Performance of Chromized and Aluminized Carbon Steel Samples in Alkaline Solution

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Introduction

One way to protect carbon steel components in industrial boilers and gasifiers is to coat them with chromia or alumina forming coatings. These coatings are created using pack cementation (or pack diffusion), which is commonly used to coat iron alloys. During the pack cementation process, the metal that is to be coated is placed in a ceramic crucible where it is then packed with the aluminum or chromium powder blend so that the metal part is completely covered and does not touch any of the walls. Then the crucible is sealed using cement. The high temperatures, often between 800^o to 1200^{o}C, cause the chromium or aluminum to diffuse into and alloy with the basis metal.

There is a concern, however, that during boiler shutdown, aqueous alkaline environments (wash water and salts) may come in contact with these coatings while cleaning and potentially affect their future protection of the carbon steel components. The objective of this experiment is to test the performance of different aluminum and chromium coatings on carbon steel in a simulated wash water environment and then select the most corrosion resistant coatings for these applications. The coatings will be created using the previously mentioned “pack cementation” process. The coatings will then be evaluated using two methods: 1) Weight loss over time through direct exposure in the simulated wash water, and 2) Electrochemical tests consisting of polarization resistance and potentiodynamic behavior in the simulated wash water. The electrochemical test is another way to measure the corrosion resistance, except the corrosion rate can be plotted as a function of potential (voltage).

Currently, there is little to no information about aluminum and chromium coating behavior in aqueous alkaline solutions because most of industry manages materials in acidic conditions.

Procedure

First, pieces of SA210 were cut to 0.5”x1.0”. The “pack” powder mix was determined for each coating experiment depending on the percent of metal in the mix from Table 1. Next, the aluminum or chromium powder mix was packed into a ceramic crucible along with the metal specimen and then sealed with cement. The crucible was then placed in the furnace equipped with argon gas at the specified temperature for 8 hours.

Table 1. Experimental definitions and factors

Stamp #	Experiment Type	Pack Composition	Temp (C)
0	Plain, No Coating	-	-
1	Al Coating Exp. 1	5%Al - 2%NH_4Cl - 93%Al_2O_3	900
2	AlCoating Exp. 2	5%Al - 2%NH_4Cl - 93%Al_2O_3	1000
3	Al Coating Exp. 3	3%Al - 2%NH_4Cl - 95%Al_2O_3	900
4	Al Coating Exp. 4	3%Al - 2%NH_4Cl - 95%Al_2O_3	1000
5	Cr Coating Exp. 1	5%Cr - 2%NH_4Cl - 93%Al_2O_3	800

For the exposure tests, two liters of the simulated wash water were formulated for the autoclave; the wash water consisted of 113.73g/L Na_2CO_3, 47.9g/L NaOH, 175.55g/L $Na_2S \cdot 9\,H_2O$, 42.41g/L Na_2SO_4, 4.23g/L Na_2SO_3, and 38.23g/L $Na_2S_2O_3$. The coated specimens and the wash water were placed in the autoclave at 150^{o}C for 5 days. Upon removal, each sample was hand washed with water, sandblasted at a low pressure (less than 15psi), and rinsed in acetone to remove the scale and film that was left during the test. All final weight of samples was recorded and the corrosion rate was calculated using the weight loss over time formula, which includes density and surface area.

For the electrochemical tests, the autoclave was equipped with three electrodes; the metal was the working electrode, platinum was the auxiliary electrode, and molybdenum was the reference electrode. The polarization resistance and potentiodynamic data were recorded using a computer and the Gamry Instruments Framework program. During the entire 5 days, the voltage of the connected metal was measured with respect to the reference electrode and recorded by the Fluke data logger.

Results and Discussion

Exposure Tests:

After calculating the corrosion rate (seen in Table 2) through the weight loss formula, the chromium coating was found to significantly improve the corrosion resistance in the boiler wash water environment. The aluminum coatings did not provide any protection in these conditions; in fact, uncoated carbon steel was more resistant than the aluminized specimens. Two trends existed among the aluminum coatings: 1) As the aluminum content in the pack powder mix increased, the corrosion rate of the Al coating increased and 2) As the temperature of the furnace for coating formation increased, the corrosion rate of the Al coating also increased.

Table 2. Exposure corrosion rate in mils per year

#	Coating Type	Corrosion Rate(mpy)
0	None	228.13
1	Al	934.66
2	Al	1493.80
3	Al	605.45
4	Al	1103.89
5	Cr	0.80

Electrochemical Tests:

From the polarization resistance curves, uncoated carbon steel had a corrosion rate of 14.01 mm/yr, the aluminized sample (AlCE2) had a corrosion rate of 27.41 mm/yr, and the chromized sample had a corrosion rate of 0.45 mm/yr. This clearly shows that the chromium coating offered superior protection in boiler wash water conditions at 150^{o}C, while the aluminum coating provided no protection.

Another polarization curve which illustrates potentiodynamic behavior showed similar results; the corrosion current density for plain carbon steel and aluminized samples was almost two orders of magnitude higher than the chromized sample. The aluminum coating actively corroded, while the uncoated sample tried to form a passive layer but it never stabilized. This is because Al_2O_3, which is formed on the outside of the aluminum coatings, is soluble in high pH solutions; the uncoated metal sample also actively corroded because every time it would form its Fe_2O_3 layer on the outside, the layer would fall off.

Conclusions

The aluminum coatings did not provide any protection in the boiler wash water conditions, while the uncoated carbon steel was more resistant than the aluminized samples. The chromium coating significantly improved the corrosion resistance in the wash water environment and is therefore the best coating for these conditions.