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Meeting-report

Multi-Dimensional Characterization of Additively Manufactured Titanium Alloys using 3D FIB-SEM Tomography

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Titanium alloys are critical structural materials extensively used for aerospace industries, due to their high strength, great corrosion resistance, and low density. However, relatively high production costs associated with the extraction and manufacturing techniques utilized prevent the widespread application of titanium alloys [1]. Additive manufacturing (AM), also known as 3D printing, presents a promising solution, offering potential economic advantages over the conventional casting methods by building the component layer by layer to achieve a near net shape [2]. During AM processes, the titanium alloys undergo unique thermomechanical processes, which can influence the microstructure evolution and formation of defects within the AMed titanium alloys. Recent developments in multi-dimensional characterization techniques, such as X-ray computed tomography, focused ion beam- scanning electron microscopy (FIB-SEM) tomography and atom probe tomography enabled detailed investigation of the three- dimensional (3D) features in the AM-built parts at various length scales. Due to the good site-specific precision and highly efficient automated data collection, FIB-SEM tomography offers the unique opportunity to reveal the complex micro- to nano-scale structure and defects in the AM-built titanium based alloys and composites [3-4]. In this presentation, we will discuss our recent study focusing on the phase transformation and defect analysis in the direct energy deposited (DEDed) Ti-5Al-5Mo-5V-3Cr (wt.%, Ti-5553) alloy using 3D FIB-SEM tomography. Serial sectioning was performed using a ThermoFisher Scientific Scios 2 Dual-beam FIB/SEM, and the image segmentation and 3D reconstruction were conducted using the MIPAR image processing software.

In the first part of this study, the influence of post-heat treatment on the microstructure of the DEDed Ti-5553 was investigated through 3D FIB-SEM tomography in a volume with dimensions of 6μm × 6μm × 6μm. Within this volume, finely scaled α precipitates were uniformly dispersed throughout the interior of β grains. The morphology and sizescale of individual α precipitates are revealed in the 3D reconstruction shown in Fig. 1(a), showing an average diameter of 1.07μm and volume of 0.86μm^3. The cluster of α variants are observed, showing two α variants forming a chevron shape cluster and three α variants forming a triangular cluster respectively, to minimize the total strain energy, revealed in the Fig. 1(b). Compared with as-casted Ti-5553, finer α microstructure is formed in DEDed Ti-5553 after similar heat treatment.

The second part of this study focused on the investigation of columnar grain to equiaxed grain transition in DEDed Ti-5553 promoted by the inclusion of stainless steel 316L (SS316L) powders. The addition of approximately 30.5wt.% SS316L led to a reduction in β grain size to ~10um in diameter, accompanied by a near-equiaxed morphology. However, significant number of defects, including pores and cracks, are formed. 3D reconstruction in Fig. 2 reveals a crack spending tens of micrometers in length traversing the entire volume, alongside pores ranging in size from, micrometers in diameter to nanometers. While the addition of SS316L could lead to more nucleation sites for β grains and limit the growth of β grains by forming grain boundary precipitates, it may also concurrently promote the formation of various defects in the DEDed Ti-5553 alloy [5].

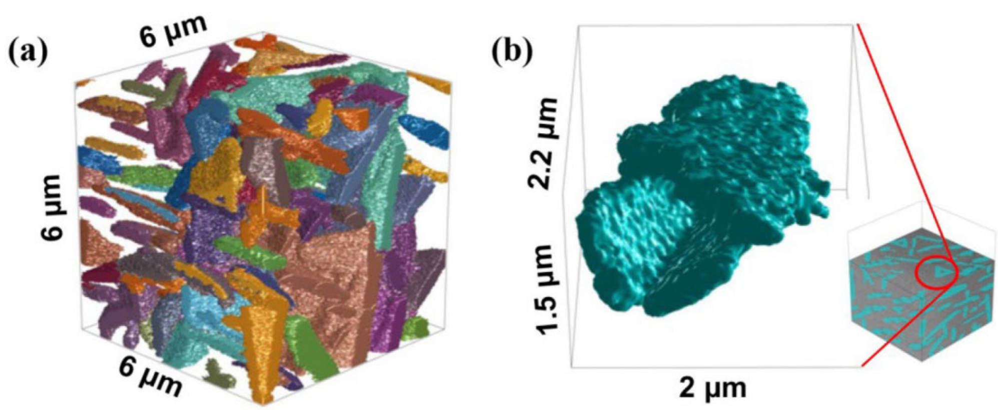

Fig. 1 3D FIB-SEM tomography reconstruction showing the finely scaled α precipitates in DEDed Ti-5553 after post-heat treatment: (a) reconstruction showing the intragranular α microstructure; and (b) reconstruction showing the cluster of three α variants in triangular morphology.

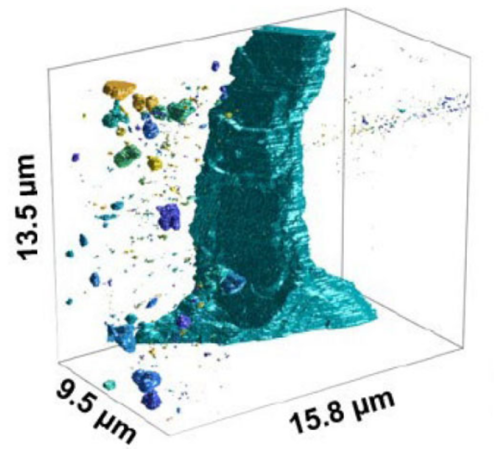

Fig. 2. 3D FIB-SEM tomography reconstruction showing the pores and crack in the DEDed Ti-5553 with addition of approximately 30.5 wt.% of SS316L.

References

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