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Structural Analysis of Welded Joints of Dissimilar Metals Joined By Friction Stir Welding

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Butt Joints,

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Abstract

Friction Stir Welding is a solid-state welding technique, using which we can attain welds with reduced distortion and improved mechanical properties in similar as well as dissimilar metals. In this project, various properties of metals and their alloys are analysed to choose the best combination of metals that can effectively create lap and butt joints. In this study Aluminum (Al) and Magnesium (Mg) are chosen as dissimilar metals due to their wide spread applications. Using Friction Stir Welding technique lap and butt joints are made which are subjected to the following methods of structural analysis. Microstructure on optical microscope. Hardness test on Vickers hardness testing machine. Tensile and shear stress on universal testing machine.

Finally the welds are compared based on the effect of metal position, microstructure, tensile and shear stresses. The results of better welds are recommended for industrial applications like Marine, Aerospace and Automotives.

The work had been presented *at an* international conference ***Fatigue Durability India 2015****, 28-30th May 2015, JN TATA AUDITORIUM, Indian Institute of Science, Bangalore.*

Introduction

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 non-weldable, are now weldable.

In friction stir welding process, the parts are subjected to relative motion under pressure so that the frictional heat developed at the interface between faying surfaces, is utilized to join similar or dissimilar metals. Such bonds are permanent, having strength approaching that of the base metals used. All thermoplastic materials can be friction welded including crystalline and amorphous material, with no additional weight. This process is easily controllable, repeatable, reliable, and is a simple machine tool technology which is having similar benefits like other solid phase welding processes. Heat affected zone is less and hence post weld treatment is not normally required to relieve internal stresses. The deposit obtained has excellent metallurgical bond with forged microstructure. The deposit is free from porosity, slag inclusions or dilutions which are generally experienced in traditional fusion welding processes. The process itself is environmentally clean, with no fumes, spatter or high intensity light emissions as in laser-based coating methods, hence it also termed as green manufacturing technology. This process can be performed in open air, with inert gas or under water. It is also energy efficient because the heat is generated and used exactly where it is needed. Bond strength is very good and these deposits are expected to serve better during service life.

Friction stir welding was invented by The Welding Institute (TWI) in December 1991. TWI filed successfully for patents in Europe, the U.S., Japan, and Australia. TWI then established TWI Group-Sponsored Project 5651,"Development of the New Friction Stir Technique for Welding Aluminum," in 1992 to further study this technique.

The development project was conducted in three phases. Phase I proved FSW to be a realistic and practical welding technique, while at the same time addressing the welding of 6000 series aluminum alloys. Phase II successfully examined the welding of aerospace and ship aluminum alloys, 2000 and 5000 series, respectively. Process parameter tolerances, metallurgical characteristics, and mechanical properties for these materials were established. Phase III developed pertinent data for further industrialization of FSW.

Fabricators wants 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.

Working Principle

The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line. Figure 1 illustrates process definitions for the tool and work piece. Most definitions are self-explanatory, but advancing and retreating side definitions require a brief explanation. Advancing and retreating side orientations require knowledge of the tool rotation and travel directions. In Fig.1, the FSW tool rotates in the counter clockwise direction and travels into the page (or left to right) the advancing side is on the right, where the tool rotation direction is the same as the tool travel direction (opposite the direction of metal flow), and

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the retreating side is on the left, where the tool rotation is opposite the tool travel direction (parallel to the direction of metal flow).

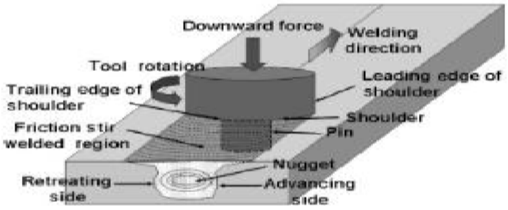


Figure 1: The basic concept of FSW

The tool serves three primary functions, that is, heating of the work piece, movement of material to produce the joint, and containment of the hot metal beneath the tool shoulder. Heating is created within the work piece both by friction between the rotating tool pin and shoulder and by severe plastic deformation of the work piece. The localized heating softens material around the pin and, combined with the tool rotation and translation, leads to movement of material from the front to the back of the pin, thus filling the hole in the tool wake as the tool moves forward. The tool shoulder restricts metal flow to a level equivalent to the shoulder position, that is, approximately to the initial work piece top surface.

As a result of the tool action and influence on the work piece, when performed properly, a solid-state joint is produced, that is, no melting. Because of various geometrical features on the tool, material movement around the pin can be complex, with gradients in strain, temperature, and strain rate. Accordingly, the resulting nugget zone microstructure reflects these different thermo-mechanical histories and is not homogeneous.. In spite of the local micro structural inhomogeneity1, one of the significant benefits of this solid- state welding technique is the fully re-crystallized, equiaxed, fine grain microstructure created in the nugget by the intense plastic deformation at elevated temperature. The fine grain microstructure produces excellent mechanical properties, fatigue properties, enhanced formability, and exceptional super plasticity.

Li and Shen[1] Successfully conducted lap joints of dissimilar AA6063 to AA5052 aluminum alloys using a tool designed from quench hardening W9Mo3Cr4V with some geometric improvements. Furthermore, they placed the two overlap plates of AA5052 on the retreating side which improved the joint integrity of the weld. They found that all the dissimilar welds produced under the welding conditions investigated were stronger than the Al-B4C MMC base materials and demonstrated 100% joint efficiencies.

Palanivel et al[2] examined the influence of tool rotational speed and pin profile on the microstructure and tensile strength of the dissimilar friction stir welded aluminum alloys AA5083-H111 and AA6351-T6. The welds fabricated using straight tool profiles had no defects while the tapered tool profiles caused a tunnel defect at the bottom of the joints under the experimental considered conditions. Furthermore, three different regions namely unmixed region, mechanically mixed region and mixed flow region were observed in the weld zone.

Hatamleh and DeWald [3] joined AA 2195 and AA 7075and investigated the peening effect on the residual stresses of the produced welds. Results showed that the surface residual stresses resulting from shot peening on both AA 2195 and AA7075 were higher compared to the laser peening due to the high amount of cold work exhibited on the surface from shot peening. Furthermore, high values of tensile stresses were noticed in the mid-thickness on the laser peened samples.

Malarvizhi and Balasubramanian[4] investigated the influences of tool shoulder diameter to pale thickness ratio on stir zone formation and tensile properties of FS welded AA6061 and AZ31B. It was found that the joints produced using a shoulder diameter of 21 mm(3.5 times the plate thickness) exhibited superior tensile properties compared to its counterparts.

Venkateswaran and Reynolds[5] performed FSW on AA 6063-T5 and AZ31B-H24 and analyzed the factors affecting the resulting weld properties. The nugget grain size on both the Al and Mg sides monotonically increased as the tool rotational speed increases.

Experimental

Two base metals of Aluminum-AA5083 and Magnesium-AZ31B of dimensions 100x75x4mm are used. The H13 non consumable mechtrode is used to perform the friction stir processing. A Tool rotational speed of 560 rpm and horizontal feed 25mm/min were employed.

Lap Weld: Figure 2. For this type of joint both the joints are held tight & plates are placed one over other. The rotating tool at a constant rotational and translation velocity with sufficient downward force is moved across the work piece. The tool used for lap joints has much longer pin then that is used for a butt joint since it has to penetrate both the sheets for proper stirring action.

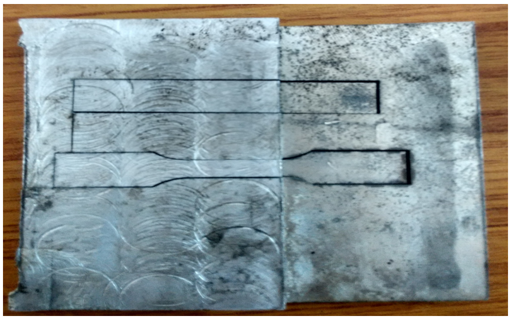


Figure 2: Lap Welding

Butt Joint: Figure 3. For this type of joint both the joints are held tight with the adjoining edges against each other. The rotating tool at a constant rotational and translation velocity with sufficient downward force is moved across the work piece.

The butt joint is formed with the same specifications of milling machine as of the lap joint; here butt joint is formed instead of lap. The tool is fed on the adjoining plates with the help of milling machine.

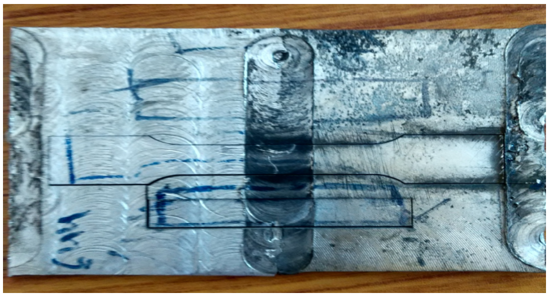


Figure 3: Butt Joint

Wire cutting of welded joints for test specimens:

Electrical discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the "tool" or "electrode", while the other is called the work piece-electrode, or "work piece".

Micro structure of the welded joints:

Microstructure (Fig. 4 and Fig. 5) examination was carried out using optical microscope on top surface of the samples of base metal, layer deposited by friction stir processing and layers modified by friction stirring process. The samples were polished on emery papers and disc cloth to remove the very fine scratches by etching using acetic glycol (19 mL water, 60 mL ethylene glycol, 20 mL acetic acid, 1 mL HNO3) for magnesium alloys and Keller's reagent for aluminum alloys. Regardless of the material in which a friction stir weld is performed, the resulting microstructure has three distinct zones that result from the welding process. The area of all three of these zones comprises what is commonly referred to as the Weld Affected Zone (WAZ). The first constituent of the WAZ is the Dynamically Recrystallized Zone (DXZ), also known as the weld nugget, which lies at the center of the weld along the weld seam. This zone is bordered on either side by the remaining two constituent zones, the Thermo Mechanically Affected Zone (TMAZ) immediately surrounding the DXZ, and the Heat Affected Zone (HAZ) surrounding the outside edges of the TMAZ. The microstructures were recorded with Image Analyzer attached to the metallurgical microscope.

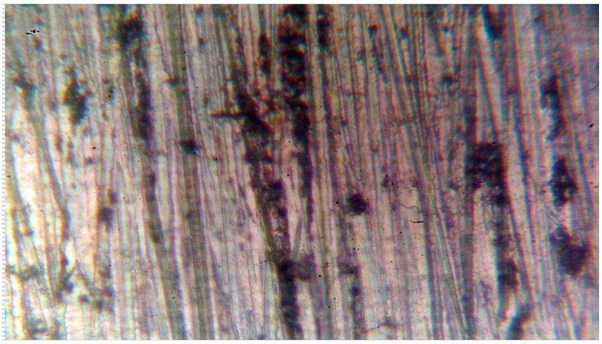


Figure 4: Lap Joint Micro structure

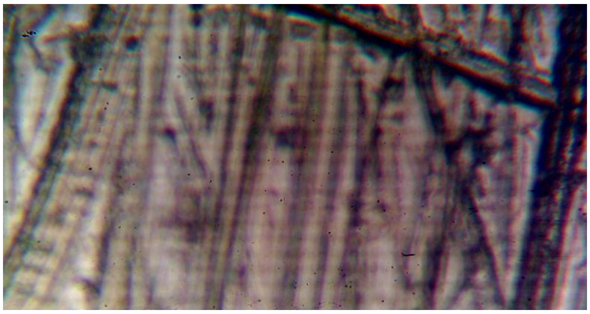
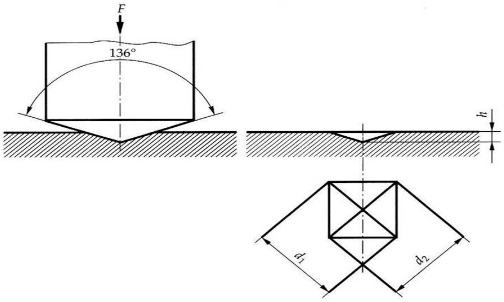


Figure 5: Butt Joint Micro structure

Vickers hardness test:

The Vickers hardness test method (Fig. 6**),** also referred to as a micro hardness test method, is mostly used for small parts, thin sections, or case depth work. The Vickers method is based on an optical measurement system. The Micro hardness test procedure, ASTM E-384, specifies a range of light loads using a diamond indenter to make an indentation which is measured and converted to a hardness value. It is very useful for testing on a wide type of materials as long as test samples are carefully prepared. A square base pyramid shaped diamond is used for testing in the Vickers scale. Typically loads are very light, ranging from a few grams to one or several kilograms, although "Macro" Vickers loads can range up to 30 kg or more. The Micro hardness methods are used to test on metals, ceramics, and composites - almost any type of material.



Key:

F = Test force, in N

d_1 and d_2 = Length of the diagonals of the indentation, in mm

h = Depth of the indentation, in mm

Figure 6: The Vickers hardness test method

Lap Joint:

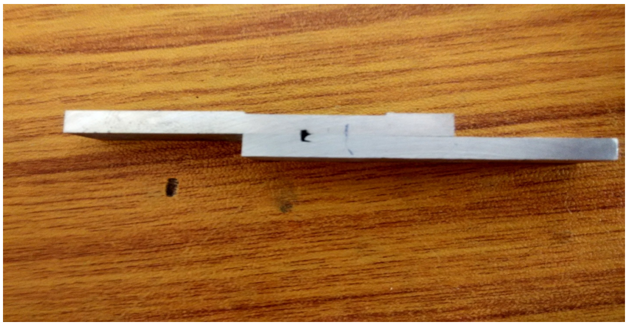
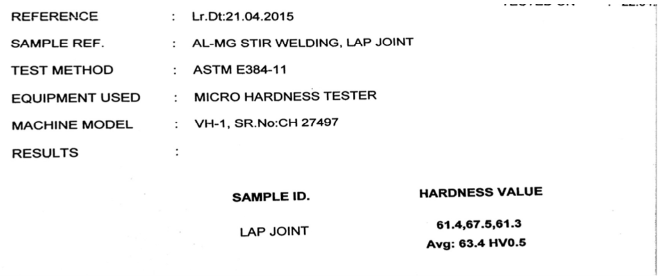


Figure 7: Lap joint

Hardness of the Lap Joint:



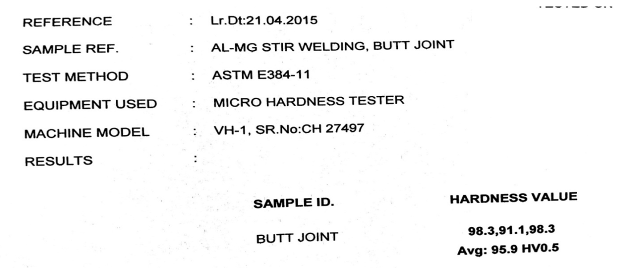
REFERENCE : Lr.Dt:21.04.2015
SAMPLE REF. : AL-MG STIR WELDING, LAP JOINT
TEST METHOD : ASTM E384-11
EQUIPMENT USED : MICRO HARDNESS TESTER
MACHINE MODEL : VH-1, SR.No:CH 27497
RESULTS :

SAMPLE ID.	HARDNESS VALUE
LAP JOINT	61.4,67.5,61.3 Avg: 63.4 HV0.5

Butt Joint:

Figure 8: Butt joint

Hardness of the Butt Joint:



REFERENCE : Lr.Dt:21.04.2015
SAMPLE REF. : AL-MG STIR WELDING, BUTT JOINT
TEST METHOD : ASTM E384-11
EQUIPMENT USED : MICRO HARDNESS TESTER
MACHINE MODEL : VH-1, SR.No:CH 27497
RESULTS :

SAMPLE ID.	HARDNESS VALUE
BUTT JOINT	98.3,91.1,98.3 Avg: 95.9 HV0.5

Tensile test on UTM:

Lap Joint

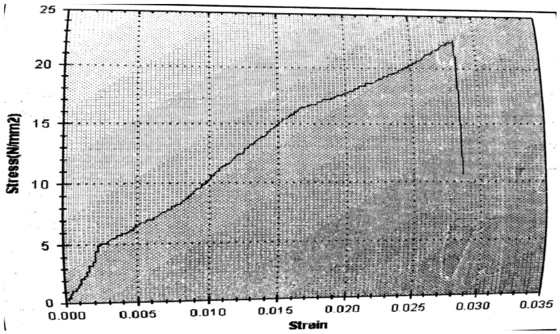
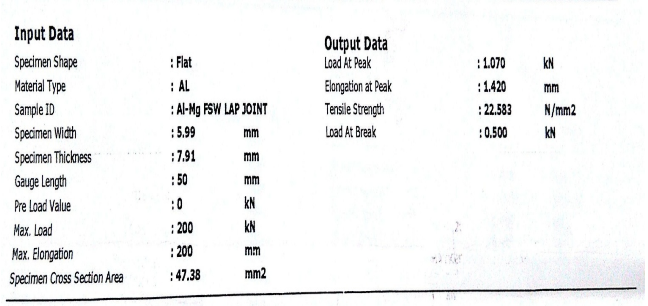


Figure 9: Tensile test for Lap joint



Input Data

Specimen Shape : Flat
Material Type : AL
Sample ID : Al-Mg FSW LAP JOINT
Specimen Width : 5.99 mm
Specimen Thickness : 7.91 mm
Gauge Length : 50 mm
Pre Load Value : 0 kN
Max. Load : 200 kN
Max. Elongation : 200 mm
Specimen Cross Section Area : 47.38 mm2

Output Data

Load At Peak : 1.070 kN
Elongation at Peak : 1.420 mm
Tensile Strength : 22.583 N/mm2
Load At Break : 0.500 kN

Butt Joint:

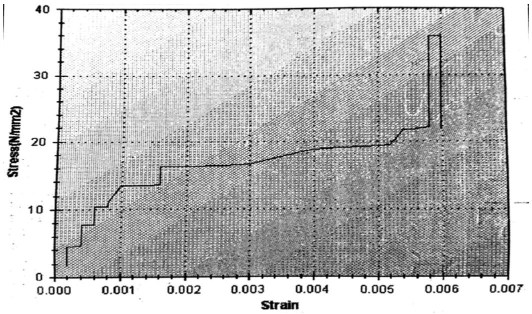
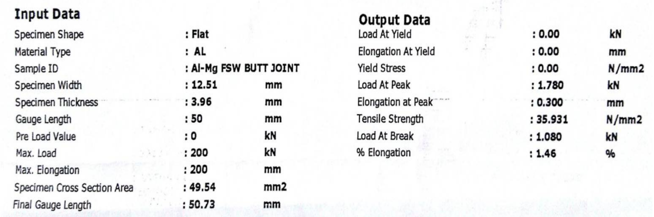


Figure 10: Tensile test for Butt joint



Input Data

Specimen Shape : Flat
Material Type : AL
Sample ID : Al-Mg FSW BUTT JOINT
Specimen Width : 12.51 mm
Specimen Thickness : 3.96 mm
Gauge Length : 50 mm
Pre Load Value : 0 kN
Max. Load : 200 kN
Max. Elongation : 200 mm
Specimen Cross Section Area : 49.54 mm2
Final Gauge Length : 50.73 mm

Output Data

Load At Yield : 0.00 kN
Elongation At Yield : 0.00 mm
Yield Stress : 0.00 N/mm2
Load At Peak : 1.780 kN
Elongation at Peak : 0.300 mm
Tensile Strength : 35.931 N/mm2
Load At Break : 1.080 kN
% Elongation : 1.46 %

Conclusions

Defect-free weld between AZ31 Mg and 5083 Al alloy was obtained using friction stir welding with a rotation speed of 560 rpm and travel speed of 25 mm/min. Grain refinement occurred in the stir zone due to dynamic recrystallization. Tensile strength of the welded specimen was about 76% of that of AZ31 Mg alloy and 60% of that of 5083 Al alloy. The mechanical properties of base metals AA5083 (Aluminum alloy) and AZ31B (Magnesium alloy) are modified with friction stir processing by using H13 tool steel as mechtrode.

Friction stir processing is ecologically desirable; closer to the clean machining methods and it will become assuming in the future. The dissimilar FSW joint between AA5083 aluminum alloy and AZ31B magnesium alloy was able to join and the joint efficiency was achieved to 61%.

References

1. Li and Shen, Friction Stir Welding Dissimilar materials: An Overview, International Journal of Mechanical, Industrial Science and Engineering. Vol:7, No:4,2013.
2. Palanivel at el, Mechanical and Metallurgical properties of dissimilar friction welded AA5083-H111 and AA6351-T6. Science Direct, Trans. Nonferrous Met. Soc. Chaina 24(2014). 58-65.
3. Hatamleh & DeWald, An investigation of peening effects on stresses in friction stir welded 2195 and 7075 Al alloys. Journal of Material Processing Technology,Vol:209, Issue 10,1June 2009. 4822-4829.
4. S.Malarvizhi, V.Balasubramaninan, Influence of shoulder diameter to plate thickness ratio of friction stir welded dissimilar joints of AA6061-AZ31B alloys, Elsevier, Materials & Design, Vol:40, Sept 2012.453-460.
5. P. Venkateswaran, A.P.Reynolds, Factors affecting properties of friction stir welds between aluminium and magnesium alloys, Material Science and Engineering 05/2012; 545.26-37.
6. LIU C, CHEN D L, BHOLE S, CAO X, JAHAZI M. Polishing-assisted galvanic corrosion in the dissimilar friction stir welded joint of AZ31 magnesium alloy to 2024 aluminum alloy [J]. Materials Characterization, 2009, 60: 370−376.
7. LEE W B, YEON Y M, JUNE S B. The mechanical properties related to the dominant microstructure in the weld zone of dissimilar formed Al joints by friction stir welding [J]. Materials Science, 2003, 38: 4183−4191.
8. W.M. Thomas, E.D. Nicholas, J.C. Needam, M.G.Murch, P. Templesmith, C.J. Dawes. GB Patent.