X-ray Tomography of Voids and Second-phase Pockets in Silicon Nitride

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Introduction

The efficiency of gas turbines is ultimately limited by the maximum turbine inlet temperature that can be sustained by the components inside the turbine. For small turbines, where blade cooling is not available, having structural materials that can function at high temperatures without cooling is critical. Structural ceramics such as silicon nitride are candidate materials for this application because of their good mechanical properties at high temperatures. The current generation of silicon nitride ceramics based on Y- and Yb-based additives (Fig. 1) is adequate for operational periods of more than 10,000 h only to temperatures below 1325ºC. However, the maximum turbine inlet temperature already exceeds this number. Thus, the potential advantage of using ceramics has not yet been realized. Preliminary measurements on newer silicon nitride grades containing Lu-based additives indicated an increase of up to three orders of magnitude in creep resistance and an increase of more than two orders of magnitude in lifetime when compared with the older grade containing Yb. However, neither the reasons for such a dramatic increase in creep resistance, nor the mechanism responsible, is understood.

Methods and Materials and Results

To improve our understanding of the mechanisms controlling creep, we have performed USAXS studies of the two silicon nitride formulations mentioned above. Ordinarily, scattering from the large volume fraction (4 to 8 vol%) of the secondary phase would dominate the scattering from the creep void fraction (less than 2%), and an analysis of creep cavities could not be done. By means of anomalous scattering measurements and analysis, such quantification is rigorously possible. The USAXS results indicated that in the new Lu-based ceramics, cavitation does not occur (compared with the older grade containing Yb). Although anomalous USAXS can quantify the secondary phases and the porous (cavity) phase as a function of deformation, it cannot be used to characterize the distribution of porosity. Electron micrographs indicated that the microstructure morphologies of the two formulations are quite different, and it has been suggested that the cavitation control exhibited by the new Lu-based ceramics is a result of the interconnectivity of the additive phase. In this study, carried out on SRI-CAT beamline 2-BM-B, we performed x-ray tomography measurements on both formulations to investigate the connectivity (or lack thereof). Both crept and uncrept samples of the two silicon nitrides were imaged. While voids and second phases were observable, the minimum tomographic resolution of 1.3 μm did not permit us to follow the submicrometer connectivity.

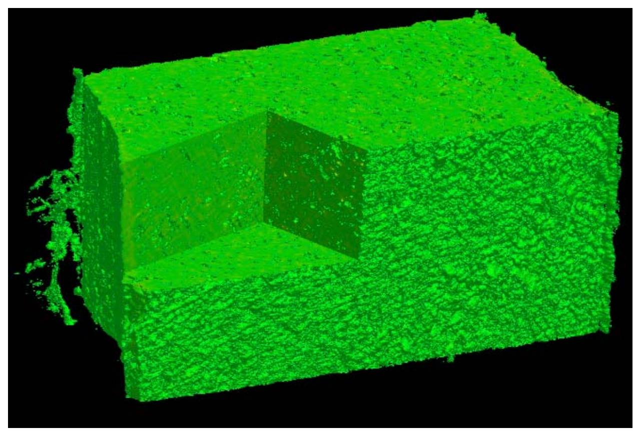

FIG. 1. A 3-D image of an undeformed silicon nitride containing Y- and Yb-based additives.

Discussion

These measurements will be repeated when the next generation of submicrometer tomographic cameras becomes available.

Acknowledgment

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