Erasmus Mundus Joint Master in Manufacturing 4.0 by intElligent and susTAinable technologies

MASTER's Degree Thesis

In Situ Control of the Phase and Grain Microstructure of 316L Stainless Steel during Directed Energy Deposition

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Abstract:
Controlling grain structure in metal additive manufacturing (AM) is critical for mitigating anisotropic mechanical behavior caused by columnar grain growth along the build direction. Grain refinement not only reduces hot cracking susceptibility but also enhances mechanical performance via the Hall–Petch effect. This study explores the feasibility of in-situ grain refinement in 316L stainless steel fabricated by Directed Energy Deposition (DED) through the direct injection of titanium (Ti) particles into the melt pool. Unlike premixed powders, which often exhibit non-uniform distribution due to differences in density, morphology, and gas interactions, direct Ti injection provides real-time control over alloying composition and enables local microstructural tailoring.

A systematic parametric study was conducted by varying nozzle velocity (up to 10,000 mm/min), Ti feed rate, and the number of rescanning passes to evaluate their combined effect on microstructure, inclusions, and the transition from coarse columnar grains to fine equiaxed grains. Experimental observations revealed that Ti injection promotes equiaxed grain formation through the precipitation of Ti-rich compounds and a shift in solidification mode within the 316L microstructure.

Complementary Thermo-Calc simulations were used to predict phase stability and inform the process design, ensuring avoidance of brittle Fe–Ti intermetallics. Results indicated that low Ti feed rates refine grains effectively without triggering phase transitions in the austenitic matrix. In contrast, higher Ti additions caused inclusions, cracking, and fully ferritic solidification. Laser rescanning mitigated inclusions and reduced crack formation by homogenizing Ti distribution.

This combined experimental and modeling approach establishes a first framework for microstructural control in 316L DED via optimized Ti injection. The findings demonstrate the potential of this strategy to achieve tailored grain structures, limit anisotropy, and improve reliability in additively manufactured stainless steel components.

Keywords: Additive manufacturing, DED, Grain refinement, Microstructure tailoring, Titanium injection, EBSD.

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