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13. ABSTRACT (Maximum 200 words) Distribution of coarse-grain alumina agglomerates within a fine grain alumina-mullite matrix results in substantial T-curve behavior. The T-curve behavior is genuine and not an artifact that may have arisen due to surface cracking and/or lateral cracking effects. In-situ observation of cracks propagating in duplex-bimodal AM revealed three potential T-curve mechanisms: (i) alumina grain bridge formation within alumina agglomerates, (ii) elastic-bridge formation and (iii) microcracking. The effect of agglomerate volume fraction and size on indentation-strength response suggest the T-curve behavior originates from bridging grains within the alumina agglomerates. However, the level of toughening observed is significantly greater than that expected based on bridging theory. This indicates that there may be some combined contributions from the different mechanisms and/or that bridging in a duplex-bimodal microstructure is more effective than in a monolithic coarse-grain ceramic.				
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10/25/95

**FINAL REPORT****"Mechanical Properties of Ceramic Composites Exhibiting Tailored Duplex-Bimodal Microstructures"****AASERT Award (FY91)****Parent Program AFOSR-91-0126  
PI's: M.P. Harmer, H.M. Chan and G.A. Miller****Materials Research Center  
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Dept. Materials Science & Engineering  
Lehigh University  
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## Toughness-Curve Behavior of Alumina-Mullite Ceramics with Duplex-Bimodal Microstructures

A. Khan, M.P. Harmer, H.M. Chan

### Technical Report

**Background:** Toughness-curve (T-curve) behavior is characterized as an increase in a material's toughness with crack extension. It is desirable in structural ceramics because it leads to flaw-tolerance, i.e. where strength is not as strongly dependent on flaw size. Clearly, such a property is highly attractive from the stand-point of engineering design. It was with this in mind that alumina-mullite (AM) ceramics with a unique duplex-bimodal microstructure were initially conceived under the parent contract to this ASSERT award. These ceramics exhibited impressive T-curve, and hence, flaw-tolerant behavior. However, the mechanisms responsible for the T-curve behavior remained unclear.

**Objective:** To identify the mechanisms responsible for T-curve behavior of duplex-bimodal alumina-mullite ceramics.

**Experimental Approach:** A series of experiments were conducted to identify the mechanism(s) responsible for the T-curve behavior of duplex-bimodal AM ceramics. Such microstructures consist of coarse-grain ( $\approx 15 \mu\text{m}$ ) spherical alumina agglomerates within a fine-grain ( $\approx 2 \mu\text{m}$ ) 50/50 vol. % alumina-mullite matrix. The experiments included evaluating indentation-strength response as a function of, (i) alumina agglomerate volume fraction (agglomerate size fixed) and, (ii) alumina agglomerate size (agglomerate volume fraction fixed). Complementary *in-situ* crack propagation experiments were also conducted to provide direct observation of crack/microstructure interaction.

**Results:** Distribution of coarse-grain alumina agglomerates within a fine grain alumina-mullite matrix results in substantial T-curve behavior. The T-curve behavior is genuine and not an artifact that may have arisen due to surface cracking and/or lateral cracking effects. *In-situ* observation of cracks propagating in duplex-bimodal AM revealed three potential T-curve mechanisms: (i) alumina grain bridge formation within alumina agglomerates, (ii) elastic-bridge formation and (iii) microcracking. The effect of agglomerate volume fraction and size on indentation-strength response suggest the T-curve behavior originates from bridging grains within the alumina agglomerates. However, the level of toughening observed is significantly greater than that expected based on bridging theory. This indicates that there may be some combined contributions from the different mechanisms and/or, that bridging in a duplex-bimodal microstructure is more effective than in a monolithic coarse-grain ceramic.

## EVALUATION REPORT

- A. AFOSR-91-0126, is the basic DOD research agreement (parent award) to which the students are linked.
- B. 1) Total funding for parent agreement was \$677,642.
- 2) Number of full-time equivalent graduate students supported by parent agreement during 12 months period prior to AASERT award was 3.
- C. Number of students 12 months after AASERT award was 1.
- D. Full-time research assistant budget \$37,634 for stipend; \$13,750 for tuition.  
1 student on award - Ajmal Khan
- Undergraduate budget - \$7,543  
Summer 1992 - Jennifer Albers  
Summer 1993 - Ellen Youngblood
- E. For certification, see original AASERT proposal.

### AASERT Award

#### Parent award years were:

12/15/90 - 12/14/91  
12/15/91 - 12/14/92  
12/15/92 - 06/14/94

#### AASERT award years were:

06/01/92 - 05/31/93  
06/01/93 - 05/31/94  
06/01/94 - 05/31/95