Dispersion Microstructure and Rheology in Ceramics Processing

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Abstract

Ceramics provide a potentially very useful class of materials owing to their physical properties; they are light, hard, resistant to abrasion, chemically inert, stable at high temperatures, and excellent thermal and electrical insulators. Further, by casting from a liquid suspension and subsequently sintering, many complex parts and shapes can be fabricated. Although the resultant properties of ceramics can be outstanding, they often suffer from extreme brittleness. This brittleness is caused by the propagation of cracks, which is in turn due to microstructural defects. These defects may be caused by a number of different factors, such as particle agglomeration, migration or segregation prior to sintering, or due to inhomogeneous volume change upon sintering. If a ceramic's microstructure can be controlled and rendered homogeneous prior to (and after) sintering optimal material properties may be realized in an economical way.

Typically, high-performance ceramics are produced using monodisperse micron-sized particulate suspensions from which the ceramics are cast. By controlling the size and processing, a dense uniform microstructure may be formed prior to sintering. This route has met with limited success even though the maximum volume fraction of ceramic particulates that can be achieved prior to sintering is 0.74. The limited success may stem from the fact that a perfect crystal of mono-sized particles has slip planes that yield easily, and from the fact that there is still a large amount of void space that must be eliminated upon sintering.

An alternate approach is to use a mixture of particle sizes. It is well known that solids fractions of 90% can be obtained with a bidisperse suspension of spherical particles. And even greater loadings are possible with tridisperse systems. Crystalline slip planes can be eliminated with a mixture of particle sizes. In addition to achieving high solids fractions, and therefore reducing potential sintering inhomogeneities, a mixture of two different types of particles can also impart desirable properties in a 'composite' ceramic. For example, zirconia in alumina has been used to arrest crack propagation owing to the transformation toughening of zirconia under stress. Owing to size or compositional differences, particle mixtures are subject to gravitational phase separation or demixing, which can severely limit the utility of these systems. Thus, processing in microgravity may provide an attractive environment for producing advanced ceramics.

For bi- or poly-disperse suspensions to be successful, the microstructure must be controlled during processing. It has been observed experimentally that for the same total volume fraction, a mixture of two particle sizes leads to a reduction in the suspension viscosity, with obvious advantages for ease of processing. Although there are several heuristic models to explain this viscosity reduction phenomena, there is no fundamental explanation and very little theoretical work has been done. Furthermore, the viscosity reduction is only one factor. Of much greater importance is the

microstructure formed during processing, for this determines the ultimate success or failure of the ceramic.

We have conducted Brownian Dynamics simulations of bidisperse suspensions for a range of particle size ratios and volume fractions of the individual species. Of particular interest is the near-equilibrium behavior of the dispersion rheology as a function of composition. Steady shear simulations probe the nonequilibrium microstructure and investigate the nature of the flow-induced order at high shear rates. Finally, a new O(N ln N) simulation algorithm with full hydrodynamics -- Accelerated Stokesian Dynamics -- is discussed.