SAND2006-6862C

TufFoam™

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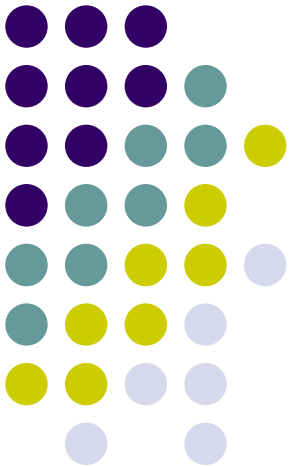
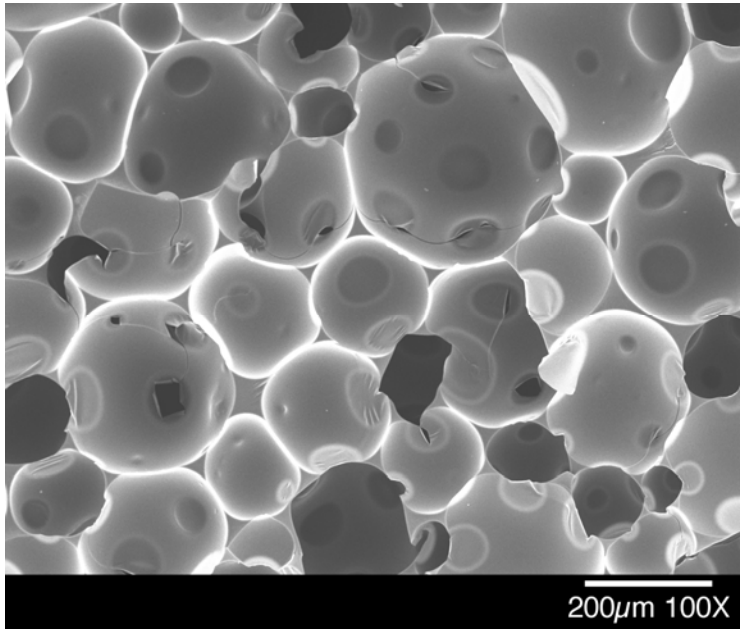
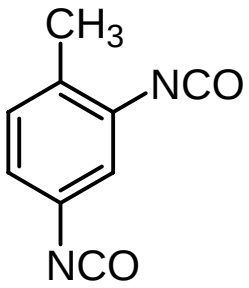
Pat Keifer



TufFoam™



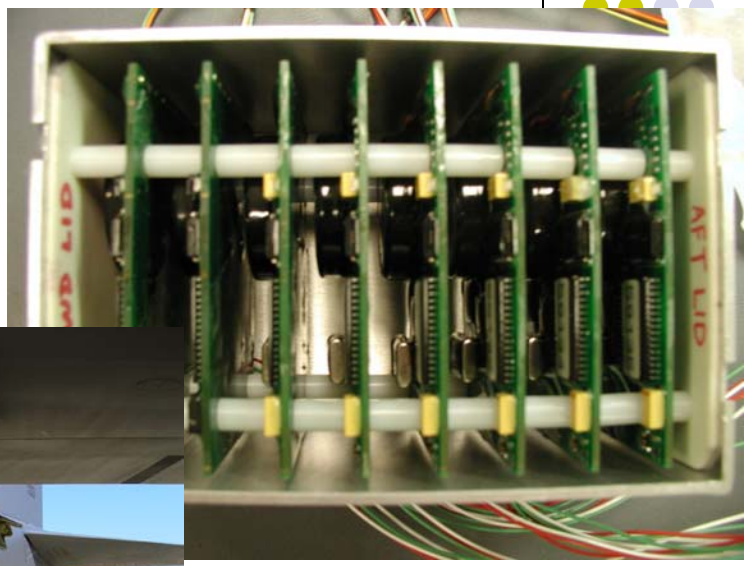
- Polyurethane Foam
- Closed-cell
- Rigid
- Water-blown
  - No Chlorofluorocarbons (CFC's)
- Modified methylene diisocyanate (MMDI) based
  - No toluene diisocyanate (TDI)
- Density range 0.032-0.8 g/cc (2-50 pcf)
- Patents Pending
- Initial application was encapsulation
  - Protect electronics from shock, vibration and impact
  - TDI replacement effort

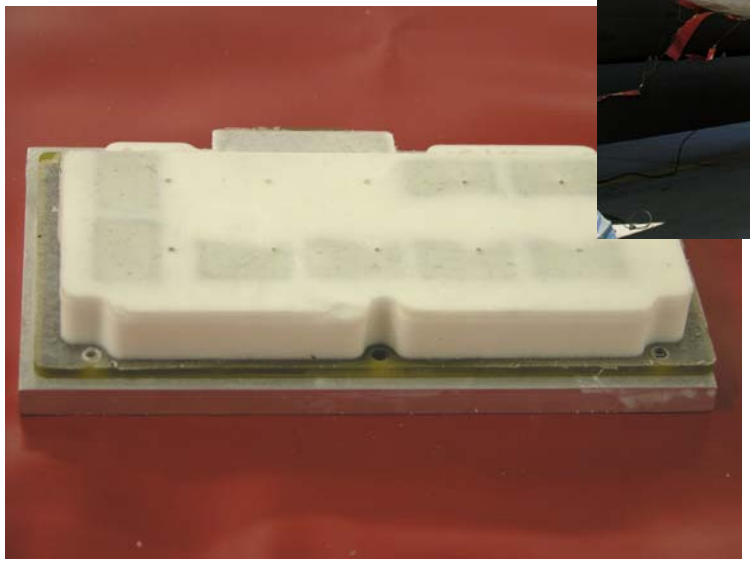


Data Recorder/Data Logger

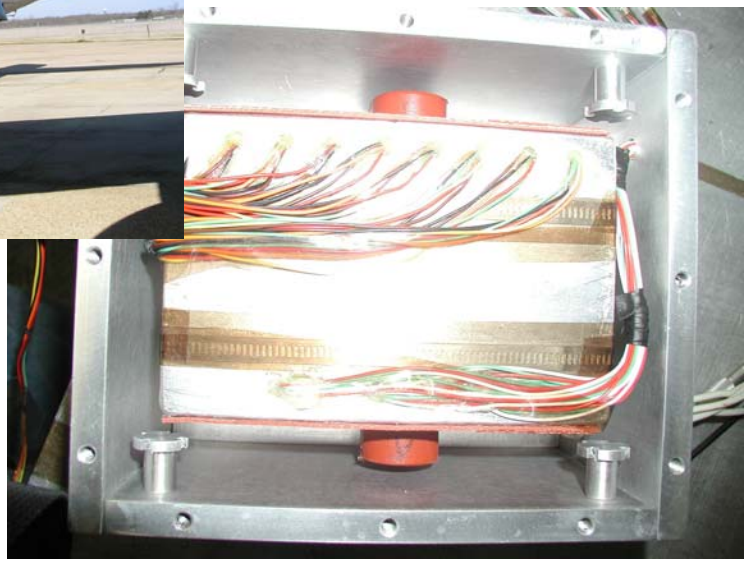
W80-3

CFTU





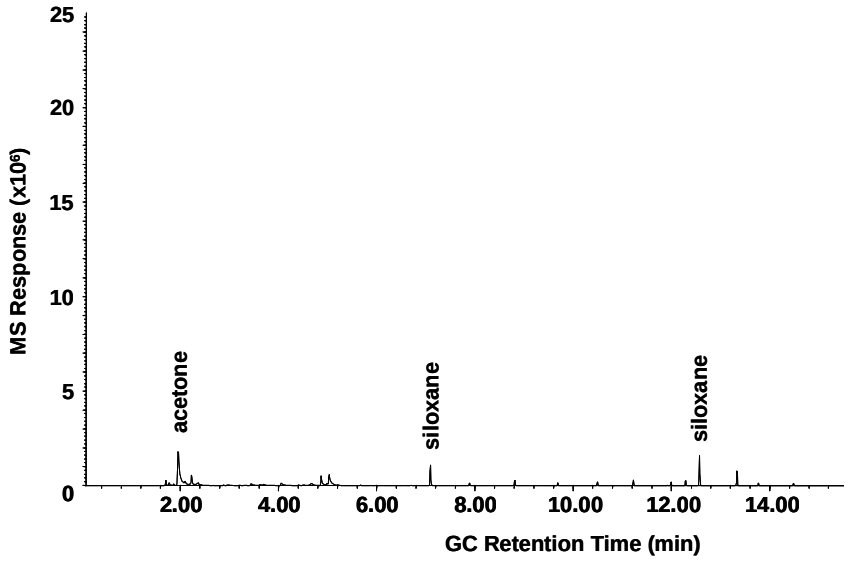
With Telemetry group (8233)



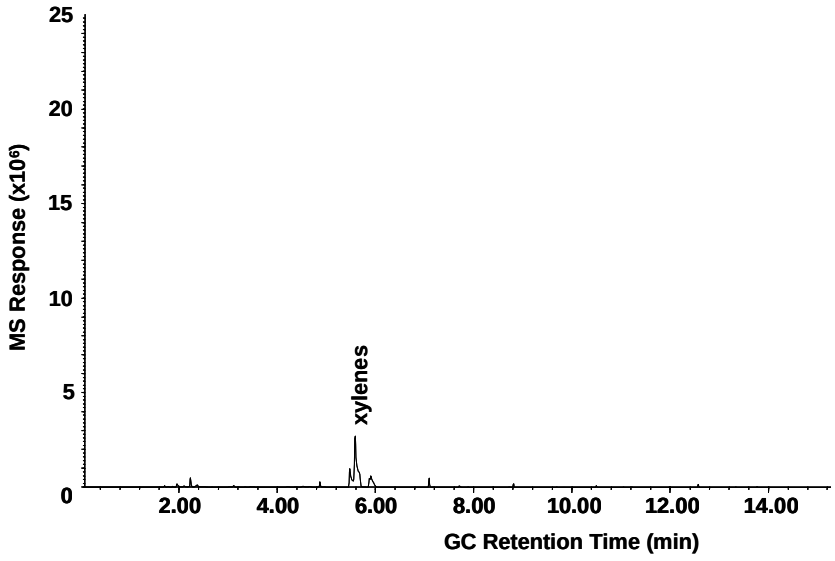
TufFoam in High g Environments

- Drop Table test-mechanical functionality
  - 5,000g over 600 µsec
  - TufFoam showed no ill effects
  - Anomaly in memory stack
- RNEP JTA Advancement Test (RJAT)-12/04
  - 3,000-4,000g over 20ms

Solid Phase Micro-Extraction (SPME) Off Gas Analysis



TufFoam™



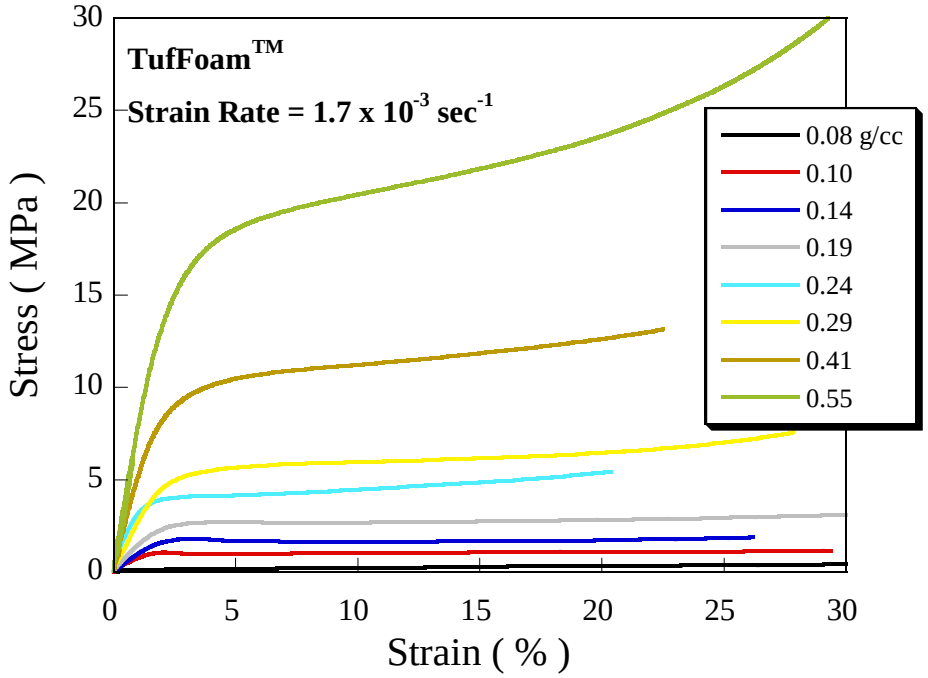
TDI Foam

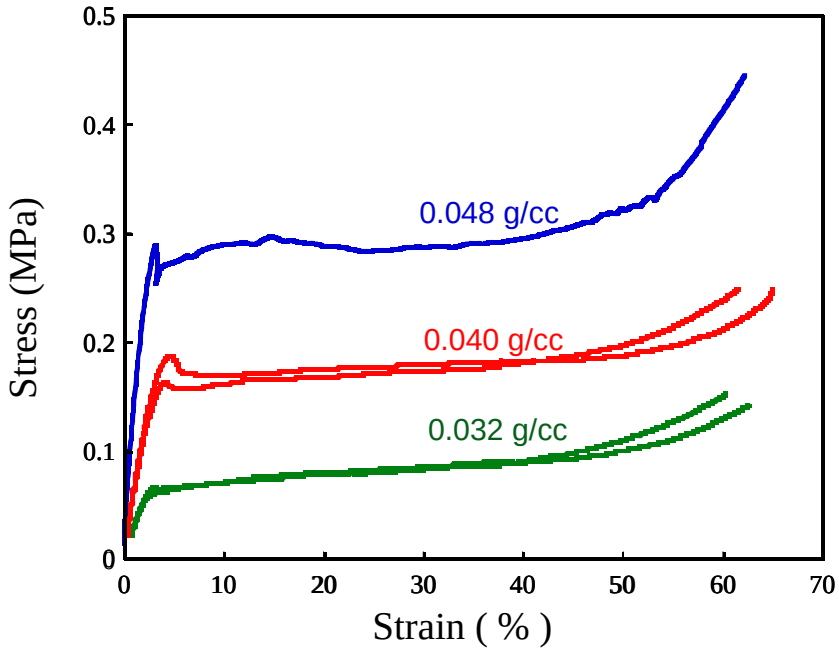
- Very little outgassing, even at 70°C

Thermal Conductivity

- 0.019 W/m•K at 0.040 g/cc (25°C)
  - 0.13 Btu•in/h•ft^2•°F
  - Comparable to CFC blown polyurethane foams
- Expanded polystyrene (EPS) is 0.029 W/m•K at 0.032 g/cc (40°C)
- Over $2 billion polyurethane rigid foam insulation market (4-5% growth expected)

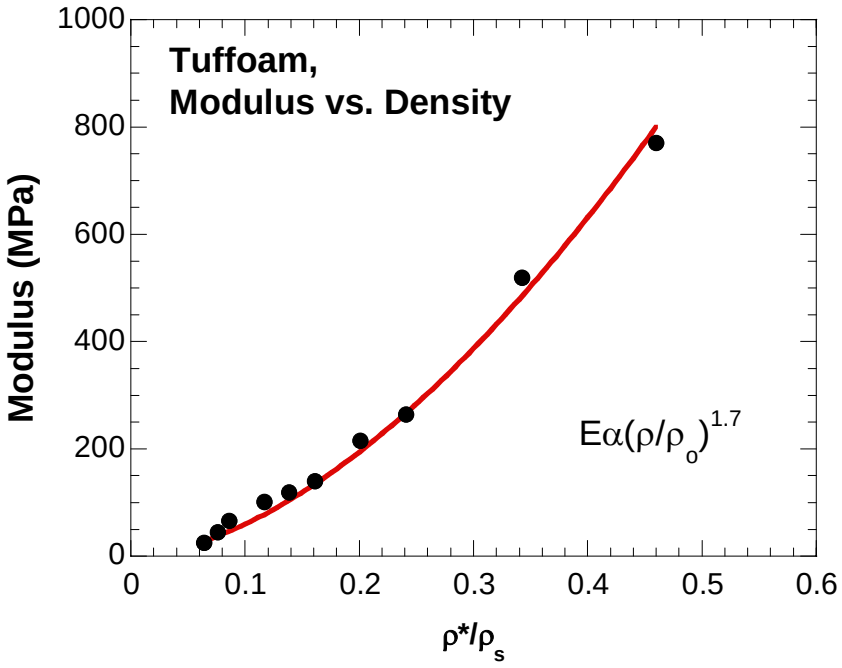
Quasi-Static Stress Strain Curves

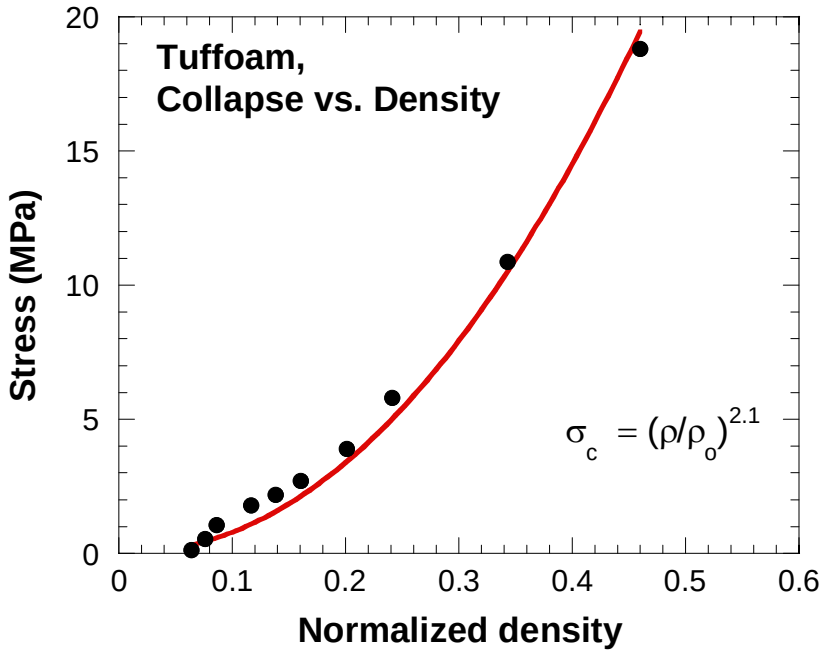




TufFoam has been formulated over a range of densities from 0.03-0.8 g/cc (2-50 pcf).

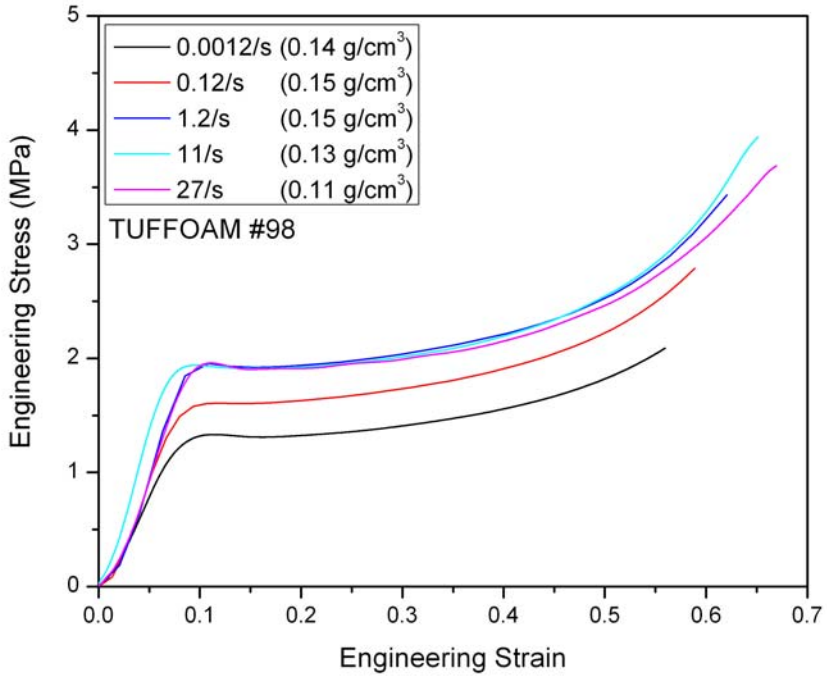
TufFoam Quasi-Static Compression Data

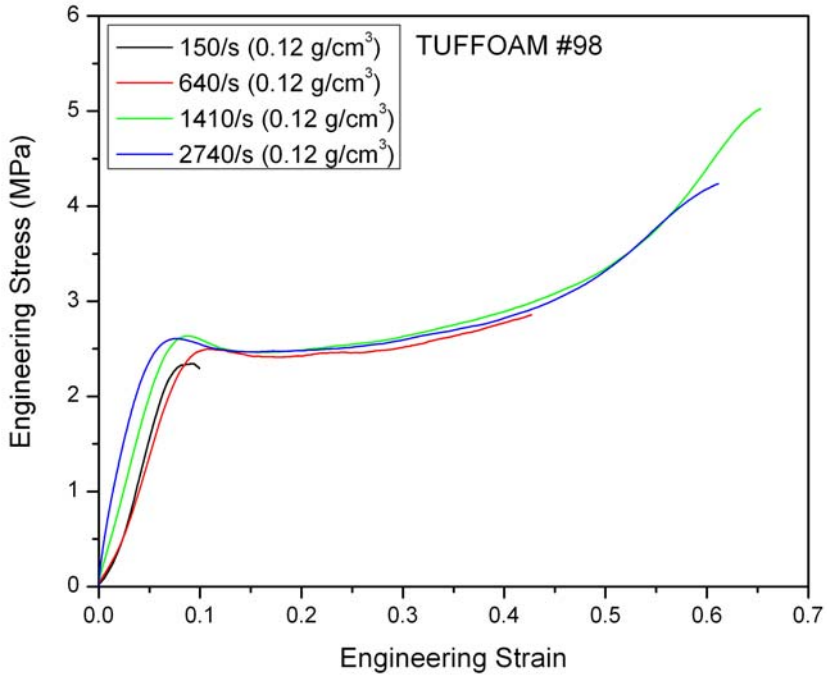




Quasi-static properties of TufFoam overlay with other rigid polyurethane foams (TDI, CRETE, RECRETE)

Strain rate effects of TufFoam (8 pcf)

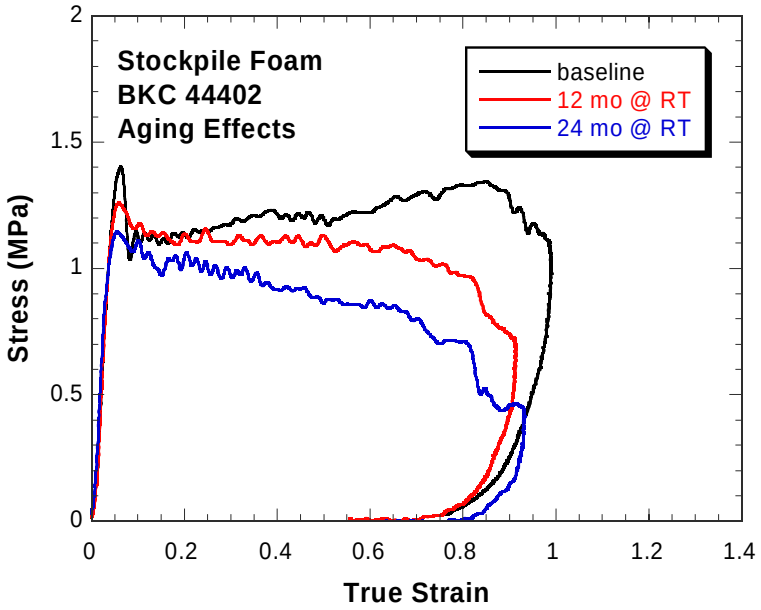




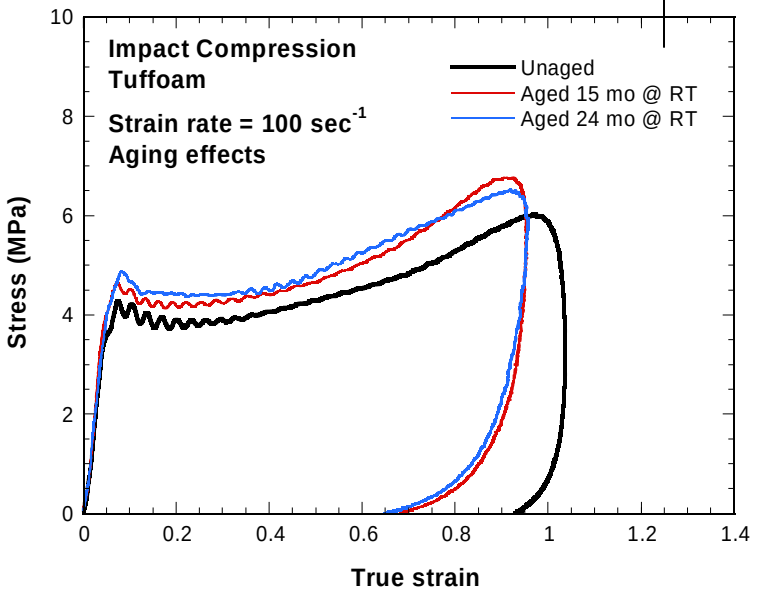
- The stress-strain curves of 8 pcf TufFoam show clear strain rate effect up to 150 /s. Above that, little rate effect is observed.

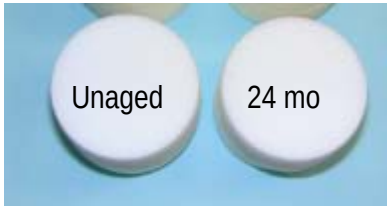
Foam Aging

TufFoam shows no such decrease in impact performance thru 2 yr of aging



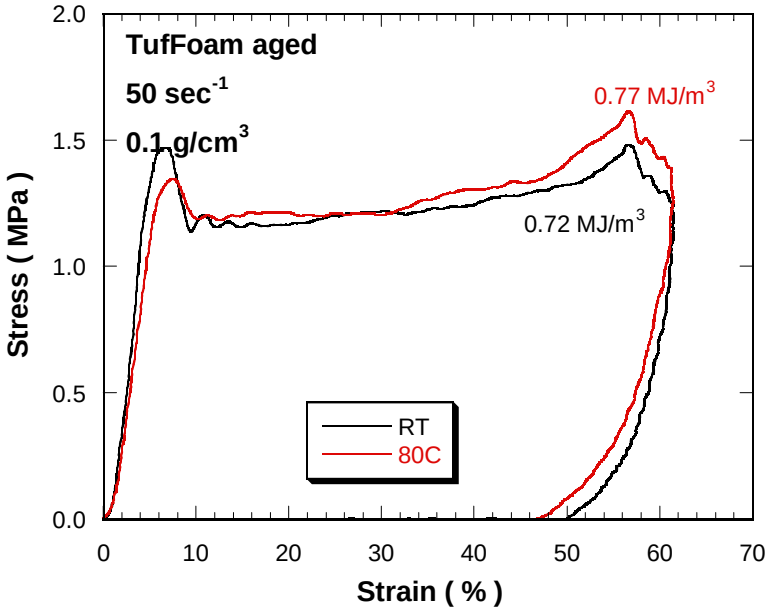
Stockpile (TDI) foam exhibits measurable loss in toughness

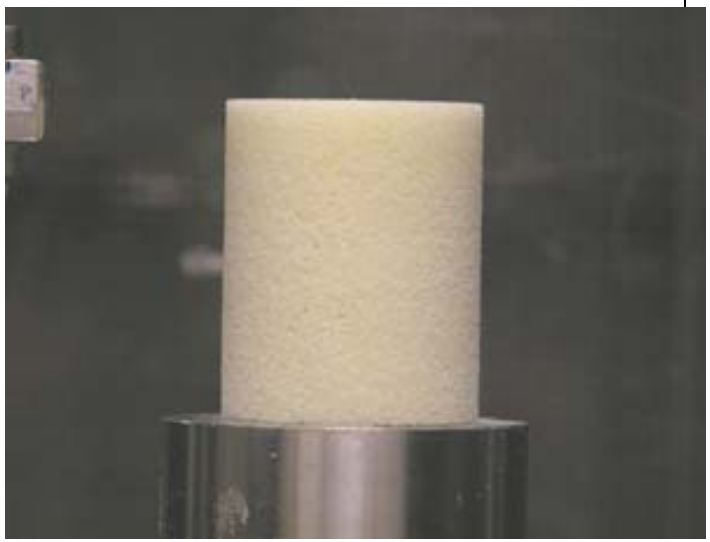


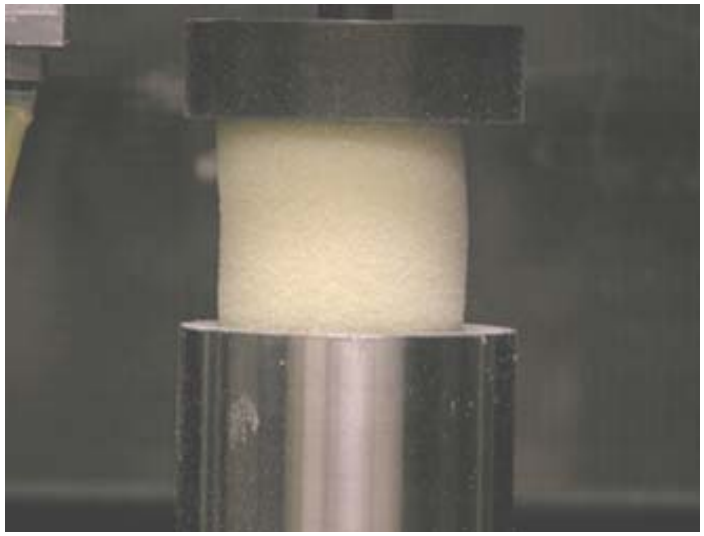


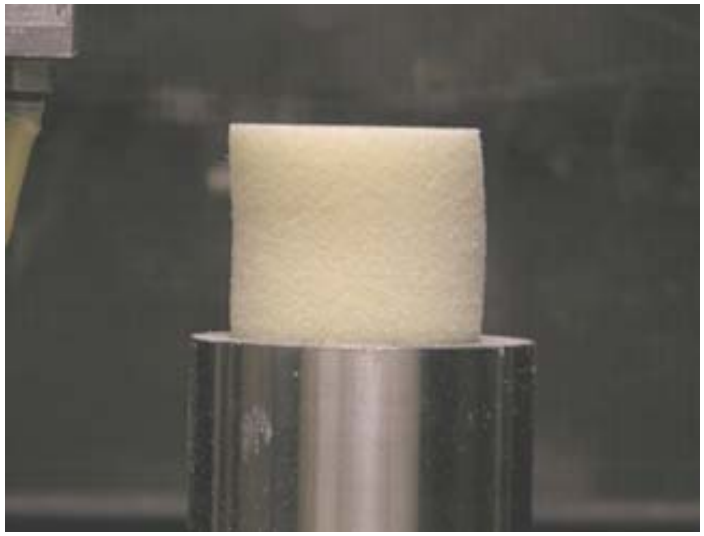
TufFoam foam retains toughness after extended aging

TufFoam Impact Testing-14 Weeks

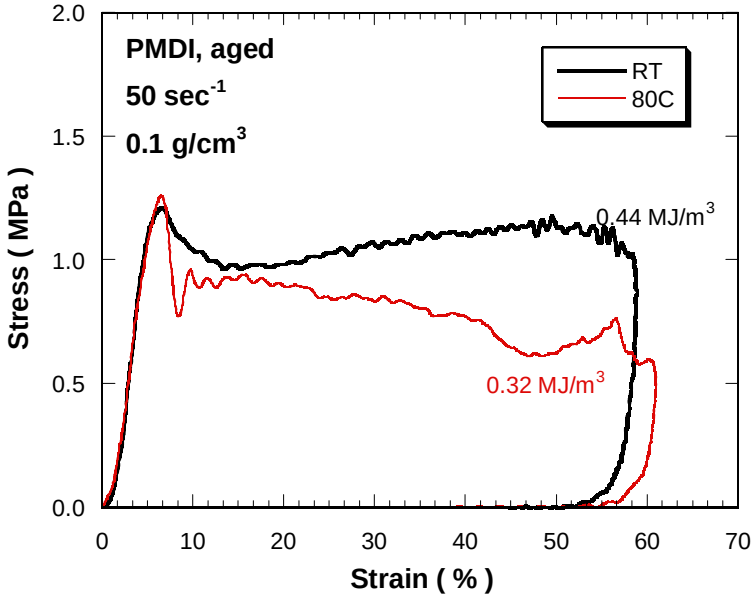


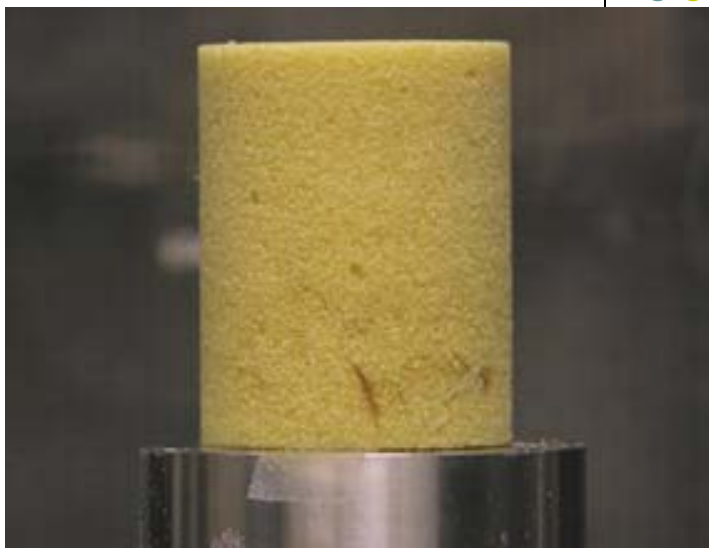


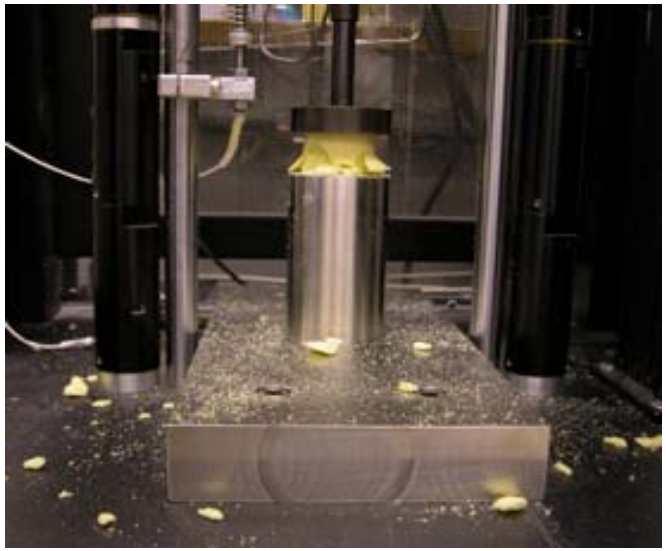


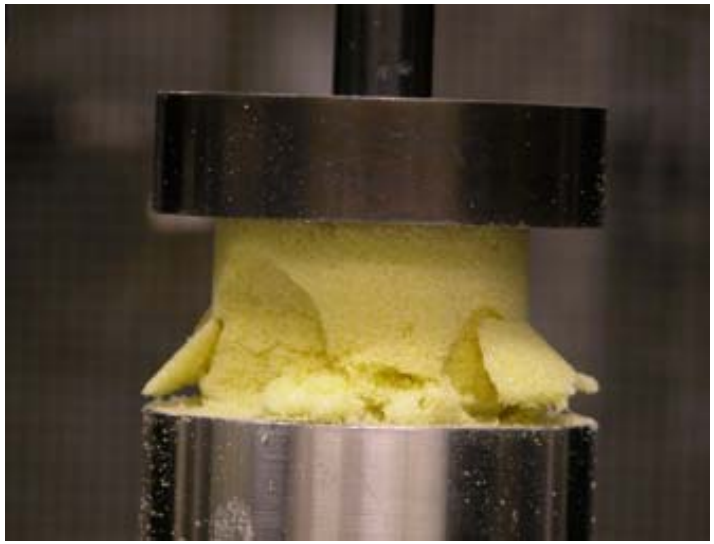


PMDI Impact Testing-14 Weeks



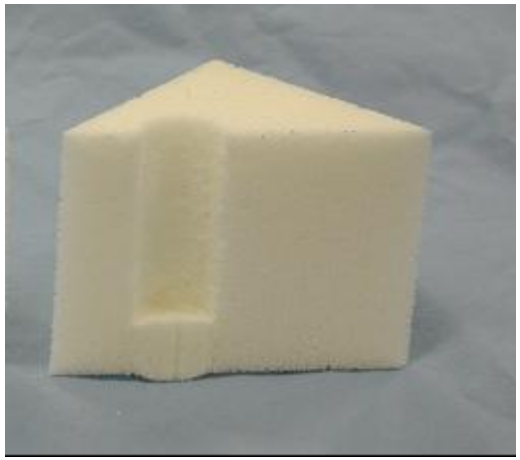






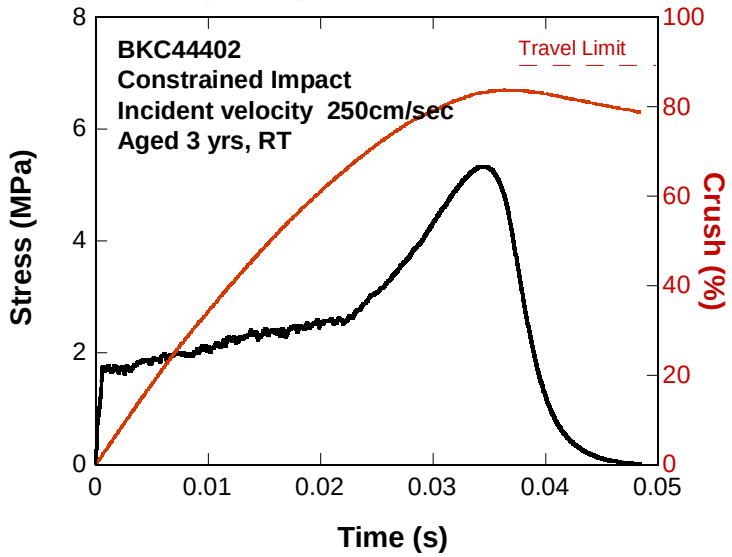
Constrained Impact

TDI

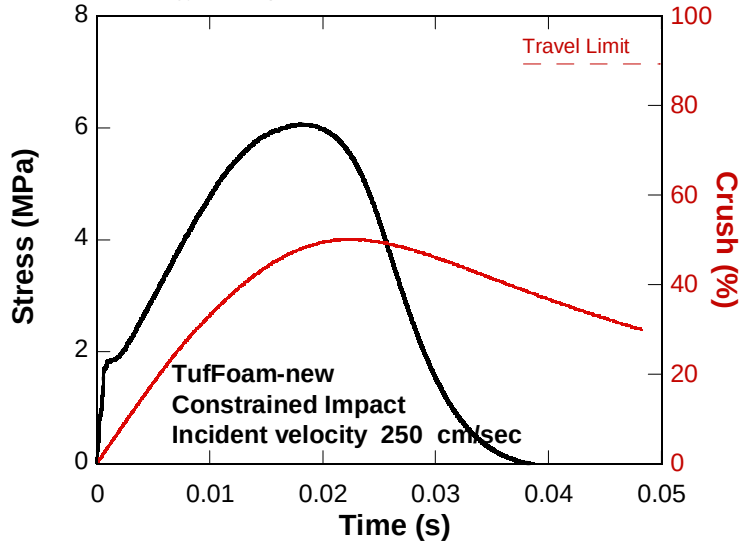


TufFoam

Energy absorption @ 50% = 18.2 J

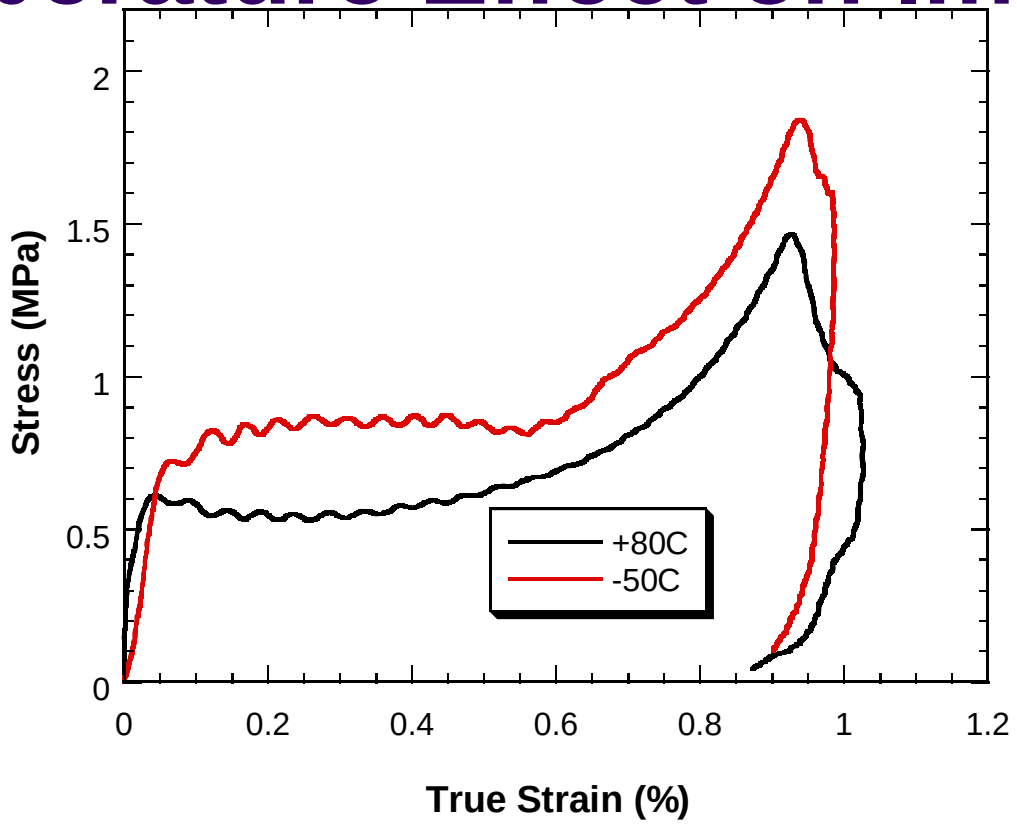


Energy absorption @ 50% = 38.1 J



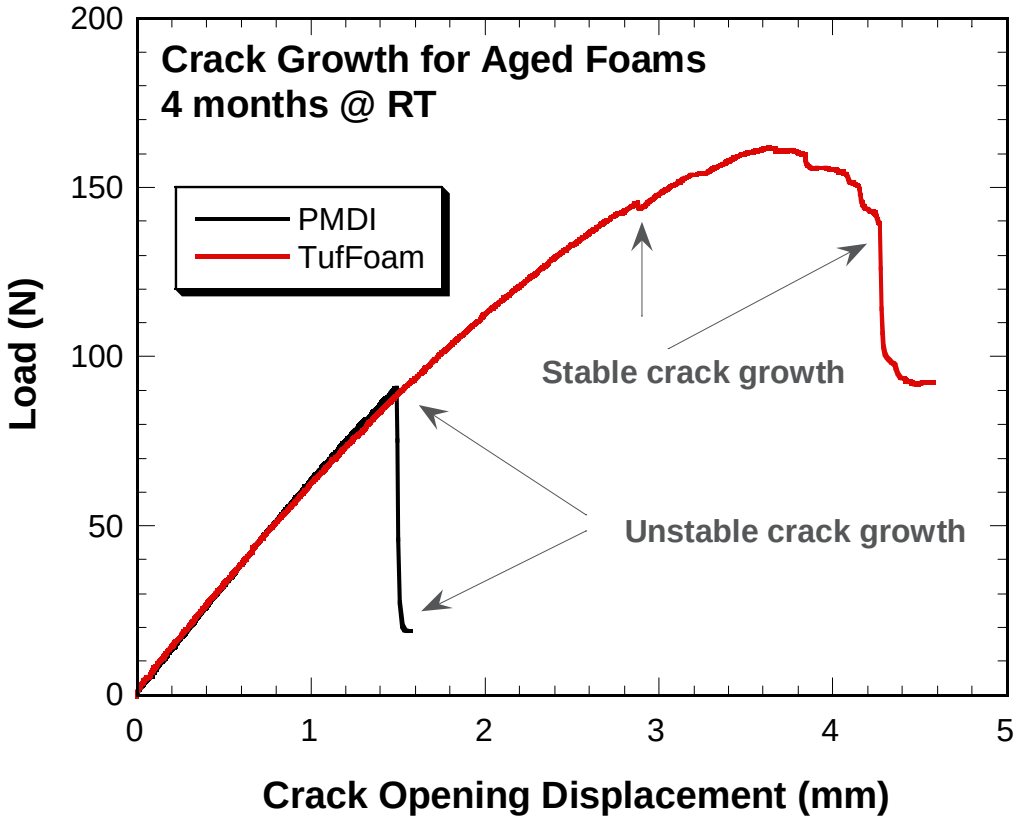
TufFoam spreads the load, limiting the travel of the plunger by approximately half.

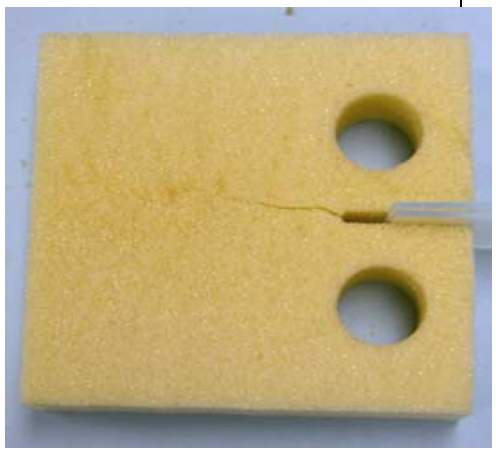
Temperature Effect on Impact



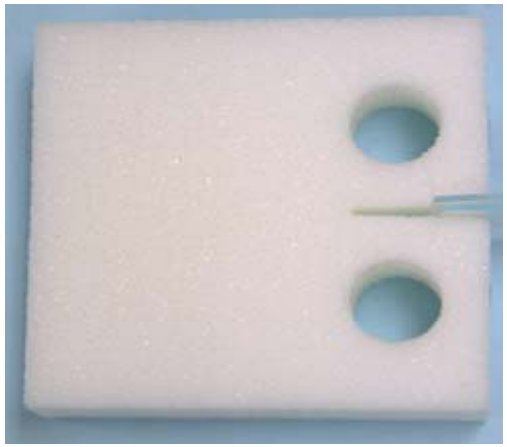
Impact trace shows that TufFoam™ retains its structural integrity at low temperatures

Crack Resistance of Encapsulant Foams, RT aging



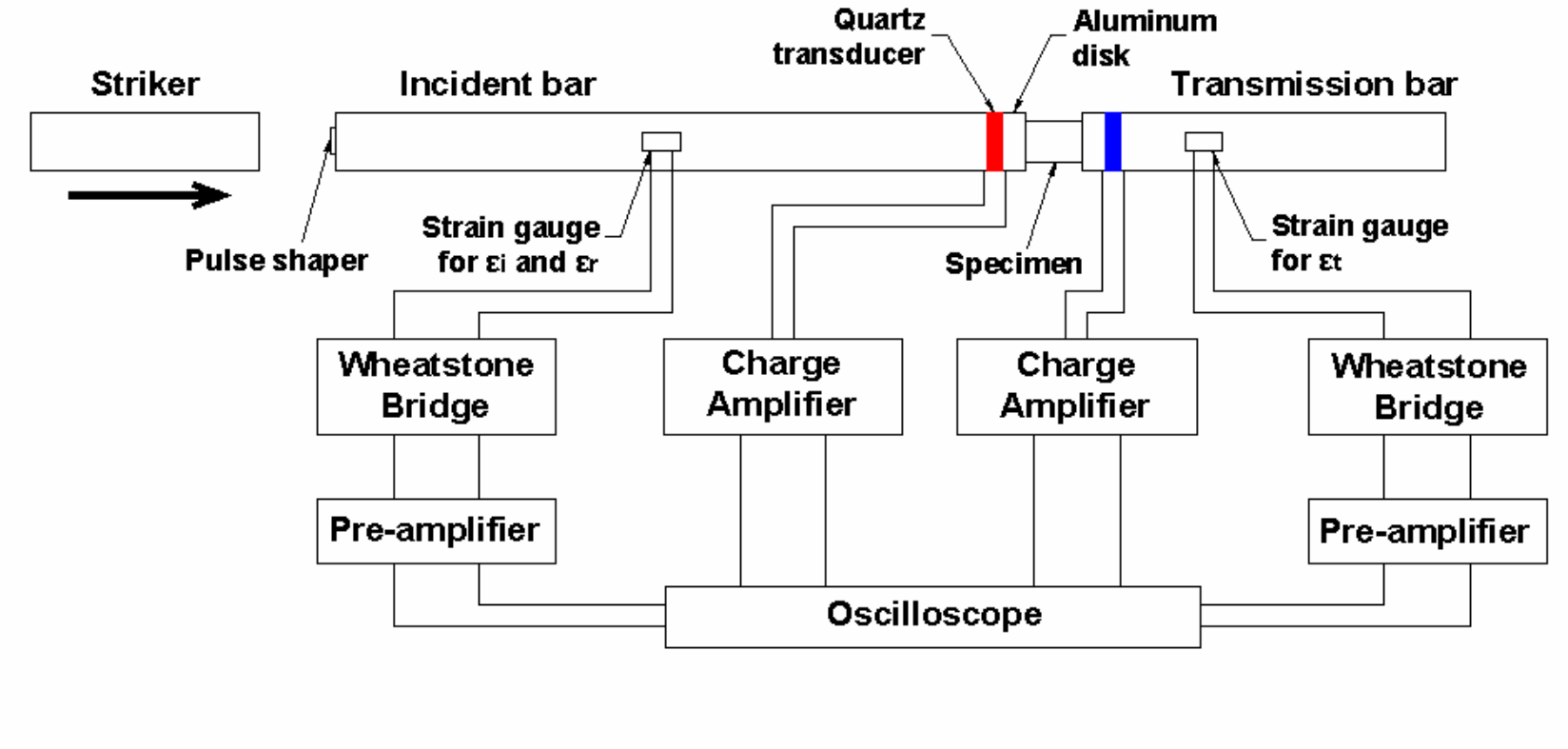


PMDI 4 mos @ RT



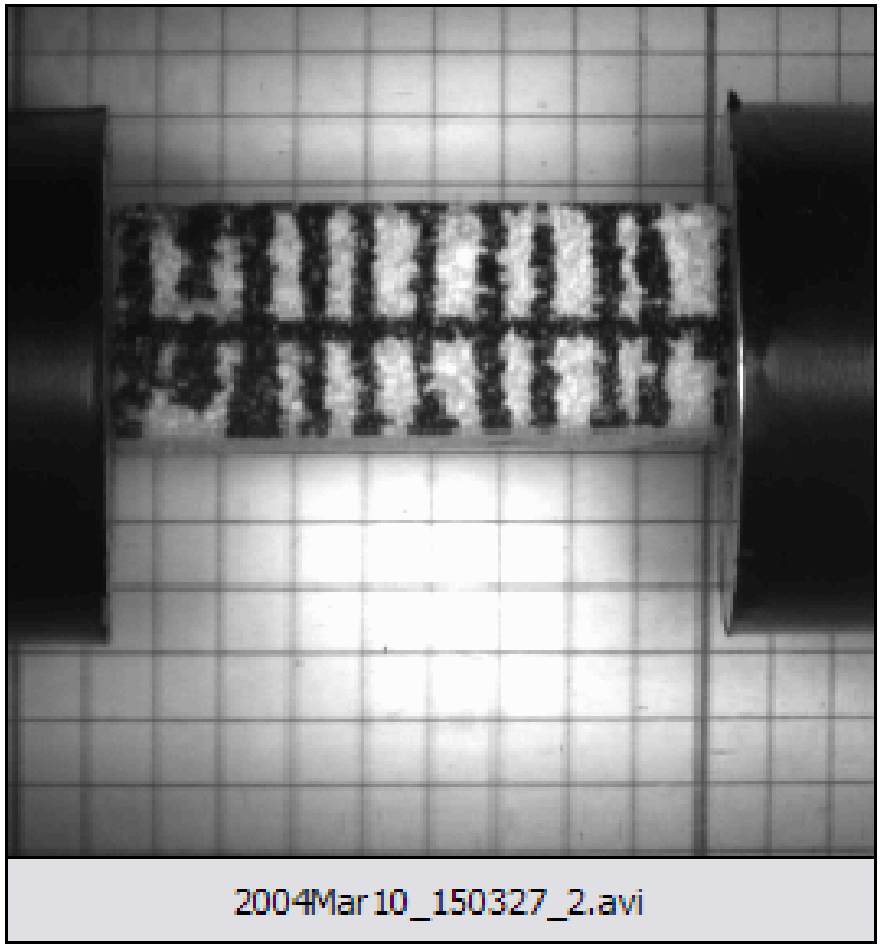
TufFoam @ 4 mos @ RT

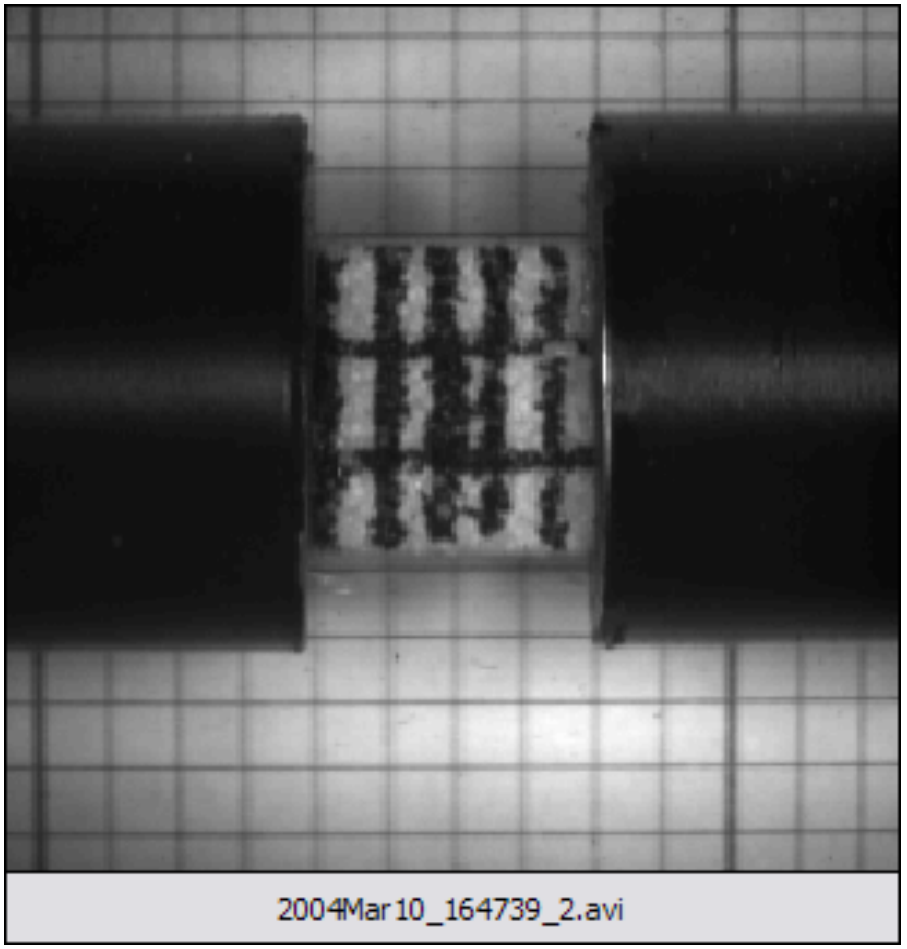
Split Hopkinson Bar Set-up at University of Arizona



High speed compression

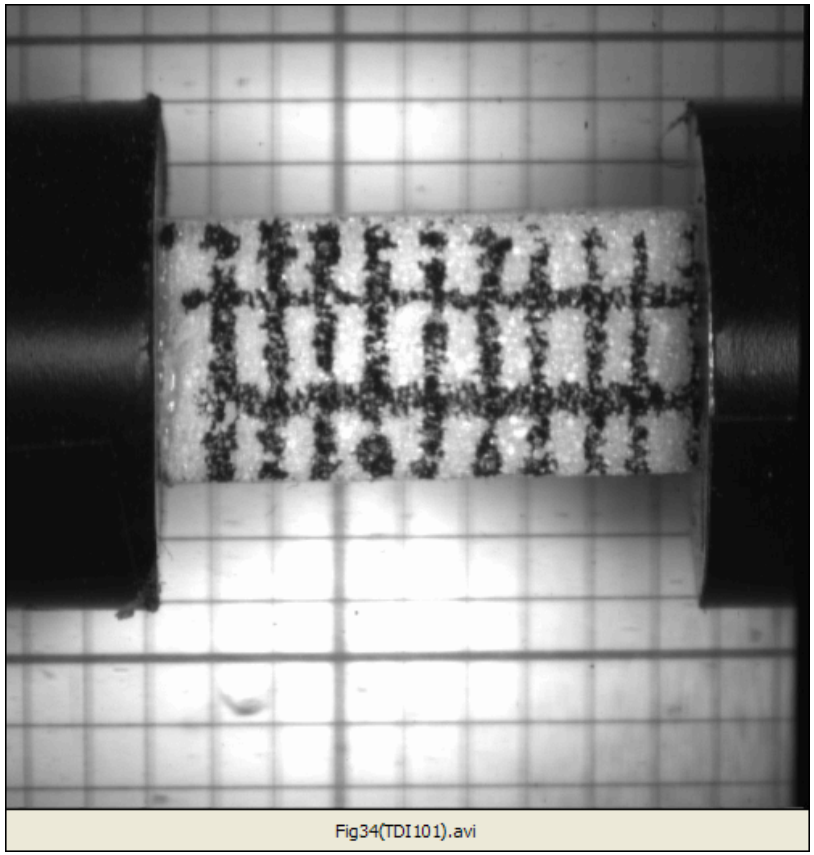
TufFoam



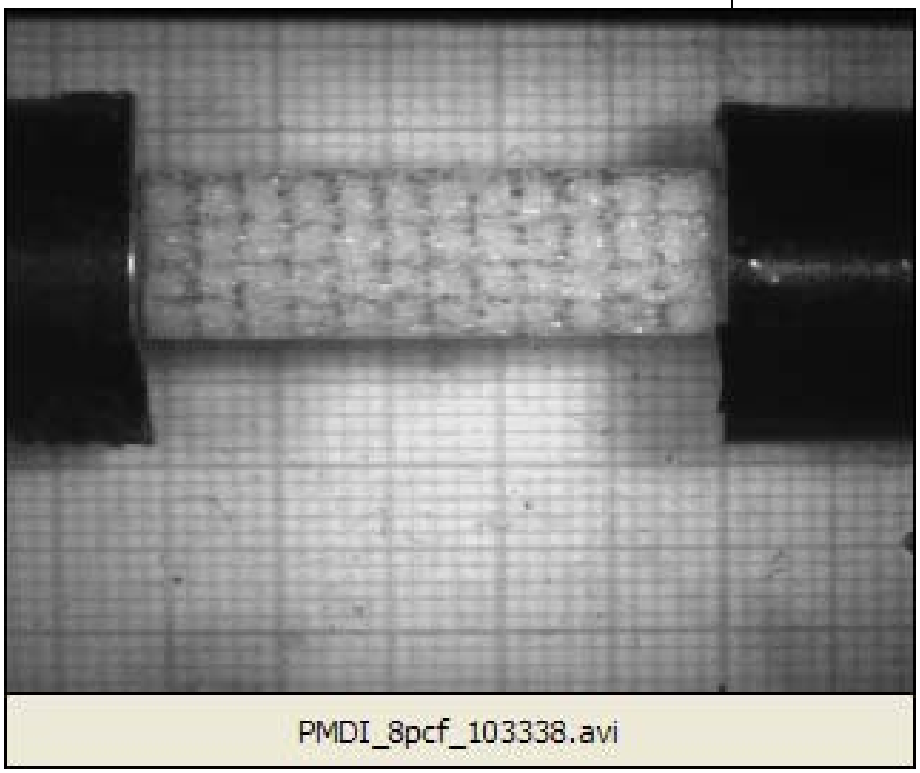


High rate testing performed at the University of Arizona by Prof. Wayne Chen

PMDI exhibits a zone of failure

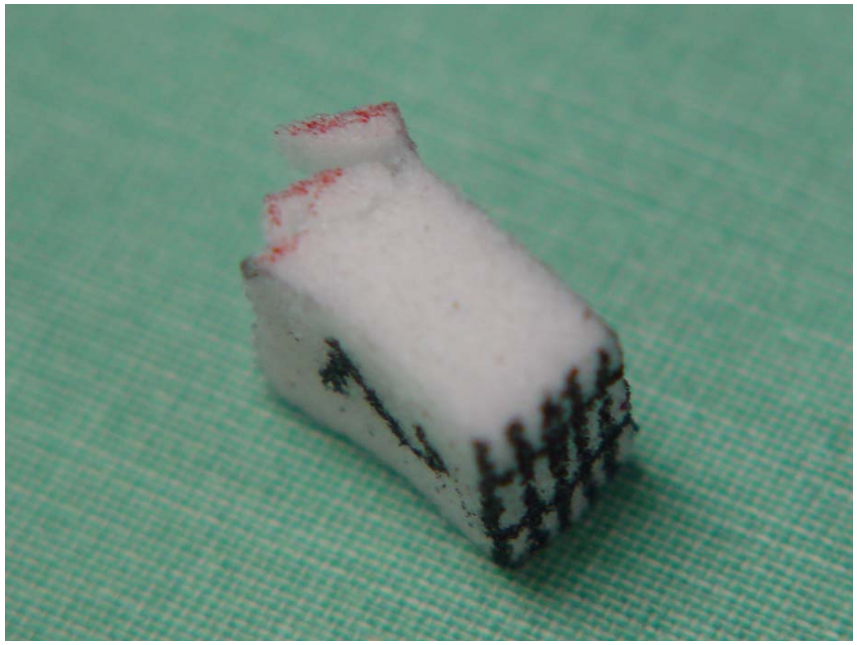


TDI

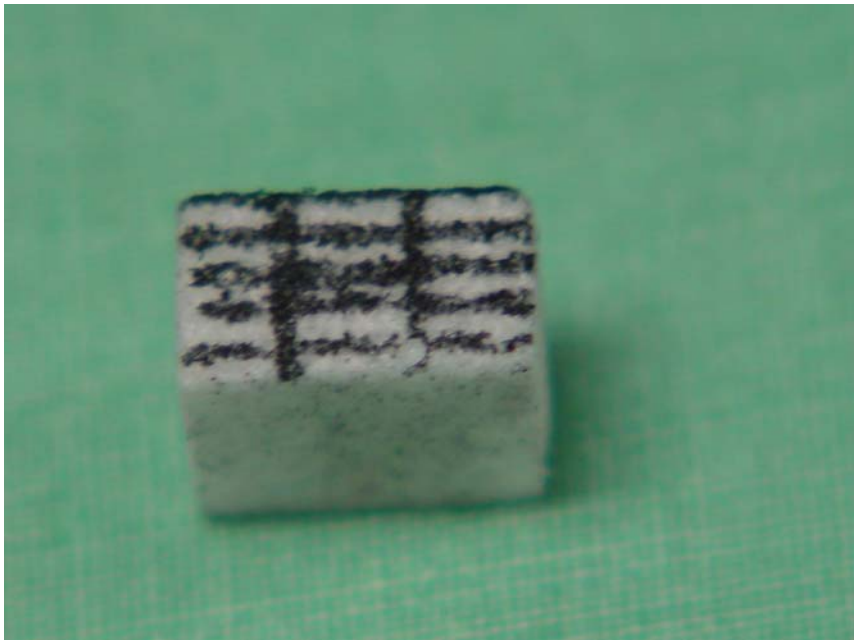


PMDI

After high rate testing



TDI

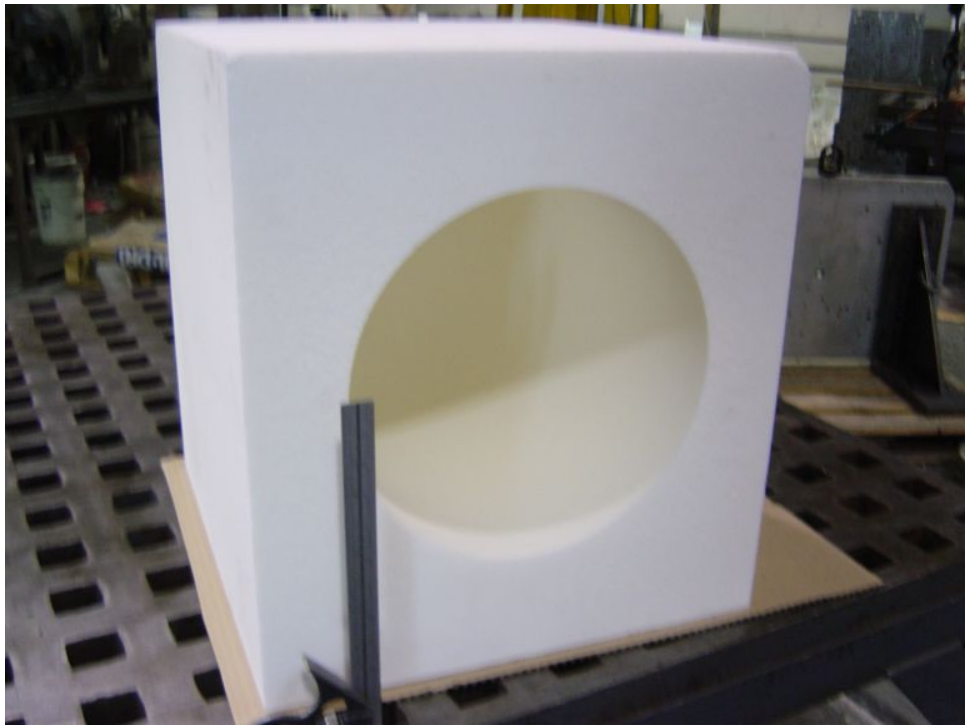


TufFoam

TDI foam shows fractures after Hopkinson Bar testing, while TufFoam remains intact

Blast Mitigation

TufFoam™ is being explored as a blast mitigation material in several applications



TufFoam™ in the News

PHYSORG.COM
SCIENCE, TECHNOLOGY, PHYSICS, SPACE NEWS

Discovery CHANNEL
discoverychannel.ca

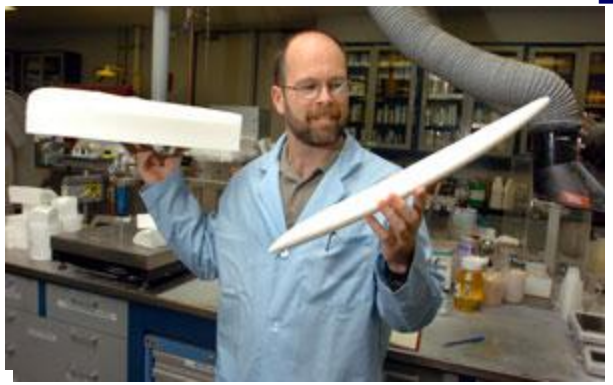
Surf Kultura
diario de un surfista

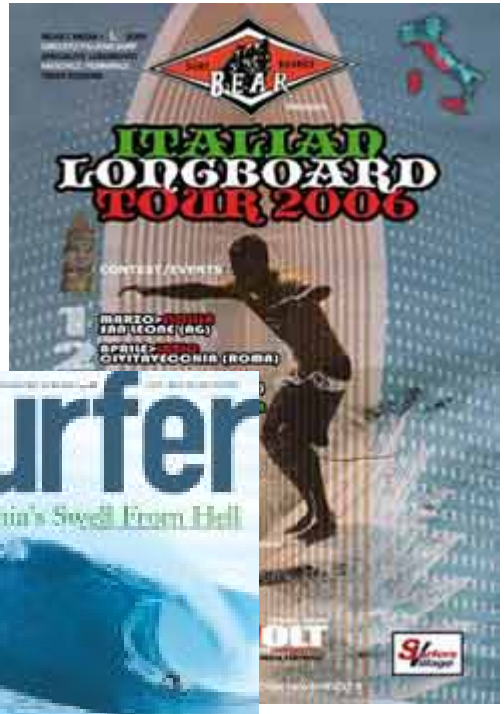
chemicalweek

COMPOSITES TECHNOLOGY

Toxics Use Reduction Institute
Working to Make Massachusetts Safer for Everyone

REUTERS
KNOW. NOW.





ABC NEWSONLINE

YAHOO! NEWS

3rd most popular news story on Fen. 16, 2006

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ContraCostaTimes.com

surfer
Tasmania's Swell From Hell

www.abqtrib.com
STATE

POPULAR science

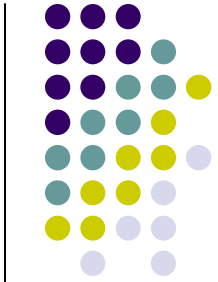
KTVU.COM

Surfboard Foam Blank Requirements & Desires

- ES&H friendly
  - Non-TDI
  - No CFC's
- Inexpensive
- Small cell size
- White
- Non-yellowing over time
- Same processing
- Moldable
- Same mechanical performance as Clark
- Gradients?
- Good adhesion
- Compatible with polyester resin
- Low water absorption

Polyurethane

Foam Comparison



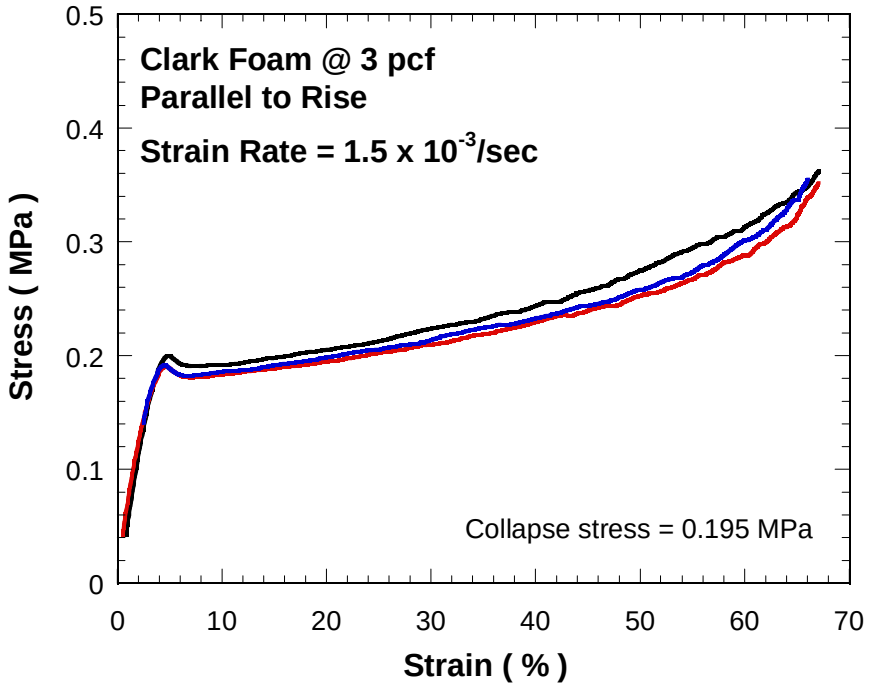
EPS

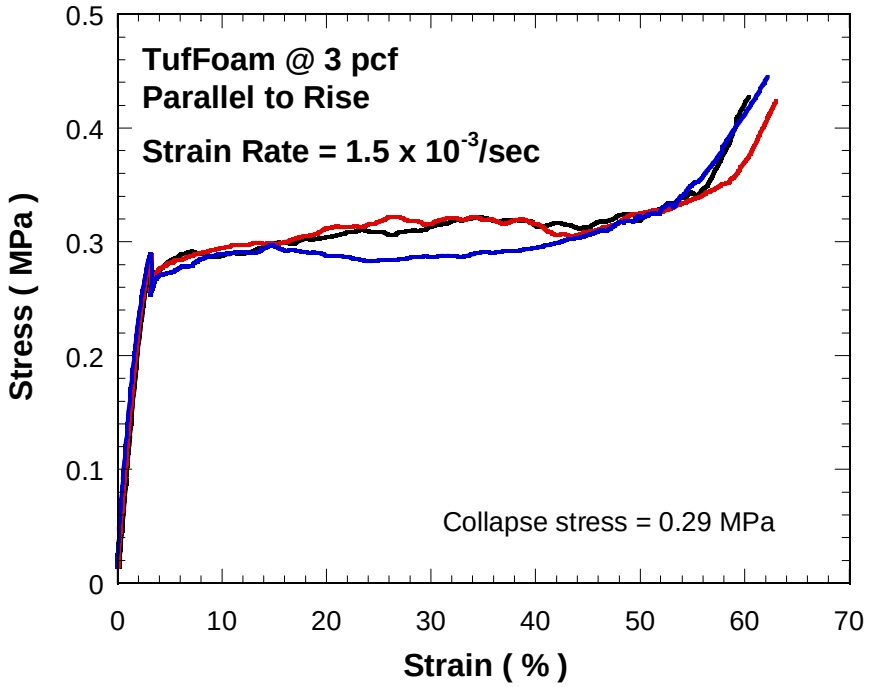
- Costs less
- More work
- Less flex
- Lighter foam, but req. more glass/resin
- Must use epoxy
- Ding resistant
- More brittle

Polyurethane

- More expensive
- Less shaping
- “Perfect” flex
- Heavier foam, but req. less glass/resin
- Polyester or epoxy
- Ding prone
- Break resistant

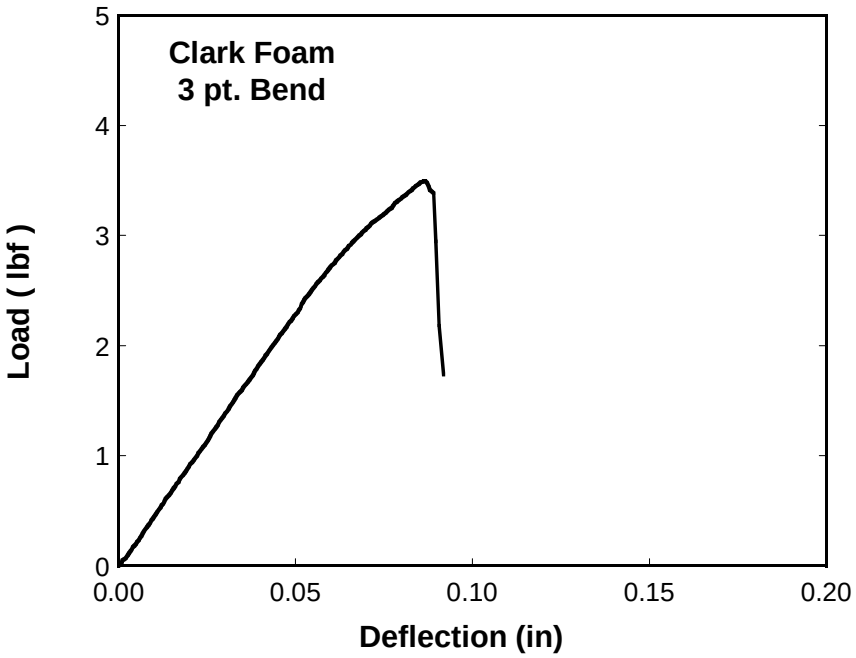
Compression Testing

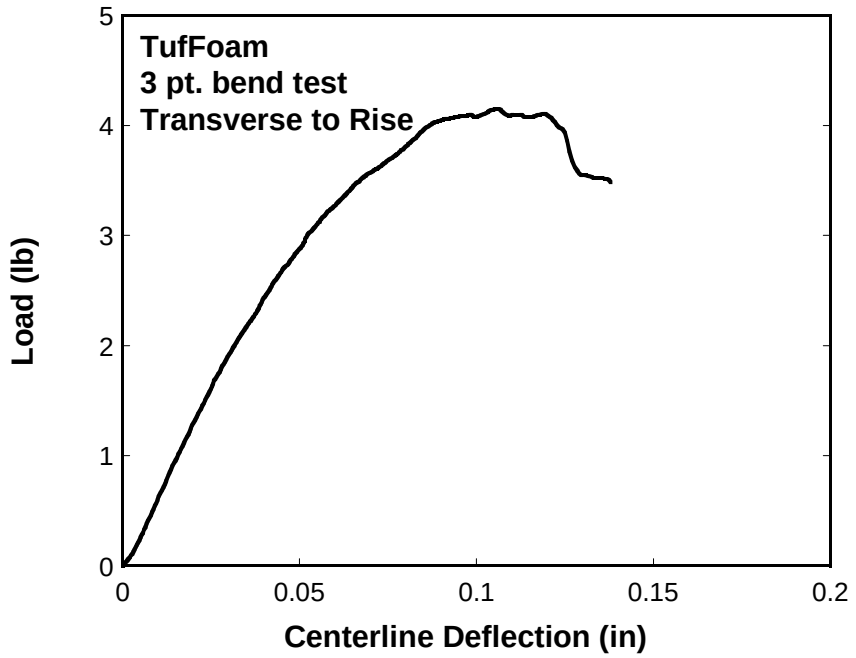




- TufFoam is a little stronger in compression

Notched 3 Point Bend Comparison

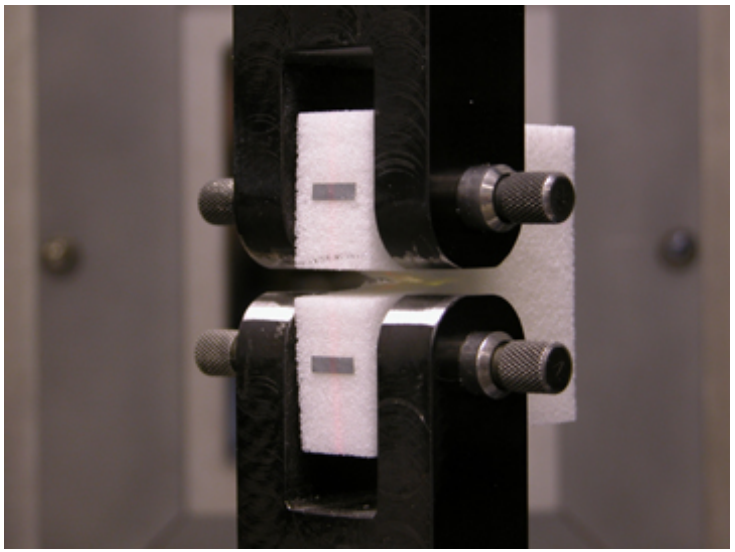


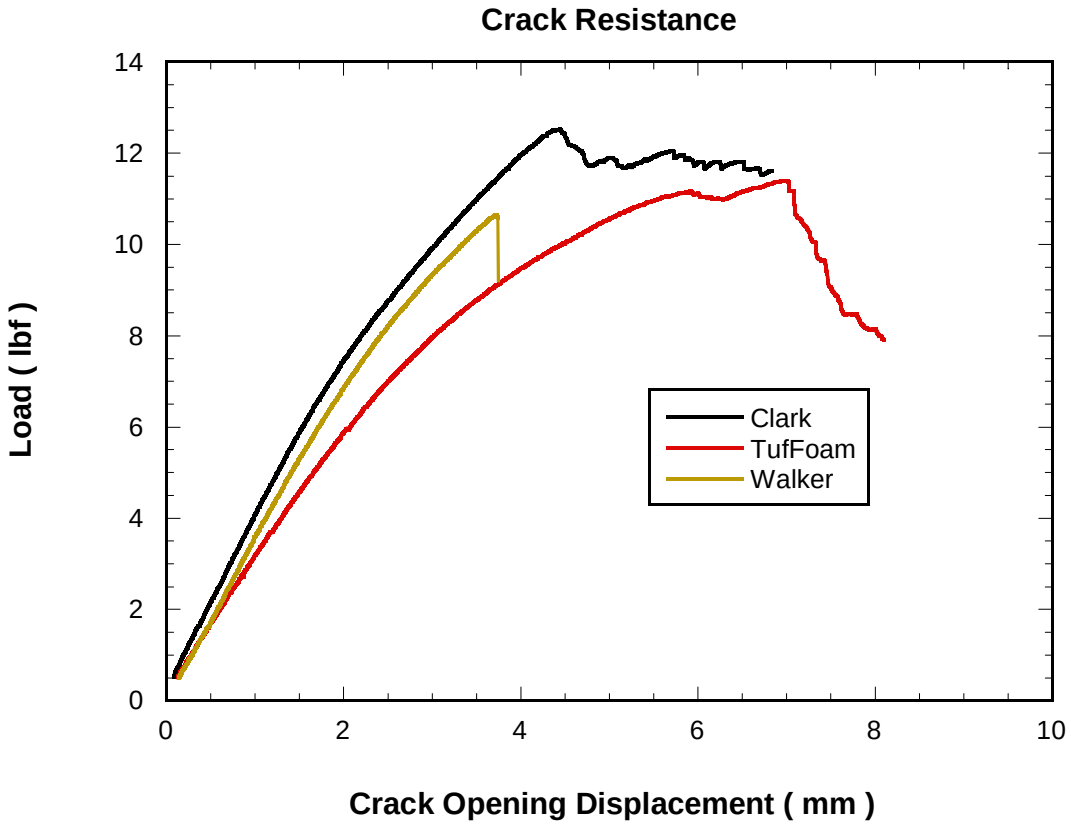


- Clark has a more abrupt failure than TufFoam™

Fracture

- Toughness is the area under the curves





Walker foam is more brittle than Clark or TufFoam

TufFoam Licensing Opportunities

We are currently looking for licensees in these and other fields of use

Structural

- Mechanical
  - Impact mitigation
  - Encapsulation
  - Structural and decorative furniture
- Lightweight core materials
  - Floatation devices
  - Surfboards
  - Boat hulls

Insulation

- Household appliances
- Industrial refrigeration
- Liquefied natural gas (LNG) tanks
- Sheathing and roofing insulation

Summary

- We are working to identify other markets for TufFoam™
- TufFoam™ has a low thermal conductivity especially considering it is CO_2 blown
- TufFoam™ is green
  - does not contain TDI
  - uses water as the blowing agent, not CFC's, HCFC's, hydrocarbons or halocarbons
- TufFoam™ mechanical properties are comparable to Clark Foam™ and better than other potential replacement foams for surfboard blanks.