Local Curvature for 3D-Characterization of Fiber-Reinforced Materials

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Keywords

Gaussian curvature, fundamental forms, fibers, image analysis, µCT.

Introduction

With the availability of micro-computer tomographs (µCT) both in industry and research, there is a growing demand for quantitative analysis of materials microstructures. One class of materials for which this technology is employed is the class of fiber reinforced materials such as glass and carbon fiber-reinforced polymers (GRP and CRP). The geometric properties of their fiber systems have a significant impact on these materials' macroscopic mechanical properties. The fiber density and direction distribution are already accessible, see e.g. (Wirjadi et al. 2014). Further mechanically relevant parameters include the fiber length distribution and – depending on the material – fiber-fiber contacts. The analysis of the fiber lengths has also been addressed in the literature, e.g. (Salaberger et al. 2011), but such approaches rely on a segmentation of individual fibers. This is problematic firstly due to often insufficient resolutions combined with high fiber densities, and secondly due to a limited field of view of µCT scanners, which does not allow for a correct estimation of fiber lengths even for perfectly segmented fibers – especially in the case of long fibers.

Materials and Methods

Regarding fiber length distributions, a parametric approach has recently been proposed (Kuhlmann, Redenbach 2015), which requires only fiber end points as input and which can deal with the situation that the expected fiber length exceeds the field of view. Here, we suggest to employ a novel algorithm for computing the fundamental forms in binary volume images (Kronenberger et al.) to detect these fiber endpoints in µCT images. Specifically, a fiber can locally be considered as a cylindrical shape. Consequently, a fiber should have zero Gaussian curvature along its lateral surface but high positive Gaussian curvature at its endpoints, see Fig. 2 for an example.

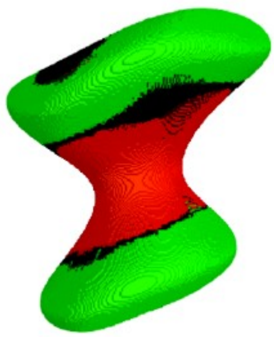
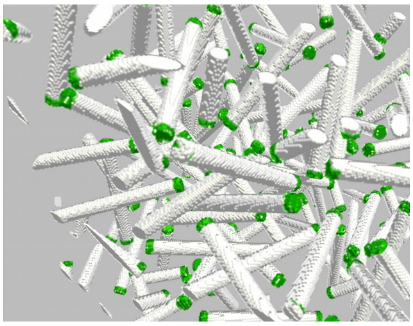


Figure 1. Gaussian curvature locally characterizes surfaces as spherical (green), flat or cylindrical (black), and saddle-shaped (red). Shown here are Gaussian curvature values on a discretized test object, computed using the algorithm from (Kronenberger et al.).

Figure 2. Fibers are expected to have high positive Gaussian curvature at their endpoints, and zero elsewhere.



Results and Discussion

Based on this idea, we were able to reach 99% detection rate with only 3.3% false positives on a simulated random fiber system. Even when adding noise, the detection rate did not drop below 96%, in our initial experiments. Based on similar considerations, we plan to use further curvature-based features, which can also be derived from the fundamental forms, to the detection of fiber-fiber contacts in 3D.

Conclusion

Local curvature measures computed on the surfaces of objects defined on regular grids (e.g. µCT data) are promising analysis tools for the 3D-characterization of fiber systems, especially fiber reinforced polymers.

References

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