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

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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

UNL BlastWave Facility

Shock Tube

Optical Measurements

Headform

High-Pressure Breech

4"-20' Barrel

Testing Chamber

Blastwave

Sample

Vents

Window

High Speed Cameras

ARAMIS

Stereo Optical Surface Strain Measurement

Head

Head and Helmet

Instrumented

Skull
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 3\(^{rd}\)-order linear viscoelastic model
- Matlab simulation provides theoretical step response
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
Gel 3-4190 HT- compression test - $M'$

DMA compression tests on brain simulant material for different preloads ($M'$)
DMA compression tests on brain simulant material for different preloads (M'')
Gel 3-4190 HT- shear test - $M'$

DMA shear tests on brain simulant material for different preloads ($M'$)
DMA shear tests on brain simulant material for different preloads ($M''$)
Gel 527 RT- compression test - $M'$

DMA compression tests on brain simulant material for different preloads ($M'$)
Gel 527 RT- compression test - $M''$

DMA compression tests on brain simulant material for different preloads ($M''$)

![Graph showing DMA compression tests on brain simulant material for different preloads $M''$. The graph plots frequency (Hz) on the x-axis and modulus (kPa) on the y-axis. The graph includes lines for different preloads: $M'' 0.1N$, $M'' 0.2N$, $M'' 0.3N$, $M'' 0.4N$, and $M'' 0.5N$. The lines show an increase in modulus with an increase in frequency for all preloads.](image)
DMA shear tests on brain simulant material

Modulus (kPa)

Frequency (Hz)
DMA Results Comparison (10Hz)

Comparison of storage and loss modulus for brain materials

- Comp
- Shear
- Room T
- High T
- Gel 527
- Gel 34190
- Pig brain
- Real brain
- Human brain (Green)

M' (kPa)
M'' (kPa)
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/cm³
• 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**
- **Poured urethane**
  - Not as stiff
  - Better density match

<table>
<thead>
<tr>
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<th>Density (g/cc)</th>
<th>Young's Modulus (GPa)</th>
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<td>1.4</td>
<td>3.2-4.5</td>
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<tr>
<td>Actual</td>
<td>0.8</td>
<td>2.9</td>
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Kolsky Bar Setup (Sensor Validation)

- Fiber optic sensor embedded in silicone gel, between input and output bars
Sensor Validation using Kolsky Bar

FISO Gage Vs Strain Gage Test 4

Strain Gage Vs FISO Gage Test 3
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
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Questions?