Investigation on aisi 430 ferritic stainless steel weldment by Tig, Mig welding and continuous drive friction welding

G Senthil kumar¹ and R Ramakrishnan ²
¹Research Scholar, Sathyabama Institute of Science and Technology, Tamilnadu, Chennai.
²Professor & Head, Department of Sports Technology, Tamilnadu Physical Education and Sports University, Chennai.

E-mail: senthilingt@yahoo.com

Abstract. This work describes the study conducted on the macrostructure, microstructure and Tensile strength characteristic of AISI 430 Ferritic stainless steel joints by TIG Welding, MIG Welding and Friction Welding. A detailed analysis was conducted on mechanical property by ANOVA for each of the weldment. The output of the investigations exhibits that the weldment made by MIG has the high tensile strength (580 MPa) than the weldment made by FW (536 MPa) and TIG (492 MPa). The influence of process parameters on mechanical characteristics of weldment by MIG, TIG and FW were individually discussed. The fracture surface analyzed using SEM and found that FW weldment free from defects like carbide precipitation, stress corrosion cracking, sigma phase formation, high heat affected zone, joint distortion were usually occurs in stainless steel weldment by TIG and MIG. The microstructure of the weldment by MIG and TIG is found to be heterogeneous and the same is found by schaeffler diagram.

1. Introduction

Ferritic stainless steel contains chromium in the range of 11-30% and some other elements like nickel and manganese. They have high ductility and formability. It has a broad range of applications in the fields of steam turbine shaft, pump shaft, furnace parts, heat exchangers tubes, solar water heaters and beverage sectors. Friction welding, MIG welding and TIG welding methods are most economical and highly productive methods in joining of Ferritic stainless steel.

Good tensile strength and bend ductility, obtained by friction welding of stainless steel and aluminium with more upsetting pressure and opportune friction time [1]. Good weld could be obtained for joining of AISI 304 Austenitic stainless steel and AISI 4140 low alloy steel by TIG welding, EBW and FW [2]. Pulsed current TIG welding is gives good fatigue performance than continuous current gas metal arc welding for joining of aluminium alloy (AA7075)[3]. Friction welding is used to join AISI 430 ferritic stainless steel which gives 90 to 95% of base material’s tensile strength [4]. The copper and alumina joined by continuous drive friction welding process which tensile specimens failed at the aluminium interface due to the micro cracks [5]. The bonding of alumina and mild steel were achieved by friction welding process through narrow intermetallic phase formation and interfacial interlocking [6]. A low thickness stainless steel plate weldment achieved without burning by Key hole-TIG welding [7]. The content of CrN decreases and austenite increases in the case of 12 mm thick plate of duplex stainless steel deep penetration TIG welding [8]. A balanced austenite-ferrite
microstructure in the weld metal exhibited in the hyperbaric flux cored arc welding of duplex stainless steel [9]. The joining of copper with stainless steel achieved by DSAW TIG-MIG welding without preheating and grooving and tensile test reveals that optimal tensile strength of 229 MPa and fracture occurs at the copper side [10]. The CrN precipitation is gradually vanished and the austenite content increased in when the heat energy input in the range of 2-2.5kJ/mm for the welding of S32101 DSS by KTIG [11]. The toughness of the weld metal increased with an increase in austenite content of S32101 DSS plates welded by KTIG welding system [12]. Dissimilar weld between P92 steel and 304H austenitic stainless steel by A-TIG Welding obtained without any defects like undercut, porosity and lack of penetration [13]. Current applied is mostly influencing than gas flow rate for MIG welding of AISI 316L Austenitic stainless steel to obtain good strength of the joint [14]. High tensile strength obtained in arc-bracing joint compared with fusion welding for titanium alloy with stainless steel material combination [15]. This work presents the study on AISI 430 ferritic stainless steel welded by TIG, MIG and FW. Every weldment, studies were conducted on mechanical properties and microstructure behaviour.

2. Materials and methods
In this work experiments were conducted by gas tungsten arc welding, gas metal arc welding and continuous drive friction welding. The material employed in this is AISI430 Ferritic stainless steel and their composition available in Table1. The process variables used for GTAW, GMAW and experimental plan shown are table 2 and table 3 respectively. The process parameters used for friction welding and experimental plan are shown in Table 2 and Table 3 respectively. Samples welded by GTAW, GMAW were 150 x 50 x 10 mm size shown in Figure 1 and FW was cylindrical shape of diameter 12mm and length 100mm. Tensile test specimens were prepared by ASTM E8M and friction welded tensile test specimen shown in figure 2.

| Element | C  | Cr  | Ni  | Mn  | Si  | S   | P   | Mo  | Fe   |
|---------|----|-----|-----|-----|-----|-----|-----|-----|------|
| %       | 0.12 | 16.39 | 0.45 | 1.59 | 0.42 | Nil | 0.028 | 0.22 | balance |

Table 1. Base metal chemical composition

Figure 1. MIG Welded Samples.

Figure 2. Friction Welded Tensile Test Specimen.
Figure 3. Photograph of Tensile Fractured Weldment made by TIG.

Table 2. Process Parameters for MIG and TIG.

| S.No | Parameters      | Ranges               |
|------|----------------|----------------------|
| 1    | Current (A)    | 100 to 140 Amp       |
| 2    | Voltage (V)    | 12 to 16V            |
| 3    | Speed (mm/min) | 110 to 130 mm/min    |
| 4    | Electrode gap (mm) | 1 to 3 mm    |

Table 3. Experimental Plan-L9 Orthogonal Array.

| S.No | Arc Current (A) | Arc Voltage (V) | Travel Speed (mm/min) | Electrode gap (mm) |
|------|-----------------|-----------------|-----------------------|--------------------|
| 1    | 100             | 16              | 110                   | 3                  |
| 2    | 100             | 14              | 120                   | 2                  |
| 3    | 100             | 12              | 130                   | 1                  |
| 4    | 120             | 16              | 110                   | 1                  |
| 5    | 120             | 14              | 120                   | 3                  |
| 6    | 120             | 12              | 130                   | 2                  |
| 7    | 140             | 16              | 110                   | 2                  |
| 8    | 140             | 14              | 120                   | 1                  |
| 9    | 140             | 12              | 130                   | 3                  |

Table 4. Process Parameters for friction welding.

| S.No | Parameters            | Ranges            |
|------|-----------------------|-------------------|
| 1    | Friction Pressure     | 20 to 30 (MPa)    |
| 2    | Friction Time         | 3 to 7 (sec)      |
| 3    | Forging Pressure      | 40 to 50 (MPa)    |
| 4    | Rotational Speed      | 600 to 1000 (rpm) |
3. Results and discussion

To predict the quality of weld, the ultimate tensile strength of welded joint obtained by three different welding techniques such as MIG, TIG and FW as per ASTM E8M standard. All the specimens’ failure takes place in the joint interface in a ductile mode, it shows that joints have low tensile strength due to base metal composition affected by welding processes. Base metal UTS is measured as 560MPa but MIG welding gives maximum of 580MPa which is 3.57% greater than base metal while minimum of 552MPa which is 1.42% lesser than base metal. TIG welding produces maximum of 492MPa which is 12.14% less than base metal while minimum of 320MPa which is 42.85% lesser than base metal. In friction welding joint attains maximum of 536MPa which is 4.28% less than base metal while minimum of 507MPa which is 9.46% lower than that of base metal. Welding of metal AISI430 by MIG, TIG and FW techniques produced satisfactory joints in terms of mechanical properties at atmospheric temperature. The UTS of joint made by MIG is higher than TIG and FW. In this work the Signal/Noise ratio has been selected as per criterion greater is best to maximize all the output result. The main effect plot for ultimate tensile strength has shown in figures 4, 5 and 6 for MIG, TIG and FW respectively. This plot developed using MINITAB software. The rank (1) in Table 7 shows that electrode gap is a most significant effect rank (2) speed, which is a more significant effect, while rank (3) voltage is significant effect and rank (4) current has minimum effect on MIG welding process.

Table 5. Experimental Plan-L9 Orthogonal Array.

| S.No | Friction pressure(MPa) | Friction time (sec) | Forging pressure (MPa) | Rotational speed (rpm) |
|------|------------------------|---------------------|------------------------|------------------------|
| 1    | 20                     | 7                   | 40                     | 1000                   |
| 2    | 25                     | 5                   | 45                     | 800                    |
| 3    | 30                     | 3                   | 50                     | 600                    |
| 4    | 20                     | 7                   | 40                     | 600                    |
| 5    | 25                     | 5                   | 45                     | 1000                   |
| 6    | 30                     | 3                   | 50                     | 800                    |
| 7    | 20                     | 7                   | 40                     | 800                    |
| 8    | 25                     | 5                   | 45                     | 600                    |
| 9    | 30                     | 3                   | 50                     | 1000                   |

Table 6. Mechanical properties of weldment by MIG, TIG & FW.

| Sample | Ultimate Tensile Strength (MPa) |
|--------|---------------------------------|
|        | MIG   | TIG   | FW    |
| 1      | 564   | 453   | 518   |
| 2      | 558   | 459   | 508   |
| 3      | 557   | 465   | 518   |
| 4      | 570   | 320   | 507   |
| 5      | 553   | 490   | 515   |
| 6      | 565   | 492   | 530   |
| 7      | 567   | 486   | 523   |
| 8      | 580   | 491   | 534   |
| 9      | 552   | 480   | 536   |
Table 7. S/N Ratio of UTS for MIG Welding.

| Level | Arc Current (A) | Arc Voltage (V) | Travel Speed (mm/min) | electrode gap (mm) |
|-------|----------------|-----------------|-----------------------|-------------------|
| 1     | 54.96          | 55.07           | 55.11                 | 54.91             |
| 2     | 55.00          | 55.02           | 54.96                 | 55.02             |
| 3     | 55.06          | 54.93           | 54.95                 | 55.10             |
| Delta | 0.10           | 0.14            | 0.16                  | 0.19              |
| Rank  | 4              | 3               | 2                     | 1                 |

Figure 4. S/N Ratio plot for Tensile strength of MIG welded AISI 430 Metals.

Table 8. S/N Ratio of UTS for TIG Welding.

| Level | Arc Current (A) | Arc Voltage (V) | Travel Speed (mm/min) | electrode gap (mm) |
|-------|----------------|-----------------|-----------------------|-------------------|
| 1     | 53.24          | 52.32           | 53.59                 | 53.52             |
| 2     | 52.58          | 53.62           | 52.32                 | 53.60             |
| 3     | 53.73          | 53.60           | 53.63                 | 52.42             |
| Delta | 1.14           | 1.30            | 1.31                  | 1.18              |
| Rank  | 4              | 2               | 1                     | 3                 |

Table 8 shows that Travel Speed of welding has a most significant effect, Arc voltage has more significant effect, electrode gap has significant effect and current has minimum effect on TIG welding process.
Table 9. S/N Ratio of UTS for Friction Welding.

| Level | Friction pressure(MPa) | Friction time(s) | Forging pressure(MPa) | Rotational speed(rpm) |
|-------|------------------------|------------------|-----------------------|-----------------------|
| 1     | 54.23                  | 54.25            | 54.44                 | 54.37                 |
| 2     | 54.27                  | 54.30            | 54.27                 | 54.32                 |
| 3     | 54.50                  | 54.45            | 54.30                 | 54.31                 |
| Delta | 0.27                   | 0.20             | 0.17                  | 0.06                  |
| Rank  | 1                      | 2                | 3                     | 4                     |

Table 9 shows that friction pressure has a most significant effect, friction time, which has a more significant effect, forging pressure has significant effect and rotational speed has minimum effect on Friction welding process.
4. **Macrostructure**

Joints produced by MIG, TIG and FW were fully penetrated. Macrostructure of the joints shown in figures 7-9. The width and depth of penetration are unlike for weldment made by above 3 joining technique. This is due to changes in parameters and energy input used in the different joining techniques.

**Figure 7.** Macrostructure of MIG welded AISI 430 Metals.

**Figure 8.** Macrostructure of TIG welded AISI 430 Metals.

**Figure 9.** Macrostructure of FW welded AISI 430 Metals.
5. Microstructure

In the MIG and TIG welding process rapid heating at a temperature of 750ºC, the microstructure of the Ferritic stainless steel nearer to the weld portion shows indication of carbide precipitation is shown in figures 10 and 11. The microstructure of the weldment is not homogeneous and variation in structure found by schaeffler diagram is shown in the figure 6. In Stainless steel welding, Schaeffler diagram is helpful for estimating the microstructure of the weld deposit. Schaeffler diagram contains chromium equivalent equations in X-axis and nickel equivalent equations in Y-axis. Ferrite raising elements are included in the chromium equivalent equations and austenite raising elements included in the nickel equivalent equations [16]. In this equation nitrogen element not included in nickel equivalent equations even as a strong austenite promoter. So it has been simply incorporated into the diagram at a constant value of 0.06wt%. The chromium and nickel equivalents are calculated to predict the microstructure of the weldment by following equations.

\[
\text{Cr-Equivalent} = \left[ \%\text{Chromium} + \%\text{Molybdenum} + 1.5\%\text{Silicon} + 0.5\%\text{Niobium} \right] \\
\text{Ni-Equivalent} = \left[ \%\text{Nickel} + 30\%\text{Carbon} + 0.5\%\text{Manganese} \right]. \quad [17]
\]

For base metal AISI 430

\[
\text{Cr-Equivalent} = \left[ 16.38 + 0 + (1.5 \times 0.41) + 0 \right] = 16.995 \\
\text{Ni-Equivalent} = \left[ 0.46 + (30 \times 0.13) + (0.5 \times 1.58) \right] = 5.15
\]

Filler metal for MIG Welding (AISI 347)

\[
\text{Cr-Equivalent} = \left[ 17 + 0 + (1.5 \times 1) + (0.5 \times 0.5) \right] = 18.75 \\
\text{Ni-Equivalent} = \left[ 12 + (30 \times 0.08) + (0.5 \times 2) \right] = 15.4
\]

Filler metal for TIG Welding (AISI 308)

\[
\text{Cr-Equivalent} = \left[ 21 + 0 + (1.5 \times 1) + 0 \right] = 22.5 \\
\text{Ni-Equivalent} = \left[ 12 + (30 \times 0.13) + (0.5 \times 2) \right] = 16.9
\]

As per Schaeffler diagram for MIG welding weld metal structure consist of 10% Ferrite and remaining Martensitic & Austenite. TIG Welding concern 10% Ferrite and 90% Austenite structure obtained. In friction welding microstructure obtained is same as that of base metal.

![Figure 10. Microstructure of MIG Welded AISI 430.](image-url)
Figure 11. Microstructure of TIG Welded AISI 430.

Figure 12. Schaeffler diagram for TIG and MIG welded AISI 430.
The microstructure of fractured surface of friction welded AISI 430 by scanning electron microscope shown in figure 13. The fracture takes place in the weld interface and coarser Ferritic features were observed. In addition to that well developed grain boundaries and extensive grain growths are noticed in the fracture surface.

6. Conclusions

1. Good tensile strength obtained by MIG, TIG and FW welding techniques for AISI 430 Ferritic stainless steel.
2. Maximum ultimate tensile strength obtained by MIG welding techniques which gives maximum of 580MPa which is 3.57% greater than base metal compared to TIG and Friction welding.
3. The microstructure of the weldment by TIG and MIG welding is heterogeneous but homogeneous structure obtained in friction welding.
4. The microstructure of the weldment obtained MIG Welding is combination of austenitic, Ferritic and martensitic but TIG welding is austenitic and Ferritic. There is evidence of carbide precipitation which tends to seriously impair the corrosion resistance.
5. The fracture surface of the weldment by friction welding is homogeneous and free from carbide precipitation and other defects.
6. The macrostructure shows diffusion is more in the case of MIG welding as compared to weldment by TIG and Friction welding.

7. References

[1] Kimura M, Suzuki K, Kusaka M and Kaizu K 2017 Effect of friction welding condition on joining phenomena and mechanical properties of friction welded joint between 6063 aluminium alloy and AISI 304 stainless steel Journal of Manufacturing Processes 26 178-87

[2] Arivazhagan N, Singh S, Prakash S and Reddy GM 2011 Investigation on AISI 304 austenitic stainless steel to AISI 4140 low alloy steel dissimilar joints by gas tungsten arc, electron beam and friction welding Materials & Design 32 3036-50

[3] Balasubramanian V, Ravisankar V and Reddy GM 2008 Effect of postweld aging treatment on fatigue behavior of pulsed current welded AA7075 aluminum alloy joints Journal of Materials Engineering and Performance 17 224-33

[4] Sathiya P, Aravindan S and Haq AN 2007 Effect of friction welding parameters on mechanical and metallurgical properties of ferritic stainless steel The International Journal of Advanced Manufacturing Technology 31 1076-82
[5] Li P, Li J, Dong H and Ji C 2017 Metallurgical and mechanical properties of continuous drive friction welded copper/alumina dissimilar joints Materials & Design 127 311-9
[6] Seli H, Noh MZ, Ismail AI, Rachman E and Ahmad ZA 2010 Characterization and thermal modelling of friction welded alumina–mild steel with the use of Al 1100 interlayer Journal of Alloys and Compounds 506 703-9
[7] Cui S, Liu Z, Fang Y, Luo Z, Manladan SM and Yi S Keyhole process in K-TIG welding on 4 mm thick 304 stainless steel Journal of Materials Processing Technology 243 217-28
[8] Shi Y, Cui S, Zhu T, Gu S and Shen X 2018 Microstructure and intergranular corrosion behavior of HAZ in DP-TIG welded DSS joints Journal of Materials Processing Technology 256 254-61
[9] Hu Y, Shi Y, Sun K, Shen X and Wang Z 2018 Microstructure and mechanical properties of underwater hyperbaric FCA-welded duplex stainless steel joints Journal of Materials Processing Technology 261 31-8
[10] Cheng Z, Huang J, Ye Z, Chen Y, Yang J and Chen S Microstructures and mechanical properties of copper-stainless steel butt-welded joints by MIG-TIG double-sided arc welding Journal of Materials Processing Technology 265 87-98
[11] Cui S, Shi Y, Cui Y and Zhu T 2019 The influence of microstructure and chromium nitride precipitations on the mechanical and intergranular corrosion properties of K-TIG weld metals Construction and Building Materials 210 71-7
[12] Cui S, Shi Y, Cui Y and Zhu T 2018 The impact toughness of novel keyhole TIG welded duplex stainless steel joints Engineering Failure Analysis 94 226-31
[13] Sharma P and Dwivedi DK 2019 A-TIG welding of dissimilar P92 steel and 304H austenitic stainless steel: Mechanisms, microstructure and mechanical properties Journal of Manufacturing Processes 44 166-78
[14] Ghosh N, Pal PK and Nandi G Parametric optimization of MIG welding on 316L austenitic stainless steel by Grey-Based Taguchi method Procedia Technology 25 1038-48
[15] Cheng Z, Huang J, Ye Z, Yang J and Chen S 2019 Butt brazing of titanium alloys/stainless steel plates by MIG-TIG double-sided arc welding process with copper filler metal Journal of Materials Research and Technology 8 1566-70
[16] Lee S, Lee CY and Lee YK 2015 Schaeffler diagram for high Mn steels Journal of Alloys and Compounds 628 46-9
[17] Prabakaran MP and Kannan GR 2019 Optimization of laser welding process parameters in dissimilar joint of stainless steel AISI316/AISI1018 low carbon steel to attain the maximum level of mechanical properties through PWHT Optics & Laser Technology 112 314-22