

Synopsis

Structural ceramics such as alumina are known to have excellent hardness and high temperature mechanical properties. In view of this, they are used as refractory linings to mitigate the effect of high temperature exposure. It is a highly stable compound and it has excellent chemical inertness and biocompatibility: it finds use in hip replacements. As a high bandgap electrical insulator, it does not absorb electromagnetic radiation in a fairly wide range of frequencies. This property is exploited to make optical and infrared transparent windows with high density pore free alumina. In addition, it is widely used in numerous applications in diverse fields.

In view of its widespread use, it remains as a material which has been subject to extensive scientific study. However, for structural applications, alumina suffers principally from a lack of respectable fracture toughness, in other words it is prone to brittleness. This limitation severely restricts it from being used to the fullest of potential. Also, at high temperatures finegrained.

alumina is prone to rapid static and dynamic grain growth, hindering the possibility of forming complex shapes by superplasticity. Carbon nanotubes (CNTs) are wonder materials with exceptional strength and stiffness and are expected to be ideal reinforcements, which may improve fracture toughness in their host matrices. Good dispersion in a ceramic matrix is critical to realize the promise offered by CNTs as reinforcements. Very limited studies have been carried out on the microstructural stability and the high temperature mechanical behaviour of these composites, which may redress some of the shortcomings related to pure alumina.

The aim of the present of the thesis is to tailor processing methodologies to obtain uniform, well dispersed CNT reinforced alumina composites and study their high temperature grain growth and creep behaviour. It was observed that a colloidal processing technique yielded composites with the desired dispersion. Three different volume fractions (0.5, 3 and 8 %) were chosen based on electrical percolation behaviour, from conductivity data. The 0.5 volume per cent composite was below the percolation threshold, the 3-volume composite was above the threshold, and the 8-volume composite was significantly above the percolation threshold. The initial grain sizes of all the composites were in the submicrocrystalline size regime.

Transmission electron microscopy of the as synthesized composite revealed that the CNTs were preferentially attached to alumina grain boundaries. The microstructural stability of these composites on high temperature exposure and their mechanical properties at elevated temperature were studied. Grain growth experiments were performed in flowing argon through a custom made setup in a high temperature furnace, to probe the microstructural stability at high temperature. The grain growth experiments performed at 1573 K showed that CNTs had an extraordinary influence in stabilizing the alumina grain size to the submicrocrystalline range. A parabolic law was found adequate to capture the grain growth kinetics for all volume fractions. A clear tendency for grain growth saturation was also observed for higher volume fractions. The drag force exerted by cylindrical CNTs on the moving grain boundary was calculated analytically. The non-random distribution of CNTs and their cylindrical morphology do not lend themselves for a conventional Zener particle-drag based treatment to obtain limiting grain sizes in alumina. A simple geometrical model was proposed to capture the limiting grain size of the composite with volume fraction. The experimental data were consistent with the predictions from the geometrical model.

Creep experiments were performed in flowing argon in a constant load creep frame.

Creep experiments at 1573 and 1473 K exhibited fairly high strain rates at moderate applied

stresses on account of the very fine initial grain size of the composites. A nominal steady state was observed for all composites for all test conditions. The matrix microstructure was observed to be very stable during creep deformation. Stress induced grain growth was also not clearly discernible in the composites. Experiments were performed on pure alumina to evaluate the effect of CNTs on the creep deformation of the composites. The stress exponent, an inverse grain size exponent and activation energy were calculated from creep experiments and they were found to be consistent with a Coble diffusion creep deformation mechanism at high stresses. A transition to an interface reaction-controlled creep process was observed at lower stresses. Volume fraction of CNTs did not affect the creep properties of the composites at high stresses, although, a pronounced drop in creep rates were observed at lower stresses for the 8CNT composite, which may be related to some effect of load sharing by CNTs. Comparison of the experimental creep data with theoretical models for Coble diffusion creep based on oxygen and aluminium ion grain boundary diffusivity from recent experiments in the literature revealed that the experimental creep rates are in between the theoretical lines for oxygen and aluminium ion controlled deformation. Conventionally, in creep of ceramics the slowest moving species diffusing along the fastest path is expected to control deformation; however, experimental data obtained here is at variance with this expectation. The ultrafine stable composites with high steady state strain rates at modest stresses offer excellent scope for low temperature superplasticity in alumina ceramics.