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Short-Term Corrosion Characteristics of Molten Salt Reactor Materials and Cladding

Ji-Hyun Yoon [a*], Giseung Shin [a], Chaewon Kim [a], Hyeon-Geun Lee [a], Chang Hwa Lee [a], Jeoung Han Kim [b]
[a]*Korea Atomic Energy Research Institute 111, Daedeok-Daero 989, Yuseong-Gu, Daejeon, Korea*
[b]*Hanbat National University 125, Dongseo-daero, Yuseong-Gu, Daejeon, Korea*
[*]*Corresponding author: jhyoon4@kaeri.re.kr*

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1. Introduction

In the design of Molten Salt Reactors (MSRs), ensuring the integrity of structural materials plays a crucial role in guaranteeing the safety and longevity of the reactor, especially in the harsh operating environment of high-temperature corrosive molten salts [1]. To address issues caused by corrosive salts, research has been initiated at advanced research institutions abroad to enhance corrosion resistance, wear resistance, and high-temperature oxidation resistance by effectively coating the surfaces of structural materials with corrosion-resistant materials [2].

Various chemical and physical methods exist for these coating technologies, but, in terms of technological maturity, overlay by welding and laser cladding, which involves depositing corrosion-resistant metals on the surface of base material, are prominent. Currently, Type 316H stainless steel is considered a promising candidate material for MSRs, with nickel (Ni) being evaluated as a suitable coating material. However, research results on the corrosion characteristics of structural and coating materials in high-temperature molten salts are limited, especially in chloride salts [3].

In this study, specimens were machined from Type 316H stainless steel, Hastelloy N, Alloy 617, Inconel 625, and coating materials such as Ni-201, Ni overlay welded cladding, Corrosion immersion tests were conducted in a molten salt environment of 57 mol% NaCl–43 mol% $MgCl_2$ at 650ºC for 502 hours.

2. Experimental

2.1 Materials

To evaluated the corrosion characteristics in the high-temperature molten salt environment of candidate materials for MSRs and corrosion-resistant coatings, specimens were machined from five materials and claddings, as listed in the Table 1.

Ni cladding on Type 316H stainless steel substrate was performed using two methods: gas tungsten arc (GTA) welding and directed energy deposition (DED) laser cladding. Figures 1(a) and (b) in Fig. 1 illustrate cross-sections of test blocks with nickel onto Type 316H stainless steel through GTA welding and laser cladding, respectively.

Table 1. Chemistry of Type 316H stainless steel (in wt%)

wt%	Ni	Fe	Cr	Mo	Co	C
Type 316H	10.29	bal.	16.82	2.12	-	0.049
Incoloy 800H	30.18	bal.	20.43	-	-	0.07
Hastellloy N	bal.	3.66	7.66	16.0	0.25	0.072
Alloy 617	bal.	1.26	22.20	9.52	12.30	0.090
Inconel 625	bal.	3.87	21.53	8.94	0.1	0.02
Ni-201	bal.	0.40	-	-	-	0.02
Ni-weld*	bal.	1.0	-	-	-	0.15
Ni-laser	bal.	-	-	-	-	0.02

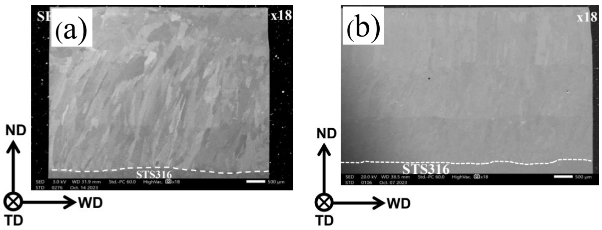

Fig. 1. Cross-section of Ni-cladded Type 316H stainless steel blocks; (a) GTA weld cladding, (b) DED laser cladding.

2.2 Corrosion Testing

The specimens were subjected to immersion corrosion tests in 57 mol% NaCl–43 mol% $MgCl_2$ at 650ºC for 502 hours. Prior to the test, a mixed salt was heated at 300ºC for 24 hours, followed by a descaling process at 600ºC using Mg for 48 hours to eliminate O_2 and H_2O. During the test, O_2 levels was maintained with below 20 ppm and H_2O levels below 2 ppm. A cylindrical Al_2O_3 crucible was inserted into a furnace, as depicted in the Fig. 2. The specimens were passed through using stainless steel hangers and inserted into the furnace. To prevent galvanic corrosion between the specimens and the hangers, Al_2O_3 insulators were inserted in between.

Fig. 2. Test rigs for immersion corrosion testing in molten salt.

3. Results and Discussion

3.1 Compositional Changes in Cladding Layer

The changes in chromium (Cr) contents of the GTA welding cladded layer and laser cladded layers according to the distance from the interface of substrate and clads were shown in Fig. 3.

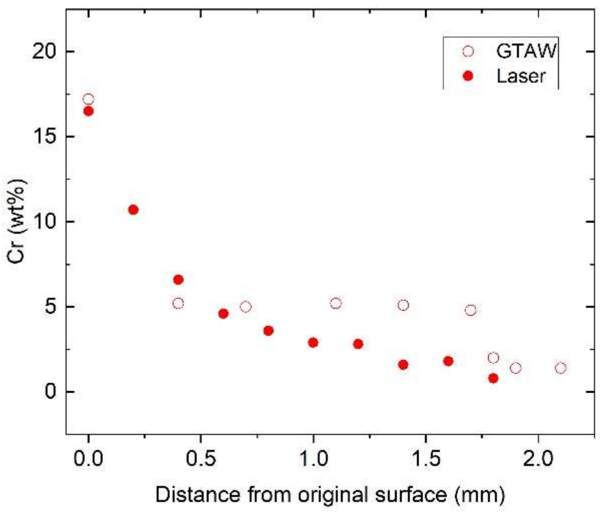

Fig. 3. Comparison of Cr content profiles in clad layer formed by GTA welding and clad layer formed by laser deposition.

The clad layer produced by laser deposition exhibited a more continuous decrease in Cr content with distance from the interface comparing to clad layer formed by GTA welding.

3.2 Corrosion Resistance

The overall corrosion resistance of both Ni and Ni-based alloys was higher than that of Type 316H stainless steel or Incoloy 800H alloy as shown in Fig. 4. The corrosion resistance followed the order of pure Ni, Ni-based alloys, and Type 316H stainless steel.

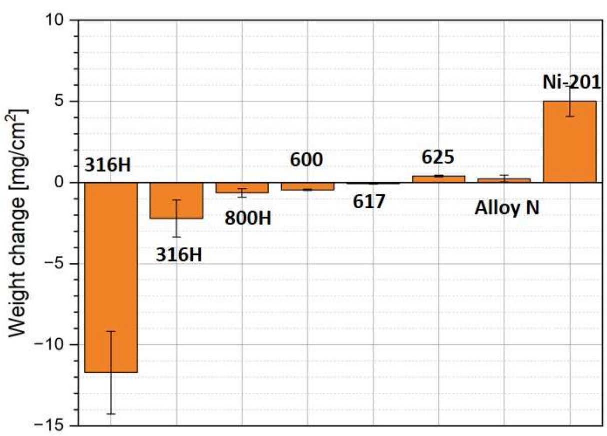

Fig. 4. Results of immersion corrosion testing for 502 hours in molten salt (57% NaCl–43% $MgCl_2$) at 650°C.

Fig. 5. Illustrates the comparative corrosion characteristics base on the position of Ni clad layer.

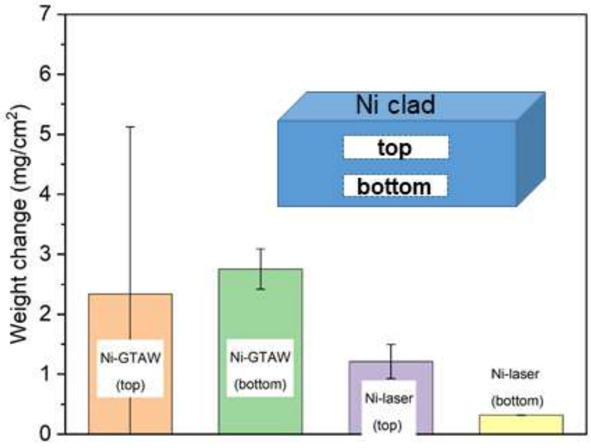

Fig. 5. Comparison of corrosion characteristics based on the position of Ni clad layer.

The overall corrosion was to be minimal to the extent that weight loss was negligible in almost all specimens while there were some differences.

4. Summary

The corrosion immersion testing was conducted for 502 hours at 650°C in 57 mol% NaCl – 43 mol% $MgCl_2$ molten salt for nine materials, including clad layers deposited on Type 316H stainless steel using laser and GTA welding processes. The overall corrosion resistance on Ni and Ni-based alloy was found to be higher than that of Type 316H stainless steel or Incoloy 800H alloy.

ACKNOWLEDGEMENT

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