RX16-13

1. **Research Title:** Stochastic Structure-Property Relationships of Continuous Ceramic Fiber Reinforced Ceramic Matrix Composites in Application Environments

2. **Individual Sponsor:**
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3. **Academic Area/Field and Education Level:** Materials Science and Engineering, Mechanical Engineering, Chemical Engineering, Computer Science, or equivalent (M.S, PhD level)

4. **Objectives:** The objective of the effort is to characterize the fundamental structure-property relationships in continuous fiber reinforced ceramic matrix composites (CMC) to the damage response (e.g., creep, fatigue, oxidation). Important to this work is identifying the attributes of the material (e.g., fibers, coatings, matrix, pores, secondary matrix phases, residual stress) that have the most influence on the operant damage mechanisms in application environments (e.g., high temperature, in moisture, in combustion gases). Appropriate statistical approaches must be developed that can describe the material response as a function of the stochastic material structure at relevant scales. Understanding the influence of the material attributes on the fundamental operant damage mechanisms can then inform the development of physics based material response models for the Integrated Computational Materials Engineering (ICME) for the concurrent materials development and design of CMC components.

5. **Description:** Ceramic matrix composites (CMCs) offer significant advantages in terms of temperature capability and lower density relative to traditional high temperature metals like Ni-base superalloys. However, current CMCs systems are relatively immature and lack application experience and much remains to be understood regarding the fundamental behavior of this material class. It is likely that the stochastic material structure on multiple scales dictates much of the significant response variability that is observed experimentally. Current approaches that characterize material structure typically focus on only on a few aspects of the microstructure such as the fiber architecture, volume fraction, average fiber coating thickness, or matrix pore volume fraction. More detailed descriptions of complex CMC structure is lacking; moreover, there is no quantifiable connect between distributed structure and the response. There are significant statistical variations in distributive CMC 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 CMCs such as local clustering 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. Additionally, residual stress resulting from certain processing routes can have a significant influence on the material properties. 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 fiber reinforced [3]. Other work has characterized the three dimensional textile weave and its variations from the ideal [4]. Recently, researchers have linked correlated attributes with fatigue response in metals [5, 6], but similar approaches have not been applied to composites. To enable the Integrated Computational Materials Engineering (ICME) of CMC based components a better understand of the fundamental relationships between the stochastic material structure and damage response along with appropriate physics based models must be developed.

   References:

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[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.
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[5] C. P. Przybyla and D. L. McDowell, "Microstructure-sensitive Extreme Value Probabilities for High Cycle Fatigue of Ni-base Superalloy IN100," *Int. J. Plasticity,* vol. 26, pp. 372-394, 2010.
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6. **Research Classification/Restrictions:** This research is unclassified

7. **Eligible Research Institutions:**

DAGSI (Wright State University, AFIT, Ohio State University, University of Dayton, Miami University, Ohio University, University of Cincinnati)

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