Type the title: Advanced Manufacturing of Ceramic Matrix Composites (CMC) by Field Assisted Sintering Technology (FAST)

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Purpose

The objective of this proposal is to demonstrate that high-temperature high-performance SiC/SiC CMC can be fabricated in various forms with various fiber architectures by hot superplastic forming with little loss in fiber properties and with strong and effectively zero- porosity SiC matrices.

The challenge is to select SiC fibers with nano-sized b-SiC grains and SiC matrices with nano-sized b-SiC particulates and then use a high-temperature fabrication process that employs short-time forming conditions to avoid excessive grain growth within the constituents, while at the same time yielding complex-shaped CMC materials. It was proposed to address this challenge by using the unique Field Assisted Sintering Technology (FAST) capability at Penn State where rapid deformations (< 20 min) can be generated at very high temperatures by the simultaneous application of pressure, temperature and high electric current density through the material.

FAST is 250 ton unit and capable in making components up to diameter 300 mm and sintering can be done up to 2200ºC.Premixed powder or composite is placed and compacted within a graphite die by concurrently applying high density current, high pressure (i.e., load) and temperature.

Due to the rapid heating rate (up to 500 C/min), temperature (up to 2400ºC), pressure (75MPa), high density current (10,000 amps), particles deformed and fused together by the concurrent volumetric heating, i.e. Joule heating, and radiant heating contributing to lower sintering temperature and activation energy (30-40% lower). Depending upon the processing conditions, the sintered product will have near theoretical density. Since the processing cycle takes few minutes (~2-10 minutes, rather than hours in conventional method) to sinter the product with theoretical density 100%. It is possible to retain sub grained microstructure in the sintered products that will offer superior mechanical properties under extreme environments.

Background

SiC/SiC CMC will make significant contributions toward reducing fuel burn and emissions by enabling increased overall pressure ratios (OPR) of gas turbine engines and reducing or eliminating cooling air in the hot-section components. It has been estimated that application of 2700ºF SiC/SiC CMC in hot section components of gas turbine results can result in 6% fuel burn reduction and 33% NOX reduction. A key requirement for achieving long-term durability in SiC/SiC CMC at high temperatures is to have a dense CMC. The Fundamental Aeronautics Program (FAP) in ARMD is currently developing SiC/SiC materials and components with 2700ºF capability using combinations of commercially-available silicon-free matrix processes (such as PIP and CVI), which have inherent limitations for producing a dense composite. Therefore, this proposal has the strong potential to achieve this goal by using innovative and unconventional super plastic forming to achieve dense complex-shaped SiC/SiC CMC components with high strength, high thermal conductivity, long life, and temperature capability well beyond the current state-of-the-art. Also, the long-term N+3 goal is to have uncooled high-pressure turbine components (HPT vane and blade) with up to 3000ºF temperature capability. Another significant advantage of super plastic forming using the FAST process is the low cost. The success of the Phase I will be followed by Phase II, with the objective to demonstrate industry-adaptable production methods for super plastically formed SiC/SiC components that are robust and low cost.

Today the only process for achieving very low SiC/SiC matrix porosity involves a final step of high-temperature infiltration of molten silicon, but this limits current CMC use temperatures to below 2400ºF due to poor creep- resistance caused by residual silicon in the matrix. If CMC with higher operating temperatures and dense silicon-free matrices could be developed, engine performance benefits would further increase, such as, reduced component cooling air and reduced engine fuel consumption and emissions. So far, conventional processing techniques, such as polymer impregnation and pyrolysis (PIP) and chemical vapor infiltration (CVI) that can provide silicon-free matrices with temperature capability well above 2400ºF, have failed to achieve matrix porosities less than 10%.