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Transition from elastic to inelastic deformation identified by a change in trend of seismic attenuation, not seismic velocity – A laboratory study

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The transition from elastic to inelastic deformation occurs at the yield point in a stress-strain diagram. This yield point expresses the moment when a material undergoes permanent deformation and is marked by the onset of fracturing in the brittle field at relatively low pressures and temperatures or the onset of dislocation and/or diffusional creep processes in the ductile field at higher temperatures and pressures. Detection of this transition in materials under stress using an indirect measurement technique is crucial to predict imminent failure, loss of material integrity, or of approaching release of energy by seismic rupture.

Here we use a pulse transmission method at ultrasonic frequencies to record the change in acoustic wave form across the transition from elastic to inelastic deformation in a rock-fracturing experiment. In particular, we measure both the acoustic wave velocity and attenuation with increasing strain from the elastic regime all the way to macroscopic failure.

Our results show that the transition from elastic to inelastic deformation coincides with a minimum in attenuation. Below this minimum, pre-existing microfractures close, leading to a reduction of attenuation. Above this minimum, formation of new microfractures occurs and attenuation increases until peak stress conditions, at which larger fractures are formed and the rock starts to lose its strength and integrity. At the same time, the acoustic wave velocity continues to increase across the transition from elastic to inelastic deformation; hence the acoustic velocity is not a valid indicator for this elastic to inelastic transition.

We propose that analysis of attenuation, not velocity, of acoustic waves through stressed materials may thus be used, for example, to detect imminent failure in materials, onset of crack formation in pipes or the cement casing in boreholes, or onset of fracturing in the near wellbore area. On a larger scale, attenuation monitoring may help predict the imminent release of energy by seismic rupture.