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Microstructural Analysis of Additively Manufactured Corrosion Resistant Duplex Stainless Steel Clads on Carbon Steel Substrate

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The low carbon steel finds extensive applications due to high strength to cost ratio; however, due to its low corrosion resistance, its service life is significantly reduced. On the contrary, the super duplex stainless steels (SDSS) manifests superior pitting corrosion resistance (PREN >40)[1] in chloride containing environments resulting in excellent service life. However, high SDSS cost limits its applicability. Cladding corrosion resistant SDSS on low carbon steel (LCS) substrate is a plausible solution to reduce the material costs while maintaining the performance level and the service life of the component. In this research, additive manufacturing technique; powder bed fusion- selective laser melting (PBF-SLM) was used to clad SDSS on LCS substrate. This study investigates the metallurgical aspects of the PBF-SLM clads using the elemental area and line mapping modes of scanning electron microscopy- energy dispersive x-ray spectroscopy (SEM-EDS).

In this study, the LCS substrate was used in plate form (3 x 3 x 1/8 in^3) (Fig.1b) and Sandvik's gas atomized SDSS powder feedstock [15-45 µm (D_{50}=30 µm)] (Fig. 1c) was used as a cladding material. Energy density (Fig. 1a) is the governing parameter for the clads. For all clads, PBF-SLM parameters such as a laser power (P) of 200 W, hatch spacing (h=30 µm), hatch orientation (90^o), powder layer thickness (d=50 µm), and total thickness (T=500 µm) were maintained constant, and all clads were produced at a laser scan speed ranging from 100-1000 mm/s, resulting in volumetric energy density (VED: J/mm^3) in the range of 133-1333 J/mm^3.

After laser melting, the samples were prepared for EDS analysis using metallographic preparation methods. The EDS line scans and area mapping were performed across the clad-substrate (SDSS-LCS) interface for elemental analysis and area maps (Fig. 2a) show the contrast observed due to atomic weight difference for Cr, Ni, and Fe elements. This contrast is due to the difference of the elemental atomic weight in Cr, Ni-rich SDSS clad layer and Cr, Ni-deficient LCS substrate. Furthermore, the back scattered emission (BSE) imaging mode of SEM was used to investigate the clad thickness measurements. It was observed that increasing energy density had a positive impact of the clad thicknesses. The maximum average clad thickness of 65.8 µm was achieved at the highest VED of 1333 J/mm^3, whereas the lowest VED of 133 J/mm^3 resulted in the thinnest clads.

Figure 2(b) illustrates the EDS line scans for Cr content in SDSS clads at different energy density. It was observed that the clads had lower chromium content than the feedstock powder (~25 wt. %) due to evaporative losses experienced during laser melting process. Furthermore, at a higher energy density of 1333 J/mm^3, the Cr content in the clad dropped to about 13 wt.%, and increasingly higher Cr contents were measured in clads region with decreasing energy density, e.g., at E=133 J/mm^3, clad showed Cr content of ~24.8 wt. % which was very close to the SDSS feedstock powder composition. Albeit the Cr losses, the clads had adequate chromium contents in the range of 13-15%, which is necessary for good corrosion resistance. Previous studies [2] noted that, depending on the laser power and scan speeds, the localized melt pool temperatures could reach as high as ~7000 K. Since these local melt pool temperatures were well above the vaporization temperatures of iron (3134 K), and chromium (2944 K), the Fe and Cr metal loses were experienced due to evaporation [3]. Furthermore, the Cr losses were more dominant at the highest energy density due to higher melt pool temperatures resulting due to larger laser-dwell times. Irrespective of increasing chromium content, fig. 2(d) shows increasing corrosion rate with decreasing energy density, and this could be attributed to various factors such as decreasing grain size, increasing defects in the clads with decreasing energy density and typically higher defects results in increased corrosion rates. This study uses SEM-EDS to study the compositional variation in SDSS clads resulting due to change in PBF-SLM process parameters, and establishes a correlation between the corrosion resistance of the clad and PBF-SLM energy density.

References:
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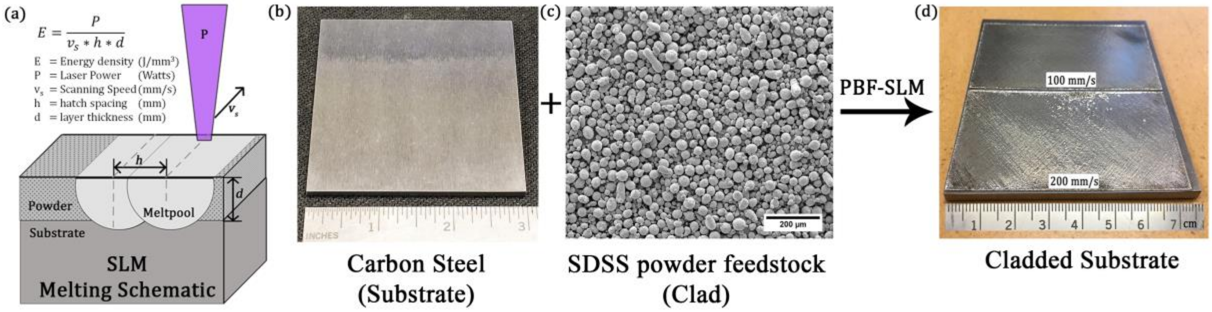

Figure 1. (a) PBF-SLM melting schematic (b)LCS substrate (c) SDSS clad powder (d) SDSS cladded LCS substrate

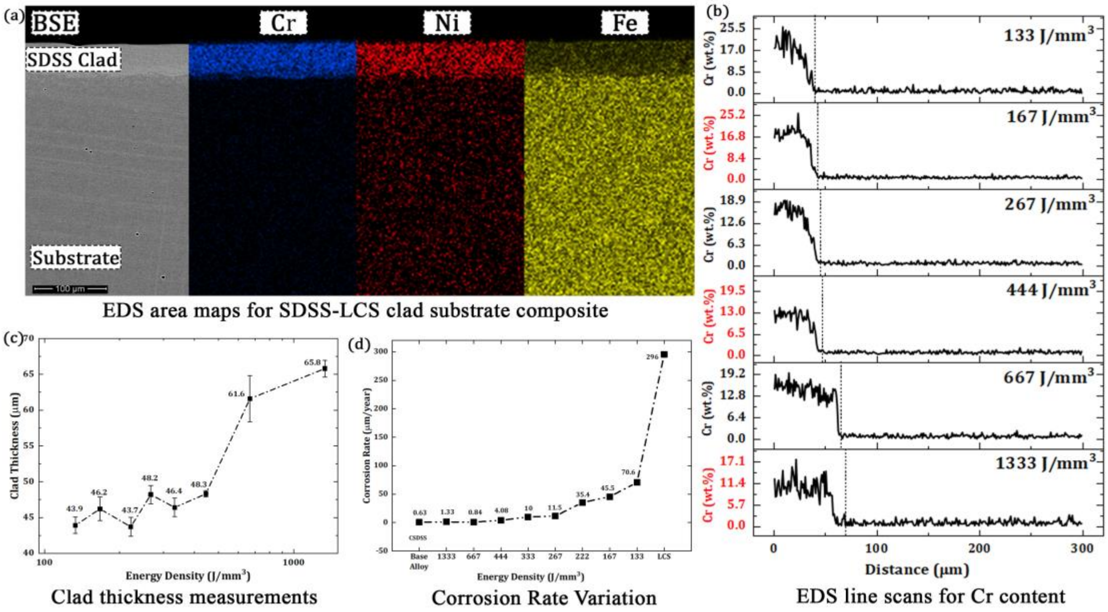

Figure 2. (a) EDS compositional area maps at clad-substrate interface (b) EDS line scans (c) clad thickness variation (d) corrosion rate variation