MICROSTRUCTURE AND DEFECTS IN ADDITIVE MANUFACTURED TITANIUM: A COMPARISON BETWEEN MICROTOMOGRAPHY AND OPTICAL MICROSCOPY

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Summary: The aim of this work has been to compare two different analysing methods; x-ray microtomography and light optical microscopy, when it comes to defects and microstructure of additively manufactured Ti-6Al-4V. The results show that both techniques have their pros and cons: microtomography is the preferred choice for defect detection by analysing the full 3D sample volume, while light optical microscopy is better for analysing finer details in 2D.

1. INTRODUCTION

Electron Beam Melting (EBM) is an Additive Manufacturing (AM) method that manufactures, through melting layer-by-layer of metallic powder with an electron beam, near net shaping products [1] with little material waste. Its high accuracy makes it attractive for several different applications, such as for example medical implants as well as for aerospace industry, where high complexity and functionality is normally required. Compared with most other conventional manufacturing equipment and methods, the EBM equipment is more expensive which has the effect that the actual material cost of the final component produced becomes a smaller part of the total part cost. This makes titanium alloys, which are normally more expensive than other metallic materials, to be attractive for use in such AM processes. Further reasons to use titanium is due to its good mechanical properties, having the same mechanical properties as some steel grades, while having half the density, thus giving titanium a high specific strength. Furthermore titanium also has good biocompatibility and great corrosion resistance. For cyclic loaded components manufactured with AM, defects such as pores and Lack Of Fusion (LOF) have previously been found to dramatically decrease important mechanical properties, such as fatigue strength. In order to understand where and why such defects form during additive manufacturing, cutting of material and metallographic cross-section investigations is normally performed. This way of examining built material is time consuming and, even more important, not completely accurate because of that only limited part of the built material is investigated. In addition, this examination method permanently destroys the material.

2. EXPERIMENTAL METHOD

X-ray microtomography (XMT) is a method for 3D imaging of a specimen, based on the density distribution in the material. During a scan, a large number of x-ray projection images are captured at equal angles as the sample makes one full rotation, and the full 3D-microstructure is reconstructed using tomographic reconstruction software.
The experiments were performed using a LOM, Nikon eclipse MA200, and the XMT machine Zeiss Xradia 510 Versa. The sample was manufactured using the Electron Beam Melting technique by Arcam using the powder size 50 μm of Ti-6Al-4V. The sample diameter ranged from 6 to 10 mm, and the height was 30 mm. To obtain images for the LOM the sample first had to be cut into a cross-section perpendicular to the layers, then polished according to conventional methods and finally etched with Kroll's etchant. For the microtomography no sample preparation was needed. The scanning was carried out with a field of view of 11.6 mm, and a spatial resolution of 11.3 µm.

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3. RESULTS, DISCUSSION AND CONCLUSIONS

In this work a small tungsten particle was detected in the XMT images, while being undetectable using the LOM, on the EBM sample. The tungsten particle should not be present in the build as this small, and detrimental, inclusion could be a crack initiation site. In material science the microstructure is a very important as it determines the mechanical properties of the material. In AM the microstructure is hard to predict as it depends on both heating cycles and cooling rate, which for AM can be complex. In additively manufactured titanium prior beta grains grows epitaxially with a β <100> crystal growth [2-3] from one layer to another towards the heat source. Figure 1 shows two representations of these prior beta grains, captured using XMT (left) and etched LOM (right). XMT on one hand gives a full 3D representation, which is especially important when there are local variations in the sample that could stay undetected in a 2D representation. The high spatial resolution in LOM on the other hand allows studies of much finer details, but restricted to 2D. XMT usually do not require any sample preparation, compared to for example LOM, where the sample first has to be cut, polished throughout many grinding steps and finally etched.

Both XMT and LOM have their positive and negative sides, and the best way forward is probably to use them complementary and get the best aspects from both. The fact that XMT scanning is non-destructive allows us to do just that. First scan the entire batch of samples with XMT at a spatial scale that gives sufficient resolution for identification of the features of interest, and still with scanning times that are acceptable. From the complete 3D XMT data it should be possible to identify certain regions of interest, where one can cut and prepare the sample for a more thorough high-resolution study using LOM.

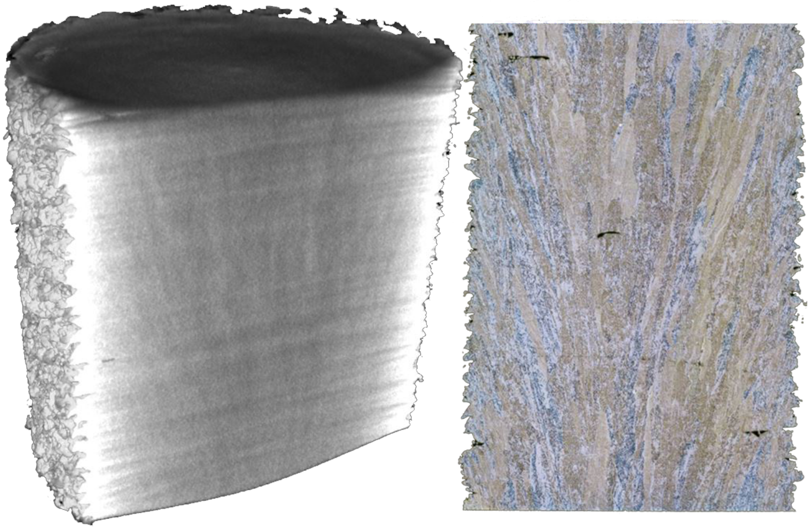

Figure 1: 3D visualization of the prior beta grains in an AM sample, captured using XMT (left), and an etched optical microscopy image (right)

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