Mechanics of Materials

The reliability of brittle materials may be improved through study of their microstructure, mechanical properties, and failure mechanisms. Fractography, computational modeling tools, and transmission electron microscopy are being used to study the effects of structure, particularly the role of flaws and defects, on the strength and reliability of ceramic components.

George Quinn, Edwin Fuller, Jr., and Bernard Hockey

Ceramic materials, by virtue of their light weight, good, high-temperature performance, and broad-ranging electronic and optical properties, offer many highly desirable qualities to the designers of devices and components. However, problems can arise when high-fracture toughness or accurate lifetime prediction are required because of the inherent brittleness of most ceramics and their propensity to fail from small flaws or defects. We study the effects of microstructure on the mechanical properties of brittle materials, including microstructural features that result from such manufacturing processes as coating deposition or surface grinding or machining.

The strength of a brittle material is very often determined by the size of the largest flaw in a test specimen; large flaws concentrate stress and lower strength. In the case of ceramic parts that are brought to their final shape by an abrasive grinding process, the largest flaws can be those created at the surface by the machining process. Sometimes small changes in that process can have a dramatic effect on the strength of the part. An intensive study of damage in ground ceramic surfaces has been completed and important trends documented in NIST Special Publication 996. The telltale signs of machining cracks were identified, and schematic illustrations and simple techniques to detect these features were added as a major revision to the fractography standard ASTM C 1322. The size and severity of cracks were correlated to grinding conditions. Wheel grit size and grinding direction were reconfirmed to be dominant factors, and the effect was quantified for the first time. Grinding damage maps for silicon nitride were determined; an example is shown in Figure 1.

Another area of work concerns the structure and mechanical properties of alumina and zirconia thermal barrier coatings (TBCs). Transmission electron microscopy examination of plasma spray coatings made with submicron-sized powders revealed that the coating microstructures were very non-uniform and showed improved hardness and wear resistance relative to conventional plasma sprayed coatings. Controlled indentation flaws were also used to characterize interfacial fracture toughness in TBC systems.

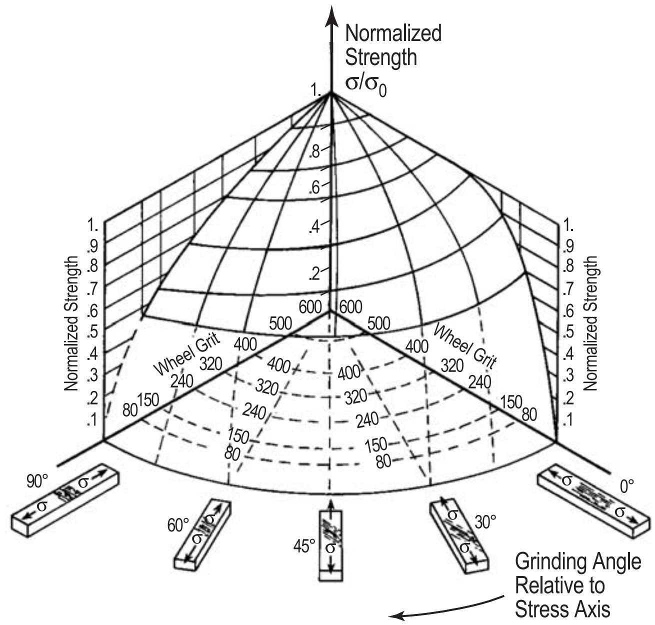

Figure 1: *Grinding damage map for silicon nitride.*

Microstructure-based finite-element simulations, based on the NIST object oriented finite element (OOF) code, were used to elucidate crack–microstructure interactions. Experimental studies and corroborative OOF simulations on particulate-reinforced ceramic matrix composites showed strong crack path variations with changes in the loading/unloading rate and microstructure. OOF simulations were used to elucidate the influence of grain orientation texture on bulk physical properties (*e.g.*, coefficients of thermal expansion) and on physical behavior (*e.g.*, residual stresses and microcracking propensity). Misorientation distribution functions were shown to have a profound influence on the residual stress networks that were observed in both real and simulated microstructures.

Contributors and Collaborators

D. Saylor, L. Ives (Ceramics Division, NIST); W. Luecke (Metallurgy Division, NIST); M. Bartsch, B. Baufeld (German Aerospace Research Laboratory, Germany); S. Wu, B. Palted (University of Alabama); A. Wereszczak, M. Ferber (Oak Ridge National Lab); S. Lee (Sun Moon University, Korea)