Corrosion performance of laser-wire-directed energy deposited austenitic stainless steel claddings in marine environments

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Introduction

- Carbon steel has adequate mechanical strength for structural applications but readily corrodes in marine environments.
- Stainless steel (SS) claddings are a suitable coating method for marine structures because of their strong metallurgical bonding and corrosion resistance [1].
- Here, we clad austenitic 309L SS on low carbon steel and examine its corrosion behavior in a salt spray environment, mimicking offshore energy applications.

Experimental

- Laser-wire-directed energy deposition, a low heat input additive manufacturing technique was used to clad 309L SS on low carbon steel substrates [2].
- SS cladding, wrought 304 SS, and carbon steel specimens were exposed to a 35 °C 5 wt% NaCl salt spray environment from 3 hours up to 30 days. Three samples were exposed per alloy / time.
- After exposure, samples were first cleaned by ultrasonicating in DI water and isopropyl alcohol. The second and third cleanings used light scrubbing to remove well-adhered corrosion products [3].
- Corrosion rate (CR) was calculated using ASTM G1 [3] and compared with prior room temperature 3.5 wt% NaCl immersion environment data [1].

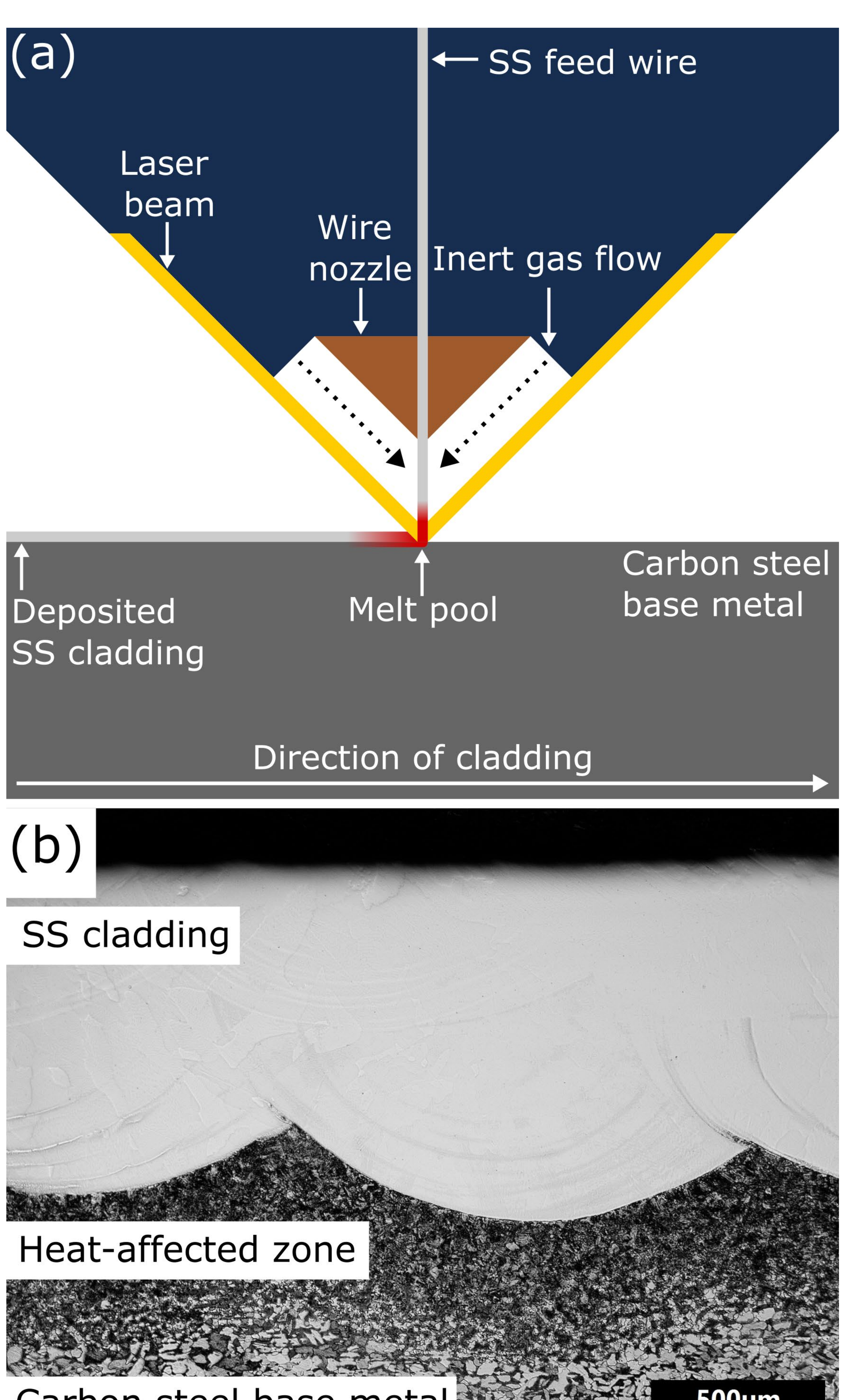

Fig. 1: (a) Schematic of laser-wire-directed energy deposition process [2], (b) Cross-section of SS cladding-carbon steel interface

Results

- The carbon steel specimens form heavy corrosion products after only 3 hr, which thicken with longer exposure times (Fig. 2a-c). Hard-clinging corrosion products caused high variation in the CR measurement after the first cleaning; after 30 days, some carbon steel samples had corroded through, which also increased error (Table 1, Fig. 3a).
- The 304 SS (18Cr-8Ni) contains small pits after 3 hr, which grows into a hard-clinging and semi-uniform scale (Fig 2d-f).
- The 309L SS cladding (23Cr-12Ni) only contains small pits after 3 days. Some larger uneven corrosion products are visible after 30 days, but much of the ground surface is visibly untouched (Fig 2g-i).

Discussion

- Corrosion rates are ~8-10x higher in the 5 wt% NaCl salt spray test compared to the 3.5 wt% immersion test due to the elevated temperature and salt concentration (Table 1), consistent with Montgomery et al. [5].
- The SS cladding's CR is 56 % less than the 304 SS and 99.8 % lower than the carbon steel.
- We attribute this high corrosion resistance to the cladding's higher Cr content, which can be tuned to meet performance demands with minimal cost increase compared to fabricating structural components out of bulk SS alloys.

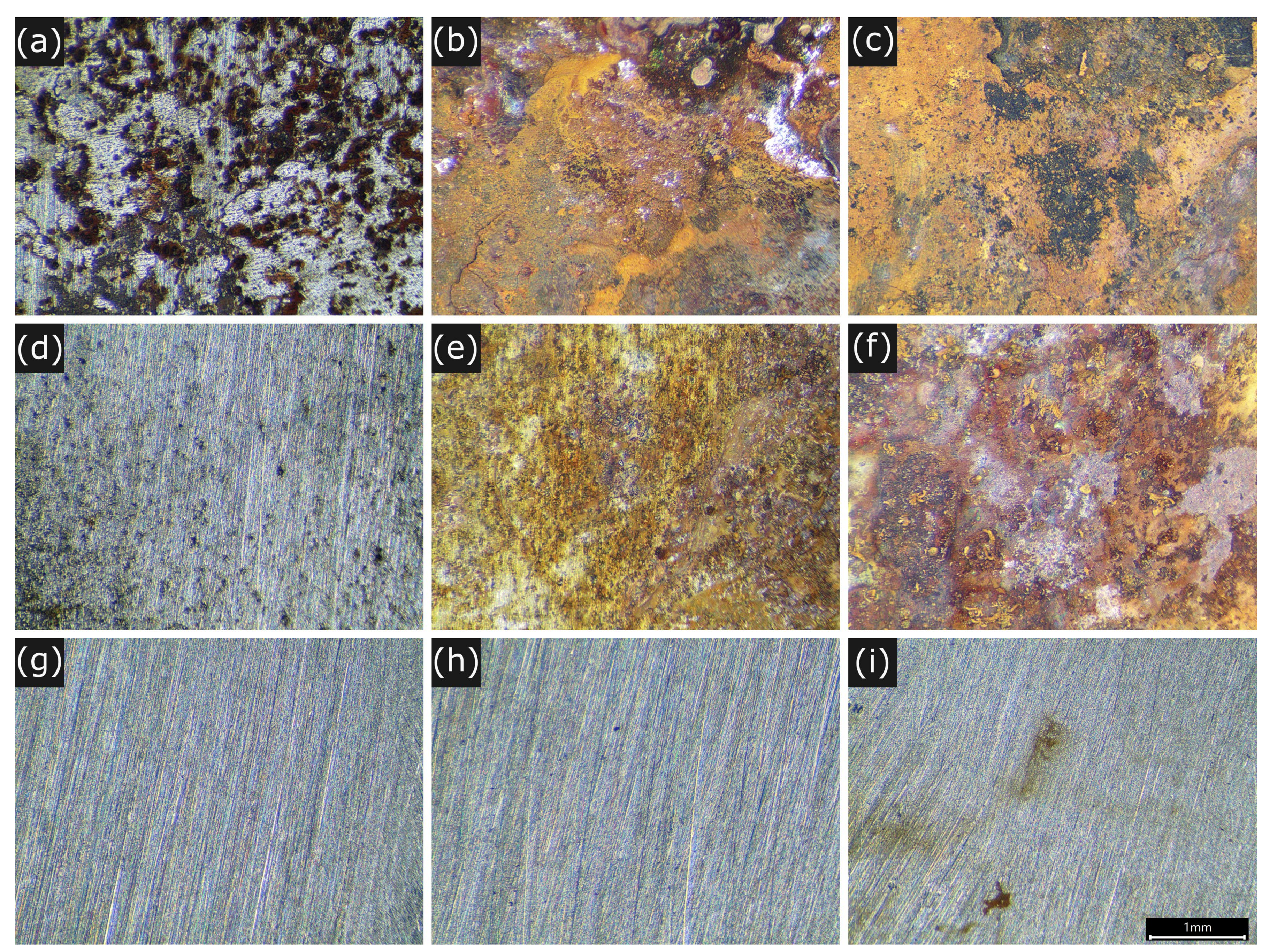

Fig. 2: Optical images of corroded surfaces after exposure (a) - (c) Carbon steel, (d) - (f) 304 SS, and (g) - (i) SS cladding. (a), (d), and (g) 3 hr, (b), (e), (h) 3 days, and (c), (f), and (i) 30-day exposure

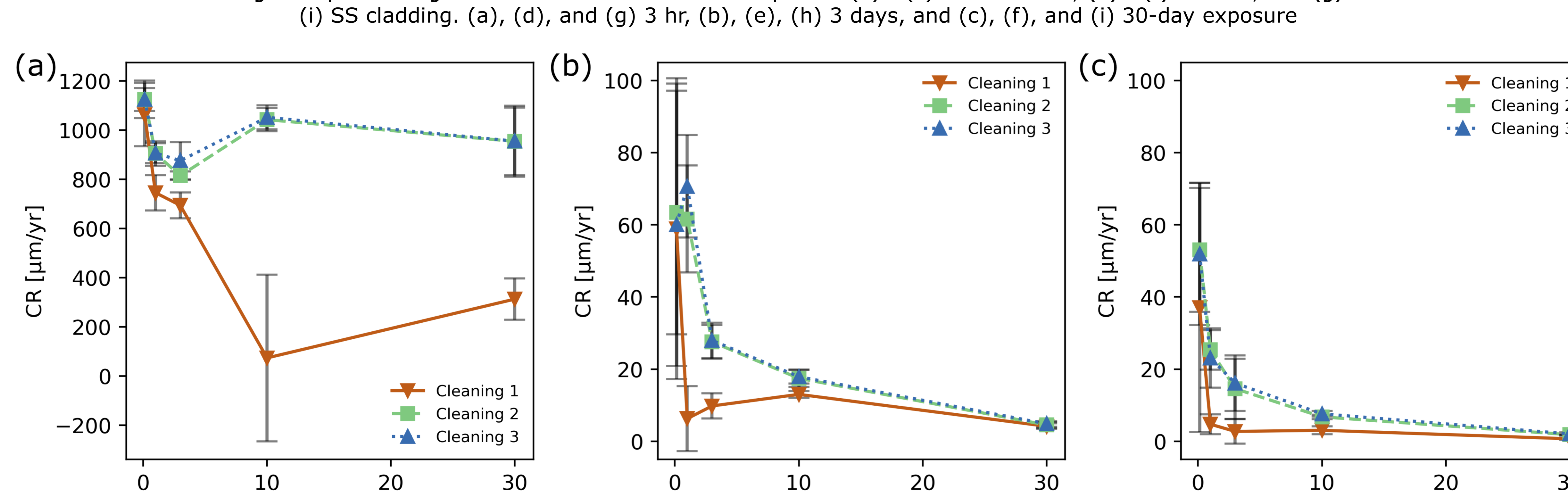

Fig. 3: Calculated corrosion rates for (a) Carbon steel, (b) 304 SS, (c) SS cladding

Table 1: Corrosion rate comparison [μm/yr]. 3.5 wt.% NaCl immersion corrosion rates were calculated using linear polarization resistance following ASTM G102 [4] in ref. [1]

Testing	NaCl concentration	Temperature [°C]	Carbon steel	304 SS	SS cladding
Salt spray (this work)	5 wt.%	35	1051 ± 49	4.8 ± 0.8	2.1 ± 0.4
Immersion [1]	3.5 wt.%	20	126 ± 8	0.55 ± 0.11	0.22 ± 0.13
	Ratio		8.34	8.73	9.55

[1] S. C. Bozeman, J. D. Tucker, and O. B. Isgor, "Corrosion resistance of 309L stainless steel claddings on carbon steel produced with wire-fed directed energy deposition," *Corrosion*, vol. 79, no. 7, pp. 771–781, 2023.
[2] S. C. Bozeman, O. B. Isgor, and J. D. Tucker, "Effects of processing conditions on the solidification and heat-affected zone of 309L stainless steel claddings on carbon steel using wire-directed energy deposition," *Surface and Coatings Technology*, vol. 444, no. 128698, p. 11, 2022.
[3] ASTM G1 – 03 (2017) Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
[4] ASTM G102 – 80 (2015) Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements
[5] E. L. Montgomery, L. Marina Calle, A. C. Jerome Curran, and M. R. Kolody, "Timescale Correlation between Marine Atmospheric Exposure and Accelerated Corrosion Testing," in Corrosion 2011, 2011, pp. 1–15.

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