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Thermomechanical response of HTPB-based composite beams subjected to near-resonant inertial excitation

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ABSTRACT

At this time, there is a pressing need to develop new technologies capable of detecting, identifying, and potentially neutralizing energetic materials, preferably from a stand-off distance. To address this need, an improved understanding of the mechanics of energetic materials, prior to detonation or deflagration, must be developed. In light of this, the present effort seeks to characterize the thermomechanical response of a polymer-based composite material, which is a mechanical surrogate for a traditional composite explosive or propellant. This research focus is motivated by the fact that many polymer-based materials demonstrate significant self-heating when subjected to dynamic loading, due to the combination of appreciable internal dissipation and poor thermal diffusion. Such self-heating has the potential to enhance existing stand-off, vapor-based detection systems, due to the temperature sensitivity of vapor pressure attendant to many polymer-based energetic materials. In this effort, a thermomechanical model of a polymer-based composite beam is developed. The composite is modeled as a homogenized linear viscoelastic material and the mechanical response is determined using Euler–Bernoulli beam theory in conjunction with a harmonic base excitation. The system is excited near its first resonant frequency to elicit large mechanical responses and, thus, maximum heating. The heat generation resulting from the harmonic loading is derived using the hysteretic characteristics of the system. The Fourier Law of Conduction is then used in conjunction with the derived heat source, as well as numerical solvers, to obtain the thermal response. In addition to the aforementioned modeling efforts, experiments were conducted using a HTPB-based beam with embedded ammonium chloride (NH_4Cl) crystals. The sample was subjected to harmonic base excitation and the thermal and mechanical responses were recorded using infrared thermography and scanning laser Doppler vibrometry, respectively. Direct comparisons of the results obtained through theory and experiments are presented for several distinct forcing levels. The acquired results show a strong dependence of the temperature distribution on the stress and strain fields produced by the mechanical loading. The effect of convection at the surfaces is also evident in the thermal response. Close agreement between the model predictions and experimental results is observed. In conclusion, by adopting a unified research approach, the authors hope to build upon recent research efforts related to explosives detection by bridging the substantial gap that exists between theory and experiments. The authors also hope that this effort will advance the worldwide research effort aimed at detecting and defeating hidden explosive materials.