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Research Article

Mechanical and Microstructure properties analysis of Friction Stir Welded Similar and Dissimilar Mg alloy joints

Akshansh Mishra[#*], Anish Das Gupta[^], Abhishek Kumar Sharma[!], Gopikrishna Nidigonda[$]

[#,^]Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattangulathur, India
[!]Department of Mechanical Engineering, Inderprastha College of Engineering, Ghaziabad, India
[$]Department of Mechanical Engineering, SR Engineering College, Warangal, India

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Abstract

Friction Stir Welding is used already in routine, as well as critical applications, for the joining of structural components made of aluminium and its alloys. Indeed, it has been convincingly demonstrated that the process results in strong and ductile joints, sometimes in systems which have proved difficult using conventional welding techniques. The aim of this study was to evaluate microstructures, tensile strength and Hardness of welded specimen of Magnesium-Magnesium (Mg/Mg) similar joints and Magnesium-Aluminium (Mg/Al) dissimilar joints.

Keywords: *Friction Stir Welding; Similar joints; Dissimilar joints; Material flow*

1. Introduction

Friction stir welding is the joining process that is being used in various industries as it is as solid state joining process. Effect of the Friction Stir Welding parameter such as rotational speed, change in material of the tool, tool profile on microstructure and strength of the welded joint. Magnesium alloy is raw material used in various industries due to light weight, good thermal conductivity and high strength. Aluminium alloy has found its uses in various departments such as transport, building and architecture, packaging machined components, road barriers and sign. The aluminium alloy has the density which 1/3 of steel hence is lightest metal commercially available, corrosion resistance is also there due to the availability of Al_2O_3 and excellent thermal and electrical conductivity.

In FSW a cylindrical shouldered tool with a profiled pin is rotated and plunged into the joint area between two plates. For proper welding the plates must be clamped during the process with the help of jig and fixture. Friction Stir welding is a solid state joining process and the heat generated during the rotation of the tool will cause the materials to get joined without reaching melting point. The plasticized material is transferred to the trailing edge of the tool pin, is forged with the tool shoulder and pin. Koilraj *et al.,* (2012) in their work, optimization of process parameters of friction stir welding of dissimilar aluminium alloys (copper, aluminium and magnesium alloys)using Taguchi technique (Taguchi L16 orthogonal design of experiments), considered parameters rotational speed, traverse speed, tool geometry and ratio between tool and shoulder diameter and pin diameter for optimization to investigate tensile strength of the joint. The results were analyzed with the help of analysis of variance (ANOVA) and concluded that optimum levels of tool rotational speed is 700 rpm , traverse speed is 15mm/min , ratio between tool shoulder diameter and pin diameter is 3, pin tool profile is cylindrical threaded and finally friction stir welding produces satisfactory butt welds. Yahya Bozkurt et al., (2012) has done work on optimization of friction stir welding process parameters to achieve maximum tensile strength in the polyethylene slab. Three process parameters, tool rotational speeds, tool traverse speed, and tilt angle of the tool were identified for optimization. The material taken for study is high density polyethylene sheet which is a thermoplastic to determine welding process parameters on ultimate tensile strength of the weld for good joint efficiency. The optimization technique applied is Taguchi's L9 orthogonal array, signal to noise ratio and ANOVA. The results depicted are tool rotational speed of 3000rpm contributes 73.85% to the overall welding parameters for the weld strength and the tool tilt angle has least contribution. Elatharasan et al., (2013) in their research study, experimental analysis of process parameters of friction stir welding and its optimization. They identified different process parameters like tool rotational speed, welding speed and axial force that have significant role in deciding joint characteristics on

*Corresponding author's ORCID ID: 0000-0003-4939-359X
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an aluminium alloy. They have adopted Response Surface Methodology (RSM) and ANOVA for the optimization of process parameters. The outcomes of the experimentation are ultimate tensile strength, yield strength increased with increase in tool rotational speed, welding speed and tool axial force. The percentage of total elongation increased with increase in rotational speeds and axial force but decreased when there is increase in welding speed continuously. The results documented as maximum tensile strength is 197.50MPa, yield strength is 175.25MPa, percentage of total elongation is 6.96 was exhibited by the friction stir welding joints fabricated with optimized parameters of 1199 rpm rotational speed, 30mm/min welding speed and 9 KN axial force.

The aim of the project is to study the influence of FSW parameter on microstructure and mechanical properties of similar joint Magnesium AZ91 to Magnesium AZ91 and dissimilar joint of Magnesium AZ91 to Aluminium Al 1100 alloy. The present work focused on the weldability and reliability of friction stir welding but joint from the metallurgical point of view.

2. Experimental Procedures

The materials used in this case studies were AZ91 and Al 1100 alloy plates of dimensions 150 mm X 75 mm X 6mm. The compositions of the both materials are shown in Table 1 and Table 2. FSW was performed with the H13 tool steel in the butt configuration. Shape and dimensions of the H13 tool steel is shown in the Fig. 1. The travel speed and rotational speed were 40 mm/min and 1000 rpm for joining of similar AZ91 alloy plates. While for joining of dissimilar alloy plates of AZ91 and Al 1100, travel speed and rotational speed were 40 mm/min and 1200 rpm.

The methodology for carrying out the experiment is shown in the Fig. 2. Welding Tool design is critical in FSW processes Optimizing tool geometry will produce more heat there by breaking the oxide layer, higher welding speeds etc. Tool material should possess high hardness at elevated temperatures and should maintain that hardness till the end of the process.

Weld quality and tool wear are two important considerations in the selection of tool material, the properties of which may affect the weld quality by influencing heat generation and dissipation. The weld microstructure may also be affected as a result of interaction with eroded tool material. H13 tool steel is usually used for FSW .The shape of the pin design depends on the material thickness, ability to break the oxide layer formation, heat generation etc. A no profiled tool is capable of producing enough heat.

FSW of the similar and dissimilar alloy plates was mainly performed on retrofitted vertical milling machine. For this welding operation a fixture is needed on which the plates which are to be butt welded is to be bolted. In this case study first fixture is designed using CATIA software keeping certain things in view like groove of fixture to be such that it accommodates both back plate and metal plate to be welded, then development of fixture is done using CATIA drawing. Apart from this a number of clamps is also manufactured for holding the plates firmly and subsequently a key is also manufactured for the purpose of fixing and balancing of plates to be welded. As far as the fixture design is concerned, it is always regarded as the first problem to be overcome due to the high temperatures reached during the process; under such extreme conditions, the welded blanks are likely to remain stuck to the back plate compromising both the soundness of the joint and the integrity of the fixture itself distortion in shape.

Table 1: Chemical composition (weight %) of AZ91 Magnesium alloy

Composition	Mg	Al	Zn	Mn	Si	Cu	Fe	Ni
Weight %	88.7	8.3	0.35	0.15	0.1	0.03	0.005	0.002

Table 2: Chemical composition (weight %) of Al 1100 alloy

Composition	Al	Si + Fe	Cu	Mn	Zn	Other Metals
Weight %	99.00	0.95	0.05	0.05	0.10	0.05

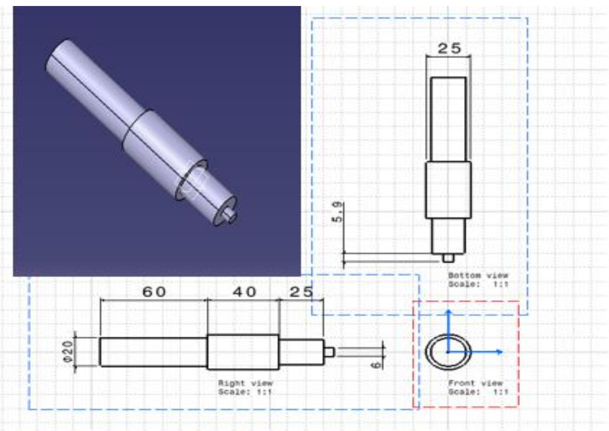

Figure 1: Cylindrical tool design and dimensions

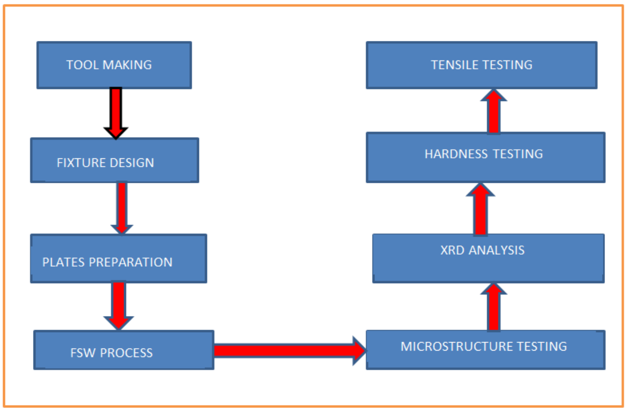

Figure 2: Methodology for Friction Stir Welding Process

3. Results and discussions

3.1 Microstructure Analysis

Microstructure 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 aluminium 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 as shown in the Fig. 3 and Fig. 4 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 centre 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 Analyser attached to the metallurgical microscope.

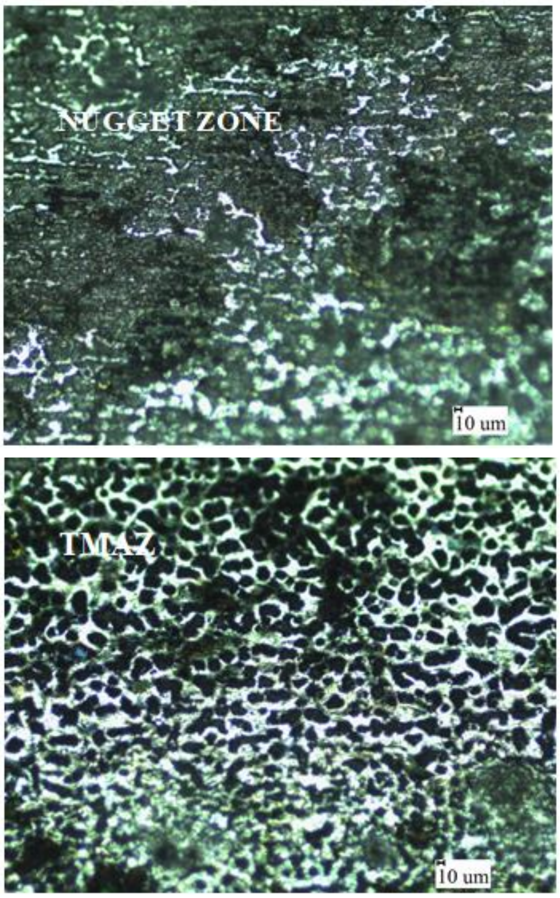

Figure 3: Microstructure of similar joints of Mg – Mg alloy . a) Nugget zone b) TMAZ

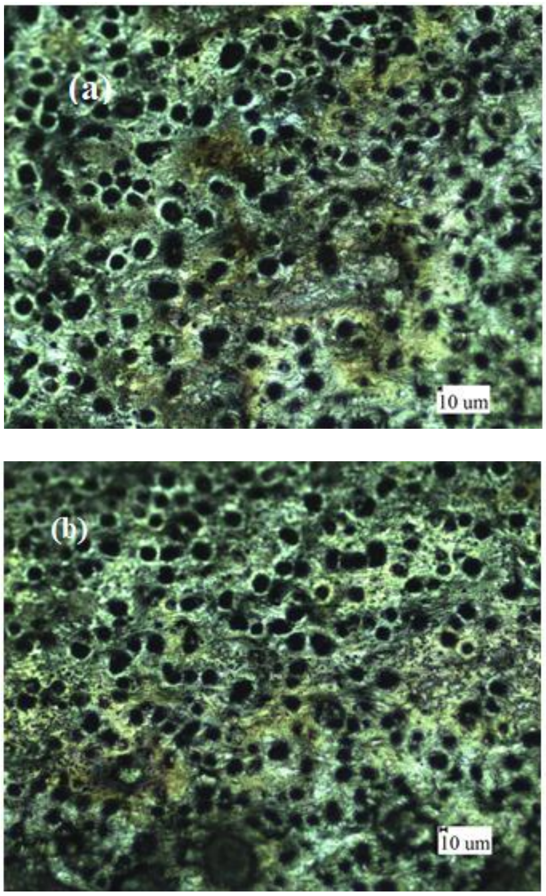

Figure 4: Microstructure of dissimilar Mg – Al alloys. a) Nugget Zone; b) TMAZ; c) HAZ

3.2 XRD Analysis

X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies in geology, environmental science, material science, engineering and biology. The sample prepared for XRD testing is shown in the Fig. 5.

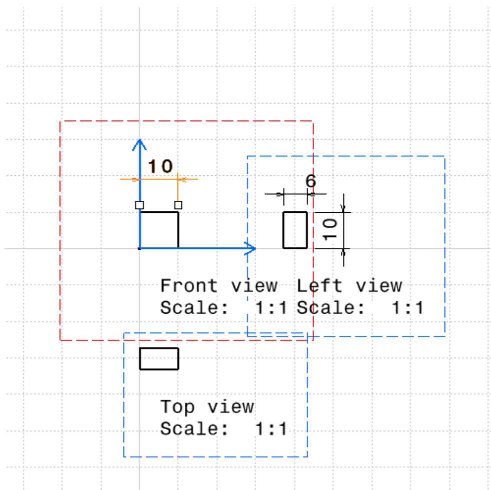

Figure 5: XRD specimen dimensions

The XRD spectrum of the powder obtained in the irregular shaped region is indicated in Fig. 6. Large peaks of intermetallic compound $Al_{12}Mg_{17}$ are detected, though this figure contains some peaks obtained from matrices of Al and Mg alloys which were mixed into the powder of the second phases. The XRD spectrum con- firms that the irregular shaped region of the dissimilar weld contains a large volume of the intermetallic com- pound $Al_{12}Mg_{17}$.

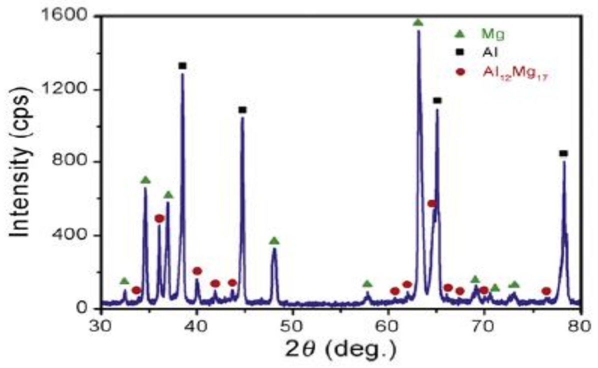

Figure 6: XRD analysis of dissimilar Mg – Al FSW joints

3.3 Tensile Testing

The machine used was UTM (ultimate tensile test). The specimen was setup in the manner shown below in the diagram. Universal testing machine (UTM), also known as a Universal tester is used to test the tensile strength and compressive strength of materials. The "universal" part of the name reflects that it can perform many standard tensile and compression tests on materials, components, and structures.

Firstly, the tensile test was conducted on the similar joints of Mg - Mg specimen. As shown from the graph, shown in Fig.7 and the test results which is tabulated in the Table 3 it is seen that the joint is rather a poor one. It has tensile strength of just 5.4 N/mm2. Irregular variation is seen in the joints at the initial stages. This is due to the fact that the joint has not been welded properly and breaks easily. The red point here depicts the end of elastic point and the blue point shows the max tensile strength that is available with the the joint. Further using a Vernier Calliper we saw that the length of the final piece was reduced.

Table 3: Tensile Test of Similar Mg – Mg joints

Input Data			Output Data		
Specimen Shape	: Flat		Load At Yield	: 0.66	kN
SpecimenType	: wELDED		Elongation At Yield	: 1.130	mm
Specimen Description	: MAG AZ91+MAG AZ 91		Yield Stress	: 4.261	N/mm2
Specimen Width	: 25.39	mm	Load at Peak	: 0.840	kN
Specimen Thickness	: 6.1	mm	Elongation at Peak	: 1.330	mm
Initial G.L. For % elong	: 80	mm	Tensile Strength	: 5.424	N/mm2
Pre Load Value	: 0	kN	Load At Break	: 0.010	kN
Max. Load	: 200	kN	Elongation At Break	: 2.370	mm
Max. Elongation	: 200	mm	Breaking Strength	: 0.065	N/mm2
Specimen Cross Section Area	: 154.88	mm2	% Reduction Area	: 2.17	%
Final Specimen Width	: 25.21	mm	% Elongation	: - - -	%
Final Specimen Thickness	: 6.01	mm			
Final Gauge Length	: 80	mm			
Final Area	: 151.51	mm2			

Table 4: Tensile test for dissimilar joints

Input Data			Output Data		
Specimen Shape	: Flat		Load At Yield	: 7.8	kN
SpecimenType	: wELDED		Elongation At Yield	: 3.370	mm
Specimen Description	: MAG AZ91+AL 1100		Yield Stress	: 49.793	N/mm2
Specimen Width	: 25.68	mm	Load at Peak	: 9.880	kN
Specimen Thickness	: 6.1	mm	Elongation at Peak	: 3.730	mm
Initial G.L. For % elong	: 100	mm	Tensile Strength	: 63.071	N/mm2
Pre Load Value	: 0	kN	Load At Break	: 0.120	kN
Max. Load	: 200	kN	Elongation At Break	: 4.090	mm
Max. Elongation	: 200	mm	Breaking Strength	: 0.766	N/mm2
Specimen Cross Section Area	: 156.65	mm2	% Reduction Area	: 1.71	%
Final Specimen Width	: 25.62	mm	% Elongation	: 0.50	%
Final Specimen Thickness	: 6.01	mm			
Final Gauge Length	: 100.5	mm			
Final Area	: 153.98	mm2			

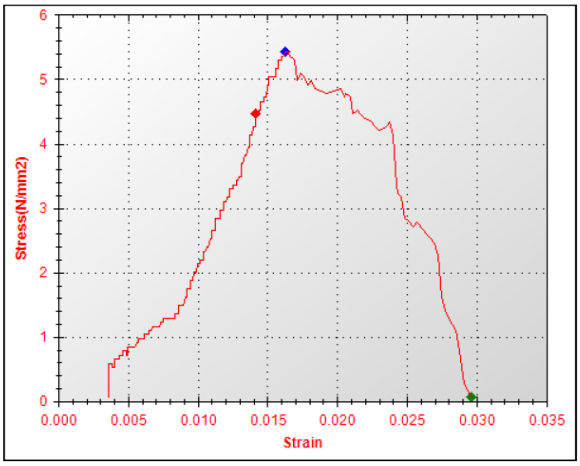

Figure 7: Stress strain curve for similar joints

Secondly, the tensile test was conducted on the dissimilar joint of Mg – Al alloy. The crack sounds were heard as soon as the UTM machine started and this lead to breakage in the welded portion . As seen in the outcome of the test from the Table 4, we can infer that the strength of the joint was approximately 50% of that of the base metal. The initial portion of the curve which is shown in Fig. 8 shows that the specimen was not clamped properly and this led to graph being shifted towards the X axis. Then it is seen that this is regular variation in the Stress Strain curve this is due to that the fact the test has now begun. This corresponds with the Hookes Law which states that stress is directly proportional to strain till the elastic limit which is seen at 50 N/mm^2. Further it is seen that the ultimate strength is at 63 N/mm^2.

Also it is observed that the downwards slope is due to the fact the joint is now broken and there was a delay in the shut down of the test. Thus it is seen that joint was a good one.

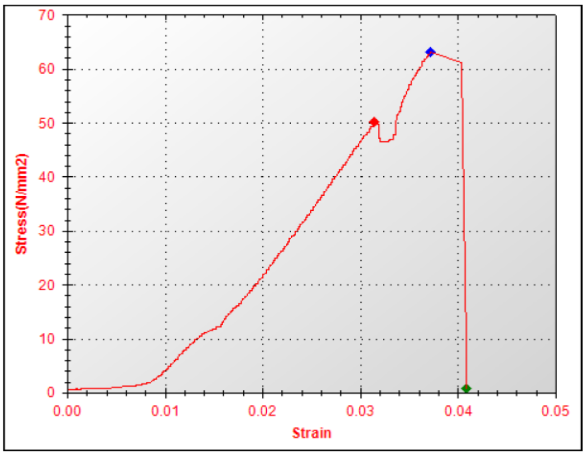

Figure 8: Stress strain curve for dissimilar joints

3.4 Hardness Testing

The Vickers hardness test method 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. The modelling of the specimen with the given dimensions for Vickers hardness is shown in the Fig. 9. The prepared specimen for the Vickers hardness is shown in the Fig. 10.

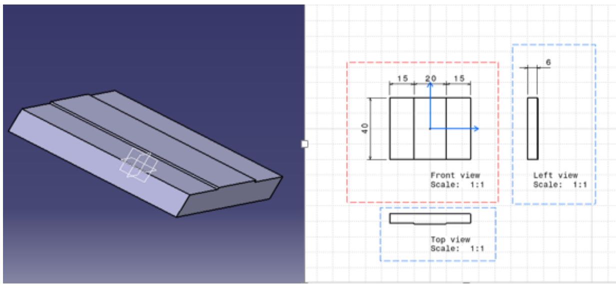

Figure 9: Modelling of Hardness test specimen with dimensions

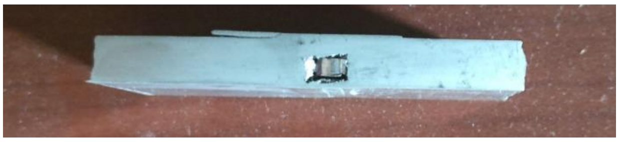

Figure 10: Hardness test specimen

Table 5: Vickers Hardness test for dissimilar joints

S. No	Weight (Gram)	Zone of hardness	Hardness value (HV)
1.	200	Nugget Zone	41.62
2.	200	TMAZ	40.58
3.	200	Without heat zone (Mg side)	45.92
4.	200	Without heat zone (Mg side)	44.81
5.	200	Without heat zone (AL side)	35.55
6.	200	Without heat zone (AL side)	30.10

Table 6: Vickers hardness for similar joints

S.No	Weight (Gram)	Zone of Hardness	Hardness Value (HV)
1.	200	Nugget zone	42.53
2.	200	TMAZ	41.72
3.	200	Without heat zone (Left side)	47.22
4.	200	Without heat zone (Left side)	45.41
5.	200	Without heat zone (Right side)	47.87
6.	200	Without heat zone (Right side)	46.46

Conclusions

Dissimilar welding of aluminium (Al) and magnesium (Mg) alloys would achieve weight reduction and high efficiency of production by a substitution of Mg alloys for Al alloys. However, fusion welding of Al and Mg alloys always produces coarse grains and large brittle intermetallic compounds in the weld metal. This situation suggests that fusion welding of Al and Mg alloys cannot be practically used.

Our study has established that the use of Friction Stir Welding at varied revolution and also using different material to find out the optimum parameters that are used to produce a good FSW joint. The Friction Stir Weld has no gaseous releases as compared to other welds and should be used more often than the types of weld .The welding is also safe as compared to the others.

The results are in agreement with previous studies which used conventional methods and thus our methodology being economical and accessible looks extremely promising for any future development.

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