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Microstructural characterization of 316L stainless steel fabricated by selective laser melting by advanced electron microscopy techniques

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Nowadays, additive manufacturing by selective laser melting (SLM) is widely used to fabricate parts for various applications due to their excellent mechanical properties, such as superior strength and ductility. The SLM process significantly affects the structural integrity and microstructure of materials. In this study, microstructural characterization of 316L stainless steel employing advanced microscopic techniques is presented. Austenitic 316L stainless steel alloy is an attractive industrial material combining outstanding corrosion resistance, ductility, and biocompatibility, with promising structural applications and biomedical uses. However, 316L has low strength and wear resistance, limiting its high-performance applicability. Additive manufacturing by the SLM can overcome these problems, improving the performance and thereby the applicability of 316L [1].

Two 316L specimen types were used in this study. The first one, a thin foil prepared by automatic electrolytic thinning, was characterized by a low voltage scanning transmission electron microscopy (STEM) using a conventional STEM detector and a pixelated STEM detector (MediPix [2]). A transmission electron diffraction technique (t-EBSD) was utilized for crystallographic analysis. The second specimen, i.e. bulk specimen, was prepared by a conventional electropolishing technique. The structure of the bulk specimen was investigated by a low voltage scanning electron microscopy (SEM) and a conventional EBSD technique. A combination of various techniques enables us to obtain deep insight into the 316L microstructure. Comparison of the as-built specimen and the specimen after fatigue test will be also presented.

Figs. 1 and 2 show the 316LN structure after the fatigue test. Fig. 1 presents the results obtained using the thin foil specimen. Fig. 1 (a) shows a series of the STEM micrographs of the same area of view obtained with various landing energy of the primary electrons. The final landing energy was controlled by a negative specimen bias. As is visible, the micrographs obtained with higher landing energies are sensitive to dislocation structure. In contrast, the micrographs obtained at low landing energies (< 5 keV) contain information about chemical heterogeneity. Fig. 1 (b) shows examples of transmission Kikuchi diffraction (TKD) patterns obtained from selected areas on the 316L specimen using a TimePix detector. The effect of various foil thicknesses can be observed. Fig. 1 (c) shows a crystallographic orientation map acquired from a thin foil using a transmission electron backscattered diffraction (t-EBSD) technique. The misorientation within a primary grain is very low and low-angle grain boundaries become obvious. The small dark dots indicate the presence of nano-precipitates, i.e. Mn and Cr oxides.

The bulk specimen of 316LN after the fatigue test was investigated by the low energy SEM, as illustrated in Fig. 2. The SEM micrographs were obtained at 1 keV landing energy of the primary beam. The signal electrons were collected by the last outer segment of a concentric backscatter electron detector (CBS). The specimen bias was fixed at – 4 kV. It secures collimation of the signal electrons towards the detector. The detected signal is created dominantly by the elastically backscattered electrons and the micrographs show the channeling contrast. The internal structure created by fine cellular and the dendritic region is visible.

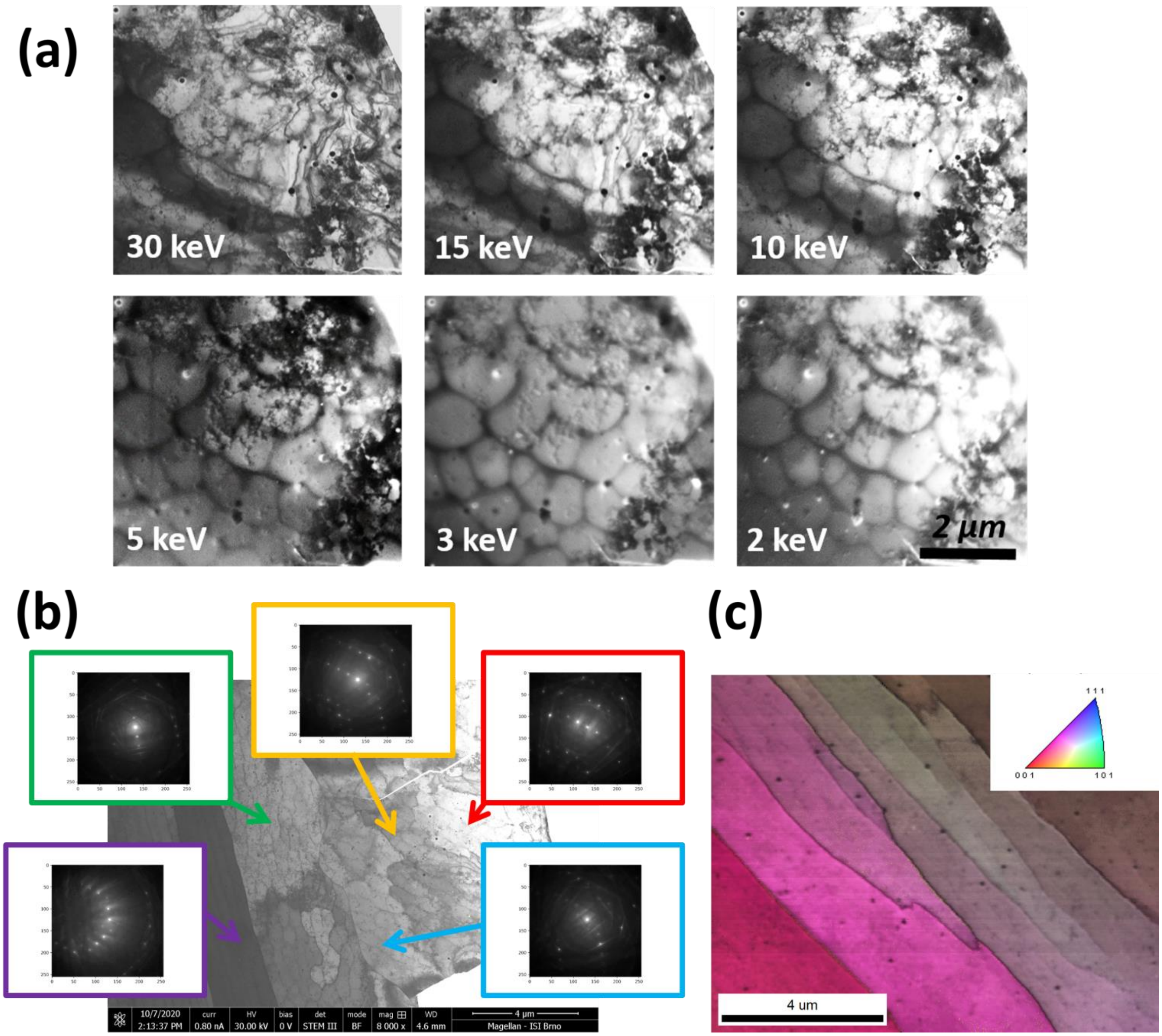

Figure 1. The SLM 316L thin foil specimen: bright field STEM micrographs of the same area imaged with various landing energy of the primary beam (a), TKD patterns acquired by the TimePix detector from selected areas (b), t-EBSD orientation + image quality map (c).

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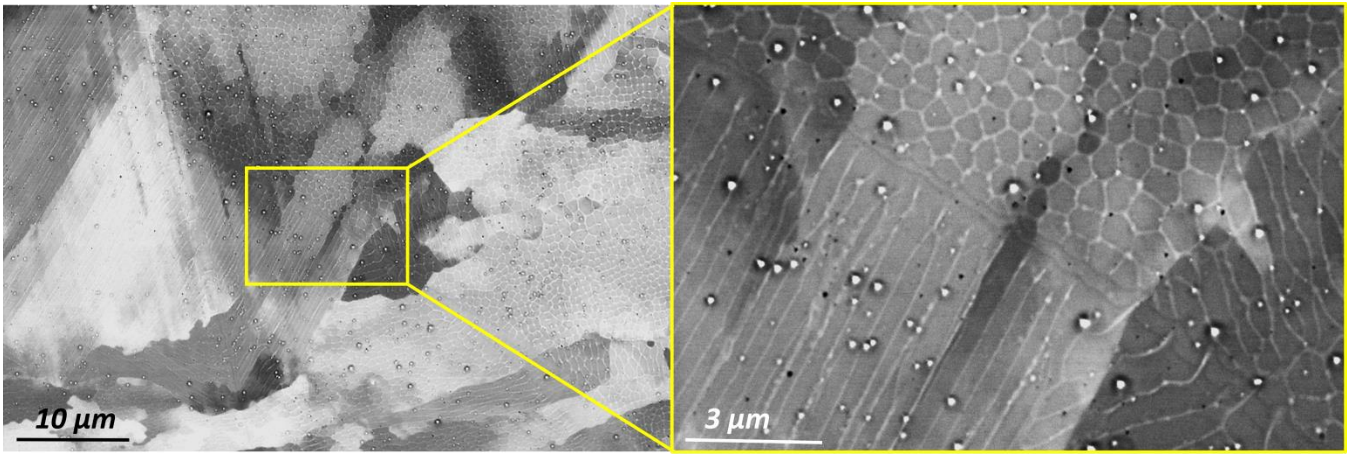

Figure 2. The SLM 316L bulk specimen imaged at 1 keV landing energy of the primary beam using the last outer segment of the CBS detector.

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