U.S. ARMY RDECOM

Enhancement of Fracture Toughness In Presence of Microwave Field

ARL open campus

S&T Campaign: Materials Research
High Strain and Ballistics

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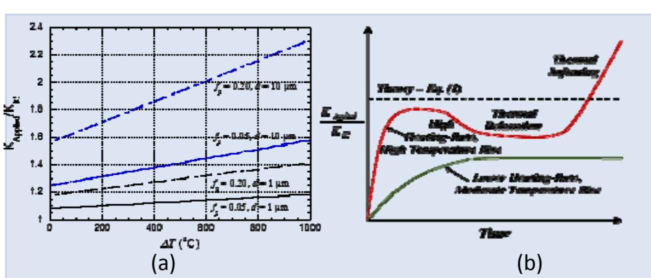
Research Objective

- A fundamental question we seek to answer is whether or not the fracture resistance of ceramics can be enhanced in the presence of microwave (MW) fields and if so, by what mechanism or mechanisms and by how much? Both experimental and modeling (analytical and computational) components are utilized.
- A variety of approaches, have been developed to significantly improve fracture resistance (i.e. toughness). These approaches involve either engineering grain boundaries or adding second phases with/without engineered interphase boundaries. Toughening mechanisms, such as stress-induced particulate volume expansion (e.g. transformation toughening), crack-deflection, microcracking, crack-wake bridging, and frictional sliding, act to lower the stress-intensity at the crack-tip effectively "shielding" it from the "full-force" of the far-field applied tensile stresses. We are investigating a novel way of fracture toughness enhancement by applying an external electromagnetic (EM) field to functionalize a second phase microparticles. The proposed approach has a benefit of better control of the fracture toughness enhancement process and of higher efficiency.

Challenges

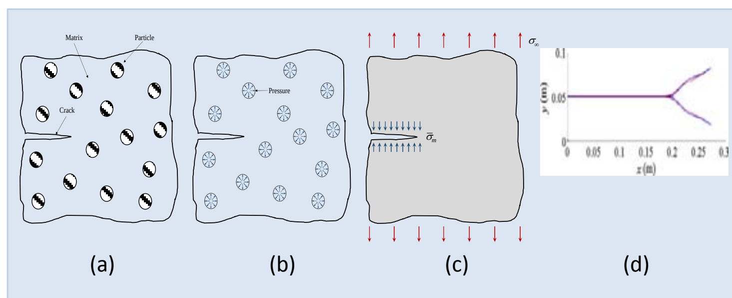
- Processing to full density a "suitable" model material system that allows a time-dependent fracture resistance to be achieved as illustrated below. A possible model material system is either Al_2O_3-SiCp or Al_2O_3-TiB_2p.
- Determining the temperature and MW field-induced stresses in the model material system as a function of MW field parameters.
- Design and fabrication of specimens and mechanical fixtures that will be used to measure fracture resistance in the presence of MW fields.



(a) Predicted fracture resistance of a SiC-TiB_2p ceramic composite as a function of TiB_2 particle size, volume fraction, and temperature rise in the presence of a MW field. (b) Variation in fracture resistance with time due to heat transfer, thermal relaxation, and thermal softening.

ARL Facilities and Capabilities Available to Support Collaborative Research

- **Experimental facilities include:**
  - Anton Paar "Multiwave Pro" microwave reaction system
  - Experimental Setup for In-Situ measurement of fracture toughness of the samples under microwave field (in design)
  - Hot press for two-phase ceramic samples fabrication
- **Modeling/simulation approaches include:**
  - Static finite-element analysis of dilute solutions of particles
  - J-integral to determine the stress intensity factors at crack tip
- **References:**
  - Rybakov et al., *J. Am. Cer. Soc.*, **96** 1003 (2013).
  - Evans, *J. Am. Cer. Soc.*, **73** 187 (1990).
  - Clark and Sutton, Annu. Rev. Mat. Sci., **26** 299 (1996).
- **ARL expertise:** multidisciplinary approach that includes expertise in the fields of MW physics and processing, ceramics processing, fracture mechanics and electromagnetic fields modeling



(a) 2D schematic illustration of particles embedded in a matrix with semi-infinite crack. (b) In the presence of a MW field, the particles heat up and expand, pressurizing the matrix. (c) The resulting matrix compressive stress ( ) reduces the crack-tip stress-intensity associated with the far-field tensile stresses.(d) Comparison of crack paths hybrid (red) and peridynamics (blue)

Complementary Expertise/ Facilities/ Capabilities Sought in Collaboration

- Expertise in in-situ fracture toughness measurements of samples under electromagnetic fields.
- Facilities to measure in-situ fracture toughness in the samples under electromagnetic fields.
- Expertise in thermal kinetics in the two-phase ceramic system

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