R X14-16

Attachment 1 – Research Topic Template

1. **Research Title:** Stochastic Microstructure-Property Relationships for Damage of Continuous Ceramic Fiber Reinforced Ceramic Matrix Composites in Gas Turbine Engine Environments
2. **Individual Sponsor:**

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3. **Academic Area/Field and Education Level:** Materials Science and Engineering, Mechanical Engineering, Chemical Engineering, or equivalent (M.S, PhD level)
4. **Objectives:** The objective of the effort is to develop appropriate relationships to link stochastic material microstructure in continuous fiber reinforced ceramic matrix composites (CMC) to the damage response (e.g., creep, oxidation). Important to this work is identifying the mechanisms of damage of laboratory coupons when tested at elevated temperatures and/or in representative gas turbine engine environments. Appropriate statistical microstructure metrics must be defined that can be used to describe the material response as a function of the distributed microstructure (e.g., fibers, coatings, matrix, pores). A better understanding of the influence of the key microstructure attributes on the fundamental operant damage mechanisms is required for the development of better physics based models.
5. **Description:** A framework for characterization of the microstructure attributes most important to the operant damage mechanisms of CMCs is lacking. Current practices focus only on a few crude aspects or metrics of the microstructure: fiber architecture and volume fraction, average fiber coating thickness, and matrix pore volume fraction. More detailed descriptions of complex FRC microstructures are lacking; moreover, there is no quantifiable connect between distributed microstructure and the response. There are significant statistical variations in distributive FRC microstructural features such as fiber diameter and spacing, fiber coating thickness [1], matrix porosity and second phases. Metrics derived from current practices cannot adequately describe the structure relevant to dominate behavior in the material. Local fiber spacing distributions in ceramic matrix composites (CMCs) especially regions containing "clumping" of fibers, are sites that nucleate interlaminar failure, and have other significant effects on mechanical properties [2]. In all cases, the coupled effects of variability of different microstructure features, such as interactions between fiber spacing and matrix pore size distributions, are not well understood. Discrete microstructural features that are deliberately introduced, such as ply drops and ply bends, also lack quantitative description. Preliminary work has examined the utility of higher order stochastic microstructural relationships, but has been limited. Fiber clustering using the 2nd order intensity function and the pair distribution function were used to quantify fiber clustering in idealized FRC [3]. A rigorous framework defining the spatial correlations of local states in the microstructure already exists in the form of *n*-point correlations or *n*-point statistics [4]. Despite the existence of these statistical constructs, little work has been done to standardize this practice and produce tools that aid in the interpretation of the types of higher order stochastic microstructure metrics. Moreover, the amount of data that is captured using these statistical descriptions can be immense and little work has been done to develop intelligent ways to analyze the data and identify key relationships in FRC.

<u>References:</u>

[1] R. S. Hay, G. Fair, P. Mogilevsky, and E. E. Boakye, "Measurement of Fiber Coating Thickness Variation," *Ceram. Eng. Sci. Proc.*, vol. 26, pp. 11-18, 2005.

[2] G. N. Morscher, H. M. Yun, and J. A. DiCarlo, "In-Plane Cracking Behavior and Ultimate Strength for 2D Woven and Braided Melt-Infiltrated SiC/SiC Composites Tensile Loaded in Off-Axis Fiber Directions," *J. Am. Ceram. Soc.,* vol. 90, pp. 3185-3193, 2007.
[3] R. Pyrz, "Quantitative Description of the Microstructure of Composites. Part I: Morphology of Unidircetional Composite Systems," *Compos. Sci. Tech.,* vol. 50, pp. 197-208, 1994.
[4] S. Torquato, *Random Heterogenous Materials: Microstructure and Macroscopic Properties*: Springer, 2002.

6. **Research Classification/Restrictions:** This research is unclassified
7. **Eligible Research Institutions:** Indicate to what organizations this topic should be provided.

■ DAGSI (Wright State University, AFIT, Ohio State University, University of Dayton, Miami University, Ohio University, University of Cincinnati)
PA Approval #: 88ABW-2013-3426

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☐ USAFA (only)
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