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Comparison of Process Parameters of Dissimilar Materials of Friction Stir Welding

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Abstract - Friction Stir Welding is a joining technique that necessitates material distortion. Throughout the operation, the tool will generate pressure and temperature while also forming a solid-state weld. This process is suitable for integrating materials with variable mechanical and chemical properties, as well as material architectures. In fusion welding procedures, weldability of many aluminium alloys is low. The oxide layer on the surface of aluminium alloys tends to develop at higher temperatures due to the formation of thin oxide layers. This research focuses on the fundamental idea of friction stir welding, microstructure development, influencing process factors, common FSW flaws, and contemporary applications. In addition, the lecture will go through other FSW process options, such as Friction Stir Processing.

Keywords - *Tool rotational speed, Friction Stir welding, dissimilar aluminium alloy*.

1. Introduction

The Welding Institute in the United Kingdom created FSW in December 1991. (TWI). When compared to traditional fusion welding procedures for the welding of lightweight alloys, FSW is a revolutionary solid-state welding technology that has gained international interest, particularly in the automotive and aerospace sectors. The use of lightweight materials is the most efficient way to reduce the weight of cars. The tool rotation and weld direction are comparable on one side, referred to as the Advancing Side (AS), and opposite on the other, referred to as the Retreating Side (RS).

Welding aluminium alloys using traditional fusion welding methods is a significant difficulty. Conventional fusion welding procedures are prone to welding flaws such as cracks, voids, porosity, and so on. Because of the thin oxide layer development, high thermal conductivity, high coefficient of thermal expansion, solidification shrinkage, and high solubility of hydrogen and other gases in molten state [14], which leads to concerns.

There is an increase in demand for parts made by combining dissimilar materials such as metal-to-metal, polymer-to-polymer, and metal-to-polymer, which are currently in high demand. There is a greater emphasis on metal-to-polymer welding in this section than metal-to-metal and polymer-to-polymer welding, since metal-to-polymer welding is a novel technique, as there are fewer publications in this area [15]. It is shown in Figure 1 that a schematic representation of the FSW process is shown. The shoulder is pressed against the surface of the material being welded, while the probe or pin is forced between the two components by a downward force. The rotation of the tool under this force creates frictional heat, which reduces the material's resistance to plastic deformation as a result of the frictional heat generated by the rotation of the tool.

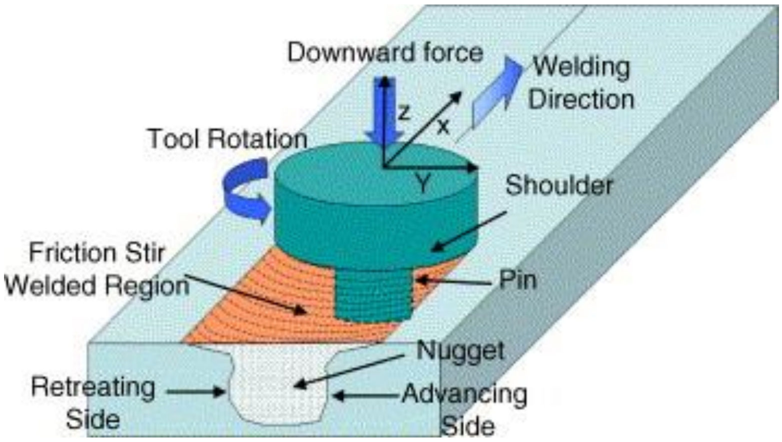

Fig 1: FSW Process [14]

2. AZ31 Mg Alloy to 6061 Al alloys:

Dissimilar friction stir welding between AZ31-O Mg and 6061-T6 Al alloys was investigated using 3 mm thick plates of aluminium and magnesium. Friction stir welding operations were performed at different rotation and travel speeds. The rotation speeds varied from 600 to 1400 r/min, and the travel speed varied from 20 to 60 mm/min. Defect-free welding was obtained with a rotation speed of 1000 r/min and a travel speed of 40 mm/min. Results of tensile tests indicate that the welded specimen has tensile strength about 76% that of Mg alloy AZ31 and 60% that of aluminum alloy 6061 [15].

3. The Influences of The Friction Stir Welding onAluminium 6063 and 7075:

The effect of friction stir welding on the hardness of aluminium 6063 and 7075 was investigated in this study. Rotational speed of 2000 rpm, welding speed of 50–200 mm/min, and tilt angle of the pin tool of 2° are the characteristics that effect welding. As a consequence, we discovered that the maximum tensile strength at welding speeds up to 100 mm/min is 105 MPa. The hardness test results revealed that the greatest measured hardness at the weld centre was 152 HV with a welding speed of 50 mm/min [6].

4. Friction Stir Welded Cast and WroughtAluminium Alloy Joint:

During the FSW process, the non consumable tool rotates to plunge and travels along the weld line to produce a high quality of joint. FSW process eliminates the fusion welding problems such as crack, porosity and solidification shrinkage. The aim of the work was to evaluate the microstructure and mechanical properties of friction stir welded AA6061 cast and wrought aluminium alloy joint. In FSW, the process parameters such as welding speed of 50 mm/min, rotational speed of 800 rpm and axial force of 8 kN was used to make the joint. Twosamples were welded by keeping one sample of wrought alloy as an advancing side and cast alloy in retreating side and another sample of weld is produced by keeping the plate alternatively on both sides. The welded samples were characterized byusing metallurgical microscopy and universal tensiletesting machine [13]. The microstructures of 6061- T6 cast Al alloy and 6061-T6 wrought Al alloy is shown in Fig. 2.

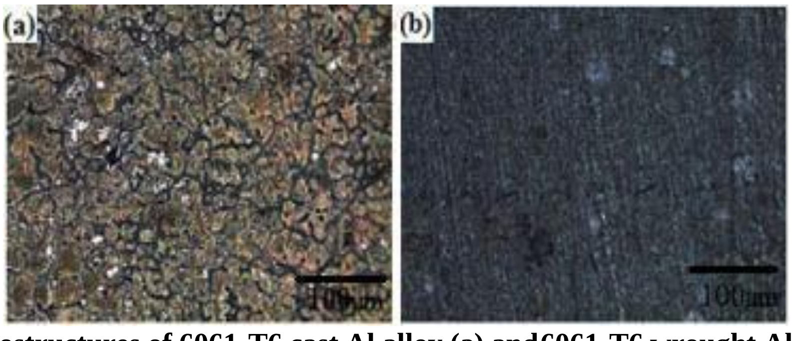

Fig 2: Microstructures of 6061-T6 cast Al alloy (a) and6061-T6 wrought Al alloy (b).

5. Effect of Heat Input on The Properties of Dissimilar Friction Stir Welds of Aluminium and Copper:

The effect of heat input on the resulting propertiesof joints between aluminium and copper produced with the friction stir welding process. The welds were produced using three different shoulder diameter tools, viz., 15, 18 and 25 mm by varying the rotational speed between 600 and 1200 rpm and the traverse speed between 50 and 300 mm/min in order to vary the heat input to the welds [10].

6 Dissimilar AluminiumAlloys (6061&7075) By Using Computerized Numerical Control Machine:

Friction stir welding, a solid state joining technique, is widely being used for joining Al alloys for aerospace, marine automotive and many other applications of commercial importance. FSW trials were carried out using a computerized numerical control machine on (Al 6061 & 7075) alloy. The tool geometry was carefully chosen and fabricated to have a nearly flat welded interface (cylindrical & taper) pin profile. Important process parameters that control the quality of the weld are a) rotation speed (1600&1250rpm) b) traverse speed (120mm/min) and c) tool tilt angle 2 and these process parameters were optimized 0 to obtain defect free welded joints. The main aim in this work was to find the mechanical properties of friction stir welding of dissimilar aluminium alloys (6061&7075) by using CNC vertical milling machine. The limitations of FSW are reduced by intensive research and development. Its cost effectiveness and ability to weld dissimilar metals makes it a commonly used welding process in recent times [16].

7. Aluminium Alloy to Steel:

Butt-joint welding of an aluminium alloy plate to a steel plate was easily and successfully achieved. The maximum tensile strength of the joint was about 86% of that of the aluminium alloy base metal. Many fragments of the steel were scattered in the aluminium alloy matrix, and fracture tended to occur along the interface between the fragment and the aluminium matrix. A small amount of intermetallic compounds was formed at the upper part of the steel/aluminium interface, while no intermetallic compounds were observed in the middle and bottom regions of the interface. A small amount of intermetallic compound was also often formed at the interface between the steel fragments and the aluminium matrix. The regions where the intermetallic compounds formed seem to be fracture paths in a joint [1].

8. AA6061 and Az61:

Friction Stir Welding Process (FSW) is a solid state welding method developed by The Welding Institute (TWI). This research work involves the friction stir welding of two dissimilar metals namely AA6061 and AZ61. The geometry of the tool inFriction Stir Welding (FSW) plays a principle role inquality of the weld. In this study several FSW tools have been considered for the fabrication of a numberof butt joints. The tool geometry names are as follows: (i) Straight threaded tool, (ii) Taper Threaded tool, (iii) Inverse tapered tool, (iv) Concave shaped fluted tool. These geometries are analyzed for the identification of sound weld throughANSYS [11].

9. Optimization of AA6061-AA7075 Dissimilar Friction Stir Welding Using the Taguchi Method:

In this study, the Taguchi method was utilized to determine the optimum process parameters for dissimilar friction stir welding between AA6061 and AA7075 aluminium alloys. The Taguchi L9 orthogonal array and optimization approach was applied on three levels of three critical factors, namely rotational speed, transverse speed and tooltilt angle. The optimum levels of process parameterswere determined through the Taguchi parametricdesign approach. Through the parameter analysis, the predicted value of the dissimilar joint's tensilestrength was calculated to be 209.7 MPa, which is inclose proximity to the experimental data (219.6MPa) with 4.5% error. It is concluded from thiswork that a high tensile value of 219.6 MPa was achieved using 1000 rpm rotational speed, 110mm/min travel speed and 3˚ tilt angle [21].

10. Dissimilar Friction Stir Welding Between 5052 Aluminium Alloy and AZ31 Magnesium Alloy:

Dissimilar friction stir welding between 5052 Al alloy and AZ31 Mg alloy with the plate thickness of 6 mm was investigated. Sound weld was obtained at rotation speed of 600 r/min and welding speed of 40 mm/min. Compared with the base materials, the microstructure of the stir zone is greatly refined.Complex flow pattern characterized by intercalation lamellae is formed in the stir zone. Micro hardness measurement of the dissimilar welds presents an uneven distribution due to the complicated microstructure of the weld, and the maximum value of micro hardness in the stir zone is twice higher than that of the base materials. The tensile fracture position locates at the advancing side (aluminium side), where the hardness distribution of weld shows a sharp decrease from the stir zone to 5052 base material [5].

11. Friction Stir Welding Parameter on Mechanical Properties in Dissimilar (AA6063- AA8011) Aluminium Alloys:

Friction stir welding (FSW) is a technique in which the work pieces were joined by means of frictional heating and plastic deformation typically at temperatures below the melting temperature of the materials to be joined. The scope of this investigation was to evaluate the effect of joining parameters on the mechanical properties of dissimilar aluminium alloys (AA6063 and AA8011 aluminium alloy) joints produced using friction stir welding. Friction stir weld was performed on the dissimilar aluminium alloys using different rotational speeds and traverse speeds and the influence of these parameters on the mechanical performance of the weld has been investigated in terms of hardness and tensile testing [20].

12. Semi-Solid Metal 356 and AA 6061- T651 :

The investigation is on effect of welding parameters on the microstructure and mechanical properties of friction stir welded butt joints of dissimilar aluminium alloy sheets between Semi- Solid Metal (SSM) 356 and AA 6061-T651 by a Computerized Numerical Control (CNC) machine. The base materials of SSM 356 and AA 6061-T651 were located on the advancing side (AS) and on the retreating side (RS), respectively. Friction Stir Welding (FSW) parameters such as tool pin profile, tool rotation speed, welding speed, and tool axial force influenced the mechanical properties of the FS welded joints significantly. For this experiment, the FS welded materials were joined under two different tool rotation speeds (1,750 and 2,000 rpm) and six welding speeds (20, 50, 80, 120, 160, and 200 mm/min), which are the two prime joining parameters in FSW. A cylindrical pin was adopted as the welding tip as its geometry had been proven to yield better weld strengths. From the investigation, the higher tool rotation speed affected the weaker material's (SSM) maximum tensilestrength less than that under the lower rotation speed. As for welding speed associated with various tool rotation speeds, an increase in the welding speed affected lesser the base material's tensile strength up to an optimum value; after which its effect increased. Tensile elongation was generally greater at greater tool rotation speed. An averaged maximum tensile strength of 197.1 MPa was derived for a welded specimen produced at the tool rotation speed of 2,000 rpm associated with the welding speed of 80 mm/min. In the weld nugget, higher hardness was observed in the stir zone and the thermo-mechanically affected zone than that in the heat affected zone. Away from the weld nugget, hardness levels increased back to the levels of the base materials. The microstructures of the welding zone in the FS welded dissimilar joint can be characterized both by the recrystallization of SSM 356 grains and AA 6061-T651 grain layers [7].

13. Aluminum Aa6061 and Aa2014 Alloy Joints:

In this study, Dissimilar Friction Stir Butt Welds made of 2014 and 6061 Aluminium alloys were performed with various welding parameter. The study involved the influence of square profile pin on friction stir welded joint. FSW parameter such as tool rotational speed, welding speed and axial force plays a significant role in the assessment of mechanical properties. Using ANOVA and signal to noise ratio, influence of FSW process parameters is evaluated and optimum welding condition for maximizing mechanical properties of the joint is determined. An Artificial Neural Network (ANN) model was developed for the analysis and simulation of the correlation between the Friction Stir Welding (FSW) parameters of aluminium (Al) plates and mechanical properties and compared the experimental values with the ANN predicted values [17].

14. Joining of Titanium and Aluminium Dissimilar Alloys:

Titanium alloy TC1 and Aluminium alloy LF6 were butt jointed and lap jointed by friction stir welding (FSW), and the influence of process parameters on formation of weld surface, cross- section morphology and strength were studied. The results show that, Titanium and Aluminiumdissimilar alloy is difficult to be butt joined by FSW, and some defects such as cracks and grooves are easy to occur. When the tool rotation rate is 950 r/min and the welding speed is 118 mm/min, the tensile strength of the butt joint is 131MPa which is the highest FSW is suitable for lap joining of TC1 Titanium alloy and LF6 Aluminium alloy dissimilar materials, an excellent surface appearance is easy to obtain, but the shear strength of the lap welding jointis not high. At the welding speed of 60 mm/min and the tool rotation rate of 1500 r/min, the lap joint has the largest shear strength of 48 MPa. At the welding speed of 150 mm/min and the tool rotation rate of 1500 r/min, crack like a groove occurs on the interface and the shear strength is zero [8].

15. Dissimilar Metal Joining of 2024 and 7075 Aluminum Alloys to Titanium Alloys by FrictionStir Welding:

The friction stir welding (FSW) process is a solid-state joining technology with a lower joining temperature than fusion welding. As a result, for dissimilar metal welding, FSW is thought to offer numerous benefits over fusion welding. The present study used friction stir welding to test the weldability of duralumin and titanium alloys. The aluminium plates utilised in this work were 2024- T3 and 7075-T651, whereas the titanium plates used were pure titanium and Ti-6Al-4V. The average tensile strength of the Ti/2024 FSW joints was 311 MPa, and the tensile strength of the Ti/2024 joint was higher than that of the Ti/7075 FSW joint when the joining circumstances were the same. At the joint interface, a mixed area of Ti alloy and Al alloy was discovered, and the joints primarily cracked at this region, where there was an intermetallic compound layer. XRD found a $TiAl_3$ intermetallic complex in this area[9].

16. Dissimilar Friction Stir Welded Joints between 2024-T3 Aluminium Alloy and AZ31 Magnesium Alloy:

Dissimilar alloys such as 2024-T3 Al alloy and AZ31 Mg alloy of plates in 3mm thickness has been friction stir butt welded. The welding was carried out at a constant rotation speed of 2500 per min and welding speeds of 200, 300, 400 and 550 mm/min. Effects of welding speeds on microstructures and hardness distributions of the joints were investigated. Distribution of phases in the stir zone (SZ) was analyzed by a scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectroscopy (EDS). Increasing welding speed brought about a redistribution of phases in SZ where the regions occupied by 2024 Al alloy concentrated in the lower portion of SZ while AZ31 Mg alloy concentrated in the upper region beneath the tool shoulder. The laminated structure was formed in the SZ near the boundary between SZ and TMAZ on the advancing side of 2024 Al alloy regardless of the welding speed. The hardness value fluctuates in the SZ due to formation of intermetallic compounds that formed by constitutional liquation during welding [3].

17. Aluminium Alloys EN AW 2024-0 and EN AW 5754-H22:

It was found in this work that the two aluminium alloys can be friction stir welded if the welding parameters are carefully selected. Hardness value in weld area for EN AW 2024-0, there is an increase about 10- 40 Hv. For EN AW 5754-H22 there is a decrease of hardness value because of recrystalization. Welding performance of EN AW2024-0 is reached to 96.6 %. This value is 57 % for EN AW 5754-H22. It is possible to performdissimilar welding using different aluminium alloys. Elding performance of dissimilar aluminium alloys EN AW 2024-0 and EN AW 5754-H22 is reached a value of 66.39%. Purpose of the author is to investigate the friction stir welding capability of the EN AW 2024-0 and ENAW 5754-H22 Al alloys are studied, because two aluminium alloys are widely used in the industry and friction stir welding is getting widened to be used to join the aluminium alloys [2].

18. Microstructure and Mechanical Properties of Friction Stir Butt Welded Dissimilar Cu/Cuzn30 Sheets:

The tensile strength of dissimilar Cu/CuZn30 joints was found to be about same and 46% lower than that of Cu parent metal (PM) and CuZn30 PM, respectively. The root and the surface bend strengths of the joints were found to be about 47% higher and 31% lower than that of Cu PM and CuZn30 PM, respectively. The average hardness at the top and bottom lines were found to be about 92 Hv0.1 and 102 Hv0.1, respectively. These hardness values are higher and lower than that of Cu PM and CuZn30 PM, respectively. Different microstructure zones were determined by optical microscopy. It was illustrated that the stirred zone (SZ) exposed to the two main structures: (1) recrystallized grains of CuZn30 and (2) intercalated swirl and vortex-like structure which can be characterized both therecrystallized brass grains and copper layers. In this study, dissimilar Cu and CuZn30 sheets was butt joined by FSW. It has been investigated microstructure properties, micro hardness, tensile and bending tests, in order to evaluate the joint performance and the weld zone characteristics ofdissimilar copper/brass (Cu/CuZn30) joints [4].

19. Evaluation of Bending Strength For Dissimilar Friction Stir Welded AA6061T651 - AA7075 T651 Aluminium Alloy Butt Joint:

Aluminium alloys have gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to weight ratio and good corrosion resistance. Modern structural concepts demand reductions in both the weight as well as the cost of the production and fabrication of materials. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process was invented in 1991 by TWI, in which the material that is being welded does not melt and recast. The major advantage in FSW process is that the maximum temperature reached is less than 80% of the melting temperature (TM), i.e. the joint is performed in the solid-state and excessive micro structural degradation of the weld zone is avoided. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces.

The welding parameters such as tool rotationalspeed, welding speed, axial force etc., and tool pin profile play a major role in deciding the joint strength. This paper focus on Bending Characteristics for friction-stir welded dissimilar precipitation hardenable aluminium alloys between 6xxx (Al-Mg-Si) and 7xxx (Al-Zn-Mg) in varying the process parameters such as rotational speed, welding speed keeping axial force and tilt angle (0º) as constant. Three different tool profiles (taper cylindrical threaded, taper square threaded and Simple Square) are used for this investigation and in that taper cylindrical threaded tool give good result in evaluating bending strength of the above dissimilar butt joints [12].

20. Investigation of Fatigue Behavior and Fractography of Dissimilar Friction Stir Welded Joints of Aluminum Alloys 7075-T6 and 5052-H34:

The fatigue behavior of friction stir welded joints for dissimilar aluminum alloys 5052-H34 and 7075-T6 was studied. Friction stir welding (FSW) has been done on 4.826mm (0.19) in thick plate by using MTS-5 axis friction stir welder. FSW were carried out under optimum welding parameters with travel speed of 187mm/min (7in/min), rotational speed of 400rpm and forge load of 9KN (2000lbf). Mechanical tests and inspection were performed to characterize the welded joints and determine it to be defect-free. Tension–tension fatigue tests had been done at a frequency of 7Hz with stress ratio R=0.1. Also topography analysis was done using scanning electron microscopy combined with energy dispersive spectroscopy. The fatigue failure has beenanalyzed [23].

21. Joining of dissimilar aluminium alloys AA2014 T651 and AA6063 T651 by friction stir welding process:

In this study, friction stir welding was used to combine two different aluminium alloys, AA2014 T651 and AA6063 T651. The weld was produced by adjusting the tilt angle (2-4), tool offset (0.5mm towards AS, centre line, and Rs), and Pin diameter (5mm – 7mm). Tensile strength and %Elongation tests were performed to determine the weld's strength. The homogeneous churning of materials was investigated using an optical microscope. The results reveal that a 4 degree tilt angle results in greater material interlocking and bonding. Tensile strength is increased when the tool is offset to the AA2014 side due to full fusing of the harder material. When it is shifted to the AA6063 side, it produces inadequate heat on the advancing side. As a result of this, leads to incomplete fusion of AA2014. Pin diameter has greatest impact on heat generation. The 6 mm pin diameter, 4 degree tilt angle and 0.5 mm offset towards advancing side give the optimum tensile strength of 371 Mpa [24].

22. Effect of Travel speed on Joint properties of Dissimilar Metal Friction Stir Welds:

The influence of traverse speed on the joint characteristics of dissimilar metal friction stir welds formed by aluminium and copper sheets was investigated. Butt joint welds were created between 5754 aluminium alloy (AA) and C11000 copper (Cu). The welds were made at a constant rotating speed of 950 rpm, with the traverse speed varying between 50 and 300 mm/min while all other parameters remained constant. Microstructural analysis of the welds demonstrated that at a fixed rotational speed and altering the traverse speed, the lowest traverse speed resulted in improved mixing of both metals and metallurgical bonding. As the welding speed rose, the average ultimate tensile strength of the welds decreased. The thermomechanical impacted zones have higher Vickers micro hardness values. TMAZ and Stir Zones (SZ) of the welds as a result of dynamic recrystallization and the presence of intermetallic compounds generated in the joint areas. Unlike identical metal welds, which displayed a smooth force feedback curve, dissimilar metal welds revealed a considerable difference in force feedback data [25]

23. Mechanical Properties of Aluminium-Copper Joints Welded by Friction Stir Welding:

This study looked at butt welding aluminium with copper using friction stir welding. The primary welding characteristics impacting welding quality discovered in this study are the tool rotation direction and the probe offset with regard to the centre of the butt line. When aluminium is positioned on the advancing side and a suitable probe is offset to the aluminium side, sound welding is accomplished. In addition, a defect-free Al-Cu welded junction is formed when the copper is positioned on the advancing side with the probe offset to the aluminium side. As a result, probe offset is more critical than rotation direction in friction stir welding Al-Cu [22].

CONCLUSIONS

Finally, a review of friction stir welding of dissimilar materials, with an emphasis on aluminium, has been performed. The latter is concerned with dissimilar aluminium alloys such as aluminium to magnesium, aluminium to steel, and aluminium to copper. Furthermore, this article evaluation revealed that great progress has been made in the FSW of heterogeneous materials. Most of the research studies referenced are primarily concerned with studying the microstructure and physical characteristics of different welds. FSW technology must be further refined before the process may be used in industry. To meet the enormous demand in industries like as manufacturing and aerospace, a thorough grasp of the disparate FSW process is required. More research is required to improve multi-scale finite element modelling approaches to include FSW process defects.

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