CORRODION CONTROL
BY MODERN WELD OVERLAY TECHNOLOGY

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INTRODUCTION

In many large industrial plants, such as, power generating plants, pulp and paper mills and refineries, most major plant equipment, such as boilers and pressure vessels, is manufactured from carbon steels or low alloy steels for pressure containment. These components are generally designed and constructed based on strength requirements following codes and standards, such as ASME Codes. Although most of these components have corrosion allowance build into their initial wall thickness, wastage rates due to corrosion can be excessive for carbon steels or low alloy steels. Thus, boilers or vessels, in many cases, could not operate economically without some sort of surface protection against corrosion or corrosion/erosion. One cost-effective, engineering solution is to use a surface protection layer to protect carbon steel (or low alloy steel) boiler tubes or vessels against corrosion attack. This approach allows the substrate material (i.e., carbon steels or low alloy steels) to provide strength requirements to meet codes and standards for pressure containment while relying on the surface protection layer to protect the equipment against corrosion, thus, allowing the equipment to operate in a cost-effective manner

Weld overlay had been used in the past as a temporary, “band-aid” type repair in the field until a somewhat permanent fix could be developed to address the corrosion problem. Thanks to advances in automatic welding system and process control, it is now possible to overlay a large area of major equipment, such as, the waterwall of a boiler or the internal diameter of a reactor vessel, with a corrosion-resistant alloy to significantly minimize or essentially eliminate the corrosion problem. Modern weld overlay has now become a long-term fix to fireside corrosion problems for boiler tubes in waste-to-energy boilers, coal-fired boilers and recovery boilers, and to corrosion problems due to processing streams in reactor vessels in pulp mills, refineries and petrochemical plants.

The present paper discusses briefly the status of the modern overlay technology for applying a corrosion-resistant alloy as an overlay in the field to the existing equipment for corrosion control. Corrosion problems and the successful overlay alloys used to solve the corrosion problems in boilers, such as, waste-to-energy boilers, coal-fired boilers and recovery boilers, and in vessels in pulp mills and refineries are described.

MODERN WELD OVERLAY TECHNOLOGY

Modern overlay machines are mechanized, and are equipped with real time display of welding parameters, such as, voltage, current, travel speed, wire feed speed, and torch oscillation, etc. in order to insure the consistent quality of the overlay. It is particularly important when the overlay area in a boiler or vessel can be hundreds of square meters (or thousands of square feet). Generally, multiple machines are employed at the same time in a boiler or vessel in order to reduce the total project time. Accordingly, overlaying a 100 square meters area (approximately 1000 square feet) can be routinely accomplished in seven days on a two 12-hours shifts per day schedule.

The lower furnace of the boiler is typically constructed using a tube-membrane design to contain the combustion zone inside the furnace. Both tubes and membranes (i.e., steel plate or rib connecting the adjacent boiler tubes) are typically made of carbon steel or a Cr-Mo steel. For overlay welding of waterwall in a boiler, the process generally starts with the first weld bead covering the membrane in a vertical down progression, which is then followed by a second weld bead, third bead, etc., covering the tube portion of the waterwall. Each weld bead overlaps part of the previous weld bead in order to insure that no missing spot is resulted. Once the weld bead sequence is pre-programmed, the machine then automatically follows the bead sequence covering the waterwall from the membrane to the tube section. The thickness of the corrosion-resistant overlay applied to the boiler's waterwall is typically 1.8 mm (0.070") minimum. Figure 1 shows a schematic of the weld bead sequence and the overlapping of weld beads in overlaying waterwall. In this example, the weld beads on the membrane are not shown. Figure 2 shows a cross-section of the overlay on a boiler tube sample, which was obtained from the boiler's waterwall. The sample shows a small portion of the membrane on both sides of the boiler tube. The overlay is clearly revealed in the figure.

For overlaying the internal diameter of a vessel for corrosion protection, it is traditionally applied in a horizontal welding mode. This process typically results in a weld overlay with a minimum of about 4.8 mm (0.1875") thick. Figure 3 shows the portion of the weld overlay of type 317L performed in a horizontal mode on the internal diameter of a crude distillation column (refinery vessel). A vertical down mode of welding progression has recently been developed, which results in a higher overlay speed and a thinner overlay, typically about 2.5 mm (0.100") thick. Further improvement in welding efficiency in a vertical down mode was made more recently by equipping each machine with two weld heads instead of the traditional one weld head per machine. This latest machine design significantly reduces the welding time required for the same project, thus, improving productivity and reducing labor cost.

Pulse sprayed gas metal arc welding (PSGMAW) has been selected for the weld overlay process. This welding process combined with automatic overlay welding involving fast oscillation results in fine cellular dendritic subgrain struture for austenitic alloys, showing no carbide precipitation, which is indicative of fast cooling of the molten weld metal deposit. The resultant weld overlay generally exhibits good ductility. A detailed description of the microstructure and properties of the overlay produced by this process can be found elsewhere.(1) Other characteristics of the overlays produced by the process include low dilution in overlay chemistry (typically 10% or less), crack-free, minimal heat affected zone, minimal distortion, etc. Low dilution in overlay chemistry is critical in providing corrosion protection by the overlay. For example, an overlay welding process that produces a 10% dilution, when type 309 weld wire with 24% Cr is used to deposit an overlay on carbon steel substrate, will result in a type 309 overlay having about 22% Cr. Overlays containing about 22% Cr should have adequate corrosion resistance in many industrial environments where carbon or low alloy steels are in use but with high corrosion rates. However, if the overlay process produces an overlay with 30% dilution, chromium in the type 309 overlay will be down to about 17%, which can be too low to provide adequate corrosion protection in many industrial environments.

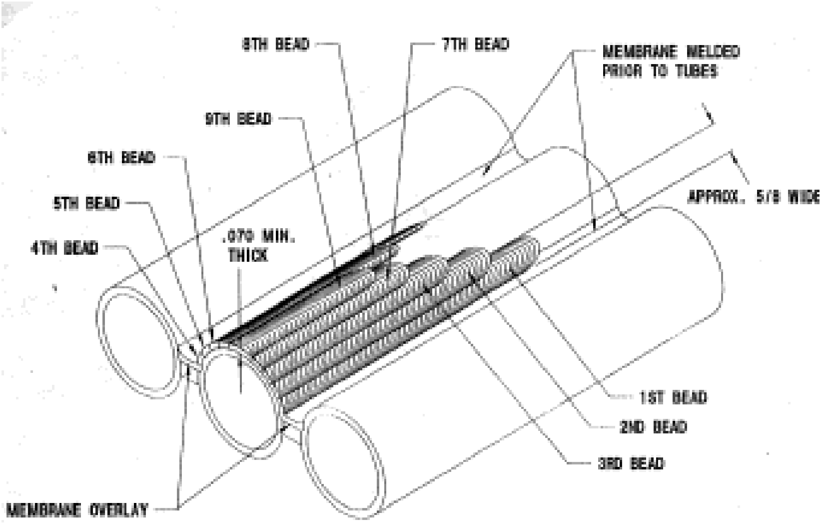

Figure 1. Schematic showing the weld bead sequence in overlaying the waterwall of a boiler

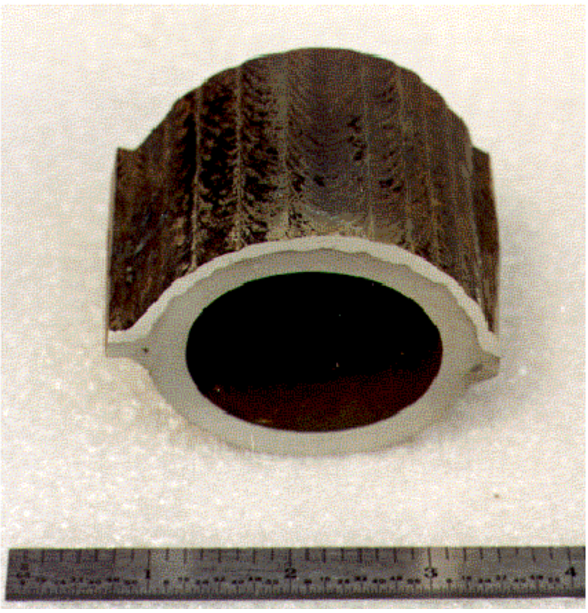

Figure 2. Cross-section of a type 309 SS overlay boiler tube sample, which was obtained from a recovery boiler’s waterwall. The overlay is clearly revealed in the figure.

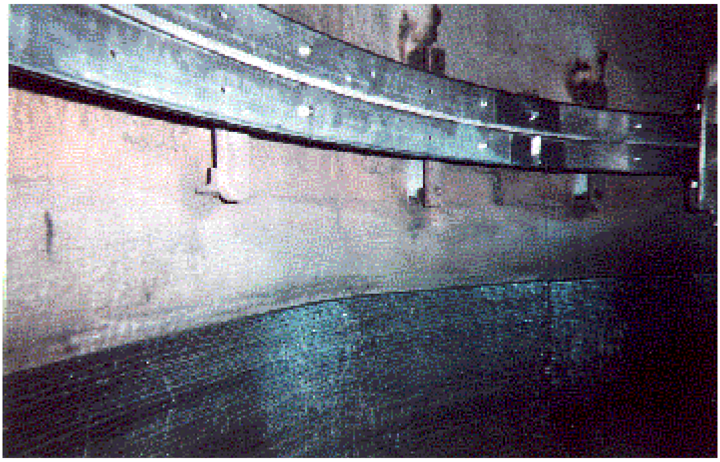

Figure 3. Type 317L overlay applied in a horizontal mode on the internal diameter of a crude distillation tower. The track used to guide the welding machine was still visible.

CORROSION CONTROL

Waste-To-Energy Boilers

Municipal waste is often contaminated with chlorine, sulfur, sodium, potassium, zinc, lead and other metallic constituents. During combustion of this waste, corrosive species of chlorides and sulfates are formed in the combustion zone. Corrosion of metals by chlorides and sulfates in waste incineration environments is very well documented in the literature.(2-5) At metal temperatures below approximately 650 C, chloride corrosion attack dominates the corrosion reaction. For higher metal temperatures, the corrosion reaction is then dominated by the combination of both chloride attack and sulfidation. Thus, waterwalls and superheaters are subjected to chloride attack. Wastage rates of 1.3 –2.0 mm/year (50-80 mpy) have been observed for carbon steel waterwall tubes. The levels of chloride vapors and deposits were sufficiently high in many waste-to-energy boilers that stainless steels were found to be inadequate. In chloride-bearing environments, iron is a detrimental alloying element, and tends to form high vapor pressure and low melting point iron chlorides as corrosion products. As a result, steels and Fe-base alloys are generally more susceptible to chloride attack than nickel-base alloys. For best performance for waterwalls and superheaters, nickel base alloys are required.

In mid 1980s, Welding Services Inc. (WSI) pioneered field overlay welding of waterwall in a waste-to-energy boiler using nickel-base alloy 625 filler metal (Ni-21.5Cr-9Mo-3.7Nb alloy). The alloy 625 overlay was proven to be so successful against fireside corrosion due to chloride attack that approximately 127,000 kg (280,000 lbs) of alloy 625 weld metal had been applied by WSI by 1990 for 15 waste-to-energy plants. Overlay welding with alloy 625 has since become a standard industry fix to the waterwall corrosion problem in waste-to-energy boilers. A sample list of the waste-to-energy boilers whose waterwalls were overlaid with alloy 625 by WSI in 1996 is tabulated in Table 1. Today, waste-to-energy boilers continues to rely on alloy 625 overlays for corrosion protection of boiler tubes which include waterwalls, superheaters and generating banks.

Table 1. Sample list of waste-to-energy boilers whose waterwalls were overlaid with alloy 625 by WSI in 1996

Location	No. of Boilers	Surface Area m^2 (ft^2)
Lancaster, PA	4	288 (3100)
Spring Hill, FL	1	20 (210)
Marietta, PA	2	116 (1250)
Alexandria, VA	2	65 (700)
Rahway, NJ	1	10 (107)
Lawrence, MA	1	65 (700)
Jamesville, NY	2	47 (500)
Rochester, MA	3	251 (2698)
Westbrook, ME	1	19 (205)
Oxford, NJ	1	28 (300)
The Netherlands	5	1051 (11311)

Utility Coal-Fired Boilers

Combustion of coal takes place generally in the lower furnace, which is surrounded by waterwalls (typically a tube-membrane construction). Typically, the waterwall is constructed from carbon steels or Cr-Mo steels. The combustion of coal typically takes place under highly oxidizing conditions. Under these conditions, the waterwall made of carbon steels or Cr-Mo steels forms Fe_3O_4 and Fe_2O_3, and exhibits relatively low oxidation rates. As a result, tube wall wastage rates have been manageable in general without any surface protection.

However, recent installation of low NO_x burners in some utility coal-fired boilers has resulted in significantly higher wastage rates for the waterwall. In these units, ash deposits were found to contain unburnt carbon and pyrite (FeS). This is indicative of reducing conditions generated under low NO_x combustion. Carbon steel or Cr-Mo steel tubes were found to suffer sulfidation attack.(6-9) Wastage rates of 1.3-1.5 mm/yr (50-60 mpy) or higher have been observed for carbon steel and Cr-Mo steel waterwalls.

Some test trials had been performed to test overlays of type 309 SS and nickel-base alloy 625 in some boilers in late 1980s. Initial results had been very encouraging. Large scale applications of type 309 SS and alloy 625 overlays in boilers began in the 1993-1994 period. More and more utility coal-fired boilers are now relying on either type 309 SS or alloy 625 overlays for waterwall protection against sulfidation attack under low NO_x combustion. Table 2 shows a sample list of the overlay jobs performed by WSI on the coal-fired boilers in the U.S.

In coal-fired boilers, slag deposits on boiler tubes are common, and those deposits can affect the heat transfer of boiler tubes. A common practice in the industry is to use soot blowers to remove those deposits periodically. The soot blowing steam often causes severe erosion/corrosion problem for carbon steel or Cr-Mo steel tubes. Without any surface protection, these tubes may only last for 1-1/2 year to 2 years. The damage mechanism is believed to be due to steam impingement, which removes the scales and deposits from the tube, exposing the fresh tube surface to corrosive gas stream for more corrosion, followed by removal of these corrosion products and scales by soot blowing steam. Tube wastage is, thus, accelerated by this erosion and corrosion interaction. The use of type 309 SS or alloy 625 overlays has been found to be very successful in minimizing or eliminating erosion/corrosion problem. (9)

Table 2. Sample list of U.S. coal-fired boilers with waterwalls overlaid by WSI

State	Boiler	Overlay Area $m^2(ft^2)$	Alloy	Date Performed (m/y)
Alabama	"A"	93 (1000)	309	2/94
Florida	"A"	37 (400)	309	3/95
	"B"	47 (500)	309	6/96
	“C”	507 (5450)	309	4/98
	“E”	124 (1328)	309	4/98
Georgia	"A"	65 (700)	309	4/93
	"B"	93 (1000)	309	12/94
	"C"	28 (300)	309	9/96
Illinois	"A"	47 (500)	625	10/93
Indiana	"A"	93 (1000)	309	10/94
	"B"	93 (1000)	309	10/94
	"C"	465 (5000)	625	3/96
	"D"	79 (850)	625	5/96
	"E"	930 (10000)	625	10/96
	“F”	428 (4600)	625	10/98
Maryland	"A"	47 (500)	309	10/93
	"B"	47 (500)	309	10/96
New Jersey	"A"	149 (1600)	625	5/96
Ohio	"A"	93 (1000)	309	10/96
	“B”	372 (4000	309	10/98
Pennsylvania	"A"	47 (500)	622	9/87
	"B"	56 (600)	625	9/95
	"C"	595 (6400)	625	10/95
	"D"	470 (5000)	309	11/95
	"E"	84 (900)	625	3/96
	"F"	140 (1500)	625	5/96
	"G"	930 (10000)	625	9/96
	"H"	140 (1500)	625	3/97
	“I”	390 (4200)	625	10/98

Recovery Boilers in Kraft Pulp Mills

In kraft pulping process, black liquor is produced as a by-product from the cooking operation in digesters where the lignin and other organic matter are dissolved from wood chips so that fibers can be recovered from spent cooking liquor. This spent liquor is then concentrated through a series of evaporators before it is being fed into a “black liquor” recovery boiler for combustion. The cooking liquor consists of mainly sodium sulfide and sodium hydroxide. The main functions of the recovery boiler are to recover the inorganic cooking chemicals used in digesters and to generate steam for the mill.

The black liquor contains organic solids and sulfur compounds, such as, Na_2SO_4 and $Na_2S_2O_3$, along with some NaCl. Combustion takes place under reducing conditions in the lower furnace, transforming sodium sulfate to sodium sulfide and forming sodium carbonate. Carbon steel waterwall tubes above the smelt bed in the lower furnace are exposed to reducing sulfidizing, gaseous environment, and are subjected to sulfidation attack. Wastage rates of carbon steel tubes have been reported to be 0.2-0.8 mm/y (8-32 mpy).(10) Application of type 309 weld overlay has been very successful in protecting the carbon steel waterwall above the smelt bed against gaseous sulfidation attack. One recovery boiler whose waterwall (above smelt bed) being overlaid with type 309 SS has been in service since 1989 without problems. A tube sample shown in Fig. 2 was cut from the 309 overlaid waterwall in a recovery boiler after one year of service. There was no evidence of sulfidation attack or other types of materials degradation. The same overlay was inspected visually this spring after two years of service, and again, was not shown to have any evidence of sulfidation attack. Weld bead ripples were still clearly visible. Other boilers using type 309 overlays to protect carbon steel waterwalls above the smelt bed are listed in Table 3.

Table 3. Partial listing of recovery boilers with surface overlay protection in pulp & paper mills in the U.S., Canada and Chile.

Mill Location	Overlay Alloy	Component	Year Overlaid
Midwest	309L	Waterwall above smelt bed	1989
South	309L	Waterwall above smelt bed	1995
South	309L	Waterwall above smelt bed	1996
Southeast	309L	Waterwall above smelt bed	1996
Southeast	309L	Waterwall above smelt bed	1996
South	625	Floor tubes/membranes	1995
Canada	625	Floor tubes/membranes	1996
Southeast	625	Floor membranes	1995
South	625	Floor tubes/membranes	1997
Southeast	625	Smelt spout wall	1994
Canada	625	Smelt opening	1987
Southeast	625	Smelt opening	1994
Chile	625	Smelt opening	1996
South	625	Smelt spouts	1994

During combustion, inorganic solids, such as sodium sulfide, sodium hydroxide, sodium carbonate, sodium sulfate, thiosulfate, sodium chlorides and others, melt and flow out of the boiler from the furnace bed through smelt spouts. The furnace floor (bed) is typically constructed with a tube-membrane design, using co-extruded composite tubes with type 304L as an outer tube cladding to protect carbon steel substrate. These floor tubes are typically exposed to the smelt bed. In recent years, however, an increasing number of recovery boilers have been experiencing cracking of the 304L cladding. It is now believed that stress corrosion cracking was the major cause for the 304L cracking.(11) Alloy 625 belongs to a Ni-Cr-Mo alloy family, and is known to be highly resistant to stress corrosion cracking. Application of alloy 625 overlay onto the outer diameter of the individual carbon steel tubes has been successfully developed. The tubes with alloy 625 overlay on the outer diameter have been used with great success for floor tubes and other critical areas such as spout walls, smelt openings, etc. These successful applications are also illustrated in Table 3.

Digesters in Kraft Pulp Mills

Digesters are used in kraft pulping process to dissolve the lignin and other organic matter from wood chips in a cooking liquor so that fibers can be recovered by separating them from spend liquor discharging from digesters. The cooking operation is carried out in either a continuous digester or a series of batch digesters. Digesters are generally constructed from carbon steel, and the cooking liquor can be quite corrosive to carbon steel due primarily to thiosulfates and polysulfides.(12) Weld overlay with austenitic stainless steels, particularly type 309 SS, has been widely used for both batch and continuous digesters. In recent years, however, many batch digesters have been experiencing much higher corrosion rates, and require a better corrosion-resistant alloy than type 309 SS. In their most recent laboratory testing, Wensley, et al. (13) found that Cr is the most important alloying element in resisting corrosion attack, with preference of 25% or higher Cr. Accordingly, type 312 SS with 28-32% Cr in weld wire is gaining wider applications for corrosion protection of batch digesters. Table 4 shows a list of digesters overlaid with type 309 SS and type 312 SS by WSI in 1997 and 1998. Overlays performed in earlier years are not included in the table.

Table 4. Partial listing of batch digesters with weld overlays performed by WSI in 1997 and 1998 in the U.S., Canada, South America, Europe and Asia.

Mill Location	Overlay Alloy	Welding Mode	Overlay Area (m^2)	Year Overlaid
Florida	309	Horizontal	41	97
Spain	309MoL	Horizontal	56	97
Wisconsin	312	Horizontal	56	97
Georgia	309	Horizontal	140	97
Brazil	309	Horizontal	558	97
Ohio	309	Horizontal	124	97
South Carolina	312	Horizontal	90	97
Canada	312	Horizontal	100	98
Canada	312	Vertical	246	98
Australia	309	Horizontal	86	98
Georgia	312/309	Vertical	441	98
Brazil	309	Horizontal	372	98
Ohio	312	Horizontal	187	98
Wisconsin	312	Vertical	51	98
Tennessee	312	Vertical	65	98

Petroleum Refineries

Corrosion is an important issue to deal with in the operation and maintenance of processing equipment in petroleum refining. The constituents in crude oil that can cause corrosion problems in the processing units are sulfur compounds, salt water, inorganic and organic chlorides, inorganic and organic acids and nitrogen. The refinery operation consists of numerous processing units with different feeds, processes and operating conditions, thus resulting in different corrosive constituents and different corrosion modes. In general, the corrosive constituents present in petroleum refining include naphthenic acid, chlorides, sulfur compounds, H_2S, NH_3 HCN, SO_2, H_2, HCl, HF, CO_2, etc. Corrosion of alloys in petroleum refining processes is well documented in the literature. (14,15)

In crude distillation units, both atmospheric and vacuum towers are generally constructed from carbon steel, Monel clad steel, 410 clad steel, or 316L clad steel. Because of naphthenic acid corrosion and sulfidation, 309L and 317L are the common weld overlay alloys for corrosion protection of these vessels. Figure 3 shows the internal diameter of an atmospheric tower, which was overlaid with type 317L SS. The unit was made of carbon steel. In coking units, where the bottom resid from the vacuum tower is converted into petroleum coke and lighter hydrocarbon fractions, sulfidation is a major corrosion mode for coke drums, which are typically made of carbon steel, Cr-Mo steels, 405 clad steels or 410 clad steels. Alloy 82 (Ni-20Cr-2.5Nb+Ta-3Mn) performs very well as a weld overlay for coke drums, with no sulfidation problems operating at temperatures up to 510 C (950 F). Coke drums also experience thermal cycling during operation. The alloy 82 overlay exhibits good thermal fatigue resistance. In amine treating units, sour gases such as H_2S and CO_2 are removed from refinery process off-gases by absorption in aqueous amines, such as DEA (diethanolamine) and MEA (monoethanolamine). The weld overlay with 309L has been successfully used for amine regenerators. Weld overlay is also used successfully for corrosion protection in many other processing units.

SUMMARY

Major corrosion problems in waste-to-energy boilers, coal-fired boilers, kraft recovery boilers, digesters in pulp mills, and refinery vessels are described. Modern weld overlays applied by advanced automatic overlay welding machines are discussed. The merits for using these modern weld overlays for corrosion protection for large industrial equipment are also discussed. The use of modern weld overlays has been proven to provide long-term corrosion protection for the aforementioned systems. Overlays of nickel-base alloy 625 has been extremely successful to minimize the chloride corrosion attack on waterwalls and superheaters in waste-to-energy boilers. Both type 309 SS and alloy 625 overlays have been very successful in reducing or essentially eliminating sulfidation attack on the waterwalls of coal-fired boilers equipped with low NO_x burners. Also successful in mitigating corrosion problems in kraft recovery boilers are alloy 625 for floor tube and membrane overlays and 309 SS and 625 overlays for corrosion protection in lower furnace waterwalls. Kraft digesters have relied on 309 SS and 312 SS weld overlays for corrosion protection. Many vessels, towers and columns are weld overlaid with austenitic alloys, such as, 309L, 317L, alloy 82, etc., in petroleum refineries. The weld overlay approach has also been used as an effective means to manage corrosion and wear problems for vessels and reactors in petrochemical/chemical processing, for waste heat boilers in mineral ore roasting operations, and other industrial systems.

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