Additive Manufacturing of Ceramic Matrix Composites (CMCs) for Propulsion Systems

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Purpose

The objective of the proposed effort is to establish the feasibility of fabricating SiC-based ceramic matrix composites (CMCs) with desired properties by the additive manufacturing method of laminated object manufacturing. In order to demonstrate the feasibility of this concept, it is essential to develop carbonaceous prepreg compositions with appropriate properties (viscosity, curing behavior, high char yield, etc.), study prepreg material properties, establish laser cutting parameters for fabrics and prepregs, optimize lay-up schemes, and devise high temperature treatments for conversion to ceramic matrix composites. In addition, optimization of processing, microstructure, and thermomechanical properties of CMCs is being carried out.

Background

Advanced SiC-based CMCs are expected to make significant contributions toward reducing fuel burn and emissions by enabling high overall pressure ratio (OPR) of gas turbine engines and reducing or eliminating cooling air in the hot-section components, such as shrouds, combustor liners, vanes, and blades. The first generation CMCs are projected to be used in commercial gas turbine engines starting in 2016-17. Current generation of SiC-based composites are typically fabricated by multiple steps, which include fabrication of performs, fiber coatings, and matrix densification either by chemical vapor infiltration (CVI); melt infiltration (MI); polymer infiltration and pyrolysis (PIP); or by hybrid processing approaches combining CVI, MI, and PIP processes. All these processes require extensive manual labor in various manufacturing steps (cutting and hand lay-up of preforms, composite fabrication, machining, etc) leading to high cost and scatter in properties.

Additive manufacturing (AM) approaches could provide a cost-effective production route and further speed-up the implementation of these enabling materials. However, majority of additive manufacturing efforts are focused on polymers and metallic systems and ceramic based systems are still in infancy due to numerous material and processing challenges. There has not been much research and development activity on additive manufacturing of ceramic matrix composites (CMCs) and very limited data has been reported in the literature. Klosterman and coworkers have reported on the use of ceramic grade Nicalon (CG-Nicalon) fiber based phenolic prepregs with alternating layers of monolithic ceramic tapes. A number of issues related to weak interlayer bonding were encountered. In addition, weak composite flexural strength was exhibited due to inadequate fiber coating and poor high temperature stability of SiC (CG-Nicalon) fibers. Windsheimer and Travitzky et al have reported the fabrication of Si-SiC material using pre-ceramic paper derived performs. For the additive manufacturing of tough SiC/SiC composites using the Laminated Object Manufacturing (LOM) approach, BN coated high temperature silicon carbide fabrics, new prepreg compositions with desirable properties, and processing conditions need to be developed and optimized. The current effort will address some these challenges and provide a pathway for application of additive manufacturing technologies for ceramic systems.