Abstract

Nowadays, there has been a growing interest in increasing the knowledge of additive manufacturing technologies in order to develop and produce high-performance materials for industrial applications. In particular, laser powder bed fusion (L-PBF) and electron beam powder bed fusion (EB-PBF) reached large-scale production, thus highlighting the interest attracted from both research and industrial fields. The realization of complex near-net-shape components layer-by-layer drastically reduced the post-process operation, making the powder bed fusion technologies suitable for materials hard to process by traditional manufacturing. Among these materials, Ni-based superalloys represent one of the more critical categories. Their high strength and hardness reduce the workability and machinability, with overall difficulty shaping the requested part. The use of L-PBF and EB-PBF technologies allowed to overcome those processability issues, however, the crack sensitivity of these alloys has to be taken into strong account to prevent crack formation during the building step.

In this thesis, three well-known Ni-based superalloys, Inconel 625 (IN625) and IN625/TiC composite, Inconel 718 (IN718), and Inconel 738 (IN738), were processed by powder bed fusion techniques to investigate new aspects of processability and microstructural evolution.

IN625 is a low crack-sensitive Ni-based superalloy with well-established L-PBF processability knowledge. Starting from this knowledge, the first part of the work focused on the L-PBFed IN625 evolution under heat treatments, providing a guide that merges microstructure, residual stress, and mechanical properties. As-built, 1 h stress relieved at 600°C, 800°C, and 870°C, and 2 h solution annealed at 1150°C conditions were investigated, finding the best-relieved condition in the 870°C one. The second work investigated the realization of an IN625 complex shape resonant igniter for rocket engines. Two different intricate geometries were successfully produced by L-PBF, highlighting the advantages in terms of both time-saving and component efficiency. The IN625 superalloy was also investigated as a metal matrix for IN625/TiC composite production due to the peculiar chemical affinity shown with TiC particles. The first study was performed with the addition of 1 wt.% of TiC. The composite was compared with IN625 in the as-built, 1h annealed at 980°C, and 2h solution annealed at 1150°C conditions. In as-built conditions, the presence of TiC increased the hardness and tensile strength without drastically reducing the ductility behavior. Under heat treatments, IN625/TiC composite revealed higher thermal stability, retaining the as-built microstructure in all the conditions investigated. Moreover, the TiC addition triggered homogeneous carbide precipitation along the grain boundaries, further increasing the pinning effect on the grain structure. A second work was performed with the addition of 2 wt.% TiC. Alloy and composite were investigated in the as-built, solution annealed (1150°C 2h), and after thermal exposure at 1000°C for 100h, simulating the service condition. The increase in TiC concentration activated the beginning of a refining effect in the as-built condition, increasing the percentage of recrystallized grains. The thermal stabilization was observed in solution-annealed and prolonged thermal exposure conditions.

IN718 possesses good processability with L-PBF technology and a novel approach was used for its production in the frame of this thesis work. Shelled samples were successfully produced with a fast L-PBF scanning strategy and densified by hot isostatic pressing (HIP) with considerable time-saving. Using a controlled porosity core instead of a loosened powder reduced drastically the shrinkage and prior particle boundary formation, thus pushing the mechanical performances close to the bulk dense reference sample.

The last part of the thesis was devoted to the processability of the IN738 superalloy using EB-PBF. The high crack sensitivity of the alloy makes the EB-PBF technique more suitable for its production compared to the L-PBF. The work compared the effect of two tailored preheating conditions effect on the microstructural evolution. Samples at preheating temperatures of 1025°C and 950°C were produced and deeply characterized. Lowering the preheating temperature caused more homogenous phase precipitation, which resulted in lower stresses, avoided crack formation, and increased and stabilized microhardness.