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Characterization of defects/porosity in additive manufactured components using computer tomography

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The Future Metrology Hub

Introduction

- Additive manufacturing (AM) is relatively new technology, with the absolute ability of producing complex shapes that are impossible to be made using traditional subtractive machining.
- Currently there are several challenges stopping most manufacturers from producing critical components using additive manufacturing. These include a lack of repeatability, absence of well-established quality control systems and inconsistent mechanical properties due to internal defects/porosity, the lack of well operating monitoring processes that can detect imperfections (ex: incomplete fusion or porosity). Some of these have been highlighted previously by the UK AM special interest group (SIG) (Everton, Hirsch, Stravroulakis, Leach, & Clare, 2016).
- Most manufacturers are not yet prepared to rely on additive manufacturing due to the uncertainty about meeting the design intent and the overall integrity of the component.
- The existence of internal pores/defects cannot be avoided, furthermore the effect of any pore on the mechanical properties and fatigue life of the component is not well studied.
- At the moment 100% inspection is required, this inspection is adding costs and time to the already costly additive manufacturing process.
- Using 3D computer tomography (CT) to evaluate the density of the part is very promising, but obtaining the accurate geometry of a pore can be difficult and would require verification especially if the pore is not spherical as discussed by Jones et al. (Jones, Atwood, Poologasundarampillai, Yue & Lee, 2008).

Methodology

- The component was manufactured from Ti6AL4V using an Arcam Q10 electron beam melting machine (EBM). The powder size ranged from 45 µm to100 µm.
- This experiment is investigating the effect of magnification on defect measurement accuracy, using a Nikon XTH225 industrial CT. The sample was scanned with different levels of magnification: 2.5x, 5x, 10x and 15x. The position of the largest pore within the measurement volume was used as a marker to determine that the same volume was assessed in each measurement.
- In order to reduce the number of process variables, all the measurement process parameters, such as filament current, acceleration voltage and X-ray filtering material and thickness, are kept constant. The acquired data processing, surface determination process and defect analysis was carried out using VgStudio Max 3.0 (Volume Graphics, Germany).

Table 1 Settings used for CT measurements on Nikon XTH225:

Filter	2mm Copper
Exposure	500 ms
Filament current	180 kV
Acceleration voltage	150 µA

Results

- The analysis of the data acquired at 2.5x magnification suggest a defect volume ratio of zero as shown in figure 1. This increases to 0.03% at magnification 5 (figure 2) and further increases with the level of magnification. Overall the results of the study show that defect volume ratio is inversely proportional to voxel size (figure 3).
- To detect small pores the voxel size should be smaller than 20 µm. From the graph it was noted that when the voxel size was reduced from 20 µm to 13 µm the percentage of the defect volume ratio significantly increased. The problem with using a small voxel size, and therefore high magnification, is that most industrial components will not fit within a single scanning volume and therefore time taken for scanning and data analysis will be significant and in many cases not feasible. This is a potential barrier to industrial use of the technology for in-line part inspection.

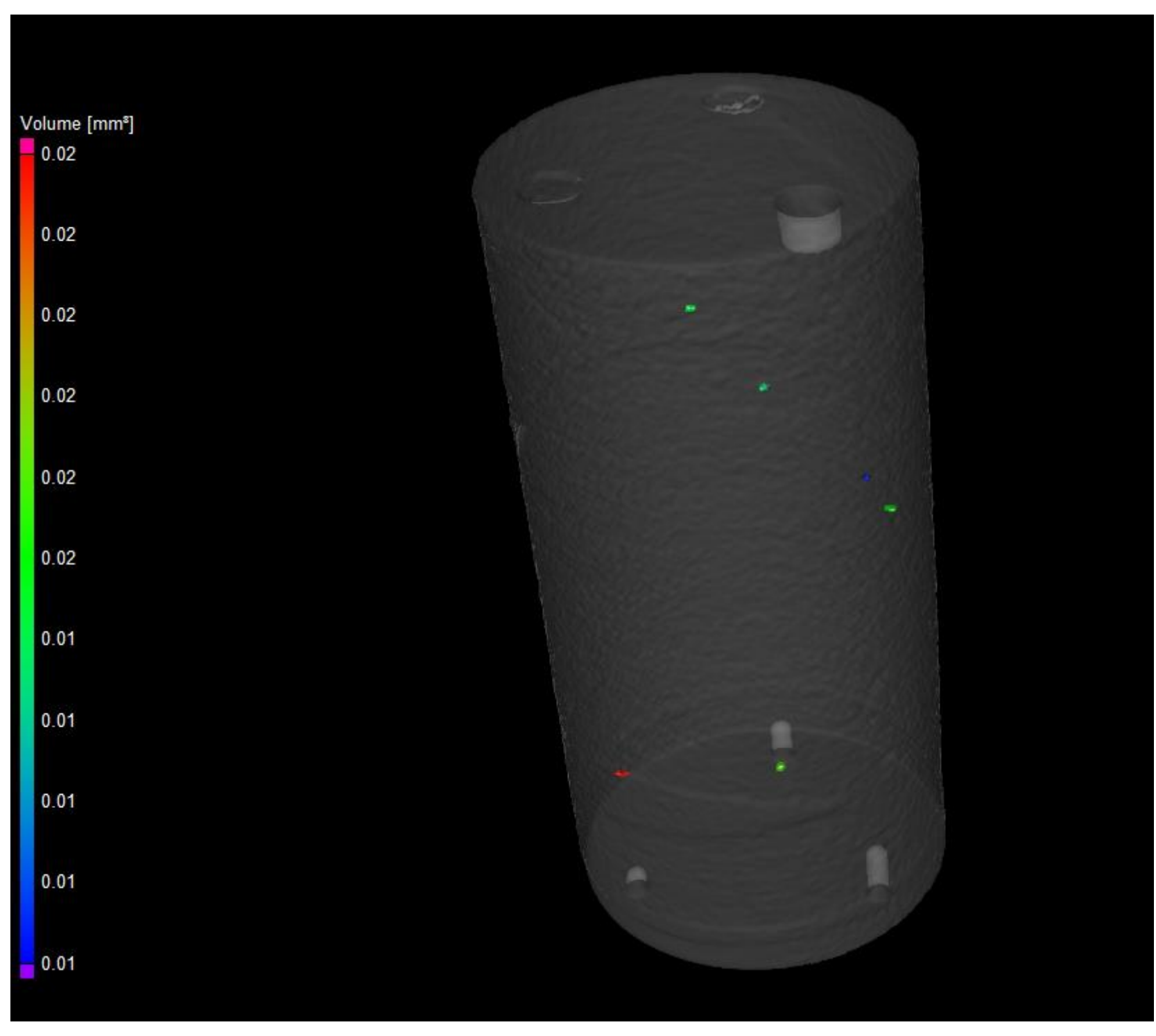


Figure 1 Results of defect analysis at Mag 2.5x Voxel size 0.07992mm

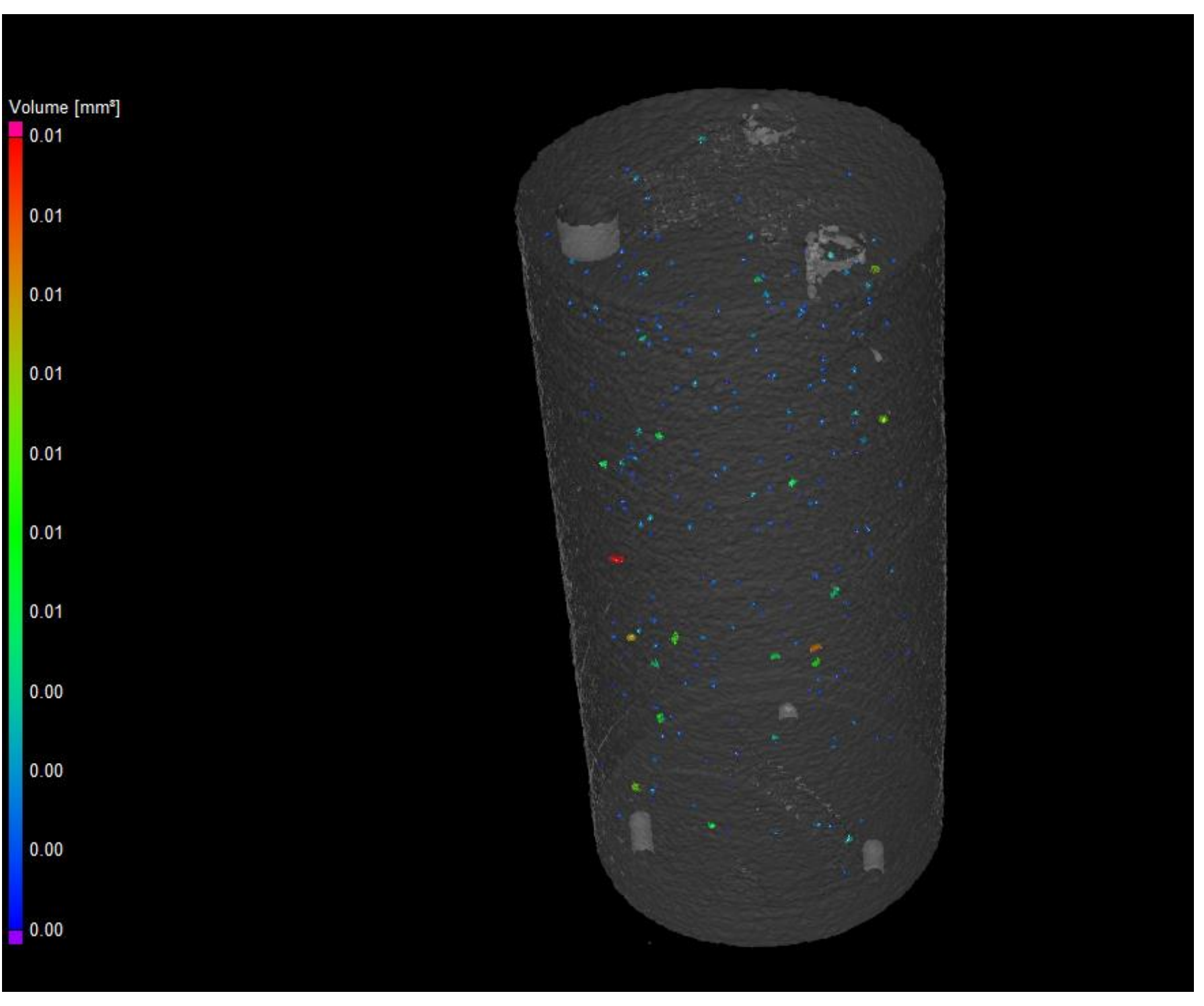


Figure 2 Results of defect analysis at Mag. 5x Voxel size 0.03991mm

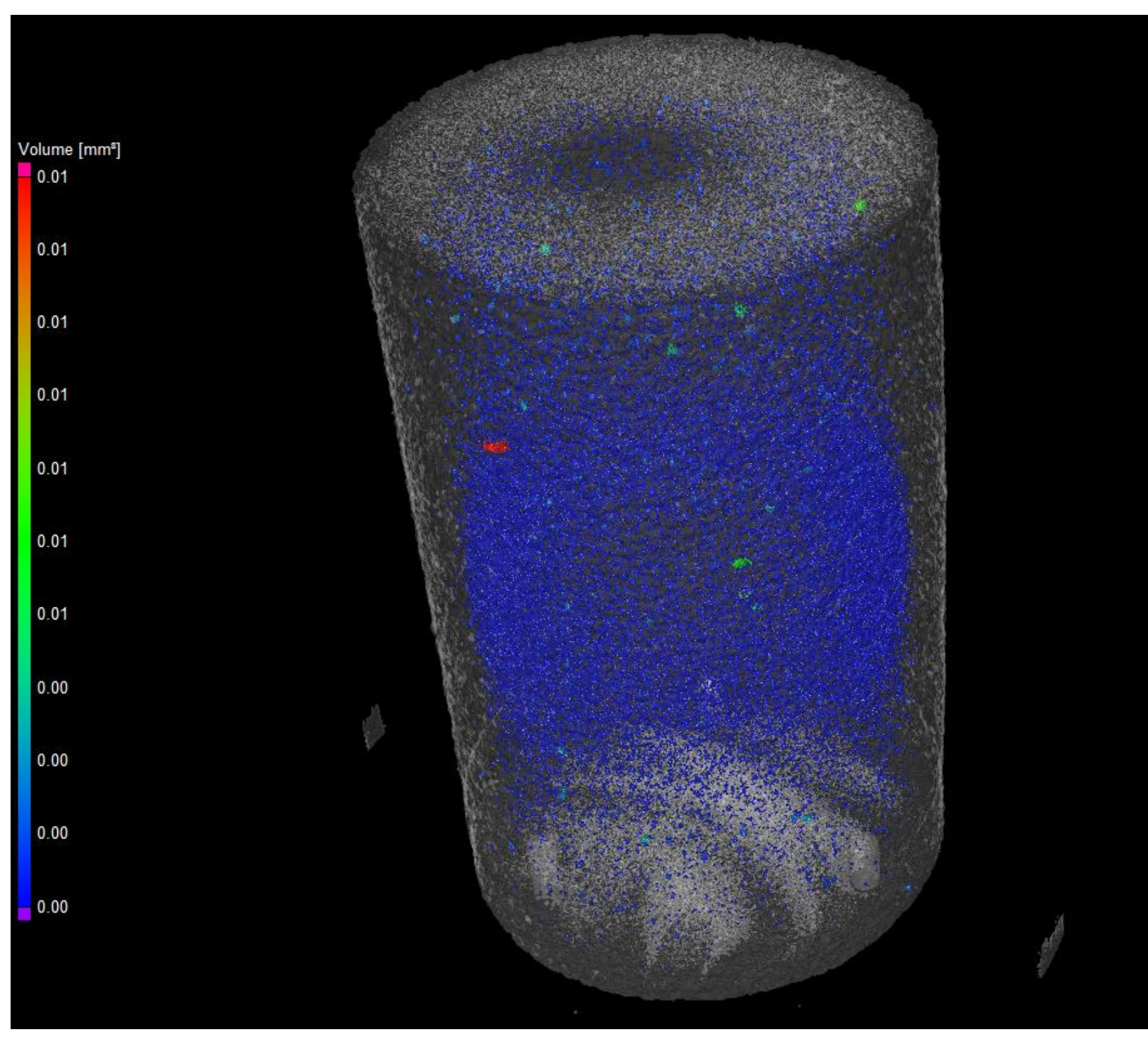


Figure 3 Results of defect analysis at Mag. 10x Voxel size 0.020

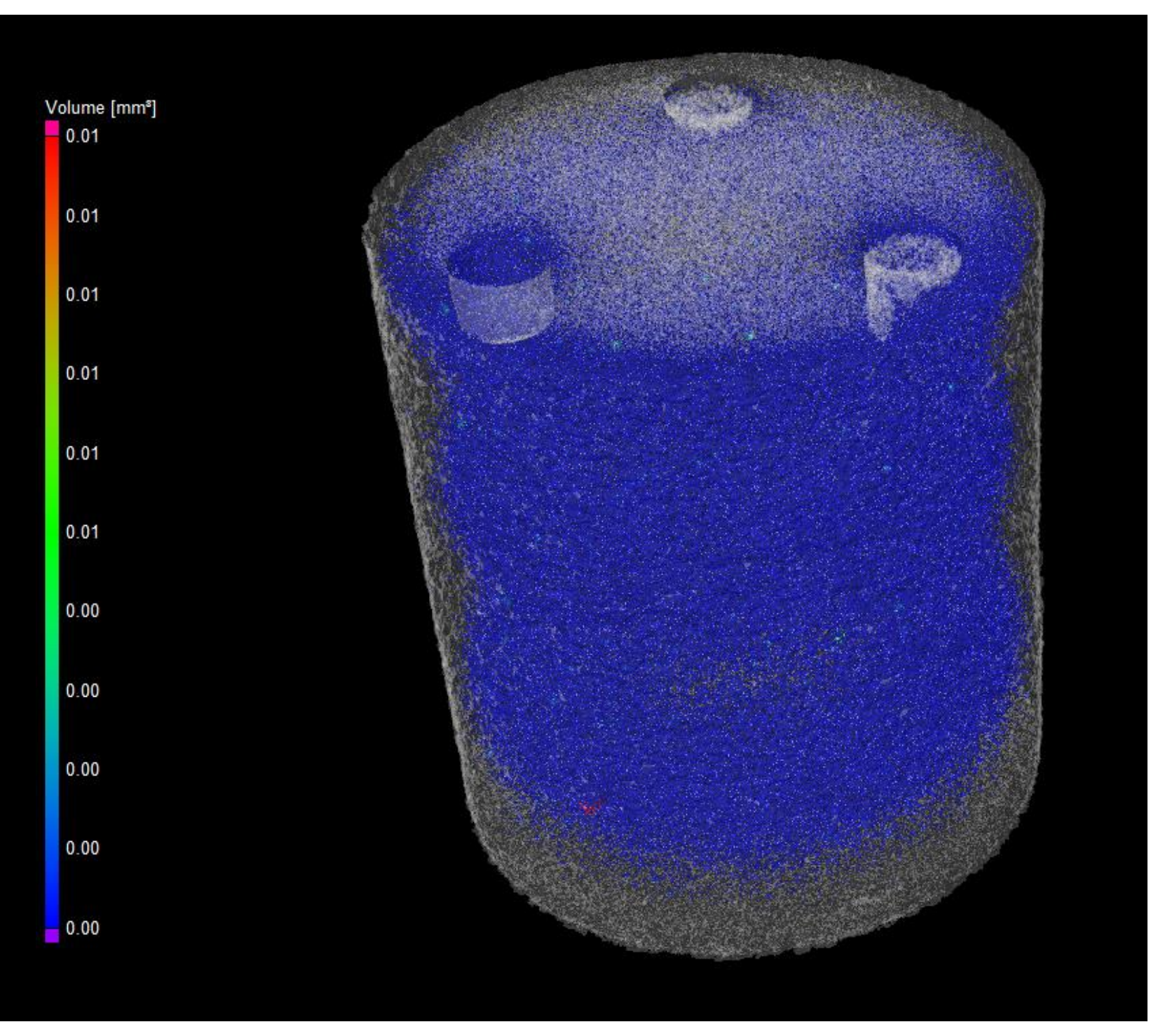
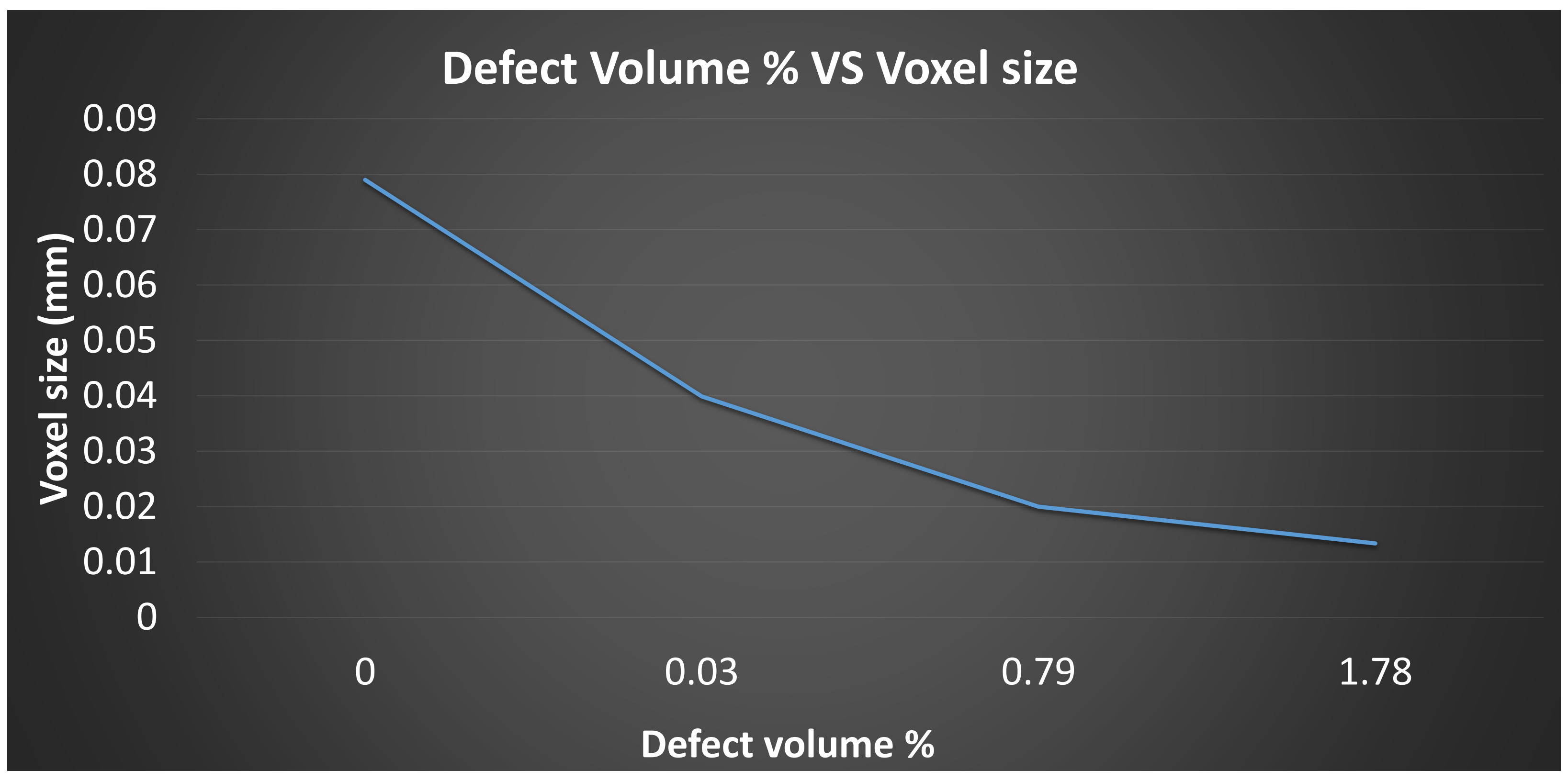


Figure 4 Results of defect analysis at Mag. 15x Voxel size 0.01336

Table 2 Largest defect/pore diameter vs Voxel size mm :

Largest pore/defect diameter (mm)	Voxel size (mm)	Magnification
0.42	0.079	2.5x
0.42	0.03991	5x
0.43	0.02	10x
0.58	0.01336	15x



Conclusions

- At high magnification detecting small pores is very challenging due to the amount of noise. This noise has great impact on the quality of the measurements and the accuracy of small pores detection.
- For this experiment all the pores less than 40 µm in diameter were filtered and assumed to be noise. In the next stage of this study this assumption will be verified by sectioning the sample. The sample will be machined in stages and measured using focus variation, by machining 20 µm each stage.
- This experiment shows that by increasing the magnification the number of detected pores is increasing; the big pores detection accuracy also improves.
- A voxel size of 7.5µm is sufficient to detect porosity accurately. Using the Nikon XTH225 industrial CT 7.5µm equates to magnification 20x enabling the scanning of a sample less than 8mm in diameter.
- The detected diameter of the two largest pores (around 0.6 mm) within the measurement volume was reduced by 9.8% from magnification 10 to magnification 15.
- Whilst scanning at high magnification definitely improves the accuracy of the obtained results there are significant practical limitations in doing this.
- In non-safety critical and partially optimised components small volume pores may be largely insignificant to the performance of the component. However, given the inherent potential of AM as a technology the optimisation of design intent will dictate that this may not always be the case.

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