

EFFECT OF WELDING HEAT INPUT ON THE CORROSION RATE OF CARBON STEEL MMA WELDING

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Abstract

Steel is one of materials which often used on steel construction, bridge construction, and high-rise building construction. Construction using welding joint is expected able to withstand construction loads for a long time. After a while weldment will be exposed to corrosion that will be construction failure in turn. One of the most important parameters in welding is heat input, however it hasn't obtained correlation between heat input and corrosion rate on Manual Metal Arch (MMA) weldment on mild steel. This paper aims to obtain correlation between heat input and corrosion rate of low carbon steel with MMA welding. The result showed that corrosion rate tend to decrease with increasing of duration, where the highest corrosion rate at heat input 0.8108 kJ/mm was 68.68 gm/m² h at duration of 5 hours.

Keywords: welding current; corrosion rate; MMA welding; low carbon steel.

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1. Introduction

Steel is one of materials that often used in steel construction, bridge construction, and high-rise construction. The type of steel that is widely used in construction is low carbon steel with carbon content <0.2% because of its good mechanical properties. Low carbon steel has an average tensile strength of 500 N/mm² and yield strength of 250 N/mm² [1]. In its use in construction there are often components of the steel material put together / assembled using bolt connections, rivets, and welded joints.

Constructions that use welded joints need to be used for a long time. On the other side, the placement of instructions in an open environment often encountered the problem of exposure to construction materials welding results with open air containing O₂, N₂, and a certain humidity. At a certain period the use of welding results will experience corrosion which can ultimately cause failure of a construction.

Generally, to prevent corrosion, the material that has been welded is protected by painting process, but this will not last long because extreme weather changes lately can also cause damage to the painting [2]. Another way is to carve out the welding process so that corrosion can be prevented or slowed down [3].

One of the very important parameter in welding is heat input [4]. The amount of heat input depends on the welding speed (travel speed), voltage and the amount of current used during welding.

Previous research regarding heat input has been

carried out by [5]. It has a relationship between heat input and geometry of the weld bead where the width of the weld bead increases linearly with an increase in heat input. While the reinforcement height and penetration depth not increase with increasing heat input. The relationship of heat input and corrosion resistance has been reported by previous researchers [4-6], which examined it in duplex stainless cladding steel welded with flux cored arc welding (FCAW). Corrosion resistance in the bandaged shows a tendency to decrease with a greater overall heat input. Whereas found that samples with high welding heat input have better corrosion resistance on carbon steel welded with Tungsten Inert Gas on its root pass and Shielded Metal Arc Welding (SMAW) on its hot pass. [7] have also examined the effect of welding parameters on the behavior of pitting corrosion on Duplex stainless steel and super duplex stainless steel welding. The results show that lower heat input gives better corrosion properties. Research on other heat inputs was also reported by Frei et.al [8] but it was not related with corrosion rates.

The rate of corrosion due to construction experiencing corrosion phenomena under the environment of sea water has also been studied by [9] to predict the rate of corrosion in steel construction exposed to seawater. The similar works are also done by previous researchers [10-11], however with the method used to predict in different way. Predictions of corrosion rates in pipelines, both in the chemical and oil and gas industries have been reported by [12].

Research on the effect of PWHT on corrosion resistance in welding stainless steel materials that are not the same has been carried out [13], the results show that higher PWHT temperatures that are higher and more susceptible to corrosion. The same thing was proven by [14] on AISI 410 stainless steel with friction stir welding.

The effect of welding on the pipe against corrosion resistance has been investigated by [15] showing that the dead of the clad pipe has better corrosion resistance compared to pipes welded by multipass welding.

This study aims to determine the influence of the heat input given during the welding process on the magnitude of the corrosion rate that occurs. The initial hypothesis was that the slower cooking rate, the longer possibility of the weld metal would be exposed to the outside air, causing corrosion. However, the rate of corrosion formation will be examined through the experiments that will be carried out.

2. Experimental and Procedures

This research method analyzes and compares the corrosion rate and the effect of welding on ST 37 material with the SMAW welding method using E 7016 welding electrodes. Test piece to be welded with a butt joint with dimensions of length x width x height of 300 mm x 100 mm x 5 mm according to ISO 9606-1 standard for welding test piece as shown in figure 1. The test piece preparation is carried out in a mechanical engineering workshop using a hydraulic plate cutting machine.

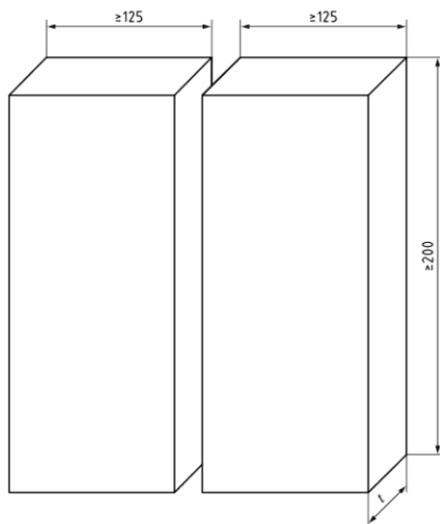


Fig. 1. Test piece to be welded

To get a different value of the heat input, parameters such as voltage and travel speed (depending on the welder's habit) are held constant while varying the amount of welding current. Therefore, the welding current is set on 3 different

welding currents, i.e 70, 75, and 80 A.

2.1 Heat Input

The amount of heat input given during welding can be estimated by the following formula [4]:

$$Q = \frac{(60 \times V \times I)}{(100 \times S)} \times \eta \quad (1)$$

where: Q = heat input (kJ/mm)

V = voltage (V)

I = current (A)

S = travel speed (mm/min)

η = welding process efficiency

The heat input is basically the amount of electrical energy supplied by the welding arc to the workpiece. The heat input affects the cooling rate of the weld, as shown in Figure 1.

From Figure 2, it can be seen that the effect of heat input on the cooling rate will be more significant at lower heat input for each preheating temperature when the thickness of the welded plate is kept constant.

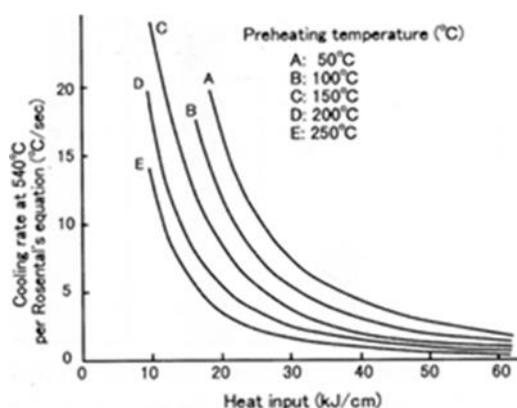


Fig. 2. Effect of heat input on the cooling rate of welding at various preheat temperatures (Plate thickness: 19 mm) [16]

2.2 Corrosion Rate

Welding causes the metal around the weld metal Heat Affected Zone (HAZ) and weld metal to undergo rapid thermal cycles resulting in changes in properties, complex metallurgy, deformation and thermal stresses and the impact of increasing the rate of corrosion. The plates which are connected or welded will be more susceptible to corrosion due to the welding process of the material causing recrystallization that can change the strength and corrosion characteristics of an engineering structure. Corrosion is the process of degradation/ deterioration/ destruction of material caused by environmental and surrounding influences.

The parameters used in measuring the level of

corrosion in a material are expressed by the corrosion rate. The measurement is done by measuring the initial weight of the material and measuring the weight of the material after corrosion testing. Corrosion testing is carried out using a ferric chloride (FeCl_3) solution as a corrosion-producing medium based on ASTM standards G 48-03 [16]. This method is also known as the Method A-Ferric Chloride pitting test. The testing procedure performed for this method follows the steps as follows:

- Ferric chloride liquid 600 ml poured into a 1000 ml measuring glass.
- Material is put into solution for 72 hours (3 days).
- Remove the specimen from the container
- Wash with aquadest.
- Dip into acetone for 5 minutes to remove corrosion products attached to the surface of the specimen.
- Weighing the final weight.
- Calculation of corrosion rates by the weight loss method.

Corrosion rate calculation using the weight loss method uses the following formula:

$$mmpy = \frac{(K.W)}{(D.A.T)} \quad (2)$$

where: mmpy = Millimeter Per Year

K = constant (3.45×10^6)

W = mass reduction due to corrosion (mg)

D = density of material (gram/cm^3)

A = area of corroded specimen (sq.in)

T = duration (hour).

The corrosion rate calculation above has been modified using the equation:

Pitting corrosion rate,

$$P = \frac{W}{(A.T)} \quad (3)$$

Where: W = weight loss (gm)

A = exposure area (m^2)

T = duration (hour)

3. Results and Discussion

3.1 Result

Welding specimens for welding currents 70, 75 and 80 A can be seen in Figure 2.

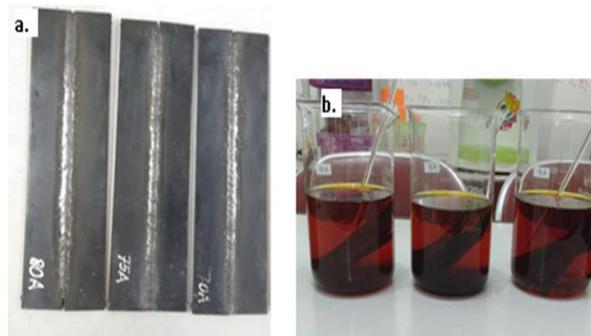


Fig. 3. (a) Welding specimen, (b) immersion of the sample in FeCl_3 solution

From these specimens, those 3 samples were taken for each welding current by cutting the specimen at the left, right and center ends of the specimen as wide as 20 mm as shown in Figure 4. Number 1 in the figure indicated 25 mm from both edge was discard. The samples were then immersed in 600 ml FeCl_3 solution wherein each beaker glass container was placed with the same welding current as in Figure 3(b).

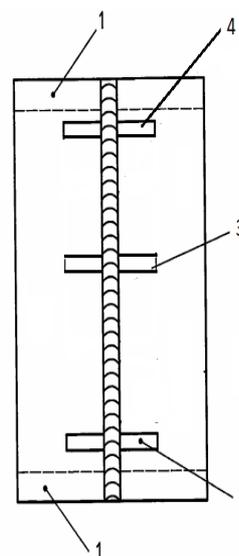


Fig. 4. Location of 3 samples taken from welding test piece (2, 3 and 4).

Data collection was carried out at 4 hour intervals where the samples were weighed before and after immersion. The loss of sample weight for the specified time duration can be seen in Table 1. Based on Table 1 and using equation 2, a corrosion rate data can be determined for 81 hours duration, as presented in Table 2. Meanwhile, the amount of heat input according to equation 1 for different currents can be seen as listed in Table 3.

Table 1. Weight loss of sample for 81 hours duration

Duration (hrs.)	70A			75A			80A		
	701	702	703	751	752	753	801	802	803
5	1.77	2.02	1.62	1.60	1.52	1.34	1.14	0.86	0.94
9	2.11	2.39	1.87	1.96	1.86	1.63	1.44	1.27	1.51
13	2.31	2.68	2.04	2.10	2.03	1.73	1.77	1.61	1.86
17	2.63	2.77	2.19	2.18	2.18	2.04	1.88	1.97	2.03
21	2.93	3.01	2.44	2.42	2.34	2.28	2.17	2.37	2.36
25	3.14	3.20	2.67	2.61	2.60	2.50	2.44	2.54	2.53
29	3.23	3.30	2.71	2.74	2.74	2.70	2.69	2.87	2.79
33	3.29	3.34	2.73	2.80	2.80	2.82	2.73	2.93	2.86
37	3.30	3.37	2.77	2.87	2.93	2.91	2.84	3.03	2.97
41	3.31	3.39	2.80	2.95	3.03	2.95	2.91	3.11	3.02
45	3.32	3.40	2.83	3.04	3.07	3.04	2.99	3.19	3.12
49	3.38	3.44	2.89	3.10	3.15	3.09	3.05	3.25	3.20
53	3.40	3.45	2.91	3.16	3.21	3.19	3.10	3.29	3.24
57	3.42	3.47	2.92	3.18	3.25	3.23	3.12	3.38	3.28
61	3.43	3.48	2.93	3.19	3.27	3.26	3.14	3.40	3.29
65	3.44	3.49	2.94	3.20	3.28	3.27	3.16	3.41	3.30
69	3.45	3.50	2.95	3.21	3.29	3.29	3.18	3.42	3.31
73	3.46	3.51	2.96	3.22	3.31	3.31	3.19	3.43	3.32
77	3.48	3.54	3.00	3.27	3.37	3.33	3.21	3.46	3.35
81	3.49	3.56	3.01	3.29	3.39	3.34	3.22	3.48	3.37

Table 2. Corrosion rates for various specimens for 81 hours duration

DURATION (hour)	Welding current (A)		
	70	75	80
5	68.6827	54.5053	34.9481
9	44.9280	37.0029	27.9097
13	34.3267	27.5378	23.9897
17	28.3409	22.9873	20.5780
21	25.3306	20.4786	19.5456
25	22.8773	18.8317	17.8663
29	20.2253	17.2228	17.1229
33	18.0045	15.5792	15.3546
37	16.1954	14.3696	14.2092
41	14.7082	13.2943	13.1121
45	13.4714	12.4137	12.2908
49	12.5789	11.6361	11.5308
53	11.6894	11.0113	10.8063
57	10.9248	10.3449	10.2041
61	10.2397	9.7262	9.5834
65	9.6388	9.1558	9.0302
69	9.1076	8.6604	8.5410
73	8.6347	8.2274	8.0975
77	8.2603	7.9028	7.7387
81	7.8838	7.5502	7.3934

Table 3. Heat input for various current variations

No	Travel Speed (mm/min)	Welding Current (A)	Voltage (V)	Heat Input (kJ/mm)
1	88.5	70	23	0.87322
2	88.5	75	23	0.93559
3	88.5	80	23	0.99797

Based on Table 1, the data is then can be plotted for the weight loss of sample for 81 hours duration for different welding amperes number. Figure 5 is a plot of weight loss of the 3 samples for 70 A welding. From this plot it is shown that there is a tendency for the weight to decrease rapidly until the 5th hour, then there is a tendency for the slope to decrease until it finally becomes stagnant at the 81st hour.

Figure 6 is a plot of weight loss of the 3

samples for 75 A welding. It is shown from this plot that there is a tendency for weight to fall rapidly up to the 5th hour indicated by steeper slope of the chart. Then the slope slowly decreases at 9th hour and 13th hour. Then it rises again at 13th hour to 29th hour. Gradually the slope decrease until it finally becomes stagnant at the 81st hour.

The plot of weight loss of the 3 samples for 80 A welding was shown in Figure 7. From this plot

it is shown that there is a tendency for the weight to decrease rapidly until the 5th hour, then the slope change from 5th hour to 29th hour, 29th hour to 57th hour and finally there is a tendency for the slope becomes close to 0 degrees (weight loss becomes stagnant) at the 81st hour.

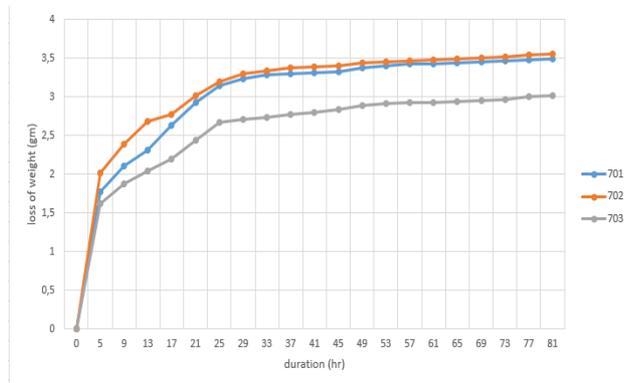


Fig. 5. Plot of weight loss of sample for 70 A welding.

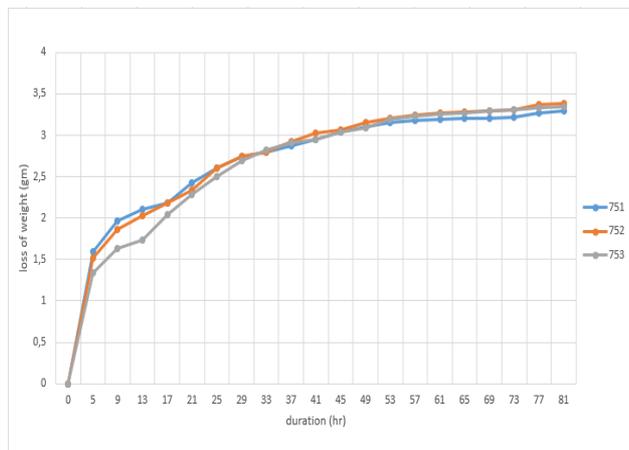


Fig. 6. Plot of weight loss of sample for 75 A welding.

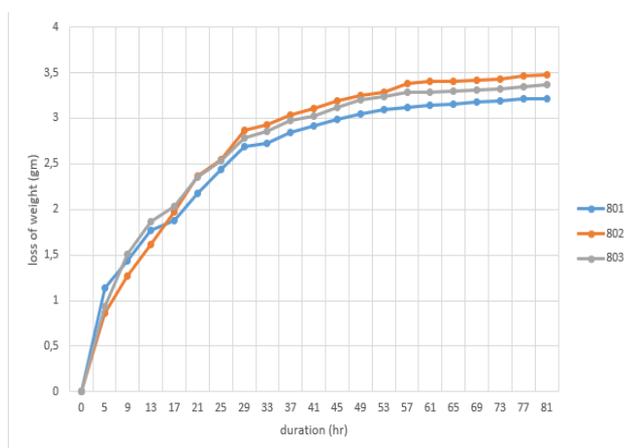


Fig. 7. Plot of weight loss of sample for 80 A welding.

From Table 2 and Table 3, the plots also can be drawn that showing the relationship between heat input and corrosion rate at a duration of 81 hours.

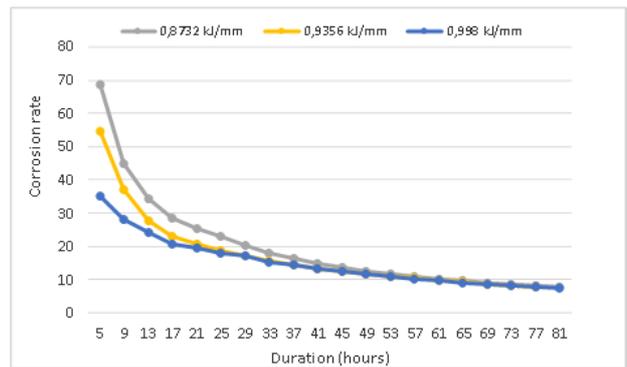


Fig. 8. Graph of relationship between input heat and corrosion rate at 81 hours duration.

3.2 Discussion

From Figure 8, it can be seen that the increasing duration of the specimens exposed to FeCl₃ solution will cause a decrease in the corrosion rate. It is also shown that the graph formed at the heat input 0.87322 kJ/mm using a welding current of 70 A is above the other two charts, followed by the graph on the heat input 0.93559 kJ/mm with 75 A and on heat input 0.99797 kJ/mm at the bottom of the graph with a current of 80A. The highest corrosion rate at a duration of 5th hours was 68.6827 g/m²h i.e. at heat input of 0.87322 kJ/mm and the lowest at the same duration was 34.9481 g/m²h i.e. at heat input of 0.99797 kJ/mm. At the highest duration, i.e. 81st hours, there is still a difference in the value of the corrosion rate for the three graphs, where the highest value is 7.8838 g/m²h at heat input 0.87322 kJ/mm and the lowest value is 7.3933 g/m²h at heat input 0.99797. This shows conformity with other studies that measure the corrosion rate for welding with current variations of 90, 135 and 180 A, where welding specimen at the highest heat input at 180 A results in a smallest corrosion rate [17]. In that study, NaOH and HCl solutions were used as a medium to accelerate corrosion.

4. Conclusions

The highest corrosion rate is at a heat input of 0.8108 kJ/mm, that is at a welding current of 70 A. At prices of welding currents above 70A, there is a tendency for the corrosion rate to decrease with increasing heat input. The magnitude of the corrosion rate tends to decrease with increasing duration of time, where the greatest corrosion rate at the heat input is 0.8108 kJ/mm at 68.68 g/m²h at 5 hours duration.

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