The Use of Amorphous Intergranular Films to Toughened Silicon Nitride Ceramics

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Abstract

Although amorphous intergranular films (IGFs) are quite common in ceramic systems, there are virtually no fundamental studies of them. In fact, they have generally been considered to be a pox; however, we are now finding that they can be a valuable asset. For instance, we have shown that high fracture strength and high toughness are achieved in silicon nitride containing amorphous IGFs when elongated grains are present. These elongated grains grow in the fluid amorphous intergranular phase during sintering and provide very strong reinforcing effects much like those seen in whisker-reinforced ceramics. Significant toughening is achieved when these elongated grains bridge the cracks, exerting a closure force. However, the bridging mechanism requires that a portion of the reinforcing grains separate or debond from the matrix; a process that prevents the crack from destroying the "bridge" by simply cutting through the reinforcing grains. In the self-reinforced ceramics, debonding occurs either at the interface between the reinforcing grains and the IGF (Case I) or within the IGF (Case II).

In Case I, the strength of the interface between the intergranular glass and the reinforcing grains can be altered by controlling the additives (e.g., Al_2O_3 + Y_2O_3), which are incorporated into the IGF and promote sintering. Experimental studies reveal that increasing the Y_2O_3 to Al_2O_3 ratio enhances the interfacial debonding. This is associated with a change in the composition of an epitaxial SiAlON layer that forms on the reinforcing grains. Thus one can tailor the additives and microstructure of silicon nitride ceramics such that both high toughness (> 10 MPa√m) and high strength (> 1GPa) are achieved. In Case II, the incorporation of fluorine in the IGF weakens it and allows the crack to circumvent the grains, a form of debonding. This also results in an increase in fracture toughness. Current theoretical studies, based on atomic cluster calculations, reveal that these two debonding processes are related to (a) strong Si-O and Al-O bonding across the glass-crystalline interface with an epitaxial SiAlON layer and (b) a weakening of the amorphous network of the intergranular film with the substitution of two fluorine atoms for a bridging oxygen. It can also be shown that the viscosity of these intergranular films is also influenced, which has a direct impact on creep resistance of the silicon nitride ceramics.

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