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Experimental Measurements of Binder Wave Speeds using Wavenumber Decomposition

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PURDUE MECHANICAL ENGINEERING

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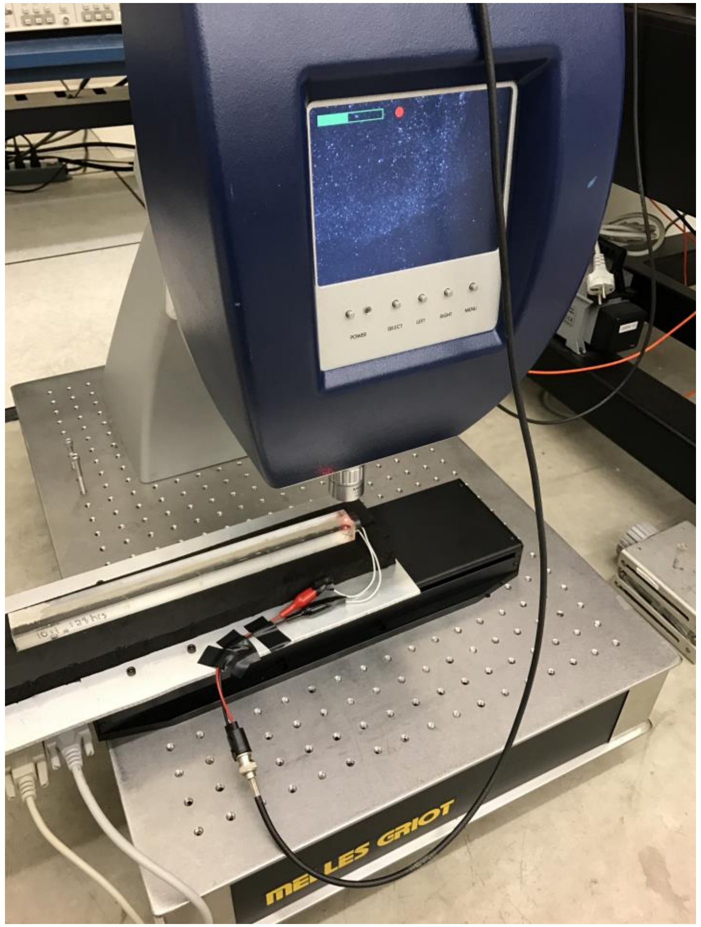
PURDUE UNIVERSITY Discovery Park

Office of Naval Research Science & Technology

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

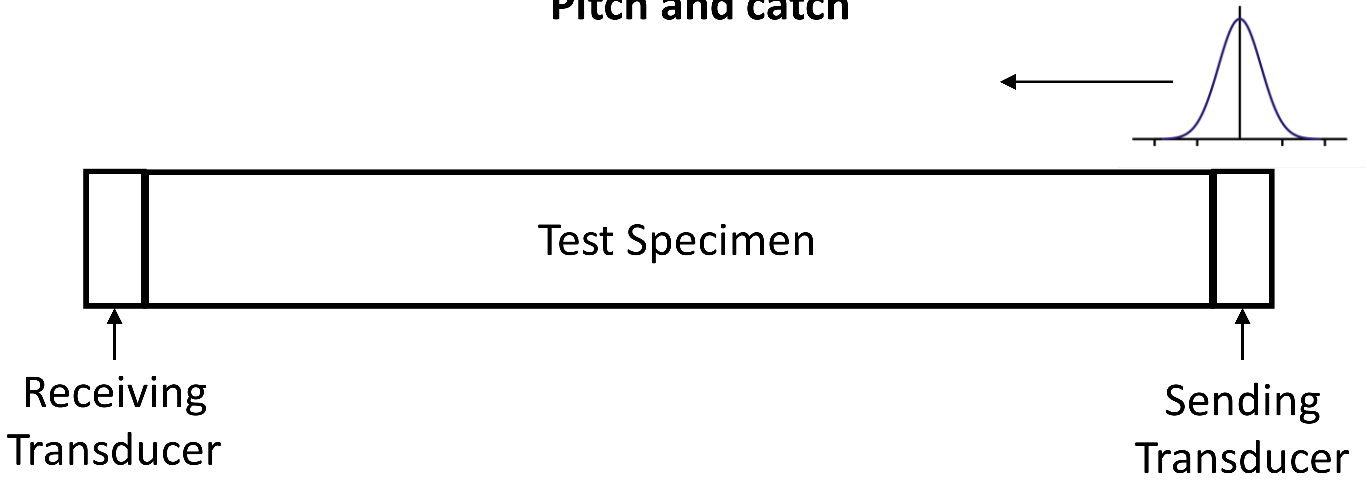


Background

- Prior work has provided few wave speed measurements for the binder materials commonly used with plastic-bonded explosives

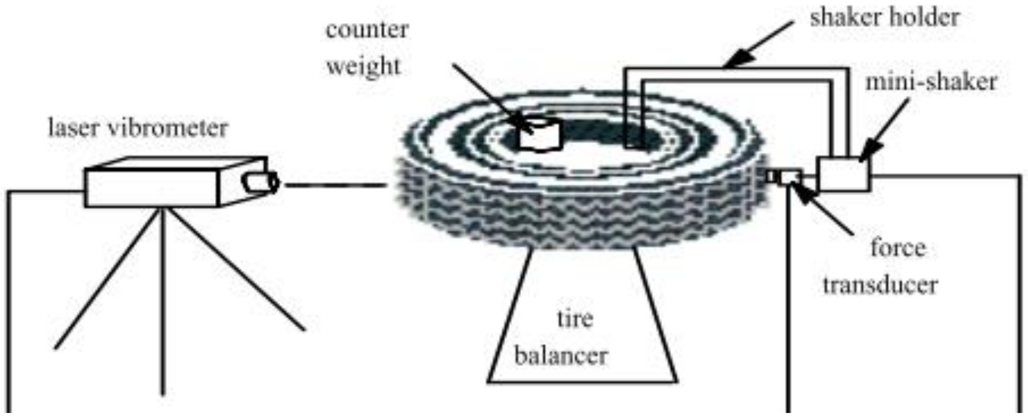
- 'Pitch and catch' methods have mainly been used to measure wave speeds and attenuation rates

'Pitch and catch'

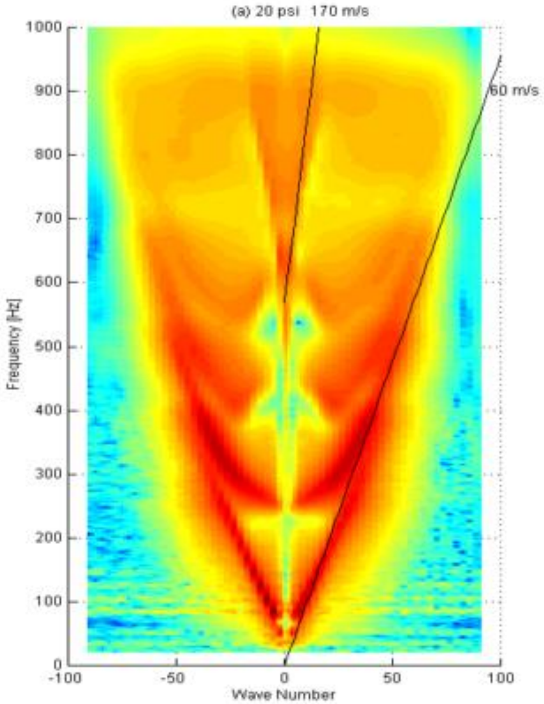


Background

- Similar wavenumber decomposition techniques have been applied to viscoelastic materials and pneumatic tires



Experimental setup for wavenumber decomposition technique applied to pneumatic tires



Resulting wavenumber decomposition

Sample Material

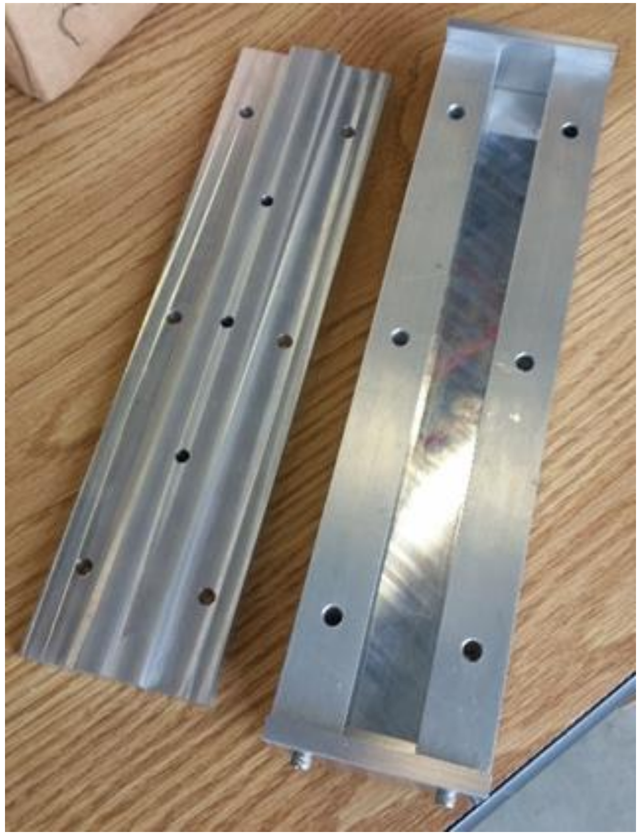
- Dow Corning Sylgard 184 Silicone Elastomer [7]
  - Includes a base and curing agent
  - Cross-linking polymer

- Common plastic-bonded explosives binder material

https://www.amazon.com/Sylgard-Solar-Encapsulation-Making-Panels/dp/B004IJENBG

Sample Preparation

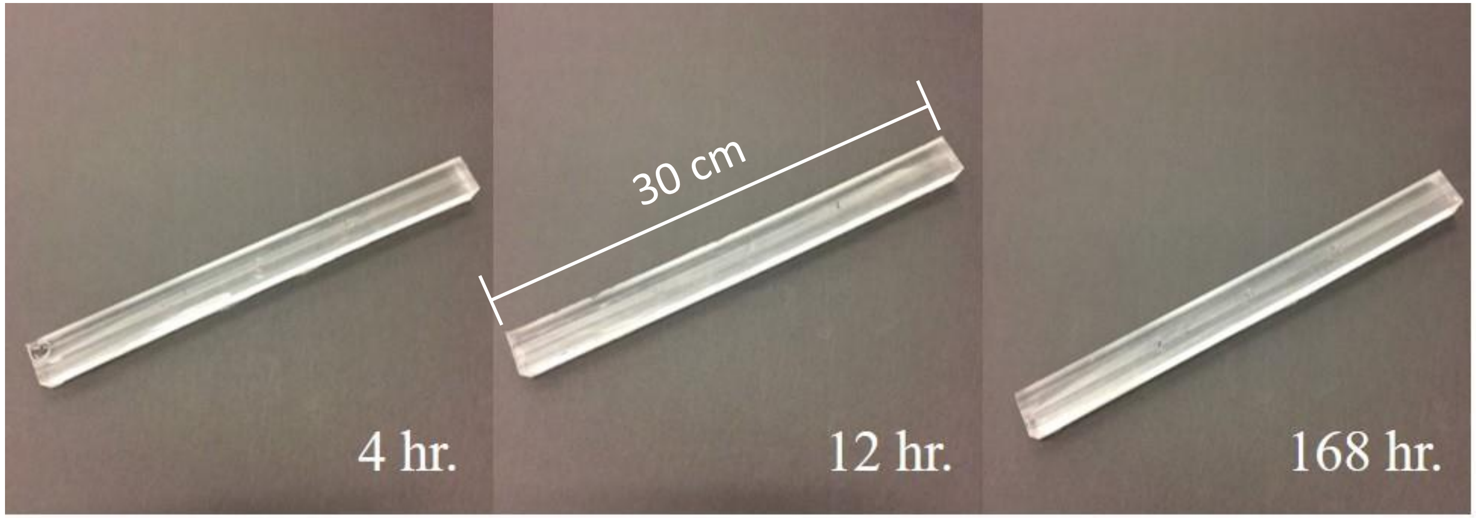
- Sylgard 184 mixed at a 10:1 base to curative ratio
- Mixture was degassed to remove air bubbles
- Mixture was poured into a 30 cm x 2.54 cm x 1.81 cm aluminum mold



Aluminum mold used to cast the samples

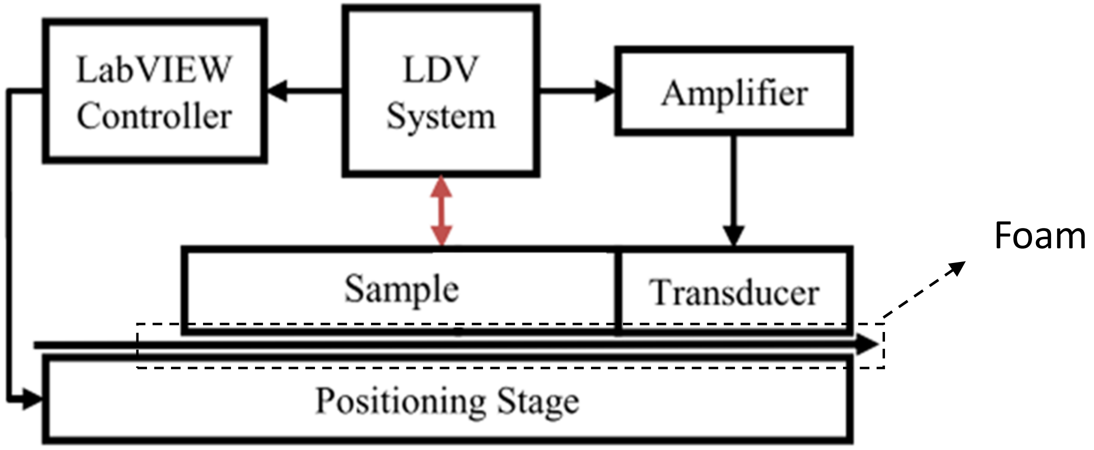
Sample Preparation

- 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

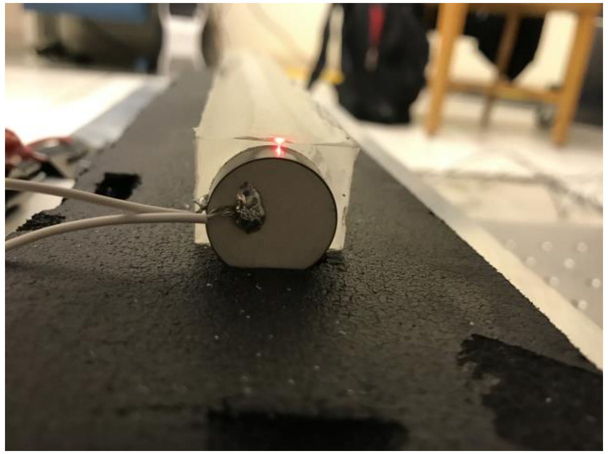


Sylgard 184 samples to be tested

Experiment Setup



Schematic of experimental setup



Side view of sample during an experiment

- 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

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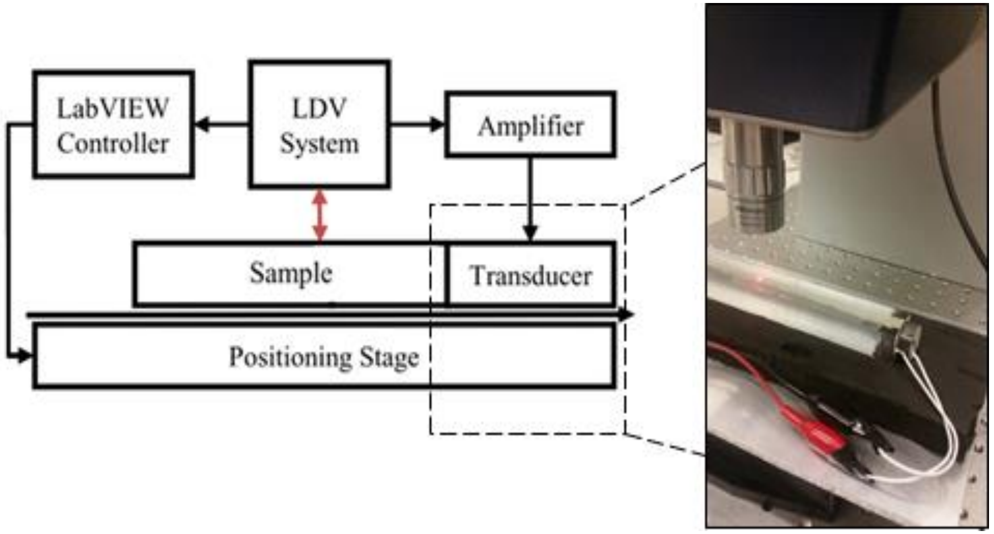
- Polytec Micro Scanning Analyzer (MSA)-400 LDV system was used to measure the vibrational response at a fixed point
- High precision positioning stage was used to move the sample relative to the fixed measurement point
- LabVIEW controller was used to trigger data acquisition at start of excitation sweep and move the positioning stage

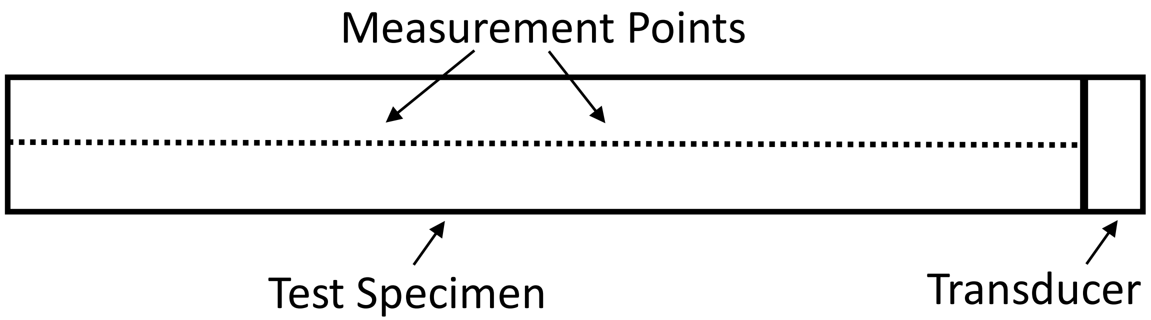
Time Lapse of a 168 hr. cured sample being tested

Data Acquisition

- Burst Chirp excitation
- Transverse surface velocity measured

Parameter	Value
Measurement Distance	30 cm
Spatial Resolution	500 µm
Excitation Frequency	100 Hz – 620 kHz
Sampling Rate	1.25 MHz
Averages	50
Time Delay	1.25 s
Magnification	2x
Power into transducer	About 2 W



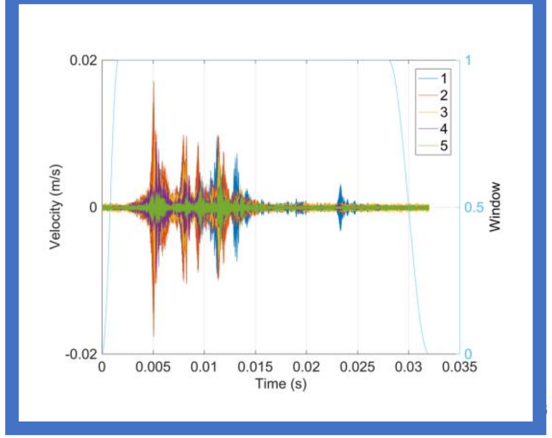


Post Processing

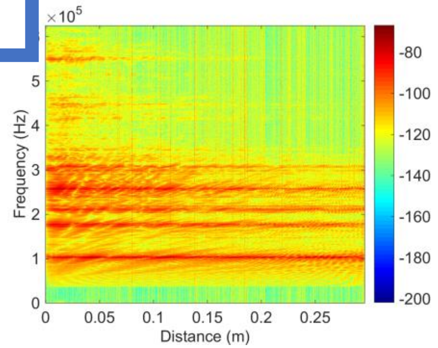
Velocity vs. Time and Space

Velocity vs. Frequency and Space

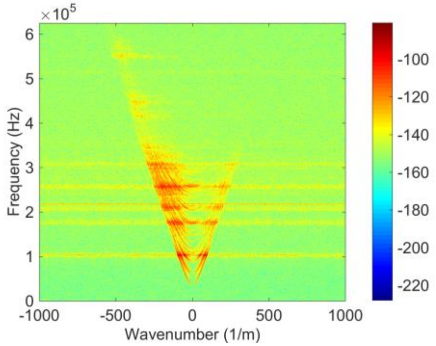
Velocity vs. Frequency and Wavenumber



DFT in Time



DFT in Space

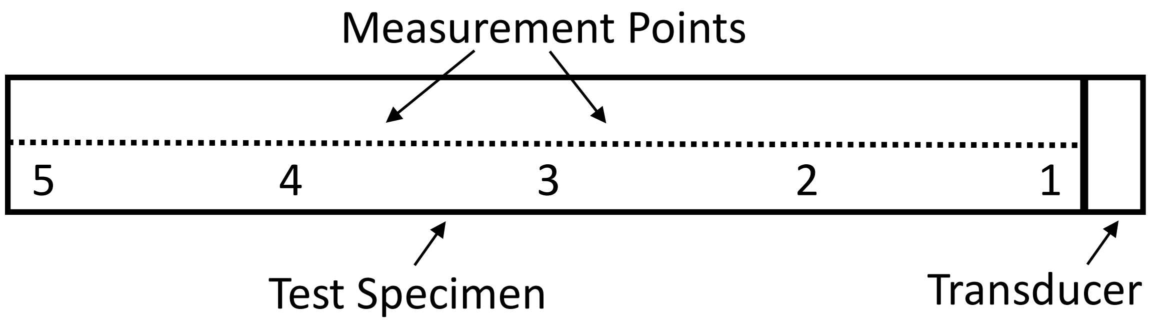


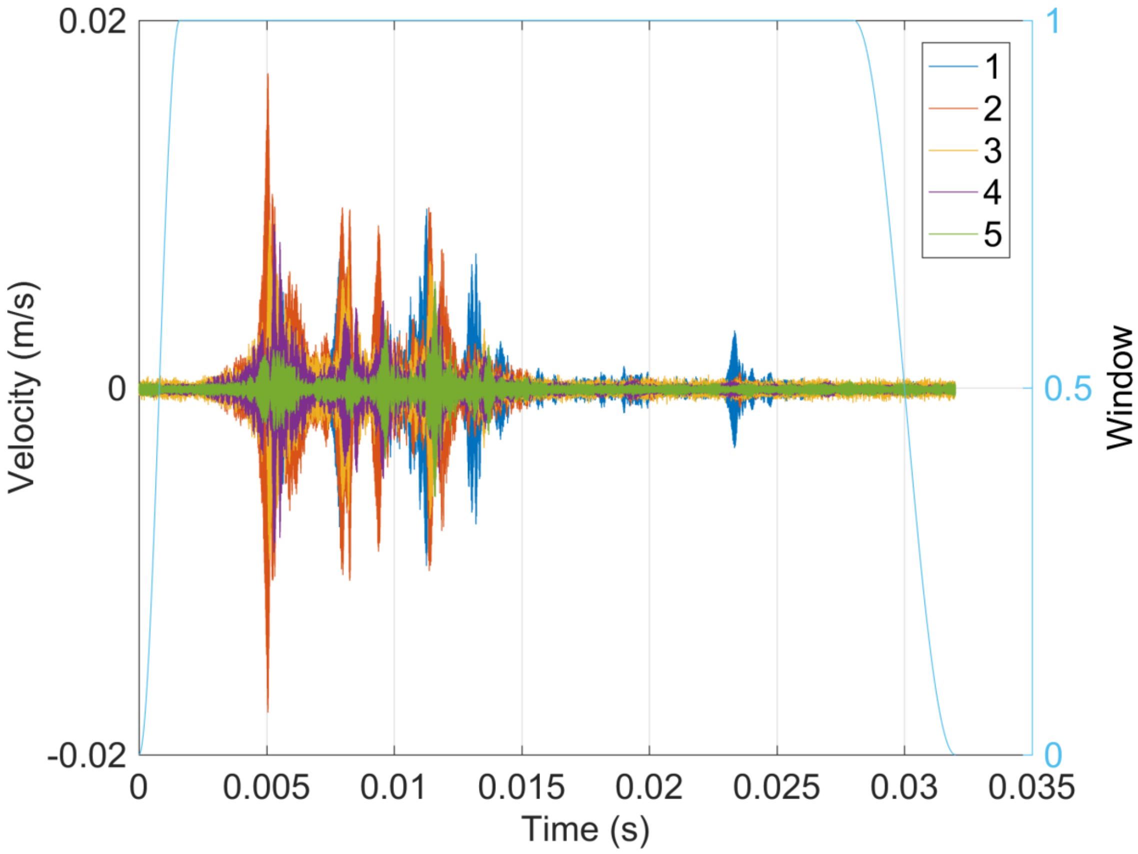
Note: All plots shown in this presentation were obtained from sample 168-03.

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

Post Processing

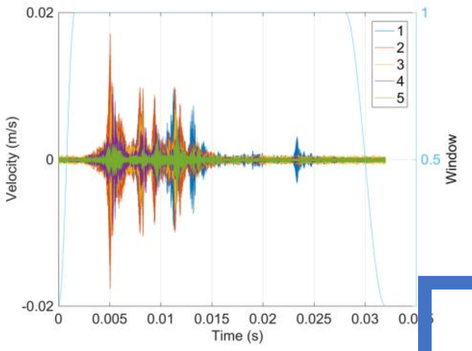
Velocity vs. Time and Space

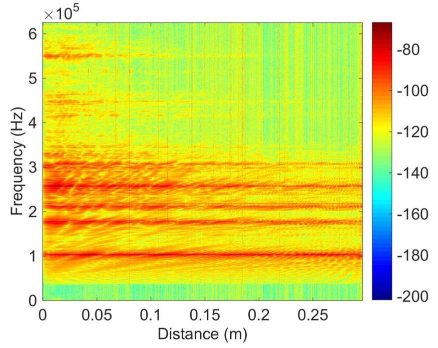
Velocity vs. Frequency and Space

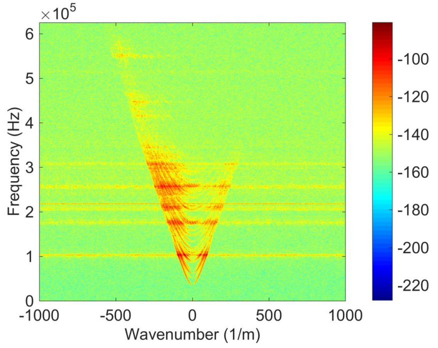
Velocity vs. Frequency and Wavenumber

DFT in Time

DFT in Space



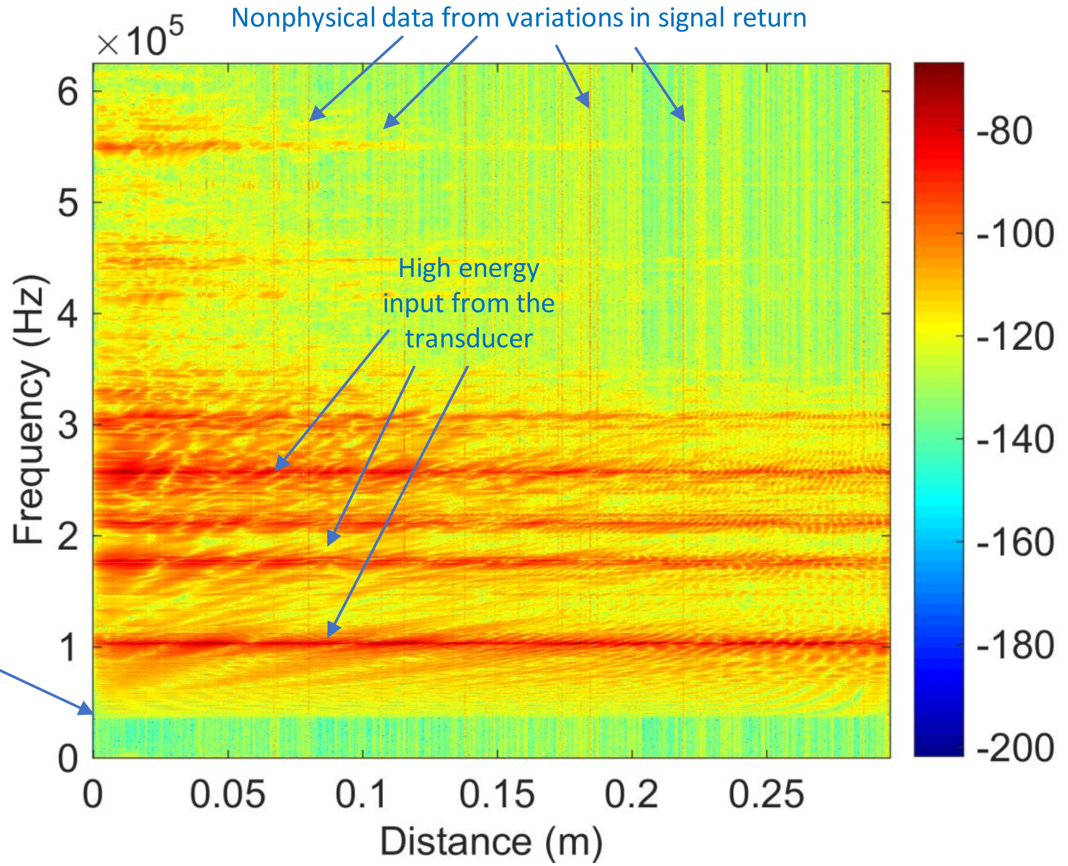




Note: All plots shown in this presentation were obtained from sample 168-03.

Frequency Transform

- 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



Magnitude of the velocity spectra depicted as a function of distance across the beam. The color axis represents velocity in dB referenced to 1 m/s

Post Processing

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Velocity vs. Time and Space

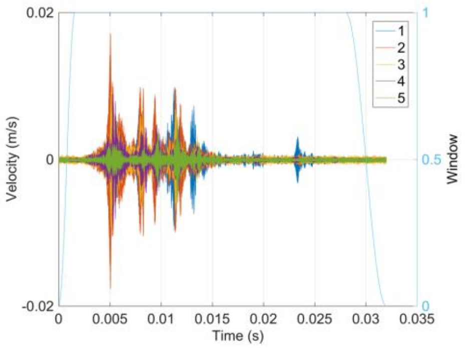
Velocity vs. Frequency and Space

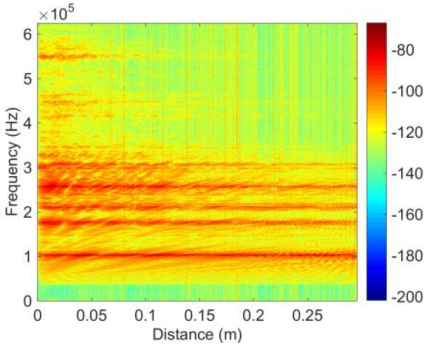
Velocity vs. Frequency and Wavenumber

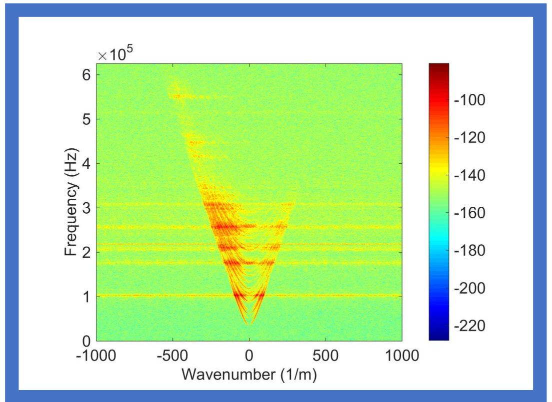
DFT in Time

DFT in Space

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

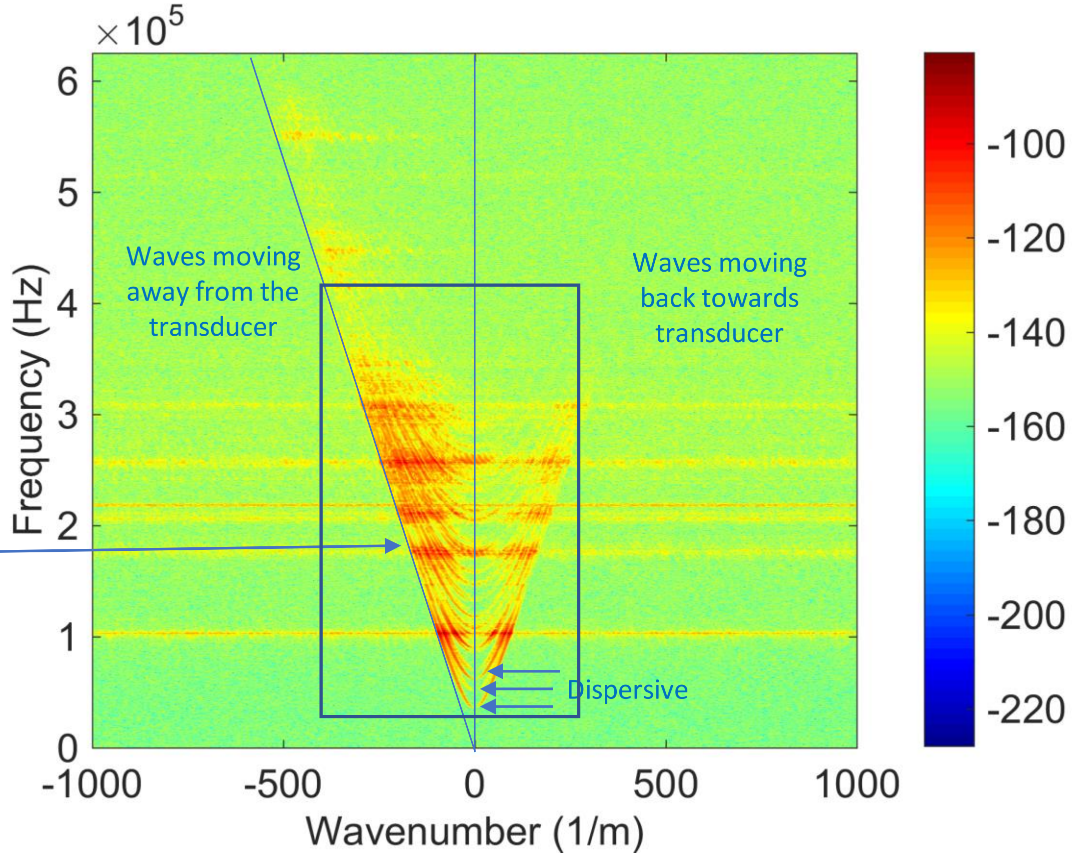






Wavenumber Transform

- 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

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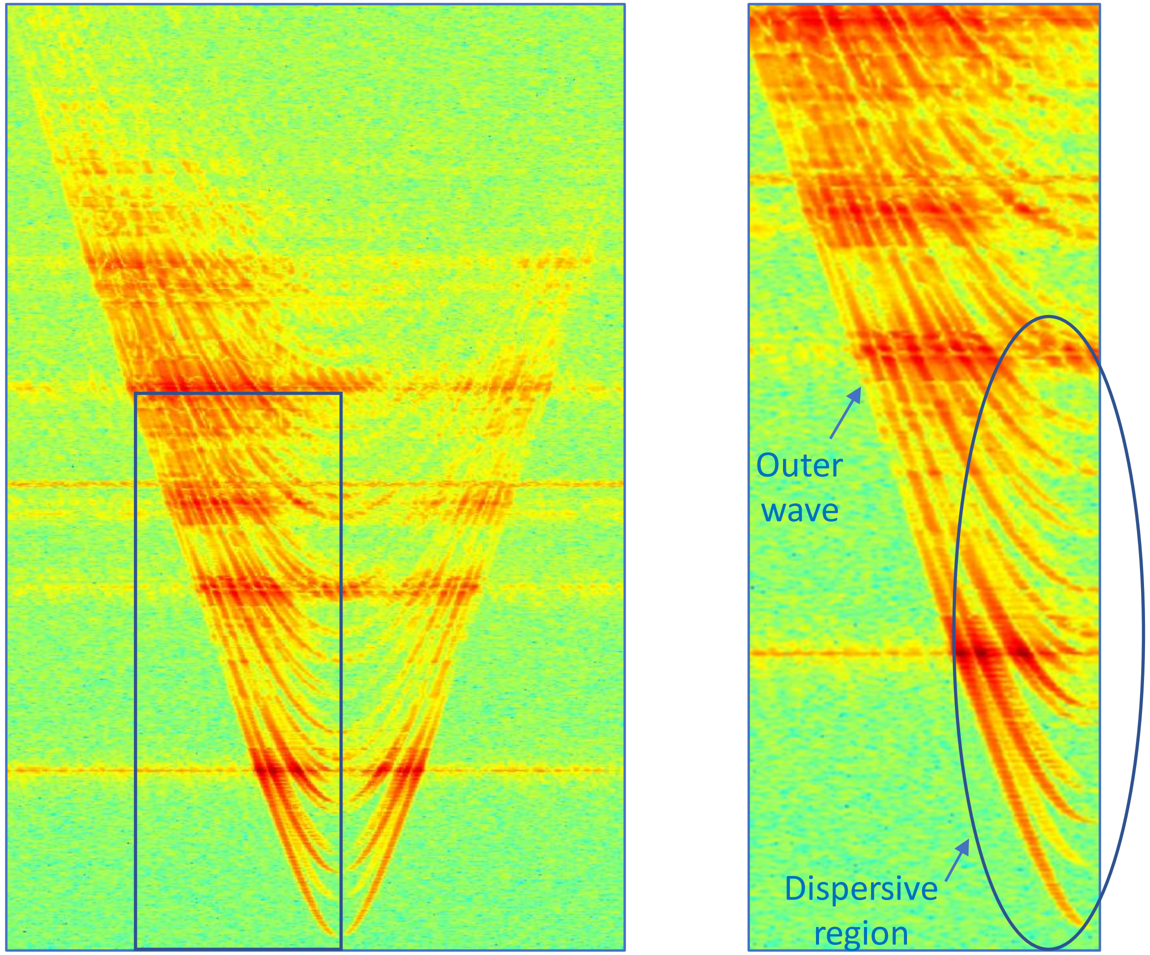


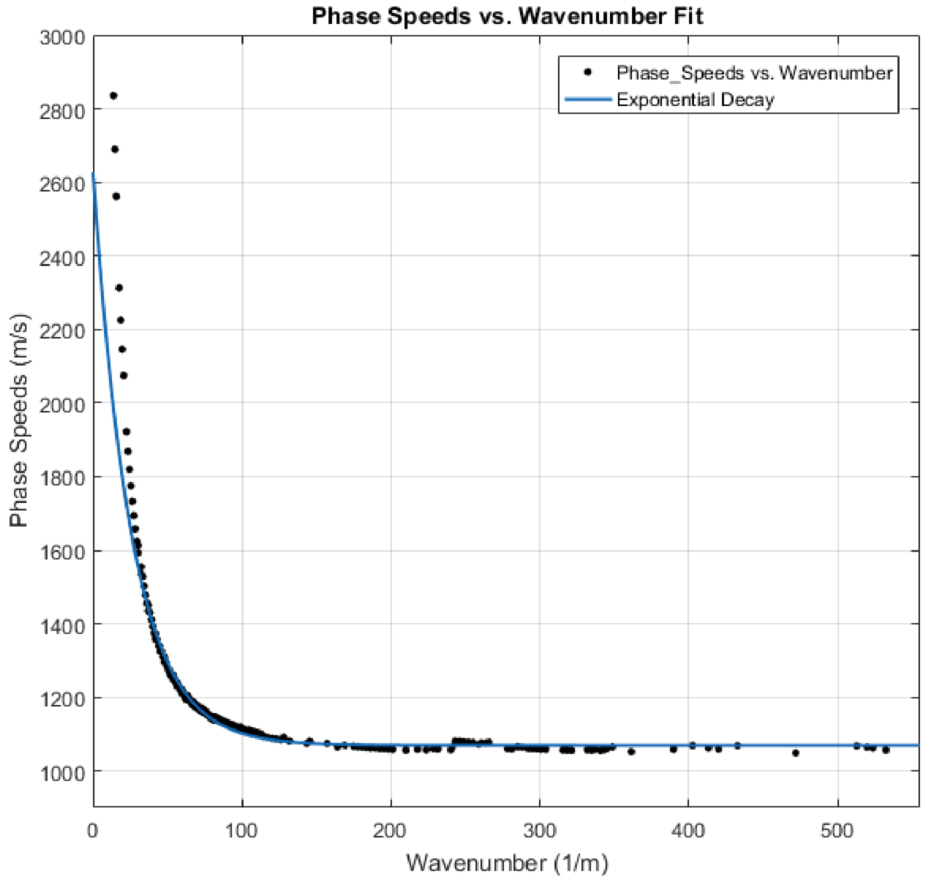
Magnitude of the velocity spectra depicted as a function of wavenumber. The color axis represents velocity in dB referenced to 1 m/s

Wave Speed Fitting

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

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

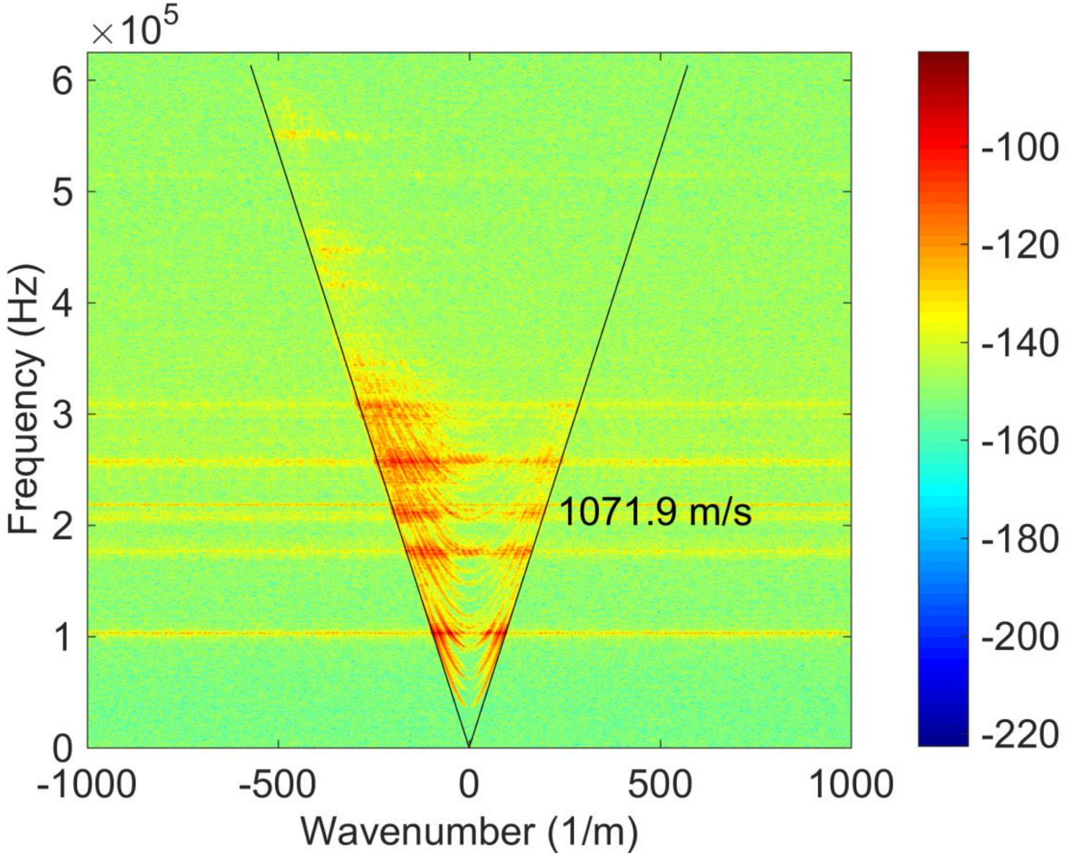
- $c = 1071.9\ m/s$



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

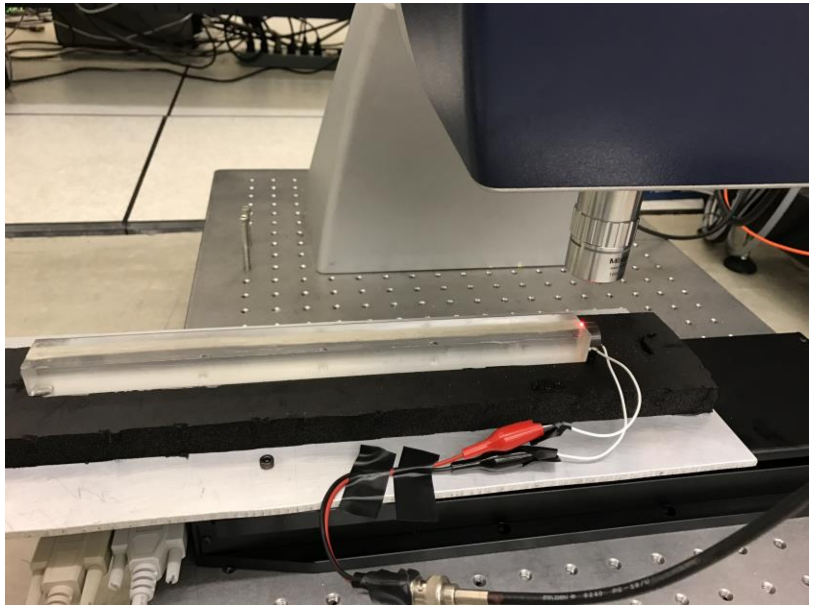
- Results indicate a gradual increase in material wave speed as stiffness is increased excluding the 004-02 sample
- Overall there is a minimal increase in wave speed as stiffness is increased

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

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

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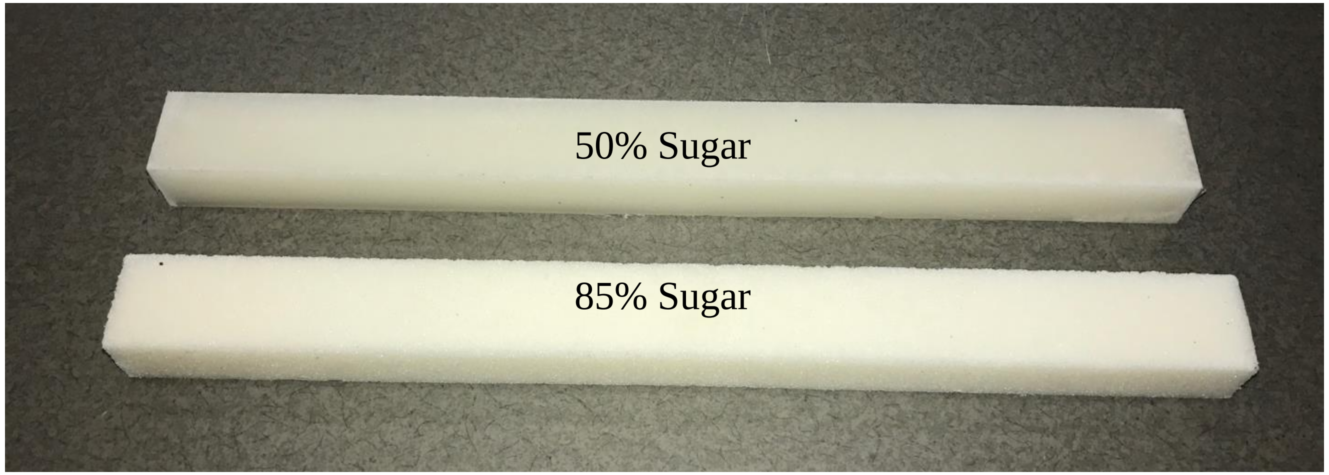
- The influence of curing time on material wave speed was studied to demonstrate the value of the wavenumber decomposition technique

- 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

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Questions?