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Abstract

Additively Manufactured Ti-6Al-4V: Effects of Heat-Treatment †

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Due to its superior specific strength, corrosion resistance, and biocompatibility, Ti-6Al-4V alloy is the most frequently used titanium alloy, with a wide range of applications in numerous industries. Additive manufacturing (AM) can solve some of the issues with traditional Ti-6Al-4V production, such as high prices due to many production stages and significant material waste during machining. Thus, AM methods enable the creation of highly customized items, which is particularly useful in medical prostheses. The laser powder bed fusion (L-PBF) technique involves a high-energy laser beam selectively melting powder, layer-by-layer. This process is characterized by short laser interaction times with the powder and high localized temperatures, which causes significant thermal gradients and high solidification and cooling rates. After solidification, the high-temperature beta phase transforms into martensite. This microstructure associated with residual stresses generated during L-PBF has a detrimental effect on the mechanical properties of the alloy. Annealing and aging heat treatments are considered capable of optimizing the properties of Ti-6Al-4V alloy produced by additive manufacturing. However, optimum heat-treatment parameters for meeting the best mechanical properties are inconsistent in the literature. Thus, a more profound understanding of the microstructure and mechanisms governing the mechanical behavior of the alloy is necessary.

The purpose of this paper is to investigate the impact of different heat-treatments on the microstructure and properties of Ti-6Al-4V alloy manufactured by L-PBF.

Several methods were used to assess the microstructural evolution, such as optical microscopy (OM), scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS), electron backscatter diffraction (EBSD), differential scanning calorimetry (DSC), and X-ray diffraction (XRD). Hardness and tensile tests were performed to evaluate the effect of heat-treatment on mechanical properties.

AM tensile test specimens with different manufacturing orientations, vertical and horizontal, were tested to assess the effect of heat-treatments and anisotropy on the properties of the L-PBF fabricated alloy.

Annealing allowed the martensite to decompose, obtaining a lamellar microstructure of the $\alpha + \beta$ phases. Water quenching after solution treatment at 950 °C leads to the formation of a martensitic microstructure with some primary α grains. The subsequent age treatment yields a microstructure similar to that of annealing. Ti-6Al-4V samples annealed at low temperature (540 °C) did not show an improvement in ductility compared to as-fabricated ones. Alloys solution treated and aged at 540 °C show low elongation values, both in alloys produced by the L-PBF and produced by conventional processes (forging). To overcome this problem, higher annealing or aging temperatures were tested. These temperatures increase the transformation of martensite into the $\alpha + \beta$ lamellar structure and

the thickness of the α-lamellae; this coarsening effect increases with increasing holding time. Ductility is improved but at the expense of mechanical strength. It should be highlighted that heat-treated AM alloys have a significant degree of microstructure heterogeneities, particularly near the surface.

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