Laser Powder Bed Fusion (L-PBF) of high-strength Aluminum alloys

Summary

The growth and technological consolidation in Additive Manufacturing (AM) over the past few decades have stimulated strong industrial interest in these processes, driving the need to expand the portfolio of materials available for these technologies. In particular, metal additive manufacturing offers the opportunity for companies to produce high value-added components by taking advantage of the possibilities that these processes offer: wide design freedom for customization or maximization of component functionality, the realization of lattice structures to lighten or increase the part's exchange surface area, as well as more sustainable use of raw materials and greatly reduced prototyping times. On the other hand, the technological principles of these processes have proven to be suitable for a few metal alloys. Conversely, other alloys require adaptation from traditional compositions to make them processable.

This is the case for the Laser Powder Bed Fusion (L-PBF) process and aluminum alloys: in this process, a high-power laser selectively melts a powder bed, producing a layer of the final component. Through the deposition of new layers of powder and the repetition of these steps, the component is built layer-by-layer to its final completion. Aluminum alloys and particularly high-strength Al alloys, however, are not easy to process with this technology: in addition to physical properties such as high reflectivity, high thermal conductivity, and poor flow behavior, these alloys have a wide solidification range and a columnar-dendritic grain growth, which results in the occurrence of solidification cracks. The presence of this defect in the final component is detrimental to the mechanical properties and structural integrity, which is why researchers have focused their attention on developing strategies to overcome this issue.

In recent years, several approaches have been developed to improve the processability of these alloys, aiming to improve the behavior of the alloy during

solidification to compensate for volumetric shrinkage, mitigate thermal gradients, or modify the solidification mechanism of the alloy. In particular, the work described in this thesis is contextualized within this research window, aiming to characterize systems based on high-strength aluminum alloys, suitably modified through the addition of precursors or inoculants to modify their solidification mechanism and improve their processability.

In this thesis, three systems based on different high-strength Al alloys were investigated and characterized. The first one was a commercial material, A6061 RAM2: this material combines Al powder with Ti and B_4C particles to design a reactive powder. During the L-PBF process, the energy provided by the laser source starts a reaction mechanism that leads to the “in-situ” synthesis of TiC and TiB_2, which are both reinforcement phases and inoculants for the Al matrix. The A6061 RAM2 system was processed using low-power L-PBF, performing a process parameter optimization and characterizing the material in terms of microstructure, mechanical properties, and system evolution. The characterization highlighted the key role of Ti in improving the alloy processability due to the formation of the inoculant phase Al_3Ti. Dense and crack-free samples were obtained, with superior mechanical properties compared to similar systems.

Similar work was carried out on the A2024 alloy, modified with the addition of Ti and Ti+B_4C to understand the different contributions of the two precursors. The comparison between the two investigated systems confirmed the key role of Ti (and Al_3Ti) in promoting equiaxed solidification, while the contribution of B_4C to grain refinement and mechanical properties was negligible. Furthermore, the two systems were heat treated according to the T6 precipitation hardening: although the two systems exhibited an increase in mechanical properties and reached similar hardness values, their comparison revealed different precipitation kinetics due to the presence of B_4C, which anticipated the peak-aged condition.

Finally, the role of the dispersion method was taken into account. Three A2618+TiB2 powder blends obtained with different dispersion methods – low-energy mechanical mix, high-energy mechanical mix, and plasma coating – were processed via L-PBF and compared with the pure A2618 alloy. After an in-depth powder characterization to evaluate the inoculant dispersions, a process parameter optimization of the three systems was performed by adopting the Single Scan Tracks (SSTs) approach, observing differences in terms of process windows and grain refinement. Finally, dense and crack-free cubic samples were produced, proving the effectiveness of the three investigated powders.