Characterization of Brittle Materials Under Multiaxial Loading

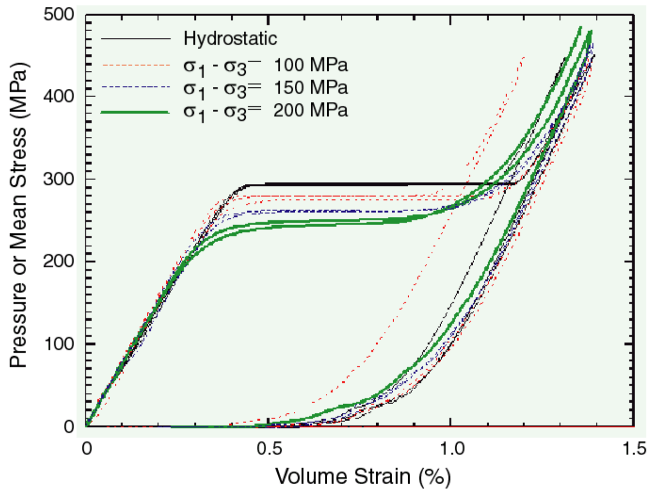
Need

Various components of nuclear weapons are routinely replaced as a consequence of known aging effects, or if problems are detected during periodic component testing. Indeed, some individual components are completely redesigned prior to fabrication and replacement. Thus, although no new weapons systems are now being designed or built, component redesign and/or fabrication are ongoing processes. The materials used in these newly-designed components must be expected to operate over a wide range of temperatures. Additionally, some of the components critical to nuclear detonation such as ferroelectric explosive neutron generators (FENGs) even rely upon shock waves supplied by conventional explosives in order to operate. Some materials used in weapons components are brittle and pressure-sensitive under ambient conditions, but become strong and ductile at high pressures. Other materials are temperature-as well as pressure-dependent.

As prototype fabrication and testing become more and more expensive, it becomes increasingly cost-effective to evaluate design changes using numerical simulations: poor design concepts can be screened out and performance optimized before a single test unit is ever fabricated. However, numerical simulations using the finite element method require accurate constitutive models and mechanical properties for the many, and often-unusual, materials used in many weapon components. The conditions under which the materials are characterized must, insofar as possible, reflect the conditions under which the components must operate.

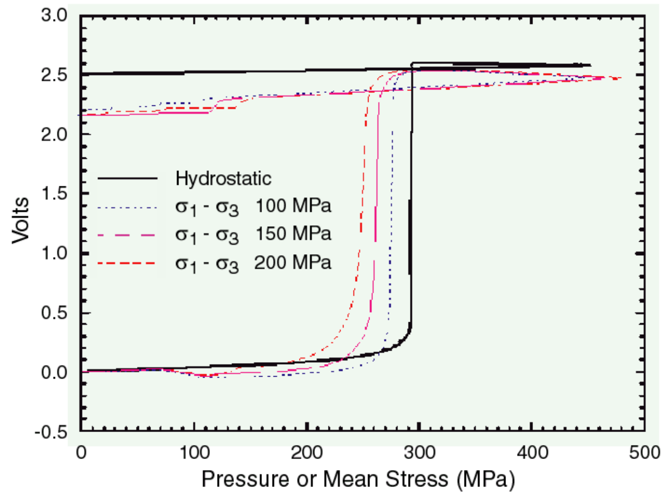
Description

The Geomechanics Department uses experimental techniques developed in the areas of rock mechanics and geophysics to simulate the inertial confinement experienced by materials during shock-wave actuation. Changes in deformation and failure mechanisms are investigated in the laboratory as functions of confining pressure and strain rate. The Geomechanics Department has long had the capability to study material properties at elevated temperatures as well as elevated pressure: one triaxial test cell is capable of 400° C at 200 MPa confinement. Work is now in progress to develop the capability to simultaneously test materials at high



Effects of constant shear stress on onset of the FR1-AO polymorphic transformation of poled PZT 95/5-2Nb. The transformation is indicated by the sharp volume decrease at a pressure of about 300 MPa. Note that increasing shear stress lowers the mean stress for onset of the transformation.

confining pressures (500 MPa) and low temperatures (-65° C) as well. Quasistatic testing in a truly triaxial stress state is available, and intermediate strain rates (up to 1000/s) can be achieve under unconfined conditions using a split Hopkinson bar.



Effects of constant shear stress on rate of charge release during depoling of PZT 95/5-2Nb ceramic. The increasing radius of curvature of the voltage-pressure (or mean stress) plots indicates a slowing in the charge release rate, because the pressurization rate was constant in all tests. Note also the reduction in mean stress with increasing shear stress.

Examples

Poled PZT 95/5-2Nb ferroelectric (FE) ceramic is the active electrical element in FENGs. The poled ceramic, which carries a bound surface charge, undergoes a phase transformation to an antiferroelectric (AFE) polymorph at about 300 MPa. Because the AFE phase is macroscopically non-polar, the bound charge is released (depoled). Under shock wave conditions high currents and voltages are achieved, in turn supplying the excess neutrons that ensure criticality. The Geomechanics Department has characterized the strength, deformation and failure properties of this important ceramic as functions of pressure and strain rate. More importantly, under shock conditions, the stress state experienced by the ceramic in not hydrostatic. We have investigated the effects of nonhydrostatic stresses on the occurrence and kinetics of the transformation. We have shown that triaxial test states have a profound effect on transformation and depoling rates, and developed quantitative models that describe these effects. Similarly, we have characterized the mechanical properties of alumina-loaded epoxy (ALOX) encapsulants used in FENGs, which empart ruggedness to the component and serve as wave transmission media. Results of both of these investigations are currently employed in the numerical models that simulate FENG power supply operation.

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