Abstract

For decades, the manufacture of strategic components subjected to high-temperature and high-stress conditions (e.g. turbine blades) has relied on Nickel superalloys due to their outstanding mechanical properties and oxidation resistance. In recent years, the transition from traditional technologies to groundbreaking Additive Manufacturing has been a matter of interest for industries, mainly regarding the Laser Based Powder Bed Fusion (PBF-LB). Indeed, PBF-LB can provide several advantages in production, the most important being flexibility and freedom of design, which allows the design of complex and hollow structures that are not achievable with traditional processing. These advantages can lead to significant weight and fuel consumption reductions, which are crucial for the transport sector. Researchers are focusing both on the optimisation of the process parameters and post-process operations on traditional composition as well as on the development of new tailored alloys.

The subjects of the present thesis are the CM247 LC and René 80 superalloys, which are considered difficult to process by PBF-LB due to the high-fraction content of γ' forming element (Al and Ti). However, our research group has previously demonstrated the possibility of achieving promising densification levels and microstructural characteristics by the synergical effect of optimised PBF-LB, Hot Isostatic Pressing (HIP) and heat treatment. The first results regarding microstructural features and densification flaws have been discussed in a former dissertation linked to the JTI Clean Sky European project Next gEneration loW pressure TurbinE Airfoils by aM (NEWTEAM), Grant agreement ID: 821274. The present work starts from the latter results and consists of two segments.

The first part is still related to the NEWTEAM project, and it wants to assess the mechanical properties of the studied superalloys associated with the microstructures coming from the final recipes of the project. More specifically, stress rupture and high-temperature fatigue (high-cycles and low-cycles) properties have been

assessed, as they represent significant loading conditions for in-service turbine blades. In particular, the stress rupture data showed that the PBF-LB superalloys are mechanically competitive with the traditionally processed ones. Fractography was also performed to highlight the fracture interaction with the main microstructural features within these tests, like the rafting occurring during the creep deformation and the fatigue nucleation site. Additionally, a specific study on the Grain Boundary Sliding (GBS) deformation mechanism acting during hot deformation of the CM247 LC has been established in collaboration with the IMDEA Materials Institute of Madrid (ES). The triggering of GBS and its dependence on the test parameters was established, as it can significantly affect the mechanical properties of the superalloys in creep-like conditions, promoting inter-granular cracking.

The second part is focused on the microstructural design of the superalloys through the optimisation of HIP and heat treatments. Firstly, the Solution Annealing (SA) temperatures were re-optimised and set at 1260ºC to obtain the proper γ' metrics and guarantee the robustness of the process. Subsequently, we have worked to assess the possibility of performing supersolvus HIP-quench, merging the HIP and SA steps in the same furnace to cut the total cycle time, the energy consumption and the environmental impact. The first trials showed that supersolvus HIP-quench can be positively applied to PBF-LB Nickel superalloys with good results in densification healing despite the precipitation of irregular coarse γ' right after the supersolvus HIP-quench. Different pressure levels and cooling rates were applied in a new experimental setup to understand their effect on the γ' precipitation. The latest work showed that γ' always precipitates with irregular morphology despite the pressure or the cooling rate. Nevertheless, the diffusion mechanisms in the subsolvus First Aging allow the formation of stable cubic shapes in this stage of the heat treatment.

The present thesis results showed that PBF-LB CM247 LC and René 80 can achieve high mechanical performance when the densification flaws inherited from the PBF-LB process are appropriately healed and the heat treatment optimised. Finally, recent advancements in the HIP equipment allow for reducing the post-process cycle time, integrating the SA in the HIP furnaces with rapid cooling systems.