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NEW GENERATION OF TUBE SURFACE TREATMENTS HELP IMPROVE EFW BOILER RELIABILITY

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ABSTRACT

Surface treatments, such as weld overlays, thermal sprays, laser claddings and fused coatings have been used for many years to protect boiler tubes operating in corrosive and erosive conditions. Several variables are typically identified that influence the choice of the technology selected, and the materials used to upgrade the boiler elements. Specifically, operating conditions such as corrosive species present, tube and gas temperatures, and the presence of erosive processes such as fly ash impingement and soot blowing significantly influence the severity of the wastage mechanisms. Given the many options available, and the uncertainty in determining reliable operating data, most selections need to be based on a “fit for all” solution. Case studies for applications of protective coatings in severe applications are useful to indicate relative performance of each system. From such results, limitations and some indication of performance can be established. As an example, AmStar cladding was field applied for EfW boiler water walls protection at 4 EfW plants. A number of superheater tube samples, cladded in the AmStar shop, were installed at another 4 EfW plants.

The AmStar 888® cladding material is a development specifically geared to environments that may see erosion, corrosion, or a combination of both mechanisms. The material is a Nickel Chrome alloy, with carbide and boride additions. The coating is applied (field or shop) using a high velocity spray system, and requires no post treatment. The material is also easily repaired if defects occur in the future. The presented field trials at EfW plants have brought very positive results for all carbon steel water wall applications and have shown some good potential for salvaging old poor quality Inconel weld overlay by spraying AmStar 888® cladding over it. The superheater tube trials are more complex due to the variety of boiler designs which may significantly affect environmental variables. Not surprisingly, these trials have shown a range of results so far: from very good at one plant to not satisfactory at another. Testing is ongoing, so more results will be coming.

Although such field tests do not provide quantitative results, they do provide comparative performance guidelines for generally aggressive boiler environments. This data is very useful to both design and maintenance engineers, who are often faced with limited options.

Key words: Energy-from-Waste (EfW) boiler, protective coating, cladding, thermal spray, weld overlay, corrosion, molten salts.

INTRODUCTION

The tube wastage and failures, which have long been a major issue of maintaining EfW boilers, are predominantly caused by fireside metal corrosion. The difficulty of combating this corrosion is that it varies from plant to plant, sometimes even from unit to unit of the same plant, and is highly related to the composition of feed, boiler design, and deviation from design conditions during the actual operation. Municipal Solid Waste (MSW) typically consists of paper, plastics, leather, wood, glass, metals and food waste. MSW combustion generates highly corrosive gases (HCl, SO₂, NaCl, KCl and heavy metals chlorides) and ashes containing alkaline chlorides and

sulphates. MSW typically contains about 0.5% of chlorine [1], but the practical concentrations vary daily due to the heterogeneous nature of the feed. Some recent studies indicate significantly increased corrosion rates when extra chlorine in the form of PVC is added to the fuel mix [2]. In addition to chlorine and a variety of metals in MSW feed, a number of other factors can also affect corrosion in EfW boilers, such as flue gas temperature and velocities, metal temperature, oxygen and carbon monoxide concentrations, heat flux, fly ash carryover, and so on. Fireside corrosion of EfW boiler tubes are typically driven by the following four simultaneously occurring mechanisms:

1. corrosion by gaseous phase including “active oxidation” by chlorine (HCl, Cl₂) [3];
2. condensation of alkali and heavy metals chloride and/or sulfates [4];
3. deposit induced corrosion and sulfidation of condensed chlorides [5];
4. molten salts eutectics cause dissolution of protective oxide scales and tube metal [6].

It is generally accepted that the intensity of all these mechanisms can be controlled to a certain degree by a proper design for an EfW boiler. Extensive studies over the years have established some proven correlations between flue gas and tube metal temperatures on fireside corrosion rates which have been utilized in the latest EfW boiler designs. For example, positioning a high temperature (finishing) superheater with metal temperature below the 320 - 430 C (700 - 800 F) range in the area of moderate flue gas temperature below 650 C (1200 F) definitely helps in corrosion mitigation [7]. However, it also requires additional superheater heating surface which makes an EfW boiler larger and more expensive.

More than that, current political reality encourages the EfW industry to play an essential role in both sustainable energy supply and environmentally sound waste management, which puts more emphasis on increasing the energy recovery efficiency. Such trends demand higher steam pressure and temperature to increase electrical efficiency, as increasing the boiler final steam temperature from 400°C to 500°C leads to a 20% increase of power generated by a steam turbine. Raising steam temperature to this level requires locating the finishing superheater in a flue gas temperature zone significantly above 650 C (1200 F), causing drastic increases in corrosion rates for EfW boilers (contrary to coal, oil and gas fired boilers, where proper material selection could provide satisfactory resistance to quite different corrosion mechanisms taking place in those boilers). Frequent superheater tube replacement has become a common practice in today’s EfW industry, especially for the higher efficiency plants with elevated steam pressure and temperature, and this, of course, elevates the cost of operation. In attempts to find more cost effective and environmentally better solutions surface treatments, such as weld overlays, thermal sprays, laser claddings and fused coatings have been used for many years to extend life for some EfW boiler components.

Different applications of the AmStar 888® cladding material, one of such surface treatments, are described in this paper, focusing on commercial projects executed at several EfW plants with different MSW boiler designs. Each presented case comprises a particular boiler design, predominant

corrosion mechanism in the application area, and results evaluation. Contrary to many lab experiments on corrosion resistant materials, where each significant corrosion-affecting variable can be individually controlled, the presented field trials provide valuable practical results of surface treatment performance in actual operating conditions with combinations of variables, some of which can be reasonably quantified, but some can not.

AMSTAR 888® CLADDING MATERIAL

The material development of Alloy 888® was initiated in 2002, in a partnership between Special Metals Welding Products Company and AmStar Surface Technology. Development focused on a group of Nickel Chrome alloys that were specifically suited to spray application. Traditionally, although easy to spray, Nickel Chrome alloys are in a highly stressed state (residual) after coating, and are prone to cracking and spalling. Further, due to the coating structure and stress state, Nickel Chrome based coatings are difficult to repair and maintain when defects and/or wastage need to be addressed.

To overcome these shortcomings of the otherwise successful alloys, emphasis was placed on the as-applied properties of the spray deposit, rather than just the corrosion resistance of the materials. To accomplish this, rigorous experiments were conducted using various ceramic additives that altered the internal structure of the coating without detrimentally affecting the corrosion properties of the alloy. An optimum blend of additives was discovered which significantly reduced the stresses within the coating, and fortuitously also increased corrosion resistance dramatically. In general, in most corrosion studies performed by end users and consulting services (unpublished), no corrosion of the coating material is typically found for metal temperatures below 800 F. Above these temperatures, some evidence of internal corrosion has been found.

The AmStar 888® system was the cladding technology developed from this research, being a combination of the new alloy and the coating technique used. The material in this system is applied using a high velocity HVCC spray system.

CASE 1: MONTGOMERY EFW BOILER WATERWALLS APPLICATION

The Montgomery County Resource Recovery Facility began commercial operation in August 1995. The facility processes an average of 1,500 tons-per-day of solid waste, generating up to 55 megawatts of renewable energy, enough power for 40,000 homes. It has three 600 ton-per-day waterwall furnaces with Martin® reverse-reciprocating grates and ash handling system. Each boiler is rated to generate 171Kpph steam at 865 psig and 830 F.

AmStar 888® cladding material was applied in January 2008 for 2 waterwalls areas:

- Pass 2: a band of 27 tubes wide and 10' tall on the Rear wall – area of the highest wastage rates in Pass 2, flue gas temperature range 1300 – 1600 F, tube metal temperature uniform at ~550 F, uneven gas flow through Pass 2 with higher velocities concentrated along rear wall;
- Roof between Pass 3 Screen and Finishing Superheater: a 3' band of cladding across the 80 roof tubes – another high wastage area of this boiler waterwalls, flue gas temperature range 1000 – 1100 F, tube metal temperature uniform at ~550 F, uneven gas flow through Pass 2 with lower velocities along the roof. Predominant corrosion in both areas is suspected to be a combination of mechanisms 1, 2, and 3 as described in Introduction.

The cladding was performed during the scheduled boiler outage. Both areas were covered by slag, especially hard (ceramic like) over 2" thick slag was found on the roof tubes (see Figure 1). Covanta plant personnel removed the slag prior to the commencement of AmStar's cladding activities.

AmStar set up 3 HVCC cladding units at the roof tubes area and 2 units in the 2nd pass location. AmStar grit blasted the areas prior to cladding using Grade 20 aluminum oxide. The grit blasting serves to clean and profile the tube surface prior to installation of the AmStar 888® cladding. After the areas were profiled, AmStar applied the cladding to a nominal thickness of 20 mils using the HVCC process. After that the cladding was visually inspected and thickness data for the areas were recorded using a magnetic lift-off coating thickness gauge. No cladding defects were observed.

Once the application was complete, the entire cladded area was coated with AmStar's HCA – 40H surface passivator (see Figure 2) which cures at high temperature upon boiler startup. The passivator serves to smooth out the surface of the cladding and acts as a de-slugging agent.

Per AmStar request the plant allotted 14 hours of outage critical path time for this application, but the whole job was completed within 12 hours.

The latest inspection of both areas was performed in February 2009 (13 months after cladding). The cladding was visually inspected and thickness data for both areas were recorded using the same coating thickness gauge (see Figure 3). No cladding defects were observed, passivator was found completely intact, and no loss of coating thickness was detected.

CASE 2: YORK EFW BOILER WATERWALLS: APPLICATION OVER CARBON STEEL

AND OVER OLD INCONEL WELD OVERLAY

The York County Resource Recovery facility began commercial operations in 1989. It serves the municipal waste disposal needs of the nearly 400,000 residents of York County, PA. The facility processes 1,344 tons of municipal solid waste per day, generating 38.1 MW of renewable electricity or enough to power 20,000 York County homes. It has three 448 ton-per-day O'Connor Rotary Combustors with Deltak boilers. Each boiler is rated to generate 138Kpph steam at 800 psig and 800 F. The boiler's radiant cross-sectional dimensions are 22 feet x 20 feet (6m x 6.7m) with a vertical height of 56 feet (17m). The rotary combustors penetrate the boilers near the bottom of the chamber. Flame impingement and high velocity furnace gas problems in the radiant section caused the original plant operator to protect a large area of the lower radiant section with refractory [8]. Furnace flue gas temperature near the entrance of the screen tubes varies in a temperature range of 1300°F – 1600°F over the typical boiler clean – fouled condition cycle.

To test the effectiveness and robustness of the AmStar 888® cladding on carbon steel waterwall tubes and over old weld overlay, in May 2008 a test area of 250 sq. ft on the furnace rear wall was cladded to a nominal thickness of 20 mils. The area was located just under the boiler's bull nose. The area cladded was appropriate as a sample area because of its high-corrosion location along with the practical challenges as this area was strewn with old refractory, anchors, and studs.

The application was completed over a 13-hour critical path window using 4 Jetstar 8000 High Velocity Continuous Combustion (HVCC) thermal spray units. After the application, the area was coated with AmStar's HCA – 40H surface passivator.

The following challenges were identified during the pre-job boiler inspection. There were three large obstacles in this application:

1. The presence of bent wire refractory anchors in the area to be clad (Figure 4),
2. The presence of refractory studs in the area to be clad (Figure 5),
3. Large areas of old refractory still present in the area to be clad (Figure 6).

The coating was inspected approximately 12 months following application. The carbon steel sections appeared in perfect condition, with no signs of thinning or spalling. The performance over the weld overlay was consistent with performance on carbon steel (Figure 7). Given the practical cladding difficulties, this test showed the effectiveness of the

AmStar 888 technology in traditionally difficult-to-spray locations.

CASE 3: YORK EFW BOILER SUPERHEATER TRIAL TUBE SAMPLES

The York Resource Recover Center current boiler design [8] comprises two finishing, intermediate, and two primary superheater bundles. Many superheater modifications were made, including attempts to open the gas lanes and reduce gas velocities, and upgrading the finishing superheater material Incoalloy 800H to combat corrosion. However, changes in design and materials failed to extend the useful life appreciably and failures occurred before two years, requiring routine replacement of the pendants every two years.

Spiral wound Inconel overlaid pendants were tested in the Primary I and Finishing Superheaters in 2002. Final steam temperatures and pressures for the boilers proved too severe for the Inconel cladding that failed after six months of operation and afforded little more protection than tube shields.

As part of a test program beginning in August 2005, the AmStar 888® cladding was applied to the leading tube in the Intermediate Superheater, this area being cleaned by two steam sootblowers that enter from opposite sides of the compartment and have overlapping spray at the center. This tube section has been observed to have the highest rates of metal wear and is considered the harshest test.

A second test tube was installed as the leading tube in the pendants located in the Finishing Superheater. This bank is comprised of twenty-six pendants and shares the same overlapping sootblower problem as in the Intermediate Bank.

Previous measurements of metal loss on the leading tubes in both the Intermediate and Finishing Superheaters approached 10 mils per month. The superheater flue gas lanes generally foul in approximately eight weeks due to the amounts of entrained fly ash carried by flue gas and are therefore cleaned off-line using water. These eight-week cleaning cycles has provided the opportunity to inspect the progress of the test sections on a regular basis.

The Amstar test tubes installed in both Finishing and Intermediate superheaters showed no visible signs of failure or measured thickness loss. Figure 8 shows the Finishing superheater trial tube, which has been operating in the harsher corrosive environments than the Intermediate superheater tube with the calculated metal temperature of approximately 750°F and the flue gas temperature in a range of 1200 – 1500°F. This has been an encouraging performance record of the AmStar 888® cladding technology for the superheater applications.

CASE 4: ESSEX EFW BOILER PLATEN FINISHING SUPERHEATER TRIAL PANEL

The Essex County Resource Recovery Facility, which opened in 1990, is New Jersey's largest EfW facility, as it serves the refuse disposal needs of 22 municipalities in Essex County and the surrounding region. The facility processes 2,800 tons per day of municipal solid waste and generates approximately 65 megawatts of electricity for sale. It has three 933 ton-per-day boilers with Duesseldorf Roller Grate technology. Each boiler generates 240 Kpph steam at 650 psig and 760 F. The Stage 3 finishing platen superheater, which comprises eight ~80' panels of ten-tube platens located in Pass 2, experiences extremely high corrosion rates, - one of the highest among the Covanta EfW boiler fleet. The most severe wastage (up to 100 – 120 mils per year) takes place in the upper part of these platens with a flue gas temperature range of 1600 – 1400 F from top to bottom, and tube metal temperature variation from 750 to 825 F, uneven gas flow with higher velocities concentrated along the rear wall, and significant fly ash carryover resulting in severe slagging. The largest damage (pitting, wastage, failures) is observed on the lead and trail tubes of these panels: tubes with the largest exposure to radiant heat, high flue gas velocities, and flyash impact. Although it refers to a lead and trail tubes both tubes are subjected to the same environmental conditions, including radiant heat flux. Even Inconel weld overlay does not provide the desired protection for these tubes and it does not last more than two years.

AmStar 888® cladding material was applied in March 2008 for this most challenging upper part (39' from Pass 2 Roof) of one panel, including the lead and trail tubes. This application was done in the AmStar shop. The coated panel was delivered on site and installed with all other finishing superheater panels (see Figure 9). After this panel was installed, the AmStar crew came to the plant at the end of the outage and applied HCA – 40H surface passivator in 3 hours.

Next to the AmStar Panel 3-4 two other trial panels were installed with alternative surface treatments: Cladding X and Coating Y, and the remaining non-trial five Stage 3 finishing superheater panels fabricated with Inconel 625 weld overlay for the lead and trail tubes and 8 unprotected SA-213T22 tubes in between. The latter (hybrid panel) lately became the most successful (but very expensive for its expected 2 year life) corrosion management solution for the Essex platen superheater. The purpose of this trial was to investigate alternative cost effective options which could significantly extend the life of these panels.

The first inspection of the trial panels was performed one year after installation in March 2009. All three surface treatments

revealed some deterioration of the coating at the lead tube upper 12 feet. Cladding X looked marginally better than AmStar, and Coating Y looked worse than the two other trial panels. But the middle 8 tubes of all three panels looked very impressive in comparison to the unprotected T22 tubes in the non-trial panels (see Figure 10 and 11). As some of the middle unprotected T22 tubes lost 120 – 130 mills of wall thickness, indicated by conducted UT readings, the body of adjacent surface treatment panels was still well protected by coating with no loss of the base metal underneath.

The second inspection of the trial panels was performed in January 2010 (almost 2 years after installation). All Stage 3 finishing superheater panels were replaced according to the outage plan, and the trial panels were inspected outside the boiler. The results were consistent with the inspection after one year of operation. All three surface treatments revealed serious deterioration of the coating at the lead tube upper 20 feet and the trail upper 10 feet (see Figure 12). This time more pitting was found on the second tube and some delamination in a couple of areas of the top 20 feet. The middle 8 tubes still looked very good in comparison to unprotected T22 tubes in five other panels. Figure 13 shows the drastic difference between AmStar coated Panel 3-4 at 35' from the roof and its adjacent non-trial hybrid panel (with Inconel 625 weld overlay for the lead and trail tubes and 8 unprotected SA-213T22 tubes). In addition to visual inspection, the cladding thickness was measured by a coating thickness gauge, which revealed basically no thickness loss for these panels except the damaged areas on the upper lead and trail tubes and in a few defected areas of the middle tubes. The Essex trial results seemed to confirm a hypothesis of different corrosion mechanisms taking place on the surface of the lead and trail tube vs. middle tubes of the same panel. Predominant corrosion in the middle tubes looks like a combination of mechanisms 1, 2, and 3 (described in Introduction), as for the lead and trail tubes mechanism 4 (molten salts eutectics) kicks in and takes the lead in coating and base metal destruction. The lead and trail tubes are also more exposed to radiant heat, flue gas flow direction, and ash deposit morphology, which can highly influence corrosion rates at such metal and ash deposit temperatures [9]. The Essex trial shows the potential to extend the finishing superheater panel life if a further solution for the lead and trail tubes can be found.

CONCLUSIONS

Over the last decade the Inconel weld overlay has become the proven corrosion protection solution for EfW boiler waterwalls, evaporators, and for some lower temperature superheaters. EfW industry is looking for other cost effective alternatives for the same boiler components, as well as for new practical solutions to extend the life of more challenging high temperature superheaters. AmStar 888® cladding

technology has been tested in a number of field trials over the last 4 years at different EfW facilities. It has shown very encouraging results, with little to no thickness loss (wastage) for waterwalls (including those covered by old and deteriorated weld overlays) and certain lower temperature superheater applications. It can be concluded that the AmStar 888® cladding material is suitable for the typical EfW boiler corrosion environments, including areas where soot blowing occurs, when the metal temperatures do not exceed a level conservatively estimated to be approximately 800 F. However, some recent field trials (such as the Essex finishing superheater application) have demonstrated the challenge of establishing the exact limiting metal temperature as a threshold for effective and reliable AmStar 888® cladding superheater applications since its performance was not consistent across the entire area of the same calculated metal temperature. It appears that the actual surface temperatures (where ash deposit melting takes place) are difficult to theoretically calculate and predict for some lead tubes subjected to higher radiant heat flux and flue gas flow direction. New results from ongoing field trials should help to find the optimum locations where the AmStar 888® cladding can provide effective tube protection in the harsh corrosive environments of EfW boilers.



Figure 1. Roof waterwall area covered by slag before it was removed prior to AmStar’s cladding activities.



Figure 2. The cladding as sprayed (a), and after application of the surface passivator (b).



Figure 3: AmStar 888® cladding inspection 13 months after application.



Figure 4. Refractory anchors in area to be cladded



Figure 5. Studs and refractory in area to be cladded



Figure 6. Large area with refractory obstruction in area to be cladded



Figure 7. Visual inspection illustrating that no thinning or delamination occurred where the cladding was applied over old weld overlay.



Figure 8. AmStar 888® cladding on left tube after 3.5 years of operation in comparison to an unprotected adjacent tube being in service for only 18 months



Figure 9. AmStar 888® cladding 39 ft Panel 3-4 installed in Pass 3 without passivator



Figure 10. AmStar Panel 3-4 (left) and Coating Y Panel 3-5 (right) after one year of operation.



Figure 11. Panel 3-7 (one of five non-trials) with Inconel 625 weld overlay for the lead and trail tubes and 8 unprotected SA-213T22 tubes in between after one year of operation (with tube wall thickness readings).



Figure 12. AmStar Panel 3-4 after 2 years of operation at top 10' from Roof (lead tube at the front).



Figure 13. AmStar Panel 3-4 after 2 years of operation at 35' from Roof welded to non-trial panel with Inconel 625 weld overlay for the lead and trail tubes and 8 unprotected SA-213T22 tubes.

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