Fall 11-10-2015

Processing, properties and prospects for melt infiltrated (MI) SiCf-ceramic composites

Raj Singh
Oklahoma State University, rajns@okstate.edu

PROCESSING, PROPERTIES AND PROSPECTS FOR MELT INFILTRATED (MI) CERAMIC COMPOSITES

Raj N. Singh, School of Materials Science and Engineering, Oklahoma State University
rajns@okstate.edu

Key Words: Ceramic Composites, Processing, Mechanical Properties, Silicon Carbide, High Temperature

Abstract

Ceramic materials exhibit superior mechanical properties at high temperatures. But, their use as structural components is severely limited because of their brittleness. Fiber-reinforced ceramic matrix composites (FRCMC), by incorporating fibers in ceramic matrices, not only exploit their attractive high-temperature strength but also enhance their toughness thereby rendering these attractive for many applications. Some of these applications require an understanding of the interrelationship among processing, fiber-matrix interface and mechanical properties both at room and elevated temperatures.

Processing of FRCMC is typically done by chemical vapor infiltration (CVI), filament winding and hot-pressing, and polymer infiltration and pyrolysis (PIP) approaches. Most of these approaches do not lead to full-density unless external pressure is applied during processing. A novel approach of melt-infiltration (MI) is a promising technique for fabricating fully dense and net-shape SiC fiber-reinforced SiC composites. The processing of FRCMC by MI was pioneered, invented and developed for making fully dense, net- and complex-shape silicon carbide (SiC) fiber-reinforced ceramic matrix composites [1]. The melt infiltration process technology exhibits processing-simplicity in which a porous preform consisting of carbon, SiC particulates and reinforcing SiC fibers is infiltrated with molten silicon (Si) for in-situ formation of SiC. This innovative processing is unique in that it is complete in a few minutes and produces net-shape and fully-dense composites inexpensively compared to other ceramic composite processes requiring applied pressure at very high temperatures for densification leading to shape change upon consolidation.

The high temperature mechanical properties of MI composites may be limited by the properties of the fiber and Si-SiC matrix. In particular, the matrix properties depend on the amount of Si in the Si-SiC matrix phase. Therefore, Si-SiC composites containing 10-45 vol% Si were fabricated using melt-infiltration process and their microstructure and mechanical properties were measured between 1250-1550°C. Elastic modulus, strength, and creep behaviors were studied including the influence of the Si content on these properties. Elastic modulus and strength were shown to decrease with increases in both Si content and temperature. The composites containing large amounts of the continuous Si phase exhibited extremely low strength near the melting point of Si, while the composites containing small amounts of Si with a continuous SiC network retained 120 to 200 MPa strength even above the melting point of Si. The composites containing 10 and 20 vol% Si exhibited excellent creep resistance up to 1550□C, well above the melting point of silicon. Creep rates as low as 10^{-10} to 10^{-9} were obtained at stresses of 40 to 75% of the strengths. Microstructural examination of the crept composites with 36 and 45 vol% Si showed a correlation between the creep behavior and nucleation and linkage of cavity in the tensile side leading to tertiary creep and creep failure. These results will be discussed and presented.

Biographical Sketch

Dr. Raj N. Singh is currently Regents Professor, Williams Companies Distinguished Chair Professor, Director Energy Technologies Programs and Head of School of Materials Science and Engineering at Oklahoma State University (OSU). He received his Sc.D. degree from Massachusetts Institute of Technology, M.S. from University of Manitoba and B.S. from IIT Kanpur all in Materials Science and Engineering. He worked for several years at Argonne National Laboratory, GE-R&D Center and University of Cincinnati before joining OSU in 2012.

Raj has been recognized for his engineering leadership through his scholarly activities (250 journal articles, 95 referred reports, and 220 presentations), pioneering inventions of MI composite processing technology leading to commercialization (27 granted patents), for graduating 25 students with MS and PhD degrees and through numerous professional awards in recognition of his engineering leadership such as National Academy of Inventors Fellow (2015); Albert Sauveur Achievement Award of ASM International (2016); Regents Professor (OSU 2015); Fellow of the ASM International (1996); Fellow of the American Ceramic Society (1992); Fellow of Graduate School (UC 2007); Whitney Gallery of Technical Achievers GE-CR&D (1990); Publication Awards GE-CR&D (1984, 1988); Patent Awards GE-CR&D: Bronze, Silver, and Gold Patent Medallions (1983, 1987, 1988). He also serves as member of editorial boards of 5 international journals.