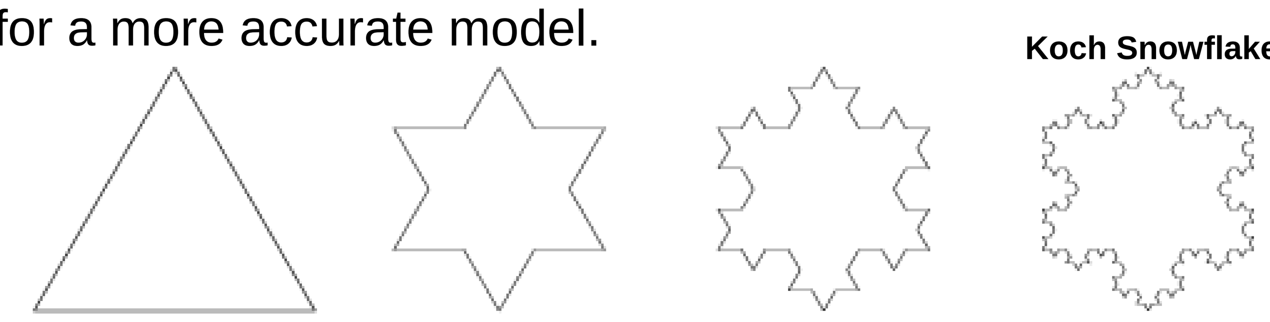
# Fractal Behavior of Smart Materials

Hannah Solheim, Eugenia Stanisauskis, Wei Gao, Paul Miles, and William Oates
In collaboration with Zhe Liu and Changchun Zeng

## Introduction

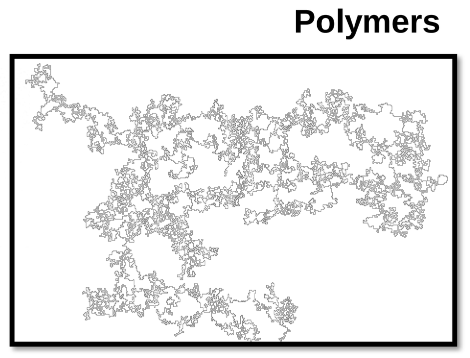
Active structures allow for real time control of a structure's shape, stiffness, and damping. Accurately characterizing the mechanical response of smart materials enhances their implementation into active structures. Research was conducted to determine whether the fractional order of a material corresponds to measurable physical properties for a more accurate model.



Koch Snowflake [1]

Shorelines [2]

Flowers [3]



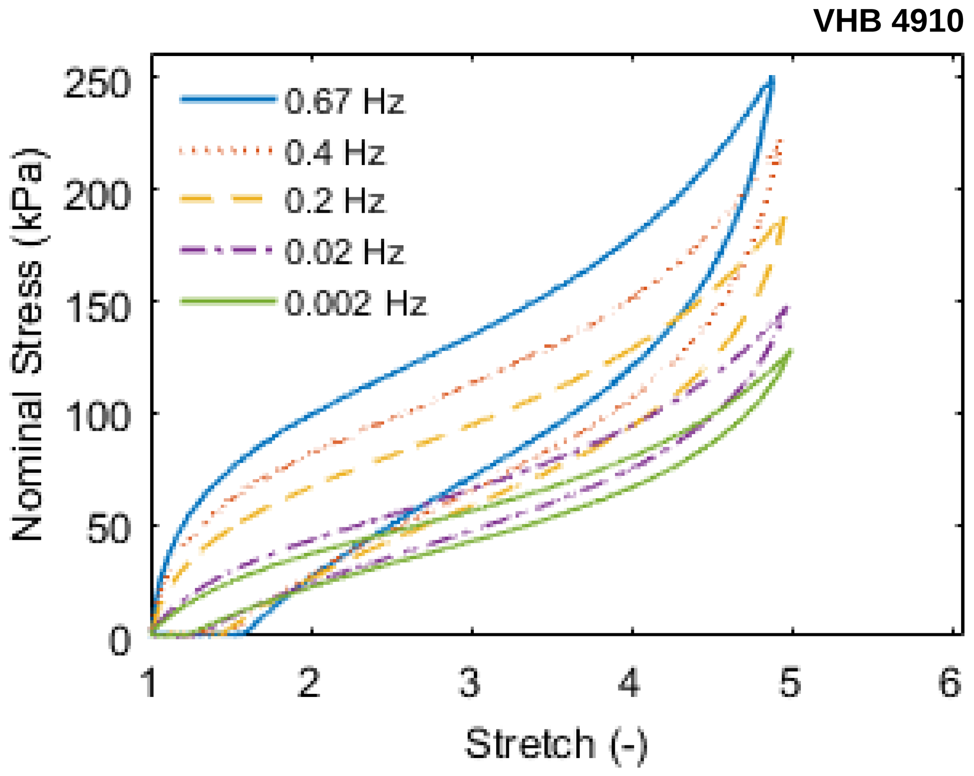
Polymers

Fractals are self-similar recursive patterns often found in materials and nature.

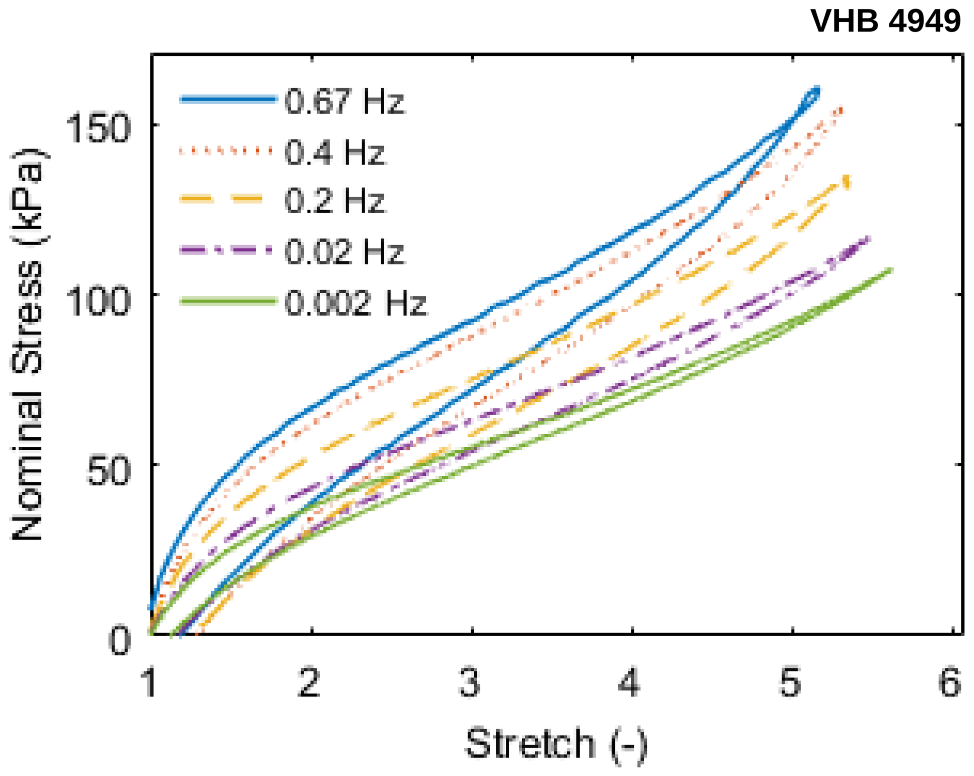
## Experimental Methods

Very High Bond (VHB) 4910, VHB 4949, and a set of auxetic foams were subjected to cyclic uniaxial loading and unloading stress tests at different stretch rates to achieve steady state hysteresis.

VHB 4910

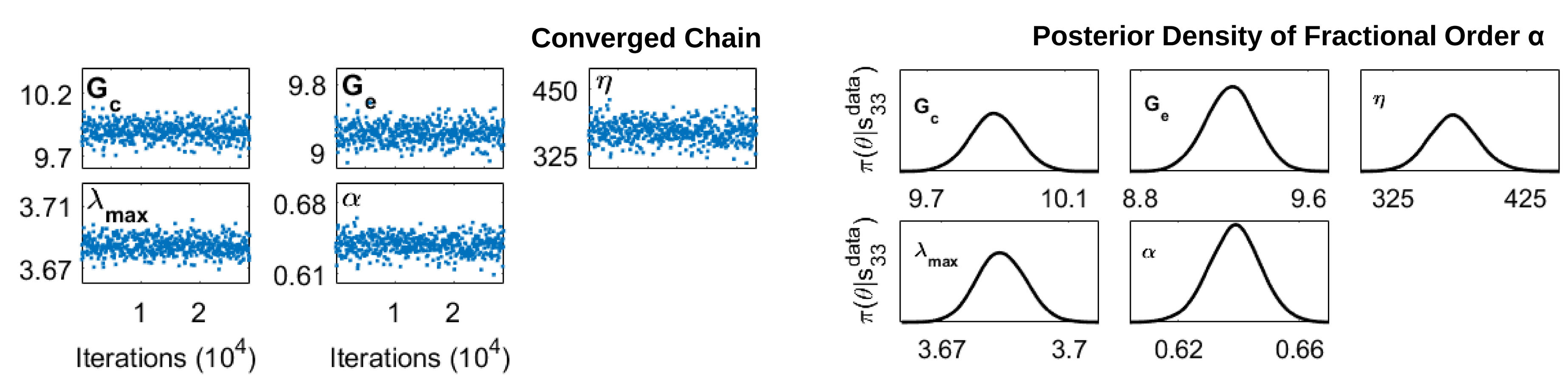



VHB 4949

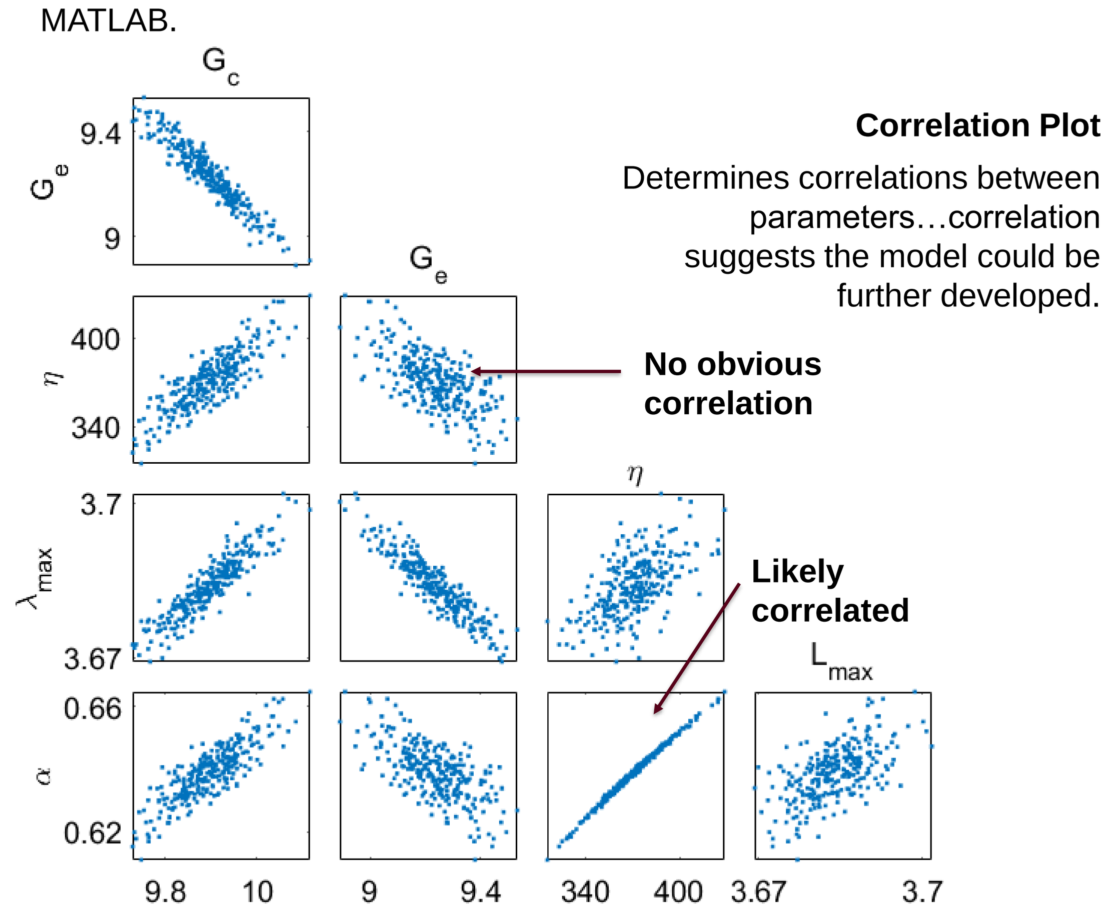


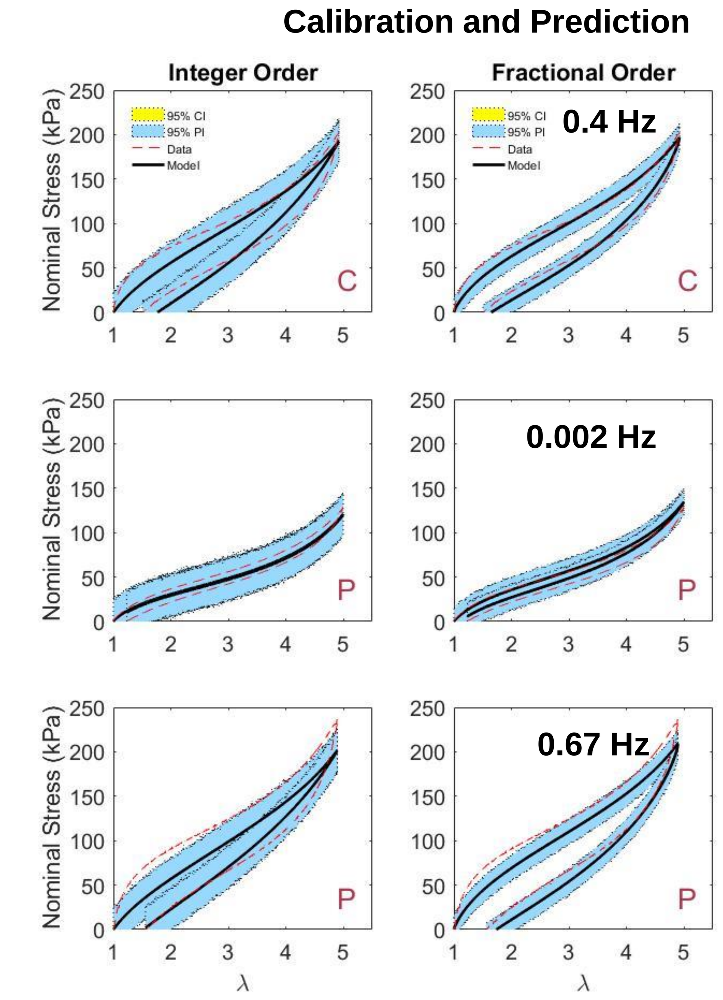

VHB 4910 and VHB 4949 are foam materials developed and sold by manufacturing company 3M.

Fractional order model for VHB 4949 uncertainty analysis results.




Chains developed using MCMC and DRAM algorithms in MATLAB.

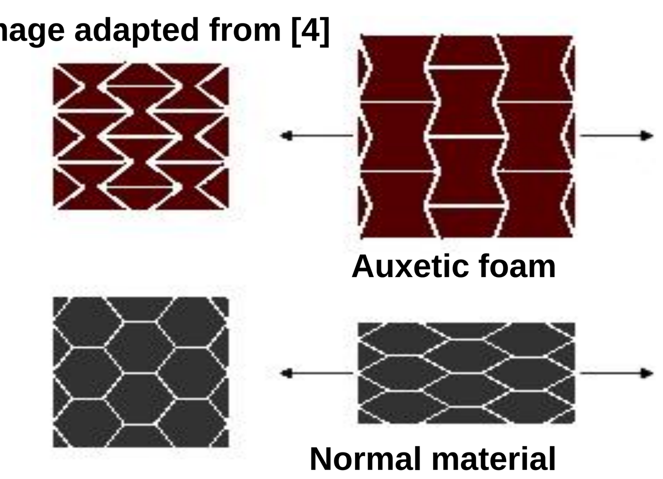


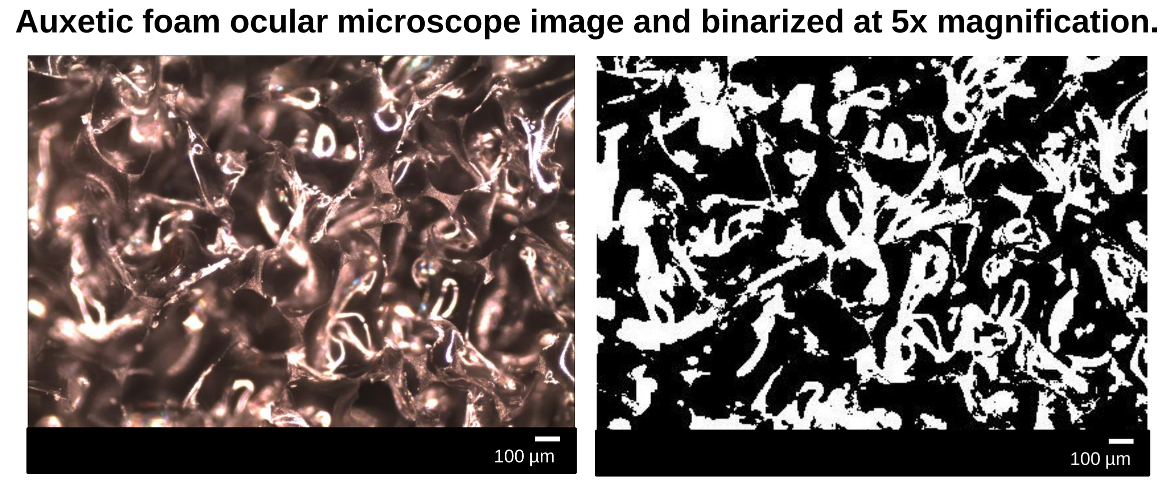

Stress responses collected in the uniaxial tests were used to inform an integer order and fractional order model using Bayesian uncertainty methods. The informed model was used to predict responses at different orders of magnitude. Greater prediction accuracy was obtained when using the fractional order model. Similar predictions were found for materials VHB 4910 and VHB 4949.

Continuing work aims to develop a model for the auxetic foam materials. The model is developed using thermodynamic principles and measured properties. Fractal dimension was quantified through determination of the Minkowski–Bouligand dimension of the images using a *boxcount.m* MATLAB routine.

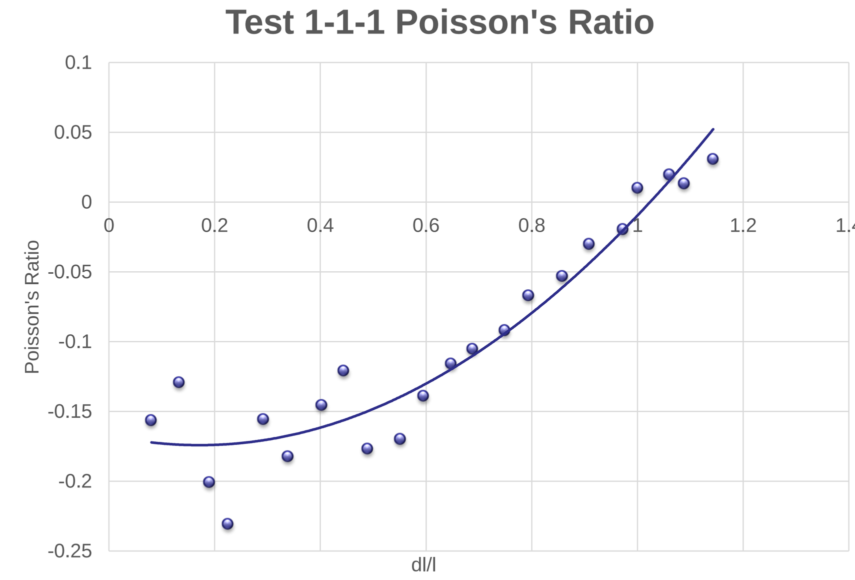
Image adapted from [4]

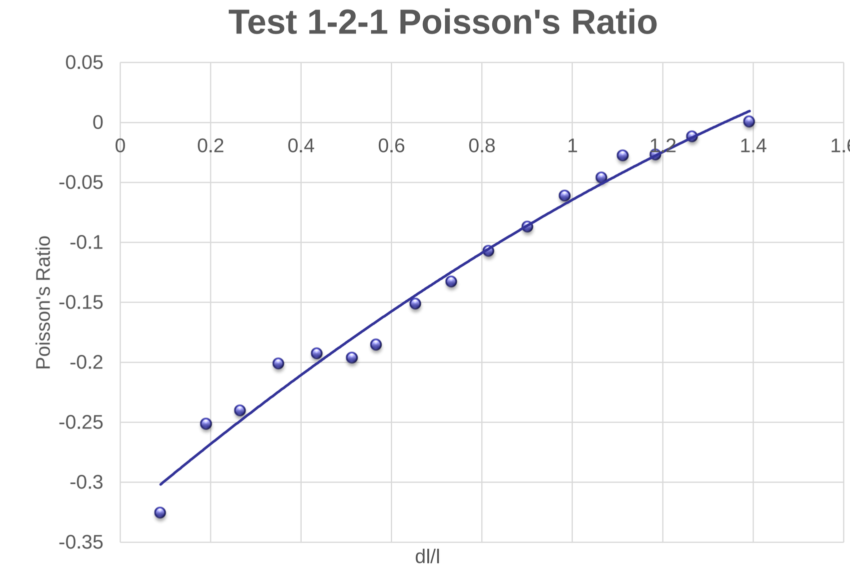



Auxetic foam ocular microscope image and binarized at 5x magnification.



Auxetic foams are known their negative Poisson's ratio. This was measured to better inform the model. Two materials' test results are shown.

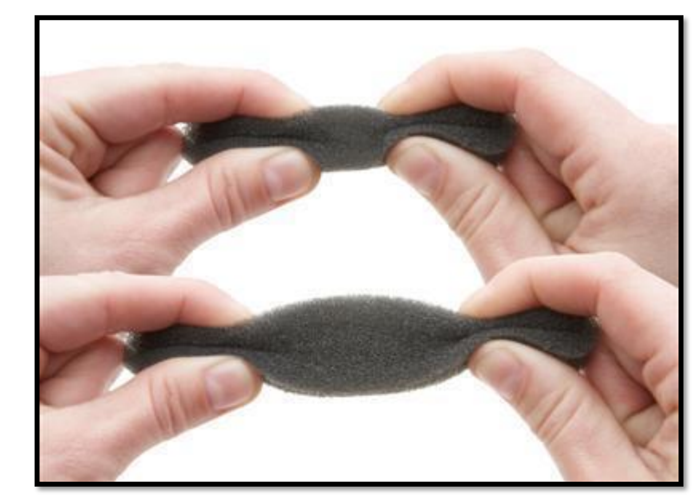



## Conclusions

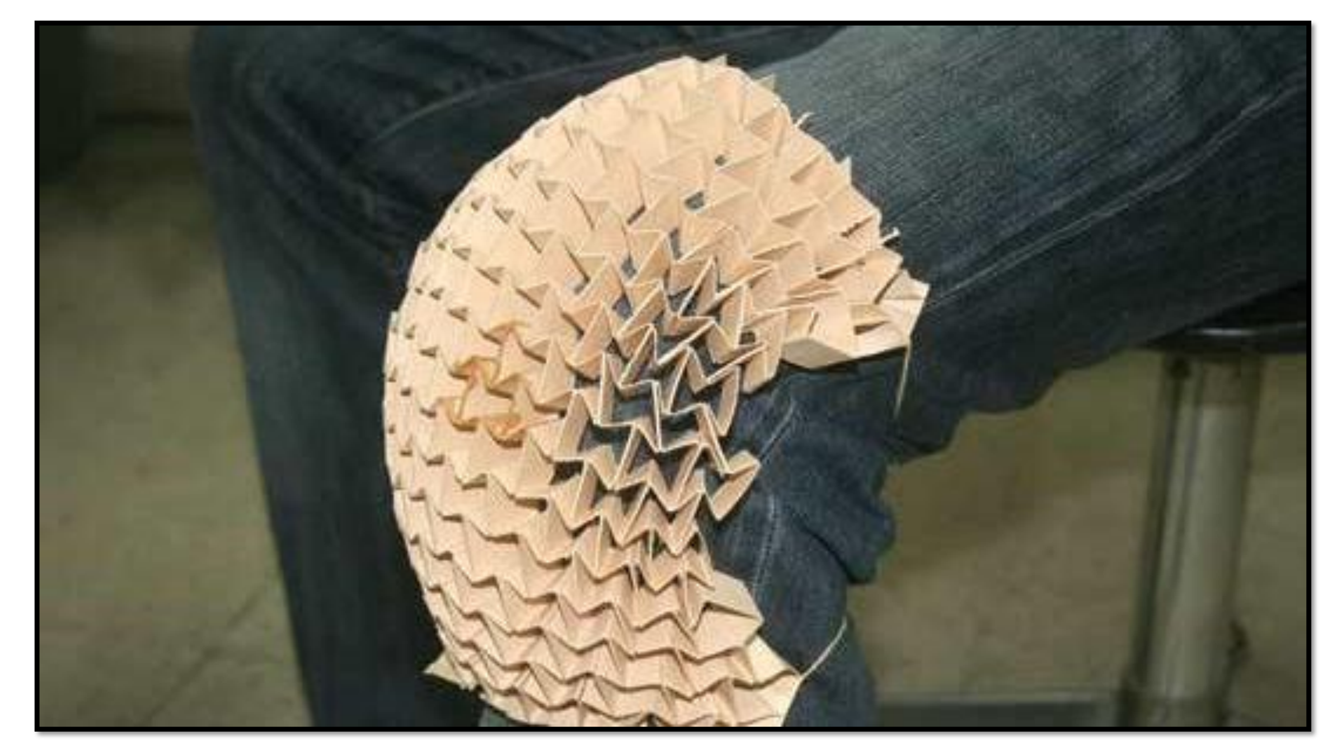
There is a potential relationship between a material's mechanical properties and its fractal structure. Implementing fractal order mathematics to model these materials could be useful in consideration of sensors, structures, and product development in the fields such as impact absorption and water filtration.

Better classification of these materials through determination of fractal properties could enhance design of products and structures utilizing materials with complex structures.



Negative Poisson's Ratio [5]

Sole Cushioning [4]



Impact Absorption [6]

## Acknowledgments

Special thanks to Wei Gao, Paul Miles, and William Oates for their guidance and mentorship. Thank you to Zhe Liu and Changchun Zeng for their collaboration and assistance.

This work is supported by the National Science Foundation under grant No. 1560337.

[1] Weisstein, Eric W. "Koch Snowflake." From MathWorld--A Wolfram Web Resource. http://mathworld.wolfram.com/KochSnowflake.html
[2] Stewart, Kevin. "Lake Mead." From Pilot. http://ukga.com/photos/view?contentId=12901
[3] Teleflora "Meaning & Symbolism of Aster." http://www.teleflora.com/meaning-of-flowers/aster
[4] Enright, Rachel. "Unconventional Materials - Auxetic Foams." From Bayly. http://www.bayly.com.au/news-about-the-product-and-industrial-design-industry/38-news-about-the-product-and-industrial-design-industry/300-unconventional-materials-auxetic-foams
[5] Zoontjens, Ralph. http://createyourcosmos.blogspot.com/2010/11/new-materials-for-industrial-designers.html
[6] TimesofMalta. https://tinyurl.com/y8jq6cvp