance to corrosion and wear, and high temperature strength. A Friction Stir Welding Exploits its solid state process behavior of join aluminum alloys. As a solid state joining process, friction stir welding has proven to be a promising approach for joining aluminium alloys. However, challenges still remains in using FSW to join aluminum alloys. This review investigates the distinction and characteristic of aluminium and its alloys and also specific attention and critical assessment have given to: (a) the macrostructure and microstructure of al alloys joints, (b) the evaluation of mechanical properties of joints. This review concludes with recommendation for future research directions.*

Keywords: Friction Stir Welding, Dissimilar, Joint, Intermetallic Compound.

INTRODUCTION

The friction stir welding (FSW) process developed by the Welding Institute (TWI) of UK in 1991 is a novel solid-state joining technology that has broad applications in joining aluminum alloys difficult to weld by conventional fusion processes. Compared to other tradition-al welding techniques, FSW is considered to be an excellent eco-friendly technology due to its fine microstructure, absence of cracks and pores, free of shielding gas and filler metal, low residual stresses, and better dimensional stability [1,2]. Aluminum and aluminum alloys have become increasingly used in production of automobiles and trucks, packaging of food and beverages, construction of buildings, transmission of electricity, development of transportation infrastructures, production of defense and aerospace equipment, manufacture of machinery and tools and marine structures with its unique properties such as corrosion resistance, thermal conductivity, electrical conductivity, high strength with low density, fracture toughness and energy absorption capacity, cryogenic toughness, workability, ease of joining (welding (both solid state and fusion), brazing, soldering, riveting, bolting) and recyclability [3].

Aluminium and its alloys are most widely used in many industries like aerospace, transportation and several structural applications because of their high specific strength, good formability and good corrosion resistance [4, 5].

Friction stir welding (FSW) is one of them and its current applications are mainly on aluminum alloys, in particular those known to be difficult to weld. Experience has demonstrated that welding without reaching the melting point makes it possible to assemble these aluminum alloys. In addition, phenomena such as hot cracking or volatile solute loss can be avoided [6].

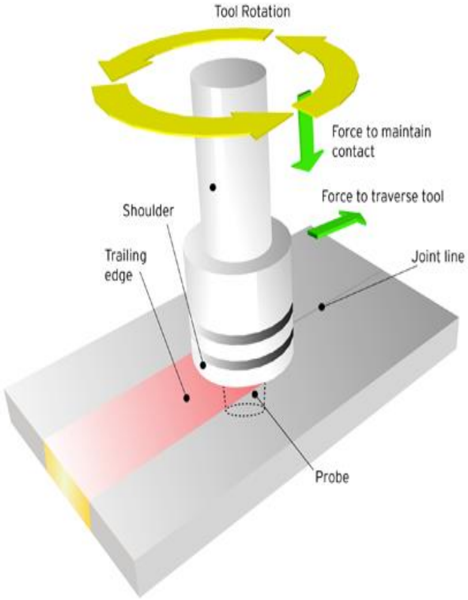
A non-consumable rotating tool harder than the base material is plunged into the abutting edges of the plates to be joined under sufficient axial force and advanced along the line of the joint. The tool consists of two parts, namely shoulder and pin. The material around the tool pin is softened by the frictional heat generated by the tool rotation. Advancement of the tool pushes plastically deformed material from front to back of the tool and forges to complete the joining process [7]. Friction stir welding has received rapid industry approval, including the transport sector, for joining aluminium components because of the numerous advantages it offers when compared to fusion welding techniques, which include having good mechanical weld qualities, ease of use in versatile welding positions, environmental friendliness etc... [8, 9].

FRICTION STIR WELDING

Friction Stir Welding (FSW), invented by Wayne Thomas, FSW is a solid-state process which produces welds of high quality in difficult to weld materials such as aluminium, and is fast becoming the process of choice for manufacturing lightweight transport structures such as boats, trains and airplanes.

Fabricators are under increasing pressure to produce stronger and lighter products whilst using less energy, less environmentally harmful materials, at lower cost and more quickly than ever before. FSW, being a solid-state, low-energy-input, repeatable mechanical process capable of producing very high-strength welds in a wide range of materials, offers a potentially lower-cost, environmentally benign solution to these challenges.

FSW was invented by TWI Ltd. Accordingly, we have a wealth of experience of applying the process industrially, in addition to in-depth knowledge of the fundamental science that underlies it.



FSW is a solid-state joining process that creates high-quality, high-strength joints with low distortion and is capable of fabricating either butt or lap joints, in a wide range of material thicknesses and lengths.

In the process a rotating FSW tool is plunged between two clamped plates. The frictional heat causes a plasticized zone to form around the tool. The rotating tool moves along the joint line. A consolidated solid-phase joint is formed. FSW being a solid-state process eliminates many of the defects associated with fusion welding techniques such as shrinkage, solidification cracking and porosity.

LITERATURE REVIEW

X.M. Wang [1], the friction stir welding of AA 3003 aluminum alloy with different initial microstructures was carried out under different welding conditions. The microstructural evolution and mechanical properties of weld joints were investigated. The results showed that the size of recrystallized grains and the amount of second-phase particles in the weld nugget zone (WNZ) decreased with decreasing welding ambient temperature.

M.N. Ilman [2], Fatigue crack growth rate behavior of friction-stir aluminium alloy AA2024-T3 welds under transient thermal tensioning. The present investigation aims to improve fatigue crack growth resistance of friction stir aluminium alloy AA2024-T3 welds using transient thermal tensioning (TTT) treatment. In this investigation, aluminium alloy AA2024-T3 plates were joined using FSW process with and without TTT.

Beytullah Gungor [3], Mechanical, fatigue and microstructural properties of friction stir welded 5083-H111 and 6082-T651 aluminum alloys. Tensile tests results showed sufficient joint efficiencies and surprisingly high yield stress values. Bending fatigue test results of all joint types showed fatigue strength close to each other. Fatigue strength order of the joints were respectively FSWed 5083-5083, and 6082-6082 similar joints and 5083-6082 dissimilar joint. Cross sections of the weld zones have been analyzed with light optical microscopy (LOM) and fracture surface of fatigue test specimens were examined by scanning electron microscopy (SEM).

J. da Silva [4], Fatigue behavior of AA6082-T6 MIG welded butt joints improved by friction stir processing. In this research, FSP appears as an alternative to traditional methods for fatigue strength improvement of weld joints, such as re-melting, hammering and blasting. This technique was applied on Metal Inert Gas (MIG) butt welds with and without reinforcement, performed on AA6082-T6 alloy plates. Friction stir processing of MIG welds does not change the hardness and mechanical strength of the weld substantially, but the fatigue strength was increased, due to the geometry modification in the weld toe, reduction of weld defects and grain refinement of the microstructure.

V. Infante [5], Study of the fatigue behavior of dissimilar aluminium joints produced by friction stir welding. The paper presents the experimental results obtained in two different structures: AA6082-T6 2 mm and AA5754-H111 2 mm thick joints, and AA6082-T6 2 mm thick joints. The results of the fatigue tests are presented as well as detailed metallographic characterization of the weld zone and also the hardness distribution at the weld region.

Hugo Robe [6], Microstructural and mechanical characterization of a dissimilar friction stir welded butt joint made of AA2024-T3 and AA2198-T3. The aim of this investigation is to evaluate the microstructural features, material flow, and post weld mechanical properties of a dissimilar joint made of AA2024-T3 and AA2198-T3 produced by friction stir welding.

Palanivel [7], Mechanical and metallurgical properties of dissimilar friction stir welded AA5083-H111 and AA6351-T6 aluminum alloys. The effect of welding speed on mechanical and metallurgical properties was analyzed. It is found that the welding speed of 63 mm/min produces better mechanical and metallurgical properties than other welding speeds. The weld zone is composed of three kinds of microstructures, namely unmixed region, mechanically mixed region and mixed flow region. The fracture mode was observed to be a ductile fibrous fracture.

Caroline Jonckheere [8], Torque, temperature and hardening precipitation evolution in dissimilar friction stir welds between 6061-T6 and 2014-T6 aluminum alloys. Torque and temperature measurements during welding as well as micrographics and hardness profiles measurements were performed after welding. It was found that the welding torque, the temper-ature, the metal flow and the welds' hardness profile depend on the proportion of each alloy included in the stirred zone. Those results are attributed to the difference between the softening temperatures of both alloys.

U. Donatus [9], Corrosion susceptibility of dissimilar friction stir welds of AA5083 and AA6082 alloys. The heat affected zones of both alloys and the transition regions between the AA5083-O and the AA6082-T6 rich zones have been identified to be the regions that are most susceptible to corrosion. Grain boundary sensitization in the heat affected zones of both alloys, distribution of Mg_2Si particles along the boundary between the two alloys (in the thermo mechanically affected zones of the welds) and the galvanic interactions between the AA5083 rich zones and the AA6082 rich zones were observed to be responsible for the corrosion susceptibility in the welds.

Maurizio Bevilacqua [10], Sustainability analysis of friction stir welding of AA5754 sheets. The results given by the life cycle assessment analysis has shown that the environmental impact of friction stir welding is strongly affected by rotational and welding speeds. The environmental impact was also related to the mechanical properties of joints, expressed as ultimate tensile strength and ultimate elongation.

R.I. Rodriguez [11], Microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminum alloys. In this work, the microstructure and mechanical properties of friction stir welded dissimilar butt joints of 6061-to-7050 aluminum alloys were evaluated. Under monotonic tensile loading, an increase in the joint strength was observed with the increase in the tool rotational speed. Regarding fracture, the joints consistently failed on the 6061 aluminum alloy side.

M.I. Costa [12], Dissimilar friction stir lap welding of AA 5754-H22/AA 6082-T6 aluminium alloys. Influence of material properties and tool geometry on weld strength. The results obtained enabled to conclude that the dissimilar welds strength is strongly dependent on the presence of the well-known hooking defect and that the hooking characteristics are strongly conditioned by base materials properties/positioning. It is also concluded that the use of unthreaded conical pin tools, with a low shoulder/pin diameter relation, is the most suitable solution for the production of welds with similar strengths for advancing and retreating sides.

Landry Giraud [13], Investigation into the dissimilar friction stir welding of AA7020-T651 and AA6060-T6. The material mixing of dissimilar configurations has been investigated by means of macro and microstructural observations and has revealed the complex mechanisms of material flow into the nugget. The as-welded mechanical behaviour has been characterized using quasi-static tensile tests. The cross-weld micro hardness has also been studied for various operating parameters. Computed maps correlated the microstructural features helping us establish weak zones.

Banglong Fu [14], Friction stir welding process of dissimilar metals of 6061-T6 aluminum alloy to AZ31B magnesium alloy. Sound friction stir welded joints of 6061-T6 aluminum alloy to AZ31B magnesium alloy are obtained with the combination of intermediate rotation rate of tool (600–800 rpm) and low traverse speed (30–60 mm/min) when Mg was on advancing side, tool offset to Mg 0.3 mm, and the tensile strength of the joints could reach up to 70% of that of Mg base metal.

I.A. Kartsonakis [15], Corrosion behaviour of dissimilar friction stir welded aluminium alloys reinforced with Nano additives. The corrosion resistance of the samples with or without Nano additives was studied by electrochemical methods. The results revealed that the incorporation of CeMo containers loaded with MBT during the FSW, enhances the corrosion resistance of the final material through the adsorption of $MoO^{-}{}_{4}{}^{2}$ ions that come from the container shell onto the surface of both AA, as well as the formation of stable complexes between the thiol groups of MBT and the alloying metals, preventing chloride penetration.

M.M.Z. Ahmed [16], Friction stir welding of similar and dissimilar AA7075 and AA5083. The microstructures and crystallographic textures of base materials (BM) and the welds were investigated using electron backscatter diffraction (EBSD) technique. The mechanical properties were evaluated using hardness and tensile testing. The fracture surface of the tensile tested samples was examined using scanning electron microscope (SEM).

S. SREE SABARI [17], Experimental and numerical investigation on under-water friction stir welding of armor grade AA2519-T87 aluminium alloy. In this investigation, an attempt has been made to evaluate the mechanical properties and microstructural characteristics of AA2519-T87 aluminium alloy joints made by FSW and UWFSW processes. Finite element analysis has been used to estimate the temperature distribution and width of TMAZ region in both the joints and the results have been compared with experimental results and subsequently correlated with mechanical properties.

S. Sree Sabari [18], Characteristics of FSW and UWFSW joints of AA2519-T87 aluminium alloy. Effect of tool rotation speed. A comparative study is undertaken to investigate the effect of tool rotation speed on the stir zone characteristics and the resultant tensile properties of the FSW and UWFSW joints. From this investigation, it is found that the UWFSW joint made using the lower tool rotation speed of 1200 rpm exhibited superior tensile properties than FSW joints. This may be attributed to the lower heat generation, higher grain boundary strengthening, and high volume fraction of precipitates and narrowing of the lower hardness distribution region (LHDR).

Shariati Avenue [19], Effect of welding heat input and post-weld aging time on microstructure and mechanical properties in dissimilar friction stir welded AA7075–AA5086. The mechanical and microstructural aspects of dissimilar friction stir welds of age-hardened AA7075-T6 and strain hardenable AA5086-H32 aluminium alloys were investigated. X-ray diffraction (XRD) residual stress analysis and tensile testing together with optical metallography and transmission electron microscopy (TEM) were performed to assess the effects of process parameters on welded joints.

M.ILANGOVAN [20], Microstructure and tensile properties of friction stir welded dissimilar AA6061íAA5086 aluminium alloy joints. The microstructures of various regions were observed and analyzed by means of optical and scanning electron microscopy. Micro hardness was measured at various zones of the welded joints. The tensile properties of the joints were evaluated and correlated with the microstructural features and micro hardness values. The dissimilar joint exhibits a maximum hardness of HV 115 and a joint efficiency of 56%. This was attributed to the defect free stir zone formation and grain size strengthening.

CONCLUSION

The friction stir welding of aluminum and its alloy with different initial microstructures were carried out under different welding conditions. The microstructural evolution and mechanical properties of weld joints were studied in the above research papers. Some grades of aluminium are difficult to weld by existing arc welding techniques, and a few, such as the very high-strength 2XXX and 7XXX series of alloys, unweldable. In FSW, its potential benefits in cost reduction, joint efficiency improvement, and high production accuracy make it even more attractive for the non-weldable series AA2xxx, AA6xxx and AA7xxx. Cavity or groove-like defect caused by an insufficient heat input in the friction stir welding. Cavity produced by the abnormal stirring.

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