

Porosity analysis in SiC/SiC ceramic matrix composites

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Ceramic matrix composites made of silicon carbide fibers embedded in silicon carbide matrix (SiC/SiC CMCs) are widely recognized as excellent replacements for denser superalloys such as Nickel based super alloys for high-temperature applications in aero engines. During the manufacturing process with chemical vapour infiltration, large amount of pores are introduced in the CMC and their presence can have considerable impact on the structural performance of a component. In this work, we analyze the pore size and spatial distribution in SiC/SiC CMCs for different geometrically-identical specimens. Porosity within specimens are quantified through computed tomography (CT) scans. Different statistical approaches are utilized for describing the amount of pores, their size and spatial distribution within each specimen.

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1 Introduction

To meet the challenging regulations on emission standards of aviation industry set by EU [1], the aero engine manufacturers have to make drastic changes in the established design principles. SiC/SiC CMCs have shown excellent potential as the new material for aero engines to optimize the overall weight and hence increase the fuel efficiency [2]. They are tough as metals, roughly one-third as dense as superalloys and possess excellent high temperature oxidation resistance. In spite of many advantages, SiC/SiC CMCs face many challenges in implementation. One of the challenges is to understand the influence of pores introduced during manufacturing process on the overall structural performance and incorporate the effect in advanced numerical models for failure [3,4].

2 Material and Imaging with X-Ray Computed Tomography

We investigated ceramic matrix composite (CMC) material which was manufactured by BJS Ceramics GmbH in Augsburg, Bavaria, Germany. The CMC material was made of Tyranno[®] standard 1.6K silicon carbide (SiC) fibers embedded into SiC matrix using the chemical vapor deposition process. The fibers were coated with pyrolytic carbon. The CMC material had plain weave structure with 0/90° fiber orientation and 5.9 threads per cm. Geometrically identical specimens of four different sizes were produced with 12 specimens of each size. The dimensions length, height and width [L, H, W] were related as $L/H = 4.2$ and $H/W = 2$. Size #1 was $L = 25.2$ mm, size #2 was $L = 37.8$ mm, size #3 was $L = 50.4$ mm and size #4 was $L = 58.8$ mm. Four such specimens, one from each size, are shown on the left of Figure 1. To quantify the size and spatial distribution of pores in the specimens, one sample from each size was scanned with the x-ray computed tomography (CT) machine Phoenix nanotom m 180 at the testing facility of the University of Augsburg.

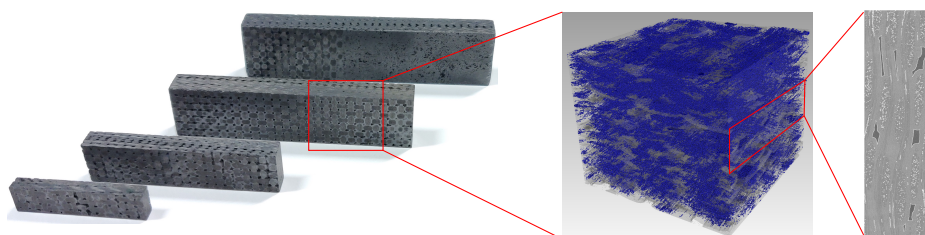


Fig. 1: Left: SiC/SiC CMC specimens with four different sizes. Middle: a scan of one specimen showing the pores mapped as blue color. Right: a further detailed view of the cross-section showing large matrix pores as well as porous fiber tows.

3 Statistical analysis of pores

The CT scan data was analyzed with DragonFly¹ and Matlab[®]. In Figure 2(a), a histogram representation of the number of pores of a certain volume is plotted. The largest pores ($> 10^6 \mu\text{m}^3$) are excluded from visualization as they occur in the smallest numbers (< 10). We compared the pore volume distributions of size #1 with the other three sizes using the quantile-quantile statistical plot (qq-plot) as shown in Figure 3. We observe that the pore volume distributions from different specimen sizes, manufactured with the same process parameters, are not identical. The histogram in Figure 2(b) shows the frequency of pores over the normalized height of the sample size #1. Similarly, the pore spatial distributions of size #1 is compared with the other three sizes using the qq-plot as shown in Figure 4. It can be observed that, like pore volume distribution, the pore spatial distribution from different sizes are also not identical. Therefore, it can be postulated that the pore volume and spatial distribution are not unique to a CMC material and depends upon the volume of the specimen.

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¹ <https://www.theobjects.com/dragonfly>



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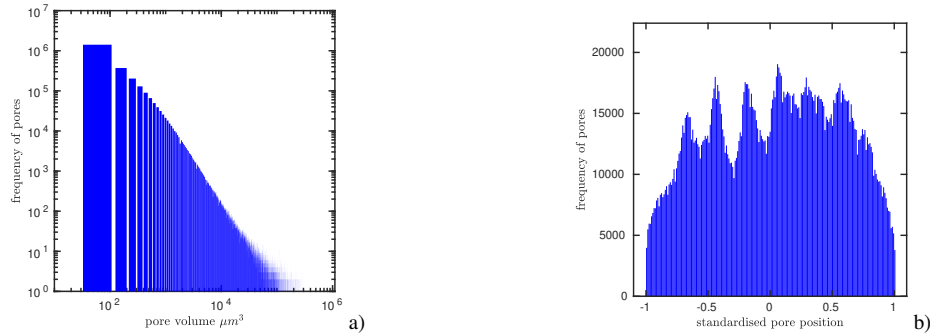


Fig. 2: Histogram plots showing in **a** the frequency of different pore sizes and in **b** the frequency of different pore positions in the normalized sample height obtained by x-ray computed tomography scan of size #1 sample.

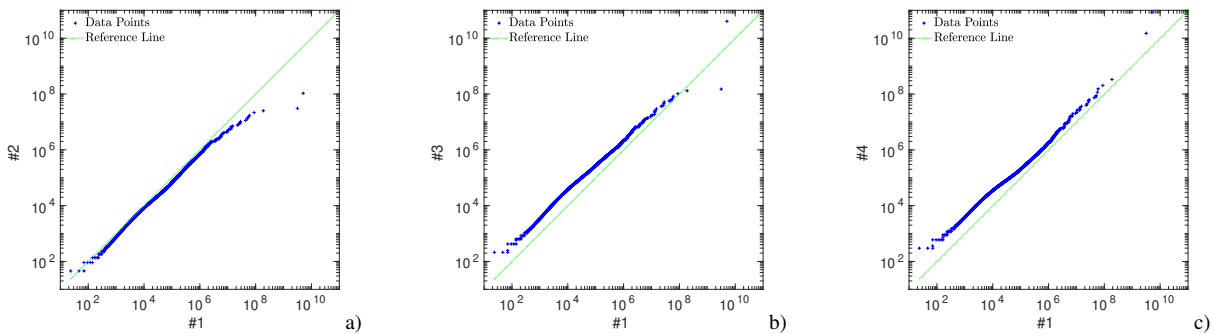


Fig. 3: Quantile-Quantile plots for comparison of pore volume distributions of size #1 with sizes #2, #3 and #4. Reference line (green) implies that distributions are identical. None of the size comparisons are following the reference line, which implies, that pore size distributions are not unique.

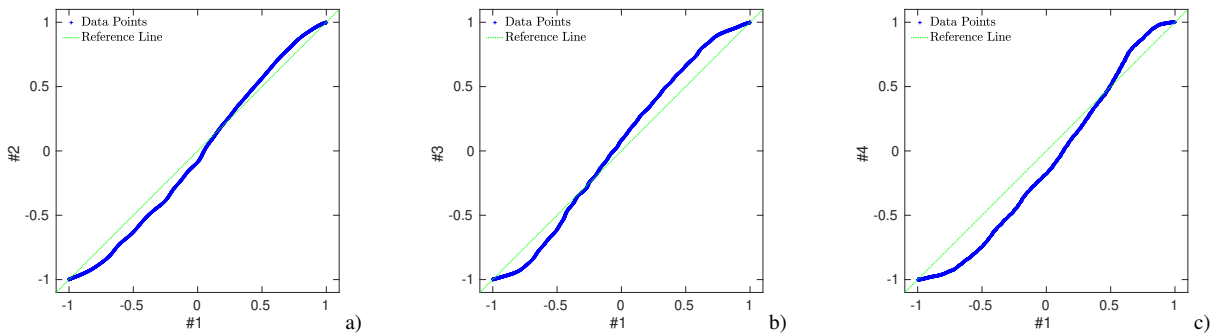


Fig. 4: Quantile-Quantile plots for comparison of pore spatial distributions of size #1 with sizes #2, #3 and #4. Reference line (green) implies that distributions are identical. None of the size comparisons are following the reference line, which implies, that pore spatial distributions are not unique.

4 Conclusion

A computationally oriented design of SiC/SiC CMC components for new aero engines will accelerate their implementation in real world applications by reducing the testing time period. However, to develop physics based models which are highly accurate, we need to understand the mechanics and physics of various microstructural features such as pores [5]. In this work, we showed that the pore volume and the spatial distribution of SiC/SiC CMCs cannot be defined by a unique distribution function and depends on the volume of the specimen. Further investigations to correlate the pore size and spatial distributions to the scatter in mechanical properties is an ongoing work.

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