

*Performance of Composite Coatings  
in a Coal-Fired Boiler Environment*

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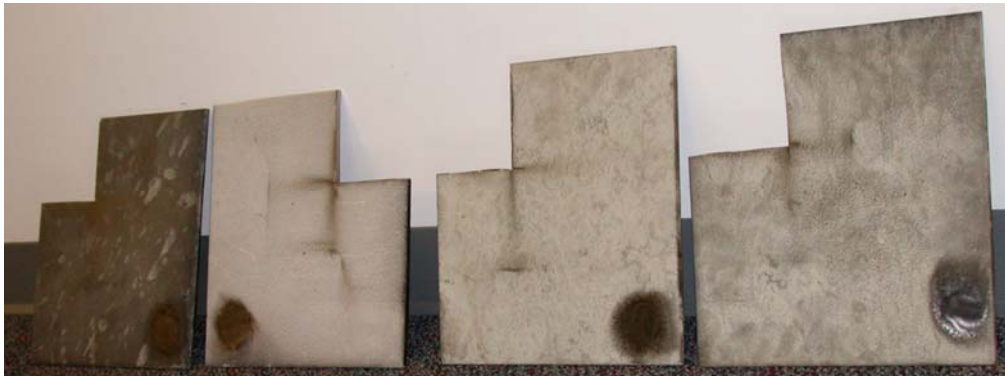
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## **Introduction**

Thermal spray coatings were tested in a coal-fired cyclone boiler for erosion/corrosion susceptibility. Saint Louis Metallizing, Inc. applied the coatings using ArcMelt® proprietary core wire consumables for Twin Wire Arc Spray (TWAS) applications. The compositions of the ArcMelt® consumables are listed in Table 1. The thermal spray coatings were applied onto 12" x 12" steel plates and subsequently installed in Edgewater Unit #4 of Alliant Energy. Unit #4 is a 7 cyclone PRB fired boiler built in 1969. While the original reason to field test the coatings has been delayed, concerns of fly ash erosion and acid corrosion of weak acids on materials remain. These test plates remained between the hot and cold passes of the tube type air heater for about 18 months. The pieces were exposed with a mean temperature variation of 584 to 610 °F (306 to 321 °C). This report summarizes the results of the destructive metallographic evaluation.

## **Experimental**

4" x 4" sections were removed from each test panel and were submitted for destructive metallographic evaluation (Figure 1).



**Figure 1. Coated samples after 18 months exposure in cyclone coal-fired boiler.**

Two cross-sections were prepared from each section. The transverse cross-section was evaluated using optical and electron microscopy to determine coating features and coating composition using Electron Dispersed Spectroscopy (EDS). The second cross-section was used to reveal the coating surface characteristics. A standard Vickers hardness indenter was used to determine hardness variation through the coating thickness and at the coating surface.

Alloy	Fe	Ni	Cr	Al	W	Co	Ti
AMC-4301	Balance	14	26	10			
AMC-4303	Balance	30		16			
AMC-3101	4	Balance	6	0.5	56	2	0.5
AMC-3201	8	Balance	44	1			1

Table 1. Nominal chemical composition of the ArcMelt® consumables used in the field test.

## Results

### AMC 4301

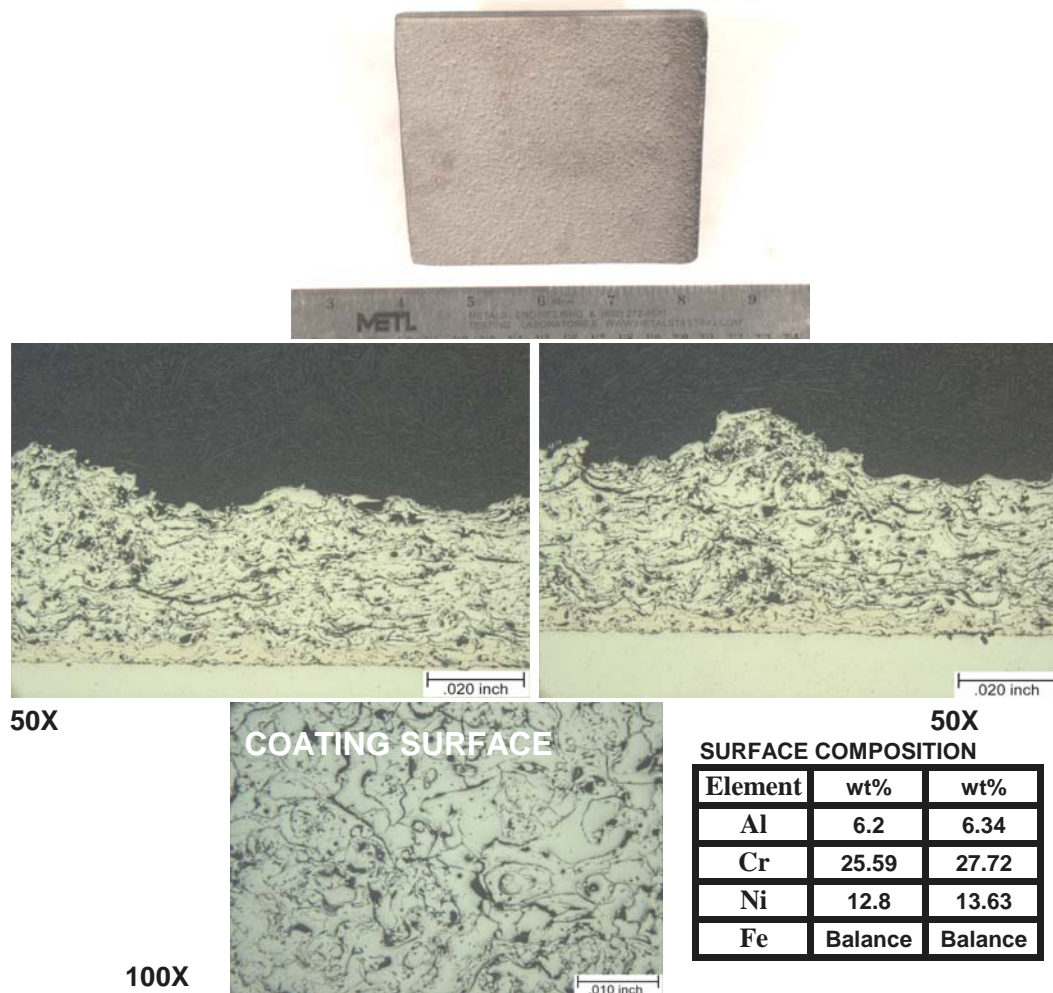
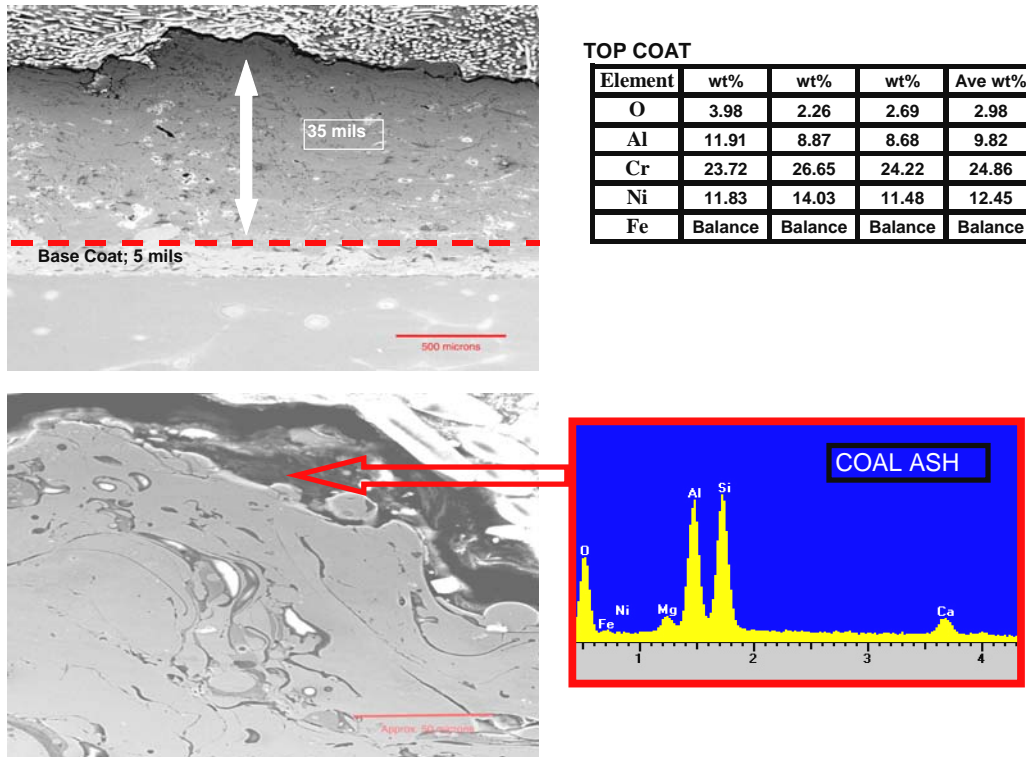


Figure 2. Surface appearance of AMC 4301 and coating characteristics after 18 months of service.

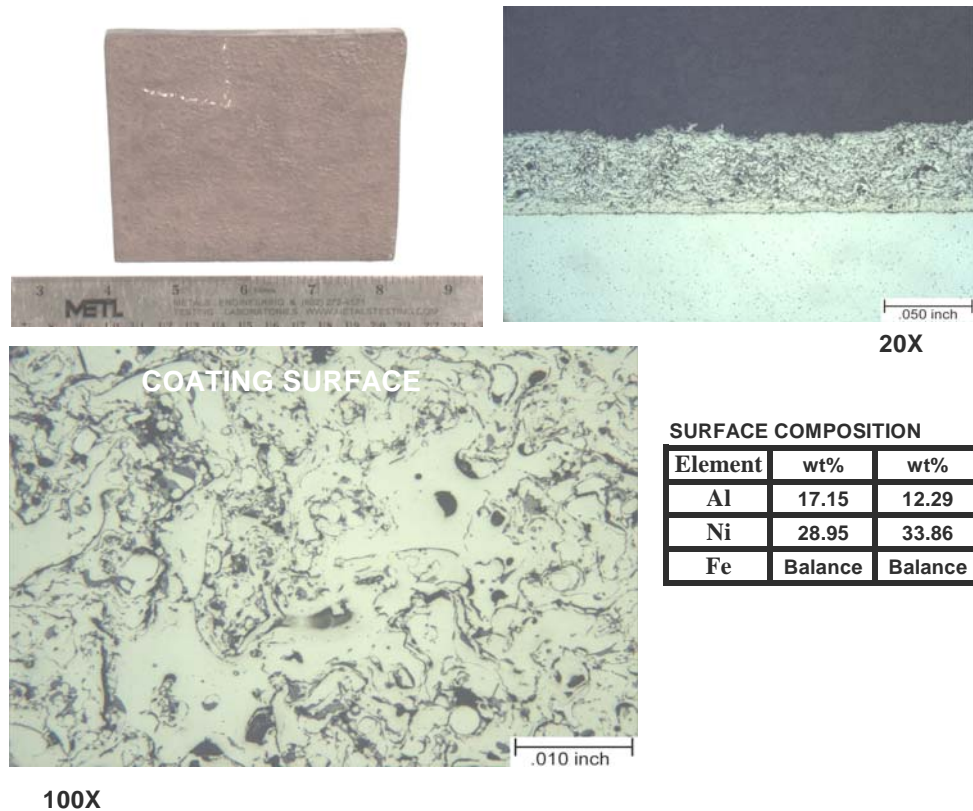


**Figure 3. Scanning Electron Micrograph (SEM) of AMC 4301 after 18 months of exposure.**

The coating contour is rather convoluted as evidenced by the micrograph in Figure 1. However, the evaluation of the surface indicated the absence of any corrosion products. A sintered thin layer of fly ash was detected at the surface (Figure 2) using the SEM. The EDS analyses indicated Si, Al, Ca and Mg as the major constituents of the fly ash. These constituents are most likely present as aluminosilicates, calcium oxide, and magnesium oxide, typical in fly ash from bituminous fuels.

There was no apparent loss of coating thickness (Figure 2). The coating structure was made of two layers, an 886  $\mu$  (35 mil) thick topcoat of AMC 4301 and a 136  $\mu$  (5 mil) thick base coat of Ni-15 Al. The Ni-aluminide base coat improves the adherence of the coating system by balancing the differences in thermal expansion coefficients between the stainless coating and the ferritic substrate. The overall thickness was 1,016  $\mu$  (40 mils), which is typical of TWAS coatings for erosion applications.

The micro-hardness of the topcoat AMC 4301 had an average through-coating value of 964 HV, equivalent to 68 HRC. A similar value was obtained from the surface of the coating (892 HV – 66 HRC). For hard-facing applications, hardness in excess of 60HRC is usually desirable. AMC 4303

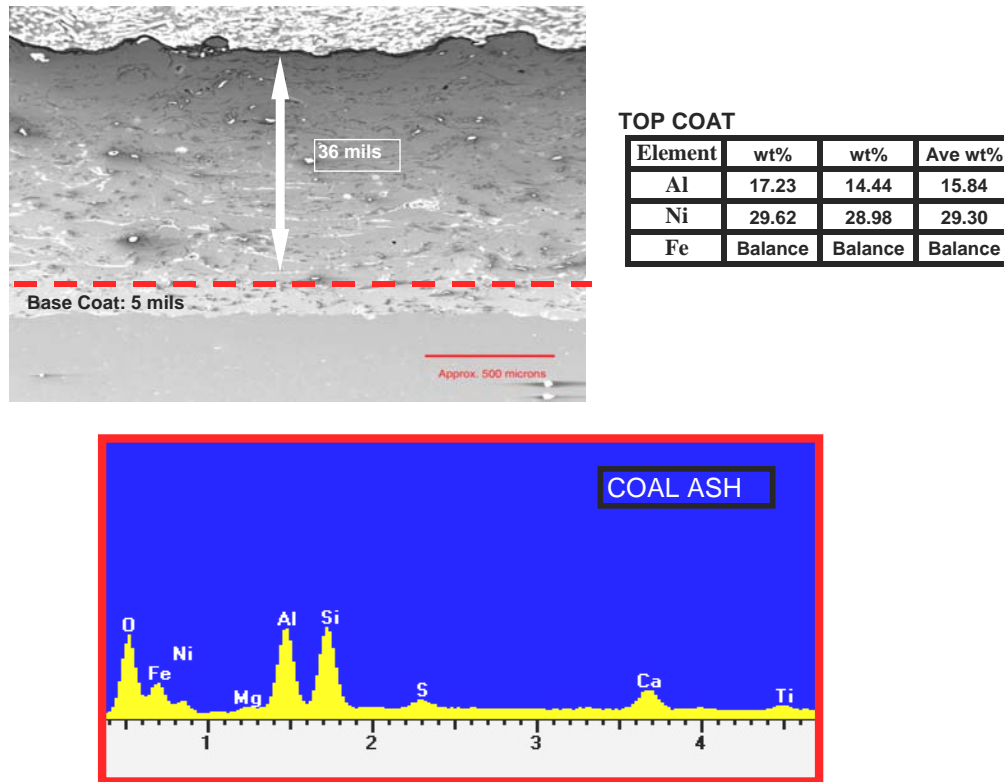


**Figure 4. Surface appearance of AMC 4303 and coating characteristics after 18 months of service in a coal-fire cyclone boiler.**

The coated layer did not show evidence of wastage either by erosion or corrosion. The coating thickness averaged 1,041  $\mu\text{m}$  (41 mil), that corresponds to the standard for TWAS coatings applied for wear resistance. The coating system was composed of two layers, a topcoat of AMC 4303, 916  $\mu\text{m}$  (36 mil) thick, and a base coat of Ni-aluminide (Ni-15 Al) 125  $\mu\text{m}$  (5 mil) thick (Figure 5). The Ni-base coat balances the differences in thermal expansion coefficient between the topcoat AMC 4303 and the ferritic base metal, improving long-term adherence.

The surface of the topcoat was covered with a thin sintered layer of ash. The EDS analysis results from the ash layer indicated Al, Si, Ca, and traces of Mg and Sulfur. Sulfur was not detected through the coating thickness, and most likely the sulfur was bound to Ca or Mg as a high-melting temperature sulfate. Al and Si were present, most likely as an alumino-silicate.

The Vickers hardness average 222 through the coating thickness and 221 HV at the surface. These values are below the B Brinnel scale indicating a rather soft material.

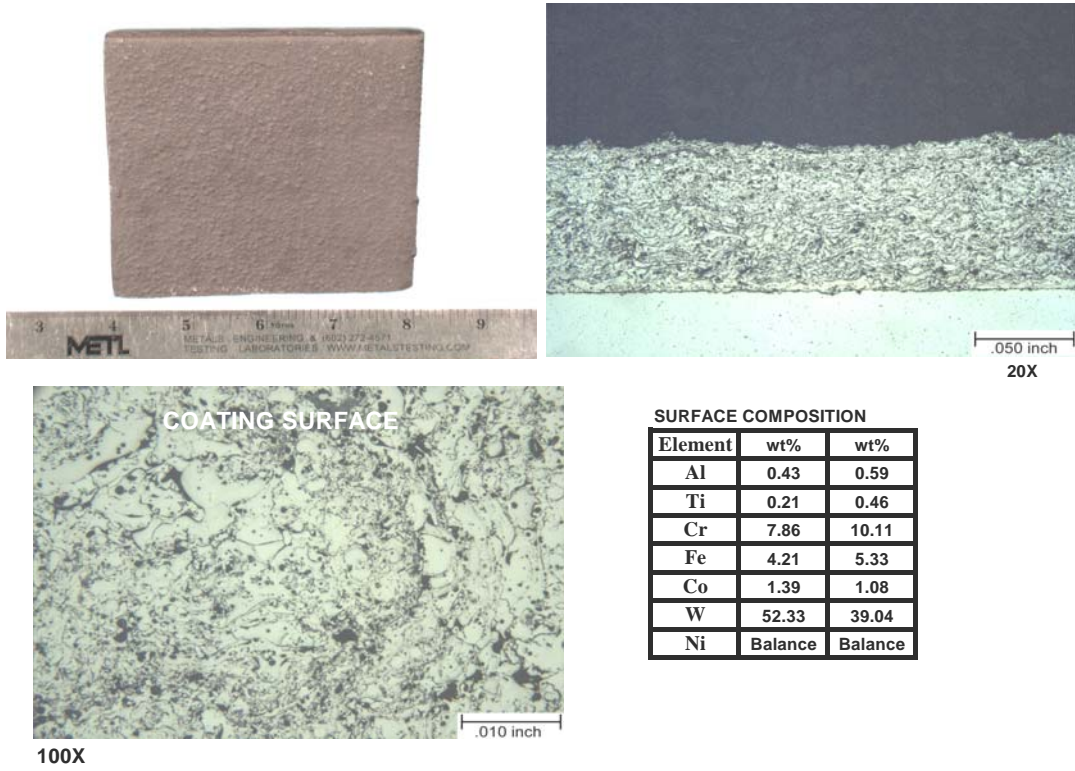


**Figure 5. SEM of AMC 4303 after 18 months of exposure.**

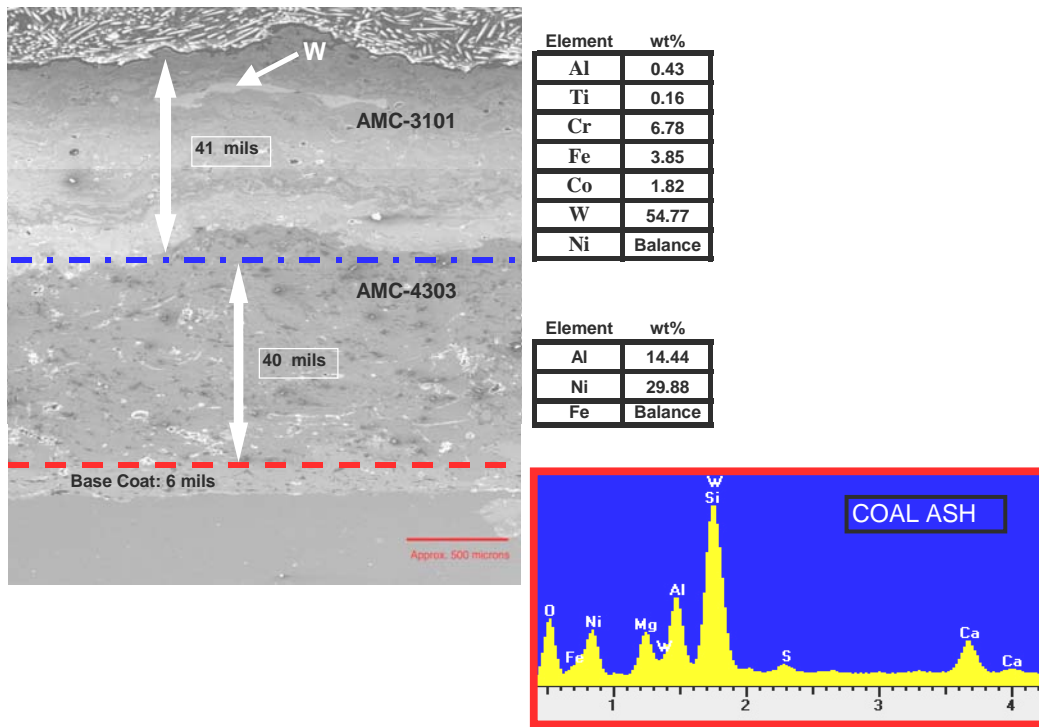
### **AMC 3101**

AMC 3101 is a Ni-base composition with as much as 55 wt% W present in solution, and not as a carbide. Figure 6 depicts the appearance of the coating after 18 months of service. The surface evaluation did not show evidence of oxidation and the cross-section of the coating shown in Figure 7 indicated a coating thickness in excess of 2 mm (2,225  $\mu\text{m}$  - 89 mil). This coating was composed of three layers including; a Ni-aluminide base coat (150  $\mu\text{m}$  – 6 mil), an intermediate layer of AMC 4303 (1,025  $\mu\text{m}$  – 41 mil), and a topcoat of AMC 3101 (1,050  $\mu\text{m}$  – 42 mil).

Coatings of this thickness, exposed to erosion attack, are normally disbonded by decohesive separation due to the significant build-up stresses during coating application, using conventional TWAS applications. This ArcMelt™ composite consumable results in the formation of strongly bonded layers since the homogeneous energy transfer of the arc allows the complete melting of the core wire. In this particular chemistry (AMC 3101), the Wc decomposes at the tip of the arc, generating a reducing gas shroud that results on a primarily metallic surface layer. The average micro hardness through the coating thickness and at the surface was 572 HV (53 HRC).



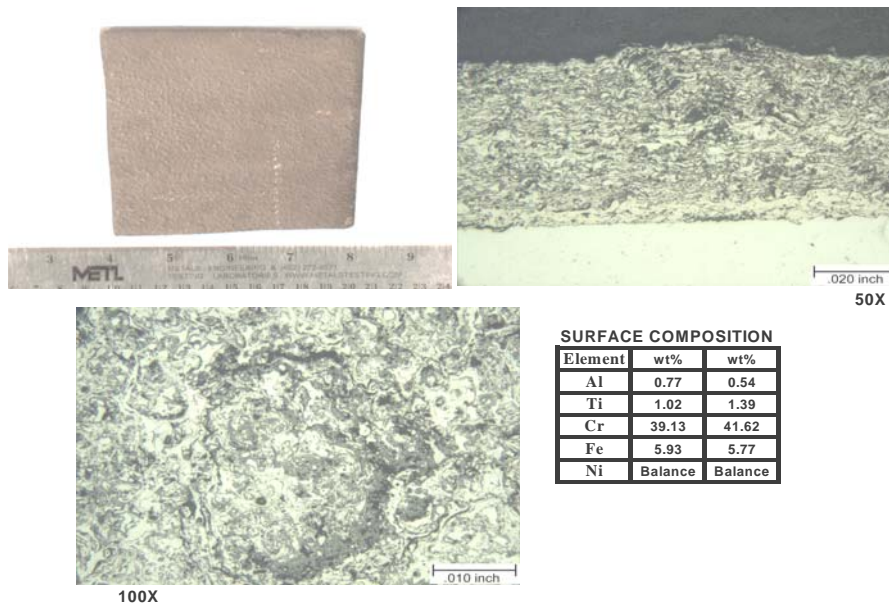
**Figure 6. Surface appearance of AMC 3101 and coating characteristics after 18 months of service.**



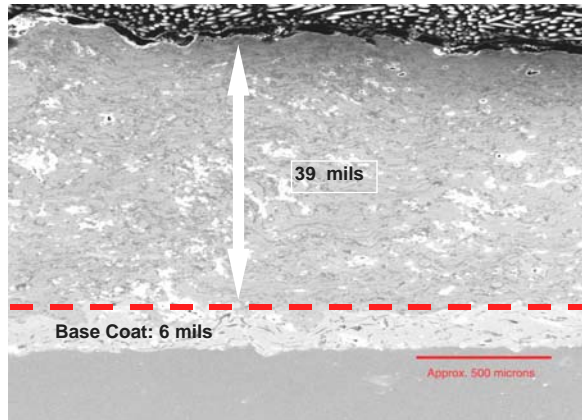
**Figure 7. SEM of AMC 3101 after 18 months of exposure.**

## AMC 3201

AMC 3201 is a composite wire similar to 45 CT or Ni-Cr 50/50. This alloy composition has been extensively used in boiler applications for corrosion control. Its welding equivalent is alloy type 72 which, as a weld overlay, experiences hardening when exposed to temperatures in excess of 538 °C (1,000 °F) for relatively long periods of time. The appearance of the test panel after 18 months of service is illustrated in Figure 8, together with micrographs through the thickness and surface of the coated layer. Like any typical TWAS coating, the structure is composed of an island of metal splats surrounded by Cr-oxides. However, different from conventional TWAS consumables, the patent pending ArcMelt® core wires result in the formation of a rather even distribution of oxides in a metallic matrix that results in lower build-up stresses. Due to this unique feature, the coating system tends to tolerate fatigue temperature cycles with no propensity to cracking. Like the other ArcMelt® products included in this test, AMC 3201 did not show evidence of wastage either by erosion or corrosion after 18 months of service. The overall thickness of the product was 1,168 µm (46 mil) of which, 150 µm (6 mil) corresponded to the Ni-aluminide base coat (Figure 9). Similarly, a fine layer of sintered ash was detected using the SEM and the EDS, analysis indicated Al, Si K, and Mg, and a strong signal for Na and S most likely present as Na-sulfate. At the operating temperatures reported by Alliant, 584 to 610 °F (306 to 321 °C), Na-sulfate poses no risk as a corrodent because its melting point is in excess of 1,562 °F (850 °C). The average hardness through the coating thickness and on the coating surface was 330 HV (33 HRC) typical of this type of alloy.



**Figure 8. Surface appearance of AMC 3201 and coating characteristics after 18 months of service.**



TOP COAT

Element	wt%	wt%
O	3.74	4.65
Al	0.85	0.76
Ti	0.79	1.05
Cr	43.26	36.89
Fe	5.68	6.5
Ni	Balance	Balance

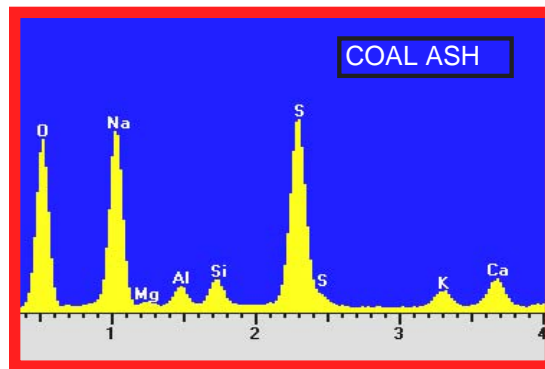


Figure 9. SEM of AMC 3201 after 18 months of exposure.

## Conclusion

- Alloys AMC 4301, 4303, 3101, and 3201 exhibit remarkable resistance to both fly ash erosion and corrosion after an 18 month field test in a coal-fire cyclone boiler.
- No wastage was apparent, and the integrity of the coated layers was not compromised.
- Fly-ash erosion was apparent only by the presence on the surface of all coatings of a thin, sintered ash layer composed of Si, Al, Mg, Ca, Na, and K oxides and sulfates.
- The field test demonstrated that the use of patent pending ArcMelt® consumables can lead to the build up of thermal spray layers in excess of 1,000  $\mu\text{m}$  (40 mils) without detriment to the structural integrity of the coating system.
- There was no correlation between coating hardness and erosion susceptibility.