Effect of Stainless Steel Weld Overlay Deposit on the Hardness of API 5L Pipes

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Abstract: To improve the corrosion resistance of API 5 L pipe, we applied a weld overlay of UNS S31603 stainless steel as filler metal. To confirm the modified material's quality, we determine the hardness of the material to be compared to API 5LD specification. We performed Vickers hardness tests at the corrosion-resistant alloy (CRA) area and the base metal and heat-affected zone. The tests show that the deposition improves the material hardness by 7.32%. The average Vickers hardness number at the CRA area was 212.32 HV, with 230 HV. Referring to API 5LD qualification, the maximum hardness allowed at the CRA area is 300 HV. Thus, the material processed by weld overlay has an acceptable quality.

1 INTRODUCTION

One of the most advantageous ways to transport oil and natural gas to date is by pipeline due to its low cost and large capacity (Zhou *et al.*, 2016). Line pipes are predominantly controlled by API 5L, which is now also an ISO specification (ISO 3183), regulating their manufacturing, testing, and classification (Singh, 2017). However, the corrosive impurities like water, hydrogen sulfide, and carbon dioxide during extraction cannot be completely removed during processing and transportation (Li *et al.*, 2017). These impurities could potentially cause material deterioration due to serious corrosion damages (Obanijesu, 2009). Switching the materials to the one with higher resistance to corrosion is not considered a possible solution since they generally possess lower strength.

A possible solution to provide a material that possesses high strength and corrosion resistance is to perform the weld overlay with metallurgically compatible corrosion resistant alloy to clad the steel (Kannan and Murugan, 2006). The term weld overlay, also known as weld cladding, is a method to improve properties of a base metal by applying a relatively thick layer of dissimilar weld metal (Rao, Reddy, and Nagarjuna, 2011). Austenitic stainless steels (ASS) are well known for their great corrosion resistance (Gupta and Birbilis, 2015; Lapechenkov *et al.*, 2020) and are proven to be successfully added to high strength low alloy steel (Rao, Reddy, and Nagarjuna, 2011). Hence, they are good candidates to be applied by weld overlay in this study. Lima *et al.*, 2020 reported that samples cladded by GTAW-hotwire show an impressive corrosion resistance.

Nevertheless, after the steel is cladded, its physical properties also change. Therefore, it is required to investigate whether the fabricated material still meets the standard's qualifications. One significant property of materials directly related to its lifetime is hardness (Lewis *et al.*, 2019). Hardness measurement is a mandatory step in manufacturing many products, and one of the standard hardness tests is Vickers (Daemi, Tomkowski, and Archenti, 2020).

This study reported a weld overlay by depositing austenitic stainless steel on API 5L pipe by the GTAW process. The fabricated material was then examined by the Vickers hardness tests to ensure that the resulting material has still complied with API 5LD specification, a standard for seamless and welded clad steel pipe with enhanced corrosion-resistant properties (American Petroleum Institute, 2015). It is shown that the resulting material could meet the related standard. Hence, the weld overlay proposed in this study could be performed on pipelines to improve their resistance against corrosion.

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2 MATERIALS AND METHODS

2.1 Base Metal

Specimens was prepared in accordance with API 5L specification. Seamless pipes was used as base metal, with specification API 5L Gr.L450Q PSL 2, P-No 1 Gr. No 2, thickness 8.18 mm, outside diameter 219.1 mm (8" NPS), heat number J7K5650, length 1000 mm, heat treatment condition: quenched and tempered, chemical composition (%): C = 0.06; CE (PCM) = 0.14; CE (IIW) = 0.31. Weld overlay length = 1000 mm.

2.2 Filler Metal

Filler metal applied in this study was austenitic stainless steel (ASS) UNS S31603. The welding process used two variant of filler metal, namely:

- Daiko ER309LMo size 1.2 mm with specifications EN ISO 14343-A: G 23 12 2 L AWS A5.9 (ER309LMo) modified, heat number: 547158, SFA-5.9, F-No.6, A-No.8.
- Novametal ER316L size 1.2 mm with specifications ASME II PART C: SFA-5.9 AWS A5.9/A5.9: ER316L EN ISO 14343-A: 19 12 3 L, heat number: 59583, SFA-5.9, F-No.6, A- No.8.

The elemental contents of base metal and filler metals can be seen in the following Table 1, while the mechanical properties in Table 2.

The weld overlay application was illustrated in the following Figure 1, with filler metal Daiko 309LMo as the inner first layer and Novametal 316L as the outer one.

Table 1: Elemental contents of materials.

Elemental Contents (%)	Material		
	Base Metal	Daiko 309LMo	Novametal 316L
C	0.06	0.0009	0.010
Si	0.21	0.300	0.310
Mn	1.24	1.430	1.940
P	0.007	0.018	0.019
S	0.001	0.004	0.009
Cu	0.01	0.087	0.140
Cr	0.17	21.240	18.540
Ni	0.02	14.740	11.800
Mo	0.01	2.570	2.580

Table 2: Mechanical properties of materials.

Mechanical Properties	Base Metal	Daiko 309LMo	Novametal 316L
Tensile Strength (MPa)	581	600	510
Yield Strength (MPa)	506	430	320
Elongation (%)	34	35	25
Impact Energy (J)	N/A	100	80

2.3 Welding Process

Welding process was conducted by DCEN pulsed gas tungsten arc welding (GTAW) without hot wire. The welding position was 1G, with the pipe placed horizontally and rotated counterclockwise. Welding travel was performed step-back and moved around 2.8 – 3.6 mm. The tungsten was 3.2 mm EWLa-2type, and the welding machine was Fronius 4500A. The welding parameters were carried out according to PQR shown in Table 3.

The weld overlay application was illustrated in the following Figure 1, with filler metal Daiko 309LMo as the inner first layer and Novametal 316L as the outer one.

2.4 Vickers Hardness Tests

The examination performed by Vickers hardness tester Mitutoyo model HV-113 S/N 500041203, with diamond indenter (face angle 136°), and load 10 kgf. The method used in this study complies with ASTM E92 (ASTM International, 2017), that is a standard method for testing Vickers's hardness of a metallic material. This study conducted a Vickers hardness test on two specimens, following the code that refers to ASME Section IX Qualification (American Society of Mechanical Engineers, 2010). Each of them tested at specific test location points based on API 5LD specification for CRA Clad or Lined Steel Pipe (American Petroleum Institute, 2015), and Aramco Drawing AB-036386, respectively. Those points are illustrated in the following Figure 2 and Figure 3.

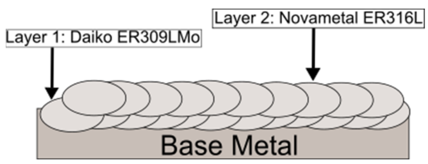

Figure 1: Weld overlay layout.

Table 3: Welding parameters.

Weld Pass/ Layer	Process, Current Type, Polarity	Filler Metal			Amps Range (A)	Volts Range (V)	Travel Speed (mm/min)	Preheat and Interpass (°C)	Heat Input (kJ/mm)	
		Classification	Size (mm)	Speed Range					Min	Max
Layer 1	GTAW/DCEN	ER309LMo	1.2	2 × 1000	190 – 230	13.1 – 14.5	400	32 – 160	0.37	0.50
Layer 2	GTAW/DCEN	ER316L	1.2	2 × 1300	200 – 240	12.5 – 13.5	400	40 – 178	0.38	0.49

As shown in the previous Figure 2, the test consists of 5 lines and each line was composed of 4 points, specifically: No. 1 at layer 1, No. 2 at HAZ, No. 3, and No. 4 at base metal. Figure 2 also shows the distances among lines. Those points out where the exact positions are. However, each line is 13 mm apart. Layer 1 and fusion line are 1 mm apart, the same as fusion line and HAZ.

Specimen 2 was tested by 5 lines with 4 points each, as shown in Figure 3. The points No. 1 located at layer 2, No. 2 at layer 1, No. 3 at HAZ, and No. 4 at base metal. The distances of lines and points, as shown in Figure 3, are similar to Figure 2, except the distance between fusion line and HAZ is a maximum 0.2 mm apart. Acceptance criteria of the examination were obtained from API 5LD specification (American Petroleum Institute, 2015) that covers the cladded API 5L pipe qualifications. The hardness test requirements are shown in Table 4.

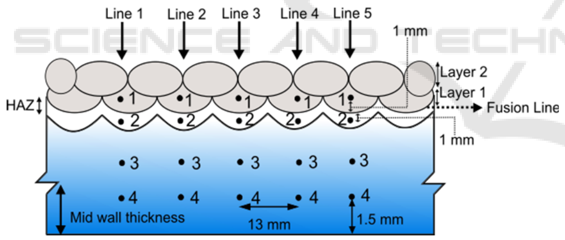

Figure 2: Specific test location points of specimen 1 based on API 5LD specification for CRA Clad or Lined Steel Pipe.

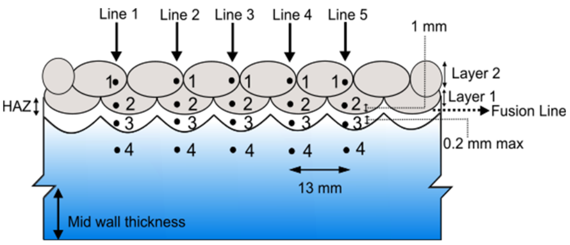

Figure 3: Specific test location points of specimen 2 based on Aramco Drawing AB-036386.

Since austenitic stainless steel was used as filler metals in this study, the maximum HV allowed at the CRA area is 300 HV10, while the hardness measured at base metal and HAZ area should be less than 248 HV10. The number 10 following HV scale represents the applied test force of 10 kgf (ASTM International, 2017).

3 RESULTS AND DISCUSSION

Data collected from the Vickers hardness test of both specimens are shown in Table 5 and Table 6. As demonstrated by Table 5, the average hardness of specimen 1 in the CRA area, HAZ, and base metal were 208 HV; 196.8 HV; and 195 HV, respectively. Table 6 shows that specimen 2 had average hardness in the outer layer 2, inner layer 1, HAZ and base metal sequentially were 213.8 HV; 219.6 HV; and 203.4 HV for the latter two. It can be calculated that the average hardness in the CRA area if both specimens are added is 212.35 HV. Referring to Table 4, the Vickers hardness number of CRA area in both specimens followed the acceptance criteria since the HV obtained was lower than 300 HV. On the other hand, HAZ and the base metal area was qualified with hardness numbers not exceeding 248 HV.

According to the measured data, it was recognized that the material hardness was increased due to the weld overlay. Comparing the HV at CRA and base metal, it is known that the hardness of specimen 1 was improved by 6.67%, while specimen 2 had increments of 5.11 % at layer 2 and 7.96% at layer 1. Hence, weld overlay increases the material's hardness around 7.32%. This observation might be due to the carbon diffusion hardens the weld metal through solid solution strengthening (Akhatova *et al.*, 2020). The fact that layer 1 was having the highest HV is expected due to being sandwiched between the base metal and layer 2, so the area contains more diffusion then more defects. However, it is required for further study to confirm the chemical composition in each layer.

Table 4: Acceptance criteria for Vickers hardness test (American Petroleum Institute, 2015).

Material	**Maximum HV allowed**
Ferritic steel base metal	248 HV10 at all locations unless otherwise agreed
Austenitic stainless steels	300 HV10 in all locations
22% Duplex stainless steels	300 HV10 in the parent material and 334 HV10 in the weld and HAZ
25% Duplex stainless super duplex steels	300 HV10 in the parent material and 378 HV10 in the weld and HAZ
Nickel base alloys	345 HV10 in all locations

Table 5: Measured hardness of specimen 1.

Test Location	No	Vickers Hardness Number (HV)					
		Line 1	Line 2	Line 3	Line 4	Line 5	Average
CRA	1	206	221	204	205	204	208
HAZ	2	192	196	202	196	198	196.8
Base Metal	3	189	188	197	199	193	195
	4	202	190	198	199	195	

Table 6: Measured hardness of specimen 2.

Test Location	No	Vickers Hardness Number (HV)					
		Line 1	Line 2	Line 3	Line 4	Line 5	Average
CRA	1	203	220	217	219	210	213.8
	2	208	219	228	230	213	219.6
HAZ	3	208	210	201	196	202	203.4
Base Metal	4	207	205	206	204	195	203.4

As seen in Table 6, the hardness of layer 2 relatively lower than layer 1. Apart from the intrinsic mechanical properties of Novametal 316L that have the most insufficient tensile strength among materials used, we expect its position relative to fusion line lead to carbon diffusion in that area was lower than the layer 1. Consequently, the outer layer of the clad had lower hardness than the inner one. The following Figure 4 and Figure 5 represent the measured HV numbers of specimen 1 and 2.

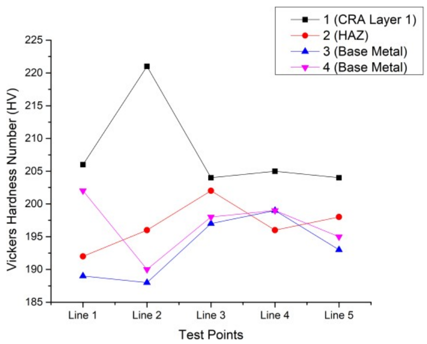

Figure 4: Graphical representation of specimen 1 measured Vickers hardness number (HV).

Those graphs show that the layer 1 consistently being the hardest part of material. However, it is yet unclear why the hardness of HAZ and base metal being alternately fluctuate.

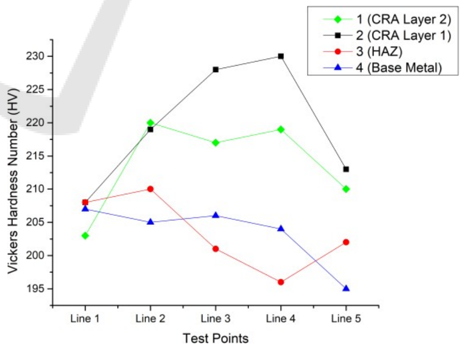

Figure 5: Graphical representation of specimen 2 measured Vickers hardness number (HV).

4 CONCLUSIONS

In this study, seamless pipes were cladded with two different filler metals to increase CRA's corrosion resistance. The hardness values on the CRA are higher than those for the untreated metal.

Nevertheless, the fabricated material could meet the acceptance criteria in API 5LD standard. However, further study is required to confirm whether the stainless steel overlay could improve the material's corrosion resistance properties.

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