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STRENGTH ANALYSIS ON FRICTION STIR WELDING JOINT OF ALUMINIUM ALLOY AA8011 GRADE

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Friction Stir Welding is a solid-state process, which means that the objects are joined before reaching the melting point and is a newly developed welding technique utilized to weld lightweight alloys, such as aluminum alloys. Low heat generation in friction welding causes poor joint due to a minimum speed of rotation, welding strength on aluminum alloy has been always challenging using conventional techniques. Welding strength can be obtaining maximum to control friction stir welding parameters like rotational speed, welding speed, and welding medium. In this research, friction stir welding of aluminum alloy 8011 & welding this with its similar plate having a cross section of 100 x 50 x 10 mm thick. The present work shows that similar materials have the highest effect on the mechanical properties of the specimens taken from the welded zone. They were tested for mechanical properties such as tensile strength and Charpy Test respectively. In this experiment using the selected control parameters are Temperature, holding time and cooling medium. The three control parameters each are two levels has been designing the experiment based on full factorial method. These results show that Charpy impact test and tensile stress increased with increase the parameter level. The optimum process parameters for the maximum tensile strength and Charpy impact joints were compared and discussed the effects.

1. INTRODUCTION

The joining of aluminum alloy materials has been an important issue for several fabrication departments. In general, various problems have been found in old-fashioned fusion welding (FW) with regard to welding of different alloys of aluminum. Welding discontinuities such as cracks, voids, porosity, and inclusions during FW considerably affect the quality and mechanical properties of the welds. Friction stir welding (FSW) is a solid-state welding process that gained much attention in research areas as well as the manufacturing industry since its introduction in 1991. For almost 20 years; FSW has been used in high technology applications such as aerospace to automotive till high precision application such as micro welding. Friction stir welding (FSW) is a solid–state, hot–shear joining process in which a rotating tool with a shoulder and terminating in a threaded pin moves along the butting surfaces of 2 rigidly clamped plates placed on a supporting plate. For the materials that are difficult to weld by fusion welding (Conventional Fusion Welding) a friction stir welding has been used effectively the industry production of vehicles and vessels. Instead in FSW, the metal is heated to forging temperature, making it soft. This has many benefits, the biggest ones being low residual stress from the heat and the ability to weld different materials having low weldability. Stir casting is one of the best methods which is widely used worldwide for preparing particle reinforced aluminum matrix composites (PR-ALMC's) in order to produce the complex shapes simply and at a low cost. The friction stir welding is the new developed innovative techniques to produce the dissimilar welding of aluminum alloys which are in industries. Due to different chemical, mechanical and thermal properties of materials, dissimilar materials joining present more challenging problems than similar materials joining by friction stir welding (FSW).

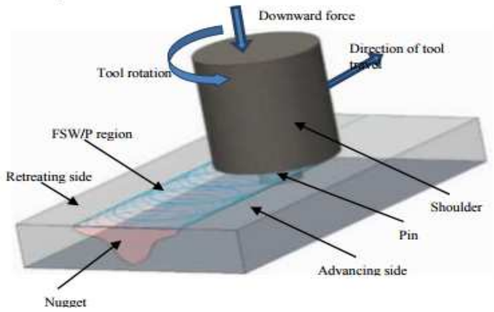

Fig 1 Schematic Drawing of friction stir Welding

A high thermal and electrical conductivity cause problems in fusion and resistance welding of aluminum alloys. Friction stir welding (FSW) is a solid state welding process and is considered the most significant development in metal joining techniques in the last decades, it was invented by The Welding Institute (TWI) of UK as a solid-state joining technique, and it was initially applied to aluminum alloys. Aluminum is the most prominent candidate to meet the challenges for future automotive regarding high strength/weight ratio, corrosion resistance, emissions, safety, and sustainability. However, the extended application of this welding process in the industry still requires accurate knowledge of the joining mechanism, and the metallurgical and mechanical transformations it induces in the base materials. Actually, the effectiveness of the obtained joint is strongly dependent on several operating parameters. First of all, the geometric parameters of the tool, such as the height and the shape of the pin and the shoulder surface of the head, have a great influence on both the metal flow and the heat generation due to friction forces. Secondly, both the rotating speed and the feed rate have to be selected in order to improve "nugget integrity" that results in a proper microstructure and eventually in good strength, fatigue resistance and ductility of the joint.

2. OBJECTIVE OF WORK

The main objective of present work is to predict the rotation of FSW tool with better response i.e. tensile strength and Charpy test of friction stir welded 8011-grade aluminum alloy. The butt-welded samples, in particular, were included for comparison purposes with the Self Reacting samples. With this information, it should be able to provide input parameter to help reduce the likelihood of failures caused by this phenomenon and predict strong weld in terms of strength and toughness. The objectives which are going to perform in this thesis are:

1. Select the parameters for stir welding to join aluminum alloy of similar grade.
2. Design the experiment according to the parameters and their level selected.
3. Perform friction stir weld on two similar grade aluminum alloys as per the generation of the design of the experiment.
4. Measure the strength and roughness via tensile test and Charpy test of the weld joint.

3. MATERIAL AND METHOD

Friction Stir Welding tools consist of a shoulder and a probe which can be integral with the shoulder or as a separate insert possibly of a different material. The design of the shoulder and of the probe is very important for the quality of the weld. The probe of the tool generates the heat and stirs the material being welded but the shoulder also plays an important part by providing additional frictional treatment as well as preventing the plasticized material from escaping from the weld region. The plasticized material is extruded from the leading to the trailing side of the tool but is trapped by the shoulder which moves along the weld to produce a smooth surface finish. Figure 2 shows the Friction Stir Welding tool.

Fig 2 FSW tool

The welding tool forms the heart of the friction stir welding process. The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. Tool shoulder was designed to produce heat to the surface and subsurface religion of the workpiece. Also, the shoulder produces the downward forging action necessary for weld consolidation. The pin was designed to disrupt the contacting surface of the workpiece, sheer material in front of the tool, and move material behind the tool. Tool pin length is determined by the workpiece thickness (4 mm for the present study) and the desired clearance between the end of the pin and backing plate. Pin diameter needs to be a large enough to not fracture due to transverse load but small enough to allow consolidation of workpiece material behind the tool before the material cools. Figure 3 shows tool pin geometry and tool dimensions.

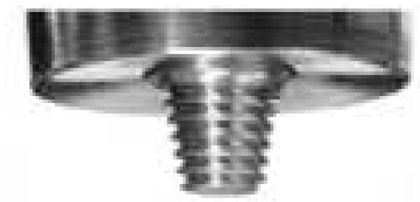

Fig 3 Friction Stir welding tool pin geometry and dimensions

In these cases, the information that was provided was used to give approximate values or present a general example to illustrate the ideas. Approximate welding parameters for self-reacting welds is presented as well as an example of a left-hand right-hand self-reacting tool which is similar in the preparation of the samples.

Chemical Composition

The following table 1 shows the chemical composition of aluminum /aluminum 8011 alloys.

Table 1 Chemical Composition

Element	Content (%)
Aluminum, Al	97.3 - 98.9
Iron, Fe	0.60 – 1
Silicon, Si	0.50 - 0.90
Manganese, Mn	$\leq$ 0.20
Zinc, Zn	$\leq$ 0.10
Copper, Cu	$\leq$ 0.10
Titanium, Ti	$\leq$ 0.080
Chromium, Cr	$\leq$ 0.050
Magnesium, Mg	$\leq$ 0.050
Remainder (each)	$\leq$ 0.050
Remainder (total)	$\leq$ 0.15

Physical Properties

The physical properties of aluminum/aluminum 8011 alloys are outlined in the following table 2.

Table 2 Physical Properties

Properties	Metric	Imperial
Density	2.71 g/cm^3	0.0979 lb/in^3

TENSILE TEST

Tensile test specimens were machined from both the rolling and transverse directions of the base metal, and in the transverse direction for the weldments. Moreover, an extensometer is used to find the elastic strain during the tensile test. The tensile tests are done on the fabricated welds according to the standards given by the ASTM (American Society for Testing of Materials), the beginning and the end of with holes are sheared and not used for the test purposes.

IMPACT TEST ON WELDED JOINT

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition and for the Charpy test, the specimen is prepared as per ASTM E23.

4. DESIGN OF EXPERIMENT

DOE is a systematic approach to the investigation of a system or process. A series of structured tests are designed in which planned changes are made to the input variables of a processor system. The effects of these changes on a pre-defined output are then assessed. DOE is important as a formal way of maximizing information gained while minimizing resources required. It has more to offer than 'one change at a time' experimental methods, because it allows a judgment on the significance to the output of input variables acting alone, as well input variables acting in combination with one another. DOE is team oriented and a variety of backgrounds (e.g. design, manufacturing, statistics etc.) should be involved when identifying factors and levels and developing the matrix as this is the most skilled part. Moreover, as this tool is used to answer specific questions, the team should have a clear understanding of the difference between control and noise factors. It is very important to get the most information from each experiment performed.

Table 3 Design of Experiment

NO. OF EXPERIMENT	TEMPE RAPTURE (IN °C)	HOLDING TIME (IN MINUTE)	COOLING MEDIUM
1	200	20	AIR
2	200	20	WATER
3	250	20	AIR
4	250	20	WATER
5	200	30	AIR
6	200	30	WATER
7	250	30	AIR
8	250	30	WATER

5. EXPERIMENTAL SETUP

Initially prepare the machine for friction stir welding of aluminum alloy of grade 8011. For this experiment, it converts the vertical milling machine into the friction stir welding machine with some setup. In this work total 16 aluminum (8011 grade) plate having cross-section 100 X 50 X 10 mm. In which we are using only 16 plates.

1. Now two plates are heated in an oven at 200°C for 20 minutes holding time. The heated plates are cooled in air. After cooling the plates are welded using friction stir welding machine having constant welding speed.
2. Further 2 plates are heated in an oven at 200°C for 20 minutes holding time. The heated plates are cooled in water. After cooling the plates are welded using friction stir welding machine having constant welding speed for better strength.
3. Now two plates are heated in an oven at 250°C for 20 minutes holding time. The heated plates are cooled in air. After cooling the plates are welded using friction stir welding machine having

constant welding speed for better strength.

4. Further 2 plates are heated in an oven at 250°C for 20 minutes holding time. The heated plates are cooled in water. After cooling the plates are welded using friction stir welding machine having constant welding speed for better strength.
5. Now two plates are heated in an oven at 200°C for 30 minutes holding time. The heated plates are cooled in air. After cooling the plates are welded using friction stir welding machine having constant welding speed for better strength.
6. Further 2 plates are heated in an oven at 200°C for 30 minutes holding time. The heated plates are cooled in water. After cooling the plates are welded using friction stir welding machine having constant welding speed for better strength.
7. Now two plates are heated in an oven at 250°C for 30 minutes holding time. The heated plates are cooled in air. After cooling the plates are welded using friction stir welding machine having constant welding speed for better strength.
8. Further 2 plates are heated in an oven at 250°C for 30 minutes holding time. The heated plates are cooled in water. After cooling the plates are welded using friction stir welding machine having constant welding speed for better strength.

6. RESPONSES

The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was followed to fabricate the joints. Non-consumable tools, made of high carbon steel were used to fabricate the joints. Joint obtained was of average quality because it has more penetration of tool at friction stir process zone. Also, the weld root on the other side was not properly filled with metal. All weld joints were prepared as per the design matrix and test specimens from these joints were prepared for tensile testing & Charpy testing.

The tensile test has been carried out in Universal Testing Machine (UTM). The specimen is loaded as per the standard. The specimen finally fails after necking and the ultimate tensile strength. Yield stress and percentage of elongation have been evaluated.

Fig 4 Tensile test of a specimen

The impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. The CHARPY IMPACT TEST of welded joints is shown in figure 5

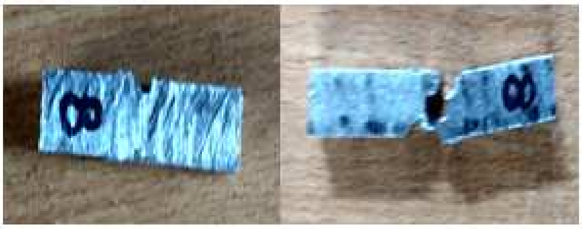

Fig 5 Charpy test of a specimen

Eight tensile and Charpy test specimens were fabricated as per the American Society for Testing of Materials (ASTM E8) and ASTM E23 standards to evaluate the tensile strength of the joints. The tensile strength of the FSW joints was evaluated by conducting a test on the universal testing machine and Charpy test results are presented in Table 4.

Table 4 Responses of Test

S. NO.	TEMP (In ^{O}C)	HOLDING TIME (In a min.)	COOLING MEDIUM	Tensile MPa	Charpy Joule
1	200	20	AIR	37	16
2	200	20	WATER	41	19
3	250	20	AIR	39	17
4	250	20	WATER	44	21
5	200	30	AIR	42	17
6	200	30	WATER	47	22
7	250	30	AIR	42	19
8	250	30	WATER	48	24

7. COMPARISON

As seen in all comparison graph increasing the parameter strength will also increase. From fig 6 it will show the comparison between the tensile test response for water and air cooling parameters. In this graph, it is clear that the level of parameters increase will increase the strength factor also.

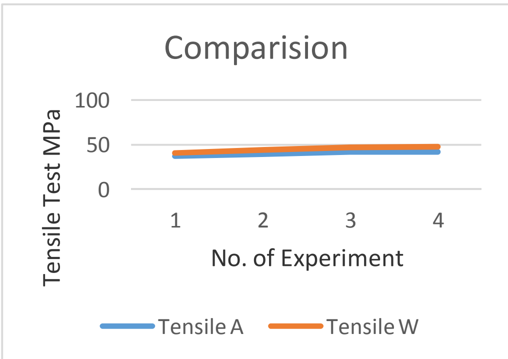

Fig 6 Comparison of tensile test Between Water and air cool

In fig 7 it will show the Charpy test response for the water and air cool. Redline shows the Charpy test for the water and also blue line shows the Charpy test response for the air.

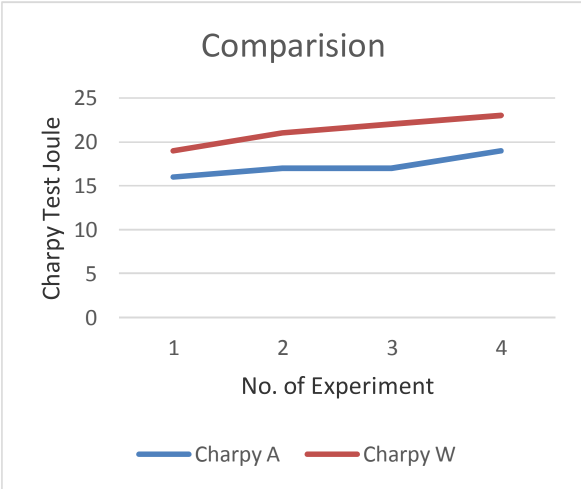

Fig 7 Comparison of Charpy test Between Water and air cool

Now prepare the graph of a comparison of temperatures for the Charpy test response. Which is shown on fig 8. The graph is first increasing and then decrease then again increase which is due to another parameter effect, but overall welding strength is depending upon the hardness of the material.

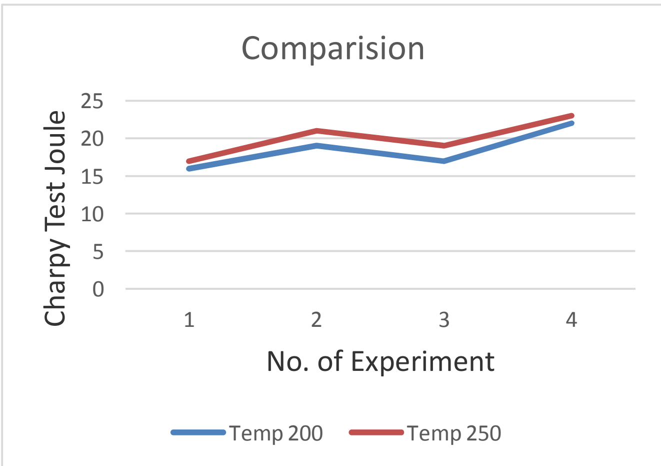

Fig 8 Comparison of Charpy test Between temperatures

The hardness of material increases the friction temperature in between tool and workpiece which allow flowing the material of workpiece for good welding strength. Fig 9 is shown the comparison of the tensile test between temperatures wherein the third experiment almost both temperature applied on specimen gives approximately equal strength.

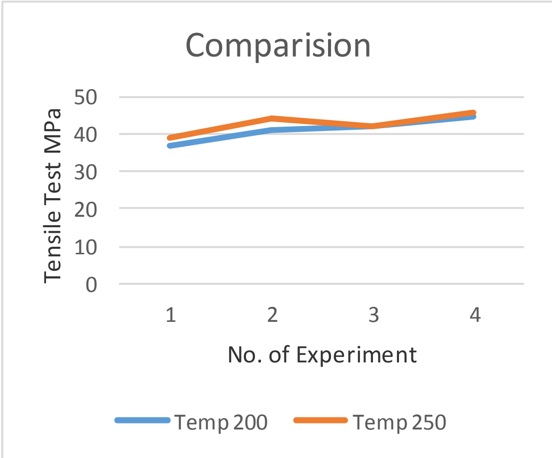

Fig 9 Comparison of Tensile test Between Temperature

8. CONCLUSION

Aluminum alloy AA8011 will be welding by friction stir weld employing different process parameters as obtain full factorial design. Their influence on the mechanical properties of developed joints will investigate in terms of tensile strength and Charpy test.

- Welding joint of two similar grade has to be made successfully.
- The tensile strength of the joints large extent depends on the cooling medium. As welding speed increased, the heat input per unit length of the joint increased resulted in inferior tensile properties due to rise in temperature.
- Cooling of the specimen is also affected the material strength so it may be extended as future work.
- Friction stir welding opening up new areas of welding.

FUTURE SCOPE

Sufficient tool diameter was required to form good weld because, at relatively minimum dia., there was a tunnel at the good weld. Development of process parameter has to predict for strength and good impact bearable factor. Also, this test will proceed on different material with different parameter.

- More investigation on the contact state variable; its values at different conditions, material and position and how it varies.
- Predict the generated forces, torque and power.
- More experimental work has to be done to investigate the effect of tool design on the process and the resulting microstructure.
- Measure the generated forces and torque, and compare to the predicted results as well as try to correlate them to the resulting microstructure.
- Investigate the effect of cooling rate on the process as well as on the resulting microstructure.
- Investigate overlapped multi-passes to process a whole sheet of material
- Design a new experiment to investigate the potential of FSP as crack repairing technique.

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