

# SRI International

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## Diffusion Coatings for Corrosion-Resistant Components in Coal Gasification Systems

Quarterly Technical Progress Report 9

Covering the period July 1, 2005 through September 30, 2005

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Prepared by:

Gopala N. Krishnan, Ripudaman Malhotra, Esperanza Alvarez,  
Kai-Hung Lau, and Angel Sanjurjo

SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025

Prepared for:

U.S. Department of Energy  
National Energy Technology Center  
P. O. Box 10940  
Pittsburgh, PA 15236

Attention: Dr. Richard Read



333 Ravenswood Avenue • Menlo Park, CA 94025-3493 • (650) 859-2000 • [www.sri.com](http://www.sri.com)

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## **ABSTRACT**

Heat-exchangers, particle filters, turbines, and other components in integrated coal gasification combined cycle system must withstand the highly sulfiding conditions of the high-temperature coal gas over an extended period of time. The performance of components degrades significantly with time unless expensive high alloy materials are used. Deposition of a suitable coating on a low-cost alloy may improve its resistance to such sulfidation attack, and decrease capital and operating costs. The alloys used in the gasifier service include austenitic and ferritic stainless steels, nickel-chromium-iron alloys, and expensive nickel-cobalt alloys.

During this period we tested coated alloy coupons under conditions designed to mimic the conditions in the filter unit after the high-temperature heat recovery unit (HTHRU). The filter unit is another important area where corrosion has caused unscheduled downtime, and the remedy has been the use of sintered metal tubes made of expensive alloys such as inconel. The objective of our test was to determine if those coatings on 400-series steel that were not able to withstand the harsher conditions of the HTHRU, may be sufficiently resistant for use in the filter unit, at the reduced temperatures. Indeed, most of our coatings survived well; the exceptions were the coated porous samples of SS316.

We continued making improvements to our coatings apparatus and the procedure began during the last quarter. As a result of these modifications, the coupons we are now producing are uniform. We describe the improved procedure for preparing diffusion coatings. Finally, because porous samples of steel in grades other than SS316 are not readily available, we also decided to procure SS409 powder and fabricate our own sintered porous coupons.

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## EXECUTIVE SUMMARY

Advanced coal gasification systems such as integrated coal gasification combined cycle (IGCC) processes offer many advantages over conventional pulverized coal combustors. Heat-exchangers, filters, turbines, and other components in IGCC plants often must withstand the highly sulfiding conditions at high temperatures. In collaboration with U.S. Department of Energy and ConocoPhillips, we are developing corrosion-resistant coatings for high-temperature components in IGCC systems.

SG Solution's coal gasification power plant in Terre Haute, IN, uses ConocoPhillips' E-Gas technology. The need for corrosion-resistant coatings exists in two areas: (1) the tube sheet of a heat exchanger at  $\sim 1000^{\circ}\text{C}$  that is immediately downstream of the gasifier, and (2) porous metal particulate filter at  $370^{\circ}\text{C}$ , which is downstream of the heat exchanger. These components operate at gas streams containing as much as 2%  $\text{H}_2\text{S}$ . A protective metal or ceramic coating that can resist sulfidation corrosion will extend the life-time of these components and reduce maintenance.

During this period, we tested coated alloy coupons under conditions designed to mimic the conditions in the filter unit after the high-temperature heat recovery unit (HTHRU). The filter unit is another important area where corrosion has caused unscheduled downtime, and the remedy has been the use of sintered metal tubes made of expensive alloys such as inconel. The objective of our test was to determine if those coatings on 400-series steel that were not able to withstand the harsher conditions of the HTHRU, may be sufficiently resistant for use in the filter unit, at the reduced temperatures. Indeed, most of our coatings survived well; the exceptions were the coated porous samples of SS316.

We continued making improvements to our coatings apparatus and the procedure began during the last quarter. As a result of these modifications, the coupons we are now producing are uniform. We describe the improved procedure for preparing diffusion coatings. Finally, because porous samples of steel in grades other than SS316 are not readily available, we also decided to procure SS409 powder and fabricate our own sintered porous coupons.

## **INTRODUCTION**

Heat-exchangers, filters, turbines, and other components in coal-fired power plants must withstand demanding conditions of high temperatures and pressure differentials. Further, the components are exposed to corrosive gases and particulates that can erode the material and degrade their performance. In collaboration with U.S. Department of Energy and ConocoPhillips, SRI International recently embarked on a project to develop corrosion-resistant coatings for coal-fired power plant applications. Specifically, we are seeking to develop coatings that would prevent the corrosion in the tube-sheet of the high-temperature heat recovery unit of a coal gasification power plant of SG Solution's plant in Terre Haute, IN, which uses ConocoPhillips' E-Gas technology. This corrosion is the leading cause of the unscheduled downtime at the plant and, hence, success in this project will directly impact the plant availability and its operating costs. Coatings that are successfully developed for this application will find use in similar situation in other coal-fired power plants.

## **WORK PERFORMED**

During this period, we tested coated alloy coupons under conditions designed to mimic the conditions in the filter unit after the high-temperature heat recovery unit (HTRU). The filter unit is another important area where corrosion has caused unscheduled downtime, and the remedy has been the use of sintered metal tubes made of expensive alloys such as Inconel. The objective of our test was to determine if those coatings on 400-series steel that were not able to withstand the harsher conditions of the HTRU, may be sufficiently resistant for use in the filter unit, at the reduced temperatures. Indeed, most of our coatings survived well; the exceptions were the coated porous samples of SS316.

We continued making improvements to our coatings apparatus and the procedure began during the last quarter. As a result of these modifications, the coupons we are now producing are uniform. We describe the improved procedure for preparing diffusion coatings. Finally, because porous samples of steel in grades other than SS316 are not readily available, we also decided to procure SS409 powder and fabricate our own sintered porous coupons.

## **EXPOSURE TO LOW-TEMPERATURE SIMULATED COAL GAS: TEST #8**

We used pairs of SS405, 409, and 410 samples that had diffusion coatings of Cr and Al. Some of the coupons were sand blasted prior to coating to remove any remaining oxide layer that may be present on the surface of the coupon. A few coupons were oxidized slowly to form a

protective layer of  $\text{Al}_2\text{O}_3$  on the surface of the coating. Also included were SS409 samples coated with TiN and (TiAl)N, as well as some porous SS316 samples coated with (Ti/Ta)N and (Ti/Al)N. The samples used in Test 8 and the salient observations following the exposure test are listed in Table 1. During the first 36 h of the test, we experienced problems with the steam generator, probably due to buildup of some back pressure. We replaced the filter with a coarser frit, and the system worked well. The test was conducted for 300 h.

The top panel of Figure 1 shows the picture of the coated samples before they were exposed to simulated gasifier conditions at  $370^\circ\text{C}$ . The bottom panel is a photograph of the samples after exposure.

**Table 1. Samples Tested and Results Test 8  
300 h (Jul 27, 2005)**

Sample No.	Material	Coating	Run	Appearance	% Wt. Gain
1	SS405	(Cr-Al)Al	72	Good, some discoloration	0.25
2	SS405	(Cr-Al)Al	72	Good, some discoloration	0.10
3	SS409	(Cr-Al)Al	76	Good, like new	0.00
4	SS409	(Cr-Al)Al	76	Good, like new	0.00
5	SS410	(Cr-Al)Al	73	Good, some discoloration	0.17
6	SS410	(Cr-Al)Al	73	Good, some discoloration	0.04
7	SS409	TiN	68	Good	0.07
8	SS316 (p)	(TiTa)N	62	Corroded, darkened	11.86
9	SS409	(TiAl)N	77	Smooth, like new	0.03
10	SS316 (p)	(TiAl)N	78	Badly corroded	19.07

As is evident from Figure 1, all the coatings except those on the porous SS316 sample performed well. The two SS316 samples gained significant weight indicating extensive sulfidation of the coupon. All other samples also gained only minimal weight ( $<0.3$  wt%). Examination of the weight gained (Table 1) shows some differences between these samples and points to SS409 alloy as the best substrate for these diffusion barrier coatings.



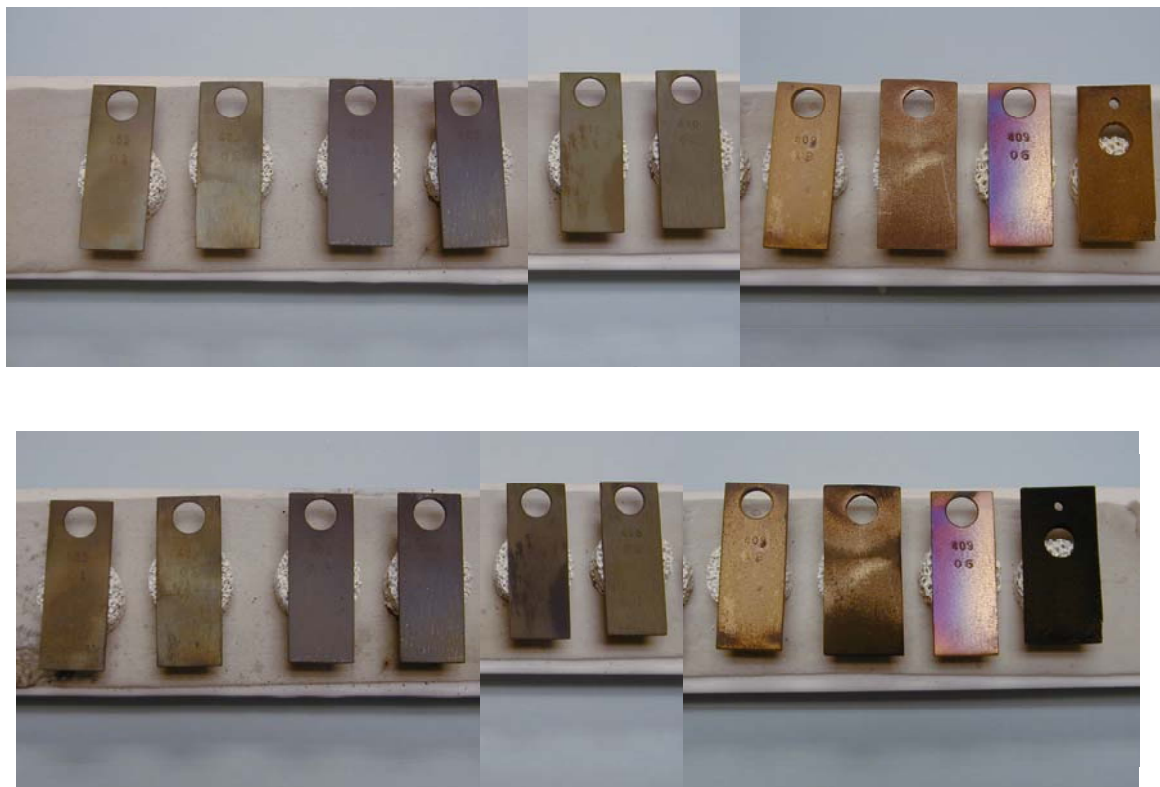


Figure 1. Samples before and after exposure to 300 h at 370°C in simulated gasifier Test 8.

## **FABRICATION OF POROUS COUPONS WITH SS409**

In view of the fact that no porous metal filters were commercially available, we procured a batch of SS409 powder (300 mesh, 0.04 mm) and fabricated our own coupons. The alloy steel powder was sintered under hydrogen at 1300°C for 12 h. Flat and mechanically strong samples were obtained by this procedure. The porosity of the coupons was determined to be about 55%.

## **APPLICATION OF DIFFUSION COATINGS**

### **Apparatus**

The schematic diagram of the Chemical Vapor Deposition and Fluidized Bed Reactor (CVD-FBR) system is shown in Figures 2. The system consists of a cylindrical

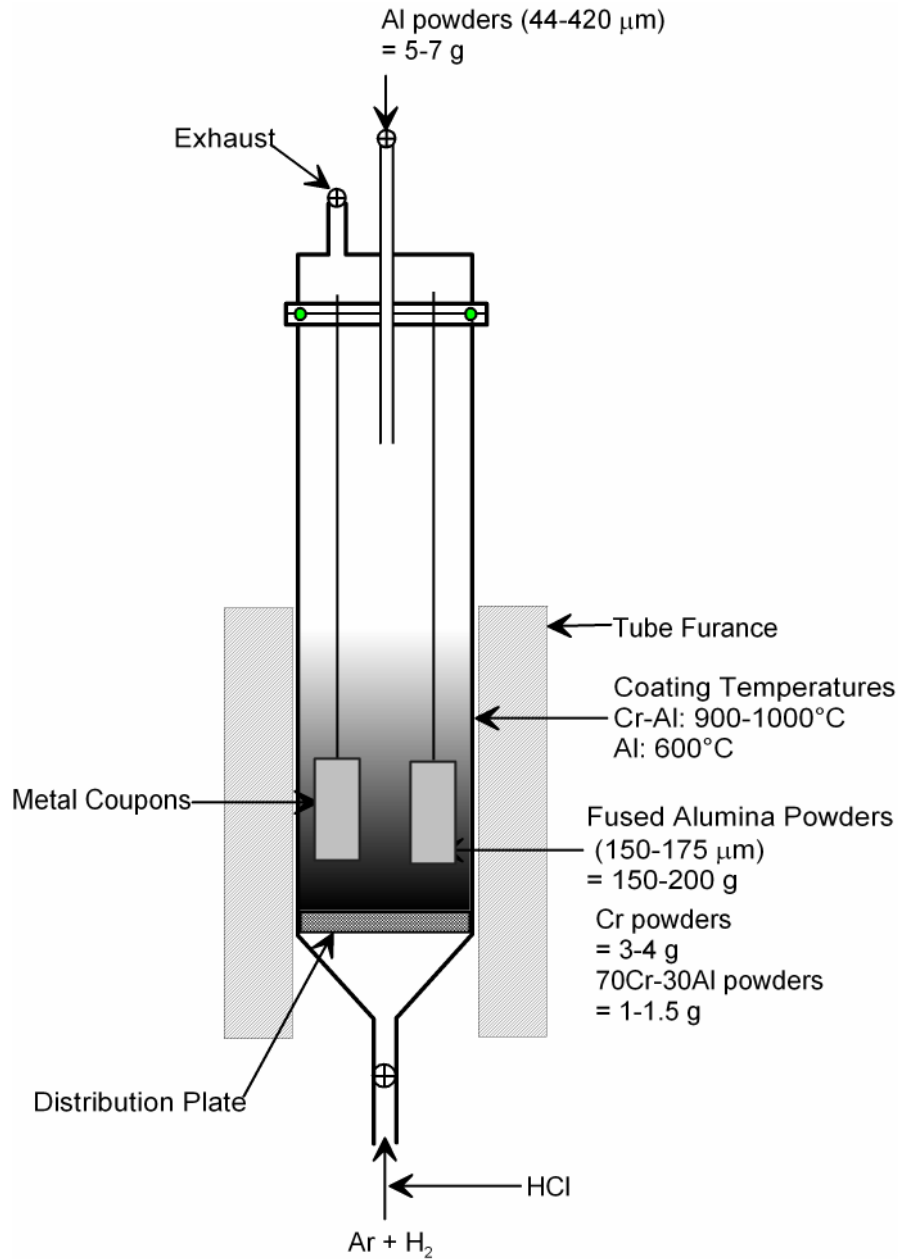


Figure 2. Schematic diagram of the fluidized bed reactor for Cr-Al and Al coatings of metal coupons.

quartz reactor (4.7 cm ID and 50 cm long) with a porous fused quartz plate to support the powder bed and serve as a gas distributor, and a gas-metering and gas-mixing unit. Fused  $\text{Al}_2\text{O}_3$  powder with particle size in the range 150-175  $\mu\text{m}$  was loaded in the reactor to form a bed between 4-6 cm high. The powder bed was fluidized by an upward flow of Ar + H<sub>2</sub> mixture and they were metered independently at atmospheric pressure. A combined flow rate between 6-8 l/min (about 6-8 cm/s linear flow velocity) was required to maintain fluidization of the bed. The metal

coupons emerged in the powder bath were loosely hung from the top and were about 1.5 cm above the porous fused quartz plate. For Cr-Al coating experiment, as shown in Figure 2, the reactor was heated using either an electric resistance furnace or a RF induction coil. The system was heated rapidly to coating temperature, and the volatile and reactive precursors were then added from the top and through the bottom of the reactor at the coating temperature.

## Procedure

For CrAl coating experiment, Cr and 70Cr-30Al powders were mixed in the fused  $\text{Al}_2\text{O}_3$  powder bed as shown in Figure 2. At the coating temperature of  $900^\circ\text{C}$  or above, HCl gas, about 1-2 mol%, was admitted together with the Ar +  $\text{H}_2$  fluidizing gas mixture through the bottom reactor. HCl gas will react with the metals in the bed forming Cr- and Al- containing reactive precursors such as  $\text{CrCl}_2$ , and  $\text{AlCl}$ . The reactive precursors will be reduced by the presence of  $\text{H}_2$  forming Cr-Al on the metal coupon. After the Cr-Al at high temperature, the reactor temperature was lowered to  $600^\circ\text{C}$  and then a small amount of Al powder was added to the reactor for additional Al coating on the metal substrates. Some of the Cr-Al and Al-coated coupons were heat-treated in Ar +  $\text{H}_2\text{O}$  mixture at  $900\text{--}950^\circ\text{C}$ , forming a thin  $\text{Al}_2\text{O}_3$  layer on the coupons.

For TiN or (TiTa)N coating, a small amount of  $\text{TiH}_2$  powders was added to the powder bed to promote the formation  $\text{TiCl}_3$  and  $\text{TiCl}_2$  reactive gaseous precursors. A gaseous mixture of Ar +  $\text{TiCl}_4$  was supplied from a  $\text{TiCl}_4$  (l) bubbler heated between  $26\text{--}40^\circ\text{C}$  using pure Ar at atmospheric pressure as carrier gas. The Ar +  $\text{TiCl}_4$  mixture was added together with the Ar +  $\text{H}_2$  fluidizing gas mixture through the bottom of the reactor. At coating temperature between  $900^\circ$  and  $1100^\circ\text{C}$ ,  $\text{TiCl}_4$  gas will react rapidly with Ti powders forming reactive  $\text{TiCl}_3$  and  $\text{TiCl}_2$  gaseous precursors, and Ti metal will be deposited on the coupon surface by  $\text{H}_2$  reduction. Ta deposition was done by reduction of  $\text{TaCl}_5$  powders by  $\text{H}_2$  when the powders were slowly added to the powder bed. After the metal coating experiment, the reactor temperature was lowered and the coating was nitrided by admitting  $\text{NH}_3$  gas from the top of the reactor.

For (TiAl)N coating experiments,  $\text{AlCl}_3$  gas was supplied to the bottom of the reactor by vaporization of  $\text{AlCl}_3$  powders from a heated reactor using Ar as carrier gas. For Ti-Al coating, 1-2 g of Al powders were added to the fused alumina powder bed to promote the formation of reactive  $\text{TiCl}_3$  and  $\text{AlCl}$  gaseous precursors at the desired temperature. The nitridation was performed at lower temperature after the Ti-Al coating experiment.

For (TiSi)N coating,  $\text{SiHCl}_3$  from the bubbler using Ar as carrier gas was admitted together with  $\text{TiCl}_4$  gas through the bottom of the reactor. The  $\text{SiHCl}_3$  bubbler was kept at ice

temperature during the coating experiments. As in other cases, nitridation was conducted at lower temperature.

## **Results**

XRF elemental analyses of uncoated alloy coupons are summarized in Table 2. Experimental conditions and XRF analyses of metal or alloy coatings on various stainless steel coupons are summarized in Table 3. Most of the metal or alloy coatings showed very good adherence on the metal substrate surface, as checked by rubbing, high-pressure air blowing and scotch tape testing. The results show that the compositions and thickness of Cr-Al, Ti-Al, Ti-Ta, and TiSi coatings can be controlled by the coating temperature and time, and relative amount of precursors admitted to the reactor. From Runs #77-90, each coating experiment was performed over two days. The first was for the Ti-Al coating and followed by (TiAl)N or (TiSi)N nitride coating on the second day. A typical elemental line scan of the cross section from Run # 77, (TiAl)N/SS409 and from Run #86, (TiSi)N/SS410, is shown in Figures 3 and 4. The line scan clearly shows two distinct coating regions: the Ti and Al diffusion coating for both runs and (TiAl)N or (TiSi)N coating on the top surfaces. It is clear that Al enhances the Ti inward diffusion. The Ti depth can be controlled coating temperature.

**Table 2. XRF Analysis of Various Metal Alloy Coupons  
(Wt%)**

<b>Element</b>	<b>SS405</b>	<b>SS409</b>	<b>SS410</b>	<b>SS316</b>	<b>HR160</b>
Fe	86.7	87.1	87.4	66.8	
Cr	12.4	11.1	11.7	18.0	28.2
Al		0.3	0.22	0.4	
Mo				2.3	
Ni	0.18		0.18	11.0	38.2
Si	0.53	0.5	0.41	1.5	2.6
Co					30.5
Ti					0.5










**Table 3. Summary of Various Metal Alloy Coatings on Stainless Steel Coupons**




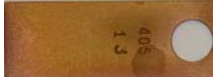

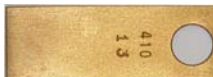
Run No	SS Coupon	Coated Materials	Coating Conditions Temperature; Time	XRF Analysis of the Surface
56 56A (3/7/05)	304 409	TiN coating (TiTa)N coating TiN coating (TiTa)N coating	1045°C; 3.5 hrs 1045°C; 1.5 hrs 1045°C; 2.5 hrs 1045°C; 3.0 hrs	<b>304 alloy</b> <b>Ti: 23.9; Ta: 9.4</b> Fe: 38.1; Cr: 20.5 Ni: 7.7 <b>409 alloy</b> <b>Ti: 24.5; Ta: 3.8</b> Fe: 60.1; Cr: 11.3
57	409-07 409-08 409-09 409-10	Cr, Al coating	1000°C; 3 hrs 750-800°C; 5 hrs	<b>409-07</b> <b>Al: 17.6; Cr: 13.1</b> Fe: 68.3 <b>409-09</b> <b>Al: 17.2; Cr: 14.3</b> Fe: 67.9
57A (from 57)	409-07 409-09	Al coating	600°C; 2 hrs	<b>409-07</b> <b>Al: 21.3; Cr: 13.6</b> Fe: 64.1 <b>409-09</b> <b>Al: 17.2; Cr: 13.8</b> Fe: 67.9
58	409-11 409-12	Cr, Al Coating	1000°C; 3 hrs	<b>409-11</b> <b>Al: 22.2; Cr: 21.3</b> Fe: 55.7
59	<b>From #57</b> 409-08 409-10 <b>From #58</b> 409-11 409-12	Forming thin Al <sub>2</sub> O <sub>3</sub> coating by controlled oxidation in Ar + H <sub>2</sub> O mixture	950°C; 1 hr	
60 (3/21/05)	HR160-09 HR160-10	TiN coating (TiTa)N coating	1100°C; 3.2 hrs 1100°C; 2.5 hrs	<b>HR160-09</b> <b>Ti: 38.7; Ta: 0.7</b> Cr: 18.7; Co: 17.6 Ni: 23.9
61	Two 316 porous coupons	Cr, Al coating	1000°C; 2.5 hrs	<b>Al: 21.5; Cr: 24.6</b> Fe: 44.2; Ni: 6.5

62 (4/7/05)	Three 316 porous coupon	TiN coating (TiTa)N coating TiN coating	950-1120°C; 3 hrs 950-1000°C; 2 hrs 950-1080°C; 3 hrs	<b>Ti: 40.5; Ta: 1.6</b> Fe: 38.6; Cr: 10.7 Ni: 6.8
63 (4/14/05)	409-13 409-14 409-15	TiN coating	1080-1140°C; 5.5 hrs	<b>409-13</b> <b>Ti: 13.7; Al: 0.3</b> Fe: 70.4; Cr: 14 <b>409-14</b> <b>Ti: 13.6; Al: 0.3</b> Fe: 69.7; Cr: 14.1
64	HR160-06 HR160-07 HR160-08	Ti coating TiN coating	1180°C; 3 hrs 1120°C; 3 hrs	<b>Ti: 22.9; Al: 0.5</b> Cr: 22.4; Co: 22.5 Ni 28.8
65 (4/21/05)	410-05 410-06 410-07	Ti coating TiN coating	1160°C; 3.3 hrs 1120°C; 2.1 hrs	<b>Ti: 11.9; Al: 0.6</b> Fe: 75.0; Cr: 11.1
66	405-15 405-16 405-17	Ti coating TiN coating	1180°C; 4.0 hrs 1120°C; 2.0 hrs	<b>Ti: 14.4; Al: 0.4</b> Fe: 71.6; Cr: 12.0
67	409-16 409-17	Cr, Al coating Al coating	955-981°C; 1.5 hrs 600°C; 1.5 hrs	<b>Al: 35.2; Cr: 9.4</b> Fe: 54.5
68 (4/27/05)	409-18 409-19 409-20	Ti coating TiN coating	1180°C; 5.5 hrs 950-1020°C; 2.5 hrs	<b>Ti: 26.4; Al: 0.9</b> Fe: 63.9; Cr: 8.0
69	Three 405	Ti coating TiN coating	1180°C; 6.5 hrs 920°C; 2.8 hrs	<b>Not analyzed</b>
70 (4/27/05)	409-16 409-17 (from 67)	Forming thin Al <sub>2</sub> O <sub>3</sub> coating by controlled oxidation in Ar + H <sub>2</sub> O mixture	950°C; 1 hrs (Ar + H <sub>2</sub> O)	<b>Not analyzed</b>

71 (6/8/05)	409-01 (sand blasted) 409-02 (as received)	Cr, Al coating Al coating	975-996°C; 3 hr 600°C; 1 hr	<b>409-01</b> <b>Al: 12.0; Cr: 22.5</b> Fe: 63.7 <b>409-02</b> <b>Al: 18.9; Cr: 19.5</b> Fe: 60.6
72 (6/10/05)	405-01 (sand blasted) 405-02 (as received)	Cr, Al coating Al coating	890-933°C; 2 hrs 600°C; 1 hr	<b>405-1</b> <b>Al: 3.3; Cr: 24.7</b> Fe: 69.7 <b>405-02</b> <b>Al: 2.3; Cr: 21.1</b> Fe: 75.4
73	410-01 (sand blasted) 410-02 (as received)	Cr, Al coating Al coating	928-1000°C; 2.5 hrs 600°C; 1 hr	<b>410-1</b> <b>Al: 4.8; Cr: 25.4</b> Fe: 67.5 <b>410-02</b> <b>Al: 5.6; Cr: 23.1</b> Fe: 70.6
74	409-01 409-02	Cr, Al coating Al coating	1000°C; 1 hr 600°C; 1 hr	<b>409-1</b> <b>Al: 31.8; Cr: 20.7</b> Fe: 46.7 <b>409-02</b> <b>Al: 30.1; Cr: 20.2</b> Fe: 49.0
75	All coated coupon from 72, 73, 74	Forming thin Al <sub>2</sub> O <sub>3</sub> coating by controlled oxidation in Ar + H <sub>2</sub> O mixture	909-920°C; 1 hr (Ar + H <sub>2</sub> O)	
76 (6/27/05)	409-14 (sand Blasted) 409-15 (as received)	Cr, Al coating Al coating	839-872°C; 2 hrs 600°C; 1 hr	<b>409-14</b> <b>Al: 18.4; Cr: 11.0</b> Fe: 70.0 <b>409-15</b> <b>Al: 16.9; Cr: 12.4</b> Fe: 70.1



Run No	SS Coupon	Coat Materials	Coating Conditions Temperature; Time	XRF Analysis	Coated Coupon
77 (7/14/05)	409-06 409-07 409-10	Ti, Al coating (TiAl)N nitridation	920°C; 3 hrs 750-800°C; 5 hrs	<b>Ti: 55.5; Al: 4.8</b> Fe: 21.7; Cr: 2.7	
78	Three 316 porous	Ti, Al coating (TiAl)N nitridation	1000-1100°C; 5 hrs 750-800°C; 5 hrs	<b>Ti: 27.1; Al: 2.2</b> Fe: 37.3; Cr: 19.15 Ni: 26.3; Si: 0.8	
79	410-03 410-04 410-05	Ti, Al coating (TiAl)N nitridation	920-1000°C: 5.5 hrs 750-800°C; 5 hrs	<b>Ti: 5.9; Al: 47.7</b> Fe: 38.1; Cr: 7.0	
80 (8/105)	405-03 405-04 405-05	Ti, Al coating (TiAl)N nitridation	920°C: 8 hrs 750-800°C: 5 hrs	<b>Ti: 4.2 ; Al: 54.4</b> Fe: 32.9.1; Cr: 6.35	
81	409-05 409-11 409-13	Ti, Al coating Ti, Ta Coating NH <sub>3</sub> Nitridation	850-920°C: 4 hrs 850-920°C: 4 hrs 920°C: 0.5 hr	<b>Ti: 7.5; Al: 3.0;</b> <b>Ta: 0.13</b> Fe: 75.8; Cr: 10.9	
82 (9/13/05)	409-08 409-09 409-18	Ti, Al coating Ti, Ta Coating (TiAlTa)N nitridation	850-920°C: 4.2 hrs 920-1000°C: 2.5 hrs 750-800°C: 5 hrs	<b>Ti: 5.8; Al: 49.6;</b> <b>Ta: 0.1</b> Fe: 35.9; Cr: 6.9	
84	410-07 410-08 410-10	Ti,Al coating (TiSi)N nitridation	800-850°C: 5.5 hrs 750-850°C: 4 hrs	<b>Ti: 3.1; Al: 0.9;</b> <b>Si: 3.9</b> Fe: 78.6; Cr: 13.5	
85	409-17 409-19 409-20	Ti,Al coating (TiAl)N nitridation	800-850°C: 6 hrs 750-800°C: 1 hr	<b>Ti: 4.0; Al: 48.4</b> Fe: 38.9; Cr: 6.7	
86	410-15 410-16 410-17	Ti,Al coating (TiAl)N nitridation	850-900°C: 6 hrs 750-800°C: 2 hrs	<b>Ti: 13.5; Al: 0.95;</b> <b>Si: 13.1</b> Fe: 61.7; Cr: 10.1	

87	405-10 409-16 410-12	Ti,Al coating (TiSi)N (Nitridation)	850-980°C: 7.5 hrs 750-800°C: 5.1 hrs	<b>405-10</b> <b>Ti: 82.3; Al: 0.15;</b> <b>Si: 3.1</b> <b>410-12</b> <b>Ti: 86.5; Al: 0.1;</b> <b>Si: 3.1</b> Fe: 8.75; Cr: 0.8	  
89 (10/18/05)	405-13 410-18 410-19	Ti,Al coating (TiSi)N (Nitridation)	870-1010°C: 8.0 hrs 750-800°C: 6.0 hrs	<b>405-13</b> <b>Ti: 31.45; Al: 0.3;</b> <b>Si: 5.3</b> Fe: 53.8; Cr: 8.9 <b>410-19</b> <b>Ti: 80.5; Al: 0.15;</b> <b>Si: 2.0</b> Fe: 15.6; Cr: 1.9	 
90 (10/25/05)	Three 410	Ti,Al coating (TiAl)N (Nitridation)	870-1010°C: 8.2 hrs 750-800°C: 5 hrs	<b>Ti: 88.4; Al: 0.1;</b> Fe: 10.3; Cr: 1.2	

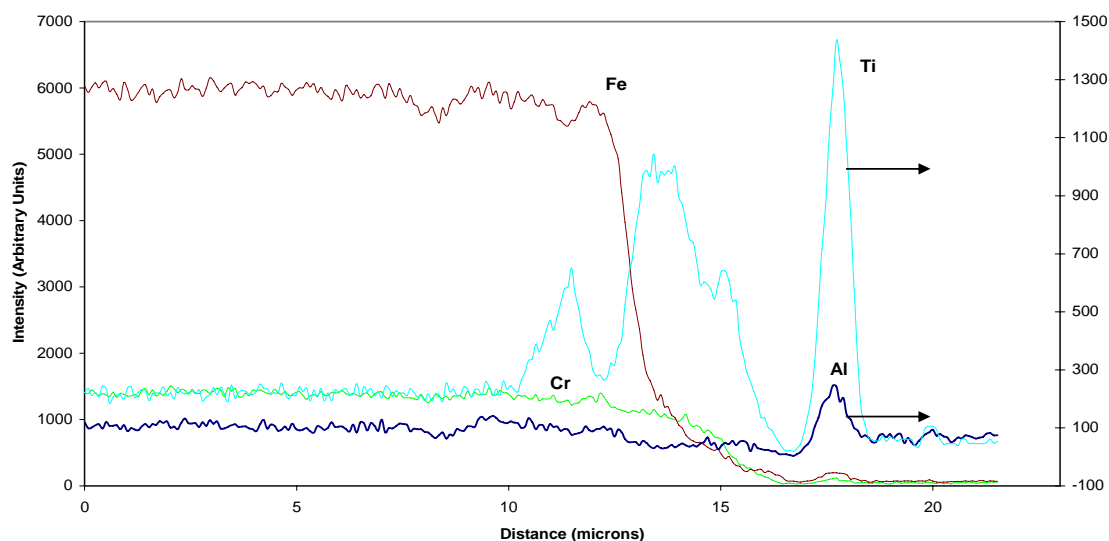


Figure 3. Line Profile of the cross section TiAl and (TiAl)N coated SS409 coupon from Run #77.

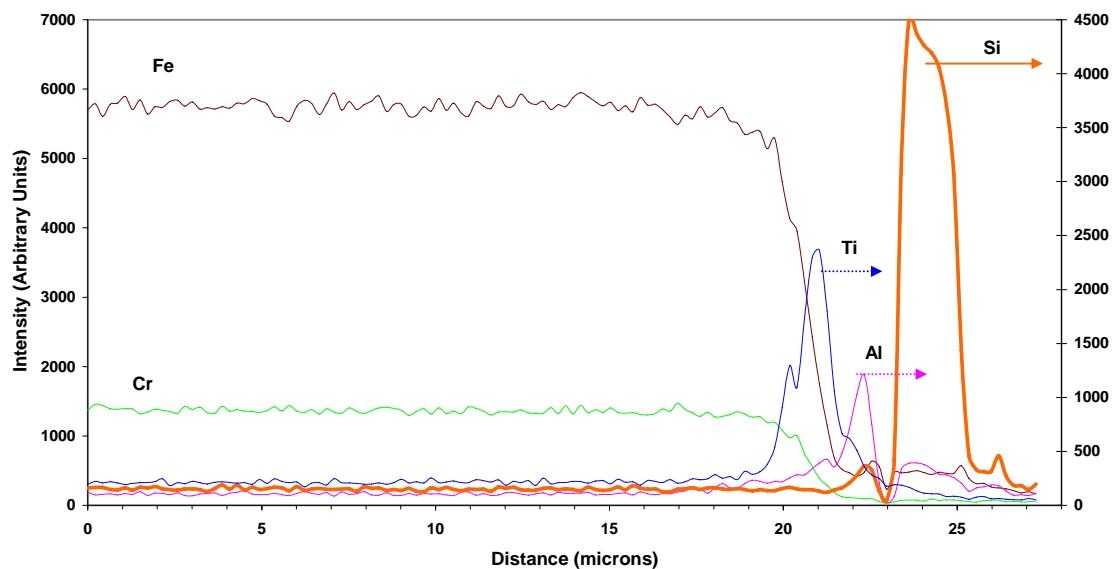


Figure 4. Line Profile of the cross section TiAl and (TiSi)N coated SS409 coupon from Run #86.

## CONCLUSIONS AND FUTURE WORK

Both, TiN and oxidized Cr/Al-Al coatings seem to offer protection against sulfidation corrosion at about 370°C when the substrate steel does not contain Ni or excess amount of carbon. We will test our improved coating procedure with filter samples made from SS409.