Manufacturing & Prototyping

Propulsion Design With Freeform Fabrication (PDFF)

Innovation for ceramic materials uses solid freeform rapid prototype manufacturing technology.

John H. Glenn Research Center, Cleveland, Ohio

The nation is challenged to decrease the cost and schedule to develop new space transportation propulsion systems for commercial, scientific, and military purposes. Better design criteria and manufacturing techniques for small thrusters are needed to meet current applications in missile defense, space, and satellite propulsion. The requirements of these systems present size, performance, and environmental demands on these thrusters that have posed significant challenges to the current designers and manufacturers. Designers are limited by manufacturing processes, which are complex, costly, and time consuming, and ultimately limited in their capabilities.

The PDFF innovation vastly extends the design opportunities of rocket engine components and systems by making use of the unique manufacturing freedom of solid freeform rapid prototype manufacturing technology combined with the benefits of ceramic materials. The unique features of PDFF are developing and implementing a design methodology that uses solid freeform fabrication (SFF) techniques to make propulsion components with significantly improved performance, thermal management, power density, and stability, while reducing development and production costs. PDFF extends the design process envelope beyond conventional constraints by leveraging the key feature of the SFF technique with the capability to form objects with nearly any geometric complexity without the need for elaborate machine setup. The marriage of SFF technology to propulsion components allows an evolution of design practice to harmonize material properties with functional design efficiency.

Reduced density of materials when coupled with the capability to honeycomb structure used in the injector will have significant impact on overall mass reduction. Typical thrusters in use for attitude control have 60–90 percent of its mass in the valve and injector, which is typically made from titanium. The combination of material and structure envisioned for use in an SFF thruster design could reduce thruster weight by a factor of two or more. The thrust-to-weight ratios for such designs can achieve 1,000:1 or more, depending on chamber pressure.

The potential exists for continued development in materials, size, speed, accuracy of SFF techniques, which can lead to speculative developments of PDFF processes such as fabrication of custom human interface devices like masks, chairs, and clothing, and advanced biomedical application to human organ reconstruction.

Other potential applications are: higher fidelity lower cost test fixtures for probes and inspection, disposable thrusters, and ISRU (*in situ* resource utilization) for component production in space or on Lunar and Martian missions, and application for embedding MEMS (microelectromechanical systems) during construction process of form changing aerostructure / dynamic structures.

This work was done by Daudi Barnes of DMX Engineering, Jim McKinnon of Frontier Engineering, and Richard Priem of Priem Consultants for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18557-1.

Economical Fabrication of Thick-Section Ceramic Matrix Composites

Applications for these composites include combustors, high-temperature filter elements, and process industry parts requiring corrosion resistance.

Marshall Space Flight Center, Alabama

A method was developed for producing thick-section [>2 in. (≈5 cm)], continuous fiber-reinforced ceramic matrix composites (CMCs). Ultramet-modified fiber interface coating and melt infiltration processing, developed previously for thin-section components, were used for the fabrication of CMCs that were an order of magnitude greater in thickness [up to 2.5 in. (≈6.4 cm)]. Melt processing first involves infiltration of a fiber preform with the desired interface coating, and then with carbon to partially densify the preform. A molten refractory metal is then infiltrated and reacts with the excess carbon to form the carbide matrix without damaging the fiber reinforcement. Infiltration occurs from the inside out as the molten metal fills virtually all the available void space. Densification to <5 vol% porosity is a one-step process requiring no intermediate machining steps.

The melt infiltration method requires no external pressure. This prevents over-infiltration of the outer surface plies, which can lead to excessive residual porosity in the center of the part. However, processing of thick-section components required modification of the con-