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Investigation of the shape deviation for gas pores measured with X-ray computed tomography

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Summary:
The component porosity is a quality attribute in additive manufacturing (AM). One way for a non-destructive three-dimensional determination of the porosity or the shape of pores is X-ray computed tomography (CT), which enables to investigate the influence of AM process parameters on the appearance and characteristics of pores. Due to the lack of a porosity standard for CT, a traceable measurement uncertainty determination is not possible. To investigate the capability of CT for porosity analysis, measurements of an optically measurable glass specimen that contains highly spherical pores are used to validate results from a digital twin of the CT system. The influence of a fixed gray value threshold for the porosity analysis algorithm and the deviation of the surface determination are investigated.

Keywords: computed tomography, porosity measurement, sphericity, silica glass, additive manufacturing

Introduction and Method

One of the main challenges in additive manufacturing is to achieve dense components. The correlation between the process related parameters such as the deposited energy or the hatch distance and the resulting pores is therefore of interest [1]. CT is a nondestructive method, which can be used to determine the shape, size und volume of inner defects. However, due to missing porosity standards for CT, there is no possibility to determine the measurement uncertainty. Furthermore, the CT porosity measurement is not traceable and reliable conclusions are difficult. This work investigates the validity of CT porosity measurements using a silica glass specimen with optical accessible gas pores. One main advantage of this material is the possibility of reference measurements with a dark-field microscope. In addition, gas pores generally have a high sphericity, so that the geometric properties can easily be reproduced with a computer-aided design (CAD) model. Such a model can be used for simulating CT measurements by means of a digital twin of the CT system and is a useful reference to determine deviations of the size, shape and position of pores. For the investigation, the sphericity (1) has been used to determine the mismatch.

$$\boldsymbol{\psi} = \frac{A_{\text{sphere}}}{A_{\text{defect}}} \qquad (1)$$

This criterion compares the detected surface of a pore A_{defect} with the surface of a sphere with identical volume A_{sphere}. Values near 100 % are expected for round gas pores. Significant lower values can be caused by measurement deviations for A_{defect}, by a pore shape that is less spherical than assumed. A comparison with results from CT simulation reveal actual causes.

Experimental

The investigated silica glass specimen has a wedge shape with outer dimensions of (12.5 x 21.8 x 6) mm³. For the CT simulation using the software aRTist 2.10 (BAM, Germany), a CAD model is used that is roughly adjusted to the real part. It contains ideally spherical gas pores with diameters from 48 µm up to 208 µm with steps of 16 µm. Real measurements were performed using the CT system Metrotom 1500 (Zeiss IMT, Germany) for a validation of the CT simulation. The resulting gray value volume data are analyzed using VGStudio MAX Version 2022.3 (Volume Graphics, Germany). A local adaptive surface determination is applied and the porosity analysis is performed with the algorithm VGDefX and a threshold of the deviation of -1 standard deviation of the material peak in respect of [2].

Results and Discussion

The sphericity of the pores obtained experimentally (orange) and by simulation (blue) are shown in Fig. 1 in dependence of the pore diameter. In comparison, the simulation can reproduce the behavior of real gas pores in glass very sufficient. Both data are almost invariant with respect to the pore size, which corresponds to the expectation of high spherical pores. However, both do not obtain 100 % sphericity. To determine whether the CT parameters or CT artefacts have an impact on the measured shape, CT measurements under idealized conditions with a minimum of CT artefacts and noise have been performed and are displayed in Fig. 1 (yellow).

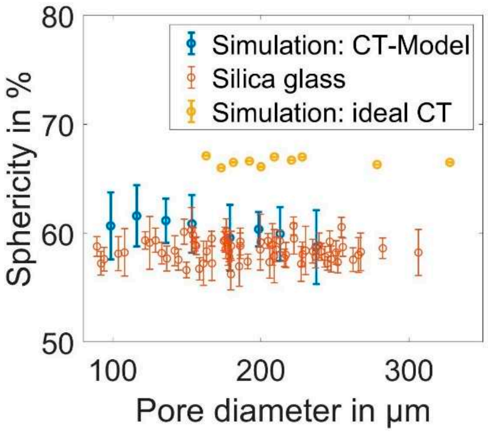

Fig. 1: CT measurement results of the sphericity of gas pores in glass (orange) and ideal pores in CT simulation (CT mode: blue) (ideal CT: yellow).

Although there is an influence of the CT parameters in the CT model, which is basically caused by the focal spot size and the related geometric blur, the sphericity is only slightly increased by the ideal CT. From Eq. (1), it is likely that there is an increase of A_{defect} in form of different shape. In order to distinguish whether the form itself is deformed because a sphericity of 60% is equal to a tetrahedron or the surface is enlarged by noise threw minor deviations like a golf ball, the pore size is compared with a reference value. The deviation of the difference can be calculated using the diameter of the CAD-model for the CT simulation and the dark-field microscopy for glass and compares it with a Gaussian fit of a sphere on the surface data points. The result is plotted in Fig. 2a) for the real (orange) and the simulated (blue). There is a minor negative difference of the diameter of the simulated pores, which does not indicate that the pore shape is preserved. Though there is a under scale of the pore size, which will lead to a smaller detectable volume, this will not affect the sphericity due to the definition in Eq. (1). The standard deviation of the surface points with respect to the fitted sphere can be calculated with a maximum value of 2 µm. In relation to the sensitivity of Eq. (1), a noisy surface of the pores can have the impact to increase A_{defect}. Furthermore, this could also affect the porosity analysis, since the threshold is defined according to the surface determination of a pore [2]. In this research, the threshold/ analyzing area is optimized for a pore with a diameter of 180 µm. The difference of the CAD-model and the calculated data of the algorithm is plotted in Fig. 2b). The deviation increases beside the optimized point, which can be explained with the correlation of the gray value, pore size and a static threshold value and will lead to over- and undersized pores. Considering the constant behavior of the sphericity even for pores on the optimized point, the scaling of the algorithm has no or a minor effect but will affects the compactness as a volume criterion [2], which is not discussed here. The sphericity criterion on spherical pore seems to be very sensitive on noisy influences but quite robust against scaling effects.

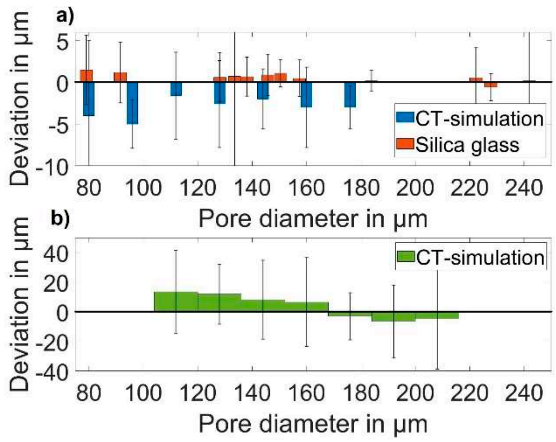

Fig. 2: a) Difference of the surface determination diameter and the CAD-model for CT Simulation (blue) and the dark-field-pore-diameter for the glass (orange). b) Difference of the CAD-model and the calculated diameter of the porosity analysis algorithm for the CT simulation (green).

Conclusion

The question whether CT is able to perform a shape constant image of gas pores cannot fully be answered without a calibrated standard. Nevertheless, the investigation with CT simulation shows that the deviation of the sphericity of ideal pores is mainly caused by noise. There is a high probability that gas pores in glass will not be recognized as such by using the CT. How this could affect materials of AM might be topic of a future research.

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