

Abstract

This doctoral dissertation concerns the tailoring of the fatigue properties of the two-phase titanium alloys Ti-6Al-4V (Ti-64) and Ti-5Al-5V-5Mo-1Cr-1Fe (Ti-55511), produced by Powder Bed Fusion–Electron Beam/Metal (PBF-EB/M), through the selection of process conditions and post-processing treatments. The topic is related to the development of additive manufacturing technologies for materials intended for use under cyclic loading. Due to their high strength-to-weight ratio, corrosion resistance and importance in aerospace applications, titanium alloys are an important group of materials in this field. However, their use requires not only suitable geometry and good static mechanical properties, but also suitable fatigue properties.

The aim of the study was to develop and optimise the PBF-EB/M manufacturing process for two-phase titanium alloys and to determine the influence of post-processing on their mechanical properties, with particular emphasis on fatigue properties. The research covered the full manufacturing route, from the characterisation of Ti-64 and Ti-55511 powders, through the selection of process parameters, to the assessment of the material in the as-built condition and after selected heat-treatment and hot isostatic pressing (HIP) variants.

In the first part of the study, the powders were characterised in terms of chemical composition, particle morphology, particle size distribution and features important for stable PBF-EB/M processing. The manufacturing conditions were then selected based on a preliminary analysis of the influence of process parameters on porosity, the formation of process-related and material defects, and the geometrical accuracy of the samples. The results showed that process parameter selection cannot be based only on minimising porosity, as process stability and the geometrical accuracy of the manufactured samples must also be maintained.

The next part of the dissertation involved the material and mechanical characterisation of the investigated alloys. This included CT-based porosity analysis, microstructural observations, phase composition analysis, hardness measurements, static tensile tests, fatigue tests and fractographic analysis of the fracture surfaces. The results showed that good static properties and low porosity were not sufficient for a clear assessment of material behaviour

under cyclic loading. Local process-induced defects, particularly planar lack-of-fusion defects, were of key importance because they acted as fatigue crack initiation sites.

The applied post-processing variants made it possible to determine their influence on the microstructure, mechanical properties and crack initiation mechanism. The improvement in fatigue properties depended on the treatment parameters and on the type of defects remaining after the PBF-EB/M process. Appropriately selected and verified post-processing variants reduced the influence of critical discontinuities, decreased the scatter of the results and changed the character of crack initiation.

The results confirm that the fatigue properties of Ti-64 and Ti-55511 alloys produced by PBF-EB/M can be tailored through the careful selection of experimentally verified process parameters and post-processing treatments. It was also shown that material behaviour under cyclic loading is determined not only by low porosity and the level of static mechanical properties, but also by the type of local process-induced defects, particularly lack-of-fusion defects, and by the effectiveness of post-processing in limiting their influence on fatigue crack initiation.

The obtained results confirmed the research assumptions and made it possible to develop recommendations for the selection of process and post-processing parameters, leading to an increase in the fatigue resistance of Ti-6Al-4V (Ti-64) and Ti-5Al-5V-5Mo-1Cr-1Fe (Ti-55511) by 120% and 50%, respectively.