Effect of Welding Current and Electrode Movement on HAZ Width and Hardness of TIG Welded 304 Stainless Steel

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Received: 2024-04-03 Received in revised from 2024-06-11 Accepted: 2024-0624

Abstract

Tungsten Inert Gas (TIG) welding is a welding technique using an electric arc between a non-consumable tungsten electrode and a shielding gas for the heat formation. This research aims to determine the comparison of the macro structure and hardness (Vickers) of 304 stainless steel in TIG welding with spiral, zig-zag and triangular electrode movements, as well as the welding current variatons of 60, 80, and 100 A. The results show that the welding current and movement affect the hardness and HAZ width of the welded 304 stainless steel using TIG welding process. The greater current leads to higher HAZ width and hardness. Furthermore, the spiral movement provides higher hardness due to its fast movement in welding which leads a faster cooling as well. The highest HAZ width reaches the value of 2.05 mm using the 100 A welding current and triangle movement. Meanwhile, the highest hardness is obtained in the value of 450.5 kgf/mm^2 in the same current and movement.

Keywords: *Electrode movement; Hardness; HAZ width; TIG welding; 304 stainless steel*

1. Introduction

Stainless steel is a high alloy steel that has good corrosion resistance. So, it is widely applied in several industries, such as the chemical, food, and beverage industries which require high chemical resistance. One type of steel that is widely used is 304 stainless steels. This steel series is also known as 18-8 stainless steel because it contains 18% chromium and 8% nickel. 304 stainless steel has good machinability and weldability [1]. Several studies have evaluated the mechanical properties of the welded 304 stainless steel to develop various welding parameters to obtain higher-quality welding results. Previous studies have proven that this stainless steel is able to weld using various type of welding. Setiawan et al. conducted the welding process of AISI 304 stainless steel with carbon steel using shielded metal arc welding (SMAW) [2], additionally, this stainless steel is also able to join using gas metal arc welding (GMAW) method [3]. Tungsten inert gas (TIG) welding method is commonly used welding method to join this stainless steel, this is used by prior studies and proven to be capable to join this steel [1], [4].

Welding is widely used to join metals in the construction industry. One of commonly used welding process is tungsten inert gas (TIG) welding. This welding process uses heat from an electric arc formed between a non-consumable tungsten electrode and a shielding gas [5]. TIG welding offers benefits such as arc stability, minimal weld contamination, excellent, and clean welding results, additionally, has ability to control power at very low levels, preventing damage to the material. So, it is commonly employed for thin and thinner gauge metals [6], [7]. TIG welding process is able to be applied for joining high carbon steel, stainless steel, and non-ferrous metal [1], [8], [9].

Numerous welding parameters have been proven to affect the mechanical properties of welded metals, such as electrical current, gas flow rate, electrode diameter, welding speed, welding groove, and electrode movement [1], [4], [10], [11]. A prior study has proven that constant use of a welding current range of 60 to 100 A shows an increase in maximum tensile strength [12]. Moreover, in term of the electrode movement, spiral movement shows relatively higher hardness results than zigzag movement in heat affected zone (HAZ) [11].

Based on several explanations above, this study aims to analyze the effect of various welding currents (in variations of 60, 80, and 100 A) and electrode movements (spiral, zigzag, and triangle) on HAZ width through the macro structural analysis and hardness value of welded 304 stainless steels using TIG welding method.

2. Method

The 304 stainless steels were cut using the dimension of 100 x 30 x 10 mm. The welding parameters including welding current, movement, and others are shown in Table 1.

Table 1. Welding parameters

Welding method	Tungsten inert gas (TIG)
Metal filler	AWS A5 9 E308L; Dia. 2.2
Current (A)	60, 80, 100
Welding movement	
Voltage (V)	12
Shielding gas	UHP Argon
Welding groove	V; 80^o
Welding speed (mm/s)	+/- 1.5
Welding position	1G

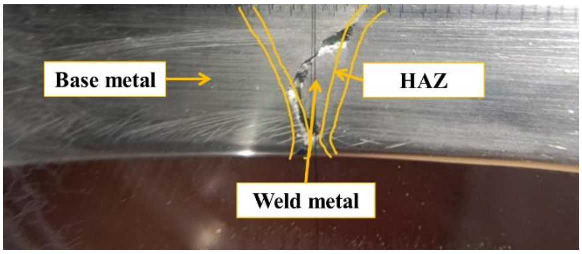
The width of heat affected zone (HAZ) was obtained through the macrostructure analysis. After the welding process, the specimens were sanded using sandpapers with a grid of 800 to 2000, additionally, polished using Autosol. Then, the welding area was dripped with a mixture solution of nitric acid and alcohol until the HAZ became visible. The visible HAZ area was observed and measured using a loop and then took the picture of the observed HAZ using a camera. Moreover, the hardness value was obtained using the Vickers method and the Hardness Universal Testing Machine. The testing was carried out in the HAZ area with 5 times indentations.

3. Results and Discussion

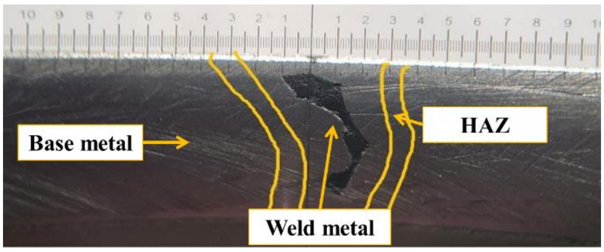
HAZ width results

Figure 1 – 3 show the macro photo analysis of the welded specimens in various welding movement and current. In several specimens, weld defects are visible, including slag inclusion (Figure 1a-b, and 3b), porosity (Figure 1c, 2a, 3a), and concavity (Figure 3c).

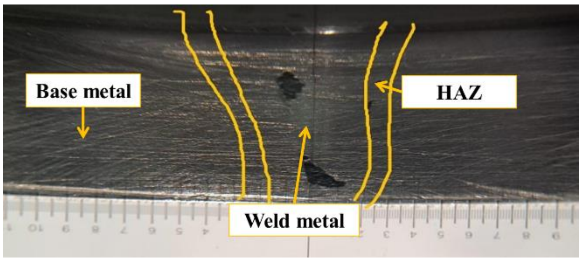
After obtaining the macro photo results, the HAZ width is obtained from each specimen. The HAZ width is shown in Table 2. From the table, it is found that a current strength of 60 A has the smallest average HAZ width, then for a current of 80 it has a HAZ width in the middle between 60 A and 80 A. For a current strength of 100 A it has the largest average HAZ width. The greater the current, the wider the HAZ width will be because the heat input received by the material will also be greater and will affect the cooling rate of the material. Apart from that, the greater the heat input received, the heat distribution in the material will also be greater so that it will affects the width of the HAZ itself [13].



(a)

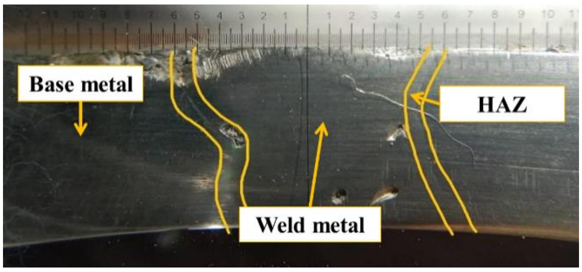


(b)

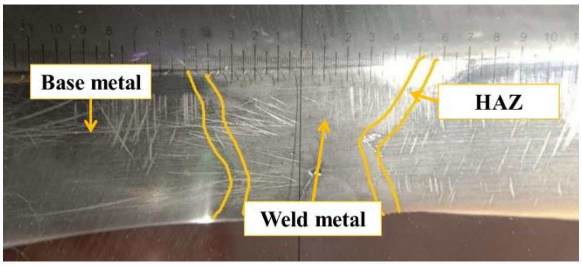


(c)

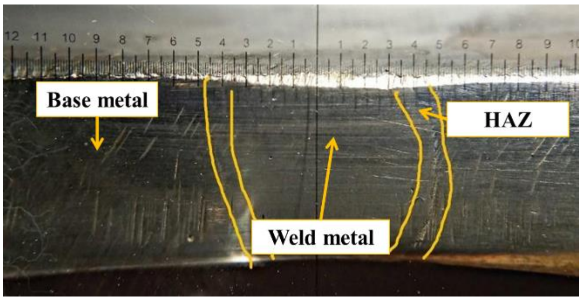
Figure 1. Macro photo of spiral welding movement results at the welding current of (a) 60 A, (b) 80 A, and (c) 100 A.



(a)

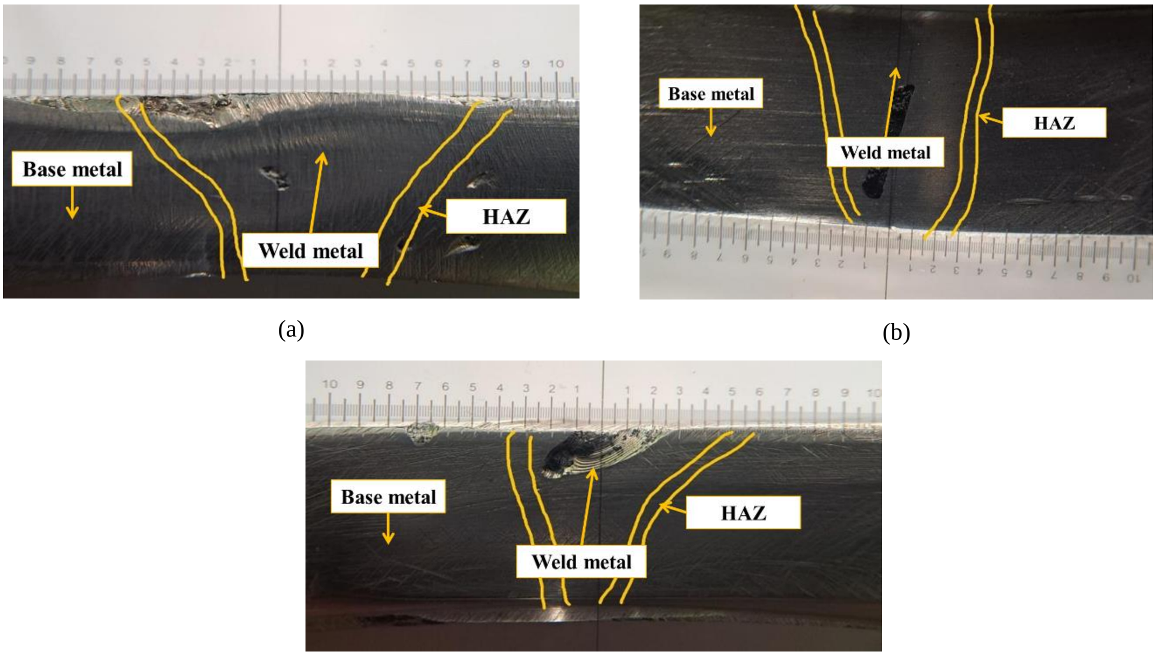


(b)



(c)

Figure 2. Macro photo of zigzag welding movement results at the welding current of (a) 60 A, (b) 80 A, and (c) 100 A.



(c)

Figure 3. Macro photo of triangle welding movement results at the welding current of (a) 60 A, (b) 80 A, and (c) 100 A.

Table 2. HAZ width of the welded specimens using various welding movement and current

Welding movement	**Welding current (A)**	**HAZ width (mm)**
Spiral	60	0.9
	80	1
	100	1.65
Zigzag	60	1.00
	80	1.7
	100	1.85
Triangle	60	1.5
	80	1.95
	100	2.05

Hardness Vickers results

The hardness values shown in Table 3 are the results of hardness tests in the HAZ area with 5 repetitions of the indentation.

Table 3. Hardness values of the welded specimens using various welding movement and current

Welding movement	**Welding current (A)**	**Hardness Vickers (kgf/mm^2)**
Spiral	60	298.5
	80	417.1
	100	412.9
Zigzag	60	224.1
	80	228.3
	100	262
Triangle	60	357.7
	80	221
	100	450.5

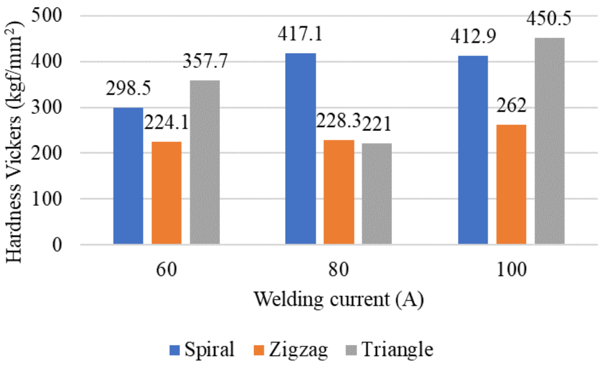


Figure 4. Hardness results of the welded specimens using various welding movement and current.

The lowest hardness is obtained in the value of 221 kgf/mm^2 with the current of 80 A and triangle movement. Meanwhile, the highest hardness is shown at the current of 100 A and triangle movement with the value of 450.5 kgf/mm^2. From Figure 4, it can be interpreted that the higher welding current leads to the higher hardness value, similar trend with the previous study [14]. The previous study mentioned that higher welding current provides high heat input, thus affecting the cooling rate in the welding process, it is known that the cooling rate affects the microstructure in the HAZ area. Meanwhile, the spiral movement relatively provides the highest hardness. This is because the spiral movement has a faster welding speed than other movements, causing rapid cooling and producing fine grains in the HAZ, resulting in higher hardness. The results of higher hardness in this spiral movement were also proven in previous research by Konsuci et al [11].

4. Conclussion

The welding current and movement affect the hardness and HAZ width of the welded 304 stainless steel using TIG welding process. The greater current leads to higher HAZ width and hardness that reaches the value of 2.05 mm and 450.5 kgf/mm^2, respectively. Furthermore, the spiral movement provides higher hardness due to its fast movement in welding which leads a faster cooling as well.

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