Effect of Welding Current on Mechanical Properties and Microstructure of TIG Welding of Type-304 Austenite Stainless Steel

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Abstract-
The aim of this paper is to study the effect of welding current on the microstructure and the mechanical properties. Material characterizations were conducted on a 6 mm thick plates of type-304 austenite stainless steel, welded by TIG welding process at two different welding currents of 150 A (Sample F3) and 170 A (Sample F4). The tensile strength and the elongation obtained from sample F4 weld were approximately 584 MPa and 19.3 %; which were higher than sample F3 weld. The average micro hardness value of sample F4 weld was found to be 235.7 HV, while that of sample F3 weld was 233.4 HV respectively. Homogenous distribution of iron (Fe), chromium (Cr) and nickel (Ni) were observed at the welded joint of the two samples. The EDS analysis revealed that Fe, Cr, and Ni made up the composition formed at the weld zone. The optimum welding current of 170 A for TIG welding of type-304 austenite stainless steel can be recommended for high-tech industrial applications.

Key words: Mechanical properties, micro hardness, microstructure, TIG welding, welding current.

1. Introduction
When an arc is created amongst a non-consumable tungsten electrode and the metallic materials that are welded, tungsten inert gas (TIG) welding is obtained. Gas is supplied with the aid of the torch to protect the liquefied weld pool as well as the electrode [1]. Whenever a filler wire is applied, it is noticeably added to the weld pool. TIG is extensively applied in welding thin sections of non-ferrous metals like magnesium, aluminum and copper alloys, as well as stainless steel. The process fosters the TIG welding process is used widely in industries for welding stainless steel due to its arc stability, less contamination in its welds, higher quality weld and smooth head appearances [2]. One of the biggest advantages of this process is that the power can be controlled really low so that the material is not damaged [3]. However, the arc is sometimes influenced by electromagnetic forces and the arc track deviate suddenly. Consequently, it will be difficult to attain a comprehensive welded links in such circumstances. And also, the permeation in tungsten inert gas (TIG) arc welding is relatively small and the process requires more set-up time which is not user-friendly.

Many recent surveys have proposed several ways by which the output work of a TIG welding process can be improved. Shanping et al [4] revealed that using an oxygen gas took a crucial
2. Methodology

In the previous studies, there was no much accessible data about the use of tungsten inert gas (TIG) welding procedure in the welding of type-304 austenite stainless steel, and its impact on the welds properties. This current study expects mechanical significance because of the numerous applications of type-304 austenite stainless steel, the low cost and the welding effectiveness of tungsten inert gas (TIG) welding procedure. Subsequently the work centers around the investigation of tungsten inert gas (TIG) welding of type-304 austenite stainless steel and the significant of the welding current on the tensile stress, hardness and microstructure properties of the weld joint.
penetration of the welds. Before the welding operation, all the ends were mechanically cleaned by silicon carbide paper of size 350 μm, and later chemically cleaned with acetone in order to evade any cause of impurity that can lead to weld defect. The chemical configurations of this Type-304 austenite stainless are listed in Table 1.

| Elements | % Requirement |
|----------|---------------|
|          | Min. | Max. |
| C        | N/A  | 0.030|
| S        | N/A  | 0.030|
| P        | N/A  | 0.045|
| Mn       | N/A  | 2.00 |
| Si       | N/A  | 0.75 |
| Ni       | 8.0  | 12.0 |
| Cr       | 17.5 | 19.5 |
| N        | N/A  | 0.10 |

The TIG welding was carried out on two plates using a TIG 200P DC/AC THERMAMAX welding machine. Two different currents of 150 A and 170 A were varied for the weld operation. The samples were designated as samples F3 and F4 respectively. The procedures were performed in two pass by using a gas tungsten arc (TIG) welding procedure.

### 2.1 Sample preparation
The samples were cut to dimension 25 × 10 × 6 mm and prepared metallographically using the ASTM E3-95 standard [12]. The mounted samples were ground, polished, rinsed with water, cleaned with acetone and then dried off using a hand drier. The samples were etched in a mixture of 2.125 g of ferric chloride, 0.6 g of cupric chloride, 31 ml of alcohol, 31 ml of hydrochloric acid and 1.5 ml of nitric acid respectively. The microstructures of different zones were observed using the DP 25 optical microscope.

### 2.2 Tensile test
The tensile test was conducted on the INSTRON machine with a load capacity of 100 kN. Three transverse samples were cut from each welds starting from the centre, and the end of the welding line by means of a water-jet cutter to obtain tensile samples. The test was conducted in agreement with the requests of ASTM E8 standard [13] as depicted Figures 1 (a) and (b) showing the loaded test sample before and after fracture.
2.3 Microhardness test
The microhardness tests were conducted on a digital microhardness Indenter in accordance with the ASTM E92-82 standard [14]. It was accounted for at the center of the fusion zone (FZ), transversely on the heat-affected zone (HAZ) and into the parent metal in order to estimate the local mechanical properties.

3. Result and discussions
The physical appearances of the welded plates are shown in Figure 2. Figures 2 (a) and (b) show the front and reverse outlooks of the TIG weld for sample F3 welded at a current of 150 A while Figures 2 (c) and (d) depict the front and reverse perspective of the TIG weld for sample F4 welded at a current of 170 A respectively.
The work piece used for the operation is of dimension 35 cm × 10 cm × 0.6 cm. The plates were properly cleaned with acetone in order to remove the surface contaminants. A 45° groove was made on each plate and bringing two plates together, a v-groove is attained with a root height of 1 mm. Figure 3 displays the microstructure of the base metal.

![Figure 3: Microstructure of base metal](image)

The microstructure of the parent metal is characterized with the austenitic-grain microstructure of the Type-304 austenite stainless steel. Figures 4 show the microstructures of the welded samples and depicting the fusion zones and the heat affected zones.

![Figure 4: Microstructure of weld samples](image)

In the microstructural analyses, it is noticed that as the welding current increases, the dendrite size and the inter-dendritic spacing in the weld metal were also increased. Similar microstructural behaviour was reported by Kumar [15] and Chen [16] when the consequence of thermal input was analysed on mechanical and the microstructure properties of TIG welding of type-304 stainless steel. The dendrite magnitude variation can be attributed to the welding current and the cooling rate depending on its current density. A steep thermal gradient is established in the weld metal when the weld current is low; however leads to a fast cooling rate. This in chance allows minor period for the dendrites to develop while at high welding current, the rate of cooling is dawdling and allows sufficient period for the dendrites to develop farther into the fusion zone.
Figure 5 displays the EDS analysis of sample F4 welded at current of 170 A.

![Figure 5: EDS analysis of sample F4 welded at current of 170 A.](image)

There is homogenous distribution of iron (Fe), chromium (Cr) and nickel (Ni) at the welded joint of the two samples. The EDS analysis revealed that Fe, Cr, and Ni made up the composition formed at the weld zone. The transverse tensile strength of the joints was evaluated and noticeable specimen’s fracture was observed at the weld region. Table 2 depicts the summary of the average tensile strength of the two samples and their corresponding percentage elongations as well as their joint efficiency.

| Sample | Ultimate tensile stress (MPa) | Shear stress (MPa) | % Elongation (mm) | Joint efficiency η (%) |
|--------|------------------------------|-------------------|------------------|------------------------|
| F3     | 517                          | 367               | 10.6             | 73                     |
| F4     | 584                          | 392               | 19.3             | 75                     |

Sample F4 welded with a current of 170 A gives the highest ultimate tensile strength of 584 MPa. A better ductility and moderate tensile strength were possessed by the welds of sample F4 due to the inter-dendritic spacing in the fusion zone of the joint. These welded joints are not usually as resilient as the base materials; thus, the strength drops as a result of weld joint efficiency [17]. The Weld Joint Efficiency (η) is the ratio of the joint strength compared with the strength of the base material normally expressed as a percentage. η varies from 100 % for a flawless weld down to 75 % for a tolerable weld. The highest η of 75 % occurs in the weld joint of sample F4 which is within the acceptable value of 75 %, and as such it is regarded as the optimum between the two parameters used.

Figure 6 shows the microhardness profiles of samples F3 and F4 welded at current of 150 A and 170 A respectively. The load of 0.5 kgf and a dwell time of 15 seconds were used.
There is a slight upturn in the value of hardness at the welded zone when matched with the heat affected zone (HAZ) and the base material. The slight escalation in the weld zone may be ascribed to the continual thermal cycles experienced during the melting and solidification of the type 316 filler metal used for the weld joint. From the graph, it can be observed that the two samples have almost the same trend and the values of micro hardness increased in the weld zone more than the parent material. The values of the micro-hardness measured were varied from 180.3 to 235.7 HV in the welded zone. The average micro-hardness of the base metal is approximately 206 HV, which indicates that the base material was not affected by the heat generated during the welding process.

4. Conclusion
The welding procedure of type-304 austenite stainless steel welded by TIG welding process was successfully achieved. The followings were concluded:

- The consequence of the welding current on the mechanical and microstructure properties was successfully analyzed.
- Adequate ductile properties were confirmed at the weld zones of the samples.
- TIG welding at welding current greater than 150 A produced the higher ultimate tensile strength.
- The hardness values of the welded samples were greater than the base material.
- The ultimate tensile strength (UTS) of the welded joint depends on the process factors such as welding current, welding feed rate and welding speed. The weld joint efficiency increases as the current was increased.
- For future work, double sided butt welding can be carried out to increase the ultimate tensile strength.
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