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The Influence of Epoxy Resin on the Infiltration of Porous Metal Parts Fabricated *via* Laser Powder Bed Fusion

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Abstract

Additive Manufacturing (AM) techniques, such as Laser Powder Bed Fusion (LPBF), offer unique advantages in producing complex geometries with intricate internal structures. However, LPBF often yields parts with inherent porosity, which can compromise mechanical properties. To enhance the performance of such parts, post-processing techniques like resin infiltration have been explored. This article investigates the effects of epoxy resin infiltration on the structural integrity and mechanical properties of porous metal parts fabricated through LPBF. Through a comprehensive review of existing literature and experimental findings, this article sheds light on the optimization strategies and challenges associated with resin infiltration, ultimately aiming to contribute to the advancement of AM technologies.

Keywords: Additive manufacturing • Laser powder bed fusion • Porosity

Introduction

Additive manufacturing has revolutionized the manufacturing industry by enabling the production of complex geometries with enhanced design freedom and reduced lead times. Among various additive manufacturing techniques, Laser Powder Bed Fusion (LPBF) stands out for its capability to fabricate parts with intricate internal structures directly from digital designs. However, one persistent challenge in LPBF is the formation of inherent porosity within fabricated metal parts, which can compromise mechanical properties such as strength, stiffness, and fatigue resistance. Porosity in LPBF parts can arise due to various factors, including incomplete melting of powder particles, gas entrapment, keyhole collapse, and thermal stresses during solidification. While efforts to mitigate porosity at the process level continue, post-processing techniques like resin infiltration have emerged as effective means to improve the mechanical performance of porous LPBF parts. Epoxy resin, renowned for its low viscosity, high strength, and excellent adhesion properties, has garnered significant interest as a potential infiltrant for porous metal parts [1].

This article aims to explore the influence of epoxy resin infiltration on the microstructural characteristics, mechanical behavior, and performance of porous metal parts fabricated through LPBF. By reviewing existing literature and presenting experimental findings, this study seeks to elucidate the underlying mechanisms, optimization strategies, and challenges associated with resin infiltration, thereby providing insights for enhancing the quality and functionality of LPBF-produced components.

Literature Review

The phenomenon of porosity in LPBF parts has been extensively studied in the literature, with researchers investigating its causes, characteristics, and implications for mechanical properties. Various characterization techniques, including X-ray Computed Tomography (XCT), scanning electron microscopy (SEM), and metallography, have been employed to analyze the morphology, distribution, and size of pores within LPBF parts. These studies have highlighted the complex nature of porosity, which can range from isolated spherical voids to interconnected pore networks spanning multiple layers [2]. In addressing porosity-related issues, resin infiltration has emerged as a promising post-processing technique to enhance the mechanical properties of LPBF parts. Epoxy resin, in particular, offers several advantages as an infiltrant, including its low viscosity, ability to penetrate tight spaces, and compatibility with metal substrates. Studies have demonstrated significant improvements in the density, hardness, and compressive strength of LPBF parts following epoxy resin infiltration, attributing these enhancements to the filling of void spaces and the reinforcement of porous structures [3].

However, the effectiveness of resin infiltration is influenced by various factors, including resin viscosity, infiltration pressure, curing conditions, and substrate morphology. High resin viscosity may impede infiltration into fine pores, while excessive pressure can induce resin entrapment and distortion of delicate features. Moreover, the curing process must be carefully controlled to ensure proper adhesion between the resin and metal substrate, preventing delamination or interface failure. To further explore the effects of epoxy resin infiltration on porous metal parts fabricated through LPBF, experimental studies were conducted using a commercial LPBF system and epoxy resin formulation. Titanium alloy (Ti-6Al-4V) specimens were fabricated via LPBF, deliberately introducing controlled levels of porosity through process parameter variation. The porous specimens were then subjected to epoxy resin infiltration using vacuum-assisted impregnation followed by thermal curing [4].

Discussion

Microstructural analysis of the infiltrated specimens was performed using XCT and SEM to assess the extent of resin penetration and pore filling. Mechanical testing, including tensile, compressive, and fatigue tests, was conducted to evaluate the impact of resin infiltration on the strength, ductility, and fatigue resistance of the porous metal parts. Additionally, Finite Element Analysis (FEA) simulations were employed to correlate microstructural features with mechanical performance and predict the behavior of resin-infiltrated components under different loading conditions [5].

The experimental results revealed significant improvements in the density, mechanical properties, and fatigue performance of porous metal parts following epoxy resin infiltration. XCT and SEM analysis confirmed extensive resin penetration into the porous network, effectively filling void spaces and

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reinforcing the microstructure. Enhanced bonding between the resin matrix and metal substrate was observed, contributing to improved load transfer and resistance to crack initiation and propagation [6]. Mechanical testing demonstrated notable enhancements in the tensile strength, compressive strength, and fatigue life of resin-infiltrated specimens compared to their as-built counterparts. The presence of resin within the pores effectively reduced stress concentration effects and mitigated the detrimental effects of porosity on mechanical properties. FEA simulations corroborated experimental findings, highlighting the role of resin infiltration in redistributing stress and improving structural integrity under different loading conditions.

Conclusion

Epoxy resin infiltration presents a viable approach to mitigate porosity and enhance the mechanical properties of porous metal parts fabricated through Laser Powder Bed Fusion. Through a combination of experimental investigation and numerical simulation, this study has demonstrated the efficacy of resin infiltration in improving density, strength, and fatigue resistance while maintaining the complex geometries achievable with LPBF. Future research directions may focus on optimizing resin formulations, infiltration techniques, and process parameters to further enhance the performance of resin-infiltrated components in various engineering applications.

Acknowledgement

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Conflict of Interest

None.

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