Investigating Fundamental Toughening Mechanisms in Nanocellular Foams

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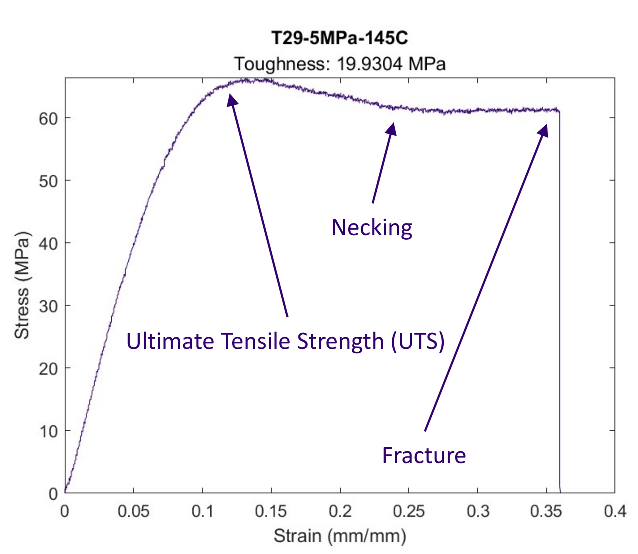
INTRODUCTION

Materials research constantly seeks to enhance the mechanical properties of existing and new materials in order to improve quality, lower costs, and open the door for new applications. Over the past few decades, new materials have emerged: solid state *microcellular* and *nanocellular* foams. These foams were created with weight reduction in mind; the microcellular foams developed in Professor Vipin Kumar's Microcellular Plastics Lab have primarily been used for creating lightweight coffee cups in the past. However, these cups were found to be incredibly tough; they can be crumpled and uncrumpled many times without cracking. This is much unlike other foams, which break under the same conditions. This observation has inspired new research into the mechanical properties of both microcellular and nanocellular foams to understand the material's behavior and therefore be able to develop new applications.

This research is in very early stages and much still needs to be done before testing systems are in place for final data collection. However, preliminary data has been obtained and systems have continued to be developed to ensure reliable data.



Tensile Testing Overview

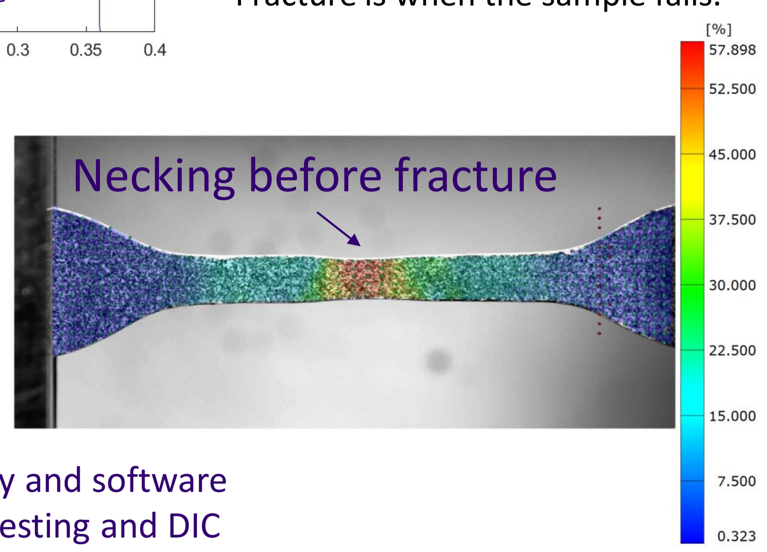
The graph to the left shows a stress-strain curve with important markers labeled.

- UTS is the maximum stress before necking.
- Necking is the reduction in sample width before fracture.
- Fracture is when the sample fails.

psylotech

GOM Correlate

Machinery and software used for testing and DIC

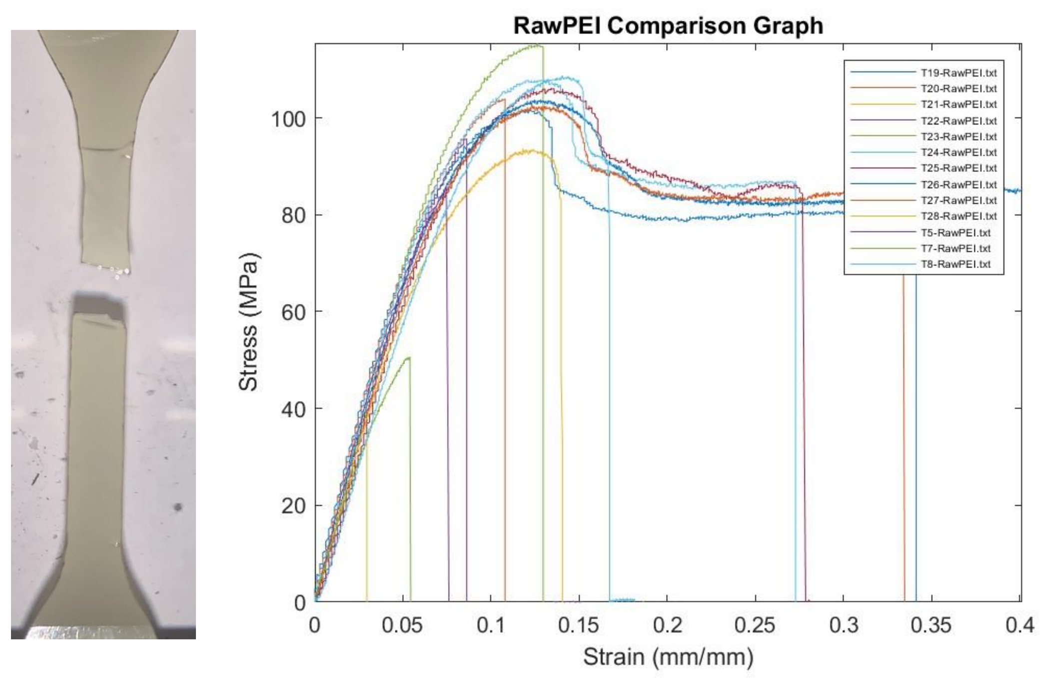


MACROSCALE TESTING

Many tensile tests have been performed, but not with consistent testing standards. Sample quality is incredibly important to ensuring that testing data is usable, but producing good samples can be difficult. When running tensile tests, small cracks or roughness along the edge of a sample can cause premature failure during testing. This is an issue that has been very prevalent in our testing, deeming many of our earlier samples unusable for data analysis.

However, recently created samples have yielded promising results, showing necking and sometimes Luder bands during tensile testing. Luder bands are the result of localized plastic deformation during necking. The sample in the photo below shows both necking and Luders bands and is accompanied by a graph comparing the stress-strain curves for different unfoamed PEI samples.

Stress-Strain Curve for Unfoamed PEI Samples



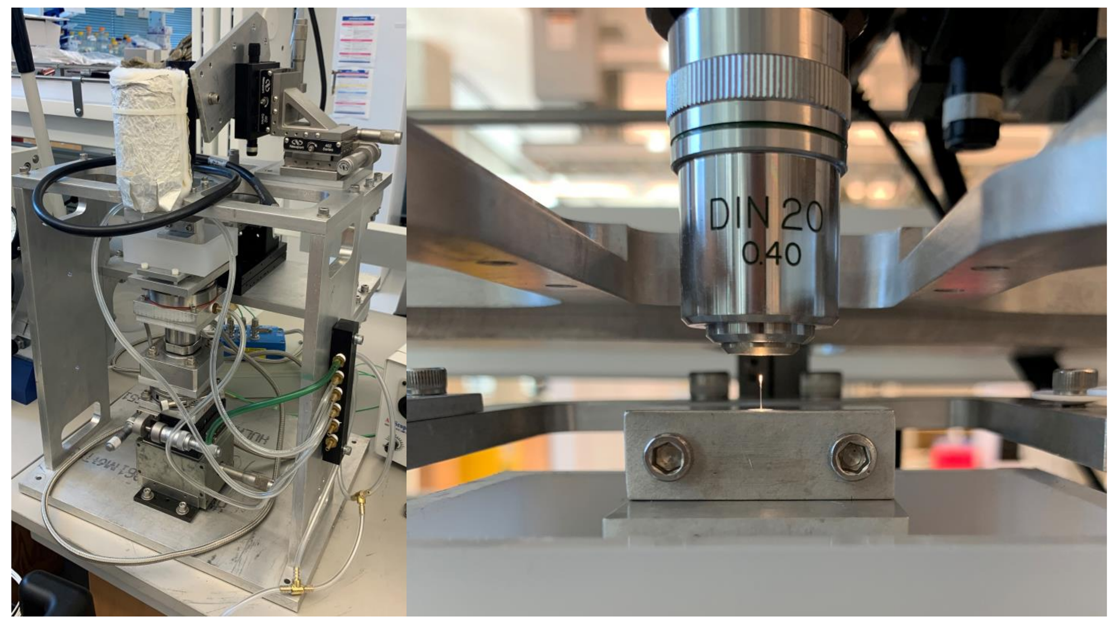
MICROSCALE TESTING

Microscale testing seeks to isolate microstructures within nanocellular foams and determine the mechanical properties of that structure in order to obtain a better understanding of what is causing macroscale trends. Obtaining samples for microscale testing requires two main steps: microtoming and microstamping.

Microtoming is the process of taking a sample and creating 0.5-100 micrometer thin slices of its cross section. It opens up the material and reveals its microstructures, but can also cause the slices to curl. Work is currently being done to reduce this curling and create flat microtomed samples.

After microtomed samples have been made, a small punch and die can be used to create **microstamped** samples of different microstructures. This is done using a microstamping device which was designed and created by Eric C. Schmitt for their masters thesis at Tufts University. The design and process flow for this machine is being altered in order to operate more smoothly.

Microstamping



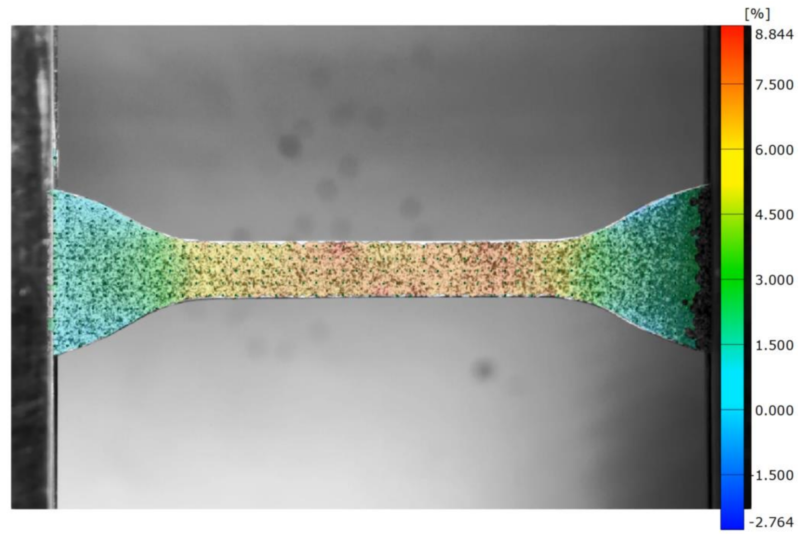
Tufts University Microstamp & Microstamping Pin

DIGITAL IMAGE CORRELATION

Digital image correlation (DIC) is a method of measuring engineering strain on a material and can be used to develop a strain field from the beginning to the end of a mechanical test. For our purposes, DIC will be used to account for both machine and human error that exists for tensile tests. Samples for tensile tests are held in clamps while they get pulled in tension, but the samples will have an amount of slippage that shows up in strain values that come directly from the load frame. Since it uses computer image correlation software to produce strain values, DIC is a great alternative to load frame data for strain.

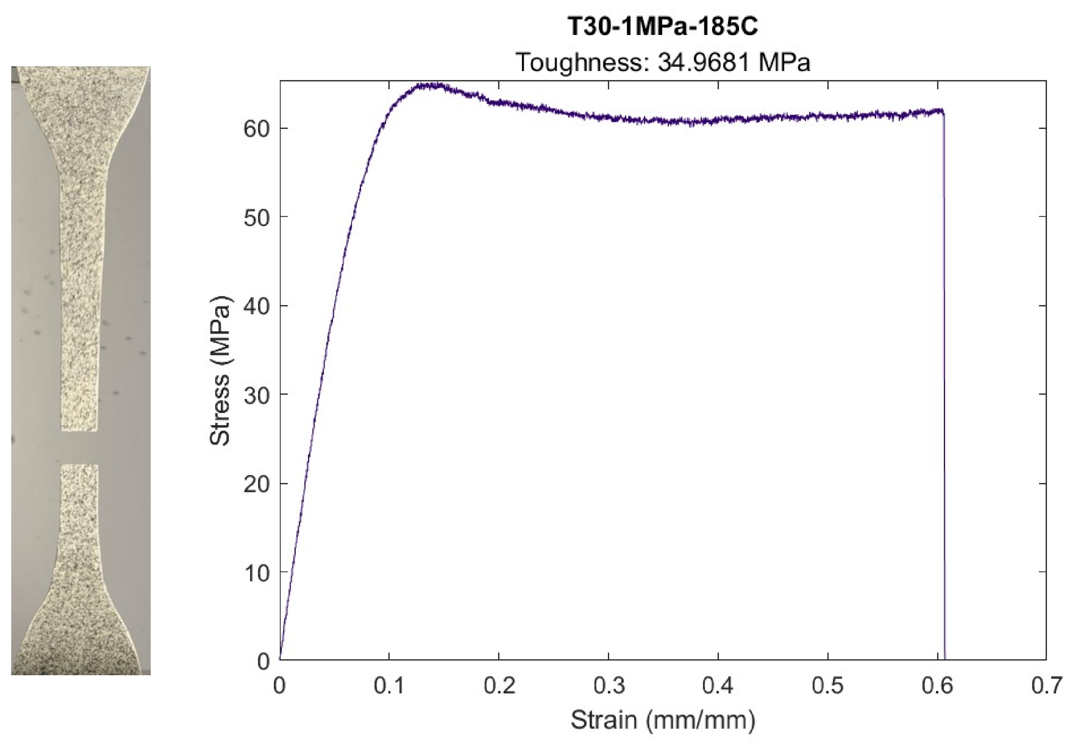
DIC works for samples that have been prepared with speckle patterning. For this application, we used spray paint to produce dots on the sample surface. During tensile tests, images of the sample are taken in even increments and the position of the sample's dots can be tracked over time using correlation to generate strain values at each point.

SCAN ME



The color bar on the right side shows the % strain on the material at respective points in the x-direction for sample T30-1MPa-185C. Positive values indicate that the material is in tension, while negative values indicate that the material is in compression. Sped up videos are available for T29-5MPa-145C and T30-1MPa-185C at the QR code link.

Stress-Strain Curve for T30-1MPa-185C



CONCLUSION

As previously mentioned, this project is in early stages of development. On the macroscale testing end, next steps include the testing of different sample preparation methods to reduce defects that cause premature sample failure as well as analysis of data from Digital Image Correlation. Microscale testing will require continued improvement to sample preparation as well. Current machining processes are inefficient and ineffective in producing the flat isolated microstructures needed for nanomechanical testing. Lastly, additional information about samples must be collected using scanning electron microscopy (SEM) images to understand how the structure contributes to mechanical properties.

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Supporting Labs

MMRG

Multiscale Analysis of Materials & Structures Lab

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All photos and figures are my own. DIC images were produced using GOM Correlate software and other graphs were made using my own MATLAB code. Logos belong to their respective organizations.