Ceramic Coating Surface Protection Solutions for Biomass and Coal Fired Power Generation Boilers

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Abstract

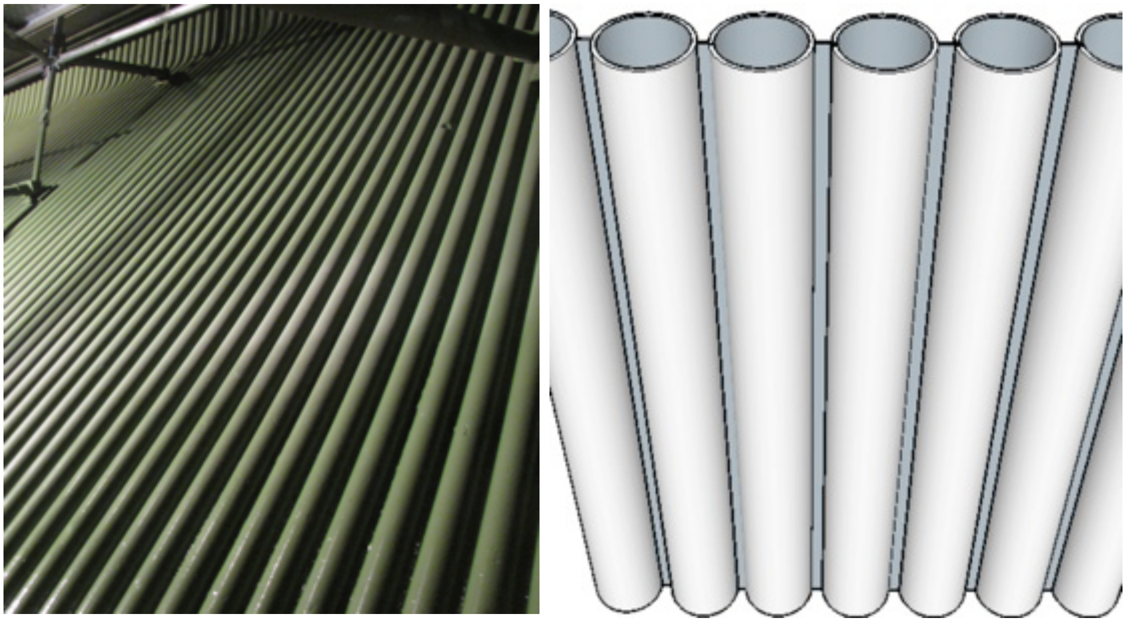
Tube loss of superheater and waterfall tubes due to corrosion is one of the leading causes of forced maintenance outages in the coal and biomass fueled power generation industry. As a result, there has been demand for advancements in innovative and cost effective materials technology to mitigate the loss of tube material and thus reduce the frequency of unscheduled and non-routine maintenance events. The use of advanced ceramic coating technology in the power generation industry has proven to be an effective means of protecting the underlying boiler tube material from corrosive material losses and has afforded additional benefits related to increased heat transfer, increased efficient and reduced fuel consumption through the reduction of slag and deposits adhering to the coated heat transfer surfaces.

This paper reviews the benefits of the use of advanced ceramic based surface protection technology, referred to as "ceramic coatings", in power generating boilers. As a result of changes in environmental regulations, new issues have arisen in boilers, creating additional maintenance expenditures. The installation of ceramic coatings are preventative measures which reduces slag build up, mitigates corrosion and reduces tube erosion in some of the most difficult to reach areas in a boiler.

Today's power generating facilities are sophisticated and highly complex. At the core of the power plant is the steam generating unit, commonly referred to as the "boiler". In order to produce electricity, the plant must obtain heat; this is usually in the form of combusting coal, biomass or other types of fuel that contain a heating value measured in joules per kilogram ("J/kg"). The combustion of fuel releases heat energy which is transferred through a set of tubes each connected by a thin membrane (the boiler's "waterwall"). The heated water within the waterwall then changes form, from water to steam. The steam is then heated further to a specific temperature and pressure to drive a turbine generator.

The operating profile of a steam generating plant has changed over the years with more stringent environmental regulations driving the need for a reduction in airborne particle matter and lower NOx flue gas emissions. Boilers have since been retrofitted with advanced technologies to improve air emission quality such as: lower NOx burner technology, staged combustion and flue gas cleaning technology.

With the advent of these retrofit changes, there has been an increase in metallic corrosion rates affecting the boiler tubes, duct work and flue stacks within plants. The addition of flue gas



Boiler waterwall configuration, Photo Furnace Mineral Products Inc.

treatment equipment has prompted some facilities to use less expensive and lower calorific grades of coal in an effort to offset the increased operations and maintenance costs associated with the equipment.

These lower grade fuels often contain high levels of sulfur and ash. It is this higher sulphur content that is driving the high corrosion rates. As FeS rich slag deposits decompose it creates corrosive sulfur species that lead to severe sulfidation corrosion of the waterwall tubes. The FeS is created through the partial combustion of pyrite (FeS_2) commonly found in coal.[1] In the boiler's back pass cooler operating temperatures can lead to acid dew point condensation corrosion that attack lower temperature components such as the duct work and stacks.

The surge in corrosion rates has resulted in a spike in operation, maintenance and reliability expenses. Today, some steam generators are required to operate efficiently and reliably for up to 60 years.[2] The cost to repair and replace key components that fail prematurely due to corrosion from sulphidation attack, acid dew point corrosion, thermal fatique, and erosion can be staggering.

Producing electricity is competitive, therefore, optimizing a boiler's reliability and extending it's run time between outages can provide the necessary financial savings to increase profitability. The alternative option of waiting for a problem to strike is no longer viable. Securing the required resources to address the problem and scheduling sufficient time during a forced outage to do a quality job with the necessary engineering and inspection may not be feasible.

Developing a long-term preventative and predictive maintenance program designed to identify early failure mechanisms and wear components ensures sustainable reliability and offers the lowest long term operating cost. This maintenance philosophy improves management decision-making and outage planning.

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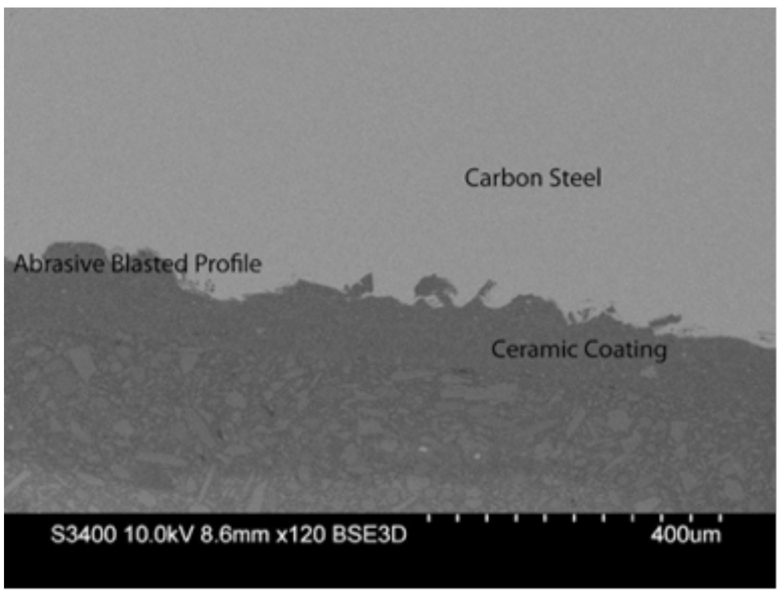
[1] 1.Wate T. Bakker, Steven C. Kung, "Waterwall corrosion in coal-fired boilers. A new culprit: FeS." NACE Corrosion 2012,

[2] Babcock and Wilcox Co., Steam, Its Generation and Use, 40th edition (1992)

The use of ceramic coating technology is one of the ways to accomplish this type of maintenance philosophy. Over the last 20 years several major power utility companies have embraced the use of ceramic coatings to maintain boiler tube reliability. Whether it is to reduce tube erosion, minimize slag adhesion or to provide a barrier for corrosion control, these ceramic coatings are a proven means to enhance and maintain the efficient operation of a power plant's boiler.

These ceramic coatings are comprised of a proprietary combination of ceramic particles and chemical compounds in a water based resin system. The coating is spray applied onto an abrasive blasted surface in thin multiple layers to a specified coating thickness, typically 150-300 μm (6-12 mils), to suit the operating conditions and service environment. The coating will dry to the touch under ambient conditions in the boiler. When the boiler is started and brought up to operating temperature, the coating cures and chemically bonds to the substrate material, maintaining its bright color and glass-like surface. A cross section of cured ceramic coating can be seen in figure below.



SEM micrograph of ceramic coating applied to an abrasive blasted carbon steel substrate, Photo Furnace Mineral Products Inc.

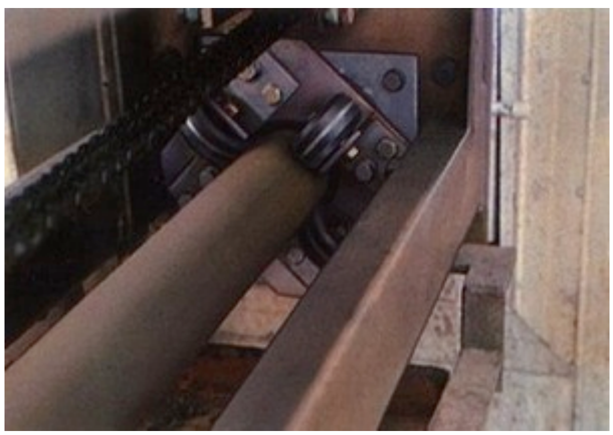
Ceramic coating installations are preventative measures which minimizes excessive slag build up, mitigates corrosion and reduces tube erosion in some of the most difficult to reach areas in a boiler.

BOILER SLAG DEPOSITION

There are two basic types of deposits that form in utility boilers. [3]

1. Slagging deposits which generally form in the combustion or furnace zone and consist of molten ash.
2. Fouling deposits which form in the post combustion or convection pass of the boiler, and are bonded together by sulfate salts.

With all types of coal or solid fuel used in power generating boilers, a certain amount of slag is expected. The amount of slag is controlled by using effective soot blowers. These blowers enter the boiler through a small furnace wall opening and rotate directing a jet of media at the slag to loosen and knock it off the tubes.



Waterwall soot blower, Photo Seelen GmBh

In any boiler too much slag can become a problem. Excessive slag can happen for many reasons.

Slag fouling on fire side boiler components can results in several negative affects;

1. Extensive slag fouling impedes extended boiler run times and leads to frequent cleaning outages.
2. Heavy fouling can lead to the formation of clinkers, which can damage the boiler and rupture boiler tubes by breaking free and falling
3. Slag deposits can lead to a marked reduction in heat transfer, loss of sufficient superheat and hotter furnace exit gas temperatures (FEGT).

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[3] Babcock and Wilcox Co., Steam, Its Generation and Use, 38th edition (1975)

4. High FEGT allows for molten particles to carry over from the combustor area and cause slagging in the convection pass.
5. Convection zone slagging can lead to blockages increasing the differential pressure, which requires the unit to run at a reduced load or it must be brought off-line to clean.

Molten fly ash from the combustion of solid fuels tends to solidify on contact with the cooler tube surface. Overtime, the deposit layer thickness will grow as the temperature of the outer most surface increases from the underlying deposit insulating the cooler water tube from the hotter flue gas. The temperature will then eventually reach the melting point of some of the slag constituents. The increase in temperature in the hot gas stream can also oxidize the iron in the slag from Fe (II) to Fe (III) [4], this change can further strengthen the slag.

As the surface temperate continues to increase and the deposit reaches its molten state the deposit material will begin to flow, leading to large formations in localized areas of the boiler. As the slag grows it gets tougher and tougher to clean, to a point where soot blowing becomes ineffective.

Many power plant operators have had limited success in solving boiler slagging. Several approaches such as chemical injection, dynamite cleaning and additional soot blowing are costly and may not be entirely effective in certain areas of the boiler.

For extended run operation full boiler abrasive blasting cleaning is one of the most effective cleaning techniques. This cleaning results in a very low differential pressure and lower flue gas temperatures with improved heat transfer. Dry abrasive blasting or vapour blasting also limits the amount of water that is used as part of the cleaning technique. The introduction of water can lead to generalized corrosion in the boiler.

Dry abrasive blasting to remove slag build up from boiler tube surface

[4] Hatt, R.M. and Bull, D.L., Morphological and chemical relationships of deposits formed in a full scale steam generator, Engng Foundation Conf., Santa Barbara, CA (February 1988).

Excessive slagging in tightly spaced tube bundles can quickly result in flue gas stream blockage. As slag begins to bridge it reduces the cross sectional area for flue gas to flow through the tube bundle. As the blockages grow, the flue gas velocity increases. Blockages between tubes like in the case of a generating bank has the effect of forcing the gas flow into smaller open passage ways in the tube banks. These open passage ways, are exposed to an increased velocity and higher temperatures due to a reduction in heat transfer from the slag insulating the tubes. This can indirectly contribute to aggressive localized tube erosion and an increase in slag build up in the next section of the convection pass.

a. Complete blockage of superheater tubes. b. Application of ceramic coating to extend boiler uptime by reducing forced cleaning outages.

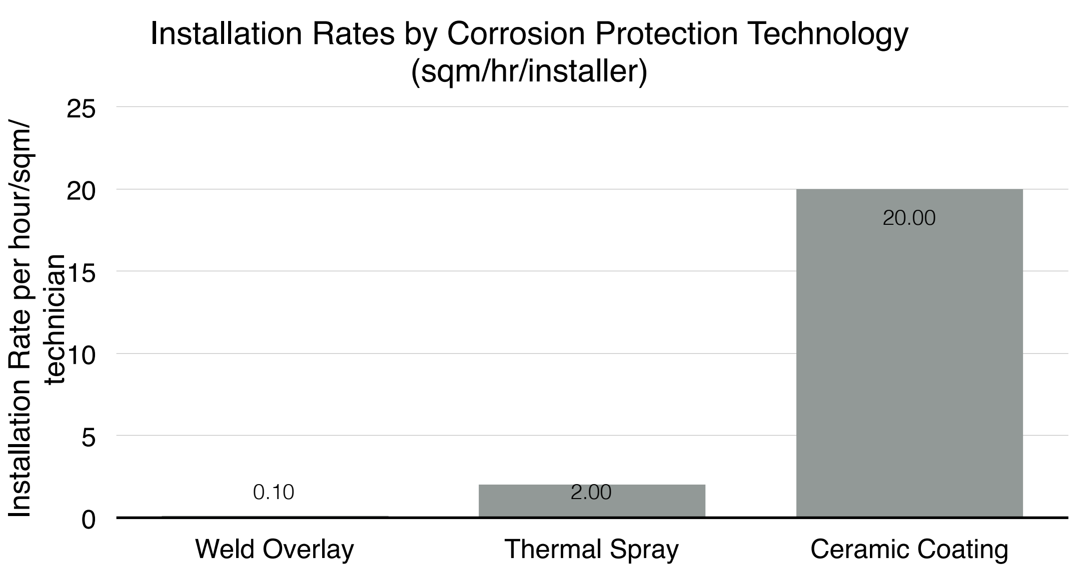
The use of ceramic coating technology as an effective barrier to limit slag adhesion on contact with the coating has a proven track record in extending a boiler run time especially in areas that are difficult to clean by soot blowing. When used in conjunction with soot blowing, ceramic coatings can enhance the cleaning action and allow the soot blower to operate less frequently and with shorter durations as the slag is easily removed from the coated tube surface.

BOILER TUBE CORROSION – BIOMASS CASE STUDY

High temperature corrosion from sulphide or chloride attack can be aggressive leading to tube failures within a few short months. Although there is no clear answer as to the preferred corrosion protection method, common practice include: weld overlay, thermal spray and ceramic coating. Each technology has its advantages and disadvantages and each has a limited life expectancy to which it will perform in a given boiler environment.
Properly designed and installed ceramic coating offers effective barrier protection to prevent the tube surface from coming into contact with the corrosive fuel species.

Ceramic coating offers the lowest installed cost per unit area and the fastest installation rate of any boiler tube corrosion protection technology.

Deep pitting observed in biomass boiler superheater tubes after abrasive blasting to remove slag deposit. Photo by Furnace Mineral Products Inc.

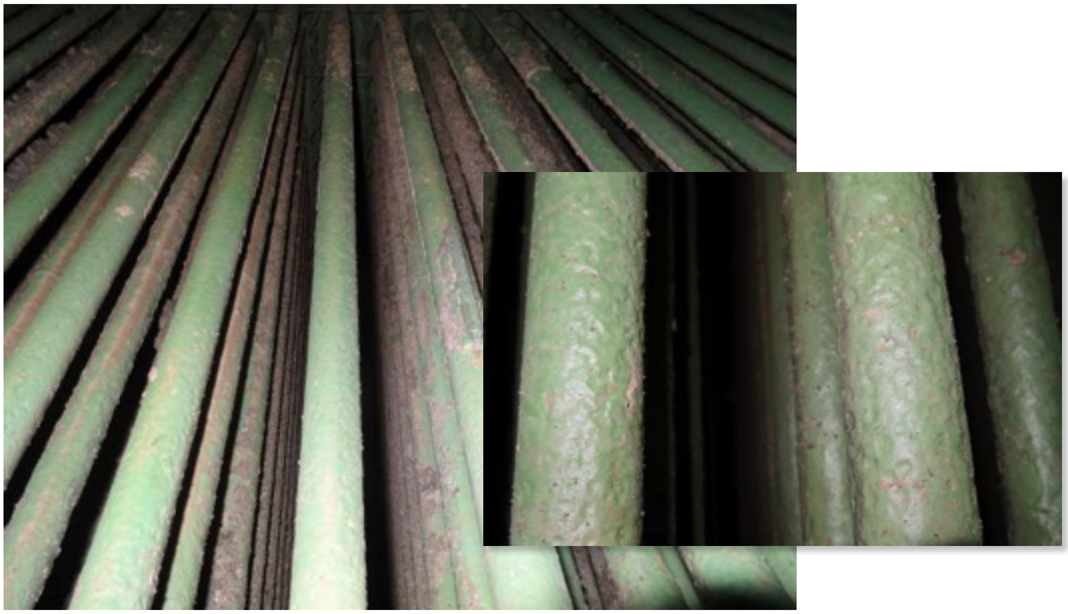


The use of biomass fuel is gaining momentum and favorable attention in many countries around the world. Biomass power is carbon neutral electricity generated from renewable organic waste. Biomass that is produced at the rate it is consumed is considered CO2 neutral because during growth it accumulates the same amount of CO2 (g) by photosynthesis as it releases during combustion.[5] In many countries the local supply of agricultural waste from rice husks, palm oil shells, straw and forest debris are in local abundance and have been traditionally dumped as landfill waste or openly burned.

One of the biggest problems faced by biomass boiler operators is corrosion, specially in the superheater. The high potassium and chlorine contents in many biomasses are potentially harmful elements with regard to corrosion. During combustion, potassium chloride and SO_2 (g) are released in the flue gas and through the condensation and deposition processes they will result in the formation of superheater deposits rich in potassium chloride and potassium sulphate.

Installation of ceramic coating technology designed specifically for corrosion resistance, Photo by Furnace Mineral Products Inc.

[5]Study of Corrosion in a Biomass Boiler, C. Berlanga and J. A. Ruiz, 2013



Inspection of ceramic coating by power washing after several months in service.
Photo by Furnace Mineral Products Inc.

The successful use of ceramic coating in biomass boilers to combat corrosion has been demonstrated for over 15 years. The liquid spray applied format of the ceramic coating allows for convenient and easy application in very difficult to access areas in the boiler's convection pass.

EROSION PROTECTION – ASIA PULP AND PAPER CFB CASE STUDY

The versatility of ceramic coating allows formulators to design their coatings specific to the client's end use and service environment. One such technology is designed to offer improved erosion resistance in circulating fluidized bed (CFB) and stoker grate boilers.

Quality control testing following the application of ceramic coating in a pulp and paper plant CFB boiler in Asia, Photo by Furnace Mineral Products Inc.

It is best practice to inspect the boiler tubes for metal loss from erosion during maintenance outages. This can be done by ultrasonic or visual inspection techniques. In general, erosion patterns appear as smooth and sometimes shiny locations on the tube. The use of a bright colored ceramic coating aids in the visual inspection for erosion of the boiler tubes. The inspection approach is easy - where you see the coating, no metal loss has taken place. Where the coating is missing these are areas that require additional monitoring and eventual coating repair. The use of an electronic coating thickness gauge allows for easy film thickness measurements to be taken quickly, mapped and tracked from outage to outage to obtain useful wear pattern data.

Erosion, the abrasive wear of ash/particulate, plays a significant role in boiler tube metal loss. Though a number of factors including particulate loading and impact angle amongst others play a role in the rate of material loss due to erosion, particle velocity is the most important parameter.

Particle velocity is a function of flow conditions in a certain area of a boiler and erosion rates are likely to be uniform throughout that area, however, accelerated localized flow conditions caused by flow impedance or other means can result in highly increased rates of erosive material loss.

Ceramic coating used to a protect hard to reach generating bank mud drum from fly ash erosion damage, Photo by Furnace Mineral Products Inc.

The limits on emission from coal fired power has necessitated the need to retrofit existing plants to meet emission requirements. Although these retrofit technologies have provided positive environmental gains it has resulted in higher corrosion rates.
The use of biomass combustion is renewable and carbon neutral, but the feedstock quality can be unpredictable with high levels of chlorides. Advancements in innovative and cost effective ceramic coating technology development over the last 20 years has proven itself beneficial into maintenance and reliability of coal fired power and biomass generation boilers. More and more boiler operators are installing ceramic coating as part of their maintenance program for the following reasons: (i) The coating be applied economically and the installation rate has minimal impact during a power plant outage. (ii) The coating offers tremendous versatility addressing mitigation, corrosion resistance and erosion resistance. (iii) The spray applied format of the liquid coating makes it very easy to apply by coating certified installation contractors. (iv) The bright color option available in ceramic coatings improves visual inspection techniques and reduces the downtime required for other inspection methods. (v) The coating can be easily repaired and removed if required by mechanical grinding or abrasive blasting.