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The Potential for Smart Materials in Shock Mitigating Systems

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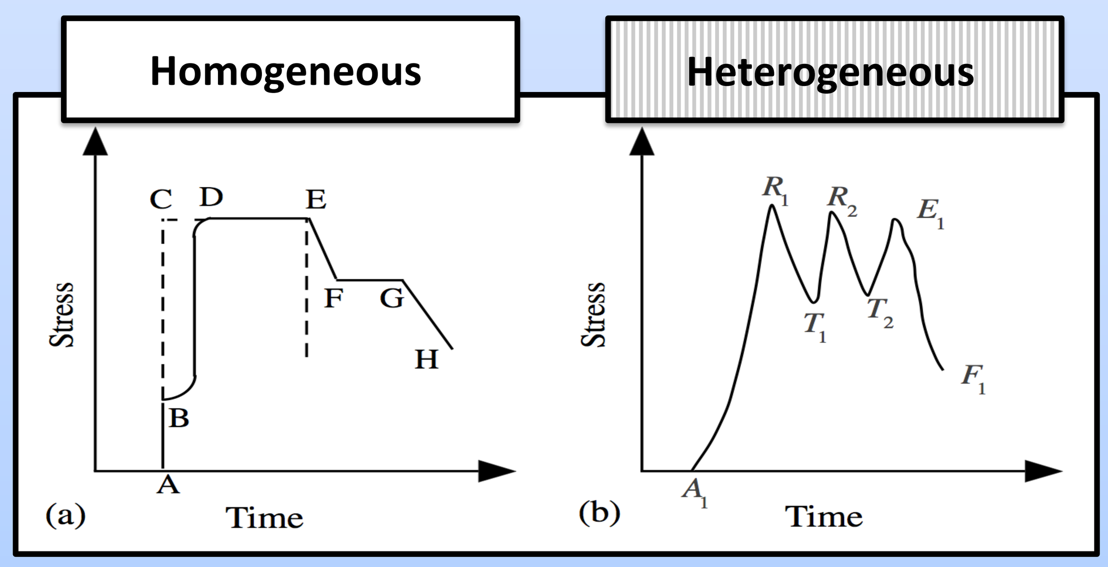
Shockwaves in Heterogeneous Media

- Blast mitigation requires controlling shock propagation.
- Heterogeneous materials have excellent shock attenuating properties due to wave scattering at the mechanical impedance-mismatched interfaces.
- Graded materials can alter the shock propagation direction.
- Shock waves reflect off interfaces of increasing mechanical impedance.
- Wave scattering increases the shock viscosity, spreading the shock front and attenuating the wave.

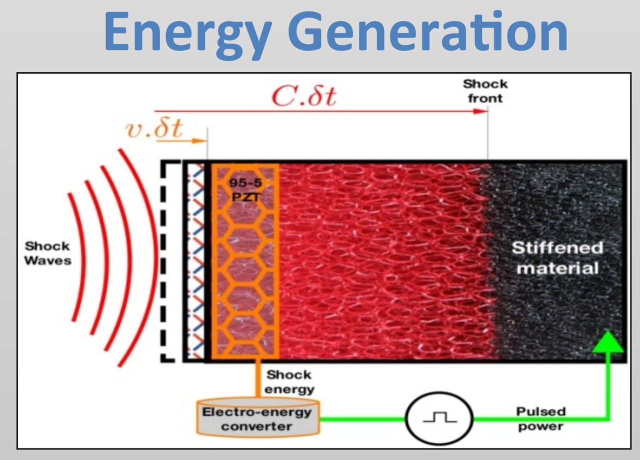


S. Zhuang, G. Ravichandran, and D.E. Grady, J. Mech. Phys. Solids 51, 245 (2003).

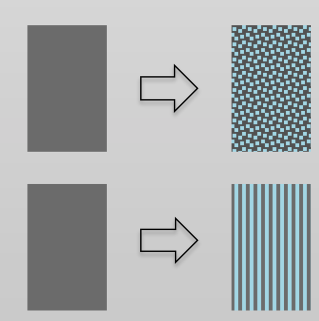
Smart Components

- Ferroelectric materials generate an electric pulse when shock compressed.
- Conversely, an electric field can induce expansion, contraction, or a modulus change through the converse piezoelectric effect.
- When multiple PZT components are placed in successive order, the electric pulse from a shocked component can be propagated ahead of the shock front to alter the response of subsequent components.
- Smart materials can be used to stiffen elements or open gaps in fractions of microseconds.

Energy Generation

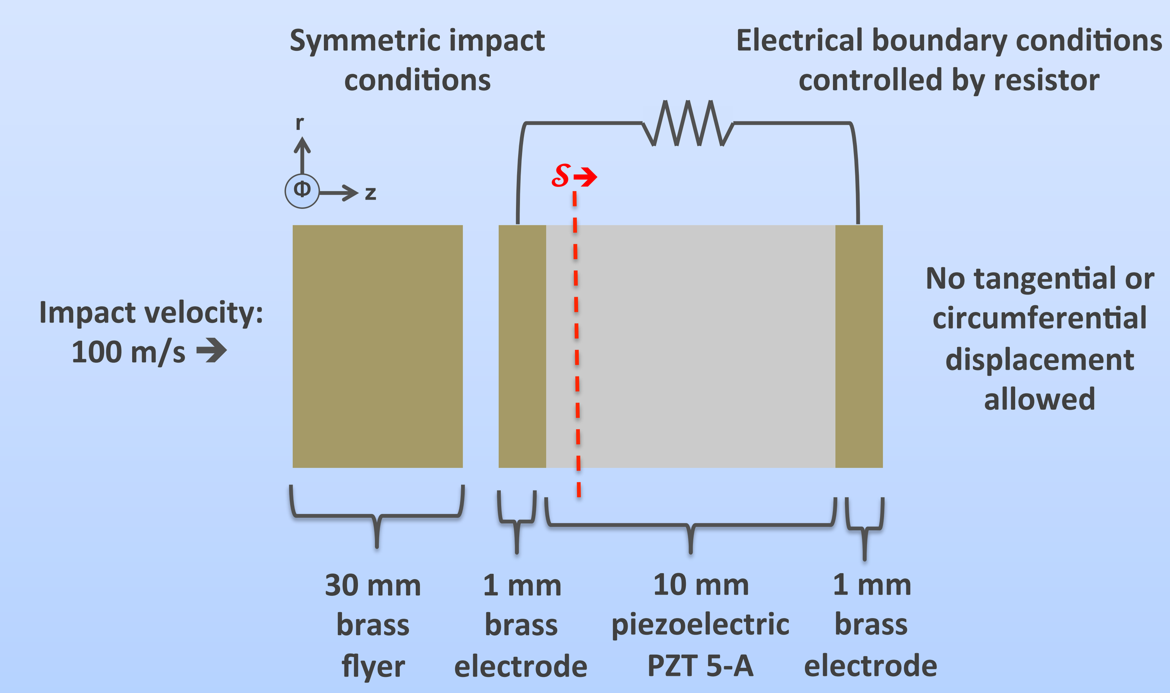


Adaptive Morphology



Multiphysics Modeling

- Representative volume elements were modeled using Sandia's multiphysics shock code ALEGRA-FE under open and short circuit conditions.
- Cylinders of PZT-5A were placed between two brass electrodes and subjected to uniaxial strain loading by plate impact with a brass flyer.



Physical Explanation: Open Circuit

- The electric field within each region of the PZT is determined from $\nabla \cdot \vec{D} = \rho$. Prior to impact, the PZT is charge balanced (E=0).
- Open Circuit = no charge transport; as the electric dipole strengths in the shocked region of the PZT decrease, an electric field develops due to the unbalanced electrode charges (piezoelectric effect).
- The electric field in the unshocked region remains zero.
- There is no electric field in the unshocked material, so it does not stiffen or contract.

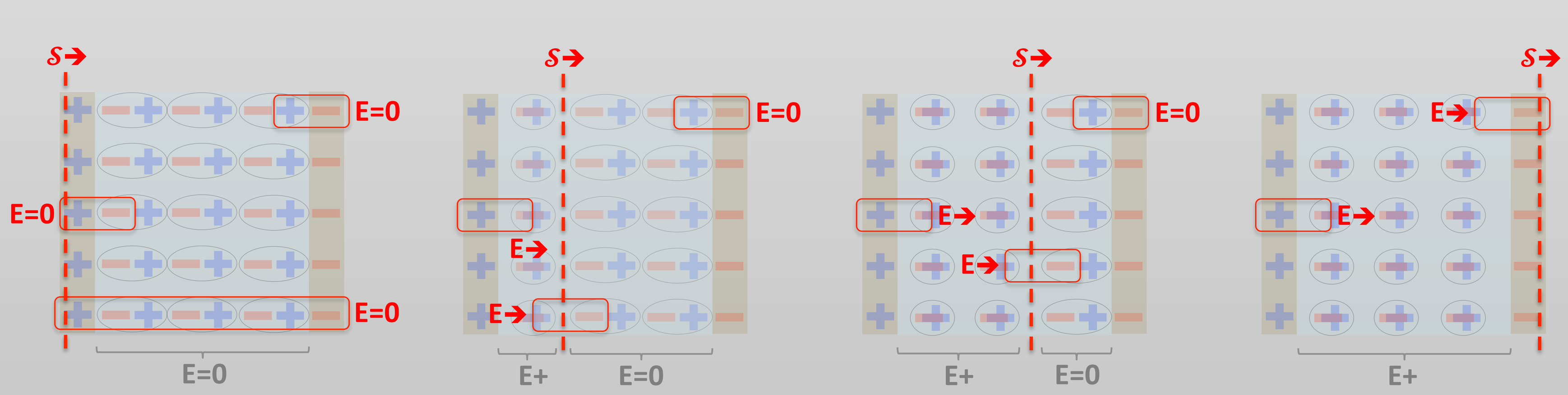
Gauss's Law

$$\oint E \cdot dA = \sum \frac{Q_{enc}}{\varepsilon}$$

Electrical Boundary Conditions

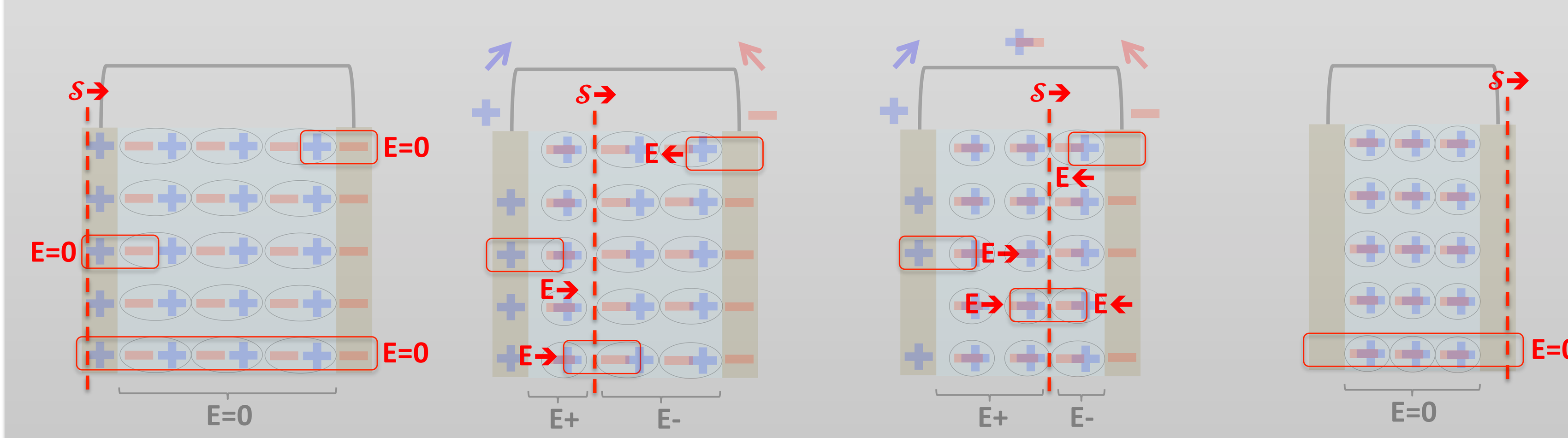
$$D = d\sigma + \varepsilon E = 0$$

$$\Rightarrow E = -\frac{d\sigma}{\varepsilon}$$



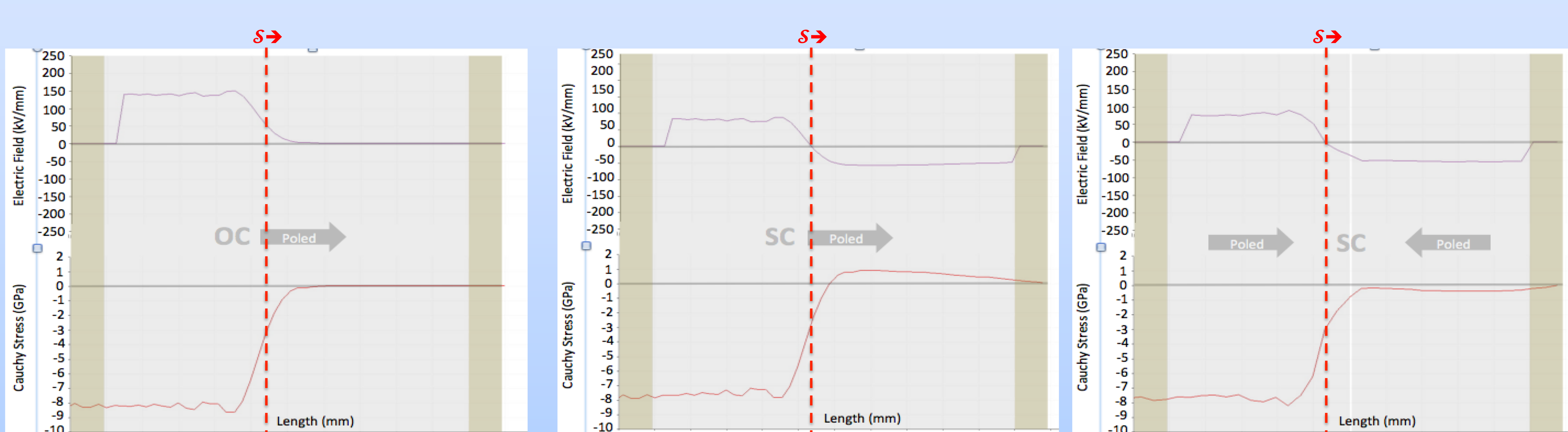
Physical Explanation: Short Circuit

- Prior to impact, the PZT is charge balanced and the electric field is zero.
- An electric field develops in the shocked region due to the piezoelectric effect.
- Charge flows to keep the electric potential the same at each electrode. This results in an electric field of opposite polarity developing in the shocked and the unshocked regions.
- The electric field in the unshocked region induces tensile stress through the converse piezoelectric effect.
- If the rear surface interface is weak or disbonded, when the electric field causes the material to contract, low impedance gaps are created.
- This induced porosity alters shock propagation.
- Control of electrical boundary conditions using the electrical signal can be used to modify shock propagation properties prior to shock arrival (microseconds).



Simulation Results

- Open circuit: a positive electric field develops in the shocked region, zero in the unshocked region.
- Short circuit: a smaller, positive electric field develops in the shocked region, a negative field develops in the unshocked region. The potential at each surface is the same.
- The negative field produces a tensile stress of ~15% that of the shock stress in the unshocked material.
- By switching the polarization direction of the back half of the PZT block, a compressive stress can be developed ahead of the shock front. This stress expands the unshocked region, effectively transferring momentum from the shocked region of the PZT to the unshocked region of the PZT.
- Multiple approaches to utilizing smart materials for adaptively controlling the shock response of shock mitigating systems have been simulated and validated.



Future Work

- Periodic systems involving heterogeneous composites with 3-3 (granular) and 2-2 (layered) connectivity will be explored under open circuit and short circuit conditions.
- The effects of induced porosity will be explored in the context of wave attenuation.
- The effects of piezoelectric stiffening on wave reflection will be explored in the context of shockwave steering.
- Schemes for practical implementation are under development.

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