Studies on Stainless Steel 304 Samples Joined by Submerged Arc Welding, MIG Welding and Hybrid Welding

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Abstract. The present paper focuses on the characteristics of Stainless Steel304 welded joints by using Submerged Arc Welding (SAW), Metal Inert Gas (MIG) Welding and Hybrid Welding techniques. MIG welding with a current of 170 A, SAW welding with a current of 105 A, and hybrid welding with currents of 105/170 A are the welding stages used. Hardness, flexural strength, and tensile strength is measured in MIG, SAW, and hybrid SAW-MIG weldments. A SAW-MIG hybrid welded specimens of 105/170A has the highest tensile strength, flexural strength, and percentage elongation of 0.591kN/mm², 15.09KN and 57.143% respectively. SAW – MIG hybrid welding can also be recommended for high-tech industrial applications like nuclear, aerospace, food processing, and the automotive industry, as well as surgical devices, jewelry, food, and beverage manufacturing.

Keywords: Stainless Steel, MIG, SAW, Hybrid welding, Hardness, Tensile, Flexural Strength.

1. Introduction

Stainless steel (SS) is used in situations where the material must resist corrosion. They are divided into different categories depending on their microstructural behaviour at room temperature, such as ferrite, martensitic, precipitation hardening, duplex, and SS [1]. Due to its amazing welding characteristics, high corrosion resistance, non-magnetic design, and high formability, austenitic SS is the most common and widely used [2]. Weldability of SS304 is mostly thought to be arc and resistance welding methods. However, owing to the deposition of coarse grains and inter-granular Chromium-rich carbides nucleated along grain boundaries in the Heat Affected Zone (HAZ), which in turn weakens the mechanical properties of the joints being welded, conventional arc welding is often delicate for industrial uses [3]. MIG welding is an arc welding technique that uses a welding gun to heat and feed a continuous solid wire electrode into the weld pool [4]. MIG welding can be used to weld a wide variety of materials of different thicknesses, it can even dig deeper, which is particularly useful for industrial applications, and it can achieve faster welds. Alongside advantages, it also has few difficulties like instability of arc, burn-back, manual wire feeding, a greater number of sparks are generated while welding, more smokes and fumes, irregular formation of the weld bead which is uneven in nature. SAW is a kind of arc welding in which an arc is formed between a continuously fed electrode and the work piece (W/P) [5,6]. Using SAW one can weld strong weld, minimal fumes,
minimal arc light, less distortion; flux can be recovered up to maximum extent [6]. Alongside advantages, it also has few difficulties like welding can perform only on flat surfaces; one must take care of flux handling system as well, it is also limited to high thickness materials as well [7]. By incorporating a hybrid welding process that includes both MIG and SAW, hybrid welding is a revolutionary way to enhance and solve the drawbacks of the above-mentioned issues. For a modern MIG-SAW hybrid welding method, the first pass of welding will be achieved by SAW, and the second pass will be performed by MIG welding, to achieve a better weld with improved mechanical properties as opposed to actual MIG and SAW specimens [3]. All the welded samples of MIG, SAW, and Hybrid are later characterized based on hardness, tensile strength, and flexural strength.

2. Experimental Procedure

2.1. Materials and process selection

For the current investigative work SS304 was selected shown in figure 1, as the materials for welding. Before welding, the samples were of size 6mm thick austenitic SS304 plates were prepared by cutting, polishing & chemical cleaning. The sample SS304 plates as per ASTM standards with dimensions 100mm×20mm×6mm (for tensile test), 120mm×40mm×6mm (for flexural test), 120mm×40mm×6mm (for harness test) [8] were obtained. Later specimens were welded using all three welding techniques via MIG, SAW and MIG-SAW hybrid welding. While welding a minimum gap of 1mm is maintained between the specimens. This helps filler material to pass in between the specimens held for joining and makes it a strong weld. Chemical composition of SS304 is mentioned in table 1, followed by physical and mechanical properties in the table 2.

| Table 1. Austenitic304SS Chemical Composition in wt.%.
|---|---|---|---|---|---|---|---|
| Alloy Element | C | Si | Mn | P | S | Cr | Ni | Fe |
| Weight Percentage | 0.03 | 0.75 | 2.00 | 0.045 | 0.03 | 19.50 | 12 | Bal. |

| Table 2. Mechanical Properties of the 304 austenitic stainless steel.
|---|---|---|---|---|---|---|
| Property | Melting Point | Density | Modulus of Elasticity | Thermal Conductivity | Tensile Strength (MPA) | Thermal Expansion |
| Value | 1450°C | 8.00 g/cm³ | 193 GPa | 16.2 W/m.K | 540 -750 | 17.2 x 10-6/K |

The MIG welding was carried out on MIG welding machine and in the similar way SAW was carried out on SAW machine with carbon di oxide gas as the shielding gas. The diameters of the filler material (Mild steel) used for MIG and SAW welding are 1.2 &2.5mm respectively.
In hybrid welding SAW is the 1st pass that was performed on 304 SS plates through the gap we maintained b/w the plates, from the start of the specimen to the end of the specimen using the filler rod of diameter 2.5mm, after that within 5minutes followed by MIG as Second pass of welding on formerly welded beads by means of a filler diameter of 1.2 mm as shown in the figures 2 and 3 respectively. Further the different welding parameters for MIG, SAW and hybrid welding are presented in the table 3.

![Submerged Arc Welding Setup](image1)

![MIG Welding Setup](image2)

**Figure 2. Submerged Arc Welding Setup.**

**Figure 3. MIG Welding Setup.**

**Table 3. Parameters for samples prepared using MIG, SAW and hybrid welding [10].**

| Parameters              | MIG Sample | SAW Sample | Hybrid Welding |
|-------------------------|------------|------------|----------------|
|                         | Submerged  |            | MIG            |
| Current (A)             | 170        | 105        | 105            |
| Voltage (V)             | 26         | 20         | 20             |
| Filler Supply Type      | Manual     | Automatic  | Automatic      |
| Gas Flow Rate (L/min)   | 10-15      | N/A        | N/A            |
| Filler Material Diameter (mm) | 1.2 | 2.5 | 2.5 |
| Shielding Gas Type      | Carbon Di Oxide | N/A | N/A | Carbon Di Oxide |
| Welding Speed (Cm/Min)  | N/A        | 25         | 25             |

3. Results and Discussions

3.1 Test Sample visual Inspection

Figures 4a to d depict the physical appearances of the SS plates prior to welding. The top and bottom views for specimens being welded using hybrid welding technology are shown in figures 4a to d, and the Surface Visual Inspection of welded specimens is shown in table 4. After observing the weldments on both the sides (top and bottom) there are no spatters observed for three different weldments that are carried on austenitic SS 304 samples. The weld shape absorbed was narrow and weld bead width varied in between 3-5mm approximately [3].
Figure 4a–d. SS304 plates before and after welding.

Table 4. Surface Visual Inspection of welded specimens.

| Weld Properties            | MIG Sample  | SAW Sample | Hybrid Sample |
|----------------------------|-------------|------------|---------------|
| Spatters                   | No Trace    | No Trace   | No Trace      |
| Cracking                   | No Trace    | No Trace   | No Trace      |
| Slag Inclusions            | No Trace    | No Trace   | No Trace      |
| Under Cutting              | No Trace    | No Trace   | No Trace      |
| Excess Penetration         | No Trace    | No Trace   | Little Trace  |
| Incomplete Penetration     | No Trace    | No Trace   | No Trace      |
| Porosity                   | No Trace    | No Trace   | No Trace      |
| Uniformity of Weld Bead    | Un Uniform  | Uniform    | Un Uniform    |
3.2 Tensile Test Outcomes

The tensile strength test is conducted to find out how strong the material joint and helps us to find out how much the material may be stretched before it undergoes into failure. Yield strength, UTS, and ductility, as well as strain hardening properties, Young's modulus, and Poisson's ratio, are all determined using this test process. Figure 5 depicts a cross-sectional image of a specimen for tensile testing in accordance with ASTM E8/E8M-13a. From the SS sheet of 304, three samples of MIG, SAW and hybrid welding were cut for performing tensile test by taking the above-mentioned specimen dimensions [4]. It is also absorbed that; the entire deformed samples are fractured at the weld zone as shown in the figure 6.

![Cross-sectional view of specimen for tensile test as per ASTM E8/E8M-13a standard.](image)

![Fractured specimens of MIG, SAW and hybrid welding after tensile test.](image)

| Table 5. Tensile strength test outcomes for SAW [1]. |
|-----------------------------------------------------|
| 1. Maximum force | 24.360KN | 6. Reduction area (z) | 20.833% |
| 2. Displacement at max force | 20.200mm | 7. Gauge length | 105mm |
| 3. Max displacement | 23.000mm | 8. Width | 20mm |
| 4. Tensile strength | 0.203KN/mm² | 9. Area | 120mm² |
| 5. Elongation (%) | 23.810% | 10. Thickness | 6mm |
| 6. Final gauge length | 130mm | 12. Final area | 95mm² |
The UTS of the submerged arc sample is recorded as 0.203 KN/mm² table 5, same for the MIG welded sample is 0.409 KN/mm² table 6 and UTS of the hybrid welding is recorded as 0.591 KN/mm² table 7. The UTS of the welded specimens are shown in the figures 7, 8 and 9 for SAW, MIW and hybrid welding, respectively. The welding parameters shown have a significant effect on the UTS produced. The hybrid sample provided by hybridization of SAW and MIG welds at currents of 105/170 A has the highest UTS of 0.591 KN/mm² among the three welded samples evaluated in this study. Whereas lowest average UTS value of 0.203 KN/mm² was evaluated for SAW weld sample, which was welded at current of 105 A [3].
Table 7. Tensile strength test outcomes for hybrid welding.

|   | Description                  | Value       |
|---|------------------------------|-------------|
| 1 | Maximum force                | 70.890KN    |
| 2 | Displacement at max force    | 60.900mm    |
| 3 | Max displacement             | 61.000mm    |
| 4 | Tensile strength             | 0.591KN/mm²|
| 5 | Elongation (%)               | 57.143%     |
| 6 | Final gauge length           | 165mm       |
| 7 | Reduction area (z)           | 25.000%     |
| 8 | Gauge length                 | 105mm       |
| 9 | Width                        | 20mm        |
| 10| Area                         | 120mm²      |
| 11| Thickness                    | 6mm         |
| 12| Final area                   | 90mm²       |
| 13| Yield load                   | 46.650 KN   |
| 14| Yield stress                 | 0.389KN/mm²|

With a value of 0.409 KN/mm², the UTS of the MIG weld sample drop between the UTS of the other samples. The UTS is critical when choosing materials for structural applications that are likely to experience high overloads and need significant quantities of energy to be absorbed.

Figure 9a to c. different graphs of tensile strength tested hybrid welded samples.

Figure 10. UTS chart for the MIG, SAW and Hybrid welded joints.
The comparisons of the UTS of all the samples are presented in the figure 10. Form the figure 10, the hybrid joint is having highest UTS than the other two joints considered in the current investigation. This result of the hybridised joint is mainly attributed to the deeper penetration.

3.3 Hardness Test Outcomes for Welded Specimens

The hardness tests were conducted on all the three weldments with a hardness profile as shown in the figure 11 for welded samples. The hardness values of welded samples were determined by indenting 5cms from left of the weld to centre of the weld and to right of the weld. As tested on HRC scale, the hardness values rise from the left to the middle, then collapse to the right after reaching the peak values in welded samples. Figure 12 also shows that the welded zone has a small rise in hardness as comparison to both the left and right adjacent zones [3]. The repeated thermal cycles encountered during the welding process with the melting and solidification of the filler metal used result in an improvement in the hardness value at the weld zone. Figure 12 shows that nearly all the samples have a higher hardness value in the welding region than in the base material and heat effected zones. At the weld region, the sample of hybrid weld has the highest hardness value of 42HRC, while the sample of MIG has the lowest.
3.4 Flexural Test Outcomes

Table 8. Flexural strength test outcomes for MIG, SAW and hybrid welding.

| Parameters         | MIG Specimens | SAW Specimens | Hybrid Specimens |
|--------------------|---------------|---------------|-----------------|
| Peak load          | 11.73KN       | 10.17KN       | 15.09KN         |
| Displacement yield | 19.4mm        | 14.7mm        | 48.5mm          |
| Displacement       | 29.9mm        | 16.8mm        | 59.4mm          |
| Break load         | 5.28KN        | 4.140KN       | 7.53KN          |
| Yield load         | 11.13KN       | 10.32KN       | 12.39KN         |
| Display yield      | 15.5mm        | 16.2mm        | 18.7mm          |

Figure 13. Fractured specimens after flexural test.

The flexural strength of the welded sample is measured by using Blue Star Make Universal Testing Machine UTE-60. The figure 13 is presents the fractured welded specimen after flexural test. From the table 8, it can be deduced that maximum peak load of 15.09KN was achieved on hybrid welded sample and minimum peak load of 10.17KN was achieved on submerged arc welding and peak load of MIG welded sample lies between the remaining two. Same with the case of displacement as well, maximum displacement of 59.4mm was achieved on hybrid weld.

4. Conclusions and future scope

This project attempts to conduct a hybrid welding of SAW-MIG welding on austenitic SS304 grade by using mild steel as filler material, the significant conclusions are as follows:

- Better Bead is obtained on SAW when compared to MIG welding. Observed excess penetration in hybrid welding due to combined welding of MIG as well SAW.
- Deeper penetration is observed in case of MIG welding when compared to SAW due to higher deposition rate of filler material (which is uncontrollable factor due to manual feeding system of filler in MIG welding)
- Hybrid SAW – MIG welding of SS304 is possible with the excellent weld joint efficiency and with the excellent percentage elongation (57.143%) of the welded sample.
- Sample of Hybrid SAW-MIG Weld which is welded at 105/170A exhibits the highest UTS of 0.591 KN/mm², when compared with the other two type weldments.
- Maximum peak load of 15.09 KN was achieved on hybrid welded sample and minimum peak load of 10.17 KN was achieved on submerged arc welding and peak load of MIG welded sample lies between the remaining two. Same with the case of displacement as well, Maximum displacement of 59.4 mm was achieved on hybrid weld.
- SAW-MIG Hybrid sample at the weld region, weld has the highest hardness value of 42HRC, while MIG sample has the lowest.
- Lack of uniformity of welding is observed in MIG welding due to non-uniform feed rate of the filler material.

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