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Riding the Waves for Design of Innovative Experiments and Probing Material Behavior

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To unravel the constitutive behavior of materials under dynamic loads, a well-defined stress state is often imposed using the wave propagation phenomenon. In this talk, I will provide three examples of novel experimental techniques that have been developed in my research group using wave mechanics principles and present sample cases for the investigated material behavior.

We have designed novel tensile and shear experiments to unravel the dynamic behavior of soft materials and create bubble collapse experiments to cause damage in the desired regions of a brain tissue. These experiments on soft materials have provided the very first physics-based bounds for the parameters of constitutive equations for hyperelastic materials, that were previously bounded using only empirical inequalities. This research highlighted the necessity of including all three primary modes of deformation (compression, tension, and shear) to ensure thermodynamic stability of a hyperelastic constitutive model. The experiments were shown to adhere to the classical continuum mechanics principles to provide accurate high strain rate constitutive response under desired stress state, stress equilibrium, and constant strain rate, the three necessary conditions for a valid test.

An innovative design concept called “Millipede bar” (patents pending) is developed to investigate wave propagation through multiple 180° bend junctions and establish conditions for one- dimensional stress wave propagation with minimal dispersion. Based on this concept, innovative practical designs were proposed for compact test fixtures (e.g., Kolsky bar) and efficient construction tools, greatly reducing the footprint required for high-throughput and intermediate- rate dynamic tests. This research also resolved the unexplained “surprising” observation by Kolsky (1972) while studying the transmitted waves through a 90° bend junction.

Finally, an on-line defect monitoring approach, employing physics-informed machine learning (PIML) and guided wave principles, is presented to extract ultrasonic spatial-spectral anisotropic and heterogeneous relationships within a material system. The proposed PIML framework extracts knowledge directly from experimental data without an underlying analytical basis and learns material characteristics from only the wave equation. Thus, the framework can adapt to many complex scenarios. An example application involving detection of manufacturing defects in highly heterogeneous S_iC_f/S_iC_m woven ceramic composite tubes for nuclear fuel cladding will be presented.