Comparative study of tungsten inert gas and friction stir welding of aluminium alloy aa5083 (armour grade) aluminium alloy joints

Mouriya Srinivasan1, SaravanaKumar.R2 and T. Rajasekaran3
1 Student, 2 Assistant professor, 3 Professor, Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattakkulathur, Chennai, India.

E-mail: mouriyasrinivasan@gmail.com

Abstract. Aluminium-magnesium Alloy AA5083 is used widely as a building and tooling material in aerospace, automobile, and marine industries. This Work shows the comparison of AA5083 (armor grade) – 6mm thickness plate weldments mechanical properties on TIG Welding and FSW processes. Welding of metals is based upon the input parameters as it has an important role of finalizing the weldment and the tool used for welding is H13 Tool Steel as the tool has less deformation due to high chromium content. Generally, the welding processes are aimed at achieving a welding joint with superior mechanical properties with minimum deformation. The tensile strength of the weldments is found by testing in the Ultimate Tensile Strength (UTM) machine. The hardness test is performed by Vickers Hardness tester to characterize the welded area. Macro Vickers Hardness is performed in the welded area of the workpiece to finalize mechanical properties in different heat-affected zones of FSW welded workpiece to analyze and find the efficient input parameter of FSW. The efficient input parameter for TIG welding is identified and a comparative study is made and the result proves that FSW welding is a better welding technique.

1. Introduction
The demand for Aluminium alloy welded joints has been increasing as the high-quality weld is required for marine and aerospace applications (Specifically AA5083). Therefore, two non-similar welding process is used to find which is better for aluminium alloy welds as Tungsten Inert Gas Welding is a conventional welding process which requires inert gases and requires a filler material, as they TIG welding has greater efficiency in conventional welding and widely used, It is compared with Friction Stir Welding (FSW).

Aluminium-magnesium Alloy AA5083 is used widely as a structural material in aerospace, automobile, and marine industries, Due to its outstanding performance in extreme conditions and AA 5083 have a higher corrosion-resistant so used in industrial chemical environment and seawater. The alloy retains its strength after welding. Alloy AA5083 is also called Armor grade alloy due to high strength and high corrosion resistance due to the presence of magnesium and zinc.
Table 1. Elemental Chemical Composition of the Base Material - Aluminium Alloy AA5083.

| 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 |

H13 alloy steel is a multifaceted chromium-molybdenum hot work steel that's commonly utilized in the production of hot and cold work tooling and its applications. The hot hardness (i.e.) the hardness at a higher temperature is high for H13 Tool Steel. Due to recurring heating and cooling cycles of tooling work production and its application the H13 Tool steel withstands the fatigue cracking in the tool [3]. The high toughness and high resistance to thermal fatigue cracking (also referred to as heat cracking) H13 are employed for more hot work tooling applications than any other tool steel and, H13 is additionally utilized in a range of cold work tooling applications due to its stability in heat treatment. In these applications, H13 provides greater hardenability due to the presence of chromium as the deformation of the shape is minimal through surface hardening and the wear resistance is higher than other commonly used steel alloys.

Table 2. Chemical Composition of Tool for FSW – H13 Tool Steel

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

TIG welding is a regular welding process which uses a non-consumable electrode and shielding gas (i.e. Inert gas) as the components of the welding process. The weld is created by an electric arc and gas is used as shielding gas to resist the formation of the oxide layer. Weld is created with or without the use of filler rod material [4]. TIG welding requires heat to create a weld to produce heat and so electric arc should be generated for that TIG welding requires a continuous AC power supply [1]. The weld area is shielded from atmospheric contamination by the use of inert gases like argon etc., TIG welding used for welding of Aluminium Alloy AA5083 has an AC power supply to change the polarity of charges while welding to produce maximum heat on the electrode to get efficient mechanical properties in the welded area. The best weld is based upon various parameters like shielding gas, Welding wire, Tungsten electrode.,

FSW is a solid-state welding process where the metal would be in a plastically deformed form due to heat generated due to friction and due to the load by which uses a third-party tool join the metals. Due to an elevated temperature between the tool and workpiece, the workpiece gets softened and the tool blends the material mechanically by applying pressure on the joining part of the workpiece [4]. The design of experiments is conducted fully based on factorial parameters from the literature review of TIG Welding processes and Friction Stir Welding (FSW). As FSW is perhaps the most efficient welding technique [4]. Though the FSW process is efficient welding technique only by the usage of proper welding parameters if not flaws are identified in the workpiece and optimization of parameters is made by destructive test result analysis.
2. Methodology

2.1 Material Selection

- Work piece (or) Base metal selection - Aluminium Alloy (AA5083)
- Tool Selection - H13 Tool Steel rod

2.2 Fixtures

- Base plate size - 675mm * 400mm * 6mm
- Work piece size - 150mm * 100mm * 6mm

2.3 Process Parameters

- Speed - 1120, 1300, 1500 (In RPM)
- Tool Profile - Cylindrical, Threaded, Hexagonal
- Feed Rate - 18, 20, 24
- Welding Current - 200, 250 (In Amps)
- Shielding gas Flow - 10, 15 (In l/min)

2.4 Welding Process

- Conversion of CNC vertical milling machine to FSW machine
- Welding based on process parameters

2.5 Destructive Test

- Micro Vickers Hardness
- Tensile Strength

2.6 Comparison of Test Result and Conclusion

- Comparison of Hardness and tensile strength test result by analysis in Minitab

**Figure 1.** The methodology of the Experiment work.

3. Experimental Work

3.1 Material Selection

The workpiece selected in research work was Aluminium Alloy AA5083 and was obtained in plate form of size 150mm X 100mm with 6mm thickness. As a proof of confirmation chemical composition of the workpiece and tool are systemized in Table 1 and Table 2 respectively. The raw material procured was cut into the required dimension by using Wire-cut EDM Machine by using water as the electrolyte.
3.2. Welding of AA5083 by FSW (Friction Stir Welding)

In this prototype work, the weld is between similar metals and AA5083 armour grade Alloy has a thickness of 6mm. The specimen was 150mm long and 100mm wide. In this work tool used was H13 tool steel which is surface hardened with tool pin design having pins of cylindrical, threaded and hexagonal profiles with pin diameter 5.9mm and 15mm shoulder diameter with a length of 5.9mm. The experiment was carried out in a vertical milling machine.

The optimized parameters for Friction Stir Welding were found by Taguchi analysis of parameters from the literature survey. The FSW between similar AA5083 and AA5083 alloys were produced using the vertical milling machine [6]. The plates are kept in a butt-joint configuration, the movement of the tool is normal to the rolling direction of the plate. The welding process was completed at three different rotational speeds at 1120, 1300 and 1500 rpm, the axial feed rate was 18, 20 and 24 mm/sec, the axial load of 12KN and tilt angle of 0° and the load and angle were kept constant throughout the process.

| 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     |
Throughout FSW, the plates are placed together in their ends as the weld formation would be in the butt-joint configuration in the workpiece holder on a vertical milling machine where the parts are fastened firmly onto a work-holding vice of the vertical milling in a way that the plates cannot be moved apart during welding. The welding is made by a welding tool made up of H-13 tool steel where the tool can be differentiated into two parts as shoulder and specially designed pin, the pin is plunged into the plates to be welded as the tool rotates and moves at a welding speed along the joint until the joint is been made. The tool is made up of H-13 tool steel as it has high chromium content the deformation in pin would be less which makes it more efficient for FSW method. The tool dimensions are calculated from the thickness of the workpiece as the length of the pin is given 0.3 mm lesser than the thickness of the workpiece if the pin length is greater hole would be formed and another important parameter of the pin is their profile, as it has a greater impact on the flow of the material while welding.

![Figure 4. Work piece Holder of FSW Machine.](image1)

![Figure 5. Friction Stir Welded Specimens.](image2)

### 3.3. Welding of AA5083 by TIG (Tungsten Inert Gas) welding

TIG welding process is an arc welding process which uses a non-consumable electrode (Tungsten) which is electrified with the use of power supply from an AC or DC power, the experimental design process parameters are formed by literature survey as the shielding gas and temperature (i.e. the temperature due to the current supplied in electrode) has maximum impact on welded joint.
The TIG Welding process is by heating the electrode by connecting it to a power supply and for Aluminium Alloy AA5083 there should be a change in polarity of electrode and workpiece, therefore, an AC power supply is used and the base material to increase the efficiency of heating to form a weld joint. The filler material can be used for welding the material which is highly mixed with the Aluminium Alloy AA5083 is AA5183 where the filler rod diameter is 3.14 mm, Electrode material-Tungsten, as it has a max of 98% of tungsten (W) and 2% of zirconium (Zr), the diameter of tungsten electrode, is 3.15 mm are the respective parameters and the power supply and flow of gas parameters are tabulated below.

| Sample No | Welding Current (A) | Shielding Gas Flow Rate (l/min) |
|-----------|---------------------|-------------------------------|
| 1         | 200                 | 15                            |
| 2         | 250                 | 10                            |
| 3         | 200                 | 10                            |
| 4         | 250                 | 15                            |

As Aluminium alloy is prone to the formation of oxide so while welding with the help of heat formation of oxide is high so to prevent from the formation of oxide shielding gas is used as it restricts alloy AA5083 from reacting with atmospheric oxygen and nitrogen, the oxidation potential of shielding gas decides the strength and toughness of the weld.

![Figure 6. TIG-welded specimen.](image)

### 4. Vickers Hardness

The Macro Vickers Hardness of the welded joint part of the specimen was tested by Vickers Hardness Tester and the indenter used for testing was diamond intender which forms a rhombus structure at different zones of weld area. The specimen’s hardness was found by applying 5Kgf of load, and according to the horizontal lines using the distance between the indentations of 0.5-1.0mm as rhombus, the structure is measured. The hardness value is measured in three places on Heat Affected Zone (HAZ), Nugget zone and Thermo Mechanical affected zone (TMAZ).
Figure 7. Plot for Vickers Hardness of different samples from the test.

![Vickers Hardness of FSW](image)

Figure 8. Plot for Vickers Hardness of different samples from the test.

![Vickers Hardness of TIG](image)

The Vickers Hardness value of sample 7 of FSW sample has the highest hardness value of 90 HV and the lowest value of 61 HV and TIG sample 4 has the highest 80.7HV in the welded area from this we conclude by the analysis of the hardness values that FSW sample has higher surface hardness value than TIG-welded sample value.
5. **Tensile Strength**

The tensile strength test specimens were designed and prepared according to equivalent American Standard ASTM E8[^5]. The specimen is prepared in such a way that the fracture elongation is measured for 50 mm in the centre of the weldment. After the tensile test, fracture locations of the specimens were measured to find the percentage of elongation, Tensile Strength. The width and thickness of the weld area are measured before and after the tensile test. The ASTM E8 standard dimension of the test specimen.

![Figure 9. The dimension of test specimen according to ASTM E8 standard.](image9)

![Figure 10. The tensile test specimen.](image10)

![Figure 11. The test specimen after the tensile test.](image11)

[^5]: ASTM E8 standard
Figure 12. Plot for Tensile strength of different samples from the test.

From the Ultimate Tensile Strength (UTS) test for Friction Stir Welding (FSW) is analysed and the best sample is selected, and the selected sample was sample 8 which has the parameters as 1500 rpm, 20mm/min and a pin profile as cylindrical pin profile. The Tensile Strength of sample 8 which has 138.378 MPa.

Figure 13. Plot for Tensile strength of different samples from the test.
6. Result and Discussion

Figure 14. The Comparative plot for Proof Stress.

Figure 15. The Comparative plot of the tensile strength of the test specimen.

Figure 16. The Comparative plot of percentage elongation of the test specimen.
6.1. Taguchi Analysis of Friction Stir Welded samples

Table 5. Design Summary.

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

Table 6. 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 7. Prediction for best efficiency.

| S/N Ratio | Mean | StDev | Ln (StDev) |
|-----------|------|-------|------------|
| 40.0863   | 106.5| 28.9914| 3.13996    |

Design Summary

Factors: 2 Replicates: 1
Base runs: 13 Total runs: 13
Base blocks: 1 Total blocks: 1

α = 1.41421

Two-level factorial: Full factorial
Figure 17. Plots for Main Effects for SN ratio based on Taguchi Analysis.

6.2. Taguchi Analysis of Tungsten Inert Gas Welded samples

Table 8. Design Summary.

| Taguchi Array | L4(2^2) |
| Factors: | 2 |
| Runs: | 4 |

Table 9. Response Table for Signal to Noise Ratios
Larger is better.

| Level | Current (Amps) | Shielding gas (l/min) |
|-------|----------------|-----------------------|
| 1     | 38.55          | 38.42                 |
| 2     | 38.44          | 38.57                 |
| Delta | 0.11           | 0.15                  |
| Rank  | 2              | 1                     |

Table 10. Prediction for best efficiency.

| S/N Ratio | Mean | StDev  |
|-----------|------|--------|
| 39.0832   | 96.956 | 31.0151 |
From the experiment and results being analysed, the plots based on tensile strength, percentage elongation, proof stress, and Vickers hardness as the respected values are compared as an efficient parameter for FSW is found by L9 Taguchi method by using Minitab software as sample 8 in FSW welded workpieces and sample 3 of TIG-welded workpiece were taken for comparison of the efficient welding method. The comparative plots show that the FSW is a more efficient method compared to TIG welding method as the tensile strength of the FSW sample is greater than the TIG-welded sample with a higher percentage of elongation.

7. Conclusion
The result from the test for FSW material is analysed by Taguchi L9 array method where the SN (Sound to Noise) Ratio is found with the condition larger is better and the parameters found out to be of 1500 RPM, 24 mm/min and with hexagonal tool profile same as FSW, TIG Welding samples result is analysed and found that sample with shielding gas flow of 15 l/min and current of 250 Amps is best to input for TIG Welding, the SN ratios of the Welding Techniques were compared. Tensile test results show that FSW joints have higher strength and higher ductility compared to TIG joints. FSW joint exhibited higher strength values compared to TIG joint. FSW is very competitive because it saves energy due to less heat input, prevents joints from fusion related defects. Heat-affected zone of friction stir welding is narrower than TIG welding process found from Macro Vickers Hardness test. From the technical and management perspective, FSW has better strength and is a cost-effective process than TIG welding.

8. Reference
[1] Bodukuri AK, Eswaraiah and Rajendar K 2017 Comparison of Aluminum Alloy 5083 properties on TIGW and FSW Processes Materials Today: Proceedings 4 10197-201
[2] Shukla R and Shah PK 2010 Comparative study of friction stir welding and tungsten inert gas welding process Indian Journal of Science and Technology 3 667-71
[3] Ahmed Khalid Hussain, Abdul Lateef, MohdJaved and Pramesh.T Influence of Welding Speed on Tensile Strength of Welded Joint in TIG Welding Process. *International Journal of Applied Engineering Research* 3 0976-4259

[4] Harinder Singh Grover, Vikas Chawla and Gurbhinder Singh Brar 2017 Comparing Mechanical and Corrosion Behaviour of TIG & FSW Weldments of AA5083-H321 *Indian Journal of Science and Technology* 10

[5] ASTM American Society for Testing and Materials 2019 Standard test methods for tension testing of metallic materials *ASTM international*

[6] Saravanakumar R, Krishna K, Rajasekaran T and Siranjeevi S 2018 Investigations on friction stir welding of AA5083-H32 marine grade aluminium alloy by the effect of varying the process parameters *InIOP Conf. Ser. Mater. Sci. Eng* 402 1-12

[7] Arun Narayanan, Cijo Mathew, Vinod Yeldo Baby and Joby Joseph 2013 Influence of Gas Tungsten Arc Welding Parameters in Aluminium 5083 Alloy *International Journal of Engineering Science and Innovative Technology (IJESIT)* 2

[8] Gori Y and Verma RP 2017 Experimental fatigue life estimation of AA5083 aluminium alloys welded by two welding processes-gas metal arc (GMA) welding and friction stir welding (FSW) *Journal of Graphic Era University* 5 10-5

[9] Firouzdar V and Kou 2009 Al-to-Mg friction stir welding: effect of positions of Al and Mg with respect to the welding tool *Welding Journal* 88 213-24

[10] M Shiva Chander, P Satish Kumar and Aruri Devaraju 2017 Influence of Tool Rotational Speed and Pin Profile on Mechanical and Microstructural Characterization of Friction Stir Welded 5083 Aluminium Alloy *ICMPC*