An Experimental Study on the Effect of Heat Input on the Weld Efficiency of TIG-MIG Hybrid welding of Type 304 Austenitic Stainless Steel

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Abstract- Welding is described as the process of joining metals so that bonding can be created as a result of inter-atomic penetration. This study investigated the impact of heat input on the efficiency of the welding joints of 304 stainless steel. Three welds joint were made from two similar 304 stainless steel plates of thickness 6 mm. The tensile strength outcomes acquired showed that apex average magnitude of 672 MPa is obsessed by the sample A1 with lower thermal input. It was discovered that the percentage elongation, tensile strength and weld joint efficiency decreased with the intensification in thermal input into the weld. The average % elongation for the entire samples ranged from 28.4 % to 36.5 %. Sample A1 had the highest joint efficiency of 94.5 %. However, the optimum welding current of 190 for TIG and MIG hybrid welding of type-304 austenite stainless steel can be recommended for advanced technological applications such as aircraft manufacturing, nuclear industry, automobile industry and processing industry.

Key words: Heat input, joint weld efficiency, microstructure, MIG-TIG hybrid welding, UTS.

1. Introduction

TIG welding of austenitic stainless steels using argon gas for shielding is limited to the highest metal thickness of 3 mm for a proper welding joint and to fairly low welding speed. Though, when hydrogen or helium is mixed with the shielding gas, then the welding speed can be considerably increased up to 160 % [1-3]. When MIG arc welding process is used as a substitute to the TIG arc welding process, it permitted the welding of a 6 mm thick welding joint in a single pass. However, the numbers of appearance flaws characteristically comprising undercut, humping and excess penetration welds were simply molded, which resist the additional development of production. Unsteadiness offered as weld bead roughness and spatter which exist in MIG welding are more than that of the TIG welding process [4]. The hybrid welding techniques of TIG and MIG welding processes is a significant approach of improving welding output and quality owing to the merit of the two methods [5]. TIG and MIG hybrid welding are economical, since neither unique protecting gas nor complex synergic powers are required. It demonstrates that MIG circular segment can be steady by straightforward hybridization of TIG despite the fact that unadulterated argon protecting gas is utilized, which implies
that, the welded metal's sturdiness is improved and welding quality is created [6]. Further investigation uncovered that it additionally has incredible possibility to build the welding speed with top notch in view of the very steady cathode spots showing up in the half breed welding [7-8]. The impact of TIG welding current on the welding properties like stability of the penetration depth, arc and repulsion between both arcs has been examined [9] as well as the heat input on 304 austenitic stainless steel [10]. There are no much researches conducted on the welding of type-304 stainless steel by the hybridization of TIG and MIG. However, in this study, 6 mm thick 304 stainless steel plates were welded by TIG-MIG hybrid welding and characterized through evolving microstructure, tensile strength and heat input.

2. Experimental methods

2.1 Base and filler materials

The parent metal used in this work was Type- 304 stainless steel of dimension 175 x 100 x 6 mm which was cut into smaller sizes with the aid of water jets cutting machine. Austenitic stainless steel filler rods of diameter 2.4 mm for TIG and 1.2 mm for MIG were used.

The chemical configuration of the base metal and the filler material used are shown in Table 1.

| Table 1: Chemical composition (wt. %) of the base metal and the filler rod used. |
|-----------------|---|---|---|---|---|---|---|
| Alloys Element  | C  | Si | Mn | P  | S  | Cr | Ni |
| Base Material   | 0.03 | 0.75 | 2.0 | 0.045 | 0.03 | 19.5 | 12 |
| Filler Rod      | 0.03 | 0.65 | 2.5 | 0.03 | 0.03 | 18 - 20 | 11.0-14.0 |

2.2 Welding procedure

In this research work, a single-groove method was used so that the welding process could be done in one pass for both TIG and MIG welding processes in order to ensure full weld penetration. All the edges of the base metal were mechanically and chemically cleaned carefully so as to eschew any source of impurity like dust, rust, moisture and oil, etc. on the welded joint during the welding process. The welding equipment, TIG 200P DC/AC THERMAMAX welding power source with the rated welding current of 200A and miller CP- 300 model MIG welding power source with rated welding current of 300 A were used for the hybrid welding of TIG and MIG. Two work pieces were lined together with welding gap of 4 mm.
Figure 1 shows the schematic view of the welding operation.

![Process schematic diagram](image)

**Figure 1: Process schematic diagram [11]**

Samples A1, A2 and A3 were made using the same 316 filler material of diameter 1.2 mm at different welding currents of 190 A, 210 A and 230 A respectively. The samples for micro hardness testing, tensile testing, and microstructure were taken from the welded pads. After grounding and polishing, the samples were ultrasonically wiped with acetone and dried off. The samples were etched after polishing stage for microstructural observation. The three specimens for each welding current were cut out from the weld pads according to the ASTM E8/E8M-13a standard [12].

3. **Results and discussion**

3.1 **Microstructures**

The microstructures of the welded samples are presented in this section. Figures 2 (a) to (c) show the microstructures of sample A1 welded at a current of 190 A. The welded zone, the transition zone and the heat affected zone (HAZ) are presented.
The weldment quality was observed at the front and back views of the jointed plate. There was no spatter and porosity observed at the weld joints. The weld shape is narrow and smooth with the width weldment of approximately 4 mm. In Fig 2 (a), columnar dendrites of austenite were observed in the weld zone towards the direction of the thermal input. In Fig 2 (b), segregation takes place in the transition zone along the grain banding as a result rate of cooling. In Fig 2(c), equiaxed ferrite grains were detected in the HAZ, and were extended towards the parent metal. The HAZs were measured to be 30 mm approximately in all the welds. A sound weld with complete penetrations was observed in sample A1 and little excess penetration were observed in the welds A2 and A3. It was noted that as thermal input decreases the inter-dendritic spacing and dendrite size in the welded sample also decrease. The intensity of the heat input gives room for coarse microstructure and therefore allows a slower cooling rate as the thermal input was amplified.
3.2 Tensile Strength

Then tensile tests were done to decide how strong the welds joint are. Three transverse samples were cut from each welds at starting point, centre and ending point of the welding line with the aid of a water-jet cutter as shown in Figure 3(a). Welds metal tests were performed on a tensile testing machine with an apex load of 100000N at crosshead rate of 3mm/min in agreement with the requirements of ASTM E8 standard.

The transverse tests was used to be sure that the weld joint sample does not crack before the failure occurs in the thinner region due to distortion. In this method, the thickness of the neck after distortion was taken as the initial thickness for estimate of the cross-section area as the rupture was predicted on the necking side. Each sample was drawn to failure on the Instron 5500R tensile machine as shown in Figure 3(b). The outcome of the tests were matched and the average values were calculated for the three welded samples. Figure 4 shows the ultimate tensile graphs, The UTS for all the samples from A1 to A3 were plotted alongside with their average. The tensile outcomes acquired uncover that most extreme normal tensile strength of 672 MPa is controlled by the example F4 which was made utilizing low welding current and thermal input combination pursued by 609MPa utilizing medium thermal input and the least esteem is 593 MPa which is the example made utilizing high thermal input combination. The high tensile strength and malleability are controlled by the joints at low thermal input, which might be credited to littler dendrite sizes and lesser between dendritic dividing in the combination zone [10].
Comparatively lower average UTS and ductility possessed by sample A3 (high heat input) may be accredited to larger inter-dendritic spacing and long dendrite sizes in the fusion zone.

The weld joint efficiency (WJE) is calculated for the samples. The WJE can be varied from 100 % for a flawless weld to 75 % for a tolerable weld [13]. However, the WJE of the welds produced in this research work is compared with the base material type 304 austenitic stainless. The WJE of the welds was calculated using Equation (1).

\[
\text{Weld joint efficiency (}\eta) = \frac{\text{UTS of the joint}}{\text{UTS of the parent material}} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots (1)
\]

Figure 5 shows the weld joint efficiency and percentage (%) elongation of the entire samples.
The joint efficiency ranges from 83.4 % to 94.5 % and the % elongation from 28.4 % to 36.5 % in a descending order from sample A1 to sample A3 respectively. All the welds samples have acceptable weld joint efficiency above 75 %, the highest was found to be sample A1 which was produced by currents of TIG- MIG hybrid of welding. This superseded the standard ultimate strength of 75 % of the base metal’s UTS value. The heat input generated for each sample was also calculated using the illustration of equation 2.

\[ H = \eta \times V \times \frac{I}{v} \]

Where H= heat input in KJ/min; \( \eta \) = efficiency in %; V = voltage in volts; I = current in Ampere and v = welding speed in mm/s [14].

Table 2 shows the summaries of the heat input and the average welding voltage for the welded samples.

| Welds samples | Welding Speed (mm/s) | Total Welding Current (A) | Average Welding Voltage (Volts) | Heat input KJ/mm |
|---------------|----------------------|---------------------------|---------------------------------|-----------------|
| A1            | 270                  | 320                       | 20.5                            | 1.378           |
| A2            | 270                  | 360                       | 24                              | 1.646           |
| A3            | 270                  | 400                       | 28                              | 2.224           |

It was noticed that as the tread of efficiency of welds is decreasing, the heat input was increasing and varied from 1.378 KJ/mm to 2.224 KJ/mm. This can be deduced that low heat input welds can produce a greater efficiency compared to high heat input welds. However, this attribute is as a result of the welding current used and it has also amount to a low efficiency compared to the sample welded at low current having a high efficiency. Thus, it can be deduced that low heat input welds can produce a greater efficiency compared to high heat input welds.

4 Conclusion

The following conclusions can be drawn from this study:-

- An excellent welded joint strength were displayed by all the welded joints which proved that TIG -MIG hybrid welding of type- 304 austenitic stainless steel is achievable for welding of 6 mm thick plate.
- It was found that the efficiency of the welded joint decreases with the increase in heat input.
- Notable grain coarsening is noticed in the heat affected zones of all the three joints and decreases in size with the decrease in heat input.
The size of the dendrite formation in the fusion zone is larger for sample A3 than the other participating samples.

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