Effects of Ethanol and Polyelectrolyte on the Processing of SiC_w/Al_2O_3 Composites

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INTRODUCTION

The low fracture toughness of pure alumina limits its application in structural components. Reinforcement of alumina with SiC whiskers has been shown to improve its fracture toughness. These improvements are limited by effective distribution of the whisker component within the matrix. Ceramic composites produced by wet processing methods exhibit improved whisker distribution through control of the suspension parameters. Thus, the suspension behavior effects the resulting composite toughness. Much is known about the suspension behavior of aqueous mixtures of alumina and SiC. However, less is understood about non-aqueous suspensions or aqueous suspensions containing polyelectrolyte salts. Thus, this paper examines the effect of 1) varying ethanol/water content and 2) varying the polyelectrolyte content on the processing and densification of SiC_w/Al_2O_3 composites.

ABSTRACT

By manipulating the interparticle attractive and repulsive forces in colloidal suspensions of ceramic particulates, mixtures of different dispersing abilities were obtained. Changing the concentration of the ionic species, pH, polyelectrolyte and the solution (electrolyte, ethanol, or a mixture of electrolyte and ethanol), alters the net interparticle force. The zeta potentials of single component suspensions of varying concentration of ionic species, polyelectrolyte addition, and solution were measured as a function of pH. Using the suspension zeta potential, the stability ratio was calculated and related to the observed suspension behavior. SiC_w/Al_2O_3 suspensions were slip cast, cold-isostatically pressed and sintered at 1600°C in flowing nitrogen. Sintered densities were measured and the microstructures examined in a scanning electron microscope.

a) The effect of ethanol
As the ethanol content increases, the absolute values of the zeta potential for both SiC_w and Al_2O_3 decrease. This leads to a decrease in stability for both materials, as verified by interparticle calculation and sedimentation experiments. The iso-electric point shifts with increasing ethanol content to more basic pHs for SiC_w and for Al_2O_3 to more acidic pHs. SiC_w and Al_2O_3 sedimentation densities in electrolyte solution at high pHs show increased sedimentation density when compared to suspensions prepared in mixtures of 99% ethanol and 1% electrolyte. Stability calculations predict stable suspension at low pHs. Therefore, these suspensions should have high sedimentation densities when compared to unstable suspensions at higher pHs. Ethanol, and mixtures of ethanol and electrolyte, reduces the overall dielectric constant of both suspensions resulting in a decrease in the zeta potential due to compression of the double layer. The calculated stability ratio predicts a decrease in the stability of the suspension as the ethanol content increases. But at pH<8, the stability between SiC/SiC improves as the ethanol content increases. The higher attractive interaction potential for SiC in

ethanol is believed to lead to improvements in the suspension stability. Photomicrographs show the SiC_w and Al_2O_3 well dispersed both in electrolyte and in 1:1 ethanol:electrolyte suspensions. Although the composite suspension is stable and codispersion of SiC_w and Al_2O_3 in electrolyte and a mixture of ethanol and electrolyte is favorable, densification was inhibited by the SiC whisker network effect.

b) The effect of polyelectrolyte

An ammonia salt of a polymeric carboxylic acid polyelectrolyte was used to control the surface chemistry and to stabilize a SiC_w/Al_2O_3 suspension. As the polyelectrolyte concentration was increased, the zeta potential versus pH curve was shifted to more acidic pHs. This corresponded to a shift in the iso-electric point (iep) from pH~9 for a suspension of alumina particles in a 10^{-3}N KNO_3 electrolyte solution to an iep of pH~4.3 for an alumina suspension containing 0.03vol% polyelectrolyte and pH~3.3 for an alumina suspension containing 0.23 vol% polyelectrolyte (see Figure 1). The iep demonstrated no further decreases with additional increases in polyelectrolyte above 0.23 vol%. By incorporating the use of polyelectrolytes with traditional ceramic processing tools such as sintering aids and ball milling, sintered densities up ~3.79 g/cm^3 were achieved (97% theoretical density) for pure alumina. Sintered densities up to ~3.40 g/cm^3 (89% theoretical density) were measured for samples containing 10 and 20 vol% SiC whiskers, respectively, where sintering occurred at 1600°C under flowing nitrogen. 2.5 volume percent polyelectrolyte stabilized the suspensions and resulted in high composite densities. However, further addition of polyelectrolyte passed the adsorption saturation limit served to leave excess polyelectrolyte in suspension and this excess polyelectrolyte lowered the densities of the composites. The final microstructures revealed homogeneous and near fully densified composites when 2.5 volume percent polyelectrolyte was used. As expected, increased hardness values for the composites mirrored increases in density. Although hardness decreased as whisker loading increased due to the whisker's ability to inhibit densification, the fracture toughness increased from 3.8 to 7.3 MPa·m$^{1/2}$ with additions of 20 vol% SiC whiskers. The fracture toughness decreased to 6.3 MPa·m$^{1/2}$ when the whiskers were ball-milled to reduce their aspect ratio.

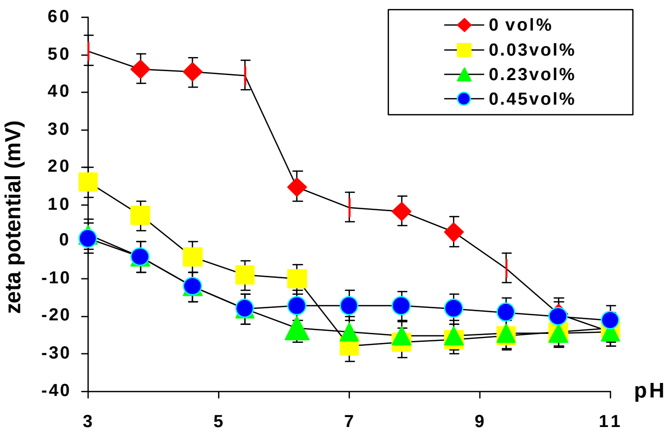

Figure 1. Zeta potential for Al_2O_3 versus pH at different concentrations of an ammonia salt of a polymeric carboxylic acid polyelectrolyte (0.001N KNO_3).