Solving Corrosion and Wear Problems with Weld Metal Overlay

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Abstract

Corrosion and wear problems are common for many industrial systems, such as fossil-fired boilers, Kraft recovery boilers, chemical/petrochemical/refinery plants, smelters, process vessels, converters in the steel industry, etc. Proper materials selection for each application is critical in dealing with these problems. Changes in operating parameters combined with improper initial material selection manifest themselves as active sites for corrosion/erosion damage. One cost-effective approach to protect the equipment from corrosion and wear damage is to apply a corrosion or wear resistant alloy as a weld overlay coating using state-of-the-art automated welding equipment. The paper discusses successful applications of this technology to solve corrosion and wear problems in coal-fired boilers, kraft recovery boilers and process vessels. Also included in the discussion are characteristics of the weld metal overlay inclusive of the automated equipment used to apply weld metal overlay to operating boilers and pressure vessels.

Palavras-chaves: weld metal overlay, overlay, revestimento com solda automatizada
Keywords: weld metal overlay, overlay with automated welding,

Introduction

Weld metal build-up consists of selective area weld deposit to restore a pressure vessel dimension and/or impart physical properties. Corrosion resistant weld metal overlay is a dissimilar weld metal deposit designed to deter the effects of corrosion. ASME Section VIII for fabrication of vessel allows corrosion resistant weld metal overlay cladding during initial fabrication; whereas, NBIC allows for build-up of wasted areas of heads, shells and tubes, as well as for the application of corrosion protection barriers.

Welding procedure qualification for build-up per ASME Section IX, QW-202.3 requires mechanical testing in the form of tensile tests to effect procedure qualification along with side bends. Qualification for corrosion resistant weld metal overlay requires liquid penetrant examination, side bends and chemical analysis. Analysis for chemical composition measured from the fusion line is critical to assure adequate surface deposit chemistry.

Pulse Spray Gas Metal Arc Welding (PSGMAW) is a welding process in which the current is pulsed to utilize the advantages of the spray mode of metal transfer at average currents equal to or less than the globular to spray transition current. This pulsing technique combined with the advanced process controls allows for high speed weld metal deposition, low dilution and

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controlled heat inputs. Control of these welding parameters allows for precise deposition of the overlay with optimum surface chemistry, affording maximum surface protection.

With the ability to control welding parameters during deposition of the overlay, it is possible to apply weld overlay to large scale areas thus making it a technically and economically viable approach to repair existing damage and enhance corrosion resistance of the existing surface without requiring replacement. The utilization of machine welding automation significantly increases the field productivity of the process which makes it a viable approach for pressure component applications in situ.

The following are select examples of implementation of this technology to resolve corrosion issues in the real world. In today's economic environment, this type of repair has become a common method. In several industries such as pulp/paper, petrochemical, and power generation, it is the standard approach for the protection of components such as boiler tube water walls, process pressure vessels, and other components affected by wholesale corrosion.

Fossil-Fired Boilers

Improvements in combustion designs to remove NOx emissions combined with clean air legislation have resulted in installation of low NOx burners in utility boilers. Low-NOx combustion systems delay mixing of air and fuel which creates a high temperature, fuel-rich zone of reducing gases around the burner, which lowers the formation of NOx. Complete combustion of the remaining fuel takes place during later stages where temperatures are lower. Reduction in NOx formation, while environmentally beneficial, has led to accelerated wastage of carbon and low alloy steel tubing.

For conventional coal-fired utility boilers, the fuel/air mixture is rich in the combustion zone and air/fuel ratios are always equal to or greater than one. During the combustion process, sulfur in the coal is oxidized primarily to SO_2 with small amounts of SO_3, while H_2S and S2 are negligible. This environment promotes the formation of relatively dense adherent oxides on metal surfaces to provide corrosion protection. In contrast, low NOx combustion systems have a fuel-rich operation where air/fuel ratios become less than one, promoting formation of H_2S. This sulfide formation results in a porous non-adherent film, which does not protect tube surfaces, and corrosion rates increase under this environment. In addition, ancillary damage from erosion further enhances tube wastage.

Accelerated fireside tube wastage at Pennsylvania Electric Company (Penelec) Conemaugh Unit 2 Station was recorded after the installation of low NOx burners. The corrosion-erosion mechanism responsible for increased wastage is fly ash erosion combined with a low NOx reducing atmosphere. Conemaugh Unit #2 is an 800Mw Combustion Engineering tangential (coal) fired once-through supercritical boiler that began operation in mid-1971, and burns bituminous coal with a 2 % to 3 % sulfur content. The unit has a maximum steam flow of 1185042 kg/h (3,175,000 Lbs./h) at 276 bar (4000 psig) at 540 ^{o}C (1005 °F). The original waterwall tubing was 38.1 mm (1 1/2") OD SA-213 T-11 (1¼Cr-½Mo) material with a minimum wall thickness of 6.04 mm (0.238"). Fireside corrosion and circumferential cracking contributed to a wastage rate of 1.27 mm to 1.52 mm (0.05" to 0.06") per year. In 1982, Conemaugh started installing replacement panels of SA-213 T-22 (2¼Cr-1Mo) and obtained some improvement in circumferential cracking, but minimal reduction in fireside corrosion rates. In 1985, 11.15 m^2 (120 sq. ft.) of waterwall in Unit #1 was overlayed in-situ with Alloy 625 and AISI 309 stainless steel. The overlay is presently still in service. From 1985 to 1987, both units received shop-overlayed and stress-relieved panels containing Alloy 625 overlay that are still in service with no identifiable problems. In 1987, Conemaugh installed concentric firing, resulting in approximately 0.508 mm/y to 0.762 mm/y (20 mils/y to 30 mils/y) wastage rate. In 1993, Conemaugh #2 installed low NOx burners; Unit #1 followed one year later.

In January 1995, Unit #2 experienced a forced outage attributed to wall thinning of a waterwall tube. Station personnel suspected that wastage rates of 2.54 mm/y (100 mils/y) were responsible. To reduce the wastage, station personnel considered a number of options, including weld overlay and chromized tubing. In fall, 1995 during a scheduled outage of Unit #2, station personnel confirmed wastage rates of 0.254 mm/month to 0.305 mm/month (10 mils/month to 12 mils/month) on tubing installed during the January, 1995 forced outage. An area of approximately 557 m^2 (6000 sq.ft.) was gritblasted and overlayed with Alloy 625 (1).

The decision to use field applied weld overlay instead of chromized tubing was based upon a number of concerns raised over cost, life expectancy and durability of chromized tubing. Costs associated with installation of a new panel, such as insulation removal and cold side attachments (buckstays, expansion joints, etc.) were also factored into the decision to use field applied weld overlay. Once chromized panels are installed, grit blasting is no longer a viable method of preparing the tube surface for examination during subsequent inspections, as the chromized layer is only 0.254 mm to 0.305 mm (10mils to12 mils) thick and would quickly be removed during grit blasting. Wall blower and fireball erosion could also result in removal of the chromized layer (although not necessarily at the same rate as unprotected low alloy steel). Once the chromized layer has been penetrated, the base metal is unprotected. Surface defects incurred during handling could result in localized areas of unprotected base metal. Thermal Spray was considered, but dismissed, as no parallel boiler activity can occur during application, and it has a propensity for spalling. Weld overlay would produce a much thicker, more durable (easily repaired) protective layer, and one that could be gritblasted without significant concern over loss of the protective layer.

Alloy 625 was selected over AISI 309 stainless steel based on its closer thermal expansion match to the substrate material and 9-years service history. Specifically, Conemaugh station had installed Alloy 625 overlayed tubes 9 y previously and a sample was removed for analysis during the fall 1995 outage. A visual examination of the service exposed overlay revealed the original weave pattern on the fireside surface suggesting that the material did not experience significant corrosion wastage. Metallographic examination of the in-service sample showed a minimum overlay thickness of 1.82 mm (0.072"). SEM/EDS analysis of the overlay chemistry showed average chromium content of 20.4 % with values ranging from 20 % to 20.6 % (wt.). Based on these results, a minimum chromium level of 20 % was deemed necessary. In order to maintain this chromium level, the weld wire utilized for application was at the upper range for the chromium content as per AWS/SFA 5.14 ERNiCrMo-3, (20 % to 23 % Cr). The actual performance data with respect to hardness and chemical analysis are shown in Tables 1 and 2, respectively.

Liquor Recovery Boilers – Lower Furnace

Westvaco, located in Charleston, South Carolina, had been experiencing tube thinning just above the composite tube butt weld to carbon steel transition as a result of sulfidation attack. In an effort to assure optimum surface protection and adequacy of repair, Welding Services, Inc. undertook a test program under the direction of Westvaco. This program applied weld metal overlay on three SA-210 A1 tubes with an original wall thickness of 5.59 mm (0.220"). The tubing had been milled down for a 180° around the tube. Two tube samples had been milled to 3.56 mm (0.140") and the third sample to 3.94 mm (0.155"). One of the 3.56 mm (0.140") sample had a build-up of carbon steel applied to a thickness of approximately 1.52 mm (0.060") followed by a corrosion resistant layer of 1.78 mm (0.070") of ER309LSi. The remaining two test specimens had a layer of 1.78 mm (0.070") of ER309LSi applied.

After completion of the weld deposition, a series of mechanical tests to determine soundness, integrity and chemistry were performed by an independent test laboratory, Thielsch Engineering. Testing included burst rupture, tensile, shear and chemical analyses. The data shows that the burst samples for the overlayed tube failed at a higher pressure than the wrought tube, which was used as a standard and contained no overlay. Tensile data was highest for the combined carbon steel/stainless deposition followed by the 3.56 mm to 3.94 mm (0.140" and 0.155") overlayed tubes. Shear test results confirmed the tensile data and chemical analysis confirmed the ER309LSi deposit. Mechanical and chemical property test data are shown in Tables 3 to 6. As a result of this data, Westvaco during the June 1996 outage overlayed 120 m^2 (1300 sq. ft.) of tubing in the lower furnace, which represented a 254 mm (10") high band on all four furnace walls.

Liquor Recovery Boilers – Floor Application

Irving Pulp and Paper, located in Saint Johns, News Brunswick, Canada, had sustained cracking in the composite floor tubing Figure 1, which had been installed in 1995. This cracking was believed to be a combined result of thermal fatigue and stress cracking mechanisms. Based on test data supplied by Babcock & Wilcox, Irving during the fall 1996 outage decided to install Unifuse®360° tubing which consisted of Alloy 625 on SA-210 A1 tubing inclusive of overlayed membrane. Chemical analysis of the tube deposit is shown in Table 7. Cross-sectional photomicrographs of the overlayed tube is shown in Figure 2. This installation represents the first time a complete recovery boiler floor was installed using Unifuse® weld metal overlay technology.

Process Vessel

Celulosa del Pacifico, located in Mininco, Chile, has experienced large scale vessel wall corrosion in their continuous pulp digester. The vessel is 55 m (180 ft ~~feet~~) tall, 7.6 m (25 ft) ~~foot~~ diameter with an average wall thickness of 50.8 mm (2.0"). The inside surfaces of the vessel are exposed to wood chip product, as well as caustic solutions used in the processing of chips into pulp. The vessel has a design temperature of approximately 177 ^{o}C (350 °F), and a design pressure of 10.68 bar (155 psi).

Yearly thickness measurements taken over the operating life of the vessel indicated that large areas of the vessel had lost approximately 1.27 mm to 2.03 mm (0.05" to 0.08") inches of wall thickness over a five-year period. Two specific areas in the vessel experienced as much as 1.02 mm (0.04") inches of wall thinning in the last year of the measurements. The large single-year corrosion rates experienced in these two areas indicated that the condition would have to be addressed in order to continue operation, since a minimum wall thickness condition could be reached during the next operating cycle.

Weld metal overlay of the high corrosion zones of the digester was selected for the repair. ER309L austenitic stainless was selected as the overlay material after laboratory autoclave corrosion testing was performed(2). The ER309L would have to be applied using a very low dilution process in order to maximize the chromium and nickel contents of the as welded surface. A total of 180 m^2 (1944 sq.ft.) of the vessel was overlayed over a nine-day period to protect the high corrosion zones without affecting the planned duration of the maintenance outage.

Conclusions

Corrosion and wear problems commonly found in a variety of industrial systems have been successfully mitigated by the use of corrosion resistant weld metal overlay. Because of the resulting mechanical integrity, durability, and corrosion resistant properties provided by this method, this process has become a standard approach for erosion/corrosion mitigation in high temperature, pressure retaining components.

Bibliographical references

1) French, S., Rumbaugh, K., Hulsizer, P. N., Jirinec, M. J. and Stamper, D. - "Fireside Corrosion-Erosion Mitigation Via the Application of Weld Metal Overlay," EPRI Second International Conference on Welding and Repair Technology for Power Plants, May 1996, Orlando Florida.

2) Private communication with Dr. Angela Wensley - Bacon Donaldson.

Tables and Data

Table 1 - Weld Parameter Hardness Data (Rockwell B/C)

Distance From Fusion Line mm (")	T-11 With Preheat	T-11 Without Preheat	T-22 No Preheat Sample Set #1	T-22 No Preheat Sample Set #2	T-22 No Preheat Actual Field Parameters
0.051 (0.002)	25	32	39	33	29
0.254 (0.010)	27	32	40	33	30
0.508 (0.020)	28	32	40	29	27
0.762 (0.030)	27	34	38	28	26
1.016 (0.040)	22	32	38	25	22
1.270 (0.050)	24	35	35	Rb 83	Rb 83

Table 2 - Chemical Analysis Data

Distance from fusion line mm (")	C	Mn	Ni	Cr	Fe	Nb+Ta	Mo	Ti	Cu
	Weight Percentage (%)								
3.175 (0.125)	0.02	0.08	64.6	20.4	1.8	3.40	8.8	0.23	0.08
1.778 (0.070)	0.05	0.14	59.1	20.2	7.9	3.33	7.4	0.31	0.11
1.270 (0.050)	0.06	0.21	54.0	18.5	17.0	2.68	7.1	0.35	0.29
0.254 (0.010)	0.06	0.19	51.8	18.1	20.5	2.51	6.3	0.33	0.22

Table 3 - Tensile Test Results

Test	Tube 1	Tube 2	Tube 3	Tube 4
Tensile 1	5023 (72,857)	5678 (82,353)	6647 (96,414)	6078 (88,151)
Tensile 2	5031 (72,982)	6229 (90,341)	7005 (101,606)	6013 (87,213)
Tensile 3	5037 (73,070)	5769 (83,667)	6628 (96,135)	6313 (91,565)
Average bar (psi)	**5031 (72,970)**	**5892 (85,454)**	**6760 (98,052)**	**6134 (88,976)**
Yield 1	3042 (46,134)	4114 (59,664)	5364 (77,793)	4166 (60,420)
Yield 2	3036 (44,035)	4413 (64,000)	5420 (78,613)	3979 (57,705)
Yield 3	3042 (44,123)	4214 (61,167)	5105 (74,049)	4065 (58,956)
Average bar (psi)	**3086 (44,764)**	**4217 (61,610)**	**5296 (76,818)**	**4070 (59,027)**
Elongation 1	27 %	31 %	15 %	31 %
Elongation 2	28 %	26 %	15 %	29½ %
Elongation 3	31 %	24 %	25 %	31 %
Average (%)	**29 %**	**27 %**	**18 %**	**30 %**
% Reduction Area 1	61 %	60 %	21 %	43 %
% Reduction Area 2	60 %	54 %	23 %	54 %
% Reduction Area 3	58 %	47 %	52 %	51 %
Average (%)	**60 %**	**54 %**	**32 %**	**49 %**

Table 4 - Shear Test Data Results

Test	Tube 1	Tube 2	Tube 3 Base Metal/**C.S.**	Tube 3 C.S./S.S.	Tube 4
Shear 1	-	4667 (67,692)	4152 (60,222)	2778 (40,297)	5470 (79,333)
Shear 2	-	4623 (67,058)	4535 (65,777)	5647 (81,901)	5198 (75,397)
Shear 3	-	4821 (69,932)	4287 (62,184)	5181 (75,149)	5539 (80,338)
Shear 4	-	-	-	6643 (96,349)	-
Average (psi)	**-**	**4704 (68,227)**	**4324 (62,728)**	**5062 (73,424)**	**5402 (78,356)**

Sample No. 1: Not overlaid – SA210-A1
Sample No. 2: Milled to 0.155, overlaid with S.S.
Sample No. 3: Milled to 0.140, overlaid with C.S. and S.S.
Sample No. 4: Milled to 0.140, overlaid with S.S.

Table 5 – Burst Test Data Results

Test	Not Overlaid	S.S. Overlaid
Tube 1	**12,100**	**12,800**
Tube 2	**12,200**	**12,700**
Tube 3	**12,100**	**12,700**
Average	**12,133**	**12,733**

Notes: Original tube approximately 5.588 mm (0.220”) thick.
Welded tube milled down to 3.556 mm (0.140”).

Table 6 - Chemical Analysis Test Data

Element (wt%)	Tube 2	Tube 3	Tube 4	SFA 5.9 ER 309L Si	SA 213 TP 304L
C	0.047	0.026	0.048	0.030 max.	0.35 max.
Mn	1.954	1.940	1.840	1 – 2.5	2.0 max.
P	0.017	0.022	0.021	0.03 max.	0.04 max.
S	0.009	0.008	0.008	0.03 max.	0.03 max.
Si	0.865	0.761	0.732	0.65 – 1.0	0.75 max.
Cr	20.914	20.652	20.038	23 – 25	18.0 – 20.0
Ni	11.904	11.348	10.866	12 – 14	8.0 – 13.0
Mo	0.084	0.132	0.129	0.75 max.	-
Cu	0.089	0.212	0.223	0.75 max.	-

Notes: All data reported is averaged of three tests.
Testing performed on outer surface of overlay after milling to smooth surface.

Table 7 - Chemical Analysis Unifuse® 360° Alloy 625 Tubing

Element (wt%)	SFA/AWS A5.14 ERNiCrMo-3	Techalloy Heat # XU483	Unifuse® ATS Report # 67455 @ 0.010" from fusion line	Unifuse® ATS Report # 67455 @ 0.100 from fusion line
C	0.10 mx.	.01	0.2	0.01
Ni	58.0 min.	64.5	60.4	61.4
Cr	20 - 23	22.24	20.2	20.5
Mo	8 - 10	8.78	8.3	8.4
Cb + Ta	3.15 - 4.15	3.59	3.16	3.24
Fe	5.0 max.	.25	7.9	4.8

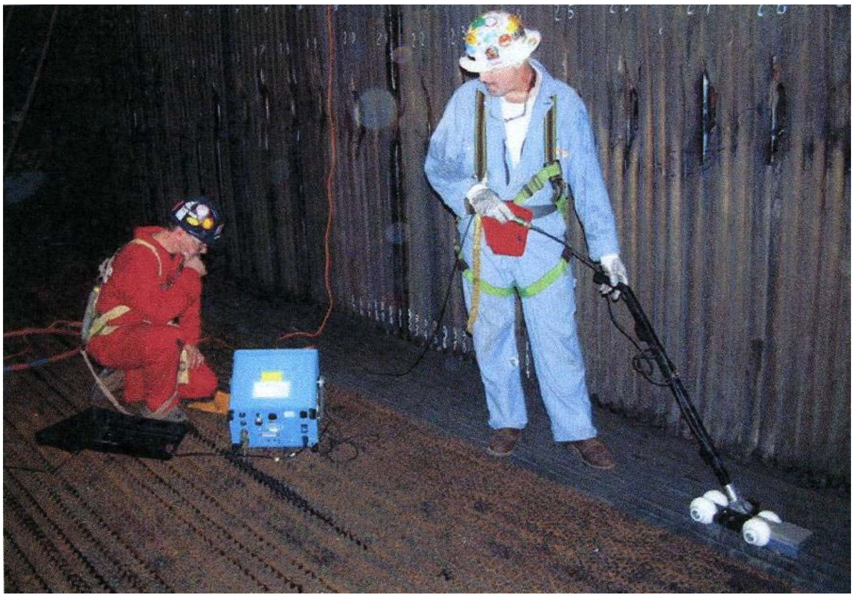

Figure 1 – Inspection of Composite Tube Flooring

Figure 2 – Overlay Tube Photomicrograph

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