Prediction of Optimum Welding parameters for Friction stir welding of Aluminium Alloy AA5083 Using Response Surface Method

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Abstract. Friction Stir Welding (FSW) is carried out on armour grade aluminium alloy AA5083 with dimensions of 100X50X6.35 mm. The process parameters like tool profile play a significant role to enhance the welding. Many processing conditions influence the microstructure progression and mechanical behaviour of the produced joints. The main parameters involved in the welding process is discussed under this work. Various parameters such as welding speed, tilt angle, spindle speed and various tool profile are used. Analysing the mechanical behaviours of joints welded like tensile strength and hardness is investigated. In this work tool profiles are designed according to the specific dimensions and the tool material chosen is H13. The tool profiles which are chosen are Cylindrical, Tapered and Hexagonal. So, for this profile, the welds are made accordingly. The Study involves the process which is going to take place are Tensile strength, Impact strength, Hardness, and Microstructure. After the finished AA5083 welded aluminium alloy, it is cut in using the EDM machine according to the ASTM standard. The experiment is designed to determine the major factors affecting the hardness and tensile strength of the joints. For the speed of the tool, tool profile and forward movement of the tool tensile strength and hardness are studied. The contribution of each factor is determined from RSM; For the nine samples, the different factors which are used in this process are compared and investigated. These sample values are compared and analysed by using ANOVA. Based on the values obtained from the test the graph is plotted and based upon the speed of the tool from 1000 to 1500 rpm and forward motion of the tool from 18 to 24 mm/min values is investigated.

1. Introduction
The second patent "Friction Stir welding" was issued 1994 by the inventors from Hydro Aluminium in Norway. It describes an improved method of FSW. The process is the same as in "Improvements Relating to Friction Welding", but the tool has an improved capability of producing vertical movement of the material under the tool, it can be slightly inclined from the direction normal to the welding surfaces (tool tilt), the tool pin has configuration for better plastic material flow and it may take advantage of concave shoulder profile. These two "basic patents are both held by TWI and they are followed by a steadily growing number of more than 1200 patent documents taking advantage of the FSW process [¹]. The invention of FSW is unquestionably a remarkable milestone in the development
of welding processes. It was almost 30 years before when the previous new welding method was introduced. The year was 1962 and the method was laser beam welding. FSW has gained a stable and growing industrial application area, especially within the aluminium sector. The first benefit of FSW is that it is a solid phase process [1]. None of the materials is melted during welding. No alloy segregation, porosity or cracking occurs. Practically all alloys are weldable with FSW, even those that are impossible to weld with ordinary fusion welding processes. An example is shown in the experimental part, where aluminium to copper dissimilar joints are welded with a joint yield strength similar to the yield strength of the aluminium, the weaker of these materials.

The development of most metal alloy compositions has over the decades been controlled by the demand for good fusion weldability. As a solid-state process, FSW removes this demand and thereby has great potential for applications where it could be used as the only welding method for specific parts. Distortion due to FSW is minimal, to a great extent due to the solid-state nature of the process and lack of molten pool shrinkage that occurs during fusion welding. Aluminium alloys, for example, are prone to large weld distortions when fusion welded [3]. This is especially the case with thin plate welding when the rigidity of the structure is low. FSW is always mechanized welding due to the high tool forces required. The variable costs in FSW production are low since no filler material or shielding gas is required. Fabrication time is less than in arc welding because oxide removal is usually not required and the welding speed is often greater than in fusion welding. Mechanical joint properties are better especially. The type of welding used in this process is Friction Stir welding where it can produce high-quality joints at low-cost. Friction stir welding is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. In this process, nine samples of AA5083 aluminium alloy are welded based upon the parameters [2]. The parameters are used in the Friction Stir welding process to attain a sturdy weld. The input parameters which are used are Spindle speed, Transverse speed and tool profile. In this process there are three types of tool profiles they are Cylindrical, tapered and Hexagonal. The material used in the tool profile is H13 and these tool profiles are designed and made according to the specific shape to obtain good weld. Later on, using the Response Surface method is used where it compares values obtained. After the Friction welding process the material is made being cut in the EDM machine where the material is cut according to the ASTM stands to do the following test Tensile, Impact and Hardness test. Later on, the certain cut is being made on the centre of the welded portion of AA5083 aluminium alloy to study the microstructure analysis [2].

2. Experimental work

The workpiece selected in research is Aluminium Alloy AA5083 and was obtained in plate form of size 150mm X 100mm with 6mm thickness respectively. The AA5083 aluminium alloy properties such as chemical, physical and mechanical are listed in table 1 respectively. The raw material procured was cut into required dimension by using Wire-cut EDM Machine by using water as electrolyte. The EDM machine is selected for this cutting process because the cut which is obtained from EDM is accurate but it is a slow process.
Figure 1. The methodology of the experiment work.

Figure 2. Before EDM.

Figure 3. After EDM.
2.1. Material aluminium alloy (AA5083)

Aluminium Alloy 5083 has Magnesium content of about 4 to 4.9 per cent and 0.25 per cent of Zinc is present so thus aluminium alloy 5083 is used as an application in a submarine where the presence of zinc act as corrosion resistance and presence of magnesium gives high strength [4]. It is the most commonly used and available material and is used in the construction of ships, Railroad cars and due to its high strength, it is used as armor for military purposes.

![Table 1. Chemical composition of the aluminium alloy 5083.](image)

| Elements | Cu  | Mg  | Si  | Fe  | Mn  | Zn  | Cr  | Ti  | Al  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Chemical composition | 0.0016 | 4.3 | 0.059 | 0.731 | 0.731 | 0.008 | 0.135 | 0.014 | Bal |

2.2. H13 steel tool profile

The tool used in FSW process is H13 Steel Surface hardened tool. The tool wear is produced when the tool rotates at high rpm on the interaction between the tool and the workpiece the tool wear is obtained. The H13 tool profile is surface hardened in order to obtain increase the wear of the tool by increasing its hardness. The H13 steel surface hardened is used in order to obtain high quality weld in the material. The tool profiles which are used are Cylindrical, Tapered and Hexagonal. In this process the tool rpm, tool wear and its transverse speed is investigated.

![Table 2. Chemical composition of tool for FSW – H13 tool steel.](image)

| Elements | C   | Mn  | Si  | Cr  | Mo  | V   |
|----------|-----|-----|-----|-----|-----|-----|
| Chemical Composition | 0.40 | 0.40 | 1   | 5.25 | 1.35 | 1.00 |

![Figure 4 & 5. Types of Tool Profiles in FSW](image)
2.3. Welding process of FSW in AA5083

The welding process which is used in this research is FSW process because high quality welds can be produced at low cost. In this welding process the joint used is Butt joint. The friction Stir welding process is used because the properties of AA5083 aluminium alloy is increased dramatically and the material becomes further strong which is used in certain applications. The rotational speed of the tool for this process is 1120, 1300 and 1500 rpm, the axial feed is 18, 20 and 24 mm/min keeping axial load 15 KN and tilt angle 0º as constant. Three types of tool profiles are used as cylindrical, tapered and hexagonal tools used are designed and machined in H13 steel and were hardened.

Table 3. Optimized process parameters of Friction Stir Welding (FSW).

| Sample no | Spindle speed (rpm) | Traverse speed (mm/min) | Tool profile |
|-----------|---------------------|-------------------------|--------------|
| 1         | 1120                | 18                      | Cylindrical  |
| 2         | 1120                | 20                      | Tapered      |
| 3         | 1120                | 24                      | Hexagonal    |
| 4         | 1300                | 18                      | Tapered      |
| 5         | 1300                | 20                      | Hexagonal    |
| 6         | 1300                | 24                      | Cylindrical  |
| 7         | 1500                | 18                      | Hexagonal    |
| 8         | 1500                | 20                      | Cylindrical  |
| 9         | 1500                | 24                      | Tapered      |

When the material AA5083 Aluminium Alloy is welded normally there are different layers or regions obtained which is classified into four types they are unaffected zone, Heat affected zone, Thermo-mechanically affected zone and friction stir processed zone. When compared to Conventional welding the heat affected zone in this friction stir welding process is less and strong welds are produced. The Welding parameters for FSW and the tool parameters plays a vital role in determining the welding strength of the material AA5083 Aluminium Alloy and the material flow behavior is determined by the tool profile which is used in this process. The material flow during this process is determined by two ways one is by the flow of material due to pin and another is layer by layer flow of material due to shoulder. There are normally two sides present where the transfer of material takes place one is Retracting side and another one is Advancing side. The flow of material is determined when the material from the retracting side moves or transfers to the top of the advancing side present on the shoulder surface. Normally in FSW process there are two types of tool speed present one is tool rpm and another one is movement of the tool. These constraints are taken into account while doing this process.
3. Destructive tests

3.1. Tensile Strength

The material AA5083 aluminium alloy is cut according to the (ASTM E8) standard using Electro Discharge Machining (EDM). After the Tensile cut is being made by using the Universal Tensile Machining (UTM) the material breakage happens and the graph between the Stress Vs Strain is obtained [6]. The change in dimension before the tensile test and after the tensile test is compared and observations were made accordingly.

![Figure 7](image7.png)

**Figure 7.** Workpiece holder for friction stir welding (FSW).

![Figure 8](image8.png)

**Figure 8.** Friction stir welded specimens.

![Figure 9](image9.png)

**Figure 9.** Dimension of test specimen according to ASTM E8 standard.
Figure 10. The tensile test specimen.

Figure 11. The test specimen after the tensile test.

Figure 12. Plot for Tensile strength of different samples from the test.
In this graph after the Friction Stir Welding process which is done on nine samples when comparing the tensile strength between the nine samples. In sample number 8 where the Cylindrical tool profile is used for FSW process where the spindle speed of the tool profile is 1500 rpm and the transverse speed of 20 mm/min has obtained higher tensile strength of 138.378 Mpa than the Sample number 4 where tapered tool profile is used for FSW process where the spindle speed of the tool profile is 1300 rpm and the transverse speed of 18 mm/min has obtained minimum tensile strength of 50.755 Mpa.

3.2. Hardness Test

At the welded part of the material AA 5083, the hardness which is selected for this test is Vickers Hardness so for this test the material is cut according to its Standard. The material before testing the emery papers of grade 600,800,1000,1200,2000 is selected and by using Hiffin spray and Diamond paste using the cotton cloth the material is rubbed slowly on the Grinding machine until the scratches present in the material disappears [7]. First, the material on the welded part a cut is being made and from that welded part the hardness is taken. To obtain correct indentation on the material mounting is done on the material so the grinding process, as well as the hardness test, is done without any discomfort. After this process by using the Vickers hardness machine the hardness value after the welded material is taken and the optimum value is chosen.

![Hardness of FSW](image)

**Figure 13.** Plot for Hardness of different samples from the test.

From the above graph the Vickers hardness values for nine samples is tested and analyzed. From the analysis of the nine samples, The sample number 7 was done at a spindle speed of 1500 Rpm and having transverse speed of 18 mm/min with Hexagonal pin profile has the highest hardness value of 90 HV and sample number 2 was done at a spindle speed of 1120 Rpm and having transverse speed of 20 mm/min with Tapered pin profile has the lowest hardness value of 61 HV.
3.3. **Impact Strength**

The material AA 5083 is cut according to the Standard. The test which is selected for this process is the Charpy test. The impact strength of a material is defined as its capability to resist a sudden applied load or force and the amount of energy absorbed by the material during the process before deformation occurs. The same experiment is repeated for 9 samples and the optimum value is considered [5]. The material AA5083 Aluminium alloy is cut by the EDM at the specified dimensions according to the ASTM standard. The material is kept at the Impact test machine so for Charpy test, the notch present in the material is kept away from the striker. There are two types of notches present in Charpy test they are U notch and V notch. The striker which is present in the impact test will strike exactly at the midpoint of the material and the shock which comes from the material due to impact is measured and noted down.

**Figure 14.** Indentation made on the material while testing.

**Figure 15.** Impact test machine (charpy).
Figure 16. Plot for Tensile strength of different samples from the test.

From this graph the charpy test for the nine samples is tested. The sample number 8 of cylindrical tool shape at 1500 rpm and rotational speed of 20mm/min has the maximum charpy value and sample number 4 of tapered tool shape at 1300 rpm and rotational speed of 18mm/min has the minimum charpy value.

4. Microstructural analysis

Analysis of the material AA 5083 Aluminium Alloy micro-structure is done with the help of following steps and certain procedures to be followed inorder to obtain the microstructure of AA5083 Aluminium Alloy. First with the help of EDM the material is cut into a small sample and resin moulding is done inorder to do the grinding process. This grinding process is done inorder to remove the scratches present in the material. Coarse grinding is done inorder to remove the damage created on sectioning and Planar grinding is done in order to reduce the size of the abrasive particle and also to obtain surface finish. In order to remove all the scratches present in the material is first rubbed using Emery paper of grades 600,800,1000,1400 and 2000 kept on the grinding machine and it is continuously rotated at 90 degree inorder to obtain good polish and .After doing this process the material is etched for around 10 to 20 seconds and it is washed immediately with water. These process are used in order to obtain clear microstructure view of material AA5083 Aluminium alloy. The microstructure images of sample 7 and sample 8 has the highest optimum value.

Figure 17. Microstructure -1500rpm-18mm/min. Figure 18. Microstructure - 1500rpm-20mm/min.
5. Result and discussion

5.1. Response Surface Analysis

The point types which is present is classified into four types they are Cube points, Center points in cube, axial points and Center points in axial. The values present in the cube points, Center points in cube, axial points and center points are 4, 5, 4 and 0 respectively.

| Std order | Run order | Pt Type Blocks |
|-----------|-----------|----------------|
| A         | B         |
| 7         | 1         | -1             | 1             | 0.00000 | -1.41421 |
| 2         | 1         | 1              | 1             | 1.00000 | -1.00000 |
| 13        | 3         | 0              | 1             | 0.00000 | 0.00000  |
| 8         | 4         | -1             | 1             | 0.00000 | 1.41421  |
| 12        | 5         | 0              | 1             | 0.00000 | 0.00000  |
| 3         | 6         | 1              | 1             | -1.00000 | 1.00000  |
| 11        | 7         | 0              | 1             | 0.00000 | 0.00000  |
| 10        | 8         | 0              | 1             | 0.00000 | 0.00000  |
| 1         | 9         | 1              | 1             | -1.00000 | -1.00000 |
| 6         | 10        | -1             | 1             | 1.41421  | 0.00000  |
| 5         | 11        | -1             | 1             | -1.41421 | 0.00000  |
| 4         | 12        | 1              | 1             | 1.00000  | 1.00000  |
| 9         | 13        | 0              | 1             | 0.00000  | 0.00000  |

From the above table (table 4) by the analysis of Response Surface Method the material AA5083 tests were conducted, performed and tabulated. The corresponding obtainable values are noted down and from the calculation the obtained values are listed and plotted in the form of graph. From the graph the maximum obtainable and the minimum obtainable for the hardness and the tensile test can be identified.
Figure 19. Individual interaction of parameters with producing response (Tensile strength).

Table 5. Experimental results.

| Rotational Speed (rpm) | Traverse Speed (mm/min) | Tool Profile | Tensile strength (MPa) | Hardness (HV) | SN | ST DE1 | ME AN | PSN RA | PM | PST DE1 | PL ST D1 |
|------------------------|-------------------------|--------------|------------------------|--------------|----|--------|------|--------|----|---------|---------|
| 1120                   | 18                      | Cylindrical  | 120                    | 67           | 38.3 | 37.4   | 93.5 | 40.1   | 106 | 28.9    | 3.1     |
| 1120                   | 20                      | Tapered      | 85                     | 61           | 36.9 | 16.9   | 73.0 |        |     |         |         |
| 1120                   | 24                      | Hexagonal    | 132                    | 80           | 39.7 | 36.7   | 106  |        |     |         |         |
| 1300                   | 18                      | Tapered      | 50                     | 70           | 35.1 | 14.1   | 60.0 |        |     |         |         |
| 1300                   | 20                      | Hexagonal    | 93                     | 74           | 38.2 | 13.4   | 83.5 |        |     |         |         |
| 1300                   | 24                      | Cylindrical  | 130                    | 72           | 38.9 | 41.0   | 101  |        |     |         |         |
| 1500                   | 18                      | Hexagonal    | 90                     | 90           | 39.0 | 0.00   | 90.0 |        |     |         |         |
| 1500                   | 20                      | Cylindrical  | 138                    | 68           | 38.7 | 49.4   | 103  |        |     |         |         |
| 1500                   | 24                      | Tapered      | 93                     | 75           | 38.3 | 12.7   | 84.0 |        |     |         |         |
5.2. Taguchi Analysis

Table 6. Design Summary.

| Taguchi Array | L9(3^3) |
|---------------|---------|
| Factors:      | 3       |
| Runs:         | 9       |

Table 7. Response Table for Signal to Noise Ratios Larger is better.

| Level | Rotation Speed(rpm) | Traverse Speed (mm/min) | Tool Profile |
|-------|---------------------|-------------------------|--------------|
| 1     | 38.33               | 37.55                   | 38.69        |
| 2     | 37.49               | 37.96                   | 36.82        |
| 3     | 38.71               | 39.01                   | 39.02        |
| Delta | 1.23                | 1.47                    | 2.21         |
| Rank  | 3                   | 2                       | 1            |

Table 8. Prediction for best efficiency.

| S/N Ratio | Mean | StDev | Ln (StDev) |
|-----------|------|-------|------------|
| 40.0863   | 106.5| 28.9914| 3.13996     |
Figure 21. Plots for Main Effects for SN ratio based on Taguchi Analysis.

6. Conclusion
The parameters which is chosen for FSW process is thoroughly studied and investigated. From the experiment and results being analyzed the plots is based on tensile strength and Vickers hardness as the values are compared and the efficient parameter for FSW is found by using Response Surface method and T by using Minitab software as sample 8 in FSW welded workpiece has the maximum Tensile and impact test values and sample 7 in FSW welded workpiece has maximum hardness value when compared between other samples. The tool profiles which is used for this process is Cylindrical, Tapered and Hexagonal. So while comparing these three different tool shapes the Cylindrical tool shape has obtained the maximum tensile strength and impact test and Hexagonal tool shape has obtained highest impact strength. The microstructure and macrostructure of the material AA5083 Aluminium Alloy has been studied.

7. References
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