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3D X-ray Inspection of a Radio Controlled Airplane Engine

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Abstract. This paper describes a typical 3D X-ray micro computed tomography (microCT) analysis of light metal parts, from a radio controlled airplane engine. This case study shows the power of 3D X-ray inspection and analysis for this type of material, including information about the size and location of casting defects, the location of turbine blade balancing weights and dimensional measurements indicating the axle was not perfectly centre. Advantages and limitations of the method for light metals are described in general.

Introduction

X-ray micro computed tomography (microCT) is an advanced materials characterization tool which is gaining popularity as its capabilities are being appreciated and service facilities make the technique accessible and cost effective, even for routine non-destructive testing. A review of X-ray microCT in materials sciences is given in [1]. In routine 2D X-ray inspections, an object is subjected to X-rays and a 2D image is formed. In this image, defects such as gas pores can be identified, but the accuracy is limited by the contrast possible, which is affected by material type, thickness and total part complexity. In microCT, 1000's of 2D X-ray images are acquired as the sample rotates, and a full 3D reconstruction is made from these images, creating a 3D volume representing the scanned object. Analysis is then made from the 3D volume data, allowing volumetric and dimensional measurements as well as advanced automated analyses such as defect analysis. The advantages are that defects are seen at a higher contrast and that less bias is present, especially for complex shapes (of the sample). Automated porosity analysis is quite simple when using commercial systems and software, as described in [2]. A case study of the analysis of a titanium casting describes the capability for defect analysis, wall thickness analysis and part to CAD comparison [3]. Furthermore, the nondestructive nature of the method allows for analysis of parts before and after treatment, as shown for titanium casting defects in [4].

This paper demonstrates the type of analysis possible on a commercial radio controlled airplane engine comprising light metal components. This analysis is done within a reasonable time, the total job time for all analysis presented here was less than 8 hrs. A typical scan and defect analysis can be performed in 2-3 hours while large batches of identical parts can be processed at further reduced times. The aim of the paper is to demonstrate the type of information available from the technique and what limitations and object considerations are inherent to the method, with a focus on light metals.

Experimental details

X-ray microCT scans were performed at the Stellenbosch University CT Scanner Facility, using in this case a General Electric Phoenix V|Tome|X L240. Most scans performed here were done with

200 kV and up to 200 µA, with 500 ms per image and scans up to 35 minutes excluding setup and post processing time. Analysis was performed in Volume Graphics VGStudioMax 2.2. The samples were provided by Clinton from Micton Hobbies in Somerset West, South Africa. The samples were from a radio controlled airplane which had crashed and had been damaged.

Results and discussion

The engine casing, a light metal casting (an aluminium alloy), was scanned with its spark plug still in place (Fig. 1a). Generally, the removal of unwanted material increases image quality but in this case it was left in place to save time. The scan data was analyzed for defects using first an automatic surface fit function (Fig. 1b), followed by an automated defect analysis. In this process, each defect found is listed in a result-table, with information about its location, surface area, volume and more. By viewing the defects in 3D colour-coded by volume, the distribution of defects and problem areas can be viewed easily (Fig. 1c). An even simpler way of visualizing problem areas is by selecting only the pores larger than 1 mm and only viewing those in 3D as demonstrated in Fig. 1d. Clearly there are more casting defects towards the right and near the bottom, which is also incidentally exactly where the breakage occurred (see red circle). Figure 2 shows a close-up view of the largest defect toward the bottom right, including 3 orthogonal slice views which allow a more detailed view of the pore shape and its vicinity.

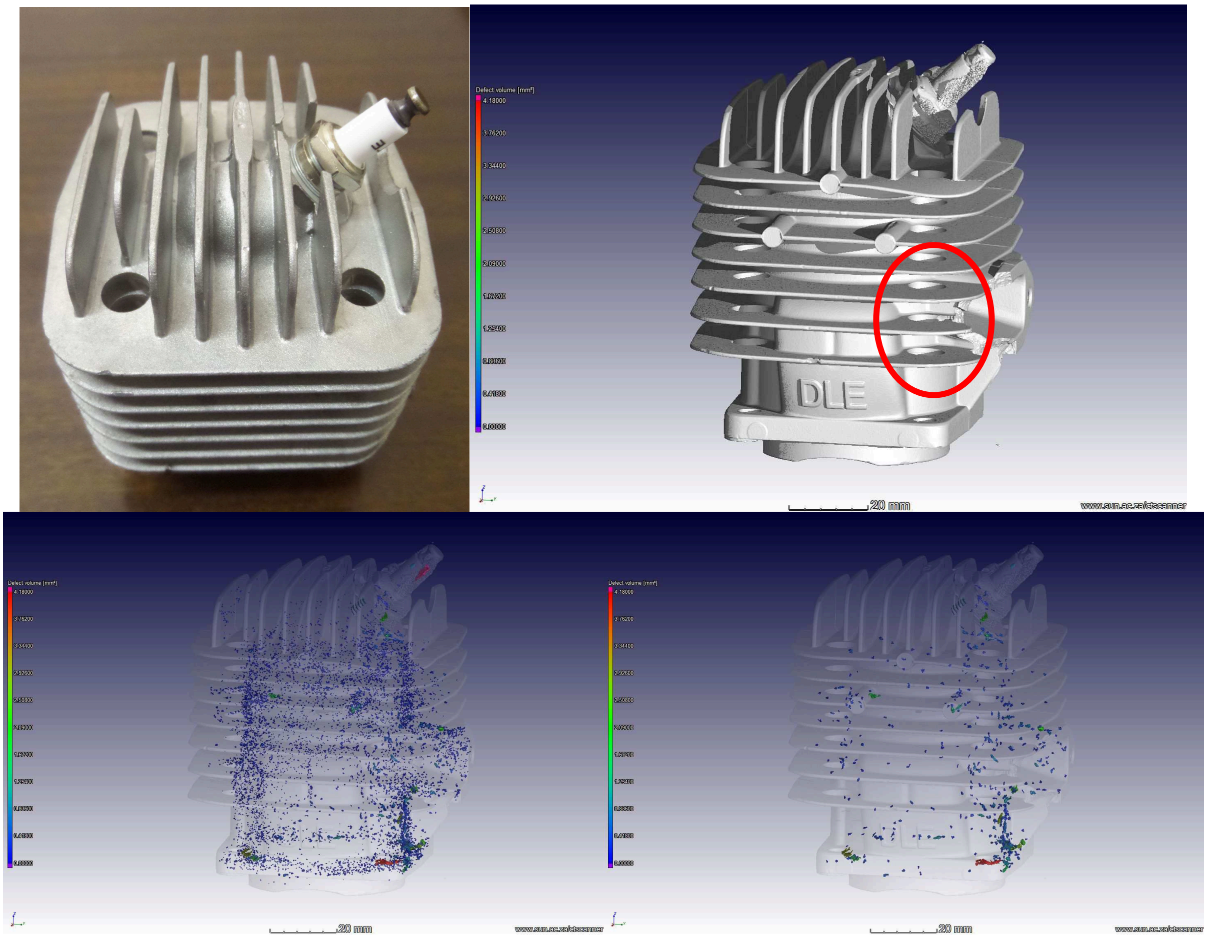

Fig. 1. Light metal engine casting (a) photograph; (b) 3D microCT surface render (c) 3D microCT defect analysis with all defects/pores > 0.2 mm; (d) 3D microCT defect analysis with all defects/pores > 1 mm

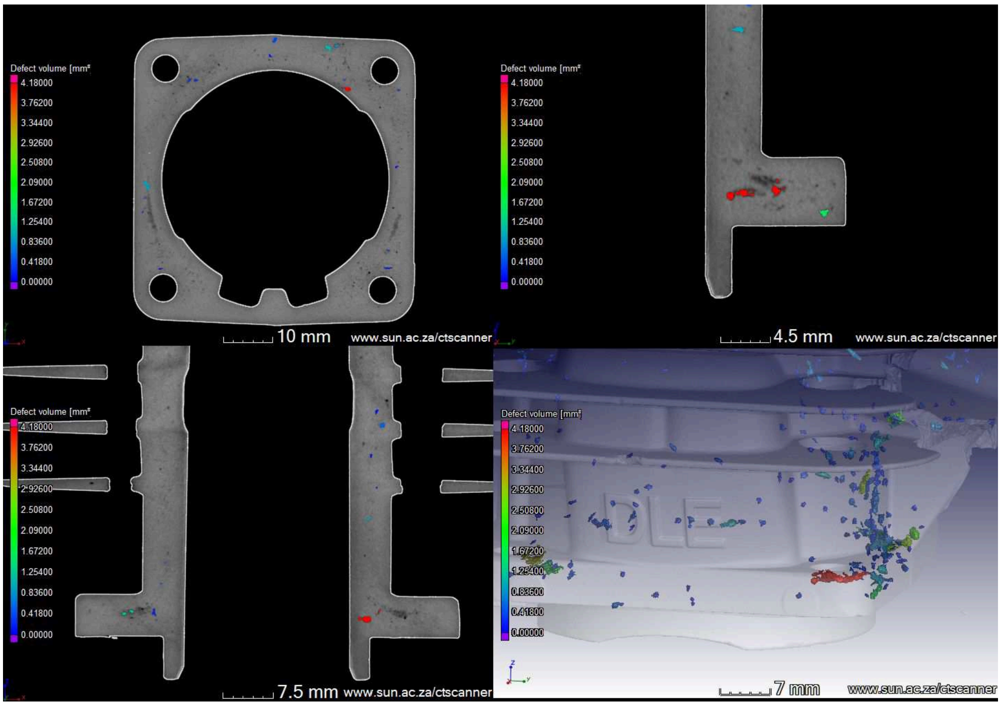

Fig. 2. An example of three orthogonal slice views and 3D close-up view to inspect the largest defect (red) in more detail.

In general there are two types of casting defects which occur frequently, namely gas pores and shrinkage pores. Two examples of these are shown in Fig. 3, where the gas pores are more spherical and well defined, and shrinkage pores are elongated, irregular shaped and are bordered by less dense regions than the surrounding material.

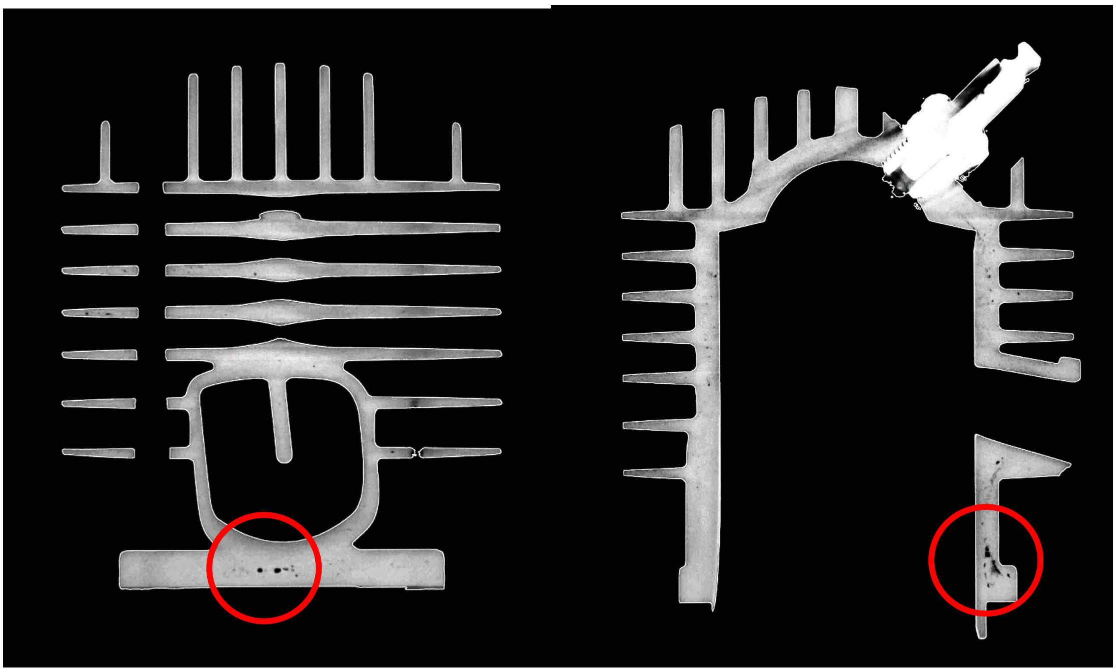

Fig. 3. Examples of slice images showing typical casting defects (a) gas pores, and (b) shrinkage pores. Gas pores are spherical and well defined and shrinkage pores are irregular shaped, with some lower-density regions surrounding them.

A physical sectioning was done on the sample and the resulting image of the largest pore in the base region is shown in Fig. 4. This 2D photograph is compared to a CT slice image of the same region, showing good correlation. The photograph is of higher image quality but not only is sectioning destructive, it only provides a single cross-sectional view while the CT data provides slice images in any direction and position in the sample.

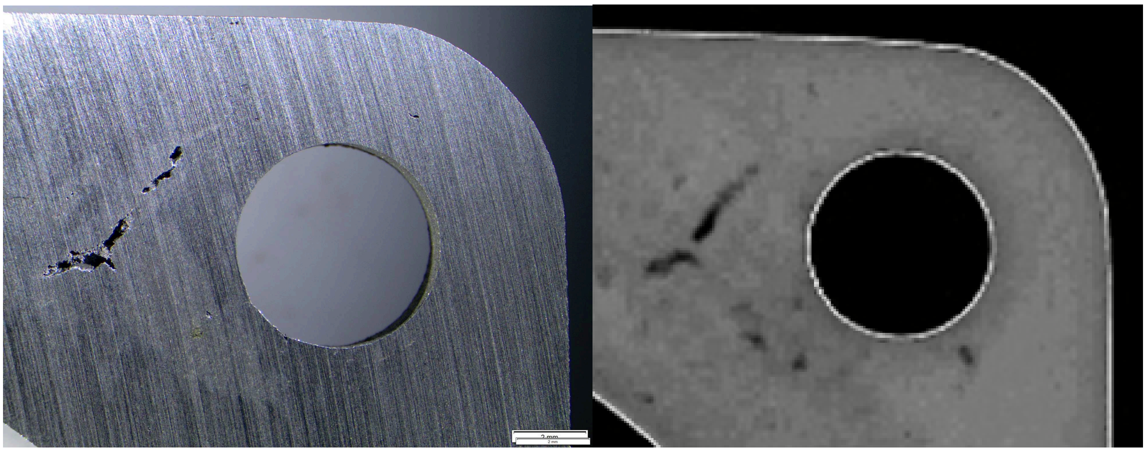

Fig. 4. Comparison between a physical cut and CT slice image of the same region. The physical cut confirms the presence of some of the largest pores visualized, but physical sectioning is much more time consuming and is destructive to the component.

Another component, a turbine assembly from the same radio-controlled airplane was scanned for potential defects. No defects were found, but other useful information gained from CT scans include the location and visualization of different components such as bolts and blade balancing inserts as shown in Fig. 5. In this case it was noted that the axle was off-centre as shown in Fig. 6. As the images are aligned on the central axle, the outer encasing tube is offset relative to the rod by almost 0.2 mm. This is an example of the type of dimensional analysis possible with the technique.

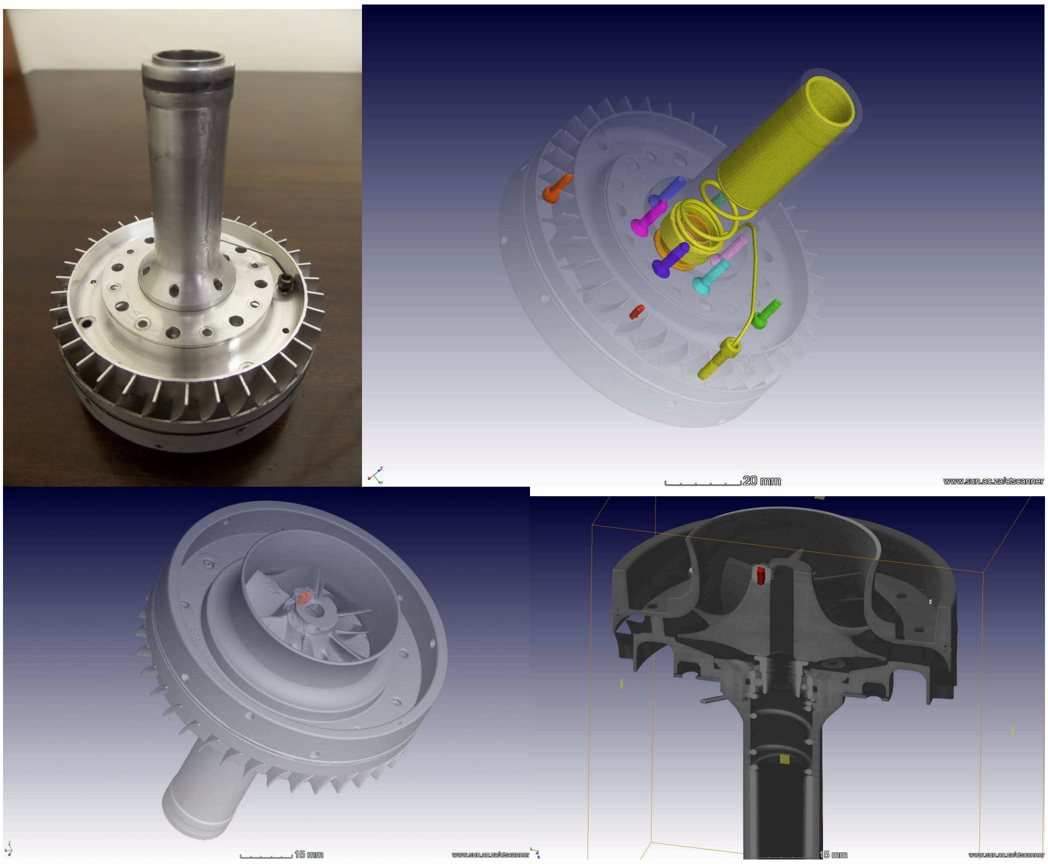

Fig. 5. Turbine assembly visualization of components in 3D, including turbine balance weights (red).

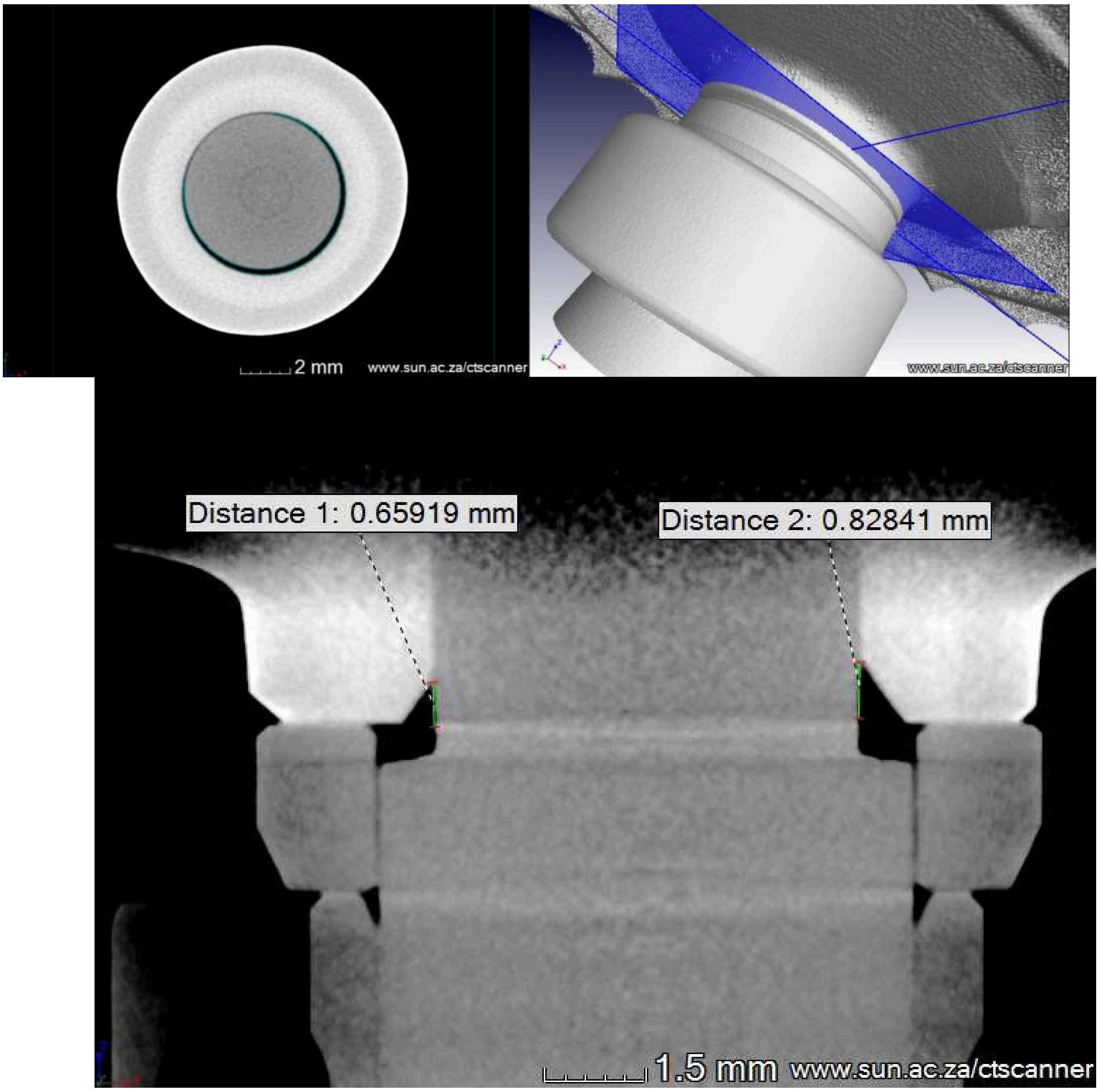

Fig. 6. Turbine assembly close-up shows axle off-centre

Additionally, the surface fit allows the generation of a STL file for reverse engineering applications, which includes internal surfaces and is cost effective for external surfaces when compared to the time consuming process of surface scanning techniques.

Furthermore, other automated analyses are possible such as wall thickness analysis, part to CAD comparison, inclusion analysis and more.

The only major limitation of microCT scanning is the sample size relative to the required scan resolution. If a resolution of 50 microns is required, the sample cannot be larger than roughly 50 mm in its longest axis (in some cases multiple scans can overcome this limitation). This means that if porosity or defects on a size scale of 10 microns need to be visualized, this can only be done in parts about 5-10 mm in diameter. Another limitation related to sample size is X-ray penetration – if a part is too dense or contains very thick walls, lack of sufficient X-ray penetration degrades the resulting image quality which can result in automated analysis not being possible. Slice images can still be successfully used for inspection but 3D analysis including those shown above cannot be done as easily. This limitation is clearly overcome in this example, and is generally not a major problem for light metals.

Summary

3D X-ray inspection of radio-controlled airplane engine parts was demonstrated, including defect analysis highlighting a problem area with many voids, which is where the part broke off. This problem area did not contain the largest void, which was identified and located in a thicker region. Gas and shrinkage pores were both shown in CT slice images demonstrating the typical quality of viewing defects manually. A turbine assembly analysis provided a unique view of the location of turbine blade balance inserts, as well as the fact that the axle is slightly off-centre. The method clearly holds many advantages for the analysis of light metals in particular, due to good X-ray penetration possible for this type of material. More images and videos of this example are shown at this weg-page: http://blogs.sun.ac.za/ctscanner/3d-x-rays-of-radio-control-airplane-engine/.

References

[1] E. Maire, P.J. Withers. Quantitative X-ray tomography. International Materials Reviews 59.1 (2014) 1-43.

[2] A. du Plessis, B.J. Olawayu, W.P. Boshoff, S.G. le Roux. Simple and fast porosity analysis of concrete using X-ray computed tomography. Materials and Structures. Accepted, available online.

[3] A. du Plessis, P Rossouw. X-ray computed tomography of a titanium aerospace investment casting. Case Studies in Nondestructive Testing and Evaluation. Accepted, available online.

[4] A. du Plessis, P. Rossouw. Investigation of porosity changes in cast Ti6Al4V rods after hot isostatic pressing. Submitted.