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13. ABSTRACT (Maximum 200 words)

A study was conducted concerning the role of cracks in the creep deformation and fracture behavior of polycrystalline structural ceramics. Grain boundary cavitation during creep in a course-grained alumina was found to cause a decrease in Young's modulus by as much as a factor of five, indicative of the contribution from elastic creep by crack growth and crack-enhanced creep to the total creep deformation. Multiple crack formation in a fine-grained alumina was found to increase the strain-rate sensitivity of the failure stress, as the result of strain-rate dependent decreases in Young's modulus. For a alumina with glassy grain boundary phase, the one-to-one correlation between creep rate and time-to-failure presented evidence for crack-enhanced creep-fracture. Silicon carbide whisker-reinforcement of alumina was found to suppress cavitation, coupled with an increase in the stress exponent. A micromechanical analysis of this effect indicated that creep deformation of SiC whisker-reinforced alumina appears to be governed by stress-dependent sliding at the whisker-matrix interface.

14. SUBJECT TERMS

Aluminum oxide, creep, cavitation, Young's modulus, strain-rate sensitivity, creep rupture, silicon carbide whisker-reinforcement

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ROLE OF CRACKS IN THE CREEP DEFORMATION

OF

POLYCRYSTALLINE STRUCTURAL CERAMICS

FINAL REPORT

by

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Objectives.

The objective of the current program was to learn about the role of cracks in the creep deformation and fracture behavior of polycrystalline structural ceramics.

Under a previous ARO-funded research program residual stress relaxation in structural ceramics was observed to occur primarily by the formation of cracks. Two primary mechanisms for the role of cracks in the creep of polycrystalline structural ceramics were identified. The first mechanism was based on the formation and growth of cracks, which would lead to a time-dependent decrease in the elastic moduli, referred to as "elastic creep". The second mechanism was based on the presence of cracks, which would lead to an acceleration of the creep rate, referred to as "crack-enhanced creep". A theoretical basis for this latter mechanism had already been established in the literature.

The primary purpose of the present research program, funded in two stages under separate contract numbers, was to establish experimental evidence for elastic and crack-enhanced creep.

During the first phase of the program, it was found that due to grain boundary cavitation, Young's modulus of a large-grained alumina subjected to deformation at elevated temperatures over a range of displacement-controlled loading conditions decreased by as much as a factor of five. This implies that the additional elastic strain created during deformation made a substantial contribution to the observed non-linear behavior. The grain boundary cavitation also made a substantial contribution to the "crack-enhanced creep", confirmed by analytical modelling.

A second study showed that multiple crack formation at elevated temperatures and associated decrease in Young's modulus increased the apparent strain-rate sensitivity of the failure stress of a fine-grained alumina. At the lower loading rates, sufficient time was available prior to failure to cause substantial multiple crack formation with associated decrease in Young's modulus, extending the samples' time-to-failure, whereas this effect was absent at the higher loading rates.

The above results suggested that the interpretation of data for the non-linear deformation and fracture behavior of polycrystalline structural ceramics must include measurements of microstructural changes and associated decreases in elastic properties.

The second(current) phase of the program was intended to be based on the identical coarse-grained alumina, which exhibited such dramatic decreases in Young's modulus during high-temperature deformation, as found in the first phase of the program. However, the manufacturer was unable to duplicate the microstructure of the second batch of material ordered for this purpose, a problem apparently related to design changes in the equipment formerly used for the manufacture of this particular alumina. A great deal of effort, associated with extensive delays, was devoted in an attempt to solve this problem without success. Fortunately, other materials were obtained which suited the objectives of the program.

The first material studied consisted of a relatively coarse-grained polycrystalline aluminum oxide with a glassy phase boundary. This material exhibited unusual behavior in that the creep rate and time-to-failure showed very poor correlation with the magnitude of applied stress. In contrast, in terms of Monkman-Grant behavior, excellent correlation was found between creep rate and time-to-failure. This latter observation suggested a one-to-one correspondence between creep rate and time-to-failure for any one specimen. This led to the hypothesis that the failure-causing crack may have accelerated the rate of creep, i. e., caused crack-enhanced creep. This hypothesis was verified by measuring the creep rate and time-to-failure of samples with artificial cracks in the form of diamond-sawed slots or indentation cracks introduced with a Vickers indenter. The slotted and indented samples showed a very rapid increase in creep rate with increasing slot depth or size of indentation flaw, in direct support of the concept of crack-enhanced creep. At the same time, the time-to-failure showed a corresponding decrease, again showing excellent correlation between creep rate and time-to-failure. These results were reported in a paper submitted to the Journal of Material Science.

The second material to be investigated consisted of SiC whisker-reinforced polycrystalline alumina. As reported in the literature, the introduction of the whiskers in the alumina matrix markedly improved its creep resistance, especially at the lower stress levels. It was felt that this increase in creep resistance occurred because the presence of the whiskers inhibited intergranular crack growth and thereby decreased or even eliminated the contributions of elastic creep by crack-growth and the corresponding crack-enhanced creep. In direct support of this hypothesis, following creep deformation of these samples no significant decreases in Young's modulus were found.

It was found that the creep rate of the whisker-reinforced alumina had a higher value of stress exponent than the alumina matrix phase without whiskers. A micromechanical analysis of the creep of whisker-reinforced composites indicated that this difference most likely can be attributed to a stress-dependent interfacial sliding.

A paper reviewing the effects of elastic creep by crack-growth and crack-enhanced creep is being prepared for presentation at the Fifth International Symposium on the Fracture Mechanics of Ceramics, Nagoya, Japan, July 15-17, 1991.

PUBLICATIONS.

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