µ-Computed Tomography for 3D Porosity Evaluation in Carbon Fibre Reinforced Plastics (CFRP)

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Abstract. One very interesting application case for µ-Computed Tomography (µ-CT) is the assessment of porosity in CFRP in 3D. Up to know the degree of porosity is mainly evaluated by 2D micrographs at certain positions and therefore the sample has to be cut and cannot be used anymore afterwards. In addition the correlation between 2D and 3D is lacking. Evaluating the degree of porosity in 3D with µ-CT could overcome these limitations. This paper presents results of a study that assesses the parameters that might have an influence on the evaluated value. Thus, a CFRP reference sample and one with porosity were measured at the same time with varying testing parameters.. The three main fields taken into account are the parameters of the CT system, the reconstruction settings, as well as the software parameters for evaluation.

Introduction

One very interesting application case for µ-Computed Tomography (µ-CT) is the assessment of porosity in CFRP in 3D. Eurocopter started already in 2003/2004 with a first investigation. So far the degree of porosity is mainly evaluated by 2D micrographs at certain positions and therefore the sample has to be cut and cannot be used anymore afterwards. In addition the correlation between 2D and 3D is lacking (Figure 1) [1]. Evaluating the degree of porosity in 3D with µ-CT could overcome these limitations and also allows inspection of components at the same time. µ-CT could be used as a reference method for porosity evaluation and as an escalation technique if indications of commonly used NDT-methods are unclear. As a result the number of rejected parts can be reduced.

This paper presents results of a study that assesses the parameters that might have an influence on the evaluated degree. Therefore, a CFRP reference sample and one with porosity were measured at the same time with varying testing parameters.. The three main fields taken into account are the parameters of the CT system, the reconstruction settings, as well as the software parameters for evaluation. The aim is to proof the ability of µ-CT for reliable porosity assessment.

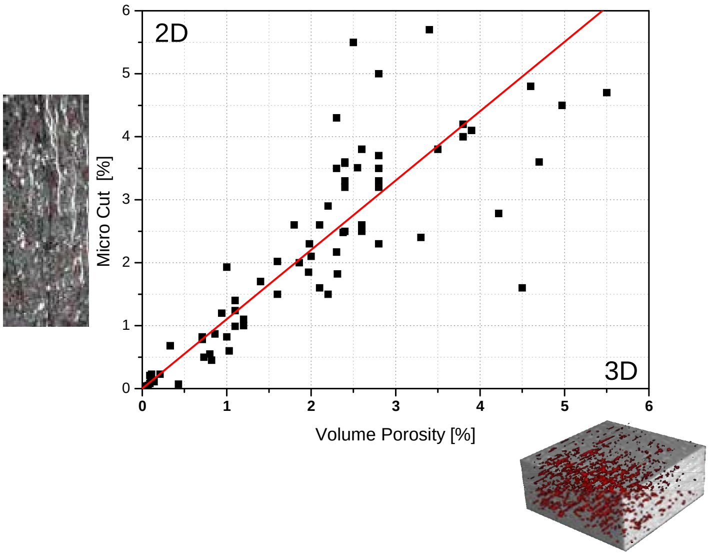

Figure 1. Correlation between degree of porosity evaluated at slices (2D) and 3D volume [1]

µ-Computed Tomography System

The µ-CT system (Figure 2) available at EADS Innovation Works was especially designed for the inspection of CFRP. The main features of the system are:

- System: RayScan 150 – RayScanTechnologies
  - <u>X-ray sources:</u>
    - Microfocus tube 10 kV – 225 kV
    - Sub-microfocus tube with diamond target 10 kV – 160 kV
    - Focal spot 2 µm – 250 µm
  - <u>Detector:</u>
    - 1024 x 1024 à 200 µm, 16 bit
  - <u>Software:</u> RayScanTechnologies, Fraunhofer EZRT, Volume Graphics
    - Acquisition, image processing, 3D and 2D reconstruction, visualization and evaluation
  - <u>Manipulator</u>: 2 translation axis (precision 1 µm) & 1 rotation axis
- Inspected volume
  - depends on application and testing mode
- Resolution:
  - X-Y: 2 µm to 150 µm

Figure 2. µ-Computed Tomography system RayScan 150 from RayScanTechnologies at EADS Innovation Works

1. Influencing Factors on the evaluated Degree of Porosity

1.1 Potential Influencing Factors on Porosity Assessment

The potential influencing factors on the assessed value of porosity with µ-CT can be split into three main sections (Figure 3).

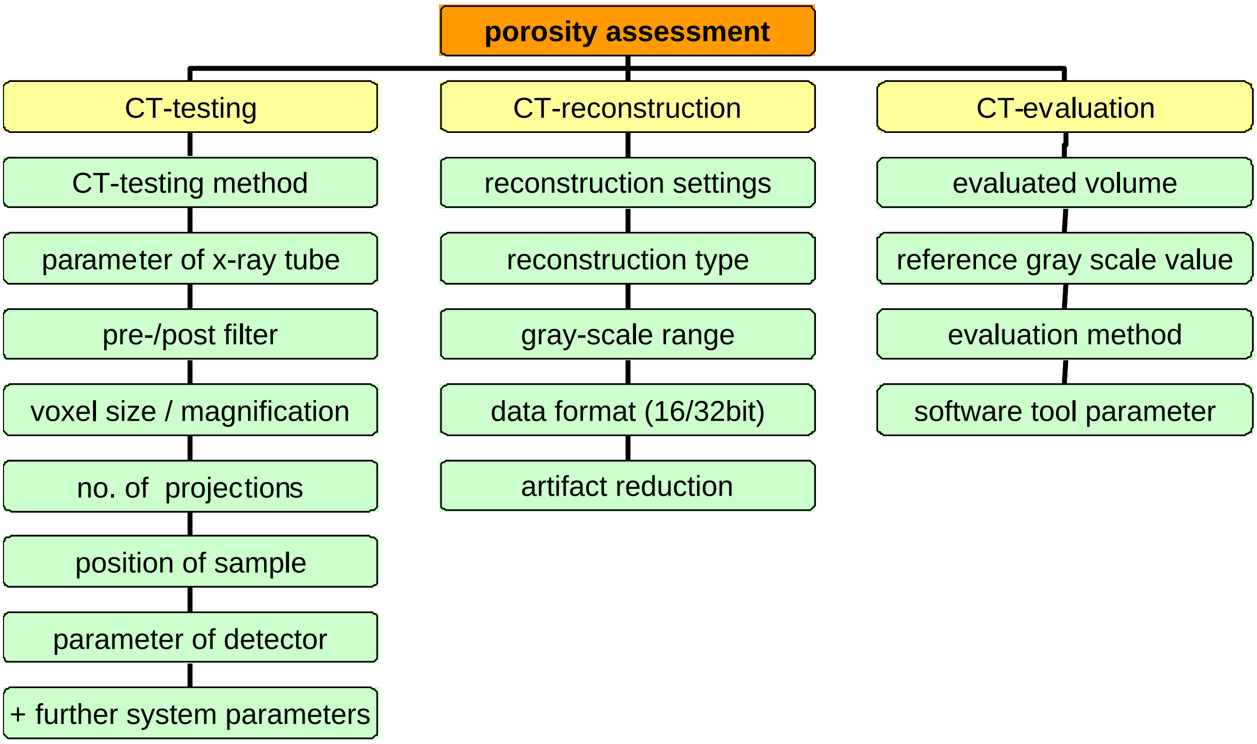

Figure 3. Overview of potential influencing factors on the porosity assessment of CFRP with µ-CT

The first area covers the CT-system itself and its parameters. This includes the testing method (3D-CT, ROI-CT, etc.), the x-ray tube settings (current, voltage, resulting focal spot size), pre-filtering at the x-ray tube, the magnification and its resulting voxel size, number of projections, as well as the detector parameters (exposure time, image averaging, gain, properties of the detector itself). The second field summarizes the potential influencing factors of the CT-reconstruction. The third section looks at the evaluation side including the CT-volume data, the assessment algorithms, and the gray-scale threshold.

The study was mainly performed at two CFRP samples (Figure 4). The sample with porosity and the reference sample were measured together.

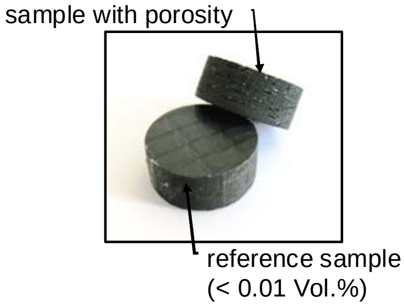

Figure 4. CFRP reference sample and sample with porosity.

In the following sub-sections selected parameters and their influence on the assessment are discussed. The parameters of the CT reconstruction are not described further in this paper since the observed effects on the assessed degree were minor.

1.2 Influencing Factor: Pre-Filtering

By placing a metal pre-filter between the x-ray tube and the sample the x-ray spectrum can be changed and beam hardening reduced. But with increasing thickness and atomic number the image noise level is increasing and therefore the evaluated value is decreasing (Figure 5).

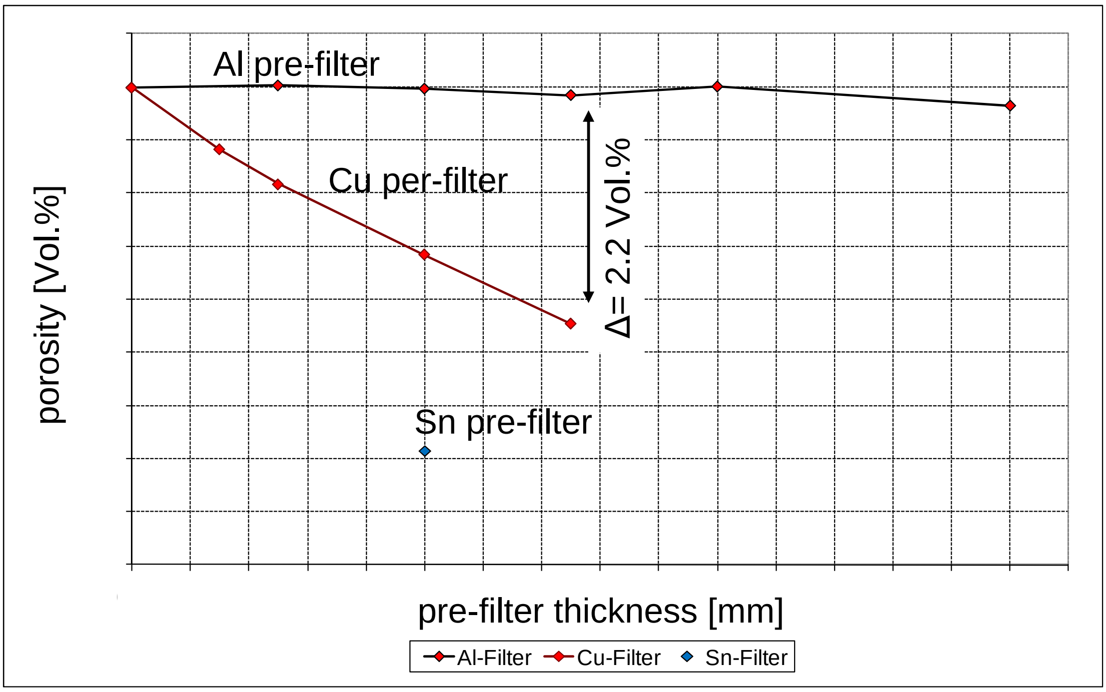

Figure 5. Evaluated porosity value versus metal pre-filter thickness

1.3 Influencing Factor: Magnification and Voxel Size

The CFRP-sample stack was tested at several positions between the x-ray tube and the detector. Thus, different magnifications were obtained and therefore different voxel sizes. With decreasing magnification and increasing voxel size the evaluated porosity value is increasing. This is caused by decreasing information content with increasing voxel size (Figure 6).

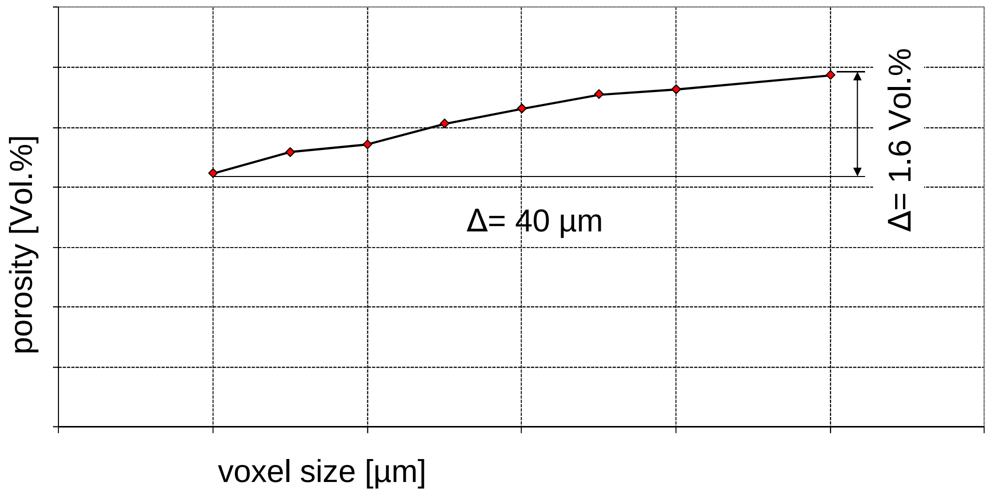

Figure 6. Evaluated porosity value versus voxel size

1.4 Influencing Factor: Number of Projections

The chosen number of projections is one of the parameter to set the inspection time. For an overview test it is regarded as sufficient that the number of projections equals 70 % of the reconstruction width in pixel numbers. For a regular test the number equals the number of pixels. For not loosing information the number of projections can be calculated according to the equation shown in Figure 7.

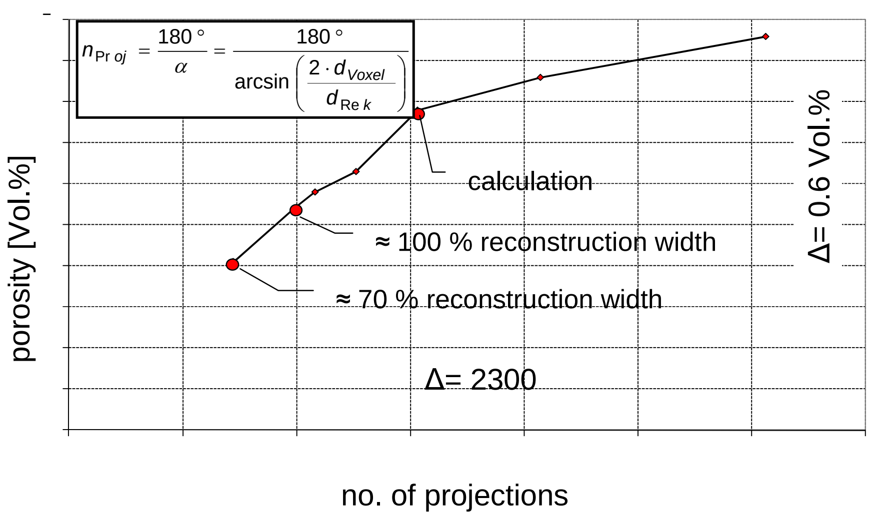

Figure 7. Evaluated porosity value versus number of projections

1.5 Influencing Factor: Evaluation Procedure and Parameters

So far selected parameters that might have an influence on the assessment of the system are explained. But how were the porosity values evaluated and what are the parameters on the evaluation side which might affect the value?

In this paper two of the investigated evaluation methods are described. One is based on the “volume analyser” tool and the second one on the “defect detection module” of VG-Studio MAX from Volume Graphics.

1.5.1 "Volume Analyser" Tool

The method is based on a gray scale value comparison between a reference sample and the sample with porosity to determine the gray value threshold to distinguish between material and pores (Figure8) [2]. Therefore, a region-of-interest with low beam hardening and with the largest possible size needs to be selected. The threshold level is adjusted to the value of 0.01 for "between cursors" assuming a porosity value of 0.01 in the reference sample. Afterwards, this gray scale value is used to distinguish between CFRP and pores in the ROI of the porosity sample. The resulting value "between cursors" is the porosity degree assessed from a 3D ROI.

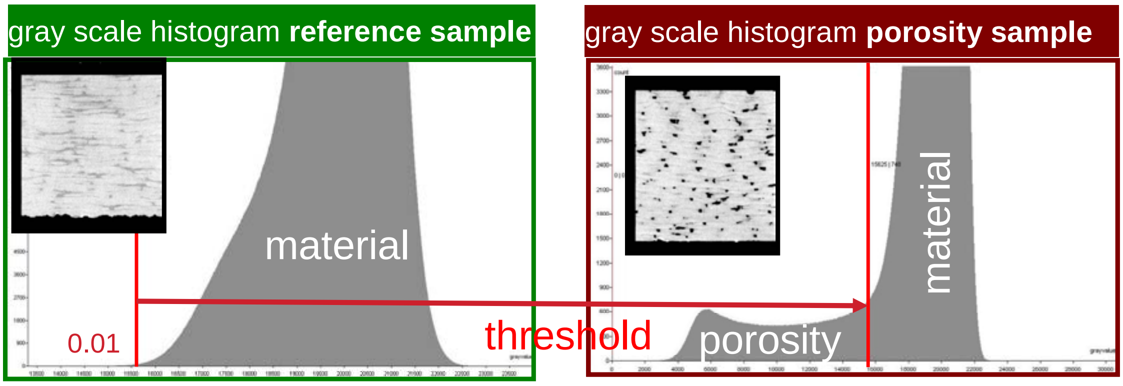

Figure 8. Assessment of the porosity value with the "volume analyser" tool evaluating the gray-scale threshold

1.5.1 "Defect Detection Module"

The second method is based on the "defect detection module". To obtain similar results as the "volume analyser" tool the algorithm "only threshold" with the same gray scale value assessed with the "volume analyser" should be chosen. The parameter "probability threshold" should be set to "0" and the "max. size" larger than the largest pore. Otherwise the evaluated value is too low. In addition the options "use calibration" and "define manually" didn't provide the same threshold as the one from the "volume analyser" tool and should be avoided. This module offers the option to display the size of pores color-coded.

2. Reliability

By taking the results of this study into account and thus choosing the best parameters for the CT-systems at Innovation Works and at Eurocopter reliability tests were performed. CT tests were repeated ten times with the best settings at different days, with repositioning of the sample, and after maintenance of the IW system. For this case the span width was 0.1 % vol. and the standard error 0.03 % vol. At Eurocopter a test with the for this system best parameters was also performed. The evaluated value was within the standard error range. After finishing the test campaign the real degree was assessed with "wet chemical analysis". There was only a difference of 0.1 % vol. This result was proofed by a study from Eurocopter comparing CT results at different samples with "wet chemical analysis" (Figure 9) [3]. The correlation shows a slope of "1" and a zero intercept and both with low standard errors.

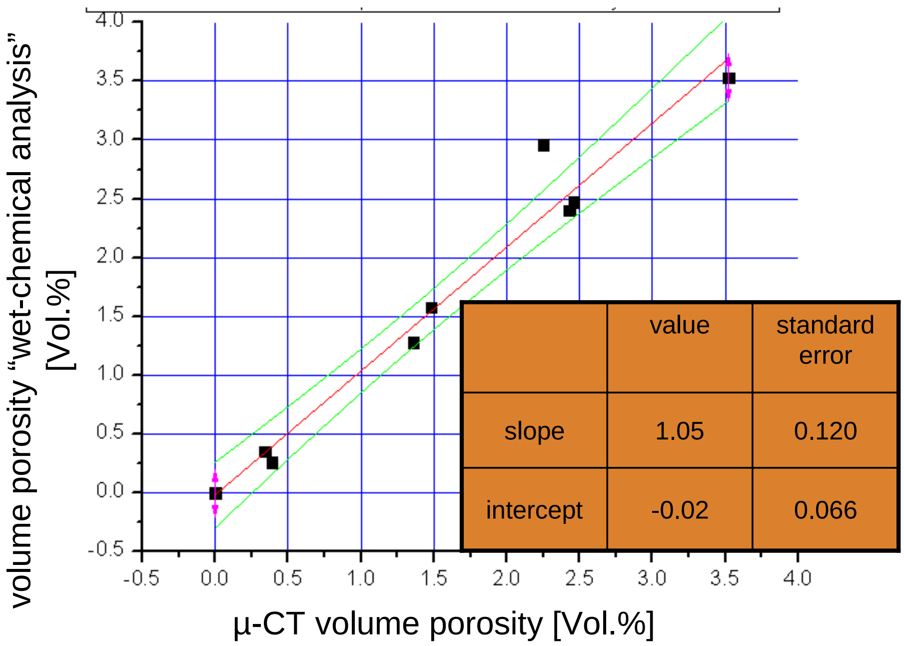

Figure 9. Volume porosity degree evaluated with “wet chemical analysis” versus the with µ- CT assessed values [3]

3. Summary

To investigate the potential and the reliability a study was performed. The assessed porosity degree depends on several parameters. By choosing adequate values obtained by this study reliable evaluation of the porosity in 3D is feasible.

References

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