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Friction Stir Welding

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Abstract

Welding is a fabrication process used to join materials, usually metals or thermoplastics, together. During welding, the work pieces to be joined are melted at the joining interface and usually a filler material is added to form a weld pool of molten material that solidifies to become a strong joint. In contrast, Soldering and Brazing do not involve melting the work piece but rather a lower melting point material is melted between the work pieces to bond them together. Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December1991. Initially, the process was regarded as a “laboratory” curiosity, but it soon became clear that FSW offers numerous benefits in the fabrication of aluminum products. Friction Stir Welding is a solid-state process, which means that the objects are joined without reaching melting point. This opens up whole new areas in welding technology. Using FSW, rapid and high quality welds of 2xxx and 7xxx series alloys, traditionally considered un-weld able, are now possible.

Keywords: Friction; Welding; Aluminum; fabrication

1. Introduction

1.1 Literature survey

Following literature survey has been summarized here under

Ericsson and Sandstrom (2002) investigated that the fatigue strength of friction stir (FS) welds is influenced by the welding speed, and also compare the fatigue results with results for conventional arc-welding methods: MIG-pulse and TIG. The Al–Mg–Si alloy 6082 was FS welded in the T6 and T4 temper conditions, and MIG-pulse and TIG welded in T6. The T4- welded material was subjected to a post-weld ageing treatment. According to the results, welding speed in the tested range, representing low and high commercial welding speed, has no major influence on the mechanical and fatigue properties of the FS welds. At a significantly lower welding speed, however, the fatigue performance was improved possibly due to the increased amount of heat supplied to the weld per unit length.

The MIG-pulse and TIG welds showed lower static and dynamic strength than the FS welds. This is in accordance with previous comparative examinations in the literature on the fatigue strength of fusion (MIG) and FS welds. The TIG welds had better fatigue performance than the MIG pulse welds. The softening of the alloy around the weld line has been modelled. Using a model without adjustable parameters, a fair description of the hardness profiles across the weld as a function of welding speed was obtained. The softening in front of the Friction Stir Welding tool was also estimated. At the low and high welding speeds a full and partial softening is predicted, respectively.

Liu et al. (2003) in their research paper discussed the friction stir weld ability of the 2017-T351 aluminium alloy and determine optimum welding parameters, the relations between welding parameters and tensile properties of the joints. Researchers found that the tensile properties and fracture locations of the joints are significantly affected by the welding process parameters. When the optimum revolutionary pitch is 0.07 mm/rev corresponding to the rotation speed of 1500 rpm and the welding speed of 100 mm/min, the maximum ultimate strength of the joints is equivalent to 82% that of the base material. Though the voids-free joints are fractured near or at the interface between the weld nugget and the thermo-mechanically affected zone (TMAZ) on the advancing side, the fracture occurs at the weld centre when the void defects exist in the joints.
Kovacevic (2003) In their research friction stir welding (FSW) is a relatively new welding process that may have significant advantages compared to the fusion processes as follow: joining of conventionally non-fusion weld able alloys, reduced distortion and improved mechanical properties of weld able alloys joints due to the pure solid-state joining of metals. In this paper, a three-dimensional model based on finite element analysis is used to study the thermal history and thermo mechanical process in the butt-welding of aluminium alloy 6061-T6.

Huseyin Uzun et al. (2004) investigated that the joining of dissimilar Al 6013-T4 alloy and X5CrNi18-10 stainless steel was carried out using friction stir welding (FSR) technique. The microstructure, hardness and fatigue properties of fiction stir welded 6013 aluminium alloy to stainless steel have been investigated. Optical microscopy was used to characterize the microstructures of the weld nugget, the heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) and the base materials.

Cavaliere et al. (2005) investigated the mechanical and micro structural properties of dissimilar 2024 and 7075 aluminium sheets joined by friction stir welding (FSW). The two sheets, aligned with perpendicular rolling directions, have been successfully welded; successively, the welded sheets have been tested under tension at room temperature in order to analyze the mechanical response with respect to the parent materials.
Kovacevic (2005) In their research thermo-mechanical simulation of friction stir welding can predict the transient temperature field, active stresses developed, forces in all the three dimensions and may be extended to determine the residual stress. The thermal stresses constitute a major portion of the total stress developed during the process. Boundary conditions in the thermal modelling of process play a vital role in the final temperature profile.

Driver a (2005) In the present paper, a three-dimensional thermo mechanical model for Friction Stir Welding (FSW) is presented. Based on the velocity fields classically used in fluid mechanics and incorporating heat input from the tool shoulder and the plastic strain of the bulk material, the semi-analytical model can be used to obtain the strains, strain rates, and estimations of the temperatures and micro-hardness in the various weld zones. The calculated results are in good agreement with experimental measurements performed on a AA2024-T351 alloy friction stir welded joint.

Marzol et al. (2006) established a friction stir welding (FSW) process parameters envelope for an AA 6061 alloy reinforced with 20% of Al2O3 particles, and determine properties of the obtained joints. After a brief description of the FSW technique, and the difficulties in joining MMCs, experimental procedure is illustrated. Microstructure has been observed with optical microscope, and images have been analyzed with image analysis software. Micro hardness and tensile tests have been also carried out. The tool's stirring effect has a substantial influence on the reinforcement particles distribution and shape. Tensile testing revealed joint efficiencies over 80% for the Rp0, 2 and of slightly more than 70% for the Rm, with failure outside the stir zone. The parameter envelope determined in the present study resulted in defect free, high strength welds.

Watanabe et al. (2006) tried to butt-weld an aluminium alloy plate to a mild steel plate by friction stir welding, and investigated the effects of a pin rotation speed, the position for the pin axis to be inserted on the tensile strength and the microstructure of the joint. The behaviour of the oxide film on the faying surface of the steel during welding also was examined. The main results obtained are as follows. Butt-welding of an aluminium alloy plate to a steel plate was easily and successfully achieved by friction stir welding. The maximum tensile strength of the joint was about 86% of that of the aluminium alloy base metal. A small amount of inter metallic compounds was formed at the upper part of the steel/aluminium interface, while no inter metallic compounds were observed in the middle and bottom parts of the interface. The regions where the inter-metallic compounds formed seemed to be fracture paths in the joint. Many fragments of the steel were scattered in the aluminium alloy matrix and the oxide film removed from the faying surface of the steel by the rubbing motion of a rotating pin was observed at the interface between the steel fragments and the aluminium alloy matrix.

Scialpi et al. (2006) studied the effect of different shoulder geometries on the mechanical and micro structural properties of a friction stir welded joints have been studied in the present paper. The process was used on 6082 T6 aluminium alloy in the thickness of 1.5 mm. The three studied tools differed from shoulders with scroll and fillet, cavity and fillet, and only fillet. The effect of the three shoulder geometries has been analyzed by visual inspection, macrograph, HV micro hardness, bending test and transverse and longitudinal room temperature tensile test. The investigation results showed that, for thin sheets, the best joint has been welded by a shoulder with fillet and cavity.

Ceschini et al. (2006) investigated that the application of this solid state welding technique to particles reinforced composites seems very attractive, since it should eliminate some typical defects induced by the traditional fusion welding techniques, such as: gas occlusion, undesired interfacial chemical reactions between the reinforcement and the molten matrix alloy, inhomogeneous reinforcement distribution after welding. The present work describes the effect of the FSW process on the microstructure and, consequently, on the tensile and low-cycle fatigue behaviour, of an aluminium matrix (AA7005) composite reinforced with 10 vol. % of Al2O3 particles (W7A10A).

Zhang et al. (2007) represent the 3D material flows and mechanical features under different process parameters by using the finite element method based on solid mechanics. Experimental results are also given to study the effect of process parameters on joining properties of the friction stir welds. Numerical results indicate that the tangent flow constitutes the major part in the material flow. The shoulder can accelerate the material flow on the top half of the friction stir weld.

Villegas (2007) studied the macro cystis integrifolia and Lessonia trabeculata form vast kelp beds providing a three-dimensional habitat for a diverse invertebrate and Wsh fauna oV northern chile. Habitat modiWcations caused by the El Niño Southern Oscillation (ENSO) are likely to alter the inhabiting communities. The aim of this study was to reveal relationships between distinct habitat structures of a M. integrifolia kelp bed, a dense L. trabeculata kelp bed and L. Trabeculata patches colonizing a barren ground, and the associated dominant macrobenthic key species.

Amancio-Filhoa et al. (2007) described that aircraft aluminium alloys generally present low weld ability by traditional fusion welding process. The development of the friction stir welding has provided an alternative improved way of satisfactory producing aluminium joints, in a faster and reliable manner.

Cavalierea et al. (2007) analyzed the effects of processing parameters on mechanical and micro structural properties of AA6082 joints produced by friction stir welding. Different welded specimens were produced by employing fixed rotating speeds of 1600rpm and by varying welding speeds from 40 to 460 mm/min. The SEM observations of the fatigue specimens, welded at 115 mm/min, showed that at higher stress amplitude levels the cracks initiate at the surface of the welds. By decreasing the stress amplitude the cracks initiate by the internal defects.

Elangovan et al. (2007) studied the influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy.AA2219 aluminium alloy has gathered wide acceptance in the fabrication of light weight structures requiring a high strength to weight ratio. In this investigation an attempt has been made to study the effect of tool pin profiles and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy. From this investigation, the following important conclusions are derived.

- Of the five tool pin profiles used to fabricate the joints, square pin profiled tool produced defect free FSP region, irrespective of welding speeds.

- Of the three welding speeds used to fabricate the joints, the joints fabricated at a welding speed of 0.76mm/showed superior tensile properties, irrespective of tool pin profiles.
- Of the 15 joints, the joint fabricated using square pin profiled tool at a welding speed 0.76mm/s exhibited maximum tensile strength, higher hardness and finer grains in the FSP region.

Muthukumaran et al. (2008) states that Electromagnetic radiation is emitted during the transient stage of elastic to plastic deformation of metals and alloys. In the present work, aluminium plates were welded by friction stir welding (FSW) at different process parameters, such as tool rotational speed, traverse speed and rake angle. The EMR fundamental frequencies emitted during the tensile failure of the welds were measured and recorded. The variation in the fundamental frequency was analyzed by fuzzy modelling using MATLAB and it was observed that an increase in the first mode of metal transfer decreases the fundamental frequency. Further, the fundamental frequency of a weld was estimated from the obtained model and found to be closer to the experimental results. It will be more useful for metal flow analysis as well as online condition monitoring of the welds which are used in critical applications.

Chen et al. (2008) Al–Si alloy and pure titanium were lap joined using friction stir welding technology. Microstructure and tensile properties of joints were examined. The maximum failure load of joints reached 62% of Al–Si alloy base metal with the joints fractured at the interface. X-ray diffraction results showed that new phase of TiAl3 formed at the interface. The microstructure evolution and the joining mechanism of aluminium–titanium joints were systematically discussed.

Moreira et al. (2008) Studied that mechanical and metallurgical characterization of friction stir welded butt joints of aluminium alloy 6061-T6 with 6082-T6 was carried out. For comparison, similar material joints made from each one of the two alloys were used. The work included microstructure examination, micro hardness, tensile and bending tests of all joints. An approximate finite element model of the joint, taking into account the spatial dependence of the tensile strength properties, was made, modelling a bending test of the weldments. This study shows that the friction stir welded dissimilar joint present intermediate mechanical properties when compared with each base material. In tensile tests the dissimilar joint displayed intermediate properties. For instance in the hardness profile the lowest values were obtained in the AA6082-T6 alloy plate side where rupture occurred, and in the nugget all type of joints present similar values.

Rodrigues a (2008) In this research paper present work friction stir welds produced in 1 mm thick plates of AA 6016-T4 aluminium alloy, with two different tools, were analyzed and compared concerning the microstructure and mechanical properties. For each tool, the welding parameters were optimized in order to achieve non-defective welds. The differences in mechanical properties between the two types of welds are explained based in TEM micro structural analysis. Despite the under matched characteristics of the ‘‘cold” welds relative to the base material, formability tests demonstrated that these welds improve the drawing performance of the welded sheets.

Jai KWON et al. (2009) performed the experiment of Friction stir welding between 5052 aluminium alloy plates with a thickness of 2 mm was performed. The tool for welding was rotated at speeds ranging from 500 to 3 000 r/min under a constant traverse speed of 100 mm/min. In all tool rotation speeds, the SZ exhibits higher average hardness than the base metal. Especially at 500 r/min, the average hardness of the SZ reaches a level about 33% greater than that of the base metal. At 500, 1 000 and 2 000 r/min, the tensile strength of the friction stir welded (Friction stir welded) plates is similar to that of the base metal (about 204 MPa). The elongation of the Friction stir welded plates is lower than that of the base metal (about 22%). However, it is noticeable that the maximum elongation of about 21% is obtained at 1 000 r/min.

Sandra Zimmer et al. (2009) presents the results of an experimental investigation, done on the friction stir welding (FSW) plunging stage. Previous research works showed that the axial force and torque generated during this stage were characteristic for a static qualification of a FSW machine. Therefore, the investigation objectives are to better understand the relation between the processing parameters and the forces and torque generated. It is an interesting way to present the experimental results. This kind of representation can be useful for the processing parameters choice. They can be chosen according to the force and torque responses and consequently to the FSW machine capacities.

Hwang (2010) This study aimed to experimentally explore the thermal history of a work piece undergoing Friction Stir Welding (FSW) involving butt joining with pure copper C11000. In the FSW experiments, The appropriate temperatures for a successful FSW process were found to be between 460 ◦C and 530 ◦C. These experimental results and the process control of temperature histories can offer useful knowledge for a FSW based process of copper butt joining.
Hattel a (2010) Studied that the post-welding stress state, strain history and material conditions of friction stir welded joints are often strongly idealized when used in subsequent modelling analyses, typically by neglecting one or more of the features above. But, it is obvious that the conditions after welding do influence the weld performance. The objective of this paper is to discuss some of the main conflicts that arise when taking both the post-welding material conditions and stress strain state into account in a subsequent structural analysis

Kanwer S. Arora et al. (2010) in this research, successful friction stir welding of aluminium alloy 2219 using an adapted milling machine is reported. The downward or forging force was found to be dependent upon shoulder diameter and rotational speed whereas longitudinal or welding force on welding speed and pin diameter. Tensile strength of welds was significantly affected by welding speed and shoulder diameter whereas welding speed strongly affected percentage elongation.

Hwang et al. (2010) experimentally explore the thermal history of a work piece undergoing Friction Stir Welding (FSW) involving butt joining with pure copper C11000. In the FSW experiments, K-type thermocouples were used to record the temperature history at different locations on work piece. This data, combined with the preheating temperature, tool rotation speeds and tool moving speeds allowed parameters for a successful weld to be determined.

Riahi (2010) In this research residual stress is lower in friction stir welding (FSW) compared with other melting weldment processes. This is due to being solid-state process in its nature. There are several advantages in utilizing stir welding process. Lower fluctuation and shrinkage in weldment metal enhanced mechanical characteristics, less defects, and ability to weld certain metals otherwise impractical by other welding processes are to name just a few of these advantages. In the prediction of results of residual stress, only heat impact was studied. This was recognized as the main element causing minor difference in results obtained for simulation in comparison with that of actual experiment.

Tozak et al. (2010) newly developed tool for friction stir spot welding (FSSW) has been proposed, which has no probe, but a scroll groove on its shoulder surface (scroll tool). By use of this tool, FSSW has been performed on aluminium alloy 6061-T4 sheets and the potential of the tool was discussed in terms of weld structure and static strength of welds. The experimental observations showed that the scroll tool had comparable or superior performance to a conventional probe tool. The shear fracture took place at smaller shoulder plunge depths or at shorter tool holding times, while the plug fracture occurred at larger shoulder plunge depths or at longer tool holding times. It was indicated that the tensile-shear strength and associated fracture modes were determined by two geometrical parameters in the weld zone.

S. Rajakumar et al. (2011) observed that AA6061 aluminium alloy has gathered wide acceptance in the fabrication of light weight structures requiring high strength-to-weight ratio and good corrosion resistance. Friction-stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The FSW process and tool parameters play a major role in deciding the joint strength. Joint strength is influenced by grain size and hardness of the weld nugget region. Hence, in this investigation an attempt was made to develop empirical relationships to predict grain size and hardness of weld nugget of friction-stir-welded AA6061 aluminium alloy joints. The empirical relationships are developed by response surface methodology incorporating FSW tool and process parameters. A linear regression relationship was also established between grain size and hardness of the weld nugget of FSW joints.

Aval (2011) In this work, the thermo-mechanical responses during the dissimilar friction stir welding of aluminium alloys have been evaluated employing a three-dimensional model and the finite element software ABAQUS. Also, both experimental and simulated results indicate that welding fixtures significantly affect the residual stress profiles as well as their magnitudes.

Kumaran et al.(2011) In this research numerous advancements have been occurring in the field of materials processing. Friction welding is an important solid-state joining technique. In this research project, friction welding of tube-to-tube plate using an external tool (FWTPET) has been performed, and the process parameters have been prioritized using Taguchi's L27 orthogonal array. Genetic algorithm (GA) is used to optimize the welding process parameters. The practical significance of applying GA to FWTPET process has been validated by means of computing the deviation between predicted and experimentally obtained welding process parameters.

Elangovan et al.(2012) The researchers **i**n this paper focuses on the development of an effective methodology to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding using response surface methodology (RSM) coupled with genetic algorithm (GA). RSM is utilized to create an efficient analytical model for welding strength in terms of welding parameters namely pressure, weld time, and amplitude. Experiments were conducted as per central composite design of experiments for spot and seam welding of 0.3- and 0.4-mm-thick Al specimens. An effective second-order response surface model is developed utilizing experimental measurements. Response surface model is further interfaced with GA to optimize the welding conditions for desired weld strength. Optimum welding conditions produced from GA are verified with experimental results and are found to be in good agreement.

Mariano et al. (2012) presents a literature review on friction stir welding (FSW) modelling with a special focus on the heat generation due to the contact conditions between the FSW tool and the work piece. A reliable FSW process modelling depends on the fine tuning of some process and material parameters. Usually, these parameters are achieved with base on experimental data. The numerical modelling of the FSW process can help to achieve such parameters with less effort and with economic advantages.

ZHANG (2012) studied that, the thermal modelling of underwater friction stir welding (FSW) was conducted with a three-dimensional heat transfer model. The vaporizing characteristics of water were analyzed to illuminate the boundary conditions of underwater FSW. Temperature dependent properties of the material were considered for the modelling. For underwater joint, the high-temperature distributing area is dramatically narrowed and the welding thermal cycles in different zones are effectively controlled in contrast to the normal joint.

Bhatt (2013) In this research we observed that Friction stir welding (FSW) of AA6061-T6 aluminium alloy has been attempted to overcome limitations of fusion welding of the same. The FSW tool, by not being consumed, produces a joint with predominant advantages of high joint strength, lower distortion and absence of metallurgical defects. Process parameters such as tool rotational speed, tool traverse speed and axial force and tool dimensions play an important role in obtaining a specific temperature distribution and subsequent viscosity distribution within the material being welded; the former controlling the mechanical properties and later the flow stresses within the material in turn.

Guo (2013) Studied that the Dissimilar AA6061 and AA7075 alloy have been friction stir welded with a variety of different process parameters. In particular, the effects of materials position and welding speed on the material flow, microstructure, micro hardness distribution and tensile property of the joints were investigated. It was revealed that the material mixing is much more effective when AA6061 alloy was located on the advancing side and multiple vortexes centres formed vertically in the nugget. l computational model.

KEIVANI (2013) have studied in their work, friction stir welding (FSW) is applied extensively in industry for joining of nonferrous metals especially aluminium. A three-dimensional model based on finite element analysis was used to study the thermal characteristic of copper C11000 during the FSW process.

Liu a (2013) In their research, the 4 mm thick 6061-T6 aluminium alloy was self-reacting friction stir welded at a constant tool rotation speed of 600 r/min. The specially designed self-reacting tool was characterized by the two different shoulder diameters. The results of transverse tensile test indicated that the elongation and tensile strength of joints increased with increasing welding speed. The defect-free joints were obtained at lower welding speeds and the tensile fracture was located at the heat affected zone adjacent to the thermal mechanically affected zone on the advancing side.

Shen a (2013) Studied that, the friction stir welding (FSW) technique is considered to offer advantages over fusion welding in terms of dissimilar jointing. However, some challenges still exist in the butt FSW of dissimilar Ti and Al metals. The present research employed a modified butt joint configuration into the FSW of Ti–6Al–4V alloy to Al–6Mg alloy with a special pin plunge setup, aiming to obtain a high-quality Ti-to-Al joint, avoid butt flaw or Al melting, and reduce the tool shoulder attrition. Under different FSW process conditions, the examinations and analyses of macro/micro-structures, mechanical tensile properties and fractographies of the dissimilar joints were conducted.

Simoes a, (2013) their work describes the thermo-mechanical conditions during Friction Stir Welding (FSW) of metals have already been subject of extensive analysis and thoroughly discussed in literature, in which concerns the FSW of polymers,
From the study it was possible to conclude that, due to the polymers rheological and physical properties, the thermo-mechanical conditions during FSW are very different from that registered during welding of metals, leading to completely different material flow mechanisms and weld defect morphologies.

Pan (2013) In their research the Friction Stir Welding (FSW) is a complex thermal-mechanical process. Numerical models have been used to calculate the thermal field, distortion and residual stress in welded components but some modelling parameters such as film coefficient and thermal radiation of the work pieces may be technically difficult and/or expensive to measure experimentally.
By comparing the FEM numerical results with experimental results, the FSW process thermal parameters have been successfully identified. This automatic parameters characterization procedure could be used for the FSW process optimization.

Ni (2014) observed that the Thin sheets of aluminium alloy 6061-T6 and one type of Advanced high strength steel, transformation induced plasticity (TRIP) steel have been successfully butt joined using friction stir welding (FSW) technique. Tensile tests and scanning electron microscopy (SEM) results indicate that the weld nugget can be considered as aluminium matrix composite, which is enhanced by dispersed sheared-off steel fragments encompassed by a thin inter-metallic layer or simply inter-metallic particles. Effects of process parameters on the joint microstructure evolution were analyzed based on mechanical welding force and temperature that have been measured during the welding process.

He (2014) Have done a relatively new solid-state joining technique which is widely adopted in different industry fields to join different metallic alloys that are hard to weld by conventional fusion welding. Numerical analysis of friction stir welding will allow many different welding processes to be simulated in order to understand the effects of changes in different system parameters before physical testing, which would be time-consuming or prohibitively expensive in practice. The main methods used in numerical analysis of friction stir welding are discussed and illustrated with brief case studies. In addition, several important key problems and issues remain to be addressed about the numerical analysis of friction stir welding and opportunities for further research are identified.

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