Immersion Characteristic by Organic/Inorganic Hybrid Solution Coating of Austenite Stainless Steel Degraded in 480-720°C

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Keywords: Organic/Inorganic Hybrid Solution, Immersion, Salt Spray Test, Austenite Stainless, Degradation.

Abstract. This study was conducted to investigate the pitting resistance due to degradation of stainless steel (STS310S, STS316L and STS347H). The three types of non-heat treated specimens did not exhibit pitting regardless of whether or not a coating had been applied. In an acidic solution, the non-coated specimen and the OIBD-2 coated specimen of degraded stainless steel had pitting, but the OIBD-1 coated specimen did not have it at all. In an alkaline solution, all of the degraded specimens did not exhibit pitting at all.

Introduction

Despite its excellent corrosion resistance and mechanical properties, stainless steel suffers from pitting that easily destroys the stable passive layer by forming local cells in an environment with halogen ions, such as chloride ions, that result in crevice corrosion and stress corrosion cracking. Many austenitic stainless steels are susceptible to carbide precipitation at elevated temperatures in the range from 500 to 800 °C, at which the carbon content in excess of 0.02% migrates to the grain boundaries of the austenitic structure and reacts with chromium to form chromium carbide. This sensitization phenomenon thus produces intergranular corrosion pits.¹,² In addition, stainless steel can be precipitated with the intermetallic sigma (σ) phase in the range from 600 to 1,000 °C and thus becomes brittle.³,⁴ In particular, the addition of Si and Nb promotes the precipitation of the σ phase, and the austenitic stainless steel becomes brittle at 475 °C⁵ with the addition of Ti and Nb.

The present study investigated the immersion characteristics of austenitic stainless steel that was artificially degraded in the temperature range from 480 to 720 °C. The degradation specimen was coated with two different types of organic/inorganic hybrid coating solutions.

Materials and Experimental Methods

This experiment used sheets of STS310S, STS316L and STS347H steel with a thickness of 5mm (produced by POSCO in South Korea). The as-received materials were degraded with heat treatment for 4 hours at each temperature of 480, 540, 600, 660 and 720 °C and were then cooled down in a furnace. The coating was conducted using bar-coater No. 3 (wet film thickness; 6.86 μm), and the specimens were subjected to heat treatment at 200 °C for 5 minutes and were immediately cooled with water. The thickness of the heat-treated coating layer was of approximately 1.1 μm. After water cooling, the specimens were treated with taping to prevent corrosion at the edges.

An acidic solution was used for the immersion test using a mixture of 6 wt.% of ferric chloride and 1 wt.% of hydrochloric acid, and the alkaline solution consisted of NaOH 6 mol/L. The specimen was observed at 24-hour intervals for 240 hours at room temperature.

The organic/inorganic hybrid coating solutions used OIBD-1 (Urethane 13 wt.% + SiO2 polysilicate 7 wt.% + Melamine curing agent 2 wt.%) and OIBD-2 (Urethane 7 wt.% + SiO2 polysilicate 7 wt.% + Melamine curing agent 5 wt.% + epoxy 6 wt.%), produced by Prepoll Tech.
The ratio of the solid content of the two solutions, which were diluted with distilled water, was 10%. The coating solution was made via hydrolysis with the sol-gel method.

**Results and Discussion**

**Appearance Observation of Immersed Specimens**

The immersion test was carried out for the uncoated, the OIBD-1 coated and OIBD-2 coated specimens. Figure 1 shows the typical results obtained in the acidic solution. This is the immersion result for 0 and 240 hours using heat-treated specimens in 480 °C. The uncoated specimen and the OIBD-2 coated specimens exhibited pitting regardless of the heat treatment temperature. However, the OIBD-1 coated specimen did not have any pitting. This indicates that the OIBD-1 coated specimen had excellent corrosion resistance in an acidic solution.

On the other hand, all uncoated, OIBD-1 coated and OIBD-2 coated specimens did not exhibit pitting in the alkaline solution, and therefore, austenitic stainless steel can be considered to have excellent corrosion resistance in such cases.

![Figure 1. Results after immersion test in acid solution using heat treated specimen at 480 °C, (a) STS310S, (b) STS316L, (c) STS347H.](image)

**Relationship of the Immersion Time and the Pitting Number**

Figure 2–4 show the relationship between the immersion time and the number of pits obtained after 240 hours in an acidic solution.

Figure 2(a), (b), (c) shows the results obtained for STS310S. The uncoated specimens in Figure 2(a) and the OIBD-2 coated specimens in Figure 2(c) did not show pitting at all in the as-received specimen, and the specimen at 540 °C, and the other specimens showed pitting. All OIBD-1 coated specimens, shown in Figure 2(b), did not have pitting.

![Figure 2. Number of pitting according to immersion time of STS310S specimen. (a) Non coating, OIBD-1 coating, (c) OIBD-2 coating.](image)

Figure 3(a), (b), (c) show the results obtained for STS316L. The uncoated specimens in Figure 3(a) and the OIBD-2 coated specimen in Figure 3(c) did not show pitting at all in the as-received specimen and the specimen at 540 °C, and the other specimen showed slight pitting. All OIBD-1 coated specimens in Figure 3(b) did not show pitting at all. Overall, STS316L shows less pitting than STS310S due to its improved corrosion resistance.
Figure 3. Number of pitting according to immersion time of STS316L specimen. (a) Non coating, OIBD-1 coating, (c) OIBD-2 coating.

Figure 4(a), (b), (c) shows the results obtained for STS347H. The uncoated specimens in Figure 4(a) and the OIBD-2 coated specimen of Figure 4(c) did not show pitting at all in the as-received specimen. The specimen at 480 °C showed pitting at 7 to 28 times that of STS310S and STS316L. The uncoated specimen in the other temperatures in Figure 4(a) showed more pitting than the other two kinds of materials. On the other hand, the OIBD-2 coated specimens showed pitting similar to that in the other two types of materials. All OIBD-1 coated specimens in Figure 4(b) did not show pitting.

The corrosion resistance of the OIBD-1 coating solution for all three types of the austenitic stainless steel is excellent. However, the OIBD-2 coating solution has poor performance. In particular, the uncoated specimens and the OIBD-2 coated specimens of STS347H were very bad in terms of their acid resistance.

Figure 5 shows the relationship between the time at which pitting occurs and the heat treatment temperature obtained from the acidic solution. These results show the characteristics of the uncoated specimen and the OIBD-2 coated specimen. Here, the specimens without pitting were shown at the end time of 240 hours. For the uncoated specimen, the time at which pitting occurs for STS347H was the fastest, and those for STS310S and STS316L were similar. At each temperature, the pitting occurred the fastest for the 480 °C specimens. That for 540 °C was the latest, and the rest were similar. The OIBD-2 coated specimens showed a delay in the time at which pitting occurred when compared to the uncoated specimen.

Figure 6 shows the relationship between the pitting counts at 240 hours and the heat treatment temperature. These were obtained from uncoated specimens and from the OIBD-2 coated specimen for the three different kinds of stainless steel in the acidic solution. The uncoated specimen and the OIBD-2 coated specimen for the STS310S and STS316L specimens showed pitting of less than 20 regardless of the heat treatment temperature. However, the uncoated STS347H specimens (heat treatment at 480 °C) showed pitting of 562, the OIBD-2 coated specimen showed pitting of 141. The OIBD-2 coating solution little effect in the pitting prevention of STS347H, but was not as effective as the OIBD-1 coating solution. The uncoated specimens (heat treatment at 540 and 600 °C) showed pitting
also showed much pitting, but pitting was inhibited in the OIBD-2 coated specimens. However STS310S and STS316L (heat treatment at 660 and 720 °C) exhibited pitting of 20 or less.

As such, much of the pitting occurred at a heat treatment of 480 and 600°C, and this resulted in embrittlement due to σ-phase precipitation or sensitization at around 600°C. This is also caused the embrittlement of austenitic stainless steel to be highest at 475 °C.

Conclusions

The uncoated specimen and the OIBD-2 coated specimen showed pitting in the acidic solution. However, the OIBD-1 coated specimen did not show pitting at all. However, the OIBD-2 coated specimen exhibited less pitting than the uncoated specimen. On the other hand, pitting did not occur at all in an alkaline solution. STS347H showed much pitting, and that for STS310S and STS316L was similar. Much pitting occurred in the temperature range at which sensitization occurred, including σ phase precipitation and embrittlement at 475 °C. Pitting was inhibited by the organic components and Si in the organic/inorganic hybrid coating solution.

Acknowledgement

This work (Grants No. C0268714) was supported by Business for Academic-industrial Cooperative establishments funded Korea Small and Medium Business Administration in 2015.

References