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EXPERIMENTAL ANALYSIS ON ALUMINUM ALLOY 5083 WELDMENTS USING PULSED TIG AND FRICTION STIRE WELDING PROCESS

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Abstract— **This study presents some research on the use of friction stir welding (FSW) and pulsed tungsten inert gas (PTIG) for the welding of aluminium alloy AA5083. Investigations into the mechanical, microstructural, and chemical characteristics of the weldments were conducted through both individual and comparative examinations of various welding methods.**

The review of the literature indicates that PTIG welding and FSW operations on AA 5083 material are less common. Additionally, there isn't much information on the comparison research between PTIG and FSW on AA 5083 in the previously published work. The optimal PTIG and FSW process parameters are recommended by this study effort in order to weld stronger weldments.

Current is provided in a sinusoidal pattern at a regular frequency from a lower level to a higher level during PTIG welding. The current's lower level, known as back current, creates a steady arc. Peak current is a higher level current that provides superior penetration and bead shape. The resistance provided during the welding process determines which filler material is used in PTIG.

The solidus state welding procedure known as FSW uses a spinning cylindrical tool made up of a profiled pin and shoulder. The tool in this procedure spins and is gradually inserted into the margins of the two weld plates. Process variables and mass flow rate affect how much heat is generated in FSW.

Three chosen process parameters were the basis for complete factorial experiment designs in both welding processes. We carried out a total of 27 trials in both welding procedures, holding two parameters constant and altering one. In this work, 4 mm of AA 5083 alloy is employed as the base material. The test specimens were created in compliance with industry standards for welding. Both weld techniques employed the same material and weld samples. Three welding parameters are chosen for PTIG welding: filler rod diameter, gas flow rate, and welding current. In this investigation, an ER 5356 electrode with three diameters—1.6 mm, 2.4 mm, and 3.2 mm—is employed. Three welding parameters are used for FSW welding: tool tilt angle, welding speed, and tool rotational speed. In this procedure, a Flat Tool H13 material with an 18 mm diameter and 3.7 mm length is made and used.

In this study project, the following five mechanical and chemical characteristics of weldments are examined. Impact Energy (IE), Yield Strength (YS), Tensile Strength (TS), Micro Hardness (MH), and Percentage of Elongation (PE). The base metal TS was found to be greater from the trials than the TS and YS of the PTIG and FSW weldments. However, compared to PTIG tensile strength weldments, the TS and YS of FSW weldments are greater. Compared to PTIG, FSW welded samples had a greater percentage of elongation. Compared to PTIG joints, the average impact energy in FSW was somewhat higher, although it was lower than in base metal. This could have occurred as a result of FSW's superior stirring effect.

Hardness was found to be somewhat enhanced at the weld location in FSW. Because of the welding heat during PTIG, the hardness in the weld zone was somewhat reduced. Based on all of the experimental research, it was shown that FSW welding performed better overall than PTIG welding.

Index Terms— **FSW, AA 5083, PTIG, Mechanical testing etc.**

I. INTRODUCTION

The technique of uniting two metals by heating, melting, applying pressure, and adding filler metal to produce a metallic connection is known as welding [1].

A. NEED FOR WELDING

With the development of technology, several sophisticated welding techniques have been created. It would satisfy the need for increased manufacturing rates, automation, and accuracy. The production rates and quality of welding may be anticipated to increase with the use of innovative techniques and automated machinery.

B. ALUMINIUM AND ALLOYS

Strong and electronegative metals like aluminium are rare. It is not entirely contained within the 19th century. The alkali metals' isolation has allowed for the availability of a potent reducing agent [4].

1) The oxide film in AA 5083

A thin layer of outer oxide is immediately applied to the surface of Al metal when it is exposed to the outside environment. This oxide coating deforms and degrades the material very fast. Within a day, a limiting oxide layer thickness of 2 to 3 nm (nanometers) will be generated at ambient temperatures [7].

2) Welding of AA 5083

Pressure vessels and automobiles are among the things made using this kind of welding. These materials have a high strength. For this reason, traditional welding techniques are inappropriate for certain kinds of materials. For these kinds of metals, PTIG and FSW are better options. The material grade, appropriate welding parameter selection, and welding technique all affect the quality of the weld.

C. ADVANTAGES OF TIG WELDING

- Best for welding both ferrous and nonferrous metals;
- No flux is utilised, thus slag production occurs throughout the welding process;
- For welding of narrow concentrated area welds.
- Spatter and fumes are not produced during welding; instead, shielding gas is utilised to protect the weld pool and generate better-quality weld.

Behavior of material AA 5083

- The 5083 AA, It has an exceptional combination of weldability, corrosion resistance, and manufacturing economy. 4.9%–4.9% of it is magnesium.
- The non-heat-treatable, medium-strength alloy AA 5083. Magnesium gains strength in proportion to its quantity.
- When welding Al alloys, porosity and cracking are the main causes for worry. Low porosity and cracking are visible during the welding process in AA 8083.

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D. ADVANTAGES AND APPLICATIONS OF PTIG WELDING

In case thin metals being worked on are susceptible to distortion when heat is applied. The best option in such case would be a PTIG welding. There is considerable control over heat input with this method of welding. It is possible to get the highest quality weld, and certain PTIG welders provide a pulsing process. The benefits of welding are listed below.

- Welding thin metal sheets.
- PTIG To achieve sufficient penetration into the metal, the welding arc must be precisely focused on the weld joint.
- Less welding power is required, and it offers a certain amount of speed, control, and precision [8].

Uses

- Dissimilar welding is welded.
- Welding unevenly sized work pieces.
- Welding thin copper, manganese, aluminium, and stainless steel sections.
- The centrifuge basket's welding.

E. ADVANTAGES AND APPLICATIONS OF FSW

- Some of the FSW process advantages are listed below.
- FSW suits for quantities ranging from prototype to high production.
- It is environmentally friendly method and it does not require any consumable like flux and filler wire.
- It is suitable for welding of irregular cross sections.
- FSW provides welding of dissimilar materials.
- It reduces maintenance cost.
- FSW is accurate, precision and repeatable process.
- In a long welding it maintains excellent welding qualities with low distortion.
- Compare with fusion welding process its energy is very high [9, 10].

Applications

- Welding of automobile parts
- Welding of ship building parts
- Welding of aerospace parts

F. OBJECTIVES

The goal of the research project was to determine the mechanical characteristics and microstructures of FSW and PTIG welded joints on 4 mm thick AA 5083 material. The optimal process parameters for producing weld joints with improved strength and quality are suggested by the study work. Three sizes of Electrode ER 5356—1.6 mm, 2.4 mm, and 3.2 mm—are utilised in PTIG welding. H13 material was utilised in FSW welding on AA 5083 material using a flat tool.

- To research the mechanical characteristics of weldments on PTIG and FSW processes, including microhardness, yield strength, impact strength, percentage of elongation, and tensile strength.
- To suggest a filler rod diameter in PTIG that works well for welding AA 5083.
- To identify the best tool for FSW.
- To contrast the PTIG and FSW welding processes' mechanical characteristics on AA 5083.

G. SIGNIFICANCE OF THE RESEARCH

The research project's objective is to identify the ideal welding settings for high-quality weldments by conducting experimental investigations on 5083 aluminium alloy weldments utilising friction stir and pulsed TIG welding methods. An analysis was conducted to determine the optimal welding procedure by comparing FSW with PTIG welding.

II. LITERATURE SURVEY

Sasidharan et al. employed the low thermal characteristic material AA 2219 in their investigation. TIG and FSW welding is handled by DCSP. An FSW configuration has been developed in a conventional vertical milling machine to produce welds. Their research indicates that friction stir welding raises UTS and PE whereas TIG causes a decrease.

Malarvizhib et al. studied the effects of fatigue fracture on three welding procedures (GTAW, FSW, and EBW) by looking at AA 2219. A tensile test was performed on the weldments. Because of its fine grain composition, friction stir welding has been demonstrated to have superior fatigue fracture development resistance when compared to GTAW and EBW.

Zhen et al. compared the characteristics of Al-Mg-Mn-Sc-Zr alloys using TIGW and FSW. Determining the mechanics and microstructure of welds is the aim of the study. The friction stir welding joints have a stronger bond than TIGW. The FSW nugget zone has better grain formation than the TIG weld molten zone.

Research on FSW and TIG welded Al-Mg-Sc alloy weld plates was done by Zhao and associates. The influence of the mechanical and metallurgical properties is analysed. The results demonstrated that FSW has better mechanical properties than TIG welding. The YS and TS are higher than the TIGW joint.

Cabello et al.'s evaluation of the literature contrasts solid state and fusion welding. For their investigation of the mechanical and microstructural characteristics, they selected the alloys Sc, Mg, and Al at 4.5 and 0.26, respectively. The results show that friction stir welding has less of an effect on hardness than tungsten inert gas welding.

III. EXPERIMENTAL WORK

A. PULSED TIG WELDING

With pulsed TIG welding (PTIG), welding current is delivered in a sinusoidal pattern at a regular frequency from a lower level to a higher level. Back current is the term for the lower level of the current. A stable arc is produced by the back current. Heat is transferred to the base metal during brief periods of lower level current. in a way that results in a small heat-affected zone. Peak current is a higher level current that provides superior penetration and bead shape. The fact that sufficient heat is provided during peak current pulses to melt the base metal is another key benefit of this type of welding. Over the course of the welding process, steady heat is delivered in a TIG welding. However, with PTIG welding, the heat source automatically cuts off when the base metal melts at the desired temperature. More heat is transferred to the base metal in this way. Thin sheet welding and tube joining are the best applications for this kind of welding. Actually, because the heat input cannot be controlled, welding thin sheets is quite challenging. We can prevent burn through and excessive penetration when we weld using this technique. Numerous studies have led to the conclusion that PTIG welding improves the fusion zone's grain size while also reducing the HAZ width. The weldments' mechanical qualities are significantly enhanced as a result of this phenomenon. The figure 3.1 illustrates the PTIG welding process.

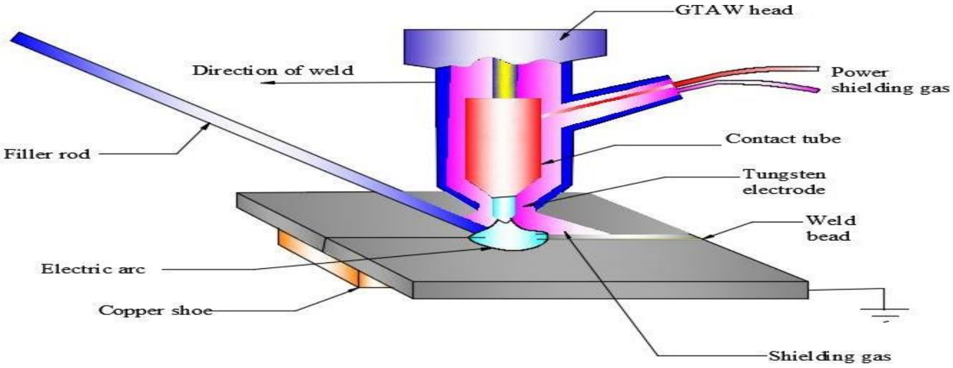

Figure 3.1 PTIG Welding Process
(Courtesy: Shodhganga.inflibnet.ac.in)

A 500 Watt PTIG AC/DC welding machine with AC and DCSP was utilised in this study to weld AA 5083. Figure 3.2 illustrates how the equipment is configured.Table 3.1 lists the equipment characteristics and weld settings.

Figure 3.2 PTIG Welding Machine- Model AC/DC

Table 3.1 Specifications of PTIG Welding Machine

S.No.	Description	Detailed Specification
1	Welding machine type	Pulse TIG AC/DC 500 welding machine
2	Input voltage	415 V
3	Phase	3 phase
4	Frequency	50 Hz
5	Power factor	0.9
	Pulse weldingfrequency	Conventional pulse frequency from 0.5Hz to 10 Hz Sophisticated variable HF pulse 15 KHzor higher mechanical frequency control, according to the welding current.
7	Welding polaritycontrols	AC with sinusoidal, triangular and square wave forms selection option. DCSP
8	TIG torch cooling system	Water cooled

B. FRICTION STIR WELDING

In 1991, the United Kingdom's Welding Institute (TWI) created the FSW welding procedure [9]. This procedure unites all alloys made of aluminium and magnesium. When compared to the TIG and MIG procedures, this is the method best suited for Al alloys. It is a solidus state welding procedure with a non-consumable spinning cylindrical welding tool. The cylindrical tool is made up of a profiled pin and a shoulder. The instrument spins and inserts itself gradually into the margins of the two fused plates. The plates' alignment and clamping are crucial. The first cylindrical tool gently plunges into the work item after touching its edges. The instrument plunges up to its shoulder, making contact with the workpiece. The change and appropriate material mixing occur when tool travelling begins. In this procedure, the materials of the tools and the welding factors are crucial. The pace at which material flows in mass and heat is generated depends on the welding parameters. Figure 3.3 displays the schematic diagram for the FSW Process.

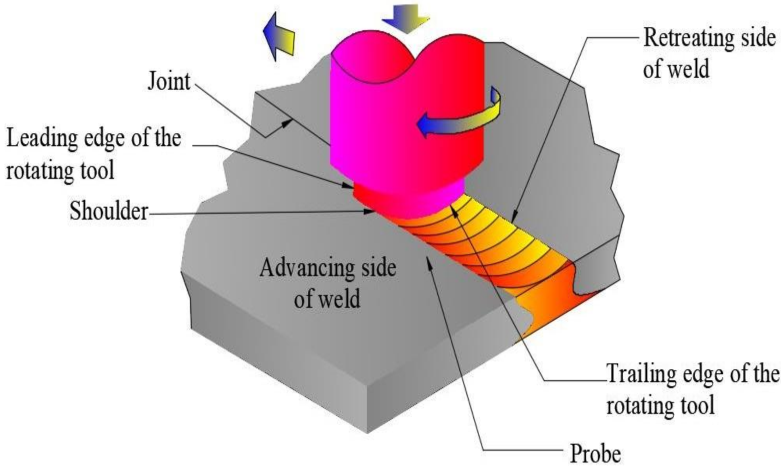

Figure 3.3 Schematic Diagram of the FSW Process
(Courtesy: material science and engineering)

The work piece is securely secured to the work table in a straight forward butt joint to stop it from moving as a result of the lateral, longitudinal, and vertical forces that are produced. Generally speaking, the probe height is marginally less than the thickness of the work piece. The shoulder then makes contact with the work piece surface after its vertical penetration into the item is heated. Using a downward forging force instead of further frictional heating aids in the material's softening. Mostly, it works well with basic butt joints. In FSW, the tool rotates at a slow speed, and it advances longitudinally slowly when the heat approaches the plastic state. Therefore, welding only occurs when the material is plastic and does not require filler rods or other consumables.

C. PREPARATION OF BASE MATERIAL

Base Material is AA 5083 plates having a thickness of 4 mm is used in this research work. Same material and weld preparation used for PTIG and FSW. The test specimens were prepared in accordance with the practice followed in the welding industry. All the work piece samples were cleaned thoroughly. In order to avoid like dust, scale and rust are cleaned mechanically and chemically.

D. SELECTION OF PROCESS PARAMETERS

The following welding parameters were selected based on extensive trial runs and pilot experiments.

- Work Piece thickness = 4 mm
- Welding Current (WC) = 180 A, 210 A, 240 A
- Gas Flow Rate (GFR) = 8 L/min, 10 L/min and 12 L/min
- Filler Rod Diameter (FRD)= 1.6 mm, 2.4 mm and 3.2 mm
- Tool Rotational Speed (TRS)= 700 rpm, 900 rpm, 1100 rpm
- Welding Speed (WC) = 60 mm/min, 80 mm/min and 100 mm/min
- Tool Tilt Angle (TTA) = 900, 90.50, 910

IV. RESULTS AND DISCUSSIONS

INTRODUCTION

In this chapter addresses the mechanical and micro structural properties of weldments. A comparative study of PTIG and FSW welding and their performance results are presented below.

A. MECHANICAL AND MICROSTRUCTURAL TESTS

Design of experiments was conducted for 09 samples on PTIG and FSW welded processes. The following mechanical and chemical properties of weldments are tested in research work.

- Tensile Strength (TS)
- Yield Strength (YS)
- Percentage of Elongation (PE)
- Impact Energy (IE)
- Micro Hardness (MH)

B. TENSILE TEST PROPERTIES

Tensile tests for all 09 samples—which are welded using the PTIG and FSW welding processes—were carried out on UTM. UTM creates the stress-strain curves using PTIG and FSW sample samples that are chosen. Table 4.2 contains a tabulation of all the pertinent data for TS, YS, and PE as read from S-S curves for all samples. We examined the base material AA 5083 in order to compare the weld qualities. The data in Table 4.1 includes TS, YS, and PE. The S-S curve may be seen in picture 4.1.

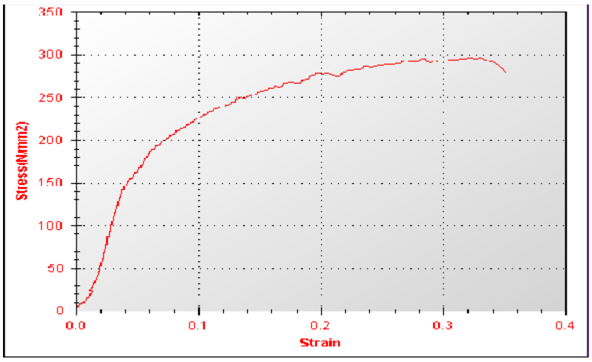

Figure 4.1 S-S Curve - BM-AA 5083

Table 4.1 Tensile test results for BM AA 5083

S. No.	TS in N/mm^2	YS in N/mm^2	PE in %
BM AA 5083	296	170	21

Table 4.2 Average TS, YS and PE of PTIG and FSW Weldments

S. No	Sample ID	Weldments	TS in N/mm^2	YS in N/mm^2	PE in %
1	SID1	PTIG 01	140	120	3
		FSW 01	220	150	4
2	SID2	PTIG 02	128	141	3
		FSW 02	240	155	5
3	SID3	PTIG 03	152	122	3
		FSW 03	265	159	7
4	SID4	PTIG 04	99	78	1
		FSW 04	179	136	3
5	SID5	PTIG 05	124	100	2
		FSW 05	235	152	6
6	SID6	PTIG 06	154	122	3
		FSW 06	250	152	6
7	SID7	PTIG 07	93	73	2
		FSW 07	160	135	11
8	SID8	PTIG 08	102	89	2
		FSW 08	209	141	8
9	SID9	PTIG 09	118	99	3
		FSW 09	227	139	6

The figure 4.2 represents the bar diagrams of TS, YS, and PEof PTIG and FSW, for comparative study.

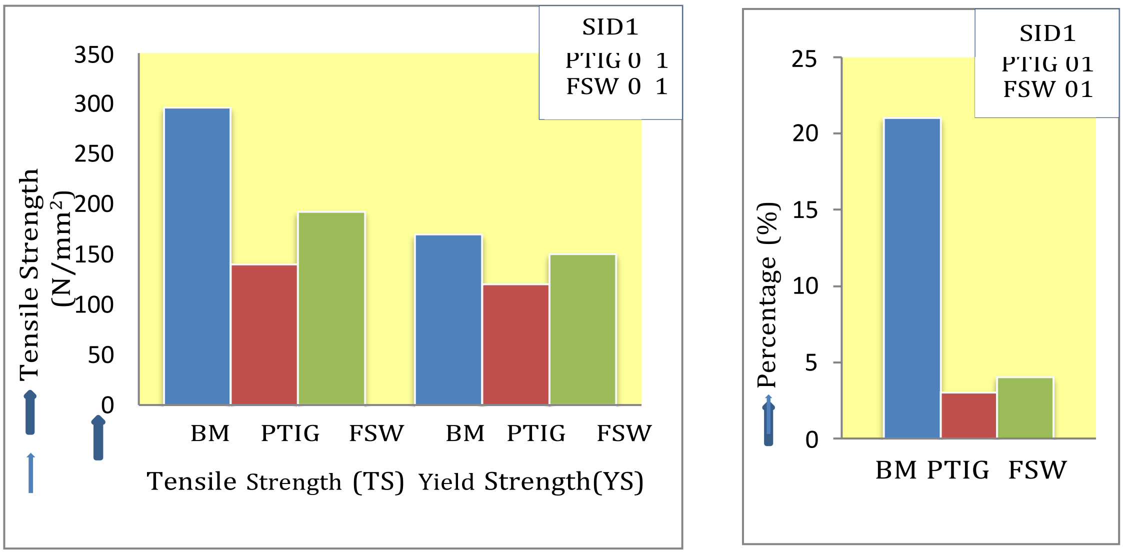

Figure 4.2 Comparison of TS, YS & PE - SID1

C. RESULT AND ANALYSIS OF PTIG WELDING

The impact of welding process parameters on mechanical qualities is examined in this section. It was spoken about TS, YS, and PE on the welded joints.

1) Effect of WC on TS, YS, and PE

PTIG welding experiments are performed to examine the effect of tensile strength on weldment for a certain FRD, WC, and GFR. Three WC have been chosen in this situation: 180 amps, 210 amps, and 240 amps. For the three FRD levels, they are 1.6 mm, 2.4 mm, and 3.2 mm. In the same manner, the GFR is 8 L/min, 10 L/min, and 12 L/min. Each variable significantly affects the weld junction's characteristics. The matching curves for the previously indicated parameters are displayed in Figures 4.3, and the results are tabulated in Table 4.2.

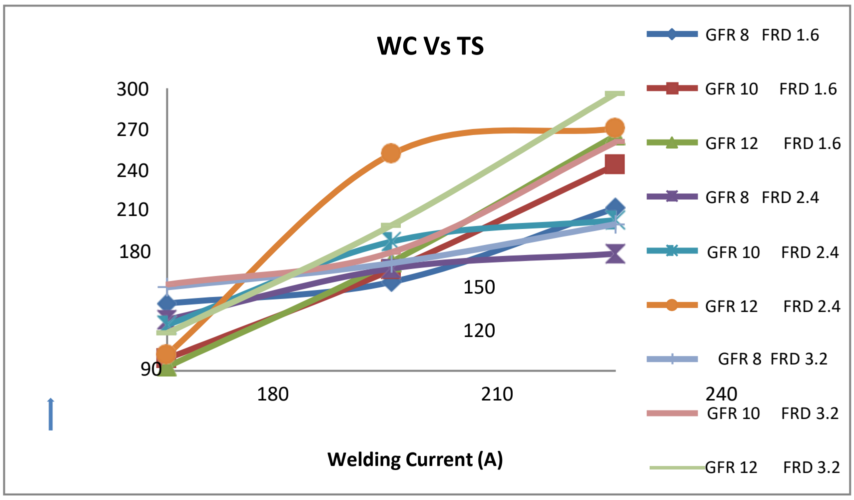

Figure 4.3 WC Vs TS

The data show that, when the WC rises from 180 to 240 Amps, the average tensile strength increases significantly because PTIG welding requires a greater current. Furthermore, it has been noted that YS and PE alter in accordance with the tensile strength attribute.

A crucial factor in PTIG welding is the work current (WC), which represents the overall propensity for weld spatter to occur at high current and filler rod sticking to occur at low current. The graphs show the same phenomena.

D. RESULT AND ANALYSIS OF FSW

The intended effort is broadened to include FSW in order to do a comparison analysis of FSW and PTIG welding properties. This section provides a detailed explanation of the FSW procedure and results.

The impact of welding parameters, such as TS, YS, and PE, on the mechanical properties of the welded connection is covered in this section. Failure happens when the specimen is subjected to uniaxial stress.

1) How TRS affects TS, YS, and PE

Tests are conducted on FSW to look into the effects of TS, YS, and PE mechanical characteristics on weldment for a certain TTA and WS.

In this context, three WS have been chosen: 60 mm/min, 80 mm/min, and 100 mm/min. Three TTA levels—900, 90.50, and 910—have been chosen. Each FSW variable affects the weld joint's TS, YS, and PE characteristics. Table 4.2 lists the outcomes of the previously indicated parameters, and Figure 4.4 displays the pertinent curves.

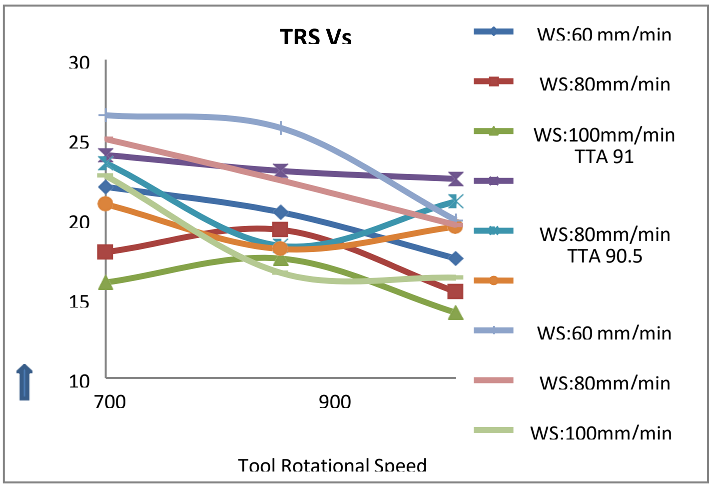

Figure 4.4 TRS Vs TS

2) Comparison of FSW and PTIG

An examination of the mechanical properties of FSW and PITG welding was done.

The average tensile strength of the PTIG and FSW weld joints was found to be 176 N/mm2 and 207 N/mm2, respectively, after the findings were examined. This implies that compared to BM, PTIG has altered by 40% and FSW has reduced by 30%.

The investigations' findings demonstrate that BM has a higher fundamental tensile strength than PTIG and FSW. However, FSW weldments have a higher tensile strength than PTIG weldments. This suggests that the strength of FSW welded joints is higher than that of PTIG welded joints.

The average YS of FSW and PTIG weld joints was determined to be 147 N/mm2 and 135 N/mm2, respectively, based on the result analysis. This suggests that, in comparison to BM, there is a 13% change in PTIG and a 7% decrease in FSW.

Both PTIG and FSW weldments have an average percentage of elongation of 5%. However, it is evident from every sample that the FSW welded samples had a greater percentage of elongation than the PTIG samples.

Test results show that, in comparison to BM, the TS and YS of the weldments are lower in both methods. On the other hand, TS and YS decline less in FSW than in PTIG.

E. IMPACT TEST

Nine samples that were welded using PTIG and FSW underwent impact testing. The Vickers hardness tester was used for all of the studies to determine the Impact Energy values of the welded potions. We examined the base material AA 5083 impact energy, which is displayed in table 4.3, in order to compare the weld qualities. Table 4.4 lists the Vickers hardness values for each sample. A comparison bar chart for the impact energies of BM, PTIG, and FSW is shown in Figure 4.5.

Table 4.3 BM AA 5083

Sample ID	IE in joules
BM-AA 5083	14

Table 4.4 Experimental Results of PTIG and FSW

S. No	Sample ID	Weldments	IE in Joules
1	SID 1	PTIG 01	8
		FSW 01	8
2	SID 2	PTIG 02	8
		FSW 02	10
3	SID 3	PTIG 03	6
		FSW 03	12
4	SID 4	PTIG 04	2
		FSW 04	10
5	SID 5	PTIG 05	4
		FSW 05	8
6	SID 6	PTIG 06	8
		FSW 06	12
7	SID 7	PTIG 07	4
		FSW 07	8
8	SID 8	PTIG 08	2
		FSW 08	4
9	SID 9	PTIG 09	4
		FSW 09	8

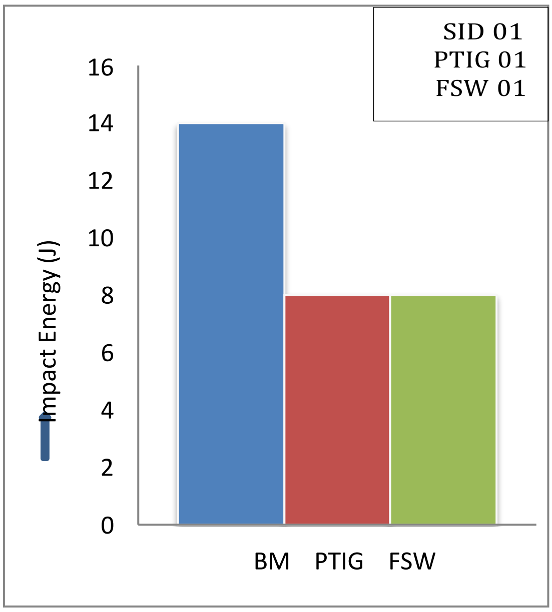

Figure 4.5 Comparison of IE – SID 1

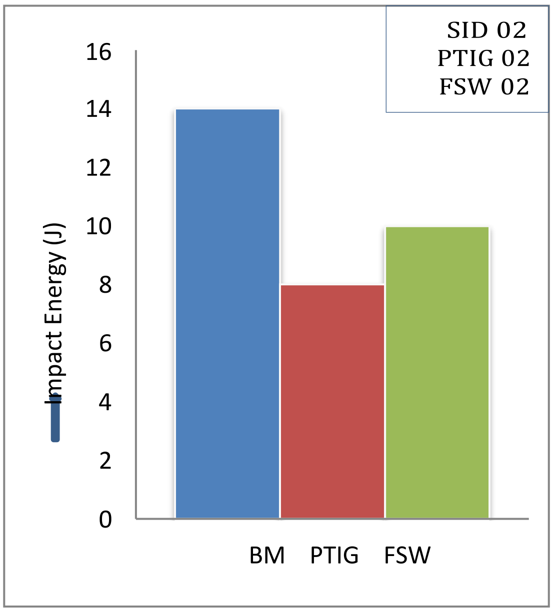

Figure 4.35 Comparison of IE –SID 2

F. MICRO HARDNESS TEST

The base metal micro hardness measured values are presented in table 4.5. The average Micro hardness tests samples result are presented in table 4.6.

Table 4.5 BM Hardness value

Sample ID	Micro Hardness in HV
BM –AA 5083	78

Table 4.6 Average Hardness Values of PTIG and FSW

S. No.	Sample ID	Weldments	Micro Hardness in HV
1	SID3	PTIG 03	73
		FSW 03	80
2	SID6	PTIG 06	72
		FSW 06	80
3	SID7	PTIG 07	75
		FSW 07	76
4	SID9	PTIG 09	74
		FSW 09	79

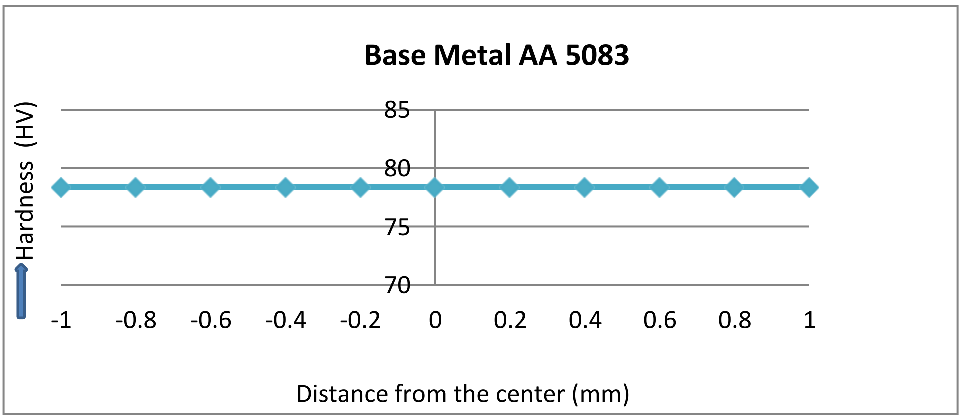

Figure 4.6 MH profile of BM - AA 5083

V. CONCLUSIONS

A. CONCLUSIONS

The goal of this research project is to determine the microstructures and mechanical properties of PTIG and FSW welded joints on AA 5083 material. The thickness of the plate is 4 mm in size. The study's findings recommend the ideal process variables to produce weld joints with improved strength and quality. Three sizes of Electrode ER 5356—1.6 mm, 2.4 mm, and 3.2 mm—are utilised in PTIG welding. H13 flat tool material was utilised in FSW welding.

The study work's general results are described in full below.

1. Based on the analysis of the results, the average Tensile Strength of FSW and PTIG weld joints was determined to be 207 N/mm2 and 176 N/mm2, respectively. This suggests that, in comparison to BM, there is a 40% change in PTIG and a 30% decrease in FSW.

2. Test results show that, in comparison to BM, the TS and YS of weldments are lower in both methods. On the other hand, TS and YS decline less in PTIG than in FSW.

3. It has been noted that in PTIG welding, the weld joint's tensile and impact strengths improve with increasing welding current.

4. It was noted in FSW that the weldment's tensile strength increases with decreasing weld speed. When the material is properly stirred at the weld zone during the welding process, this phenomena happens.

5. The yield of PTIG and FSW weldments is 5% and the average percentage of elongation is the same. However, it is evident from every sample that the FSW welded samples had a greater percentage of elongation than the PTIG samples.

6. It has been noted that Impact Energy increases with decreasing WC in PTIG welding. Additionally, it is noted that the grains are equally distributed at HAZ with smaller spacing at WC 210 amps and 180 amps. Ultimately, it is determined that the joint's impact toughness is greater at 240 A current.

7. Compared to PTIG joints, the average impact energy in FSW was somewhat higher, although it was still lower than in base metal.

8. It was seen in FSW that when the tool rotates faster, the heat input to the weld rises. The TMAZ and HAZ are enlarged by this process. As a result, the weldment's tensile strength declines.

B. Future Directions

- The existing research work can be extended, to find welding characteristics on materials like 6XXX and 7XXX Aluminium alloys.
- The existing work of single pass weld bead technique, can be extend to multi pass weld bead both welding processes.

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