Investigation about new TiAl alloy to be processed by Electron Beam Powder Bed Fusion

Intermetallic γ-TiAl-based alloys are interesting structural materials because of their low density (around 4 g/cm^3) and outstanding properties, such as high specific tensile strength, high specific Young's modulus as well as excellent creep resistance for components working at elevated temperatures (600-750 °C), especially when compared with the heavier Ni-base superalloys (about 8 g/cm^3). The utilization of γ-TiAl alloys allows the reduction of fuel consumption, NO_X emissions, and noise when compared with former engines. Apart from the amin application as low pressure turbine (LPT) blades, intermetallic γ-TiAl-based alloys also find application in the automotive sector, where they are employed as the constituent material for turbine wheels in turbochargers to increase engine efficiency and decrease harmful emissions.

At present, the state of art for the production of γ-TiAl-based alloy LPT blades is done by precision casting. Electron beam-powder bed fusion (EB-PBF) started to be considered a very attractive additive manufacturing (AM) technique to process γ-TiAl-based alloys. The high preheating temperature allows the production of crack-free components, while the controlled vacuum limits the concentration of interstitial elements in the component.

In this thesis, three different γ-TiAl alloys processed via EB-PBF have been studied to assess the best-performing one and find the most reliable combination of material and processing route for the production of LPT blades. In particular two new chemical compositions were compared in terms of mechanical response with the GE TiAl 4822 alloy as reference. The starting material of EB-PBF is gas-atomized powders, which need to have specific rheology characteristics to be processable by AM powder bed technique. Therefore, the starting powder of each alloy has been characterized in composition, size distribution, rheology, and internal porosity. Then the starting powder was processed via EB-PBF to produce specimens. The process parameters of the electron beam highly influence the volumetric defects and microstructure of the final components. Indeed a comprehensive study has been done on the influence of beam current, beam speed, and line offset on the internal porosity, microstructure homogeneity and hardness with the reference γ-TiAl alloy (Ti-48Al-2Cr-2Nb). The first object was to select a set of optimized parameters to obtain-full dense specimens, as results. Increasing the line-offset values, the optimal process window shift to higher beam current values and lower beam speed, since as is expected a higher beam current and a lower beam speed results in higher line energy and, consequently, higher aera energy with constant line offset. The porosity in the component is depending also by the internal porosity of the starting powder, indeed the Ar content remaining in the gas atomized powder is not completely eliminated during the EB-PBF and remain entrapped in the gas pores of the final component. As regards the general microstructure of γ-TiAl components produced by EB-PBF is constituted by an inhomogeneous distribution of Al. Indeed, due to the EB-PBF process's nature, the electron beam's high energy and the vacuum environment are the perfect combination for light element evaporation, in this case, Al evaporation from the top of the melt pool. The resulting consequence is an inhomogeneous distribution of α_2-Ti_3Al phase, with higher concentration in the Al depleted zones, hindering the γ-TiAl growth, which is possible only in the Al-rich zones. When heat treated, the samples with Al lean and rich zone results in a banded fashion microstructure with a zone of big lamellar bands and coarse γ-TiAl bands. The inhomogeneity of the Al distribution is reflected on the hardness component, in terms of average value and distribution, Al lean zone results in harder region.

A small set of printing parameter has been selected for the investigation of the different γ-TiAl chemical compositions, and successfully produced a set of specimens for the mechanical test. The processing route of these alloys consist in a step of hot isostatic pressing treatment (HIP) to completely eliminate the residual porosity, followed by an heat treatment to tailor the microstructure. Indeed, mechanical properties are highly depending on the lamellar content in the final microstructure. Due to the different chemical composition the heat treatment setpoint was determined for each alloy by establishing the α-transus temperature via TMA analysis. The heat treatment set point determination was done with the aim to obtain comparable content of lamellar grains in all the three different γ-TiAl alloys.

The heat treated specimens were used for tensile, fatigue and creep properties test. As regards the tensile properties, the Alloy2.A shows no elongation debt due to a higher interstitial element content at least up to a duplex microstructure type (lamellar content up to 50%), while the YTS of this alloy is better than the baseline. Also as regards the high cycle fatigue properties the Alloy2.A shows a better performance compared to the other two investigated alloy, this behaviour is reported as regards creep properties. The Alloy2.A after this work was selected for a more in deep characterization as promising chemical composition for LPT blades via EB-PBF application.

The major achievement of the current thesis is the determination of a promising γ-TiAl chemical composition for EB-PBF production of LPT blades, indeed this alloy showed improved creep properties with low lamellar content, which historically and reported in the literature, reports the most creep debt.

Furthermore, the effect of the focus offset parameters on the microstructure has been studied as side project and reported in the appendix. The focus offset determine the spot size diameter of the electron beam, influencing the energy density and local temperature of the melt-pool. This have an high impact on the final Al content and distribution. A larger focus offset correspond to a wide and shallow melt-pool, resulting in a more homogeneous microstructure.