Abstract

This research develops an integrated sustainable route for producing and processing UNS S32760 super duplex stainless steel by Powder Bed Fusion - Laser Beam / Metal (PBF-LB/M), starting from gas-atomized powders produced from industrial waste. The originality of the work lies in the continuity of the investigated chain, from close-coupled gas atomization modelling and optimization to powder design, PBF-LB/M processing, heat treatment, mechanical and corrosion qualification testing.

Vacuum induction melting gas atomization was first investigated by CFD simulations and experimental trials to identify conditions suitable for maximizing the yield in the 20–63 μm particle-size range required for PBF-LB/M. The effect of inert gas pressure was correlated with jet morphology, atomization stability, particle size distribution, debris formation, and gas consumption. This approach enabled the selection of an optimized atomization condition and a physically grounded validation of the process window. In parallel, a carbon footprint evaluation quantified the environmental implications of converting UNS S32760 waste into additive manufacturing powder, highlighting the potential of a waste-to-powder strategy to reduce production impact.

The influence of process gas composition, specifically argon and nitrogen, on atomized UNS S32760 powder properties was then examined. Different combinations of melting-chamber atmosphere and atomizing gas were assessed in terms of particle size distribution, morphology, true density, light element content, nitrogen uptake, and ferrite-austenite phase balance. Nitrogen, when used as the melting-chamber atmosphere, increased the nitrogen content of the alloy, promoted a higher austenite fraction in the powders, and reduced intraparticle porosity compared with argon-based conditions. These results show that process gas selection is not only a fluid-dynamic variable, but also a metallurgical tool for tailoring the chemistry of super duplex powders before PBF-LB/M processing.

Powders were then used to optimize PBF-LB/M processing parameters for UNS S32760 components. A process window was identified to enable the fabrication of dense specimens with limited defectiveness and a relative density suitable for structural applications. The as-built material revealed the competing effects of nitrogen loss, solidification kinetics, cooling rate, and austenite formation, showing that nitrogen content decreased with increasing hatch energy density (HED) during PBF-LB/M. Although high-nitrogen powders promoted partial austenite formation, post-process heat treatment remained mandatory to restore a balanced duplex microstructure. Moreover, the comparison between low- and high-nitrogen powders demonstrated that nitrogen content plays a decisive role in the microstructural evolution of heat-treated PBF-LB/M components.

Heat treatment was carried out to control the ferrite-austenite ratio, limit detrimental secondary phases, and improve suitability for service conditions. The PBF-LB/M material was qualified through tensile, Charpy impact, and high-cycle fatigue testing. These analyses established relationships between powder chemistry, build orientation, process parameters, heat treatment, microstructure, and mechanical response. Localized corrosion resistance was assessed by ferric chloride testing according to ASTM G48 Methods A and E, comparing as-built and heat-treated PBF-LB/M conditions with conventionally processed reference materials. The discussion was framed according to NORSOK M-630 requirements, owing to the use of UNS S32760 in oil and gas applications exposed to chloride-containing environments and stringent acceptance criteria. Overall, this research demonstrates the feasibility of a circular manufacturing route for UNS S32760 components, from atomization modelling and waste-derived powder production to PBF-LB/M processing and performance assessment, contributing to lower-environmental-impact additive manufacturing pathways for super duplex stainless steels.