Summary

This doctoral thesis presents a comprehensive investigation into the microstructural and mechanical properties of steels processed using the additive manufacturing (AM) technique known as Laser Directed Energy Deposition (L-DED), using as raw materials powders or wires. The primary objectives were to develop the main process parameters to fabricate effective objects with different types of steels and to repair industrial tools. The present thesis begins by providing a thorough technological background, explaining the processes involving different feedstocks, and trying to establish a metallurgical foundation for the steel alloys studied.

The subsequent chapters are organized based on the specific steel studied, each chapter delving into the material properties and characterization, into the main process parameters optimization, and then into the post heat treatment effects.

Beginning with stainless steel 316L (Chapter 2), the study progressed from characterizing the powder employed in the L-DED process to optimizing the main process parameters of the system employed to obtain bulk dense samples. Detailed analyses of the microstructure and mechanical properties of the bulk 316L samples fabricated by L-DED were conducted. Investigations into different deposition strategies were also undertaken, focusing on understanding the impact of heat accumulation. A factor screening approach was employed, measuring multiple responses concerning various factors and covariates. The chapter dedicated to stainless steel 316L concluded in determining also the optimal process window for another L-DED system with the starting material in wires.

It was found that the optimized process parameters using a Laserdyne 430 by Prima Additive with 2 mm laser spot diameter utilize a specific volumetric energy density of 133.3 J/mm^3, ensuring the production of fully dense, crack-free specimens. The microstructural analysis exhibited a typical AM microstructure with micro-segregation and some Mn/Si oxide inclusions. The microhardness exhibited a decrease towards the top of the samples due to reduced cooling rates, with a mean value of 203 HV.

Processing 316L stainless steel wire with the LAWS 250 system by Liburdi, which utilizes a 0.3 mm laser spot diameter and has a fixed wire feeding position, revealed the main process parameters for all feeding directions. However, challenges emerged with the wire feeding system, resulting in issues such as porosity and misalignment during subsequent track depositions. The following experimental chapter (Chapter 3) delved into hot work tool steels, in particular the W360 steel (from Böhler), to be processed through Laserdyne 430 system. This segment commenced with characterizing the starting powder, followed by the

optimization of the main process parameters. Heat treatments were then applied to the as-built L-DED samples of W360, leading to discussions on microstructural evolution of the as-built, as-quenched, and hardened W360 samples. Optimized parameters yielded a specific volumetric energy density of 82.1 J/mm³ for samples with 99.85% relative density. The as-built W360 sample exhibited a typical AM microstructure, characterized by a cellular-dendritic pattern with small carbides observed in the intercellular regions. The effect of post processing heat treatment was also investigated. Post-quenching, the samples displayed the typical microstructure of hot work tool steels, consisting of small martensite laths and carbides. After three consecutive tempering cycles on the quenched samples microstructure exhibited a tempered martensite matrix with grown Mo-rich carbides. The as-built sample demonstrated a mean microhardness of 642 HV, while as-quenched sample had 744 HV and tempered samples showed 634 HV microhardness.

Chapter 4 was then focused on the 18Ni-300 maraging steel, again in powder form. The exploration commenced with characterizing the initial powder, proceeded to optimize the main process parameters, and culminated in a detailed analysis of the microstructural and mechanical properties of the samples fabricated by L-DED using a LAWS 250 system with 0.3 mm laser spot diameter. Optimized parameters yielded a specific volumetric energy density of 121.9 J/mm³ for building samples with 99.62% relative density. The as-built 18Ni-300 samples revealed a typical AM microstructure with a cellular-dendritic pattern comprising both equiaxed and columnar dendrites together with the Ti-rich black nanoparticles. The mean microhardness value of as-built 18Ni-300 sample was 331 HV.

The final chapter, Chapter 5, focused on studies involving the application of L-DED in repair processes, starting from powders and using Laserdyne 430 system. A thorough investigation of D2 tool steel was conducted to comprehend its behaviour in the L-DED process used as a substrate. Once understood, the deposition of W360 on the D2 steel substrate was executed to investigate the feasibility of the repairing process by L-DED. The initial worn industrial blade, made of D2 cold work tool steel in a hardened state, featured large carbides dispersed within the martensitic matrix, presenting challenges for repair attempts. Through an annealing process, the microhardness of the D2 substrates decreased, facilitating successful welding on annealed D2 substrates. Subsequently, crack-free, nearly fully dense W360 samples were deposited onto annealed D2 steel substrates, indicating promising results for repair applications. Optical micrographs revealed a typical AM microstructure, and EDS analysis indicated Cr and V-rich carbides. However, microhardness measurements highlighted the need for adjustments in the heat treatment process for W360 steel to achieve the desired microhardness, emphasizing the importance of careful consideration and optimization of repair process parameters.

In summary, these findings underscore the significance of careful consideration and optimization of the repair process parameters to ensure successful and durable repairs of industrial components made in tool steels.