Nitrogen outgassing in laser powder bed fusion

Development of a new processing route for the additive manufacturing of highnitrogen, corrosion resistant, martensitic steels by combining PBF-LB/M and HIP with process-integrated quenching

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In Short

- Laser powder bed fusion
- High nitrogen steel
- Martensitic stainless steel
- Nitrogen outgassing

This project aims to develop and understand a novel process chain for the additive manufacturing of high-nitrogen, corrosion-resistant martensitic steels (MSS). These materials offer an excellent combination of high strength and superior corrosion resistance, but their conventional production is challenging [1]. The proposed process route combines Powder Bed Fusion-Laser Beam/Metal (PBF-LB/M) with Hot Isostatic Pressing (HIP) and integrated quenching. This approach seeks to overcome the limitations of conventional manufacturing and to produce materials with properties that exceed those of current state-of-the-art materials [2].

Martensitic stainless steels (MSS) are characterized by their high strength and good corrosion resistance, primarily due to their chromium content and martensitic microstructure. However, the addition of carbon, which enhances strength, can lead to the formation of chromium carbides, depleting the matrix of chromium and reducing corrosion resistance [3]. Nitrogen is an interstitial alloying element that can serve as a substitute for carbon, simultaneously increasing strength and improving corrosion resistance, particularly against chloride-induced pitting [4]. Its positive effect on the microstructure is well-documented, as it stabilizes austenite and hinders the formation of detrimental chromium-carbides. Nevertheless, the low solubility of nitrogen in the steel melt makes its conventional production via melt metallurgy challenging, often requiring expensive pressure-assisted processes.

Additive manufacturing, specifically PBF-LB/M, offers a promising alternative for producing complex, high-performance components. However, processing high-nitrogen steels with PBF-LB/M presents its own set of challenges, including nitrogen loss due to evaporation from the melt pool and the formation of gas porosity (see Fig 1) [5]. Previously was shown that while it is possible to process pre-alloyed powders, the nitrogen content is limited. Gas nitriding of pre-alloyed, low-nitrogen powders can introduce higher nitrogen levels by the formation of nano-scaled nitrides. The HIP allows to dissolve those nitrides interstitially, allowing for higher-than-equilibrium nitrogen concentrations in the solid part.

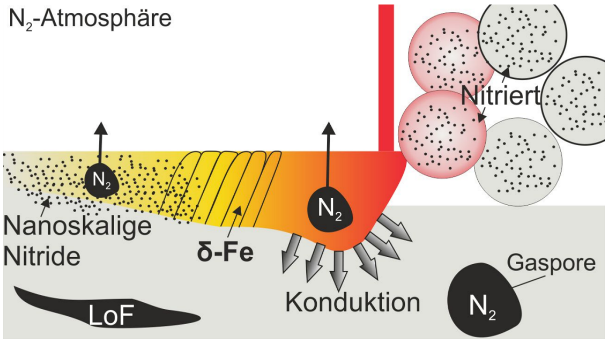

***Figure 1:** Schematic representation of the laser powder bed fusion process with high nitrogen steel particles.*

2. Project Goals and Research Questions

The main objective of this project is to achieve a comprehensive understanding of the microstructural evolution processes and the nitrogen transport phenomena throughout the entire process chain, from powder production to additive manufacturing and final post-processing.

The research questions are divided into two main areas:

- **PBF-LB/M Processing and Process Modeling:** What are the critical time scales governing nitrogen transport and loss during PBF-LB/M? How can process windows be identified to systematically decouple the achievable nitrogen content from the maximum melt solubility? How can adaptive path planning strategies be used to scale these processes to larger components?
- **Microstructure and HIP Post-Treatment:** How does nitrogen behave during the microstructural formation of martensitic C+N steels in PBF-LB/M and subsequent HIP with integrated quenching? What is the influence of HIP pressure on nitrogen solubility, phase stability, and microstructure? How do nitrogen content and microstructure evolve along the entire process chain as a function of alloy composition and process parameters?

Additive Manufacturing and Modeling The numerical part of the project will investigate the kinetic and thermal phenomena during the PBF-LB/M process. A computational fluid dynamics (CFD) model, based on open-source software (OpenFOAM v2112), will be developed to simulate the coupled transport of momentum, heat, and mass on the melt pool scale. This model will be validated through single- and multi-track experiments with in-situ pyrometry. The goal is to identify critical time scales that have to bed avoided to kinetically inhibit nitrogen outgassing. By using these insights, multi-objective adaptive path planning strategies will be developed to understand nitrogen retention while maintaining an acceptable level of porosity that can be fully densified in the subsequent HIP step. The use of high-performance computing is critical for the success of this project. The CFD simulations, which aim to model the complex multi-physics of the PBF-LB/M process with multiple layers and tracks, require significant computational resources. Simulating multi tracks near 2 mm length on the powder-scale, for example, requires approximately 21,000,000 cells. The scale and complexity of these simulations necessitate the use of an HPC environment to ensure timely and effective model development and validation.

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More Information

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Project Partners

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