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Non-destructive analysis of the porosity identification process using computed tomography

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Abstract
The identification of internal defects, such as pores and cracks, is essential to ensure the structural integrity and mechanical performance of industrial parts. X-ray Computed Tomography (XCT) has emerged as a valuable tool for non-destructive testing in industrial applications, allowing for detailed inspection of internal structures without damaging the object. However, the reliability of XCT measurements strongly depends on factors such as the XCT system configuration or the post-processing software employed for the inspection.
This study evaluates the porosity detection capabilities of two different software programs applied to a polymeric part fabricated via additive manufacturing and measured using a high-precision XCT system. The work involved the design, manufacturing and measurement of a reference part using Fused Deposition Modelling (FDM) technology. The measurement has been performed by the Zeiss Metrotom 800 XCT system. Internal defects generated during the manufacturing process were analysed as porosity using two software programs: Zeiss Inspect X-Ray and VGStudio. The results were compared to determine the consistency and reliability of defect detection across the two platforms. It was observed that smaller pores were detected only by VGStudio, while larger pores were identified by both software programs, although their size was reported as smaller in Zeiss Inspect. This study highlights the importance of selecting appropriate post-processing software for precision XCT measurements.

Keywords: Computed tomography; Internal defects; Porosity; Non-destructive testing.

1. Introduction

Additive Manufacturing (AM) processes are increasingly employed to produce functional end-use parts rather than just prototypes. This technology is characterized by its design freedom and process flexibility, as it enables the creation of parts with complex geometries while minimizing waste.
However, internal defects such as pores, cracks, or inclusions can still occur during the manufacturing process. These defects can be identified by non-destructive testing (NDT) techniques, such as ultrasonic testing, the Archimedes method or X-ray computed tomography (XCT) [1].
XCT is a powerful tool capable of inspecting external and internal structures in many industrial applications as well as providing accurate geometrical information with very high accuracy [2]. Porosity analysis using XCT offers significant advantages over other NDT: its high resolution enables precise detection of microdefects beyond the capabilities of ultrasound. Unlike other NDTs, it requires no physical contact and identifies internal defects.
Nevertheless, it must be taken into account that the accuracy of metrological inspections of tomographed parts is highly dependent on the configuration of the XCT system, as reported in the literature [3]. Moreover, the choice of software employed for inspection also influences the final outcomes [4]. The aim of this study is to evaluate porosity detection results in a tomographed part, using two different software programs: Zeiss Inspect X-Ray and VGStudio. The analysis focuses on assessing the consistency of results concerning global porosity percentage, pore quantity, and defect volume.

2. Design and methodology

2.1. Test workpiece

For the study, a sphere integrated into a base has been designed. The sphere is positioned on a support that includes a marked corner, ensuring a single alignment during software processing. Without this mark, the symmetry of the piece would result in four possible alignments, complicating the comparability of inspection results between the two software programs. The sphere has a nominal diameter of Ø14.9 mm and the base dimensions are 21 mm x 15 mm x 15 mm.

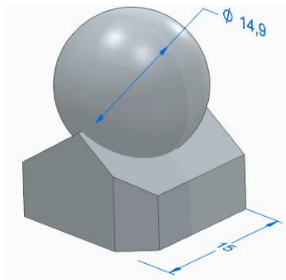

Figure 1. Sphere test workpiece.

The test workpiece has been manufactured using a Ultimaker S5 Fused Deposition Modelling (FDM) printer with PETG material, a layer thickness of 0.15 mm and a wire width of 0.4 mm. While the part was intended to be solid, the inherent characteristics of this manufacturing process result in gaps between the printed wires, which will be analysed as porosity.

2.2. Measurements

Experimental measurements have been performed by the XCT machine Zeiss Metrotom 800 G3/225 kV (integrated software Metrotom OS 3.12). Relevant XCT parameters used in this study are as follows: a voxel size of 30 µm, a current of 494 µA, a voltage of 100 kV, a number of projections of 1200, and an integration time of 500 ms. In previous studies, it has been observed that these parameters are appropriate for this type of test workpieces.

Three measurements of the test workpiece have been performed to observe the repeatability of the results obtained.

2.3. Post processing software

The internal defects of the test workpiece were analysed using two software programs: Zeiss Inspect X-Ray and VGStudio Max 4.3.2.

In Zeiss, a study of volume defects can be carried out in the mesh or in the tomography volume, obtaining a greater number of defects in the second case. In contrast, VGStudio only allows for volume defect analysis. A study of volume defects has been carried out in both programs, obtaining the global porosity percentage, the total number of defects (pores) and the size of each defect, for Zeiss and VGStudio.

No filters have been applied during post-processing in any of the programs, but pores smaller than 27000 µm³ have been manually removed because the voxel size used is 30 µm. This allows for the exclusion of volumes smaller than the voxel volume.

3. Results

The test workpiece was scanned and analyzed three times using both software tools, revealing repeatable behavior.

The mean defect global volume percentage (porosity) in Zeiss Inspect X-Ray is a 0.194% with a maximum deviation of 0.015% between the three measurements, while in VGStudio the mean is 10.708% with a deviation of 0.017%. If defects smaller than the selected voxel volume were considered, the percentage for Zeiss Inspect X-Ray would remain unchanged, whereas VGStudio percentage would increase to 12.775%. This additional 2% consists of very small defects that could lie at the boundary of multiple voxels, resulting in a separate defect being identified in each voxel.

In the VGStudio analysis, a higher number of pores and larger defect sizes are observed, while Zeiss detects fewer pores and identifies smaller volumes of porosity. The blue bars in the histogram in Figure 2 highlight the larger defects identified in VGStudio, which closely match the total defects detected by Zeiss Inspect (red bars) in terms of defect count and distribution. However, these pores are identified with a smaller volume in Zeiss. The green section represents small volume defects detected by VGStudio that Zeiss Inspect X-Ray does not detect, as verified through individual pore comparisons in the software.

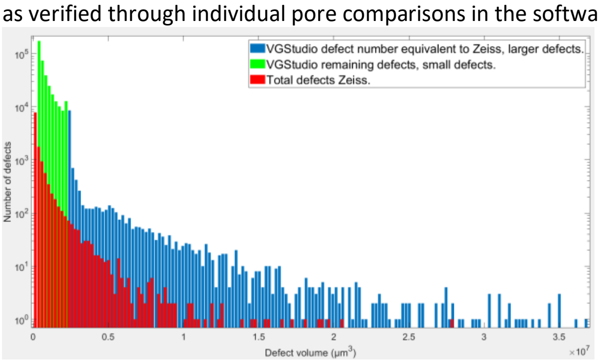

Figure 2. Defect volume histogram in Zeiss and VGStudio.

When comparing the same section of the tomographed part in Zeiss Inspect X-Ray and VGStudio (Figure 3), it can be observed that the pore distribution in terms of geometry is similar, but the volume sizes differ. The distribution of smaller defects in Zeiss resembles that of larger defects in VGStudio, as seen in Figure 2. Additionally, the smaller internal defects identified in VGStudio are not detected by the Zeiss Inspect, although in the tomography volume they appear as darker areas.

This explains why porosity percentage in VGStudio is two orders of magnitude higher, as shown by the curves of the graph in Figure 2. This difference can also be visually verified in the section analyzed with each program (Figure 3).

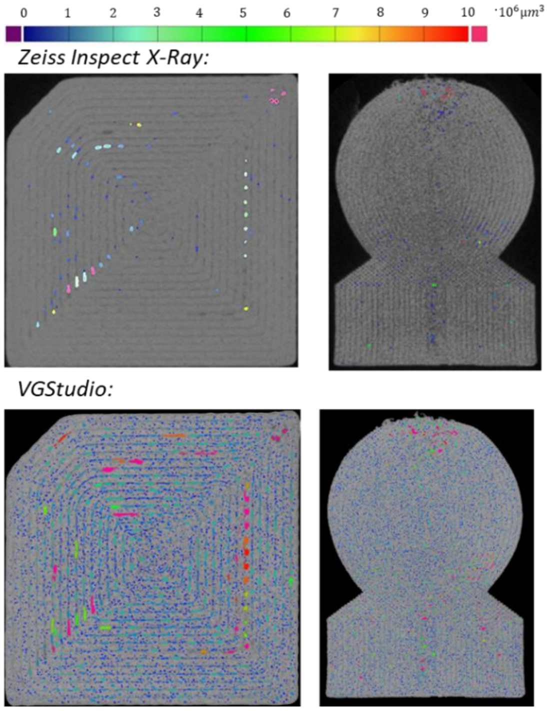

Figure 3. Distribution of internal defects for the same section in Zeiss Inspect X-Ray and VGStudio.

4. Conclusions and future work

This paper presents an analysis of internal defects using two software on a tomographed workpiece manufactured through additive manufacturing.

The results show that Zeiss Inspect X-Ray fails to recognize the smaller pores detected by VGStudio, while it does identify the larger pores, but with a smaller volume than VGStudio. This highlights the limitations of post-processing software in identifying small internal defects and emphasizes the importance of understanding these limitations when conducting a porosity study in XCT measurements.

For future work, it would be valuable to verify whether the pore volumes detected are comparable to those obtained through other calibrated measurement methods, such as the focus variation microscope. However, the main challenge lies in designing parts in such a way that measurements can be performed without damaging the samples.

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