

Corrosion behavior of Cold-Spray Ni and Ti Coatings for Spent Fuel Storage System

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1. Introduction

As carbon-neutrality goals expand, nuclear power is increasingly valued as a low-carbon energy source. A key challenge, however, is managing spent nuclear fuel. While deep geological disposal is a long-term option, most countries still rely on interim wet and dry storage, and wet pools are nearing capacity. Dry cask systems have proven structurally resilient in extreme events (e.g., Fukushima Daichi Accident) but remain vulnerable to long-term degradation in coastal, salt-laden atmospheres. In humid conditions, deposited salts can form brine on canister surfaces and trigger stress corrosion cracking (SCC) in stainless steel. Because SCC requires tensile stress, a corrosive environment, and a susceptible material, the welded regions are particularly at risk [1].

Cold spray deposits metallic coatings at low temperatures, minimizing oxidation and avoiding phase transformations, while also introducing compressive residual stress. Together with the coating's barrier effect against chloride ingress, these features can reduce SCC susceptibility and improve the long-term integrity and corrosion resistance of dry cask storage canisters.

A wide range of powders can be applied by cold spray. In this study, Ni and Ti were selected because their corrosion resistance and minimal galvanic corrosion concern with SS304, the canister substrate. The goal is to compare these two candidates and support coating material selection.

2. Methods and Results

This section first outlines the specimen and coating preparation procedures, then presents results comparing the corrosion resistance of the deposited materials.

2.1. Substrate Material

Square, flat stainless steel (SS) 304 substrates (150 mm × 30 mm × 3 mm) were heat-treated in air at 650 °C for 48 h to reproduce the sensitized microstructure typically found near welds in dry cask storage canisters.

2.2 Coating Preparation

Ni and Ti coatings were deposited using a commercial cold spray system equipped with an industrial robot, a converging-diverging nozzle, a gas preheater, and a powder feeder, with nitrogen used as the propellant gas.

Other deposition parameters, including spraying distance, nozzle transverse speed, feed rate, and spray angle, were maintained constant throughout the process. Key coating parameters are summarized in Table. 1.

Table.1. Cold Spray coating parameters.

Parameters	Condition
Base material	Sensitized SS304
Coating material	Ni / Ti
Temperature [°C]	1,000
Pressure [bar]	50
Stand-off distance [mm]	30
Step distance [mm]	1
Powder feed rate [rpm]	3
Traverse speed [mm/s]	500
Pass number [layer]	1

2.3. ASTM G48 FeCl₃ pitting corrosion test

Pitting corrosion resistance was evaluated by ferric chloride (FeCl₃) immersion testing following ASTM G48. Sensitized and cold-sprayed specimens were sectioned into 15 mm diameter disks by wire-cut EDM, then polished, rinsed, and dried. To suppress crevice corrosion, each disk was coated with a corrosion-resistant paint, leaving an exposed area of ~0.5 cm². The tested specimens are listed in Table 2.

Table.2. Type of samples used in each group.

Type of samples				
Sensitized SS304	Non-polished Ni coating (NP-Ni)	Non-polished Ti coating (NP-Ti)	Polished Ni coating (P-Ni)	Polished Ti coating (P-Ti)

The specimens were then immersed in a 6 wt.% ferric chloride solution at 22 °C for 72 h. After testing, the samples were rinsed with deionized water and dried with air. Optical microscopy (OM) images were subsequently acquired to examine the morphology of the corrosion damage in detail.

2.4. Microstructural characterization

The samples before and after corrosion tests were sectioned, mounted, ground, and polished. Microstructural characterization was performed using optical microscopy (OM; BX53M, Olympus, Japan) and JSM-7100F Scanning Electron Microscope (SEM, JEOL, Japan).

As shown in Fig. 1, the coating shows a dense microstructure with no obvious gaps or delamination at the coating-substrate interface and between adjacent splats, suggesting intimate interfacial contact formed by the severe plastic deformation of particles upon impact [2]. No significant cracks were observed at the interface or across the coating thickness.

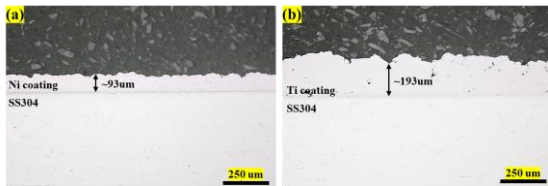


Fig. 1. Cross-sectional OM image of as-deposited cold spray coated samples: (a) Ni coating (b) Ti coating on sensitized SS304 substrate.

Fig. 2 presents OM images before FeCl_3 exposure. The polished specimens (Fig. 2a-c) show visible SiC grinding scratches but are substantially smoother than the as-deposited coatings (Fig. 2d-e), whose higher roughness arises from the deposited particles.

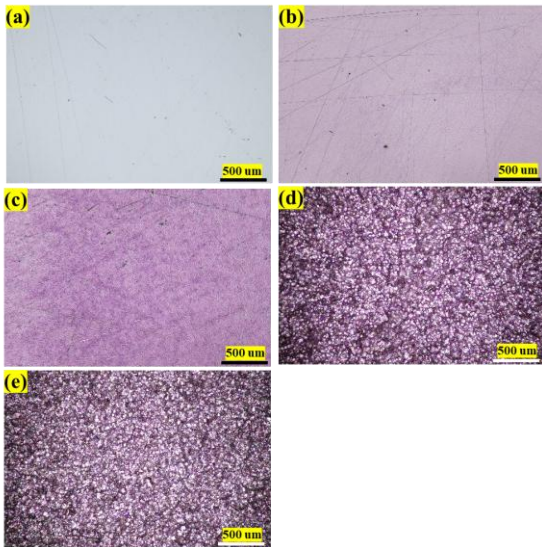


Fig. 2. OM image of the samples before corrosion test. (a) SS304 (b) P-Ni (c) P-Ti (d) NP-Ni (e) NP-Ti before FeCl_3 corrosion test.

Fig. 3 shows OM images after FeCl_3 exposure. The uncoated sample (Fig. 3a) exhibits numerous surface defects and pitting, indicating extensive corrosion. The Ni-coated sample (Fig. 3b) shows pronounced corrosion, particularly along a network that appears to follow particle-particle boundaries, consistent with prior reports [3]. In contrast, the Ti-coated sample (Fig. 3c) shows few corrosion features, with polishing scratches being more prominent. For the as-deposited surfaces (Fig. 3d-e), the high initial roughness obscures clear identification of

corrosion-related damage.

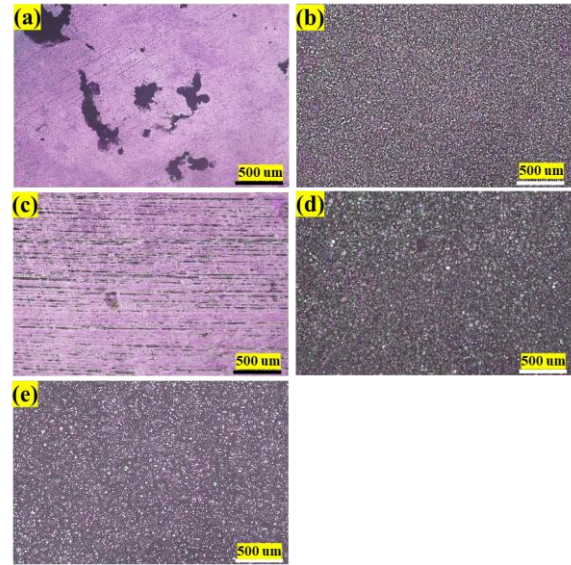


Fig. 3. OM images of the (a) SS304, (b) P-Ni, (c) P-Ti, (d) NP-Ni and (e) NP-Ti samples after FeCl_3 corrosion test.

To better assess corrosion-induced surface degradation, SEM was performed on the polished Ni (P-Ni) and Ti (P-Ti) specimens, since the high roughness of the Non-Polished samples hindered OM-based characterization. The P-Ni surface (Fig. 4a) shows severe damage, with preferential attack along particle-particle boundaries, which is discussed further in the future analysis. In contrast, the P-Ti surface (Fig. 4b) exhibits little to no corrosion damage, aside from minor staining and polishing scratches.

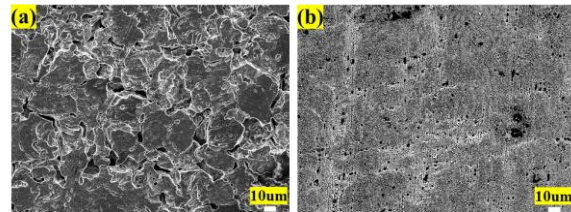


Fig. 4. Surface SEM images for both polished Ni and Ti coating sample after corrosion test.

Cross-sectional OM was used to evaluate corrosion effects on coating adhesion. In Fig. 5a, extensive debonding is observed, likely caused by FeCl_3 ingress along particle boundaries that eventually reached the substrate. In contrast, Fig. 5b shows that the Ti coating remained well adhered after exposure, with no clear evidence of solution penetration or interfacial debonding, indicating that the Ti coating largely preserved its integrity.

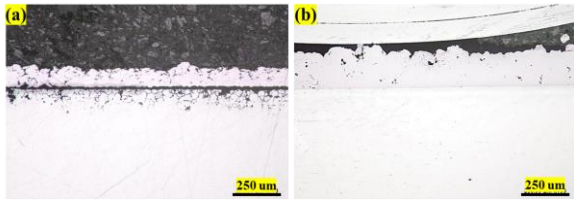


Fig.5. Cross-sectional OM images for Non-Polished Ni and Ti coating after FeCl_3 corrosion test.

3. Conclusions

In this study, the pitting corrosion behavior of cold sprayed Ti and Ni coatings was evaluated using an FeCl_3 immersion test. The uncoated SS304 substrate developed extensive pits and surface defects after exposure to the aggressive solution. Notably, the polished Ni coated sample showed clear corrosion-induced damage, while the polished Ti coated sample exhibited little to no such defects. For the as-deposited coatings, the inherently high surface roughness obscured corrosion features in surface observations. However, it can be concluded that overall, the Ti coating appears to be more promising candidate for corrosion protection of interim spent fuel storage canisters.

Future work will focus on long-term corrosion testing under mechanical loading to better simulate SCC conditions. These tests are expected to clarify both the relative performance of Ni and Ti coatings and the mechanisms governing SCC initiation and growth, enabling more informed material selection for spent nuclear fuel canisters.

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