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Current Variation Effect on Hardness and Corrosion Resistance of Formed Weld Layer

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Abstract

Hardfacing over carbon steel was carried out using the SMAW apparatus. The sample was hard-faced with a single layer using HV 800 electrode with a 1G weld position. Different welding currents were used, such as 90, 100, and 110 A. After the weld, the sample was quickly immersed in distilled water. Cooled samples were cleaned with a chipping hammer and a wire brush. Afterwards, the samples were cut for hardness and corrosion testing. The highest hardness in the sample was welded using 110A, while the lowest hardness was welded using 90A. Increasing the current from 90 to 110 A could increase hardness by approximately 2.31%. The lowest current was used during welding, resulting in a lower corrosion rate. This means that the welding layer produced at the lowest current has greater corrosion resistance than that produced at higher currents. Reducing the current from 110 to 90 A could reduce the corrosion rate by approximately 44.33%. Finally, all three specimens meet the "good" criteria of corrosion resistance.

Keywords: carbon steel; HV 800; direct quenching; Vickers; weight loss.

1. Introduction

Heavy-duty vehicles should be ready for use in various environments such as marine, lake, and swamp. Hardness and corrosion are two properties that must be considered in heavy-duty equipment operating in a marine environment [1]. The better properties can extend the life span of heavy-duty equipment and minimize maintenance costs [2], [3]. Several researchers have sought to increase the hardness and corrosion resistance of heavy-duty components by applying a protective coating, performing a heat treatment (quenching method), varying the welding layer, and incrementing the welding current [4]–[8].

Quenching method and varying welding current seem promising to result in better hardness and corrosion resistance [9]–[11]. Susetyo et al. [12] conducted direct and furnace quenching; both of these methods significantly increase the specimen hardness. Prayitno and Indayanto [5] found that quenched samples in water media had the best corrosion resistance and the highest hardness when compared to samples quenched with coconut oil. Sopiyan et al. [8] found that the higher the current used during the welding process, the harder the weld layer formed. On the contrary, Jannifar et al. [13] have found that higher current results in lower hardness, also the highest corrosion rate. Prayitno and Fikri [14] have found that increasing the welding current would increase the corrosion rate. Mubarak et al. [10] varied the welding current during welding ASTM A36 and SS304 and found a lower corrosion rate when welding using 110 A. Naufal et al. [15] have found that increasing the current from 80 to 110 A of welding could reduce the corrosion rate.

As mentioned above, a varied current could increase hardness. Besides that, it could result in a different corrosion rate. Several researchers have reported direct quenching after welding, which can significantly increase hardness and reduce corrosion rates [6], [12], [16]. Sopiyan et al. [6] added NiCr during welding using an HV 600 electrode, then directly quenched in a natural environment (air) and oil. Oil as quenching media substantially reduces the corrosion rate and increases the hardness of the weld metal. Susetyo et al., [12] conducting direct quenching after welding using an HV 600 electrode, successfully increased the weld metal hardness. Syaripuddin et al. [16] added Ti during welding using an HV 600 electrode, then directly quenched in a natural environment (air), engine oil, and palm oil. Palm oil as quenching media substantially results in the highest hardness of the weld metal for around 896.20 HV.

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Study of welding using HV 800 electrode and then quickly quenching in distilled water has not yet been found. Therefore, in the present study, hardfacing was conducted over carbon steel using an HV 800 electrode. The welding is performed using the SMAW apparatus. The sample was hard-faced with a single layer using a 1G weld position. Different welding currents were used, such as 90, 100, and 110 A. After the weld, the sample was quickly immersed in distilled water. Afterwards, the samples were cut for hardness and corrosion testing.

2. Experimental Methods

2.1. Material and Apparatus

Before hardfacing was carried out by welding, the tools and materials were prepared as seen in Figure 1. The base material used is similar to that in the previous studies [17]. HV 800 as electrode (∅ 3.2, Nikko Steel) was used in the present study with a typical chemical composition of 3.8 wt.% C, 1.2 wt.% Mn, 1.0 wt.% Si, 28 wt.% Cr, 0.8 wt.% Mo and Fe balance. Sodium chloride (Merck) and distilled water were used to prepare a 3.5% NaCl solution for the corrosion test. For the hardness test, the Vickers hardness tester (FV-300e) was used. The SMAW welding machine (Pro BF 443) was used in the present study with DC+ polarity. An oven electrode, pliers, a chipping hammer, a wire brush, welding gloves, and a welding helmet were also provided.

Figure 1. Tools and materials (a) Sodium chloride, (b) Distilled water, (c) Vickers hardness, (d) Welding machine, (e) Electrode oven, (f) pliers, (g) chipping hammer, (h) Wire brush, (i) Welding gloves, (j) Welding helmet, (k) electrode, and (l) Carbon steel

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2.2. Hardfacing using Welding Method

Carbon steel was cut for 150×10×10 mm, and the electrode was dried in the oven at 150 °C for 1 hour. Hardfacing over carbon steel was carried out using the SMAW apparatus. The sample was hard-faced with a single layer using a 1G weld position (see Figure 2). Different welding currents were used, including 90, 100, and 110 A, with a travel speed of 0.758 ±0.15 mm/s. After the weld, the sample was quickly immersed in distilled water (Figure 3). Cooled samples were cleaned with a chipping hammer and a wire brush, and the result is presented in Figure 4. Afterwards, the samples were cut for hardness and corrosion testing.

Figure 2. Hardfacing using the SMAW method

Figure 3. Distilled water for quenching media

Figure 4. Specimens after welding

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2.3. Hardness and Corrosion Test

A hardness test was performed at room temperature with a 30 kg load. Five repeatable measurements were conducted at the top of the welding layer. The indentation is shown in Figure 5.

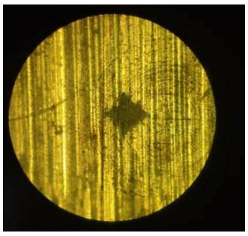

Figure 5. Vickers' hardness indentation documentation

Corrosion testing was conducted using the weight loss method. The specimen was cleaned with a wire brush, then covered with hot glue, leaving a test area of 1 × 5 cm on the weld layer. Next, the specimen was immersed in a 3.5% NaCl solution for 72 hours, then weighed every 24 hours to observe the mass reduction. The 3.5% NaCl solution was also periodically (24 hours) replaced with a new solution (fresh solution). Documentation of the corrosion test using the weight-loss method is shown in Figure 6.

(a) (b)

Figure 6. Weight loss method (a) initial immersing and (b) after 24 hours of immersing

After the weighing data has been obtained completely for 72 hours, the corrosion rate is calculated. The corrosion rate is calculated using equation (1) as follows [18].

$$\text{Corrosion rate } (mpy) = \frac{k \times w}{\rho \times A \times t} \quad (1)$$

where k is the corrosion constant, w is the mass loss of the weld layer (g), ρ is the density of the weld layer alloy (g/cm^3), A is the area of the corrosion test specimen (cm^2), and t is the total immersion time (hours).

3. Results and Discussion

3.1. Hardness

The current effect on the hardness is presented in Figure 7. It can be seen that increasing the current leads to an increase in the hardness, which is similar to other studies [8], [19], [20]. The highest hardness in the sample was welded using 110 A, while the lowest hardness was welded using 90 A. Compared to the manufacturers of a diverse range of advanced welding consumables, the present study results are higher than those of the standard [21]. According to that standard, a single-layer welded would result in hardness between 450-520 HV [21]. This condition was significantly influenced by direct quenching in the distilled water after welding.

Increasing the current during welding would increase the heat input [22], [23]. According to Moustahid et al. [24] 80, 90, and 100 A of welding current would result in heat inputs of 32.664, 80.983, and 112 J/mm, respectively. Increasing the heat input could decrease the cooling rate and decrease the hardness [25]. This statement contradicts the results of the present study, probably due to direct quenching after welding was conducted. Direct quenching after welding significantly increased the material's hardness [12].

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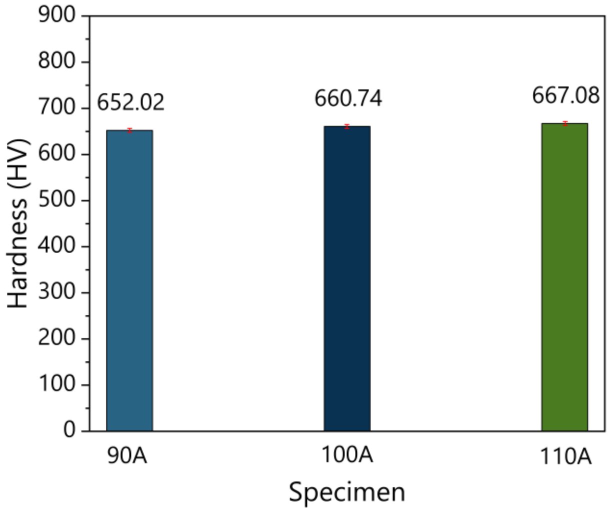

Figure 7. Vickers hardness measurement result

3.2. Corrosion

The results of the weight loss investigation for 72 hours in a 3.5% NaCl solution can be seen in Figure 8. A 3.5% NaCl solution was used in this study with the aim of simulating a corrosion test in seawater simulation [26], [27]. Based on Figure 8, the longer the immersion time, the greater the mass reduction at 72 hours. After 24 hours of weighing, the mass reduction of specimen 100 A was relatively similar to that of specimen 110 A. But the immersion times of 48 and 72 hours differ for weight-loss behavior. Weight loss at 72 hours for 90, 100, and 110 A is 0.005, 0.006, and 0.009 g, respectively.

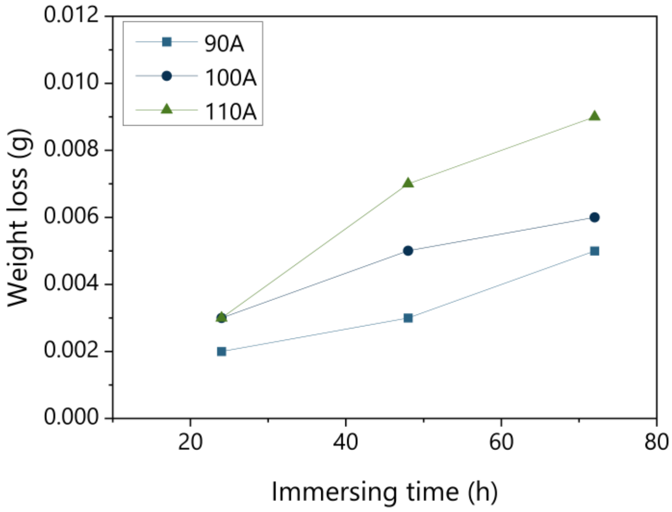

Figure 8. Weight loss measurement result

Based on the calculations using equation (1), the corrosion rates of all specimens are shown in Figure 9. From Figure 9, it can be seen that the lowest current was used during welding, resulting in a lower corrosion rate. This means that the lowest current during welding leads to an optimal heat, which causes a lower corrosion rate [28]. Moreover, Hassoni et al. [29] has state increment of welding current leading to increase corrosion rate. This condition probably due to the higher welding current results in a higher dilution rate, thereby promoting greater mixing between the electrode and the base material. The HV 800 electrode contains 28 wt.% Cr. According to a

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previous study, a higher Cr content leads to an increase in the corrosion rate [30]. Therefore, higher current samples have a higher corrosion rate, probably due to more Cr in the welding layer.

A previous study found a corrosion rate where welding was performed using 90A, single layer, without direct quenching, deriving 13.23 mpy [17]. Compared to Figure 9, it can be seen that all samples have a lower corrosion rate than the previous study [17]. Moreover, when compared to previous research, where one, two, and three layers of welding were carried out with HV-450 electrodes, the corrosion rate was still higher [7]. This is because the Cr content in HV-450 is lower than that in HV-800. The Cr content can increase the corrosion resistance of a material [31]. Furthermore, the corrosion rate observed in the three specimens ranged from 6.43 to 11.55 mpy. A corrosion rate between 5-20 mpy falls into the criteria for good corrosion resistance [32]. Therefore, three specimens meet the "good" criteria for corrosion resistance.

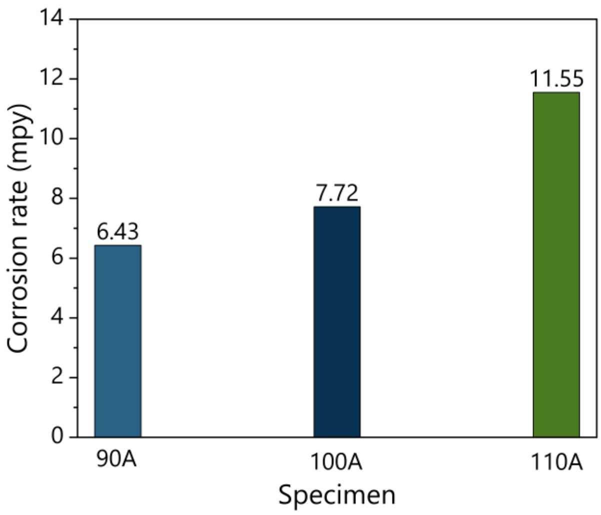

Figure 9. Corrosion rate measurement result

4. Conclusion

Based on the research conducted, the following conclusions can be drawn. A lower current was used during welding, developing a lower heat input. Lower heat input would ensue a lower hardness of the welding layer after direct quenching in distilled water. This condition also made the sample more corrosion-resistant. Finally, all three specimens meet the "good" criteria of corrosion resistance. Future recommendations include using welding current greater than 110A and varying quenching media, such as engine oil and palm oil.

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