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Current Computational Challenges for CMC Processes, Properties, and Structures

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Summary

In comparison to current state-of-the-art metallic alloys, ceramic matrix composites (CMC) offer a variety of performance advantages, such as higher temperature capability (greater than the 2100oF capability for best metallic alloys), lower density (30-50% metal density), and lower thermal expansion. In comparison to other competing high-temperature materials, CMC are also capable of providing significantly better static and dynamic toughness than un-reinforced monolithic ceramics and significantly better environmental resistance than carbon-fiber reinforced composites. Because of these advantages, NASA, the Air Force, and other U.S. government agencies and industries are currently seeking to implement these advanced materials into hot-section components of gas turbine engines for both propulsion and power generation. For applications such as these, CMC are expected to result in many important performance benefits, such as reduced component cooling air requirements, simpler component design, reduced weight, improved fuel efficiency, reduced emissions, higher blade frequencies, reduced blade clearances, and higher thrust.

Although much progress has been made recently in the development of CMC constituent materials and fabrication processes, major challenges still remain for implementation of these advanced composite materials into viable engine components. The objective of this presentation is to briefly review some of those challenges that are generally related to the need to develop physics-based computational approaches to allow CMC fabricators and designers to model (1) CMC processes for fiber architecture formation and matrix infiltration, (2) CMC properties of high technical interest such as multidirectional creep, thermal conductivity, matrix cracking stress, damage accumulation, and degradation effects in aggressive environments, and (3) CMC component life times when all of these effects are interacting in a complex stress and service environment. To put these computational issues in perspective, the various modeling needs within these three areas are briefly discussed in terms of their technical importance and their key controlling mechanistic factors as we know them today. Emphasis is placed primarily on the SiC/SiC ceramic composite system because of its higher temperature capability and enhanced development within the CMC industry. A brief summary is then presented concerning on-going studies aimed at addressing these CMC modeling needs within NASA and the Air Force in terms of their computational approaches and recent important results. Finally an overview perspective is presented on those key areas where further CMC computational studies are needed today to enhance the viability of CMC structural components for high-temperature applications.