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Overlay welding analysis on GTAW and SMAW processes in terms of mechanical properties and corrosion rate

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ABSTRACT

The Overlay welding process is a coating technique that is carried out using the welding process. In this study, a coating was conducted on carbon SA 516 gr. 70 with stainless steel electrodes. Welding was carried out with the GTAW and SMAW processes. The electrode used in the first coating for GTAW was ER309L while for SMAW was E309L. The next coating used in the GTAW electrode was ER316L and the SMAW electrode was E316L. In both welding processes, testing was carried out on mechanical properties and corrosion rates. Testing was carried out to determine mechanical properties, namely bending testing. This was done based on ASME IX. Bending test results in both processes are declared accepted because there are no defects. In testing the corrosion rate using the three-electrode cell method based on the ASTM G102, the overlay welding process with GTAW has a slower corrosion rate of 0.00890 mm/year compared to the overlay welding process with SMAW.

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1. Introduction

Currently, welding technology in the industry continues to develop. In the construction field, welding has been widely used in joints including ships, pressure vessels, condensers, heat exchangers, and so on. One example of the process in the manufacture of construction is coating carbon steel material. This process affects the mechanical properties, especially in the weld area due to heat input during welding, which is called the thermal cycle [1], [2]. The welding thermal cycle is a heating and cooling event in the weld area that causes differences in the free energy level of metal activation around the weld metal. This difference can create differences in grain size which results in the emergence of anode and cathode areas as potential corrosion [3].

Most of the corrosion occurs on the surface of the material in a corrosive environment. Surface corrosion resistance can be modified without affecting material properties [4]. Austenitic stainless steels (SS 316L and SS 304) are commonly used in corrosive environments due to their corrosion resistance, weldability, and mechanical strength. One of the methods used to provide long-term protection against corrosion, wear, and erosion by calculating cost-effectiveness is overlay welding [5]–[8].

In the process of making pressure vessels that use stainless steel, it can now be replaced by the process of coating carbon steel with stainless steel. The use of this material aims to reduce the rate of corrosion. In addition, the coating also aims to save costs, because the price of stainless steel is more expensive than carbon steel material that is coated with stainless steel [9], [10].

Coating of carbon steel material with stainless steel can be done by overlay welding. Overlay welding is a coating technique process that is carried out using a welding process [11], [12]. The coating process for this material was only to reduce the corrosion rate because the stainless-steel coating is very thin. As for the thickness, only carbon steel was used to meet the pressure requirements. For this coating, carbon steel was on the outside while for corrosion-resistant materials, it was on the inside where direct contact with the fluid took place.

2. Method

2.1. Materials

Overlay welding was carried out on ASTM A516-Gr.70 material with a chemical composition that can be seen in Table 1. In the overlay process with GTAW, the first layer of electrode used was ER309L and in the second layer, the electrode used was ER316L. In the overlay process with SMAW, the electrode layer used was E309L and in the second layer, the electrode used was E316L. The welding process was carried out at the Surabaya State Shipbuilding Polytechnic workshop using two variables, namely, overlay welding with the GTAW process and the SMAW process. Parameters with the GTAW process can be seen in Table 2 while the SMAW process can be seen in Table 3.

Table 1. Chemical Composition

Material	C	Si	Mn	P	S	Cr	Mo	Ni
A516-Gr.70	0.20	0.28	1.11	0.013	0.001	0.02	0.002	0.02

2.2. Corrosion rate testing

Corrosion rate testing was carried out using the three-electrode cell method. The three-electrode cell component consists of a working electrode, reference electrode, auxiliary electrode, potential source, potential measuring device, and current measuring device. Specimens were prepared with completely clean surface conditions. The specimen was immersed in a 3.5% NaCl solution and a current was flowed. In the test material, the auxiliary electrode, and the reference electrode were placed on the beaker. Negative voltage was applied to the circuit by connecting the positive voltage on the emf to the negative on the digital voltmeter and vice versa. Fig. 1 illustrates a simple circuit in a three-electrode cell experiment. The corrosion rate was calculated based on the change in weight to the surface area and the duration of the test. In this study, the following equation was used to calculate the corrosion rate [13] :

$$CR = \frac{K_1 \times I_{corr} \times EW}{\rho} \tag{1}$$

Where, K_1: constant (3,27 x 10^{-3}), I_{corr}: current density ($\mu A/cm^2$), EW: *Equivalent Weight* (g/mol equivalent), ρ: object density (g/cm^3).

Table 2. Welding Parameter GTAW

Layer	Current (A)	Voltage (V)	Time (min)	Travel Speed (mm/min)	Heat Input (J/mm)
1	133.4	13.4	3.50	57.18	1875.81
2	121.22	14.4	4.05	49.38	2120.87
3	121.21	14.3	3.55	56.31	1846.75
4	121.22	14.4	2.92	68.59	1527.02
5	121.21	14.3	3.90	51.23	2030.04

Table 3. Welding Parameter SMAW

Layer	Currrent (A)	Voltage (V)	Time (min)	Travel Speed (mm/min)	Heat Input (J/mm)
1	121.2	22	1.06	188.98	846.58
2	109.4	19	1.05	190.02	656.32
3	109.4	19	1.09	182.96	681.65

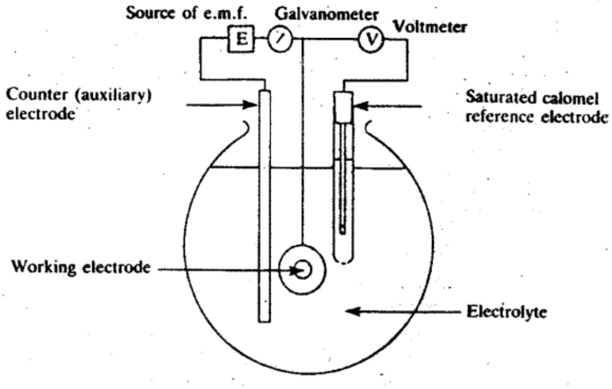


Fig. 1. A simple circuit in a three-electrode cell experiment[13]

2.3. Pengujian Bending

Bending testing is carried out to determine the extent of the flexibility and brittleness of the material and to determine the deformation capability with a certain bending radius of 180°. The one used in this bending test was 4 side bends. In this test, the mandrel with a diameter of 38 mm was chosen because the material to be tested had elongation that exceeded 20% and the thickness of the material was 10 mm. The sketch of the mandrel diameter is shown in **Fig. 2**.

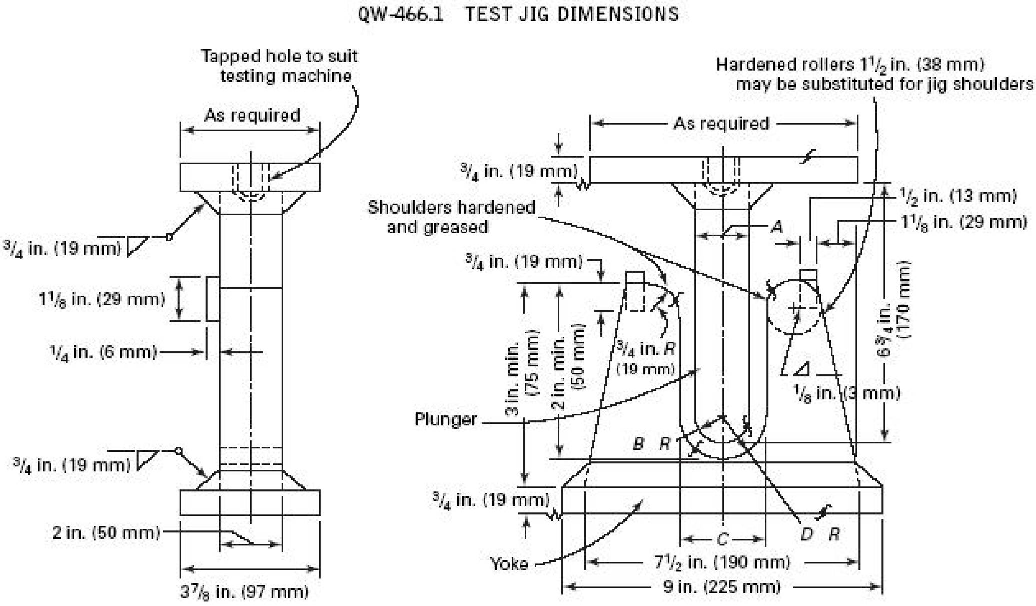


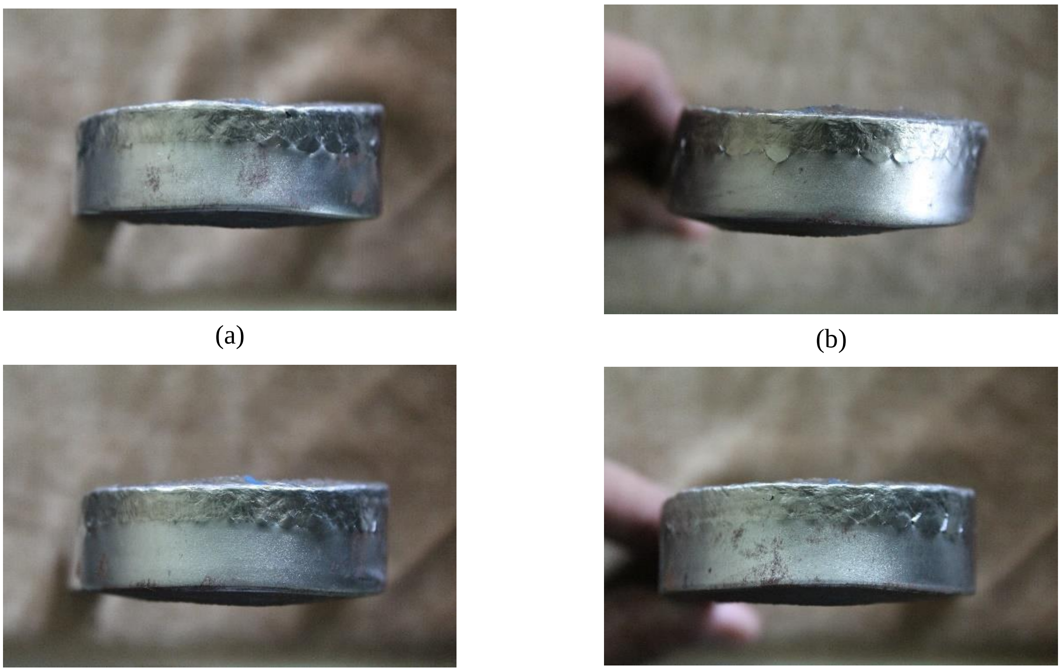
Fig. 2. Sketch of Mandrel's Diameter [14]

3. Results and Discussion

3.1 Bending Test

The bending test (side bend) has two variables, namely the GTAW and SMAW processes. The results of these tests can be seen in Table 4. Figure 3 shows that there are no visible defects in the overlay welding with the GTAW process. It can also be seen in Figure 4 that there are no defects from the overlay welding using the SMAW process. The acceptance criteria for bending testing based on the ASME IX standard is that on the bent weld surface there should be no open discontinuities of more than 3 mm, measured in all directions on the convex surface of the specimen after bending. Open discontinuities occurring at the corners of the specimen during the test were not considered unless there was evidence of such discontinuity resulting from lack of fusion, slag inclusion or other internal discontinuity.

In overlay welding, there were no open defects exceeding 1.5 mm measured from any direction, permitted if they were in the coating area with a limit of less than 1.5 mm. No open defects exceeding 3 mm were allowed if they were located along the weld surface with a limit of less than 3 mm. Based on this acceptance, the results of the side bend transverse test were declared accepted.



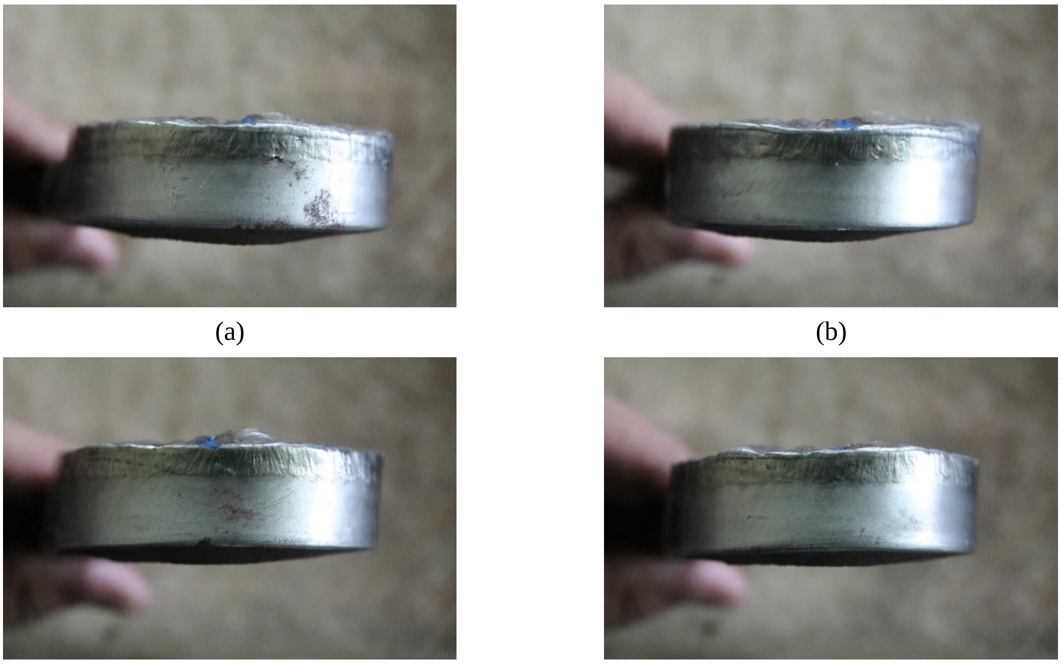
(a) (b)

(c) (d)

Fig. 3. Bending (side bend) test results with the GTAW Process, (a) specimen 1, (b) specimen 2, (c) specimen 3, (d) specimen 4

The bending test process was carried out using a 38 mm diameter mandrel because the material to be bent had an elongation of more than 20% and the thickness of the specimen to be bent was 10 mm. Where SA 516 Gr. 70 has an elongation of 24%, E309L has an elongation of 42% and E316L has an elongation of 37%.

From the above discussion, the selection of the appropriate current, the right welding speed, a suitable filler metal, the welding location and the mandrel diameter for the bending test make the four bending test specimens from the overlay welding declared accepted.



(a) (b) (c) (d)

Fig. 4. Bending (side bend) test results with the SMAW Process, (a) specimen 1, (b) specimen 2, (c) specimen 3, (d) specimen 4

Table 4. Bending test results

No	Process	Width	Thickness	Result		Keterangan
				Defect Type	***Defect Size***	
						Ømandrel: 30 mm
G1	GTAW	10	16	None	-	Accepted
G2	GTAW	10	16	None	-	Accepted
G3	GTAW	10	16	None	-	Accepted
G4	GTAW	10	16	None	-	Accepted
S1	SMAW	10	16	None	-	Accepted
S2	SMAW	10	16	None	-	Accepted
S3	SMAW	10	16	None	-	Accepted
S4	SMAW	10	16	None	-	Accepted

3.2 Corrosion Rate Testing

From the corrosion rate test, which was processed using NOVA software, data were obtained in the form of I_{corr}, $E_{corr\ Calc}$, and $E_{corr\ Obs}$. The results of the corrosion rate test can be seen in Table 5. The corrosion rate of overlay welding with the GTAW process has a slower corrosion rate than the SMAW process. This is because the GTAW process has a relatively higher heat input. When the welding results have a high heat input, the cooling rate will be slow.

Table 5. Bending Test Results

No	Specimen	I_{corr} (μa/cm^2)	$E_{corr\ Calc}$ (mV)	$E_{corr\ Obs}$ (mV)	Corrosion rate (mm/*year*)
1	GTAW	0.76561	-279.71	-280.67	0.00825
2	SMAW	10.614	-439.51	-437.89	0.11331

4. Conclusion

Based on the research results, it can be concluded that bending test results in both processes are declared accepted because there are no defects. The corrosion rate test results in the overlay welding process with GTAW are 0.00825 mm/year. This value has a slower corrosion rate than the welding process with SMAW of 0.11331 mm/year. This will provide a reference for welding projects with material SA 516 Gr. 70 with stainless steel overlay process.

References

[1] S. I. Talabi, O. B. Owolabi, J. A. Adebisi, and T. Yahaya, “Effect of welding variables on mechanical properties of low carbon steel welded joint,” *Adv. Prod. Eng. Manag.*, vol. 9, no. 4, pp. 181–186, 2014, doi: 10.14743/apem2014.4.186.

[2] J. Guo, X. Xu, M. A. E. Jepson, and R. C. Thomson, “Influence of weld thermal cycle and post weld heat treatment on the microstructure of MarBN steel,” *Int. J. Press. Vessel. Pip.*, vol. 174, no. April, pp. 13–24, 2019, doi: 10.1016/j.ijpvp.2019.05.010.

[3] Z. Ahmad, *Principles of Corrosion Engineering and Corrosion Control*. Elsevier, 2006.

[4] S. Yang, Z. Wang, H. Kokawa, and Y. S. Sato, “Reassessment of the effects of laser surface melting on IGC of SUS 304,” *Mater. Sci. Eng. A*, vol. 474, no. 1–2, pp. 112–119, Feb. 2008, doi: 10.1016/j.msea.2007.03.103.

[5] A. Aryswan, N. L. Arifin, H. Widiastuti, and D. D. W. Kirana, “Effect of Stainless Steel Weld Overlay Deposit on the Hardness of API 5L Pipes,” in *Proceedings of the 3rd International Conference on Applied Engineering*, 2020, pp. 119–123, doi: 10.5220/0010352801190123.

[6] W. Jiang, Y. Luo, B. Y. Wang, S. T. Tu, and J. M. Gong, “Residual stress reduction in the penetration nozzle weld joint by overlay welding,” *Mater. Des.*, vol. 60, pp. 443–450, 2014, doi: 10.1016/j.matdes.2014.04.032.

[7] N. Pravin Kumar and N. Siva Shanmugam, “Some studies on nickel based Inconel 625 hard overlays on AISI 316L plate by gas metal arc welding based hardfacing process,” *Wear*, vol. 456–457, no. February, p. 203394, 2020, doi: 10.1016/j.wear.2020.203394.

[8] S. Yang *et al.*, “Development of a welding process to overlay FeCrAl alloy on a thin wall austenitic stainless steel tube,” *Nucl. Mater. Energy*, vol. 27, 2021, doi: 10.1016/j.nme.2021.100958.

[9] P. Varghese, E. Vetrivendan, M. K. Dash, S. Ningshen, M. Kamaraj, and U. Kamachi Mudali, “Weld overlay coating of Inconel 617 M on type 316 L stainless steel by cold metal transfer process,” *Surf. Coatings Technol.*, vol. 357, pp. 1004–1013, Jan. 2019, doi: 10.1016/j.surfcoat.2018.10.073.

[10] T. Kannan and N. Murugan, “Effect of flux cored arc welding process parameters on duplex stainless steel clad quality,” *J. Mater. Process. Technol.*, vol. 176, no. 1–3, pp. 230–239, Jun. 2006, doi: 10.1016/j.jmatprotec.2006.03.157.

[11] R. Mohammeda, E. N. Kumarb, G. D. J. Ramb, M. Kamarajb, G. M. Reddyd, and K. S. Raoc, “Microstructure, mechanical and corrosion behaviour of weld overlay cladding of DMR 249A steel with AISI 308L,” *Mater. Today Proc.*, vol. 15, pp. 2–10, 2019, doi: 10.1016/j.matpr.2019.05.017.

[12] R. F. Liu and J. C. Wang, “Finite element analyses of the effect of weld overlay sizing on residual

stresses of the dissimilar metal weld in PWRs," *Nucl. Eng. Des.*, vol. 372, no. November 2020, p. 110959, 2021, doi: 10.1016/j.nucengdes.2020.110959.

[13] K. R. Trethewey and J. Chamberlain, *Corrosion for Students of Science and Engineering*. Longman Scientific & Technical, 1988.

[14] ASME IX, "ASME IX-Welding, Brazing, and Fusing Operators," *Am. Soc. Mech. Eng. ASME Boil. Press. Vessel Comm. Welding, Brazing, Fusing*, vol. SECTION IX, 2019.