

## NAWTEC17-2334

### A SURVEY OF EROSION AND CORROSION RESISTANT MATERIALS BEING USED ON BOILER TUBES IN WASTE TO ENERGY BOILERS

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#### ABSTRACT

Waste-to-Energy boilers, including mass-fired, RDF-fired, and biomass-fired boilers, produce very corrosive and erosive environments which can significantly reduce the life of furnace, super heater, boiler, and in-bed tubes. Combustion products from municipal waste refuse are very corrosive. This corrosion is typically caused by chloride compounds which deposit on the furnace, superheater, and boiler tubes. Due to high flue gas velocities and soot blowing required to remove ash and slag deposits, and BFB media, these tubes are also subject to substantial erosion. Since 2000, Inconel weld overlays have been used for corrosion and erosion protection on boiler tubes. During this period, many other materials have also been tested in waste-to-energy boilers with mixed results.

This paper will provide an overview of the materials that have been tested on in-bed, furnace, superheater, and boiler tubes in waste-to-energy boilers. The test results will be based on laboratory analysis used to evaluate these corrosion and erosion protection solutions. In addition, field results will be reviewed from various waste-to-energy sites to support the laboratory analysis.

#### INTRODUCTION

Waste-to-Energy (WTE) plants are being asked to extend times between major planned boiler outages. The superheater, boiler, and furnace tubes of coal-fired power plants are primarily subject to fly ash and sootblower erosion. WTE boiler tubes see this type of erosion but have an added wear component of excessive corrosion. This corrosion is caused by the chlorides formed from the burning of waste. There are theories being evaluated that state that the overall wear rate is compounded when you have both corrosion and erosion occurring at the same time.

This paper will present laboratory data and field data that show the overall wear resistance of various materials being used to protect WTE boiler tubes.

#### EROSION

Erosion is caused by the impact, cutting action, or abrasive wear of small solid particles freely immersed in the direction of fluid flow that frequently undercut portions of the material they strike [1]. Erosion is the progressive loss of original material from a solid surface due to mechanical interaction between that surface and the impinging fluid or solid particles [2].

If high erosion-resistant particles such as tungsten carbide exist in low erosion resistant or soft matrix, the impacting particles can undercut and remove portions of the material (Figure 1). However, if the high erosion resistant particles are densely packed in a matrix material that causes the impacting particles to impinge on a greater percent of the hard particle, the erosion resistance increases dramatically (Figure 2).

When evaluating the relative erosion resistance of materials, a number of factors must be considered. The obvious factors are temperature, velocity of the impacting particles, their size and shape and the impacting or impinging angle. These factors can be controlled in standardized testing but combining their range of variability to comprehensively evaluate performance is limited.

Standardized testing procedures, such as ASTM G76 Figure 3, reduce a number of the variables with the intent of providing a common baseline for comparison. This test method utilizes a repeated impact erosion approach involving a small nozzle delivering a stream of gas containing abrasive particles which impact the surface of the test specimen. A standard set of test conditions is described. However, deviations from some of the standard conditions are permitted if described thoroughly. These test methods can be used to rank the erosion resistance of materials under the specified conditions.

## ERODENT

High temperature erosion tests were carried out using the bed ash from an operating boiler as the erodent material. The particle morphology was a mixture of both round and angular with a mean particle size of 556 microns and mean particle density of 164.4 LB<sub>m</sub>/ft<sup>3</sup>. The erodent material particles were comprised of high concentrations of silicon and calcium with minor concentrations of aluminum, magnesium, sulfur, iron, phosphorus, titanium and chlorine.

## TEST CONDITIONS

Particle Velocity (40m/s) - 141.2 ft/s  
 Temperatures - 900°F (482°C)  
 1100°F (593°C)  
 Ambient  
 Impact Angles - 30°, 90°  
 Test Duration - 3 hours  
 Loading - 0.441 Lb<sub>m</sub> (0.2 kg)  
 Tests focused on elevated temperature solid-particle erosion under generally oxidizing conditions.

## REPORTING

Test results are typically reported as both a weight loss and a thickness loss for each of the tested specimens. However, since the weight measurements included the material erosion wastage (-), oxide scale (+), ash deposit (+), and different densities, the weight loss scheme was not a desirable approach for predicting the erosion rate. Therefore, the thickness loss was determined to be a more valid method for determining the erosion rates of the tested alloys.

## MATERIALS TESTED

Six materials commonly used for the protection of boiler tubes in WTE plants were selected for erosion testing. The data on four of the samples was taken from a high temperature erosion test performed by EPRI. The data for the other two samples was performed by Conforma Clad. All data was obtained using ASTM G76 standardized erosion test.

Conforma Clad WC – Infiltration Brazed

Nickel alloy 625 – GMAW  
 Inconel 622 – GMAW  
 309L stainless steel – GMAW  
 Stellite 6 – GMAW  
 Amstar 880 - HVCC

## LABORATORY EROSION TEST RESULTS

Table 1 shows lab test results of 6 materials tested in order of erosion resistance. Chart 1 shows graphically the lab test results.

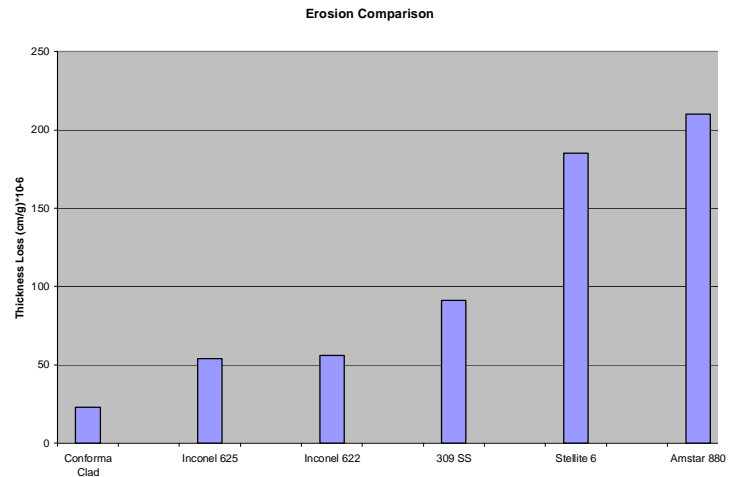
## LABORATORY EROSION TEST SUMMARY

The results indicate that among the 6 alloys tested, the material with the highest density of erosion-resistant particles, Conforma Clad tungsten carbide, showed the highest erosion resistance. The Conforma Clad material, which is an infiltration brazed tungsten carbide in a nickel-chrome-boron matrix, has an erosion resistance particle percentage of close to 70%.

Table 1

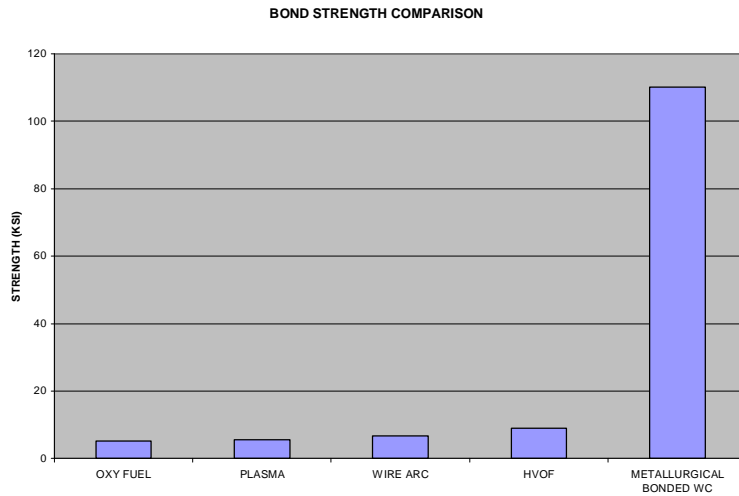
Material	Thickness Loss (cm/g)*10 <sup>-6</sup>	Impingement Angle	Temp (Deg F)
Conforma Clad	23	90	900
Inconel 625	54	90	900
Inconel 622	56	90	900
309 SS	91	90	900
Stellite 6	185*	90	Ambient
Amstar 880	210*	90	Ambient

Chart 1 Erosion Comparison

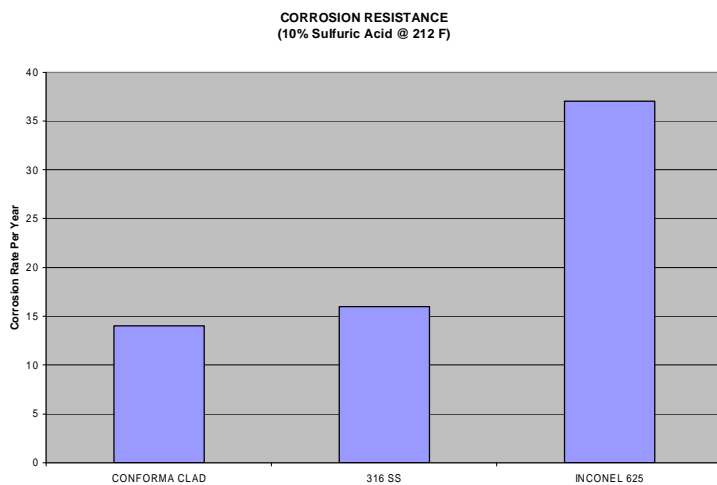


## ADDITIONAL RELEVANT LABORATORY RESULTS

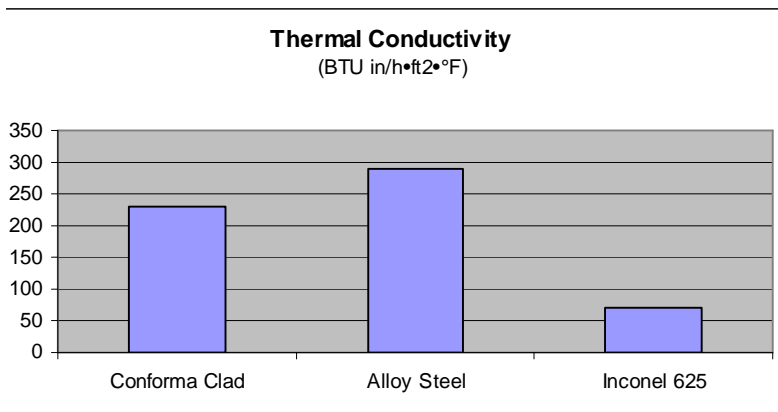
**Chart 2 Bond Strength Comparison**



**Chart 3 Corrosion Resistance (10% Sulfuric Acid @ 212 F)**



**Chart 4 Thermal Conductivity**



## CONTINUING TESTS – FIELD APPLICATION

Erosion resistance is complex, combining the many variables to actually duplicate, recreate, field environments is next to impossible in laboratory tests. Additional environmental factors such as thermal shock, erosion resistant material bond strength (Chart 2), the combination with corrosion (Chart 3), erosion resistant material thermal conductivity, as well as many others come into play. The following field tests will compare the laboratory qualified high density erosion resistant particle materials to other industry accepted methods of erosion protection.

### FIELD TEST #1

Montenay York Resource Energy  
2651 Blackbridge Road  
York, PA 17402

### PLANT OVERVIEW

The York facility generates its 35 MW with 3 Deltech boilers. This plant started up in 1989 and supplies power to York County, PA. This facility uses MSW as its fuel source. The burning of MSW creates excessive ash and high levels of chlorides. The ash adheres to the SA213-T22 superheater tubes of the boiler which reduces the heat transfer rate of the tubes, therefore reducing the overall efficiency of the boiler. Soot blowing is utilized to remove the ash from the tubes. Soot blowing is the application of high pressure steam to the tubes to remove the ash deposits. This causes premature erosion of the tubes. The chlorides that are formed from the burning of the MSW are very corrosive to the boiler tubes.

### BOILER TUBE TEST

The plant is presently using stainless steel tube shields to protect the tubes from erosion. These tube shields are being replaced every 6 months due to erosion and corrosion. The entire superheater pendants are being replaced every 2.5 to 3 years for the same reason. Several materials have been tried over the years to protect the tubes and prolong the pendant life. These materials include 310SS Tube Shields, Refractory, Inconel 800H, Inconel 625, Colmonoy 88, Amstar 888, and Conforma Clad. All of the coatings except the Amstar 888 and Conforma Clad lasted less than 18 months. Sample tubes coated with the Amstar and Conforma Clad coatings have been in service for over 2 years and are showing minimal wear. Both of these coatings are tungsten carbide with a nickel-chrome matrix. After 22 months of operation, the sample tube in the unit 3 finishing superheater with Conforma Clad tungsten carbide cladding showed only .003" of wear. Since this cladding wears at a linear rate, the tube life can be extrapolated to approximately 20 years based upon an initial cladding thickness of .030". Another sample tube clad with Conforma Clad is being tested in unit 1 showing similar results. A summary of the trial results are listed in Table 2.

## PLANT OVERVIEW

The Delano facility generates its 58MW with 2 EPI fluidized bubbling bed, biomass fed boilers. This plant started up in December 1989 and supplies electricity to San Diego Gas and Electric. This facility burns up to 1293 tons of biomass per day. The bed sand used in a biomass bubbling fluidized bed is very abrasive to the SA-234 in-bed boiler tubes. The tube temperature is approximately 600 degrees F. The flue gas temperature is approximately 1500 degrees F. The burning of the biomass creates chlorides which are very corrosive to the tubes. Consequently, the tubes are being subjected to high erosion and high corrosion.

## BOILER TUBE TEST

The plant has tried an 80% silicon carbide refractory and cast tube shields. The refractory erodes away after 4-1/2 years. The cast tube shields are also only lasting 4-1/2 years because the welds break and allow the shields to fall off. The goal of the plant is to extend the life of the tubes beyond 4-1/2 years to 10 years or more. In early 2008, in-bed tubes were installed that were clad with Conforma Clad's tungsten carbide cladding. After 1 year of operation, the tubes were visually inspected and showed no sign of wear. Another inspection using eddy current measurements is planned for May 2009. Because the Conforma Clad tungsten carbide cladding wears at a linear rate, the life of the cladding can be extrapolated based upon these measurements.

## CONCLUSION

There is an increased focus to keep WTE units online. Units burning waste have both high erosion and corrosion. This superheater of a conventional boiler and the in-bed tubes of a bubbling fluidized bed boiler are areas that are significantly affected by these modes of wear. As can be construed from the data shown in this report, there are certain characteristics of an effective boiler tube wear protection. These are: 1) Dense loading of the hard particle, 2) A corrosion resistance matrix, 3) A strong bond to the substrate (>20,000 psi), and 4) Good thermal conductivity.

## TRIAL EROSION TEST RESULTS

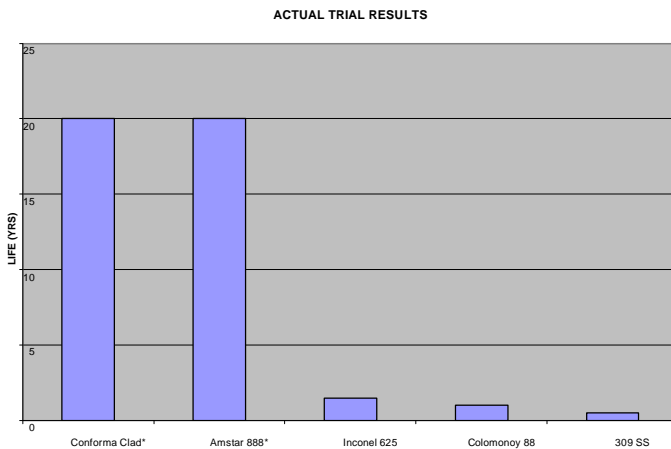
Table 2 shows test results of 6 materials tested in order of erosion resistance. Chart 2 shows graphically the results.

Table 2 Actual Test Results

Material	Life (Years)	Composition	Application	Coating Thickness (IN)
Conforma Clad*	20	Tungsten Carbide in Ni-Cr-B matrix	Infiltration Brazing	0.03
Amstar 888*	20	Tungsten Carbide in Ni-Cr-B matrix	High Velocity Continuous Combustion (HVCC)	.03
Inconel 625	1.5		Weld Overlay	0.065
Colomony 88	1	Nickel w/ Chromium Carbide	HVOF	0.065
309 SS	0.5	309 SS	Tube Shields	N/A

\* Life is extrapolated

Chart 5 Actual Trial Results



\* Conforma Clad and Amstar lives are extrapolated from trial results

## FIELD TEST #2

Covanta Delano  
PO Box 550  
Delano, CA 93216

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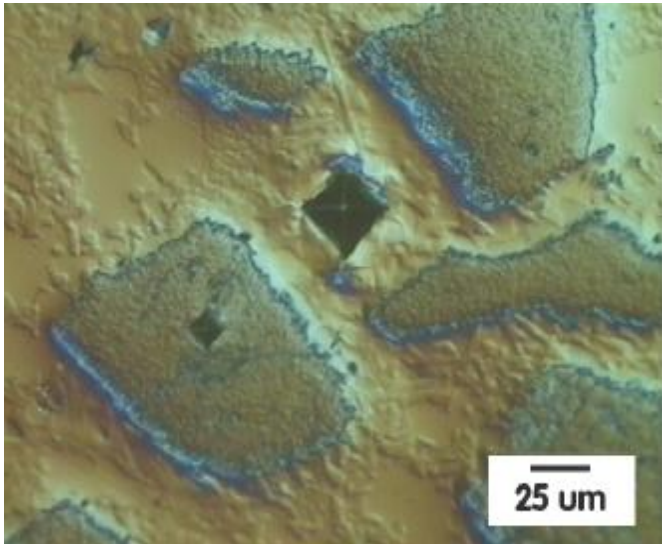
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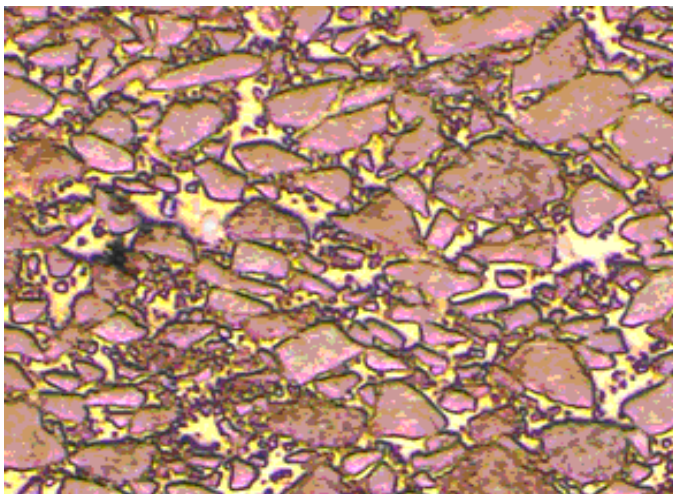
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**Figure 1 Photomicrograph of Tungsten Carbide Coating (Sparse Loading)**



**Figure 2 Photomicrograph of Tungsten Carbide Coating (Intense Loading)**



**Figure 3 ASTM G76 Testing Apparatus**

