Experimental Measurements of Binder Wave Speeds using Wavenumber Decomposition

Caleb R. Heitkamp
Purdue University, cheitkam@purdue.edu

Jacob K. Miller
Purdue University, mille411@purdue.edu

Anna Loehr
Purdue University, loehra@purdue.edu

J Stuart Bolton
Purdue University, bolton@purdue.edu

Jeffrey F. Rhoads
Purdue University, jfrhoads@purdue.edu

Follow this and additional works at: http://docs.lib.purdue.edu/herrick

http://docs.lib.purdue.edu/herrick/150

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.
Experimental Measurements of Binder Wave Speeds using Wavenumber Decomposition

Caleb R. Heitkamp, Jacob K. Miller, Anna Loehr, J. Stuart Bolton, and Jeffrey F. Rhoads

School of Mechanical Engineering, Purdue University
Ray W. Herrick Laboratories
Birck Nanotechnology Center
June 12, 2017
Motivation

• Provide an alternative method for measuring material wave speeds and discerning various wave types

• Utilize this method to characterize acoustic material properties in viscoelastic materials
  • Specifically, to provide wave speed measurements of binder materials commonly used in plastic-bonded explosives in order to assist in enhancing the detection and safe handling of explosives
Prior work has provided few wave speed measurements for the binder materials commonly used with plastic-bonded explosives.

‘Pitch and catch’ methods have mainly been used to measure wave speeds and attenuation rates.
• Similar wavenumber decomposition techniques have been applied to viscoelastic materials and pneumatic tires
Sample Material

• Dow Corning Sylgard 184 Silicone Elastomer [7]
  • Includes a base and curing agent
  • Cross-linking polymer

• Common plastic-bonded explosives binder material

Sample Preparation

- Sylgard 184 mixed at a 10:1 base to curative ratio
- Mixture was degassed to remove air bubbles
- Mixture was poured into a 30 cm x 2.54 cm x 1.81 cm aluminum mold

Aluminum mold used to cast the samples
Sample Preparation

• All samples were cured at 60 °C in a convection oven
• Samples were cured at variable curing times – 4, 12, and 168 hours in order to increase stiffness
• Three samples at each curing time were fabricated and tested
Experiment Setup

• Laser Doppler Vibrometer (LDV) system generated a burst chirp excitation that was amplified and sent to the transducer
• Sample and ultrasonic transducer were coupled using uncured Sylgard 184 and rest on a bed of foam fixed to a high precision positioning stage
• Sample surface coated with a reflective silver paint to improve signal return
Experiment Setup

• Polytec Micro Scanning Analyzer (MSA)-400 LDV system was used to measure the vibrational response at a fixed point

• High precision positioning stage was used to move the sample relative to the fixed measurement point

• LabVIEW controller was used to trigger data acquisition at start of excitation sweep and move the positioning stage

Time Lapse of a 168 hr. cured sample being tested
Data Acquisition

- Burst Chirp excitation
- Transverse surface velocity measured

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Distance</td>
<td>30 cm</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>500 µm</td>
</tr>
<tr>
<td>Excitation Frequency</td>
<td>100 Hz – 620 kHz</td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>1.25 MHz</td>
</tr>
<tr>
<td>Averages</td>
<td>50</td>
</tr>
<tr>
<td>Time Delay</td>
<td>1.25 s</td>
</tr>
<tr>
<td>Magnification</td>
<td>2x</td>
</tr>
<tr>
<td>Power into transducer</td>
<td>About 2 W</td>
</tr>
</tbody>
</table>
Post Processing

Note: All plots shown in this presentation were obtained from sample 168-03.
Time Data

• Time delay away from transducer indicates wave propagation

• A window with $\cos^2$ transitions to unity was used to minimize spectral truncation and noise effects

![Time history plot for sample 168-03 at five equally spaced points across the beam](image)
Post Processing

Note: All plots shown in this presentation were obtained from sample 168-03.
A Discrete Fourier transform (DFT) algorithm was applied to the time data. Modes appear to ‘cut on’ above 40 kHz. Multiple harmonics become evident as frequency increases.
Post Processing

- Velocity vs. Time and Space
- Velocity vs. Frequency and Space
- Velocity vs. Frequency and Wavenumber

Note: All plots shown in this presentation were obtained from sample 168-03.
Wavenumber Transform

- DFT across the space dimension
- Negative wavenumber content can be viewed as waves traveling away from transducer
- Individual waves are distinct
- Outer wave represents the primary or longitudinal wave
- Slope of the linear region of this wave is the longitudinal wave speed of the material

Magnitude of the velocity spectra depicted as a function of wavenumber. The color axis represents velocity in dB referenced to 1 m/s.
Wavenumber Transform

- DFT across the space dimension
- Negative wavenumber content can be viewed as waves traveling away from transducer
- Individual waves are distinct
- Outer wave represents the primary or longitudinal wave
- Slope of the linear region of this wave is the longitudinal wave speed of the material

Magnitude of the velocity spectra depicted as a function of wavenumber. The color axis represents velocity in dB referenced to 1 m/s
Wave Speed Fitting

- Phase speeds, $c_p = \frac{\omega}{k}$, asymptote to the material wave speed as wavenumber increases

- $c_p = -ae^{-bk} + c$

- $c = 1071.9 \text{ m/s}$

Best fit exponential decay on phase speed versus wavenumber data to find horizontal asymptote
Wavenumber Transform

• Longitudinal wave speed plotted on wavenumber data

• Note the agreement of the data and lines above 200 $m^{-1}$

Magnitude of the velocity spectra depicted as a function of wavenumber with longitudinal wave speed. The color axis represents velocity in dB referenced to 1 m/s.
Results and Discussion

• Results indicate a gradual increase in material wave speed as stiffness is increased excluding the 004-02 sample.

• Overall there is a minimal increase in wave speed as stiffness is increased.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Wave Speed (m/s)</th>
<th>R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>004-01</td>
<td>1065.9</td>
<td>0.9984</td>
</tr>
<tr>
<td>004-02</td>
<td>1070.9</td>
<td>0.9978</td>
</tr>
<tr>
<td>004-03</td>
<td>1065.9</td>
<td>0.9614</td>
</tr>
<tr>
<td>012-01</td>
<td>1068.2</td>
<td>0.9983</td>
</tr>
<tr>
<td>012-02</td>
<td>1064.3</td>
<td>0.9626</td>
</tr>
<tr>
<td>012-03</td>
<td>1066.5</td>
<td>0.9983</td>
</tr>
<tr>
<td>168-01</td>
<td>1072.5</td>
<td>0.9980</td>
</tr>
<tr>
<td>168-02</td>
<td>1069.0</td>
<td>0.9652</td>
</tr>
<tr>
<td>168-03</td>
<td>1071.9</td>
<td>0.9980</td>
</tr>
</tbody>
</table>

Resulting longitudinal wave speeds and R-squared values for nine samples.
Future Areas For Improvement

• A higher precision positioning stage for better spatial resolution

• Improved method of applying the silver reflective paint

• Minimize user interface and decisions during post processing
Conclusions

• The influence of curing time on material wave speed was studied to demonstrate the value of the wavenumber decomposition technique.

• There was a slight increase in material wave speed as curing time was increased.

• This method provides an accurate and convenient way to determine wave speeds and wave dispersion in viscoelastic materials.
Future Work

• Create a numerical model for predicting wave speeds and attenuation
• Utilize this method to test composite samples

Sugar loaded mock energetic samples using Sylgard 184 as a binder
Acknowledgements

• This research is supported by the U.S. Office of Naval Research under *Stand-off and Remote Improvised Explosive Device (IED) Detection and Neutralization* through grant No. N00014-15-R-SN16

• Dr. Jeffrey Rhoads

• Dr. J. Stuart Bolton

• Dr. Jacob Miller
References


Questions?