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# Enhanced Random Fiber Generator for CFRP Microstructures

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## Extended Abstract

An enhanced algorithm for generating realistic carbon fiber-reinforced polymer (CFRP) microstructures is introduced, addressing key limitations of conventional random fiber generation methods. While existing approaches effectively model fiber distributions, they often suffer from slow convergence, clustering artifacts, and inadequate fiber-matrix interaction handling. To overcome these challenges, the proposed method integrates Metropolis-Hastings optimization, repulsion-based distribution refinement, a hard-core disk model for fiber spacing, and advanced boundary constraints. These enhancements ensure a well-dispersed, computationally efficient microstructure representation.

CFRP composites are widely used in aerospace and automotive industries due to their high strength-to-weight ratio and excellent mechanical properties [1]. Accurately modeling their microstructure is essential for predicting material behavior and optimizing composite design [2]. Conventional fiber generation methods suffer from inefficiencies, local clustering, fiber overlap, and poor boundary condition management, compromising accuracy and scalability [3].

The enhanced algorithm improves computational efficiency by guiding fiber placement with Metropolis-Hastings optimization, reducing clustering through repulsion-based refinement, enforcing minimum fiber spacing with a hard-core disk model, and ensuring realistic boundary behavior using reflection and periodic constraints. These enhancements collectively provide a more accurate and scalable CFRP microstructure generation method, significantly reducing computation time. The enhanced algorithm was implemented in Python and tested on a CFRP microstructure containing 46 fibers within a 54 μm × 54 μm domain [4]. Compared to conventional methods, the new approach achieved a 40% reduction in computation time while significantly improving the uniformity of fiber dispersion. High performance with decreasing computational time of fiber distributions confirmed the superior agreement, demonstrating the effectiveness of the proposed enhancements.

The improved fiber generator successfully addresses the limitations of previous methods, providing a more accurate and computationally efficient approach for CFRP microstructure modeling. The generated microstructures can be used as representative volume elements (RVEs) in finite element analyses, enabling more reliable predictions of composite material properties. Future work includes extending the algorithm to three-dimensional microstructures and integrating mechanical property simulations for further validation.

## References

[1] S.-M. Park, J. H. Lim, M. R. Seong, and D. Sohn, “Efficient generator of random fiber distribution with diverse volume fractions by random fiber removal,” Composites Part B: Engineering, vol. 167, pp. 302-316, Jun. 2019. https://doi.org/10.1016/j.compositesb.2018.12.042
[2] A. Bahmani, G. Li, T. L. Willett, and J. Montesano, “Three-dimensional microscopic assessment of randomly distributed representative volume elements for high fiber volume fraction unidirectional composites,” Composite Structures, vol. 192, pp. 153-164, May 2018. https://doi.org/10.1016/j.compstruct.2018.02.075
[3] L. Yang, Y. Yan, Z. Ran, and Y. Liu, “A new method for generating random fiber distributions for fiber reinforced composites,” Composites Science and Technology, vol. 76, pp. 14-20, Mar. 2013. http://dx.doi.org/10.1016/j.compscitech.2012.12.001
[4] R. Sepasdar, A. Karpatne, and M. Shakiba, “A data-driven approach to full-field nonlinear stress distribution and failure pattern prediction in composites using deep learning,” Computer Methods in Applied Mechanics and Engineering, vol. 397, Art. no. 115126, Jul. 2022. https://doi.org/10.1016/j.cma.2022.115126