Characteristics of Ni Cladded Type 316H Stainless Steel for Molten Salt Reactor Application

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1. Introduction

Molten salt reactors (MSRs) have garnered significant attention as promising avenue for next-generation nuclear power technology due to their inherent safety features, efficient fuel utilization, and potential for reducing long-lived radioactive waste. In MSR designs, structural materials play a pivotal role in ensuring the integrity and longevity of the reactor system, especially in the challenging environment of high temperature molten salts. Among the various materials under consideration, Type 316H stainless steel has emerged as a strong candidate for MSR components due to its adequate corrosion resistance and high temperature mechanical properties [1]. However, to further enhance its performance and durability in aggressive MSR conditions, innovative strategies such as cladding with nickel (Ni) has been explored [2].

Representative methods of cladding Ni to austenitic stainless steel include overlay welding and laser cladding. Although many of these methods have already been developed industrially, a close examination of the characteristics of the cladding and clad/substrate interface should be made considering the use in the extreme environment of corrosive salt at a high temperature of 650°C or higher [3].

In this preliminary study, the microstructural analysis of the cladding material on Type 316H stainless steel by overlay welding and laser direct energy deposition (DED) cladding and evaluation of interface integrity were performed.

2. Experimental

2.1 Materials

Stainless steel plates with a thickness of 25 mm were used as the base material. The plate was solution annealed at 1040°C or above and hot rolled. The chemistry of the base material was listed in Table 1.

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

C	Si	Mn	P	S
0.049	0.57	0.59	0.027	0.002
Cr	Ni	Mo	N	Cu
16.82	10.62	2.12	0.023	0.22

The ERNi-1 (SFA-5.14) welding rods containing ~0.15 wt% carbon and ~ 3.5 wt% Ti were used for the overlay weld cladding on Type 316H stainless steel plate.

Ni-200/201 grade pure Ni powder containing less than 0.05 wt% carbon from Hoganas was used for laser direct energy deposition. More than 85% of the particle size of the powder was 45-90 ㎛.

2.2 Ni Cladding on Type 316H Stainless Steel

ERNi-1 (SFA-5.14) welding rods were deposited on a Type 316H stainless steel plate by gas tungsten arc welding (GTAW) to a thickness of about 6 mm. The weld layer was milled to 2 mm thick as shown in Fig. 1.

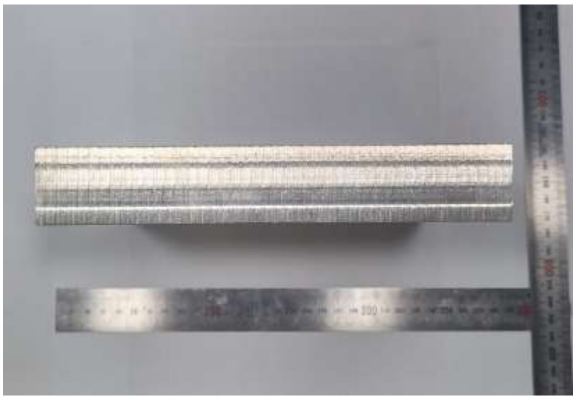

Fig. 1. Side view of Ni-cladded Type 316H stainless steel after milling.

Another plate was cladded through the laser DED technique.

2.3 Microstructural Examinations

Changes in chemical composition as a function of distance for the fusion line were analyzed by using scanning electron microscopy (SEM) in conjunction with energy dispersive system (EDS). The grain boundary structure adjacent to interface between the base material and the cladding layer was obtained through electron backscattered diffraction (EBSD).

2.4 Adhesion Evaluation of Cladding

Ultrasonic inspection according to ASME Sec. V. Art.4 / ASTM A578 (Level C) was conducted for inspecting cladding layer defects. The side bending tests were performed to confirm the bonding integrity of the cladding layer according to ASTM QW-466.1 standard practice.

3. Results and Discussion

3.1 Compositional Changes in Cladding Layer

The change in chemical composition of the overlay cladding layer according to the distance from the interface of substrate and clad was shown in Fig. 2. at 1040°C or above and hot rolled. The chemistry of the base material was listed in Table 1.

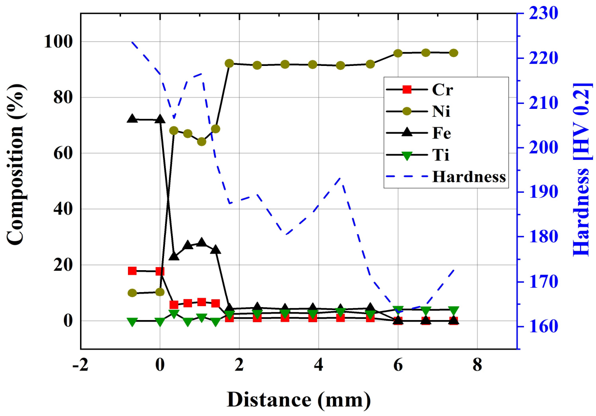

Fig. 2 Compositional change in Ni cladding layer as a function of the distance from the substrate/clad interface.

It was found that the mixed zone of the Ni-deposited layer was ranged 0.3-1.4 mm which containing about 6 wt% Cr. In the cladding layer after 1.4 mm, the Cr content was lowered below 1 wt%. It is known that the alloy containing more 7wt% is sensitive to corrosion in high-temperature molten salts due to Cr dissolution. Analysis of Ni-clad by laser DED is currently in process.

3. 2 Integrity of Clad

As a result of the penetrant test and ultrasonic inspection test for the clad, no defects that did not satisfy the criteria were observed. No separation between the clad and substrate was optically observed as shown in Fig. 3 as a result of side bending test.

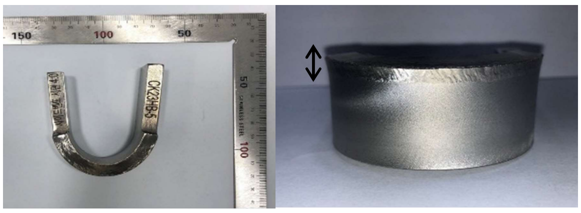

Fig. 3 Side bending tested Ni-Cladded Type 316 stainless steel.

3. Summary

Type 316 stainless steel plate for the application to structural material of MSR was cladded Ni via overlay welding and laser DED technique. The compositional change in clad as a function of distance from the fusion line.

It was found that Ni was cladded on Type 316H soundly.

REFERENCES

[1] G. Zheng, Kumar Sridharan, Corrosion of Structural Alloys in High-Temperature Molten Fluoride Salts for Applications in Molten Salt Reactors, JOM, Vol.70, p. 1535-1541, 2018.
[2] B. Barua et al., Design rules for 316H Nuclear Components Cladded with Nickel or Tungsten, ANL Report ANL 21-11, 2021.
[3] P. Cavaliere, Laser Cladding of Metals, Springer Cham, Swizerland, 2021.