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Development of an AM artefact to characterize unfused powder using computer tomography

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Abstract

Additive manufacturing (AM) is recognized as a core technology for producing high value components. Producing complex and individually modified components as well as prototypes gives additive manufacturing a substantial advantage over conventional subtractive machining. One of the current barriers for most industries in implementing AM is the lack of build repeatability and a deficit in quality assurance standards. The mechanical properties of the components depend critically on the density achieved therefore defect/porosity analysis must be carried out to verify the components' integrity and viability. Detecting unfused powder in AM parts using computer tomography is a challenge because the detection relies on differences in density.
This paper presents an optimized methodology for differentiating between unfused powder and voids in additive manufactured components using computer tomography. Detecting the unfused powder requires detecting the cavities between particles, from previous work it was found that detecting unfused powder requires voxel size as small as 4µm³. For most applications scanning with small voxel size is not reasonable; due to part size, long scan time and data analysis. In this investigation different voxel size used to compare the time for scan and data analysis showing the impact of voxel size on micro defects detection. The powder used was Ti6AL4V with a grain size of 45-100µm, typically employed by Arcam electron beam melting (EBM) machines. The artefact consisted of a 6mm round bar with designed internal features ranging from 50µm to 1400µm that contain a mixture of voids and unfused powder. The diameter and depth of defects were characterised using focus variation microscope then scanned with A Nikon XTH 225 industrial CT was used to measure the artefacts and characterise the internal features for defects/pores.
To reduce the number of process variables, the measurement parameters, such as filament current, acceleration voltage and X-ray filtering material and thickness are kept constant. VgStudio Max 3.0(Volume Graphics, Germany) software package was used for data processing, surface determination and defects/ porosity analysis. The main focus of the study is exploring the optimum methods to enhance the detection capability of pores/defects whilst at the same time minimising the time taken for scan, data analysis and effects of noise on the analysis.

Unfused powder, Defects analysis, Additive Manufacturing, Computer tomography

1. Introduction

The mechanical properties of a given component can be assessed by destructive or non-destructive testing methods. Destructive testing methods often require long testing times and by definition the component cannot be used after testing. There are various non-destructive test methods to detect internal defects/pores ex: Archimedes, materialography and ultrasonic. These methods do not provide accurate or any information about pore size, shape or distribution. A recent study has shown that the shape and location of the pore must be considered to avoid premature failure. (Lambert, Chambers, Sinclair & Spearing, 2012).

The pores/defects in additively manufactured component are different when compared to cast components. The pore in the cast component is usually hollow filled with air, in the AM component the pore could be either hollow, filled with unfused powder or filled with partially fused powder. The unfused powder can be as small as 45µm (AP&C, 2017) when considering EBM manufactured components and respectively 15µm for selective laser melting (SLM) (Slm-solutions.com, 2017).

2. Artefact development

In this experiment a Nikon XTH225 industrial XCT was used to characterise a Ti6AL4V artefact built using an Arcam Q10 electron beam-melting machine (EBM). Prior to measurement 50, 100, 500 and 1400µm holes were drilled onto the polished surface of the artefact using a CNC machine equipped with micro drills and end mills as shown in figure 1, the holes are in this case selected to be representative of typical defects. The specific dimensions for the defects were selected based on the actual pores identified earlier within an AM component. The 1.4mm and 0.5mm diameter holes were selected to be filled with powder whilst the 50 and 100µm diameter holes were left hollow. For the EBM AM machine the layer thickness is 40µm (Dsiac.org, 2017) therefore the 50µm hole will reproduce a single layer defect and the 100µm hole will replicate a two layer one depending on orientation in the XCT. The surface was machined using a diamond cut finish whilst the mating part with the same diameter was designed to enclose the drilled holes thus creating internal defects/pores. The principle of ringing the two surfaces together is similar to that employed for slip gauges.

3. Methodology

Once the artefacts were 3D printed and the defects machined/drilled, the defects were characterised using a focus variation interferometer to determine reference values.
Prior to filling 1400µm and 500µm with powder the artefact was scanned with the Nikon XCT and then once filled rescanned the area of interest with 38, 20, 15, 13 and 7µm voxel size. Figure 1a shows a 3D model of the artefact and figure 1b the defects filled with powder.
The obtained results were analysed with VG Studio Max 3.0, surface determination and porosity analysis were optimised for each voxel size scan to ensure the highest possible accurate results. The dimensions and volume for each defect was compared between different voxel sizes XCT results and the Alicona reference results. The time taken for analysis was compared against voxel size.

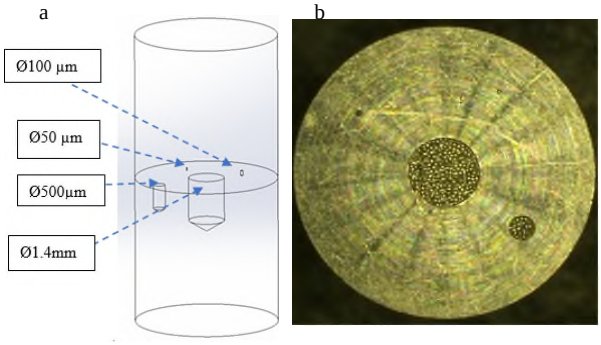

Figure 1 a) Artefact 3D model , b) top view of the artefact with defect 1 and filled with powder.

4. Results

From the Alicona measurement the diameter was measured by using 3 point best fit circle, the depth was measured by selecting 2 points to the upper surface creating a horizontal line and a point to the lowest point in the drilled hole. The volume of each defect was calculated by assuming that each defect consists of a cylinder and a cone. The XCT data was analysed using Volume Graphics VGStudio Max 3.0.3. The surface determination and defect analysis settings were optimized for low magnifications scan (Voxel size 38 and 20µm) to enhance the results accuracy. The diameter was determined by using best fit geometry measurements based on the surface determination. Three points were selected on the diameter creating to generate a circle. The depth was evaluated using the distance measurement by selecting the highest and lowest point in the defect. Figure 2a shows 3D image of the artefact scanned with voxel size 7.4 µm, figure 2b shows defect 1 filled with powder and figure 2c shows defect 2 filled with powder.

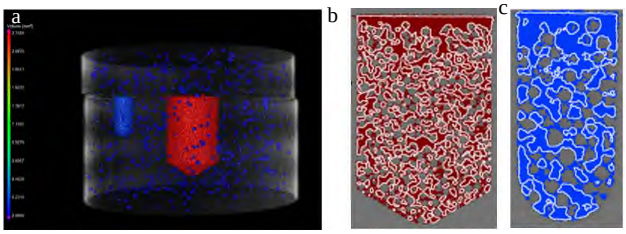

Figure 2. a) Defect analysis of artefact, b) Defect 1 filled with powder,c) Defect 2 filled with powder scan at voxel size 7.4 µm

The air gaps between the powder particles are not uniform owing to the difference in the diameter and shape of the powder particles. It is evident using the correct XCT settings that it is possible to identify the existence of powder and the overall shape of the defect as well as the size of some of the cavities between particles.

5. Discussion

The obtained results from this investigation confirm the ability of XCT to accurately quantify the internal defects dimensions and volume. While scanning using high magnification (Voxel size 7.4µm) the difference between Alicona and XCT results is 0.55% for defect 1 diameter , 1.32% for defect 2 diameter. In the case of the micro defects 3 and 4 the difference in diameter is 4.7% and 4.6% respectively.
A comparison between the volume obtained from XCT results for different magnifications found that there is 27.8% difference between the voxel size 7.4µm and voxel size 38µm. Figure 3 shows the voxel size VS time taken for analysis. The time taken for results analysis for the largest voxel size (38µm) is reduced by 95% from the smallest voxel size.

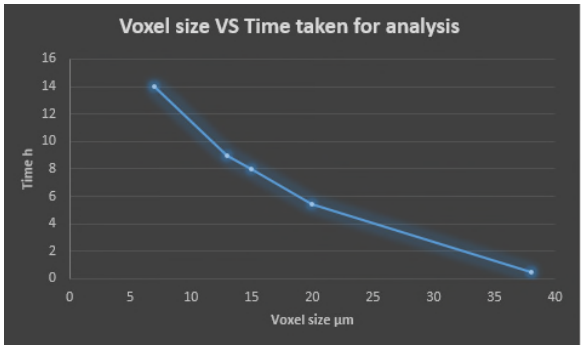

Figure 3 Voxel size VS analysis time

6. Conclusion

The developed artefact enables the user to create relevant sized defects and evaluate the capability of the defect analysis inspection process. The mechanical properties of solid material, semi fused and un-fused powder have been shown to be completely different. As such, it is well understood that a solid component will always outperform any component with internal defects. The size and quantity of acceptable internal defects is solely depending on the design intent.
This investigation proved that detecting micro defects (gaps between unfused powder) does not require high magnification (low voxel size). The best strategy is scanning the component with low magnification to identify the location of the defects, then to confirm rescan the area where the defect is located with high magnification. This method will enable scanning larger components in shorter time without compromising on the results accuracy.

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