Inconel 718 superalloy produced through Selective Laser Melting for harsh environment applications

Summary

The Additive Manufacturing (AM) is an innovative concept for the semi-automated production of components of very complex shape. The growing interest in this technology is justified by the unique possibility to produce parts which are difficult or even impossible to obtain with the conventional production techniques and with an important saving on the material and the costs of molds, dies and tools.

The additive production of nickel-based super-alloys from pre-alloyed powders is particularly interesting in the aerospace field and for applications in the chemical and energy production plants. However, the nickel-based superalloys are not all equally suitable for this application and whenever a new alloy is used in an additive technique, a preliminary study is required in order to find out the process parameters that allow to obtain a dense and defect-free product. Furthermore, the post processing heat treatment has to be optimized to account for the specific features of as built microstructure. The combination of processing parameters and post heat treatment condition highly affects the ultimate performance of the AM alloys, which in some cases may be even higher than those of traditional materials.

This thesis focuses on the processability, post-heat treatment and oxidation resistance of Inconel 718 alloy produced through Selective Laser Melting (SLM). The major target is to demonstrate the feasibility of using such alloy for the AM fabrication of complex components especially dedicated to high temperature service and harsh condition. The final type of components we have in mind is a high temperature heat exchanger, where the possibility to achieve safe and complex hollow structures is highly appealing.

After a preliminary study on the effect of the main process parameters on the residual porosity and the Brinell hardness, the microstructure of the as built SLM Inconel 718 was investigated. The collected observations are reported in chapter 3. A very heterogeneous microstructure and a strong [001] crystallographic texturing

was observed during this study. Other important features observed in the as built state are: the extremely fine dendritic sub-granular structure (the mean interdendritic distance is about 1 μm), the strong microsegregation with consequent non-equilibrium eutectic products formation and the high dislocations density at dendrites boundaries.

Starting from such highly heterogeneous structure, a post-heat treatment is normally required to optimize the final microstructure and remove the unwanted features. The study on the post heat treatment effects is reported at chapter 4. The response of the as built material to a thermal exposure was preliminary investigated by Differential Scanning Calorimetry (DSC) and Thermomechanical Analysis (TMA) in order to establish the solutioning range and the characteristic temperatures at which the precipitation of second phases occurs. Then, the optimization of the solution step was performed to obtain the maximum degree of dissolution of the eutectic phases present in the as-built state and to avoid the precipitation of new second unwanted phases and the occurrence of grain coarsening. At last, each step of the complete heat treatment cycle, i.e. solution annealing, first aging and second aging, has been optimized through the measurement of the hardness and the investigation of the as-treated microstructure.

The outcome of the thesis was the definition of the optimal heat treatment to maximize the oxidation resistance of the SLM Inconel 718. Few information is currently available in the scientific literature concerning the hot oxidation resistance of Inconel 718 produced through SLM. Therefore, short, medium and long-term oxidation tests have been performed and the results are reported in chapter 5. The structure and morphology of the oxide scale that forms after prolonged thermal exposure has also been investigated in detail. The oxidation resistance was assessed with oxidation runs up to 900 h at 850°C.

Finally, chapter 6 reports a study on the pack aluminization technique applied to SLM Inconel 718 for applications requiring additional surface protection. Such coating formation was studied to further improve the corrosion resistance of this alloy, trying to allow the possibility to work at even higher operating temperature.

The microstructures of the aluminized coatings resulting from different combinations of powder pack compositions and treatment temperatures have been investigated. Furthermore, the proposed mechanisms of coating formation and degradation are described. The coating oxidation and degradation occur both during the deposition process itself and during the subsequent thermal exposure. Despite of the work done, this technique especially on cavities and rough surfaces has to be highly improved, since it is very hard to obtain a defect-free and stable coating.