Corrosion Resistance Enhancement of LPBF-Printed In625-Based Metal Matrix Composites in Molten Salt Environments

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1. Introduction

Inconel 625 (In625) is a nickel-based superalloy widely used in aerospace, chemical processing, and energy production due to its excellent mechanical properties and corrosion resistance. Its performance stems from a composition rich in nickel, chromium, and molybdenum.

However, the extreme conditions in molten salt reactors (MSRs), a focus of fourth-generation nuclear technology, challenge conventional In625. The highly corrosive molten salt environment at high temperatures accelerates material degradation, necessitating the development of more resilient materials.

Additive manufacturing (AM) techniques, particularly laser powder bed fusion (LPBF), have opened new avenues for developing metal matrix composites (MMCs) [1–2]. These materials, integrating reinforcing phases into metal matrices, show promise in enhancing mechanical properties and corrosion resistance.

This study explores an In625-based MMC reinforced with titanium diboride (TiB_2), fabricated via LPBF. Our experiments reveal superior corrosion resistance of the TiB_2-containing MMC in molten salt environments compared to In625. This improvement, attributed to the composite's refined microstructure, highlights the potential of LPBF-processed MMCs for advancing materials in next-generation nuclear systems.

2. Methods and Results

2.1 Material

In this study, In625 powders with a particle size distribution of 15–45 μm were procured from MSE Supplies LLC (Tucson, AZ, USA), while sub-micron TiB_2 powders (average size <2 μm) were obtained from US Research Nanomaterials Inc. To prepare the composite material, TiB_2 powders were blended with In625 powders to achieve a composition of 2 wt% TiB_2. The mixture was homogenized using a high-speed blender (VM0104, Vita-Mix, USA) for 90 minutes to ensure uniform dispersion. Both the as-received In625 powders and the composite powders containing 2 wt% TiB_2 were processed into samples using LPBF on an EOS M290 system under identical processing parameters.

2.2 Corrosion test

Corrosion resistance of LPBF-fabricated In625 and In625+TiB_2 (2 wt%) specimens was evaluated in molten salt environments. Samples with dimensions of 10 mm × 5 mm were polished to a finish using 600 and 1200 grit sandpaper. The experiments were conducted in an Ar-filled glovebox with an electric furnace, using a molten salt mixture of KCl (50.5 mol%), $MgCl_2$ (46.6 mol%), and NaCl (2.9 mol%) based on the methodology described by B. D'Souza et al. [3]. The salt mixture was purified at 600°C for 48 hours in alumina crucibles, maintaining a volume-to-surface area ratio of 0.4 ml/mm².

The results showed that the In625+TiB_2 (2 wt%) specimen exhibited significantly enhanced corrosion resistance compared to the In625 specimen, with approximately 80% less weight loss after exposure to the molten salt environment. This improvement demonstrates the effectiveness of TiB_2 addition in mitigating material degradation under corrosive conditions.

2.3 SEM/EDS analysis

SEM/EDS analysis revealed distinct differences in corrosion behavior between the two specimens. The In625 sample exhibited extensive corrosion, with void spaces extending up to 50 μm from the surface. In contrast, the In625+TiB_2 (2 wt%) sample showed corrosion limited to within 10 μm of the surface, indicating superior corrosion resistance.

EDS analysis confirmed these observations by showing deeper Cr depletion in the In625 specimen compared to the TiB_2-containing composite. Cr depletion depth is a known indicator of corrosion progression, and its reduction in the composite material further supports its enhanced performance in molten salt environments.

These findings collectively demonstrate that incorporating 2 wt% TiB_2 into In625 significantly improves its corrosion resistance by reducing both the depth of corrosion attack and Cr depletion. This study highlights TiB_2 as an effective additive for enhancing the durability of In625 in harsh environments.

3. Conclusions

This study demonstrates that adding 2 wt% TiB_2 to In625 via LPBF significantly enhances corrosion resistance in molten salt environments. The TiB_2-reinforced composite showed an approximately 80% reduction in weight loss compared to pure In625, with limited corrosion penetration and shallower Cr depletion.

These findings validate LPBF as a viable method for fabricating corrosion-resistant MMCs, offering a promising solution for structural materials in MSRs. Future work will explore other ceramic reinforcements and assess long-term stability and scalability for industrial applications.

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