FULL FIELD MEASUREMENT OF SHOCK COMPRESSION DEFORMATION ACROSS THE CRYSTAL BINDER INTERFACE USING TIME RESOLVED RAMAN SPECTROSCOPY

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Abstract

In applications requiring high velocity interactions of energetic materials, the shock response of the crystal-binder interface is of great importance. We demonstrate a technique for capturing the high localized deformation of the crystal-binder interface using time resolved Raman spectroscopy at nanosecond intervals. A bi-crystal interface of polydimethylsiloxane (PDMS) sandwiched between sucrose crystals is used in the method, with the sample as a whole put on a glass surface and impacted from the opposite end. Aluminum cylindrical flyers with thicknesses of 25-50 um and diameters of 1 mm were accelerated utilizing the Laser Induced Projectile Impact Test (LIPIT) to create high velocity shock compression loads. The velocity of the projectiles was determined using heterodyne photon doppler velocimetry (het-PDV) and ranged from 0.5 to 1.5 km/s. Full field measurements of the 532nm Raman spectroscopic response were acquired using an in-house designed laser array configuration with 27 discrete laser subsets. The pressure and temperature distributions over the interface were calculated using the pre-calibrated peak shifts of the sucrose CH and CH2 bonds. The highly localized deformation generated by pressure and temperature rise as the shock front travels across the interface were measured in-situ by the time resolved Raman spectroscopic response. The results showed a close correlation of the pressure and temperature rise with the shock-induced deformation.

Keywords: Time-resolved Raman Spectroscopy, Laser Induced Projectile Impact Test, Shock Compression, Crystal-Binder Interface

1. Introduction

The polymer binder materials such as PDMS undergoes multi-physics phenomena like phase change, chemistry change and thermo-mechanical changes when they are used with energetic matrials in severe applications such as explosions. Very often they experience a shock wave travels through them in such fast occurring events. In order sustain such conditions and to improve their performance, the polymeric binders needs to be experimentally tested in laboratory. With the limitation of the measuring methods, these experiments however offer great challenges in both producing the shock compression loading and accuretly probing the physics based phenomenon in a nano-seconds time. Raman Spectroscopy is a promising tool to understand the thermo-mechanical and chemical change owing to deformation.

2. Experiments

This work presents the methodology to understand the shock compression behavior of the sugar crystals held together with epoxy interface. The sample was held in the flyer launch system. The aluminum flyer of 25 um thickness was accelerated by 1064 nm Nd-Yag laser pulse. Prior to impact the profile of the laser beam was modified to uniform intensity from normal gaussian profile. As the flyer strikes the top surface of the sucrose crystal, a shock compression wave is generated and travels through the sample at a velocity of 4.7 km/s as shown in fig. 1. The size of the compression wave was determined to be 46 um in the direction of travel and nearly 10ns in time domain for a given flyer thickness of 25 um.

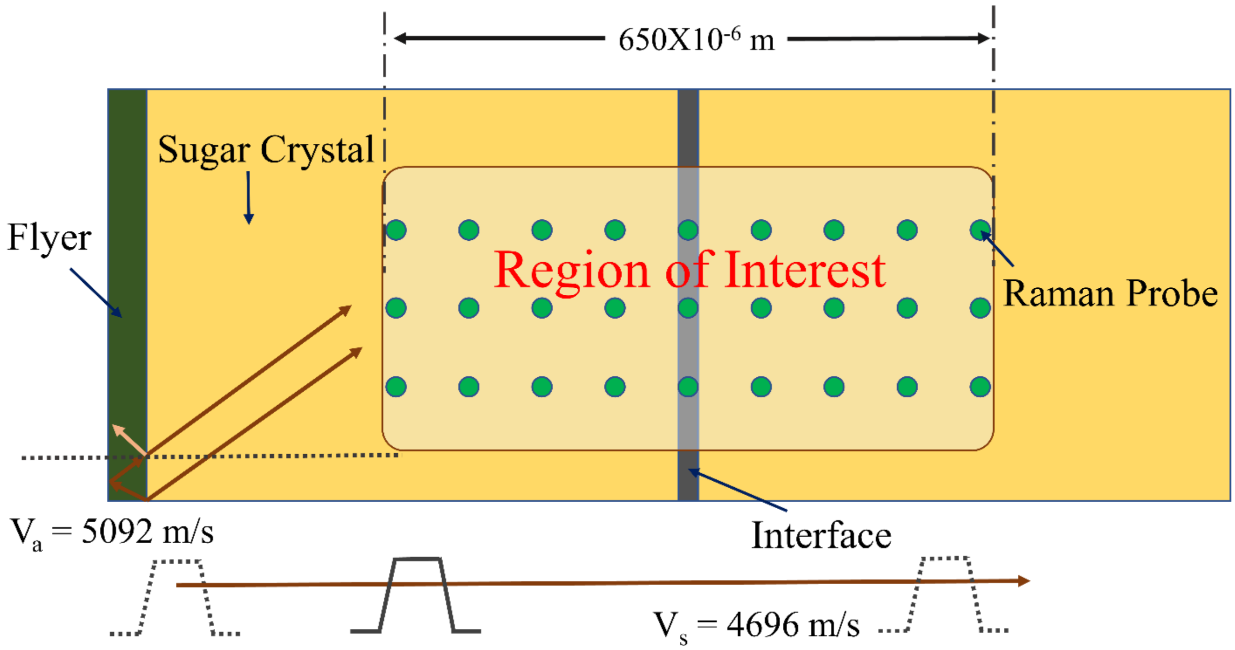

Fig.1 – The schematic of the shock compression wave deformation measurement using time resolved Raman Spectroscopy.

The velocity of the flyer and particle velocity after impact was computed by Photon Doppeler Velocitymetry (PDV) from the bottom surface. The front surface of the sample and the interface was probed using Raman Spectroscopy (RS) based spectral imaging. A 532nm green laser beam was used for the Raman excitation. The green laser was divided in an array of 9 x 3 beams and projected equidistanced over the region of interest as shown in fig. 1 with a microscopic objective. The Raman spectra from each points was collected through a spectrograph and emCCD camera. The 2D array of 9 X 3 subsets was further changed to 1D array of 27 X 1 subsets by an assembly of series of mirros. The size of the beam entering the mirror assembly was controlled with a pair of beam contraction lenses.

3. Results

The stress wave travelling through polymer bound crystal is was captured thorugh the Raman peak shifts of CH and CH2 bonds. These peaks were the used construct the full filed stress and temperature values over the 1 mm length and 80 um subset resolutions. The results showed a good correlation of the temperature rise with the stress fileds.

4. Conclusions

We have been succeffuly able to produce shock loading using laser based flyer impact system and capture the full field Raman spectra through a time-gate Raman spectroscopy with a 80um grid resolution. Additionally, it raman spectra of the sugar crystal was processed to decopuple the pressure and temperature change in the crystal when the stress wave passed through it.

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