A REVIEW ON FRICTION STIR WELDING OF ALUMINIUM ALLOYS: MECHANICAL PROPERTIES AND METALLURGICAL OBSERVATIONS

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ABSTRACT

This review presents the detailed description about the Friction stir spot welding of aluminium alloys and their mechanical properties and metallurgical observations. Experimental work are discussed and effect of some parameters such as tensile strength, shear strength, sheets thickness, temperature and temperature distribution in the welding. In this analysis of welding sheet thickness, material selection, methodology are discussed in detail. For the welding of two low cast iron metal sheets we chosen A6061. Sheets contains low carbon % and having high ductility and
weldable properties. The welding of workpiece is done upon the CNC machine and the temperature distribution phenomenon is measured with thermocouple. The resulting welded piece is consist two type of failure, weld nugget failure and shear strength failure. We consists three parameters, first we take round pin tool and we take rectangular shape pin tool and 3rd we take triangular shape pin tool. With this result it creates different types of weld joint and their microstructure are also different and their strength also alters. In this we do no of experiments for calculating the different strength and their microstructure and try to improve their weldability in the different segment.

**Key words:** Shear Strength, Research Methodology, Thermocouple, Weld Nugget Failure.


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**1. INTRODUCTION**

Welding is the phenomenon of joining of two objects with a significant manner. Friction stir welding was firstly come in use in 1991 by the UK based institute as solid state joining process. This technique was firstly taken in use on aluminium alloys. The concept of welding in this process is very much easier than other welding process. In this process of welding a non-consumable tool which consists of pin and shoulder was taken into action. This rod consists of pin and shoulder which was particularly used for welding the sheets. This tool is moving along clockwise of counter clockwise direction into the sheets as we required. This type of operation is very much similar to the friction stir processing. In this process the tools and the design of the phenomenon are very much similar to the friction stir process tools. But if we talking about the processing then it is quite similar to the friction stir welding phenomenon. Sometime it may happened that the little bit separation occur in the configuration and processing of welding is applied in the study but most of the time we conclude the similar type of cases in this FSW. Few drawbacks are also appear in this welding techniques. Like shear failure and nugget failure, Most of the cases the impression of the welding spot or place totally melted so this types of failure facing during the welding. The shear factor is also very much implemented in this type of phenomenon. The aluminum alloy is also getting failure in this test because the ductility also matter, and this material consists high ductility point. The revolution of the tool and the feed and speed also varies the fracture phenomenon and also very much inhomogeneous character show in this FSW process. Further we talking about the microstructural changes and mechanical properties also vary due to this factor. But the phenomenon doesn’t affect entirely. Spot friction stir welding comes in operation in the decade of 2003. The first who applied this process under the operation is “Mazda motor Industry”. That time there are a lot of motor industries use the aluminium sheets for cars and vans because of its reliability and their strength but the problem is occur during welding of the parts, so they implemented the new techniques as FSSW. Aluminium consists of low melting point and the high ductility and strength properties so they broadly use this. With this implementation of FSSW there are terrific change happen in welding industries, they found that this type of welding is more suitable that the other welding process because the joining of two aluminium sheets is very much impressive and easier with this
process. So now days the researchers are wildly done their studies on this process and try to reduce their failures which generates during welding. These days the aluminium sheets are also welded with steels sheets but the nugget failure also happens.\textsuperscript{1} Choi \textit{et al.}\textsuperscript{2} Tells about the FSSW tool wear problems in this study they using WC-CO alloy tool and after that analysis about the welding phenomenon and their characteristics and their joint strength. in this study the steel plates welded by the FSSW process. all the characteristics and phenomenon are analyzed and measure on the different measurement system like 3D measuring system. It produces that the tool will getting shear failure and the shape of welded area will getting damaged a bit. Malafaia \textit{et al.} (2010)\textsuperscript{3} Discovers that the comparison of two type of joining process, one is welded with FSSW process and other with the riveted joint process of AA2024 alloy. Both experiment carrying under the some expertise like temperature, load, etc. and also determine the parameter of the tensile strength and shear strength. After the completion of process they find that the phenomenon of riveted joint was very much feasible than FSSW process but some circumstances are also in favor of FSSW process. In riveted joint the specimen geometry are not affected by the joining phenomenon but the tool and specimen geometry are also affected by FSSW process due to stress contraction.

Hyung-Seop Shin and Yoon-Chul Jung (2010)\textsuperscript{4} was proposed that the phenomenon of Zr-based BMG sheets was welded under the FSSW process and after that studied about the total temperature generated during the welding process. They also studied about the behavior change with the specimen and tool geometry is changed. With this study they found that the structural and behavioral changes happen when the properties and tensile and shear test applied on welded joint. Yoshihiko Uematsu \textit{et al.} (2010)\textsuperscript{5} were stated that the two different types of specimen were welded with FSSW process and categorized their properties along this. In this study they took A6061 and low carbon steel sheets, which thickness not more than 2 mm and after that using similar material and secondly using different material. After that analysis of tensile and shear strength was considered. They analyzed that the dissimilar weld was higher strength than similar one. The shear failure also occurred in the sheets. J. Jeon \textit{et al.} (2011)\textsuperscript{6} was studied about the crystal structure of the welded work piece of aluminium sheets alloys, and also studied about the shear deformation regarding this. In this study the microstructure shown that the single crystal structure was breaks into simple grain polycrystalline aggregate. W. Yuan \textit{et al.} (2011)\textsuperscript{7} was studied that the FSSW of AL alloy 6061 sheets was evaluated under some condition if they change the tool geometry and shoulder pin geometry also, if they also varies the load and plunge depth then what the phenomenon will change, they also studied about if the tool rotation will reduced then what will be the effect on the welding parts. Due to this experiment the weld joint reflects different properties like interfacial separation, nugget fracture, top sheet fracture etc. Mustafa Kemal Bilici and Ahmet Irfan Yukler (2012) \textsuperscript{8} were studied about the welding of thermoplastic material with FSSW process. In this they just use the polyethylene sheets. and applying the different static load and parameter for welding they also studied that if they increasing the strength then welding parameter was also very specious for confederation after that applying lap shear test on that, which result that two failure were observed, first one is cross nugget and second one is pull nugget failure.

Chi-Sung JEON \textit{et al.} (2012)\textsuperscript{9} was investigated that the joining of dissimilar alloy like aluminum 6061–H32 AND 6061-T6 are uses also fabricated the properties and material mixing properties of FSSW. The mechanical and microstructural properties were investigated by the micro hardness measurement of the joints. The experimental result will be shown on the micro hardness distribution. Y.C. Chen \textit{et al.} (2013)\textsuperscript{10} was studied about the FSSW process in 1 mm thickness aluminum sheets and compare that is that process is feasible or not
A Review on Friction Stir Welding of aluminium Alloys: Mechanical Properties and Metallurgical Observations

with this FSSW process. In this process they use tool which doesn’t consists of probe in the tool, which results that there is no hole or dent creates in the weld area. With this study main aim is to investigate the post weld techniques in FSSW process. In this process they used AA611-T4 automatic alloy were used. After that use paint back on the workpiece, due to this the material behaviour become harder than parent material and no hardness were garaged during the paint back treatment after the application of welding. Dashatan et al. (2013)\(^\text{[11]}\) Stated about the checking feasibility of two dissimilar polymeric material. In this study they just weld the work pieces by FSSW process for two dissimilar polymers. The two polymers are used. In this study they used equipped improved tool for this investigation after that they make lap welded joints. Further they studied about the mechanical properties. tool speed, dwell time also varying from different parameters. with the result of this study the welded specimen by FSSW is feasible and the strength were also much better. The fracture also appeared in this welding process. Zhikang Shen et al. (2013)\(^\text{[12]}\) were studied about the parameters like revolving speed which effects on properties of 6061-T4 aluminium sheet. It results that the microstructure and other mechanical properties were altered with processing parameter. This will also affects the tool geometry and parameters of the welding process. The HAZ also signifies the properties of the welded parameter. The tensile and shear strength also increasing, in this study the revolving speed also play a very important role in the increasing of strength. There are two types of failure also described in this study first one is shear failure and nugget failure. Gianluca Buffa et al. (2014)\(^\text{[13]}\) Studied about the AA6082-T6 aluminium alloy which are welded through the FSSW process. The lap joints come under different condition and circumstances. This study also consists of temperature distribution along the HAZ area with the help of thermocouples. The microstructural behaviour and their properties also studied in this experiment. They also highlighted the local strength area of the welded parts. This studies the geometry and shear failure also occurs. H.M. Rao et al. (2014)\(^\text{[14]}\) Studied about material contains the rare earth containing ZEK100 magnesium alloy sheets which are joined with FSSW process. In this study we create under some condition like shear lap strength and various tool geometry tool rotation and shoulder plunge depth etc. the result of this study was also differ because variation take place. If the rpm increases from 1500 rpm to 2000 rpm it will show the failure but if the thickness will increases the failure will decreases. Y.F. Sun et al. (2014)\(^\text{[15]}\) studied that the high frequency heating FSSW was applied to S12 C low carbon steel plates which have thickness of 1.6 mm. with the load of 2500 kg, the rotation speed also varies however, the preheating also applied in this study therefore the strength can be significantly raising. With the process of welding the shear strength also increases with preheating. D’Urso (2015)\(^\text{[16]}\) was studied about that how temperature distribution affects the welding parameters in FSSW process. In this study they select the AA6060-T6 aluminium alloys plate which was weld about lap formation. There was 5 thermocouple inserted in the sample after joining process. A number of set of experiments were carried out in this process with different parameters. After that they simulate it on ANSYS and give the result about the temperature variation. After that they just check their shear properties of the welded material. With the help of FEM simulation was finally the result were validated. E. Fereiduni et al. (2015)\(^\text{[17]}\) was investigated about the effect of rotation speed dwell time and microstructure and tensile strength of FSSW process upon the AL-5083 aluminium alloy steel plates. The rotational speed not more than 900 and 1100 rpm were applied. And the dwell time not more than 5s to 15 s. the temperature distribution were also recorded with the thermocouple during the joining process. The EDS were also used for the optical measurement and reading. Sometimes SEM also used. The layer thickness of sheets should not more the 2 mm in this case.
Hsieh et al. (2015)\textsuperscript{[18]} was tells about the FSSW process on the low carbon steel SS400 plate with separate thickness. And tool using in this FSSW process was assembly-embedded rod (AER) and force applied on 8 KN, and rpm using 1200 and the dwell time is 100 s. when they using the thickness of plate less than 3 mm then it will causing failure but the load also matters in this. MUBIAYI and AKINLABI (2016)\textsuperscript{[19]} this weld was generated by different rotation speed. The tool geometry plunger and shoulder pin also varying in this section. With the presence of CU in this process it gives more strength to the weld joints because the CU moves up on the surface of aluminium plate and joints become much stronger. The microstructure will also show that the intermetallic properties of the aluminium to CU. the tensile strength also varies with the variation of shoulder pin length and shoulder plunge depth. In this process failure occurs. A nugget pull-out failure also occurs in FSSW process and shear failure also arriving in this type of techniques.

![Figure 1 FSSW OF AL6060 sheets under butt weld](image)

2. MATERIALS AND METHODS

In this application of the joining two sheets there are a lot of authors who used low carbon steel, aluminium alloys and lot more. Few authors uses two dissimilar types of alloys like pure copper (C11000) and pure aluminium (AA1060) sheets with different thickness. AA6060-T6 aluminum alloy sheets and low carbon steel (SS400) plate pair with different thicknesses plates will also be summarized for the testing. Further in 2015&2016 author also give preferences to the two different mixing of aluminium sheets. Some of them also prefer to do research work on polymer sheets with different thickness. But if we significantly prefer the most suitable and approachable material then the 6061 aluminium alloy are most admirable for new research work. The few authors use lap joint and few use sandwiched type joints, and the thickness of each plates which was used to weld is varying between 2 mm to 5 mm. all the welding are come under the FSSW process.

2.1. Types of FSSW joints:

A no of papers uses lap joints and sandwiched type joints of two or more than two material with different thickness. In the few authors they uses butt joint also but the phenomenon of testing of mechanical properties getting failure in most of the cases due to less thickness(less than 3 mm). So the butt joint is the preferable and newer for the research at more than 5mm thickness sheet.
2.2. Tool geometry and treatments:
In this review a no of research paper consist the H-13 steel tool which is the combination of steel and carbide. Each one consists of pin and shoulder .every tool have their own restrictions like ID and OD .it is different in every case due to dissimilar sheets thickness. Most of the author’s uses pre hardened tool and some of them uses simpler tool.

![Figure 2 Tool of FSSW](image)

2.3. The Material of FSSW Sheets:
Authors basically uses low carbon steels, aluminium alloys like 6060, 6061 .some of them uses other material like al-mg and copper- aluminium. So there will be lot of opportunity to weld some significant materials which have good industrial approaches. So in the new research work if AL6061 aluminium alloys sheets uses then the results will be more significant.

2.4. Testing Of Specimens:

2.4.1. Tensile testing:
The tensile testing has been carried out by using Universal Testing Machine. In some papers they also use different methods to measure the strength of welded sheets like impact testing with Rockwell hardness testing machine.

<table>
<thead>
<tr>
<th></th>
<th>Vickers hardness (HV20KG)</th>
<th>Yield strength(Mpa)</th>
<th>Tensile strength(Mpa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-5083 H321</td>
<td>75.7</td>
<td>264</td>
<td>322</td>
<td>7</td>
</tr>
<tr>
<td>St-12 O</td>
<td>73.5</td>
<td>193</td>
<td>284</td>
<td>48</td>
</tr>
</tbody>
</table>

Table 1.Mechanical properties of Al-5083 H321 alloy and St-12 sheets

2.4.2. Shear testing
The shear testing will also be carried out for this sample because the failure which occurs most is mechanical failure.
2.4.3. Metallurgical observations:
The micro-structures of the specimens have been tested by the following devices: optical microscope, scanning electron microscope, X-ray diffraction and EDS (Energy-dispersive X-ray spectroscopy).

Table 2: The chemical composition (in wt. - %) of the AL-5083 H321 AL alloy and St-12 sheets used in the present work.[20]

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Si</th>
<th>Mn</th>
<th>Mg</th>
<th>Al</th>
</tr>
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<tbody>
<tr>
<td>AL-5083 H321</td>
<td>0.2</td>
<td>0.49</td>
<td>0.47</td>
<td>4.45</td>
<td>Bal.</td>
</tr>
<tr>
<td>St-12 O</td>
<td>C</td>
<td>Mn</td>
<td>Si</td>
<td>P,S</td>
<td>Fe</td>
</tr>
<tr>
<td></td>
<td>&lt;0.1</td>
<td>0.5</td>
<td>0.04</td>
<td>&lt;0.05</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

Figure 3 Lap joint of AL6061 under FSSW process

3. RESULTS AND DISCUSSION

3.1. Effect of surface treatment:
Due to surface treatment of the tool material it increases its strength and prevents the depositing on the surface of material. In previous work many tool just deposited at the weld surface due to high friction heat generation so we apply quenching and annealing both segment as surface treatment.

3.2. Effect of feed & speed:
With the speed and feed increasing and decreasing it will affect the surface finishing and the weld quality also so we use atleast 10 different rpms and different feed per revolution for the same to justify the actual phenomenon. Because a lot of researchers uses Taguchi methods for the justifications of the fees and speed parameters so we also mentioned the Taguchi parameter.
A Review on Friction Stir Welding of aluminium Alloys: Mechanical Properties and Metallurgical Observations

Figure 4 Microstructure of the aluminium grades(a) AM60B, (b) and (c) AA6022-T4 in various cross-sectional views (ND: normal direction; RD: rolling direction; TD: transvers direction).

4. CONCLUSION
Friction stir spot welding of aluminum grades is now a very popular process which are uses in now days. It is used in fabrication industry and aerospace industry widely. In above discussion of FSSW processes there were a lot of experiments done on the different and dissimilar alloys and materials. The mechanical properties and their mechanical strength some of the papers also describes their microstructure observations and their metallic properties. The huge amount of experiments carried out in FSSW processes which give different results and conclusions regarding this. The phenomenon of doing the same in this is just an improvisation in the FSSW processes. Fusion welding and FSSW are both similar segment but the properties are different and their way of operation is also different. So we concluded that the FSSW of aluminum alloys and different types of fibers and materials are widely uses and the application is now spread throughout the world. It’s easier and no consumable process it is free from any type of pollutions and noise.

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A Review on Friction Stir Welding of aluminium Alloys: Mechanical Properties and Metallurgical Observations


