Optimization of FSW Parameters to Improve the Mechanical and Metallurgical Properties of Aluminium Alloy AA 5083 Joints

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Abstract. Friction Stir Welding (FSW) is carried out on armour grade AA5083 aluminium alloy having the dimensions of 100X75X6.35 mm. The FSW process and tool parameters play a major role in deciding the joint strength. Many processing conditions and material properties affect the microstructure evolution and mechanical behaviours of the produced joints. Various parameters such as welding speed, tilt angle, spindle speed and various tool profile are used. Analyzing the mechanical behaviours of joints welded like tensile strength and hardness were investigated. The tool rotation and welding direction same side are similar is called Advancing side (AS) and opposite on the other known as retreating side (RS). The input process parameters which influence the strength of the joints. Main consideration is to select the best parameter to produce the defect free joints. Experiment is designed to determine the major factors affecting the hardness and tensile strength of the joints. Effect of rotational speed, welding speed and tilt angle on tensile strength and hardness are studied. The contribution of each factor is determined from ANOVA analysis “Tensile strength and hardness increased with increasing the rotational speed 1000 rpm to 1400 rpm, traverse speed from 30 mm/min to 40mm/min”. This investigation mainly deals with Taguchi and ANOVA were performed to improve the effective characteristics of welding inputs.

1. Introduction
It is an auto geneious welding process. It improves the metallurgical properties of welded joints. FSW process can be seen in many industrial applications. Metal joining the below melting point is complicated task, but it produces low distortion, because the operating temperature is very less. Initially FSW was applied to relatively soft grade materials, such as aluminium, magnesium. Further it can be employed in other materials, steel, titanium and composite materials also. In FSW, the rotating tool plunged into the work piece interface; it creates friction and generates heat. The plastic deformation near the tool pin area (Nugget Zone) will takes more; this leads to minimize the transverse velocity of the tool, so the tool wear rate is drastically controlled [1]. The tool rotation and welding direction on side are similar is called Advancing side (AS) and opposite on the other known as retreating side (RS). The input process parameters which influence the strength of the joints. The
parameters are considered as tool rotation, tool tilt angle, welding speed and axial force. Main consideration is to select the best parameter to produce the defect free joints.

In all studies resulted, the effect of process parameters on joints has been analyzed. It is important to study the effect of producing joints of AL5083 due to their usage in aerospace industries and submarine applications. The characteristics like ballistic performance, lightness, Weldability, mobility, high strength to weight ratio are significantly important for the armour grade materials and vehicles used in defence applications. Density of armour grade materials specify the mobility of vehicles and the battle vehicles to advance the mobility. Armour grade AA5083 used to make military vehicles much lighter than earlier vehicles. It was thick enough to protect the crew and passenger and against arm fire. Alloy 5083 is more difficult to do fusion welding and thus the only way to joint individual component is by using mechanical fasteners. AA5083 armour grade has good ballistic properties, it is presently well established that FSW process can join AA plates with enhanced joint properties over other conventional welding process. FSW, as a solid state joining process has been widely used to weld various AL alloys that were difficult to fusion welding. FSW does not lead to melting of base materials, it just plastically deform the material. During FSW, the thermal condition exist in the thermo mechanical affected zone (TMAZ) and Heat affected Zone (HAZ) causes precipitate coarsening and dissolution of precipitates, hence the region attains low hardness is called LHDR [2].

Linear joints are made either with a circular rotating tool or a blade-shaped reciprocating tool. Further examples include material classes: metals, alloys, compounds (MMC) and thermoplastics. Also lap and spot welds, bobbin-tool configurations, double-sided welding and tool heating are described.

2. Project methodology

The sequential order of the steps followed in this work is given below in figure 1.

![Figure 1. Methodology.](image-url)
3. Selection of Materials

3.1. Work piece material
Material that has been chosen is AA5083 shown in figure 2. It is a military grade alloy which consists of 4.8% magnesium, which has high corrosion resistance properties. The chemical composition and properties of AA5083 is shown in table 1 and 2 respectively.

| Table 1. Chemical composition of AA5083. |
|-----------------------------------------|
| Al    | Zn    | Mg    | Cu    | Fe    | Mn    | Other |
| 94.8% | 0.25% | 4-4.9%| 0.10% | 0.40% | 0.40% | 0.15% |

| Table 2. Physical properties of AA5083. |
|-----------------------------------------|
| Density       | 2.66 g/cc          |
| Tensile strength | 385 MPa            |
| Yield strength    | 215 MPa            |
| Melting point     | 635°C              |

Figure 2. Aluminium Alloy 5083.

3.2. Tool Material
The tool material that has been chosen is H13 steel is high strength steel mostly used in high temperature applications. It Consist of 5.47% chromium so its maintain the red hardness condition without any loss of geometrical shapes. The properties of H13 tool steel is given in the table 3 below. The dimension of H13 tool and various profile of tool is shown in figure 3 and 4 respectively.

| Table 3. Physical properties of H13 tool steel. |
|-----------------------------------------------|
| Tensile strength                             | 510 MPa          |
| Yield strength                                | 370 MPa          |
| Hardness                                     | 152 HB           |
Figure 3. H13 welding tool.

Figure 4. Various tool profiles.

1. Tool with cylindrical pin profile.
2. Tool in the middle has hexagonal pin profile.
3. Tool in the right side has threaded pin profile.

These tool profiles are made up of material H13. These profiles give different properties of welded joints. Circular pin profile can be considered as multi edge cutting tool, the hexagonal pin profile can be considered as six edge cutting tool, the threaded pin profile can be considered as tool with multi cutting edges[3]. The tool profile should be such that which creates less amount of flashes. It should also prevent formation of chips and the material should be well penetrated by tool to form the sound weld joint [4].
4. Tool Hardening

For hardening the H13 tool, the component is heated slowly to 820-860°C in a furnace shown in figure 5 and then allowed to cool for a period of 30 minutes. Then quenching is done by using oil or water.

![Figure 5 Hardening furnace.](image)

5. Welding Parameters

The welding parameters are shown in the figure 6.

![Figure 6 Welding parameters.](image)

The following table 4 shows the list of parameters that has been chosen for the experiment. Only 3 parameters have been considered for the experiment while the rest are fixed [5] are listed in table 5.

| Parameters           | I       | II      | III     |
|----------------------|---------|---------|---------|
| Tool Tip Profile     | Cylindrical | Hexagonal | Threaded |
| Tool Rotational Speed| 1000 rpm | 1200 rpm | 1400 rpm |
| Welding Speed        | 20 mm/min | 30 mm/min | 40 mm/min |
| Tool Tilt Angle      | 0 degree | 1 degree | 2 degree |
Table 5. List of fixed/variable parameters.

| Parameters          | Fixed/Variable                      |
|---------------------|-------------------------------------|
| Tool rotation Speed | Variable (1000 to 1400 rpm)         |
| Axial force         | Fixed (4.6 KN)                      |
| Tool diameter       | Fixed (6 mm)                        |
| Tool material       | Fixed (H13)                         |
| Tool profile        | Threaded, Cylindrical, Hexagonal    |
| Tool angle          | \(0^{\circ}, 1^{\circ}, 2^{\circ}\) |
| Feed rate           | Variable (20 to 40 mm/min)          |
| Feed direction      | Fixed                               |
| Separation distance | Fixed (nil)                         |
| Plate thickness     | Fixed (6 mm)                        |

6. Fabrication By using EDM

On vertical milling centre machine we have done friction stir welding. The input factors were set based on L9 orthogonal array. Program was generated using Fanuc control programing to describe the Tool motion. Different profiles of tool pin were mounted on turret of machine.

AA5083 plates in the size of 100x50 mm and 6.35 mm thickness by automatic. The aluminium alloy AA5083 is fabricated by electrode discharge machining method to form a work piece of dimension 100mm x 50mm x 6.35mm shown in figure 8. The aluminium alloy is of the composition 94.53% by weight of Aluminium and 4.8% of Mg. Electrical Discharge Machining (EDM) shown in figure 7 is a suitable machining technique to fabricate aluminium alloy because it is an economical process and forms an even finish surface.

Figure 7. EDM machine.
7. RESULTS AND DISCUSSION

7.1. Tensile Test
The tensile strength test specimens were designed and prepared according to equivalent American Standard ASTM E8 shown in figure 9. The specimen is prepared in such a way that the fracture elongation is measured for 50 mm in the center of the weldment. After the tensile test, fracture locations of the specimens were measured to find percentage of elongation, Tensile Strength. The width and thickness of the weld area are measured before and after the tensile test. The tensile specimen after testing is shown in figure 10. The table 6 shows the tensile test results and it was shown in the graph shown in figure 11.
Figure 10. Tensile specimen after testing.

Table 6. Tensile test results.

| Sample No | Thickness (mm) | Width (mm) | Area (mm²) | Failure Load (N) | Tensile Strength (N/mm²) |
|-----------|----------------|------------|------------|------------------|--------------------------|
| 1         | 5.22           | 7          | 36.54      | 7673             | 210                      |
| 2         | 5.3            | 7.01       | 37.15      | 9473             | 255                      |
| 3         | 5.27           | 7.04       | 37.1       | 6418             | 173                      |
| 4         | 5.22           | 7          | 36.54      | 9098             | 249                      |
| 5         | 5.24           | 6.99       | 36.63      | 10183            | 278                      |
| 6         | 4.62           | 7.06       | 32.62      | 6226             | 191                      |
| 7         | 5.2            | 6.99       | 36.35      | 10505            | 289                      |
| 8         | 5.2            | 7.01       | 36.45      | 7982             | 219                      |
| 9         | 5.12           | 7          | 35.84      | 8422             | 235                      |

Figure 11. Tensile test.
8. Hardness Test
Vickers hardness testing was employed with 50kg load for measuring the hardness across the weld. Since the base material is aluminium alloy and diamond indenter was used. Then the readings were taken for further analysis and discussion. Photograph of the tested specimens are shown in figure 12 below. The hardness test results are shown in the table 7 and figure 13.

![Figure 12. Hardness sample specimen.](image)

| Sample No | 'd' Value | Hardness(HV) |
|-----------|-----------|--------------|
| 1         | 0.372     | 78           |
| 2         | 0.312     | 88           |
| 3         | 0.372     | 63           |
| 4         | 0.304     | 85           |
| 5         | 0.313     | 90           |
| 6         | 0.344     | 68           |
| 7         | 0.313     | 95           |
| 8         | 0.323     | 80           |
| 9         | 0.323     | 83           |
9. Design of Experiments

Since our aim was to optimize friction stir welding parameters, by increasing hardness, increasing tensile strength, we have used Minitab to develop our design matrix. The input parameters for the DOE are taken as Spindle Speed (rpm), Traverse speed (m/s), tool profiles based on literature for optimal parameters of FSW AA5083. The figure 14 shows the flowchart for DOE.

![Sample no VS Hardness](image_url)

**Figure 13.** Hardness test.

![Flowchart for DOE](image_url)

**Figure 14.** Flowchart for DOE.
The design of experiment (DoE) using factorial method has been implemented using Minitab software. Trial experiments were performed to find the working and practicable range of process parameters. The parameters and their working range for the similar FSW of AA5083 are selected. The input parameters and their levels in L9 series is shown in table 8 and their corresponding S/N values is shown in table 9. The Analysis of Variance for SN ratios is shown in table 10.

Table 8. Input parameters (Factors and their levels).

| Sample | Tool Tilt Angle Degree | Tool rotational Speed (rpm) | Tool Traverse Speed mm/min |
|--------|------------------------|-----------------------------|-----------------------------|
| 1      | 0                      | 1000                        | 20                          |
| 2      | 0                      | 1200                        | 30                          |
| 3      | 0                      | 1400                        | 40                          |
| 4      | 1                      | 1000                        | 30                          |
| 5      | 1                      | 1200                        | 40                          |
| 6      | 1                      | 1400                        | 20                          |
| 7      | 2                      | 1000                        | 40                          |
| 8      | 2                      | 1200                        | 20                          |
| 9      | 2                      | 1400                        | 30                          |

Table 9. S/N values.

| Tool Tilt Angle Degree | Tool Rotation Speed-rpm | Tool Traverse Speed-mm/min | Tensile Strength-Mpa | Hardness-HV | Signal to Noise Ratio | MEAN |
|------------------------|-------------------------|-----------------------------|----------------------|-------------|-----------------------|------|
| 0                      | 1000                    | 20                          | 210                  | 78          | 40.2909               | 144.0 |
| 0                      | 1200                    | 30                          | 255                  | 88          | 41.4113               | 171.5 |
| 0                      | 1400                    | 40                          | 173                  | 63          | 38.4563               | 118.0 |
| 1                      | 1000                    | 30                          | 249                  | 85          | 41.1200               | 167.0 |
| 1                      | 1200                    | 40                          | 278                  | 90          | 41.6623               | 184.0 |
| 1                      | 1400                    | 20                          | 191                  | 68          | 39.1422               | 129.5 |
| 2                      | 1000                    | 40                          | 289                  | 95          | 42.1192               | 192.0 |
| 2                      | 1200                    | 20                          | 219                  | 80          | 40.5281               | 149.5 |
| 2                      | 1400                    | 30                          | 235                  | 83          | 40.8813               | 159.0 |

Table 10. Analysis of Variance for SN ratios.

| Source                          | DF | Seq SS | Adj SS | Adj MS | F-Value | P-Value | Contribution |
|---------------------------------|----|--------|--------|--------|---------|---------|--------------|
| Tool Tilt Angle (Degree)        | 2  | 0.2327 | 0.2327 | 0.11635| 2.12    | 0.321   | 8.36%        |
| Tool Rotation Speed (rpm)       | 2  | 0.1119 | 0.1119 | 0.05595| 1.02    | 0.496   | 42.09%       |
| Welding Speed (mm/min)          | 2  | 0.3970 | 0.3970 | 0.19848| 3.61    | 0.217   | 35.48%       |
| Error                           | 2  | 0.1100 | 0.1100 | 0.05501|         |         |              |
| Total                           | 8  | 0.8516 |        |        |         |         |              |
9.1. Main effects plot for Tensile Strength
The main effects plot for tensile strength shown in figure 15.

![Main effects plot for Tensile Strength](image15)

**Figure 15.** Main effects plot for tensile strength.

9.2. Main effects plot for Hardness
The main effect plot for hardness is shown in figure 16.

![Main effects plot for Hardness](image16)

**Figure 16.** Main effects plot for Hardness.
This implies that Maximum Tensile Strength and hardness is obtained when feed rate was 30mm/min at a tool rotation speed of 1400 rpm when the tool tilt angle is 2 degree. During the conformation test for this parameter the S/N ratio obtained was 42.2673 for tensile strength and S/N of hardness is 38.8.

10. Conclusion

1) Joints welded with hexagonal pin profile exhibited good tensile strength, hardness, percentage elongation and joint efficiency. Better mechanical properties (hardness and tensile strength) were obtained with the FSW plate fabricated with 1000 rpm tool rotational speed, 40mm/min welding speed with hexagonal pin profile tool and tool tilt angle is zero degree.

2) The stirred zone exhibited higher strength compared with HAZ and TMAZ due to smaller grain size.

3) The hardness over the weld region was more in hexagonal pin profile welded joint as compared to threaded and cylindrical pin profile. The hexagonal pin profile weld joint has less defects like tunnel defects, voids, lack of fusion, excessive flash, surface grooves etc.

4) The hardness for the joints where influenced by the parameter, tool rotation speed 1000 rpm, traverse speed 40mm/min and Tool tilt angle 2degree which influence the property (Hardness) more.

5) Taguchi conformation test also conducted for the ranges, tool ration speed 1200 rpm, traverse speed of 30mm/min and tilt angle 2 degree

11. References

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