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Microhardness and microstructure correlations in SiC/SiC composites

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ABSTRACT

We report the microhardness of SiC fiber-reinforced SiC matrix (SiC/SiC) composites produced by a transient eutectic phase (TEP) hot-press consolidation process. The internal microstructure of the composites was evaluated by scanning electron microscopy and microhardness variations were determined, showing that both matrices and fibers have hardness values that are independent of geometrical features. This verification is of special interest for the production of SiC/SiC composite structures with more complicated geometries for prospective nuclear applications.

1. Introduction

Silicon carbide (SiC) composites are attractive materials for next-generation nuclear reactor components due to their ability to retain essential thermo-mechanical properties in the presence of high neutron fluxes, molten salts, and high temperatures [1,2], making them candidates for fuel rod support assemblies, heat exchangers, and fuel cladding. However, unlike metals, SiC cannot be easily machined and formed to produce more complex core components needed to fully realize the benefits of advanced high temperature reactors [3]. High-purity SiC composites can be produced by a variety of techniques. However, more complex 3-D architectures [4] with sophisticated geometries are needed for advanced nuclear applications.

Several groups have studied the properties of SiC composites prepared by nanopowder infiltration and transient eutectic phase method [5–8], a technique in which a transient eutectic phase forms at the interface between fibers and matrix and solidifies before cooling to effectively consolidate the composite. For example, thermo-mechanical properties of SiC composites up to 1773 K have been described [5] and irradiation effects at 1473 K have been studied [7]. Additionally, Shimoda et al. [6] have proven that two different types of SiC fiber-reinforced composites, of high pseudo-ductility and high strength, can be produced by tailoring the fabrication temperature. Also, bending and tensile performance have been evaluated with respect to processing conditions [8], showing that elastic modulus and strength of samples improves with higher processing temperature and pressure.

Microhardness characterization is a common technique to evaluate local mechanical properties of fiber-reinforced [9–11] and composite [12,13] materials. Evaluation of microhardness is a powerful approach to estimate extremely small local variations in mechanical properties of materials due to changes in composition and porosity gradients. For example, microhardness evaluation has been used to quantify the mechanical response of coated and uncoated carbon fibers inside fiber reinforced aluminum matrix composites [9]. Furthermore, this technique has been employed to verify changes in mechanical properties of glass fiber-reinforced ethylene-octene co-polymer composites as a function of fiber content [10]. Additionally, microhardness evaluation has been used to estimate variations in local mechanical properties of C—C composites across joint interfaces [12] and to verify degradation of mechanical behavior as a function of distance from an external impact [13].

In this study, we describe a detailed microhardness characterization of complex SiC/SiC composites for potential use as in-core support structures in nuclear reactors. Planar composite samples with thru-hole features were produced by the transient eutectic phase method to introduce a level of part complexity that has not yet been achieved in nuclear-grade SiC/SiC composites. The main goal is to explore the possible variability of microhardness values at the edges of the thru-holes in our composites versus microhardness values further away from thru-hole edges.

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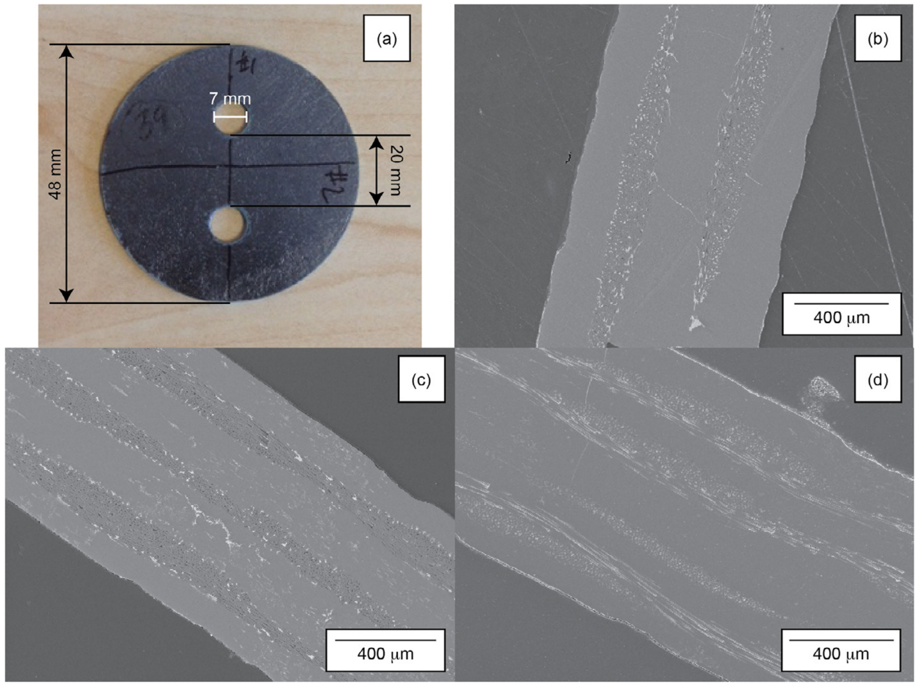

Fig. 1. (a) Sample geometry and scanning electron micrographs of (b) sample A, (c) sample B, and (d) sample C.

Table 1
Microhardness values for matrix and fibers, densities and apparent porosities, of the study samples.

Sample	Hardness number [matrix] (HV)	Hardness number [fibers] (HV)	Density (g/cm^3)	Apparent porosity (%)
A	2850 ± 120	2050 ± 390	2.96 ± 0.07	2.0 ± 0.6
B	2850 ± 160	2030 ± 290	3.00 ± 0.02	3.7 ± 1.0
C	2900 ± 130	1890 ± 280	2.98 ± 0.01	3.1 ± 0.5

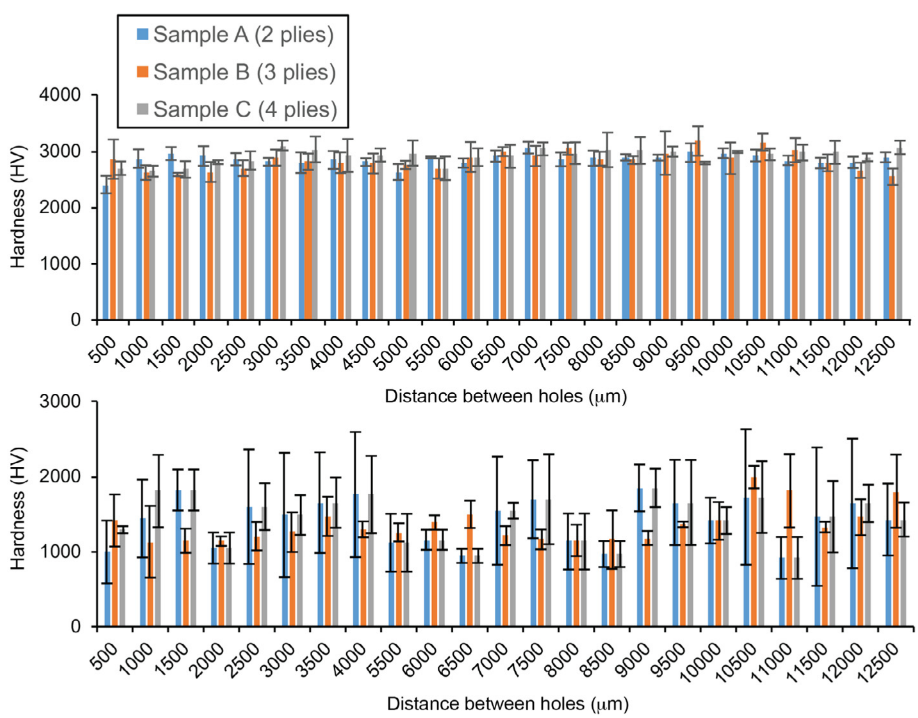

Fig. 2. Microhardness distribution for samples A, B, and C with regard to the distance between holes for (a) matrix, and (b) fibers.