Material Modeling and Development of a Realistic Dummy Head for
Testing Blast Induced Traumatic Brain Injury

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ECCOMAS
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Research Goals

- Find a material that can be used as a replacement for human brain in shock-type loading conditions
- Prepare an instrumented dummy “headform”
- Observe and record the effects of shock waves on the headform, especially stress or pressure within the “brain”

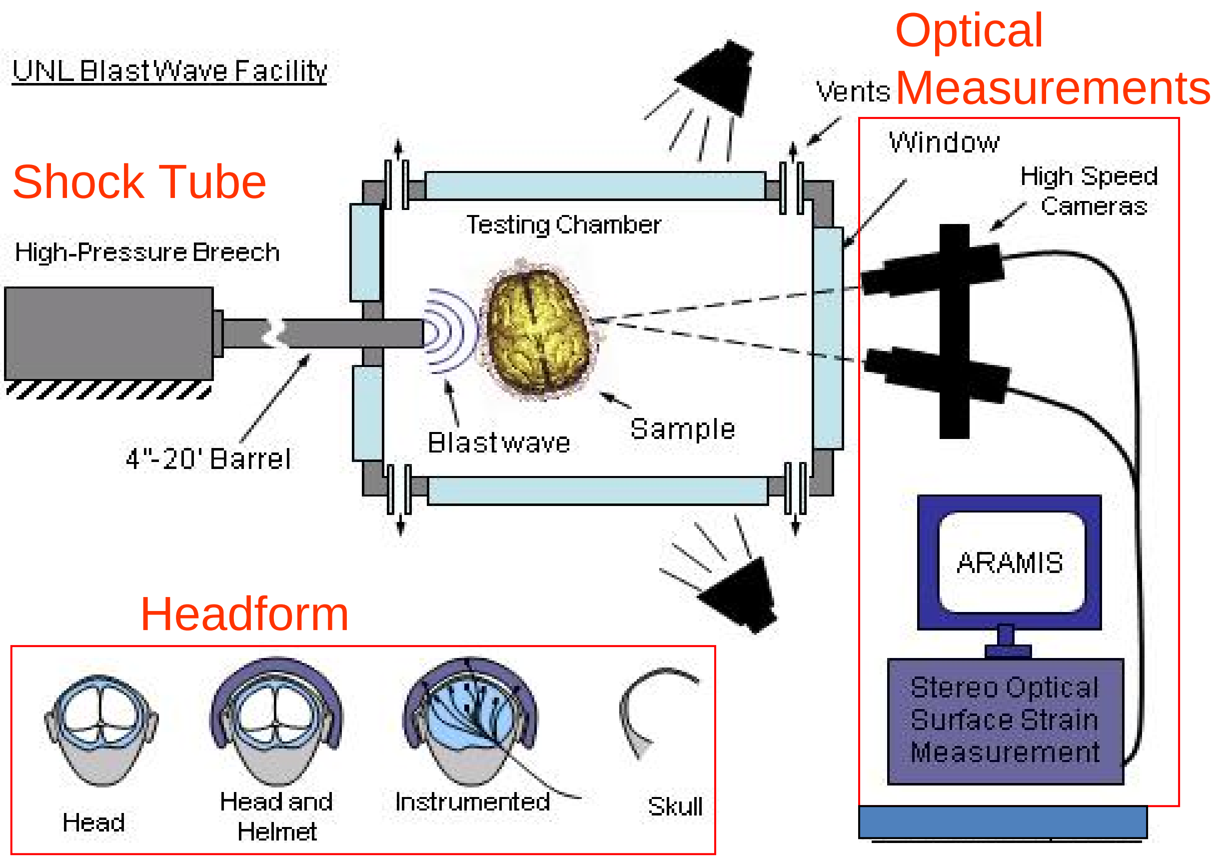
Purpose and Relevance

- High occurrence rate of traumatic brain injury (TBI)
  - 1.4 million people in US per year
  - 50,000 deaths
  - 235,000 hospitalizations
  - Prevalent among soldiers due to explosions
- Mechanisms of TBI are not well understood
- More research will yield better understanding about blast-induced TBI
- Outcomes could include improved helmet designs, insights into diagnosis and treatment, etc.

Project Overview

- Shock tube facility
  - Hundreds of kPa, 22cm square, 6.5m barrel
  - Optical surface measurement capability
- RED Head experimental target
  - Simulant materials for brain, skull, etc.
  - Instrumentation for pressure measurement inside head
- Computational modeling
  - Constitutive modeling of tissues
  - Fluid-structure interaction
  - Effects of protective equipment

An Early Project Schematic



Modeling Brain

- Many models have been proposed
- Model parameters can vary quite a bit depending on test conditions, methods, and sample preparation
  - Density close to that of water
  - Nearly incompressible
  - Loss and storage moduli on the order of 0.1 to tens of kPa

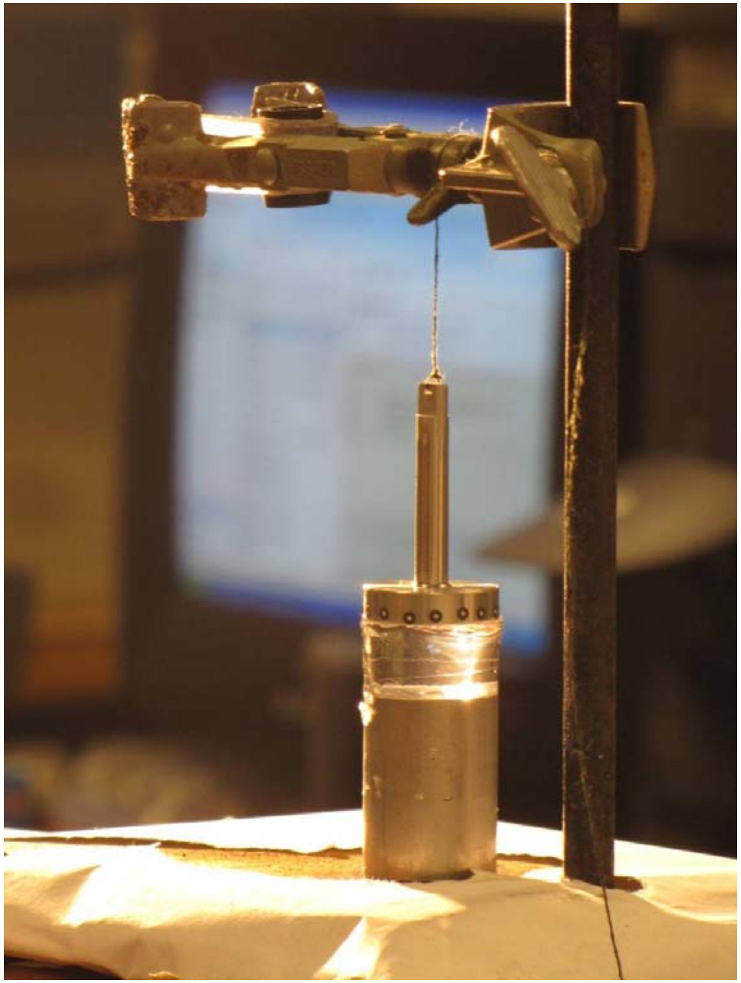
Finding a Good Brain Simulant

- Tests for determining relevant material properties:
  - Step response analysis (low-frequency screening)
  - DMA analysis under compression and shear (medium-frequency screening)
  - Ultrasonic test for longitudinal and shear waves (high-frequency evaluation)

Step Response Experiment

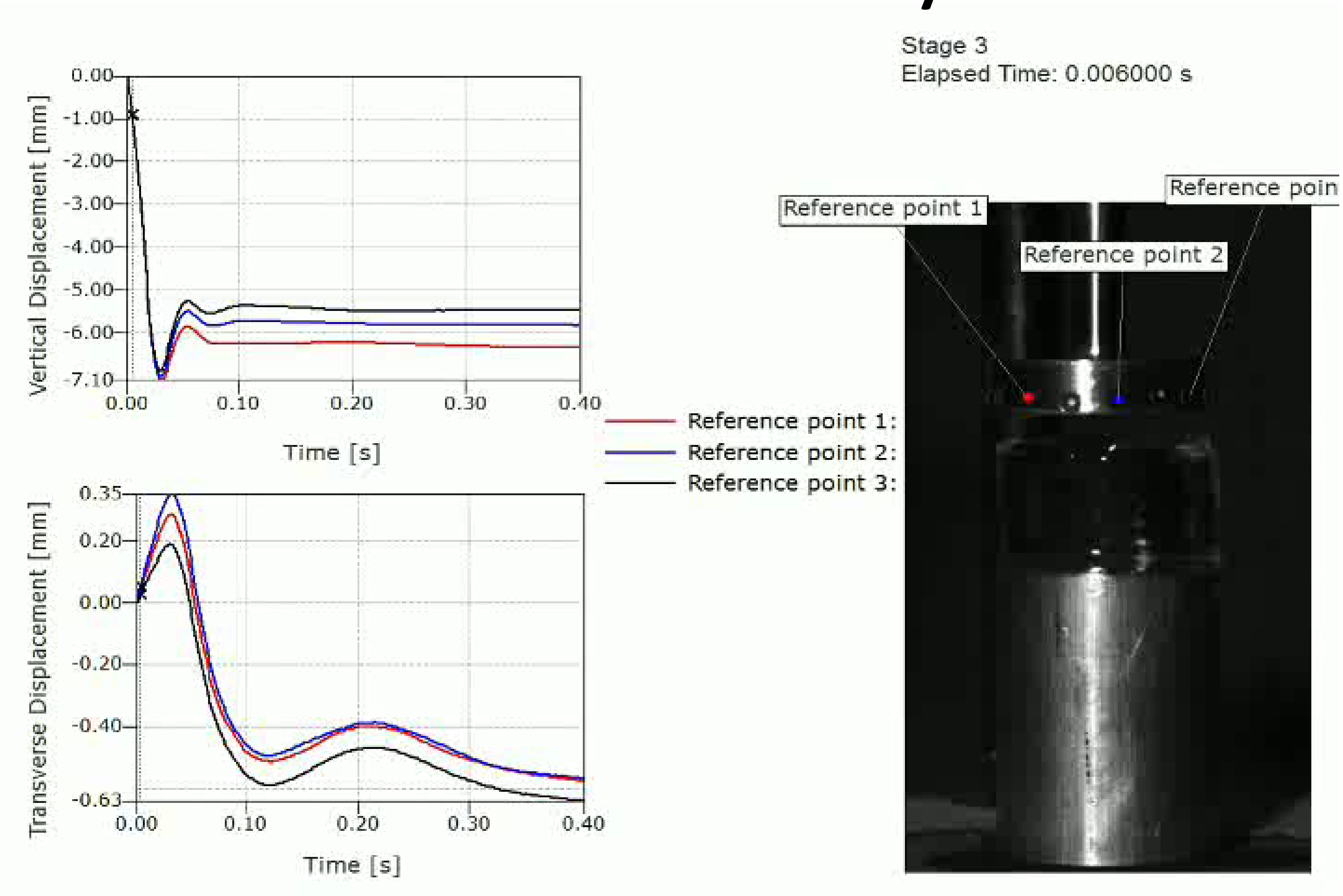
- Step load applied to sample by burning string suspending weight

ARAMIS video system capturing the experiment



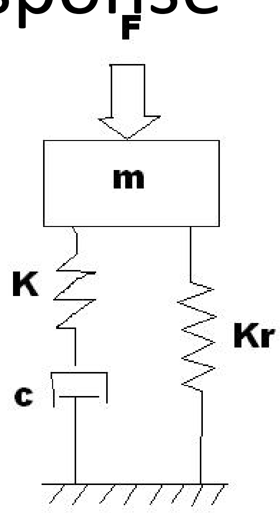
The step response test set up with gel silicone sample

Recording Step Response using ARAMIS Camera System

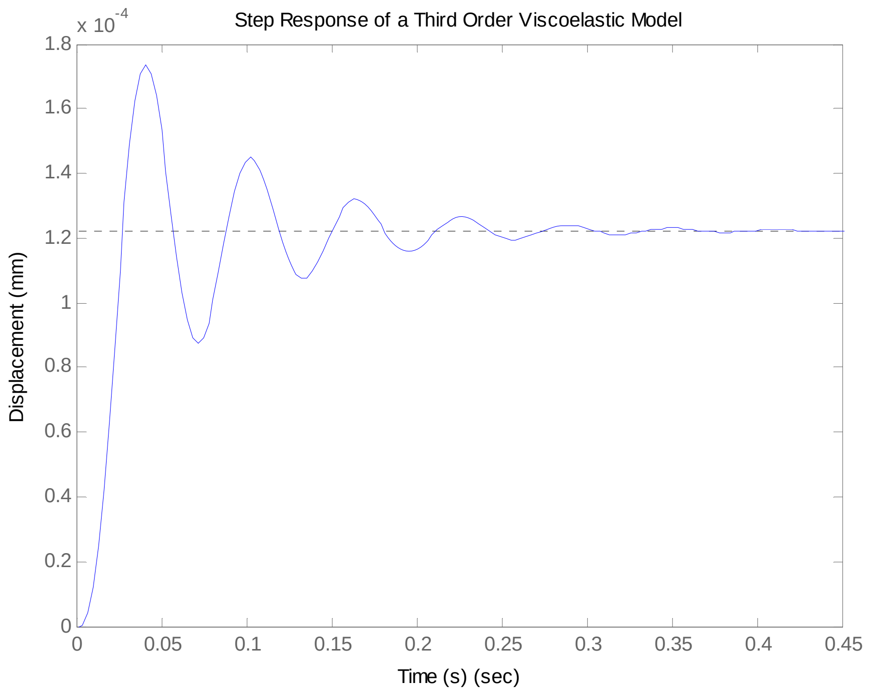


Mathematical Model for Step Response Fitting

- A 3rd-order linear viscoelastic model
- Matlab simulation provides theoretical step response

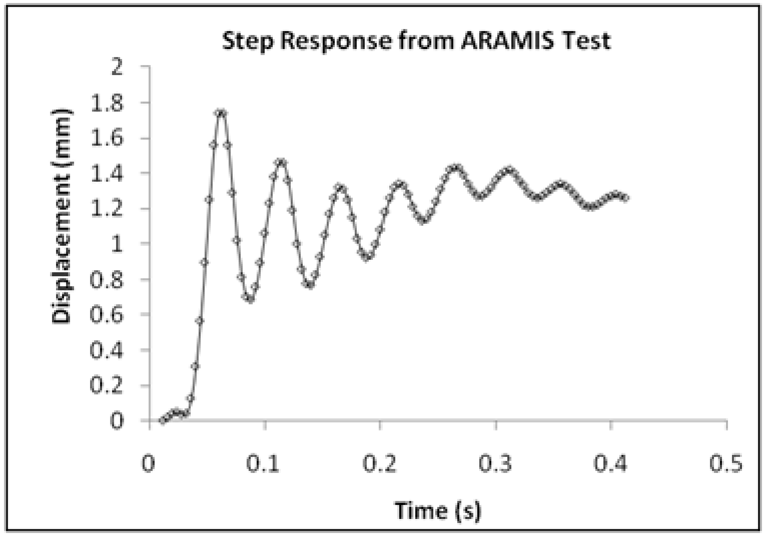


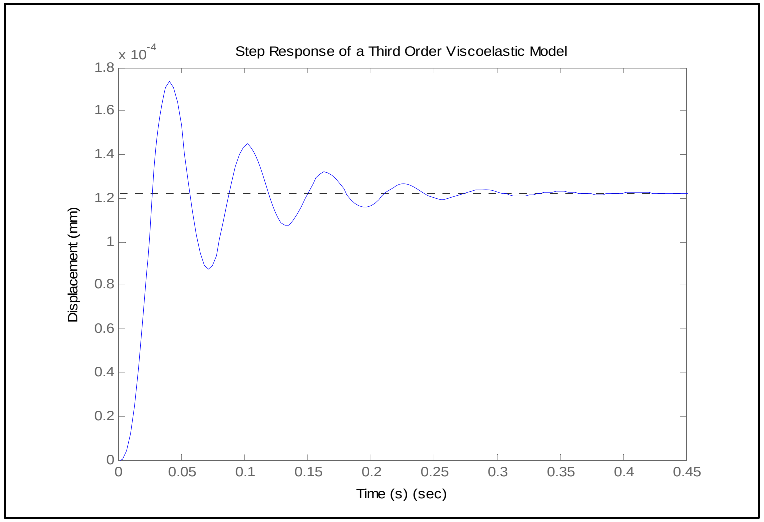
Third order viscoelastic model



Fitting Step Response Data to Model

- Matlab optimization toolbox used to fit actual and theoretical data series by changing model parameters; use this to find moduli



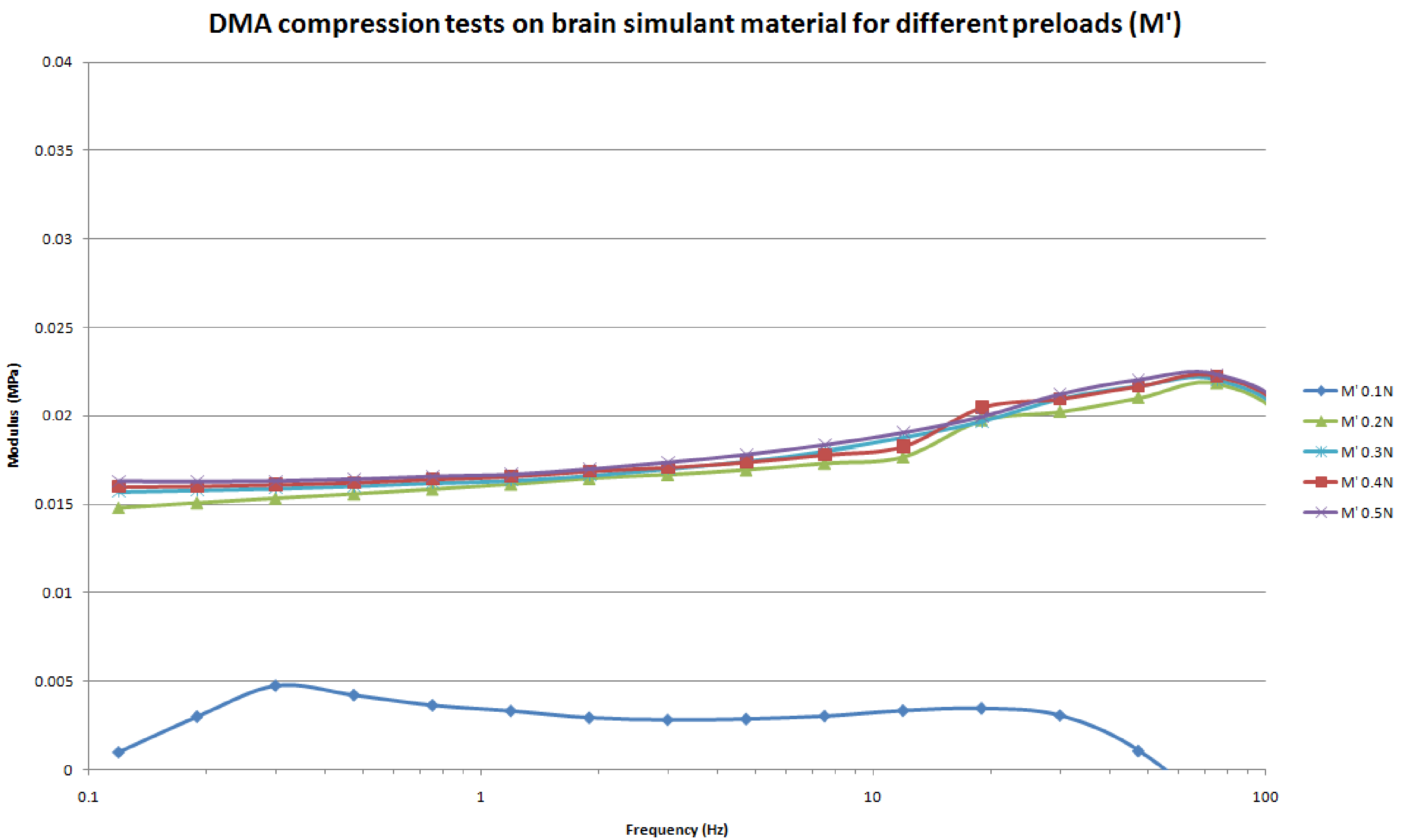


Dynamic Mechanical Analysis (DMA) of Silicone Gels

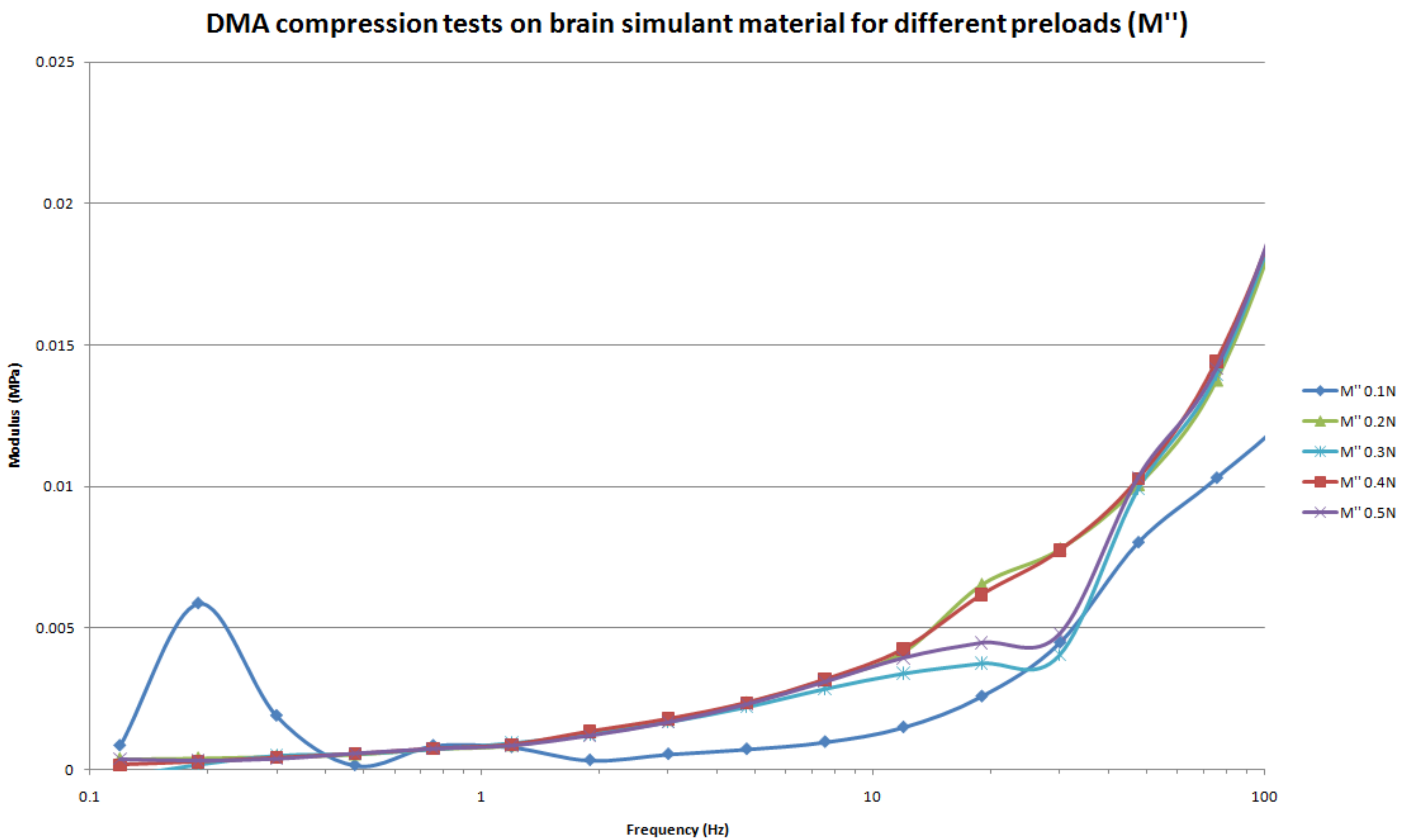
- Two types of silicone gel brain simulant samples were tested for DMA analysis
  - Both compression and shear
  - Frequency range of 0.1 Hz to 300Hz
  - Different cure methods

Silicone gel samples for DMA analysis

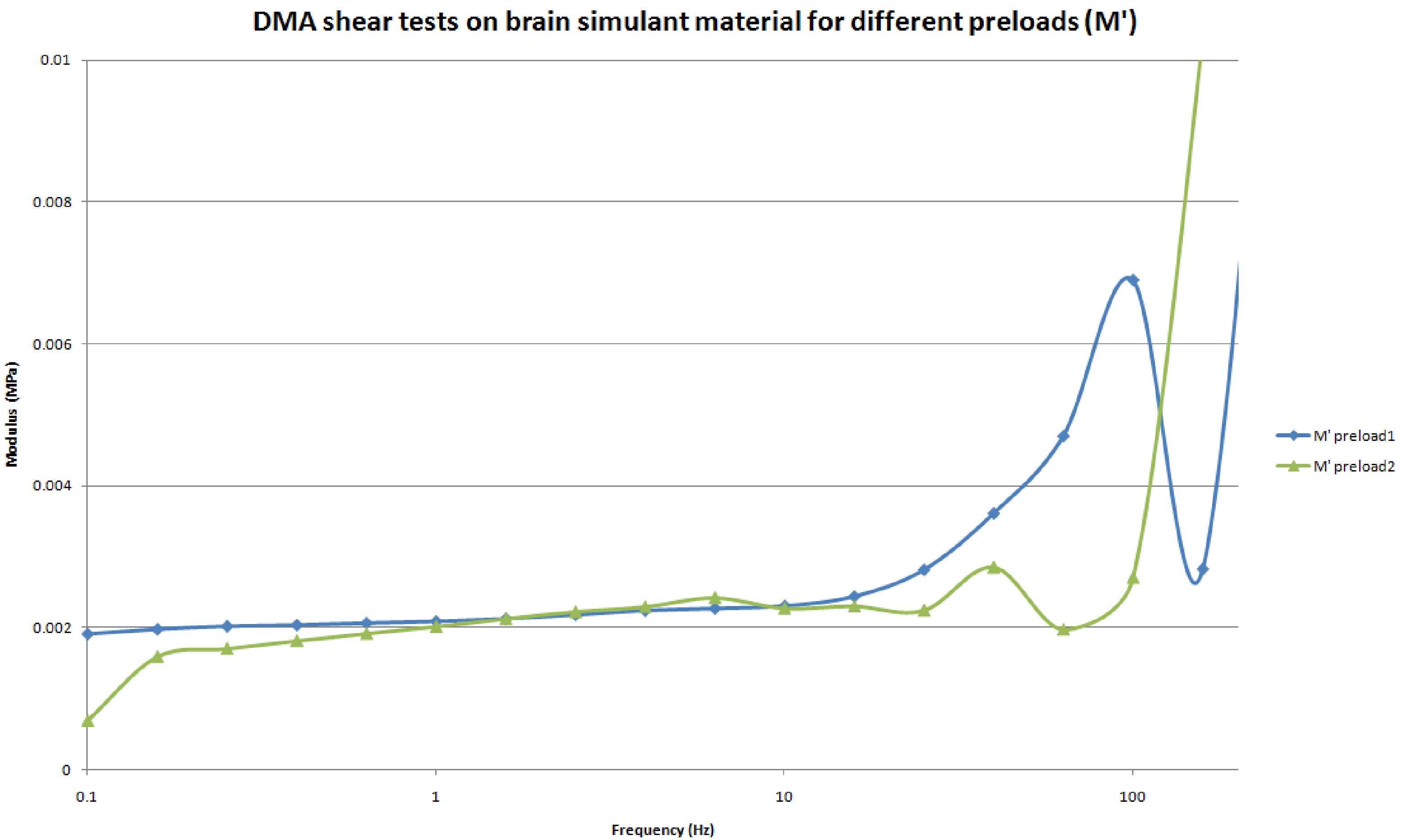
Gel 3-4190 HT- compression test - M’



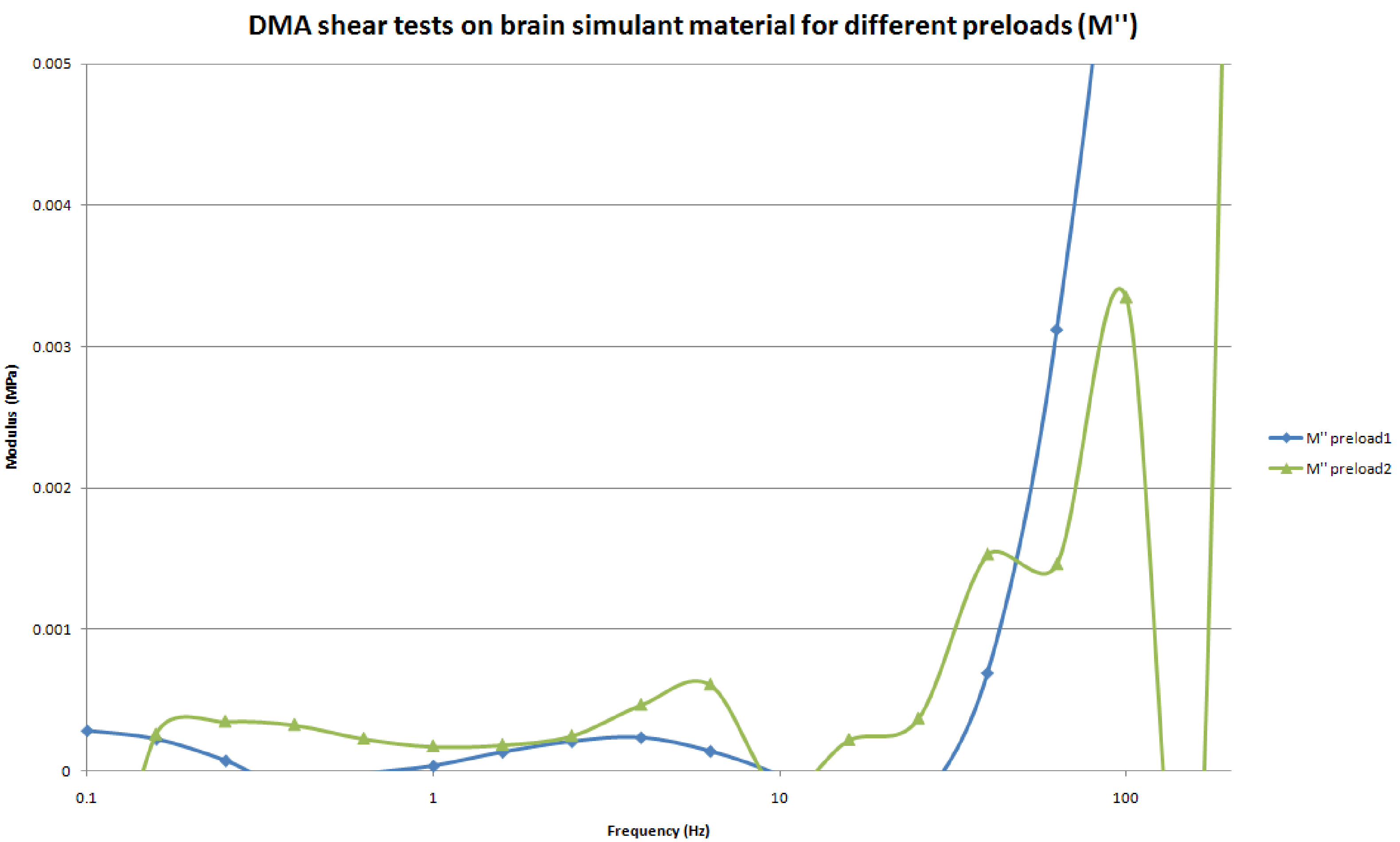
Gel 3-4190 HT- compression test - M’’



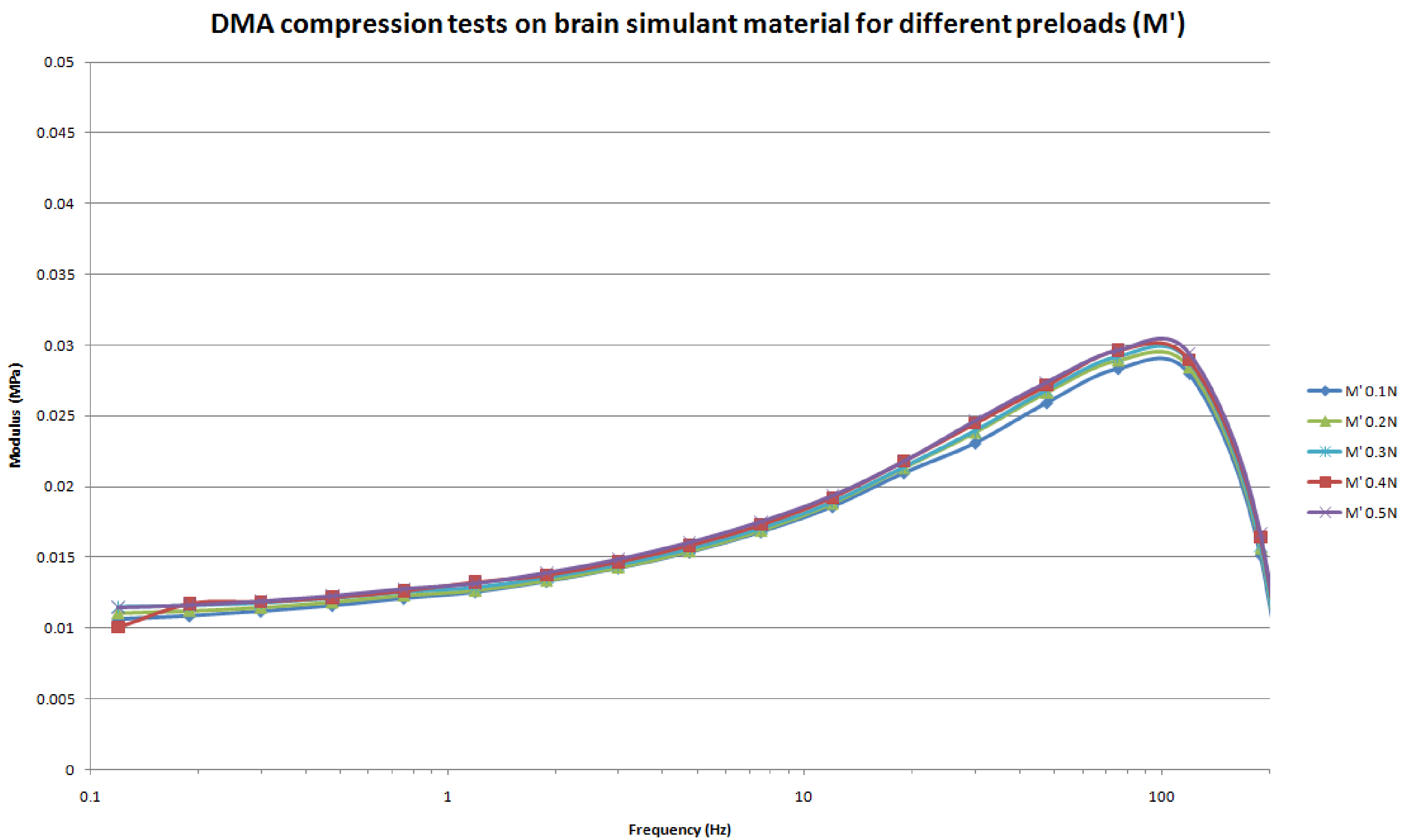
Gel 3-4190 HT- shear test - M’



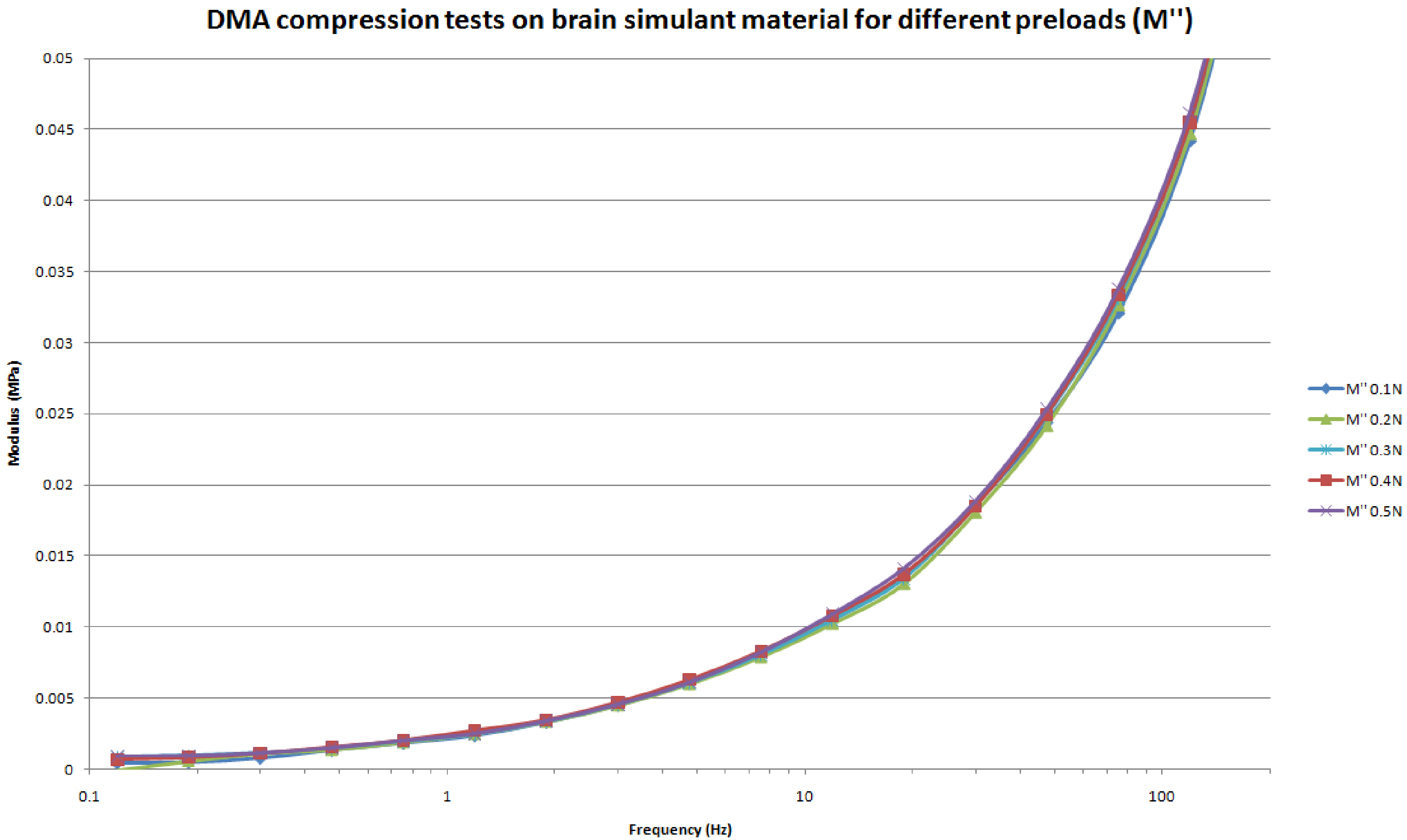
Gel 3-4190 HT- shear test - M’’



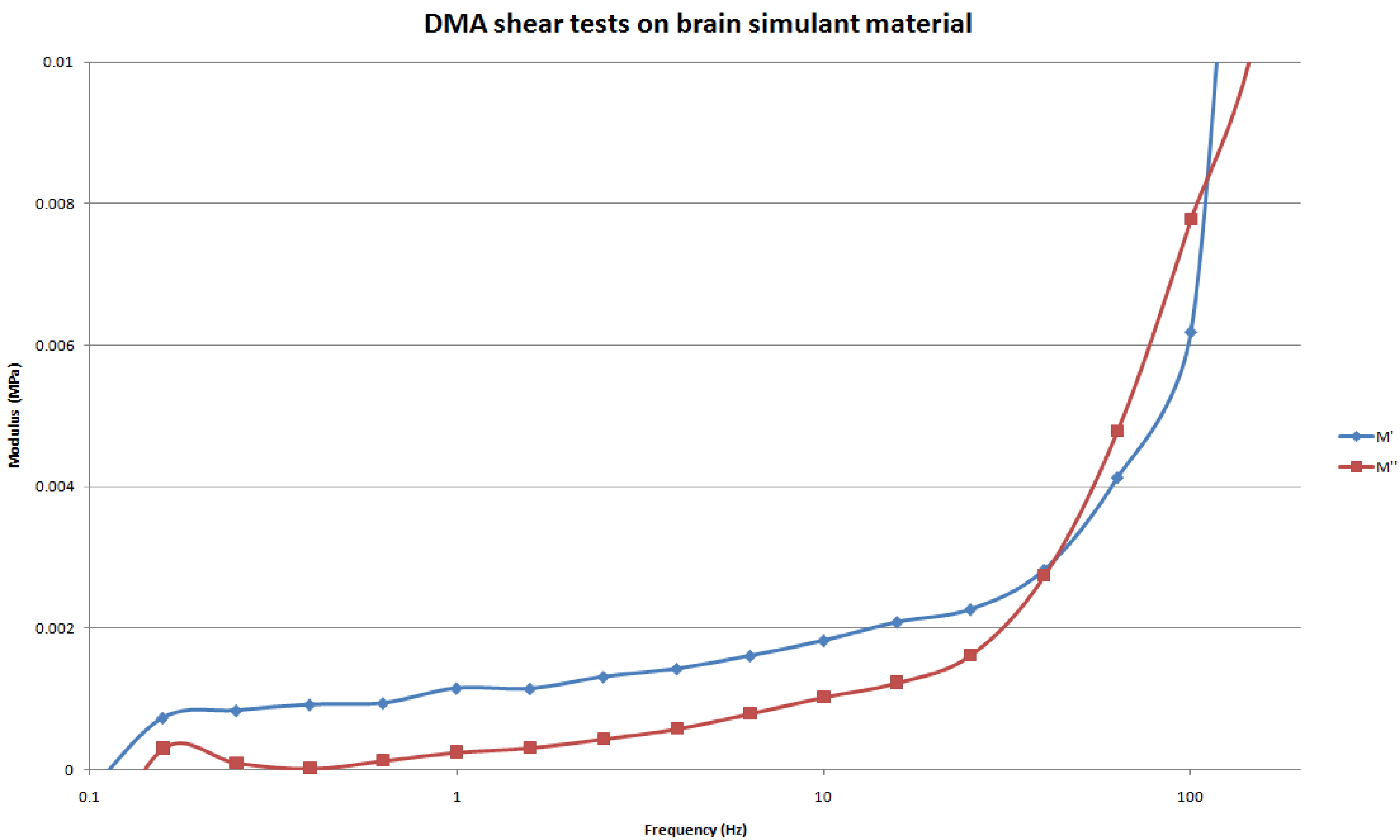
Gel 527 RT- compression test - M’



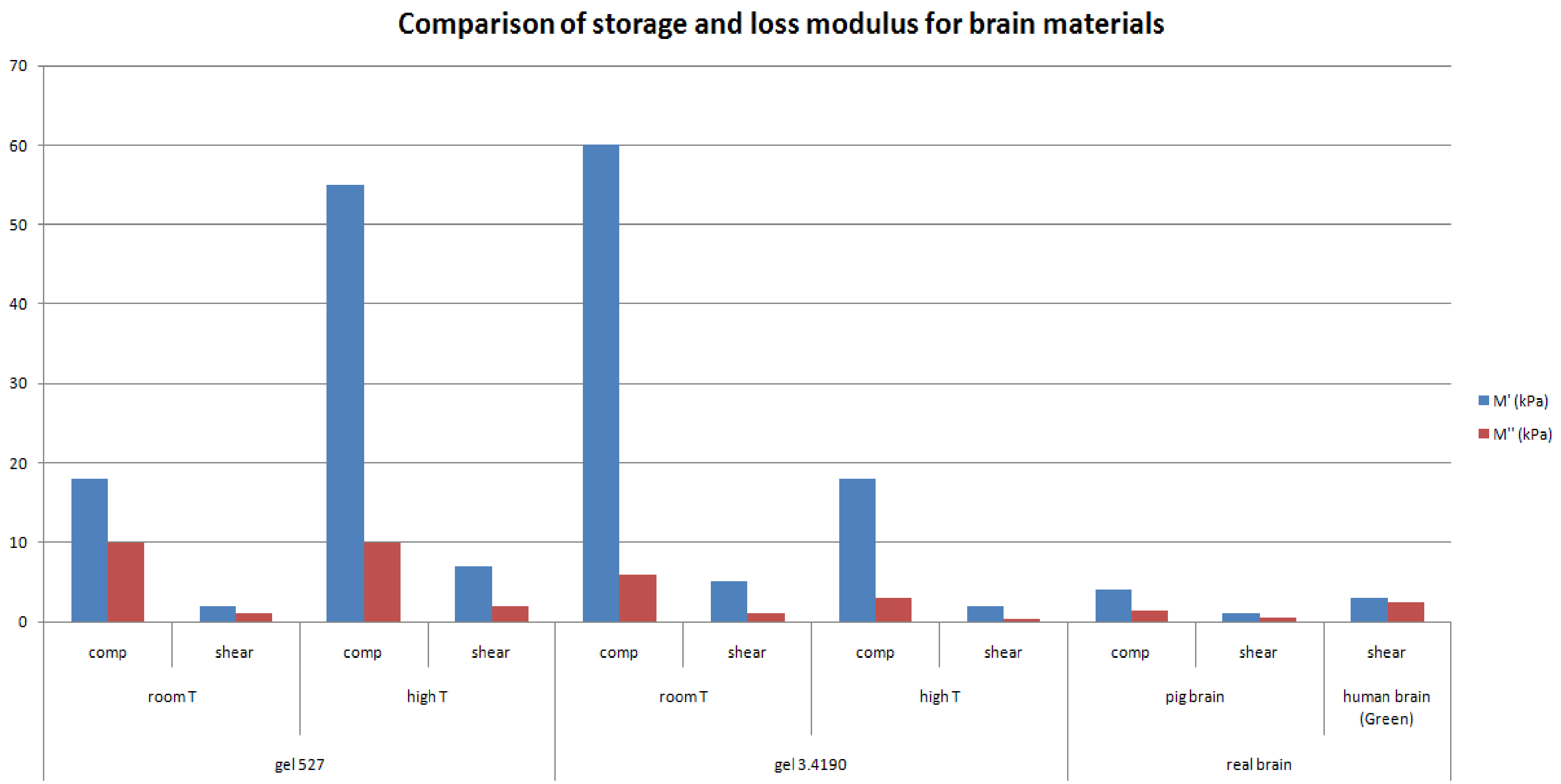
Gel 527 RT- compression test - M’’



Gel 527 RT- shear test



DMA Results Comparison (10Hz)

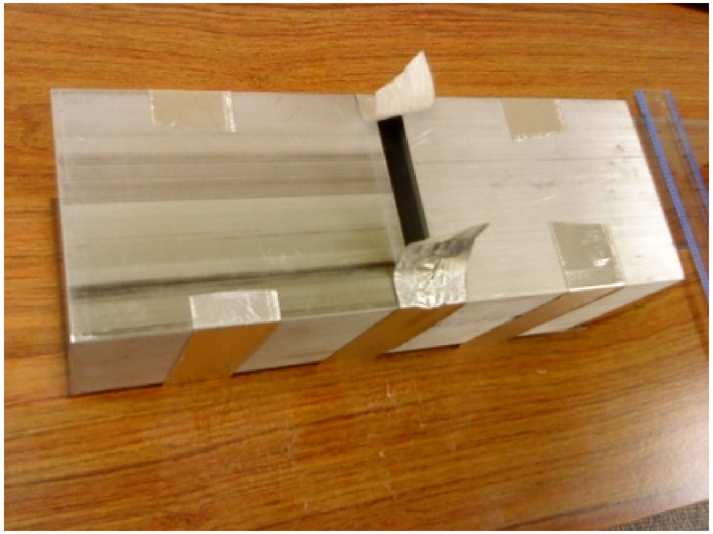


Fine-Tuning the Modulus of the Gels

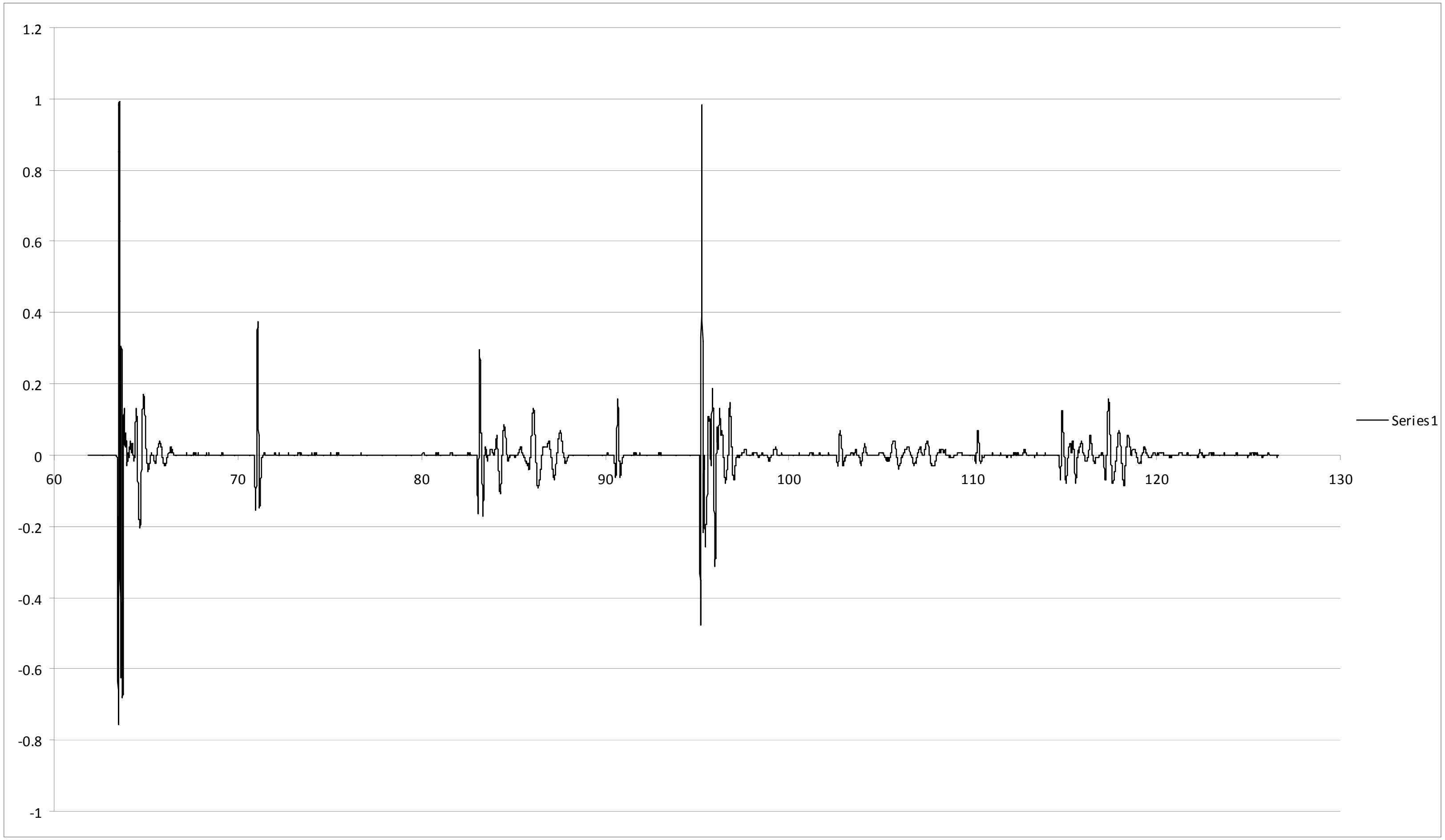
- The DMA analysis results implied that the storage modulus of the gel samples should be reduced
- Efforts are ongoing to experiment with different gel mixtures

Ultrasonic Testing

- Pulse echo / receiver technique
- Gel cured inside aluminum blocks so that no deformation occurs on the gel surfaces due to the placement of the probes

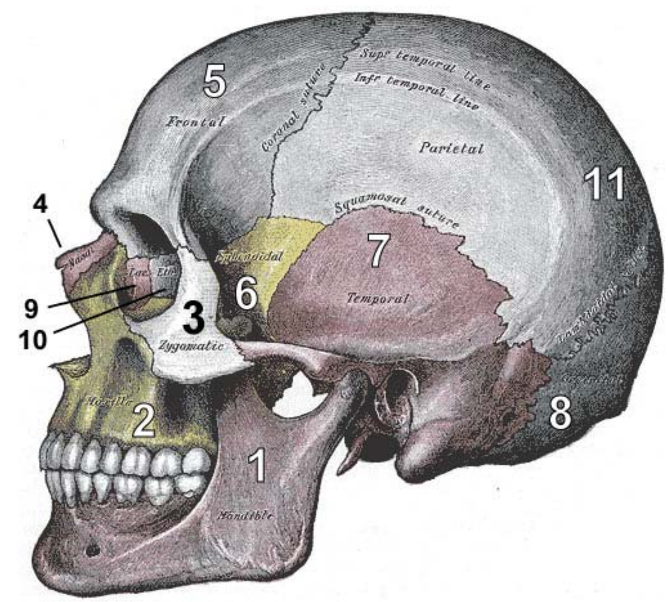


Ultrasonic Testing



Skull Properties

- Density: 1.4 g/cm^3
- Young's modulus: 3.2-4.5 GPa
- Bulk modulus: 4.8 GPa
- Nonuniform in both geometry and material
- Need to match elastic, viscoelastic, and density properties



Skull Materials

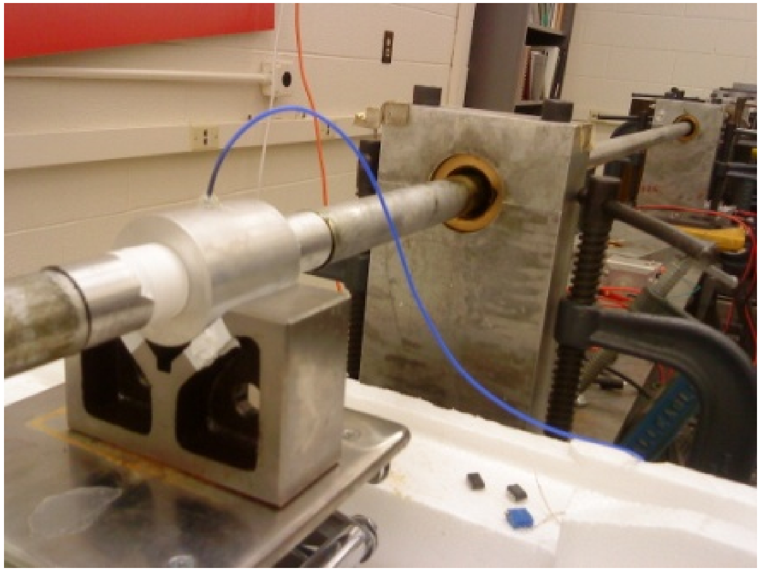
- Urethane foam

	Density (g/cc)	Young's Modulus (GPa)
Desired	1.4	3.2-4.5
Actual	0.8	2.9

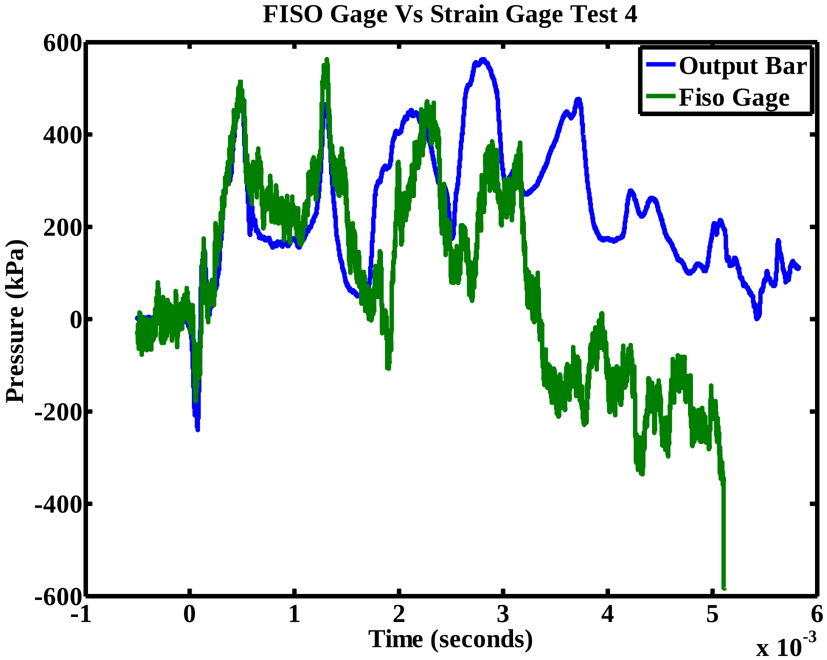
- Poured urethane
  - Not as stiff
  - Better density match

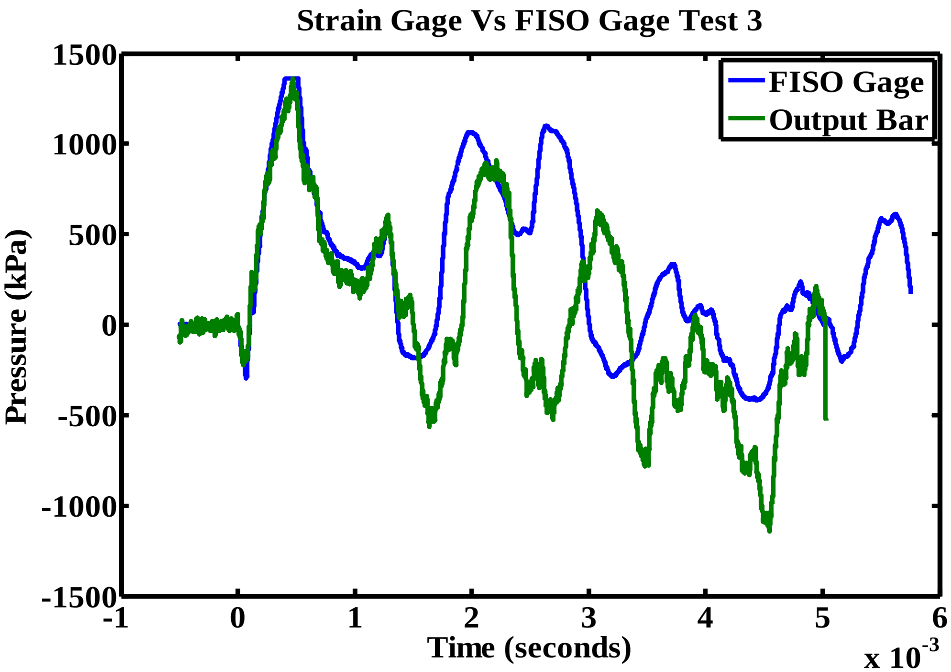
Kolsky Bar Setup (Sensor Validation)

- Fiber optic sensor embedded in silicone gel, between input and output bars



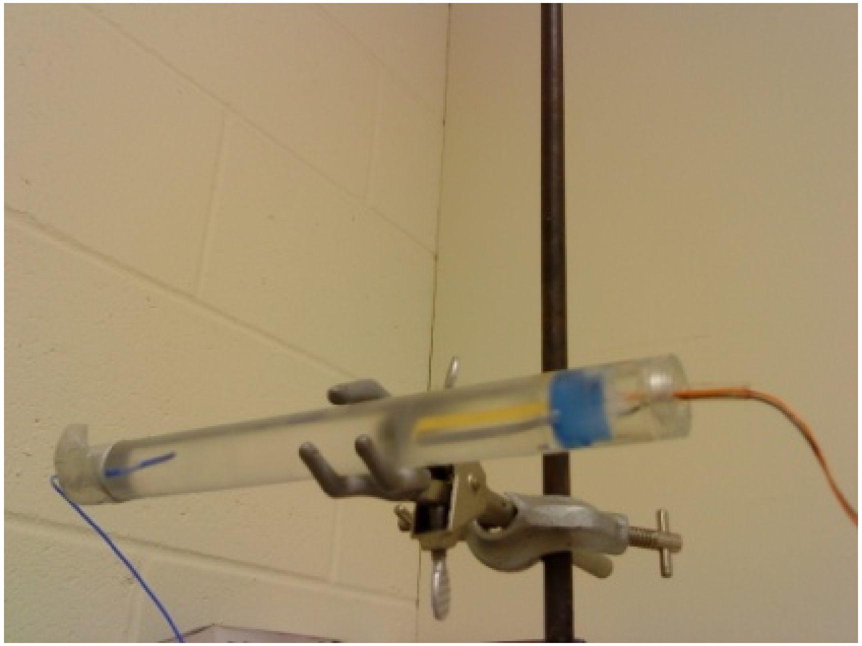
Sensor Validation using Kolsky Bar





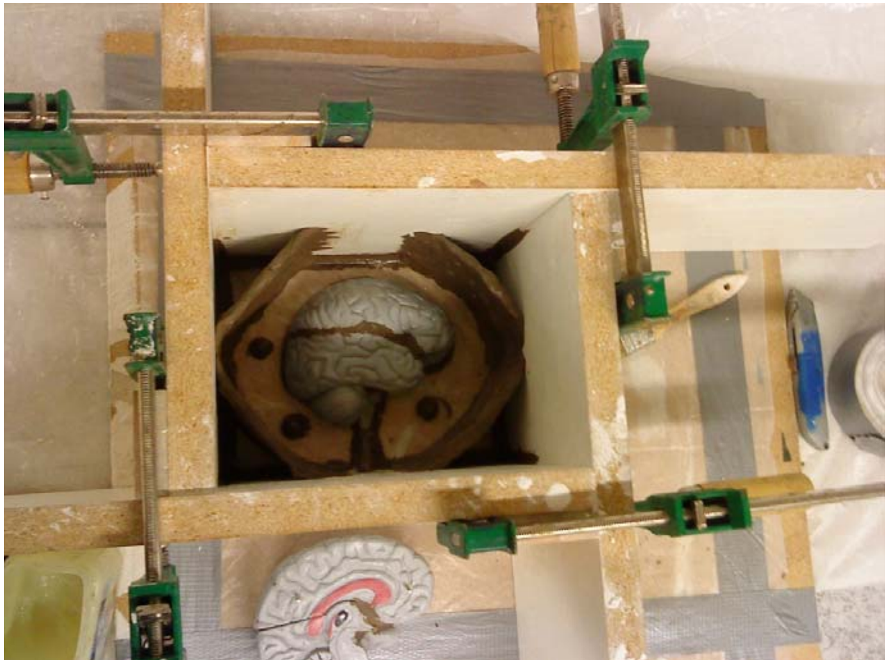
Validation using Simple Geometry

- Embed sensors in cylindrical target
- Validate computational simulations to experimental data



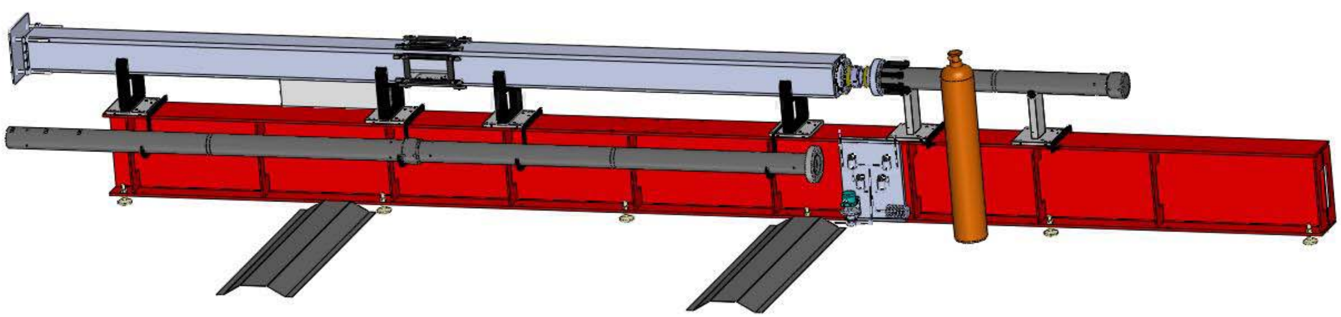
Molding the “Brain”

- A full scale demonstration model of the human brain was used to create a negative
- Plaster of Paris and silicone rubber used to create the brain mold



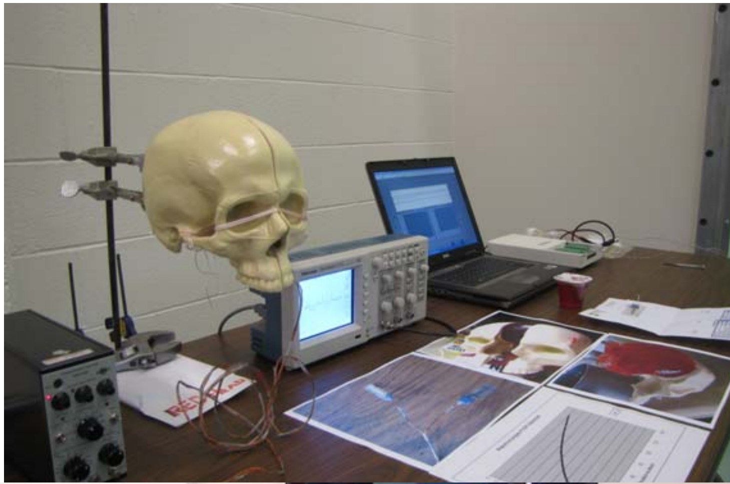
Shock Tube Setup

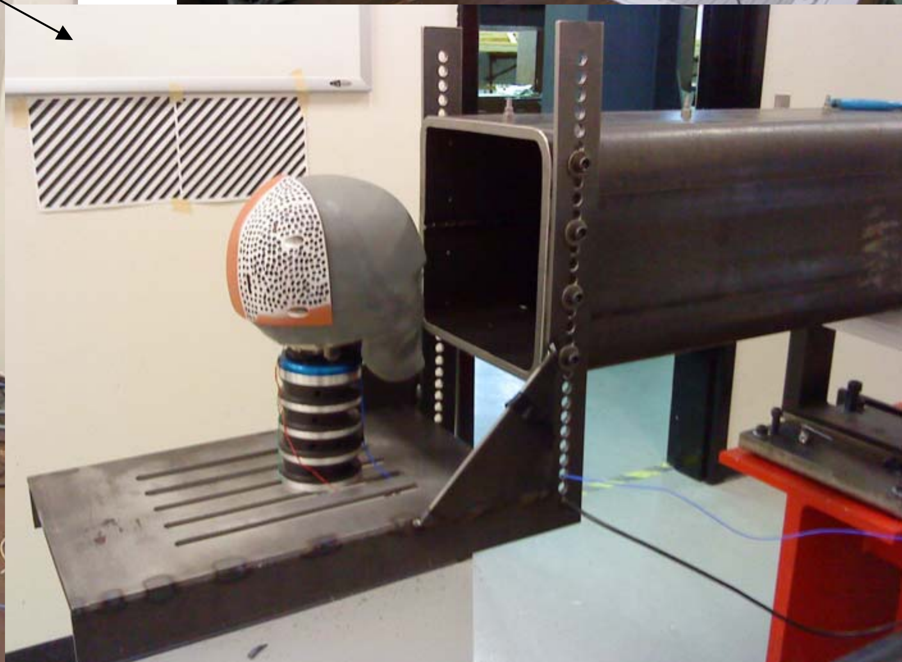
- Breech pressurized with N or He
- Mylar membranes with total thickness of 0.05 to 0.25 mm
- 10 membranes of 0.18 mm each produces breech pressure of 7300 kPa



RED Head Setup

- Version 1
- Version 2

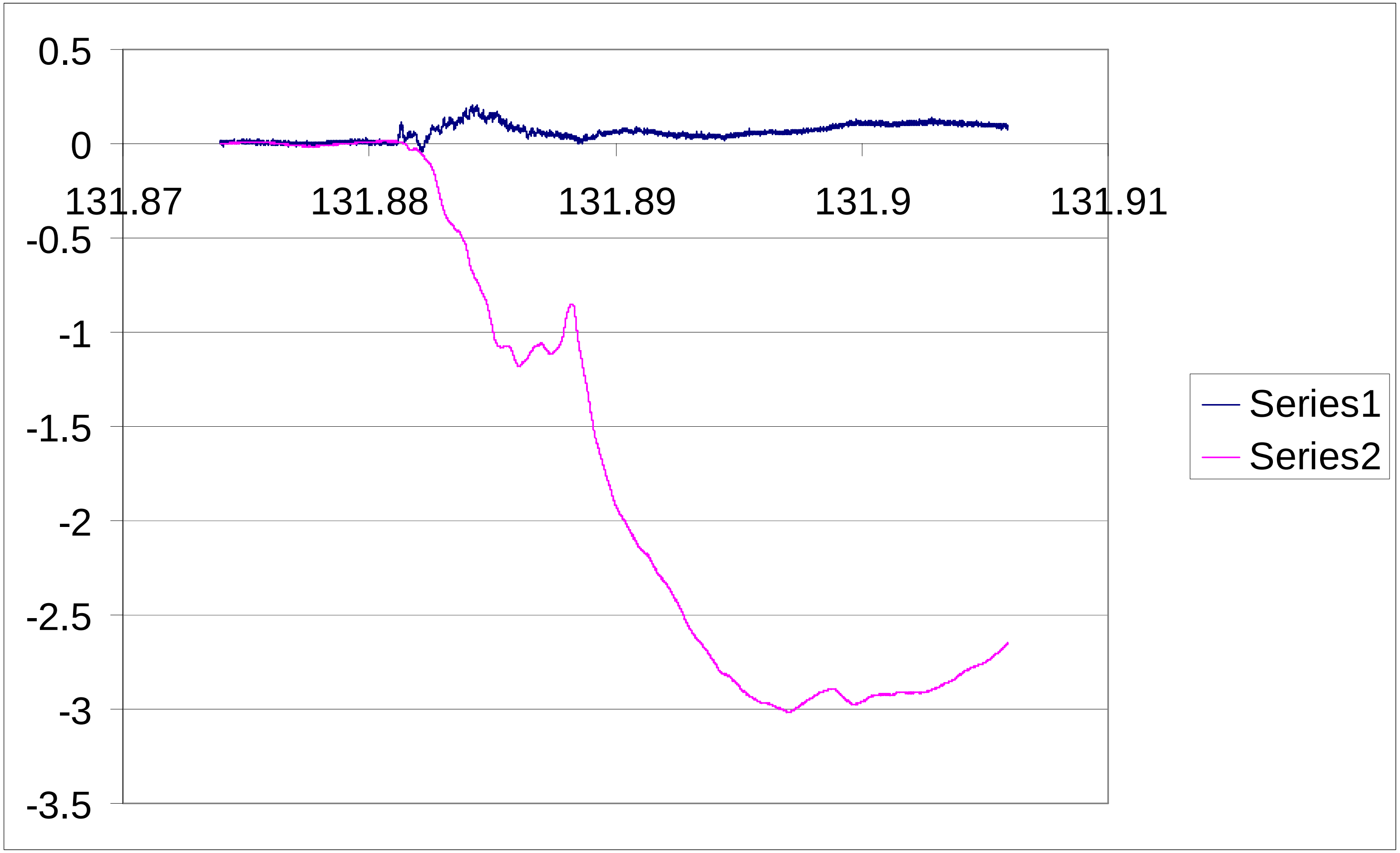




Shock Test

Shock Test

- 50-60 kPa peak, 100s of kPa breech



Conclusions

- Suitable materials have been identified to serve as simulants for head tissues
- Realistic Explosive Dummy Head (RED Head) has been fabricated and instrumented
- Experimental work is ongoing in order to validate computer modeling
- Future work will enable accurate computational simulation of head response to insults and better understanding of the mechanisms of mild TBI

Acknowledgments

- Funding from US Army Research Office
- Faculty and students at the University of Nebraska-Lincoln

Questions?