2020 Midwest Graduate Student Society for Experimental Mechanics (SEM) Symposium

Oral Presentation Abstracts

March 7, 2020 (Saturday)

Keynote Presentation

Dr. Christian Franck
Grainger Institute for Engineering Associate Professor
PANTHER Program Director
Department of Mechanical Engineering
University of Wisconsin-Madison

Abstract Title: Emerging Interface Problems in Soft Matter, Cell and Neuromechanics – Concussions and Traumatic Brain Injury

Abstract: Current prediction, prevention and diagnosis strategies for mild traumatic brain injuries, including concussions, are still largely in their infancy due to a lack of detailed understanding and resolution of how physical forces give rise to tissue injury at a cellular level. In this talk I will present some recent work on our current understanding of the origin of concussions and traumatic brain injuries and how cells in the brain interpret and react to the physical forces of trauma. Specifically, I will show that the path to a better understanding of traumatic injuries involves addressing a variety of soft matter and cell mechanics problems along the way. Finally, I hope to motivate and propose some solutions on how we might improve our prevention and diagnosis of these injuries by working together across disciplines.

2020 Midwest Graduate Student Society for Experimental Mechanics (SEM) Symposium

March 7, 2020 (Saturday)

Afternoon Session I

1. **Jenny Marsh**
   Iowa State University
   Advisor: Dr. Sarah A. Bentil

   Abstract Title: The Role of Ionic Concentration in Shock Wave-Induced Fluid Cavitation

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2. **Shalini Raj Unnikandam**
   Iowa State University
   Advisor: Dr. Ian Schneider

   Abstract Title: Viscoelastic Properties of Tumor-Mimicking Hydrogels Regulate Cancer Cell Migration and Extracellular Matrix Remodeling

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3. **Soheila Shabaniverki**
   Iowa State University
   Advisor: Dr. Jaime Juarez

   Abstract Title: Soft Functional Materials Based on 3D Printed Scaffold Removal

Effect of Ion Concentration on Shock Tube-Induced Cavitation Behavior

Jenny Marsh, William J. Jackson, and Sarah A. Bentil

Department of Mechanical Engineering, Iowa State University

Abstract

Bulk cavitation, the formation and collapse of vapor filled cavities in a liquid due to local areas of negative pressure, is a fluid behavior that can exist in biology. For instance, cavitation is hypothesized to be a mechanism of blast-induced traumatic brain injury (bTBI). The fluids in which cavitation occurs almost inevitably vary in ionic composition and concentration. The likelihood of cavitation bubble formation is partially dependent on vapor pressure, a property directly related to ion concentration. Therefore, cavitation behavior (e.g. likelihood of bubble formation, bubble properties such as the bubble's shape and size) is influenced by ionic concentration. There are limited examples in the literature where cavitation bubbles, induced by a shock wave created from a shock tube, are imaged in real time. Thus, this study utilizes a shock tube set up to examine cavitation behavior as a function of ion concentration. Specifically, this work compares cavitation bubble formation and bursting, as well as bubble properties in deionized water, artificial cerebrospinal fluid (aCSF), and as a function of increasing sodium chloride concentration in aCSF. Divergent cavitation behavior in water versus aCSF, a solution with a complex ionic makeup, are presented. Additionally, the results show how cavitation properties vary as a function of increasing ion concentration. Conclusions from this work will influence how ionic concentrations in biological fluids are modeled, when describing environments where cavitation is a concern.

Viscoelastic properties of tumor-mimicking hydrogels regulate cancer cell migration and extracellular matrix remodeling

Authors:Shalini R Unnikandam Veettil[a], Doh-gyu Hwang[b],Michael Bartlett[b] and Ian C Schneider [a, c]
a. Department of Chemical and Biological Engineering, Iowa State University, United States
b. Department of Materials Science and Engineering, Iowa State University, United States
c.Department of Genetics, Development and Cell Biology, Iowa State University, United States

Introduction: Biophysical properties of the tumor microenvironment (TME) regulate many biological processes that are critical in metastasis. Metastasis is driven by cell migration and is dependent upon extracellular matrix (ECM) deposition and remodeling. In the TME there is an increased ECM deposition, particularly collagen and hyaluronan (HA) that is accompanied by enhanced chemical crosslinking. This crosslinking results in increased stiffness and altered viscoelastic properties. Additionally, high HA content results in collapsed blood vessels and poor drug delivery. Fragmentation of the native high molecular weight (HMW) HA to low molecular weight (LMW) HA using hyaluronidases in the TME is a potential therapeutic strategy to overcome this, which in turn would lead to changes in the biophysical features, namely viscoelastic and microstructural properties of the TME. While the influence of stiffness on cell behavior has been extensively studied, the dependence of cancer cell migration and ECM remodeling on the viscous properties of remain largely unknown.

Materials and Methods: Collagen-HA composite matrices are assembled with tunable thickness by two glass coverslips as described in our previous paper[1]. MDA-MB-231 cells are embedded in the gel with HA filling the collagen fibrillar network assembled at 2 mg/mL as collagen polymerizes. In these studies, we use HMW and LMW HA of 1.5 MDa and 100 kDa respectively. Live-cell microscopy gel contraction assays are used to examine cell migration and ECM remodeling. Confocal reflectance microscopy and mechanical indentation tests are used to determine the microstructural and mechanical properties of the gels.

Results: Cell migration decreases with increase in HA concentration in the gels. At a very low HA concentration, cell speed is comparable to collagen gels. Cell speed is higher for LMW HA condition, in comparison to HMW HA, at high concentrations (**Fig 1A**). A higher degree of gel compaction is observed among gels with high concentrations of HMW HA (**Fig 1B**). Gel compaction is a bulk mechanical phenomenon resulting from the contractile force of cells on their viscoelastic surroundings. HA increases fiber pore-size (**Fig 1C**) and elastic modulus (**Fig 1D**) and decreases stress relaxation time (**Fig 1E**) in a concentration dependent manner.

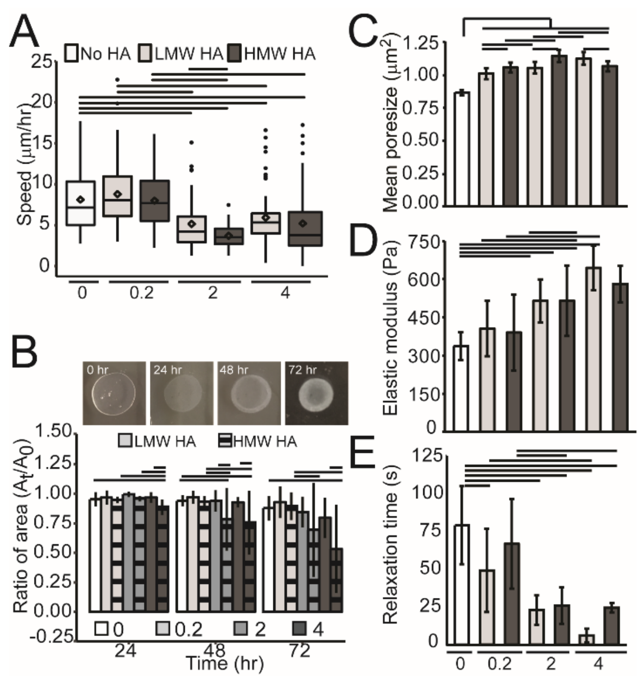

Figure 1. A) Cell speed and B) ratio of the gel surface area to the initial area observed at 0 hr observed in the gels at different concentrations of LMW and HMW HA. C) Mean pore size, D) elastic modulus and E) stress relaxation time of composite gels of 2 mg/mL collagen and 0, 0.2, 2 and 4 mg/mL LMW and HMW HA.

Conclusions: Cell migration is lower in the presence of HA, but the addition of HA increases ECM pore size. Although increases in pore-size are known to increase cell speed, in our studies these pores are filled by HA macromolecules which results in steric hindrance, physically blocking cell migration. Cell contractility and ECM compaction is higher in the presence of HA. Cell contractile force has been shown to be upregulated in response to increases in elastic modulus, but others have shown that large molecules can act to increase the stress relaxation time not elastic modulus. Here, we show that HA decreases the stress relaxation time. Likely, the large HA molecules act like a network of interconnected springs which disperses forces leading to the higher modulus and decreased stress relaxation time. Consequently, the larger modulus caused by HA likely upregulates cell contractility leading to enhanced gel compaction.

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Abstract

Fabricating soft functional materials via additive manufacturing is an emerging field with a wide variety of applications due to their ability to respond to specifically engineered stimuli (e.g., mechanical, electrical, magnetic, chemical). For example, functional materials that deform on command are ideal for applications in soft materials-based devices such as soft robots, actuators, sensors and biomedical devices. Our approach to fabricating these materials combine additive manufacturing and fluidic systems. We use fused deposition modeling-based 3D printing to custom design ABS scaffolds of milli-fluidic channels. The channels are encapsulated in polydimethylsiloxane (PDMS), before being dissolved using an organic solvent. The evacuated channels can then be infilled with a fluid that instills functionality into the PDMS channel. We showcase two examples of functionality using this approach. The first example relies on the introduction of a ferrofluid to the channel. The PDMS-ferrofluid composite undergoes a deflection when exposed to a magnetic field. In the second example, an ethanol-based hydrogel is introduced to the channel. The PDMS-hydrogel composite is shaped in such a way that the ethanol diffuses out of the composite when exposed to water. The displacement of ethanol from the hydrogel causes the composite to move under its own power, leading to potential applications in self-swimming cargo carriers, sensing platforms and mixing.

2020 Midwest Graduate Student Society for Experimental Mechanics (SEM) Symposium

<u>March 7, 2020 (Saturday)</u>

Afternoon Session II

1. **Bishoy Dawood**
   Iowa State University
   Advisor: Dr. Ashraf Bastawros

   <u>Abstract Title</u>: Characterization of the Interfacial Adhesion of Ice to Metallic Substrates

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2. **Edward J. Barron III**
   Iowa State University
   Advisor: Dr. Michael D. Bartlett

   <u>Abstract Title</u>: Mechanically Cloaked Soft Magnetic Composites for Wearable Electronics

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3. **Oluwaponmile Afuwape**
   Iowa State University
   Advisor: Dr. David Jiles and Dr. Sarah A. Bentil

   <u>Abstract Title</u>: The Influence of Grey and White Matter Volume on the Induced Electric Field of the Quadruple Butterfly Coil for Transcranial Magnetic Stimulation

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4. **Vignesh Suresh**
   Iowa State University
   Advisor: Dr. Beiwen Li

   <u>Abstract Title</u>: Deformation Measurement of Surfaces Using Phase Shifting Profilometry and Digital Height Correlation

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5. **Jialiang Tao**
   University of Wisconsin - Madison
   Advisor: Dr. Christian Franck

   <u>Abstract Title</u>: Characterization of the Viscoelastic Response of Strain-Rate Sensitive Elastomeric Foams

Characterization of the interfacial adhesion of ice to metallic substrates

Abstract

Ice accretion on engineering structures surfaces can pose a severe impact and may lead to catastrophic accidents. Understanding the mechanism of ice adhesion to different surfaces is vital toward enhancing the icing mitigation systems. The previously reported ice adhesion strength showed a large level of scatter for different testing methodologies. This paper is considered an attempt to understand the source of this scatter through a comprehensive experimental work. The interfacial adhesion strength of bulk water ice that adheres to Aluminum substrates was studied through a mode II vertical shear test. The effect of formation and testing temperature, substrate surface roughness, and ice adhesion length were studied. The experiment captures the trends in which ice adhesion strength increases with temperature decrease from -5^{o} C to -25^{o}C. In addition, the study shows the independence of ice adhesion strength on the substrate surface roughness. Also, the force required to shear a block of ice was found to increase with the adhesion area up to a critical length after which the force is independent of the ice adhesion length explaining the transition from strength-based fracture to toughness-based fracture. This fact is supported by the force displacement details as well as the micrographs of the fracture ice.

MECHANICALLY CLOAKED SOFT MAGNETIC COMPOSITES FOR WEARABLE ELECTRONICS

*Edward J. Barron III[1], Ray S. Peterson[1], Nathan Lazarus[2], Michael D. Bartlett[1,]**
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Conventional electronics are made from rigid components that offer exceptional functionality but lack the necessary compliance to safely and seamlessly interact with human tissue. Elastomers offer the required extensibility, but rigid functional additives increase the elastic modulus of the composite. Recently, liquid fillers have been used to improve the mechanical response while offering unprecedented functionality in soft composites[1,2]. Deformable magnetic backplanes have been shown to increase inductive coupling in soft wearable devices[3,4], but magnetic fluid inclusions have not been significantly explored. In this work we establish a new class of highly functional soft materials with advanced magnetic and mechanical properties by dispersing a colloidal suspension filled with functional magnetic microparticles into an immiscible liquid elastomer prior to curing (Figure 1a-b). The cured microstructure consists of stable colloidal droplets within a polymer matrix, which presents a unique mechanical response where the material becomes significantly more compliant at high particle loadings (Figure 1c-d). The material composition can be tuned to create low modulus (<40kPa) and high particle loading (~20%) materials, offering strategies to achieve soft mechanical properties with strong magnetic response. This combination of properties is enabling for various soft technologies, which we explore by studying the magneto-mechanical coupling for wireless power transfer.

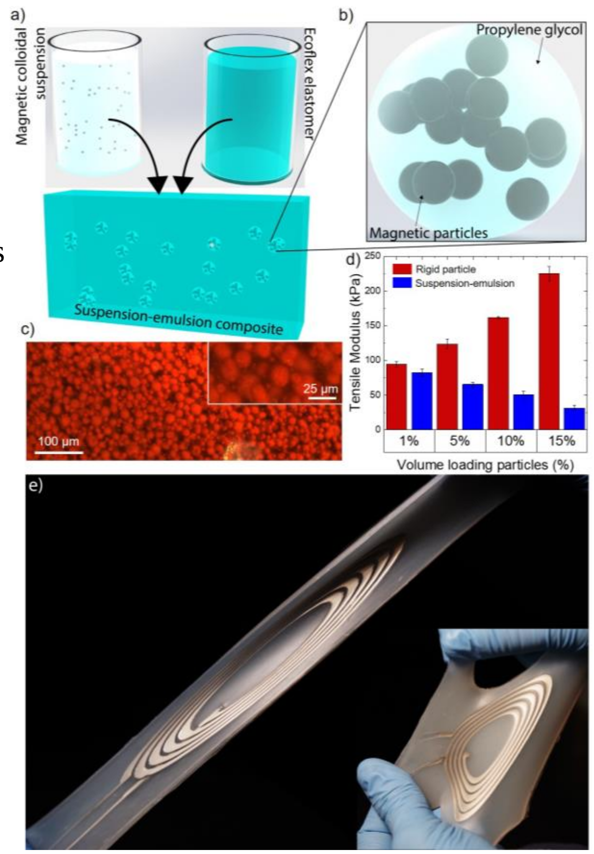

Figure 1 (a-b) Soft composite fabrication schematic and **(c)** microstructure. **(d)** Tensile modulus showing the desirable response of the suspension-emulsion. **(e)** Stretchable inductor for wireless power transfer.

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The Influence of Grey and White Matter Volume on the Induced Electric Field of the Quadruple Butterfly Coil for Transcranial Magnetic Stimulation

Oluwaponmile Afuwape [1,2], Joseph Boldrey [1,3], Priyam Rastogi [1], Sarah Bentil [2], David Jiles [1]

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Transcranial Magnetic Stimulation (TMS) is a neuromodulation technique that non-invasively activates neurons in the brain. During TMS, a pulse (or multiple pulses) of a time-varying magnetic field (H) is delivered to the brain. The H field induces an electric field (E) in the brain which, at sufficient levels, causes neurons to fire [1].

One of the challenges in the development of TMS therapy is the ability to deliver a focused magnetic field to a specific targeted region in the brain. In the process of delivering a sufficiently strong H field to the targeted region, surrounding areas of the brain can be unnecessarily stimulated. The Quadruple Butterfly Coil (QBC) is a novel design TMS coil that significantly increases the focality of the magnetic field compared to the commonly used figure-of-eight (FOE) TMS coil [2].

Research has shown that one of the significant anatomical variations in humans is the volume of grey matter (GM), the volume of white matter (WM), and the proportion of GM to WM [3]. GM and WM are the two components of the brain that exhibit the greatest response from the magnetic field through TMS.

The goal of our research is to investigate the effects that GM volume, WM volume, and the ratio of GM to WM have on the performance of the QBC. Specifically, the focality of the induced E field with respect to GM and WM volumes. Simulations were run using Sim4Life software on 50 unique head models derived from magnetic resonance imaging (MRI) scans of 50 healthy subjects (Fig. 1).

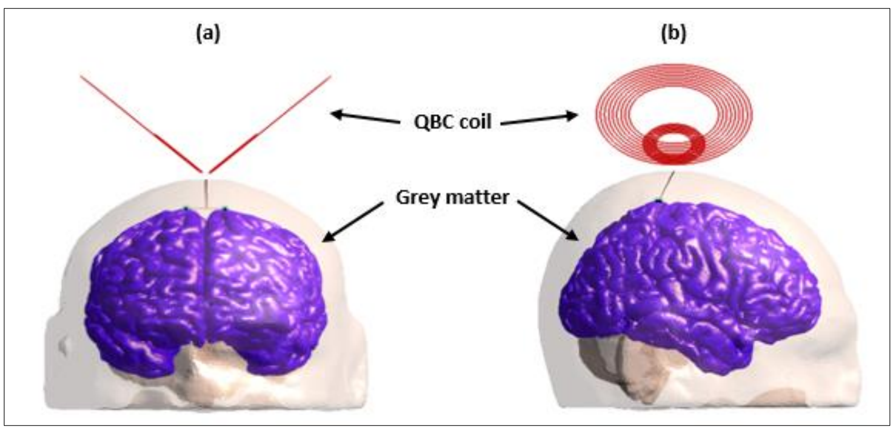

Fig. 1 Representative images of simulation model in Sim4Life software. Frontal view (a) and side view (b) of the head model, grey matter (GM), and Quadruple Butterfly Coil (QBC).

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Deformation measurement of surfaces using phase shifting profilometry and digital height correlation

Abstract

Phase shifting Profilometry (PSP) has been widely used in many fields to accurately measure the 3D geometry of complicated surfaces. However, while measuring a dynamic scene we cannot accurately estimate the displacement or motion of the object in between the frames. On the other hand, traditional Digital Image Correlation methods (DIC) has been widely used in the field of experimental mechanics to measure the in-plane displacement of the objects. However, it is difficult to recover the 3D shape of the objects using a single camera. In this paper, we propose a novel digital height correlation method for measuring surface profile and deformation measurement based on the height data measured by phase shifting profilometry. The proposed method involves measuring the 3D profile of an object with rich surface topographic variations using a high-accuracy fringe projection method. Then, the 3D profiles obtained from before and after displacement state are correlated to extract the in-plane and out-of-plane displacement. Specifically, the out-of-plane displacement is extracted by applying the correlation technique to the height map obtained from the 3D profile of the object. The accuracy and efficacy of the digital height correlation method are validated using rigid-body translation tests and tensile tests of a rubber specimen.

Characterization of the viscoelastic response of foam-like soft materials

Jialiang Tao, Xiuqi Li, Alexander K. Landauer, David L. Henann, Christian Franck

Abstract Foam-like materials are consisting of crosslinked elastic polymer and an open or enclosed liquid or air phase. Their applications are ubiquitous from consumer articles to personal protective wear in large part due to their intrinsic high energy dissipation characteristics under the application of impact loading rates. Recently, we showed that elastomeric low-density foams exhibit significant coupling between their volumetric and distortional response under the application of large deformations. In this study we expand upon our previous experimental and theoretical characterization approach to consider the effect of strain rate, temperature and localization on the constitutive response of elastomeric, low density foam materials.

2020 Midwest Graduate Student Society for Experimental Mechanics (SEM) Symposium

March 7, 2020 (Saturday)

Afternoon Session III

1. **Dr. A B M Tahidul Haque**
   Iowa State University
   Advisor: Dr. Michael D. Bartlett

   Abstract Title: Soft Composites Enabled by Programmable Liquid Metal Microstructures for Tunable Mechanical and Thermal Functionalities

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2. **Ravi Tutika**
   Iowa State University
   Advisor: Dr. Michael D. Bartlett

   Abstract Title: Mechanical and Functional Interplay in Liquid Metal Soft Composites

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3. **Somashekar Viswanath**
   University of Illinois at Urbana-Champaign
   Advisor: Dr. James M. LaFave

   Abstract Title: Experimental Investigation of the Capacity and Behavior of Concrete under Uniaxial Compressive Fatigue Loading

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4. **Mehrnoosh Taghavimehr**
   Iowa State University
   Advisor: Dr. Reza Montazami

   Abstract Title: Effects of Ionic Domain Composition on Properties of Segmented Ionenes

Soft composites enabled by programmable liquid metal microstructures for tunable mechanical and thermal functionalities

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Department of Materials Science and Engineering, Soft Materials and Structures Lab, Iowa State University of Science and Technology, 528 Bissell Rd, Ames, IA 50011, USA

Abstract

Soft, elastically deformable composites can enable new generations of multifunctional materials for electronics, robotics, and reconfigurable structures. An emerging material architecture is to create composites with liquid metal inclusions dispersed in elastomer matrices. These materials have shown exceptional combinations of soft mechanical response, tunable electrical properties, and high thermal conductivity. Such properties are strongly dependent on the material composition and microstructure. However, approaches to control the liquid metal microdroplet morphology to program mechanical and functional properties are lacking. Here, we overcome this limitation by innovative application of multiphysics mechanics to reconfigure the liquid metal droplets. Especially, we program liquid metal microstructure in thermoplastic elastomers through a thermo-mechanical approach to mechanically reshape and then thermally relax the polymer matrix to create controlled microstructures in stress-free materials. The influence of microstructure on mechanical and functional response is experimentally and theoretically investigated and a general framework is developed to guide the design of soft materials with desired functional characteristics. This technique allows liquid metal droplets to be highly loaded with prescribed particle aspect ratios, enabling control of microstructure throughout the bulk of the material. Through this microstructural control in soft composites, we demonstrate a material which simultaneously achieves a thermal conductivity as high as 13 W/mK (> 70 x increase over polymer matrix) and low elastic modulus (<1.0 MPa) in stress-free conditions. These materials and approach can create further opportunities for thermal management of programmable matter which require extreme mechanical flexibility with high thermal conductivity. We demonstrate this exceptional thermo-mechanical capability of the composite to enable quick heat dissipation in soft electronics and wearable prosthetics. We envision that the exceptional electro-thermal-mechanical combination of the composite will enable applications in wearable electronics, medical devices, heat sinks, and shape morphing soft robotics.

MECHANICAL AND FUNCTIONAL INTERPLAY IN LIQUID METAL SOFT COMPOSITES

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Introduction

Soft composites with multifunctionality are critical for stretchable electronics, energy harvesting and storage,[1] – [2] and soft, flexible materials for human-interface devices. However, conventional electronics and components are inextensible while soft polymers typically lack functionality. To overcome this trade-off, one solution is to create composites through the incorporation of liquid metal (LM) droplets such as eutectic gallium indium (EGaIn) dispersed in highly deformable elastomers. This leverages the inherent stretchability (>100% strain) and flexibility (< 1 MPa modulus) of the elastomers and the intrinsically high thermal and electrical conductivity of the LM to create functional soft materials. Although promising, the role of LM microstructure such as LM size and shape on material properties is still largely unknown. Further, model systems to study the mechanics and physics of these systems are lacking.

Here we develop model LM composite systems with controlled microstructures,[3] and perform systematic experiments and modeling to create and design soft composites with programmable mechanical and functional properties. We have focused on functional properties such as thermal conductivity, electrical conductivity, and dielectric behavior and couple it with tunable mechanical behavior to realize high thermal conductivity in soft materials,[4] soft capacitive sensors through novel LM particle size control,[5] stretchable conductive traces that feature invariable resistance,[6] and soft electronic skins for multi-site damage detection systems.[7] [8] We achieve soft materials with unique thermal-mechanical combinations, highlighted by a thermal conductivity of 11.0 ± 0.5 $W. m^{-1}. K^{-1}$ in a composite with a volume loading of ϕ = 60% LM and at a 400% strain. [4] To understand the effect of LM particle size on composite dielectrics, we created a fabrication scheme to achieve independent control of particle size and volume loading. [5] We exploited this knowledge to develop all soft matter capacitive sensors that can monitor the gestures of a proximal interphalangeal (PIP) joint. Additionally, we design stretchable conductive traces through electro-mechanical coupling, that exhibit invariable resistance up to a strain of 1500%.[6]

Results and Discussion

Thermal conductivity

Soft materials exhibit poor heat transfer properties due to the dynamics of phonon transport. To overcome this, we create a programmable LM microstructure through dispersion of the LM droplets in a silicone matrix. When this composite is stretched, the LM droplets elongate (see Figure 1a) and result in high anisotropic thermal conductivity in the stretching direction. Though liquid, the LM can provide mechanical stability due to the spontaneous formation of an oxide layer in ambient atmosphere. This oxide layer helps in wetting the polymer surface and creates good adhesion between the matrix and the LM. This thermal-mechanical coupling creates a strain-dependent high thermal conductivity biased on the direction of stretch.

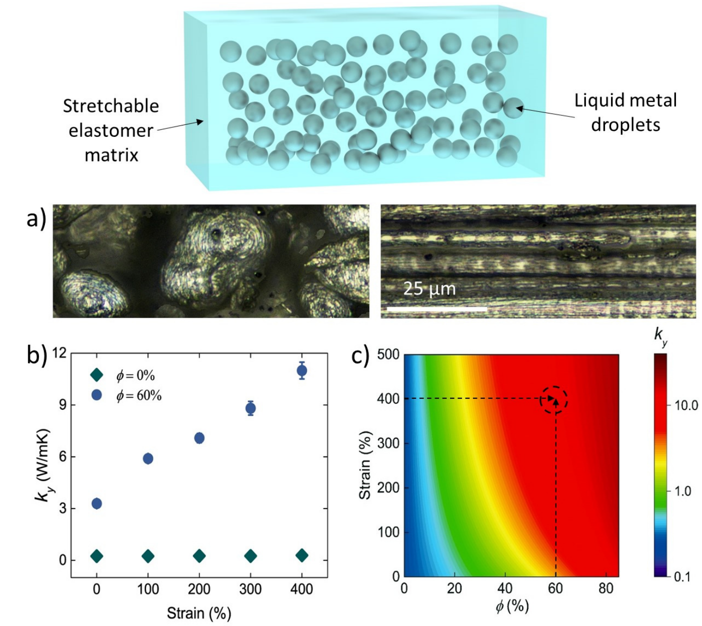

Figure 1. a) Micrographs showing the spherical and elongated LM particles in pristine and stretched composites. b) Absolute values of thermal conductivity in the direction of stretch for an unfilled elastomer (ϕ = 0%) and an LM composite (ϕ = 60%). c) Design map of composite thermal conductivity as a function of strain and ϕ based on the strain modified Bruggeman EMT.

Conclusion

In summary, we exploit the soft deformable nature of highly extensible elastomers and the functional properties of the LM to understand the mechanical-functional tradeoffs in soft composites.

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TITLE: Experimental Investigation of the Capacity and Behavior of Concrete under Uniaxial Compressive Fatigue Loading

AUTHORS: Somashekar Viswanath[a], James M. LaFave[a] and Daniel A. Kuchma[b]
[[a] = University of Illinois at Urbana-Champaign, and [b] = Tufts University]

ABSTRACT:
When dealing with the design of concrete structures subjected to fatigue loading, the codes of practice, which provide guidance and prescribe design rules, currently employ extremely simplistic and highly constrictive design recommendations. An example of such a basic as well as restrictive design recommendation is limiting the maximum fatigue stress in concrete to around 40% of its compressive strength, to allow the application of the presumed maximum possible demand of ten-million cycles of fatigue loading. Owing to the tremendous potential for structural and economic benefits, concrete is increasingly being used in structures such as railroad bridges and wind turbine towers. However, the restriction on upper fatigue stress level result in extremely large cross-sections in some cases, and the number of fatigue loading cycles well exceed the presumed limit of ten-million cycles in several other cases. Therefore, the application of concrete in such fatigue-critical structures have resulted in the need for the development of more accurate fatigue-life models, as well as the development of better fatigue design recommendations. Additionally, the fatigue loading actually experienced by the real-life structures comprise of multiple stress-levels and an associated number of repetitions at each stress level, commonly known as *"variable amplitude fatigue loading"*. The most common guidance provided for addressing such loading is to consider a *linear* damage accumulation rule, such as the *Miner-Palmgren* rule, which is definitely incorrect for an inherently nonlinear material such as concrete. In order to address these challenges, a multi-stage experimental initiative was undertaken to better predict the capacity as well as better understand the behavior of concrete under uniaxial compressive fatigue loading. The experiments only focused on the high-cycle fatigue domain in concrete.

The first stage, called the *"Basic Fatigue Test Series"* (*BFTS*), involved the testing of concrete cylinders in uniaxial compressive fatigue loading until failure. A wide range of minimum and maximum compressive fatigue stress levels were considered. The number of cycles to failure in each test were compared against several existing fatigue-life models. The most applicable model was identified, along with the loading conditions where the model was inapplicable.

Additionally, most of the existing models only focus on the *"fatigue capacity"* of concrete, i.e., the number of cycles to failure under the given stress conditions. Very few models talk about the behavior of concrete during fatigue loading, although the inherently nonlinear concrete behavior greatly affects its deformation, frequency and overall performance. Therefore, in addition to fatigue "capacity", axial deformation information in each fatigue cycle in all the tests were also obtained. Using this information, an extensive investigation of the behavior of concrete, focusing on the development of axial strains and stiffness through the test duration, was undertaken. Degradation of concrete stiffness and evolution of axial strain through the fatigue loading process were observed, quantified and reported. Based on the observations of stiffness degradation, a hypothesis for identifying the instance of fatigue failure, based on the monotonic stress-strain curve, was validated. Also, stiffness degradation was used to hypothesize damage accumulation through the fatigue loading process.

This hypothesis was evaluated in the second stage of the experimental program, called the *"Strength Degradation Test Series"*, in which fatigue loading was conducted up to a certain proportion of the failure number of cycles, and subsequently unloaded completely. These cylinders were then tested under a monotonically increasing load until failure, to determine the strength of the fatigue-damaged specimens. Utilizing the results of this test series, the hypothesis of damage-accumulation was verified by the degradation of strength, which is quantified and reported. Additionally, a hypothesis for quantifying the degraded strength of fatigue-damaged specimens, based on the monotonic stress-strain curve, was developed and validated.

The third and final stage of the experimental program, called the *"Variable Amplitude Test Series"*, was undertaken to demonstrate the inapplicability of a linear damage accumulation hypothesis, such as the *Miner-Palmgren* rule, for concrete under fatigue loading. In this test series, the cylinders were loaded under consecutive, multiple, fatigue loading combinations for corresponding different number of cycles until failure. The results demonstrate that the order of fatigue loading plays a key role in the determination of the fatigue life, thereby disproving the applicability of linear damage accumulation rule.

Thus, the multi-stage experimental program undertaken here has allowed an increase in knowledge and understanding of the capacity, and more importantly, the behavior of concrete under fatigue loading. The results of the various test series will help to establish an advanced and validated basis, which can be implemented in the concrete fatigue analysis and design process, which in turn will help in a *"performance-based"* design rather than a strength-based one.

Effects of ionic domain composition on properties of segmented ionenes

Mehrnoosh Taghavimehr and Reza Montazami

Department of Mechanical Engineering, Iowa State University, Ames, Iowa

Segmented ionenes, consisting of ionic and non-ionic groups, are a class of polymers with uniquely flexible structural design. It is exhibited that bulk electrical, thermal, and mechanical properties of segmented ionenes are dependent on the abundance and type of the ionic segments such that the control and manipulation of the ionic segments can be used as a mean to obtain desired bulk properties. In this study, three oligomeric sequences, one ionic and two non-ionic, were utilized in synthesis of segmented ionenes; and their individual and collective influences on the resultant structural properties of the segmented ionenes were systematically studied to map the correlations between structural design and structural properties.

2020 Midwest Graduate Student Society for Experimental Mechanics (SEM) Symposium

<u>March 8, 2020 (Sunday)</u>

Morning Session I

1. **Diwakar Awate**
   Iowa State University
   Advisor: Dr. Jaime Juarez

   <u>Abstract Title</u>: Fabrication of Portable Flow Cytometry Platform with Additive Manufacturing

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2. **Christopher Giuffre**
   Iowa State University
   Advisor: Dr. Ashraf Bastawros

   <u>Abstract Title</u>: Analysis Framework for Shaft-Load Blister for Thick Ice-Substrate Adhesion Testing

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3. **Dohgyu Hwang**
   Iowa State University
   Advisor: Dr. Michael D. Bartlett

   <u>Abstract Title</u>: Programmable Adhesion Using Nonlinear Kirigami Structures

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4. **Nabhajit Goswami**
   Michigan Technological University
   Advisor: Dr. Stephen M. Morse

   <u>Abstract Title</u>: Angled 4-Point Bending Test for Glass Beam

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5. **Nitesh Arora**
   University of Wisconsin-Madison
   Advisor: Dr. Stephan Rudykh

   <u>Abstract Title</u>: On the Characterization of Interfacial Layers Using Elastic Instabilities in Soft Composites

Flow cytometry involves image analysis of multiphase particulate flow of bodily fluids for different applications like cell counting which is further used in disease diagnostics. Flow cytometry is widely used tool in biomedical sciences for various cell-based assays and disease diagnostics. Most commercial flow cytometers are expensive and cost around $75,000 or more. Developing countries and resource limited settings need a low cost, compact and accurate medical diagnosis tool that can be used at the point of care. Toward this direction, we have fabricated a lightweight and cost-effective particle counter prototype using 3D printing technique. This prototype setup consists of a flow cell for particulate flow and a particle imaging unit which utilizes a 10x objectives lens with an FLIR blackfly camera connected to a laptop computer to capture particle images. These images can further be processed with a MATLAB particle tracker code to get the particle count. We tested the performance of this prototype by counting 10 µm polystyrene particles suspended in deionized water at different concentrations. Four different samples were prepared with an expected particle count of 3000 particles/mL, 1000 particles/mL, 333 particles/mL, 111 particles/mL and ran at flow rates of 1 mL/hour, 5 mL/hour, 9 mL/hour and 13 mL/hour. The error between observed and expected particle count was 6.5%, 1.2%, 3.89%, 22% for 3000, 1000, 333 and 111 particles/mL samples respectively. These results are validated using a fluid mechanics model that characterizes the flow inside our cytometer, as well as by running same samples on a commercial coulter counter. This prototype is the first step towards building a smartphone based portable flow cytometry platform which could be useful for rapid and sensitive cell-based assays for detection of cancer cells or monitoring of HIV+ patients as well as to detect food or waterborne infectious diseases especially in resource limited settings.

The accumulation of atmospheric ice on structures presents a significant hazard in cold weather climates. A fracture mechanics based approach to characterize the interfacial fracture energy is proposed in this work. The primary focus is on the development of an analytical framework for the analysis of the shaft-loaded blister test. This experimental method is capable of producing stable crack propagation along the interface between an ice layer and the supporting substrate. The framework is developed to predict the location of crack front and accounts for the observed deformation mechanisms including local indentation, the deformation of the substrate, and the bending of the ice layer. Cohesive zone finite element simulations were used to verify and calibrate the model for a range of ice layer thicknesses. Simulating the delamination along the interface using cohesive surfaces allowed for the accuracy of the framework to be verified during the crack nucleation and propagation processes. The framework was compared with experimental in situ crack length measurements and was found to be in good agreement prior to the propagation of cohesive cracks in the ice layer. By predicting the crack length over the duration of the experiment, the framework provides the interfacial toughness resistance curve for the material system. The combination of the proposed framework and experimental method will enable the interface to be precisely characterized for a range of surface finishes and ice layer thicknesses.

Programmable Adhesion Using Nonlinear Kirigami Structures

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Creating adhesion between two surfaces is critical for the success of various fields, ranging from wearable electronics and soft robotics to manufacturing and construction. Adhesion is controlled by manipulating interfacial chemistry, geometry, and loading conditions. Tuning interfacial chemistry can lead to limited reusability. Surface microstructures can control the geometry of the adhesive; however, this often requires complex fabrication techniques and equipment. To overcome these tradeoffs, we have developed reversible adhesives with high adhesion and easy release capacity by using kirigami, the Japanese art of cutting. Linear cut structures in an adhesive strip allows for effective crack arrest under loading, which results in enhanced adhesion in structured regions, as well as anisotropic adhesive properties due to the directional characteristics of the kirigami structure[1]. The kirigami cut patterns define compliant and stiff regions, where the bending rigidity determines the adhesive capacity. When the crack travels from the compliant to the stiff region, the bend shape of the adhesive strip changes, resulting in a change of stored elastic energy. In addition to linear cuts, we will present layouts of nonlinear cut patterns. The nonlinear cut structures provide an improved adhesion enhancement with respect to the linear structures. We define the *on-state* as the condition at which higher adhesion is attained, whereas the *off-state* as the condition at which lower adhesion or easy release is achieved. Under the on-state peel loading, the adhesive displays a significantly improved adhesion compared with the adhesive with linear cut patterns through additional peeling of the non-linear components. In contrast, under the off-state peel loading, the adhesive undergoes a crack arrest mechanism similar to the linear cut patterns, resulting in lower adhesion with respect to the on-state peel of the adhesive with nonlinear cut patterns.

1. D. Hwang, K. Trent, M.D. Bartlett, *ACS Appl. Mater. Interfaces*, 2018, 10, pp 6747-6754

Angled 4 point bending test for glass beam.

Structural glass components are different from infill panels as structural glass supports/carries load from other building components. Structural glass components may include axial, shear and bending moment load effects where any or multiple surfaces may be in tension. Load resistance of glass is dependent on the flaws present on the surface, edges, edge-lines of glass and is calculated using a glass failure prediction model. The glass failure prediction model, based on Weibull distribution, includes the distribution of the flaws on the surface of the glass, orientation of the flaws, load duration and glass component geometry. Currently the glass failure prediction model is limited to infill panels where the surface is primarily stressed, and the edges are not. Thus, to characterize different glass surface, different surface flaw parameters are available (e.g. surface flaw parameters for new glass, used glass etc.). As structural glass components can experience stresses in edge-lines, edge-surfaces and corners apart from the flaws on the surface, the model must be expanded to include the effect of flaws on edge-lines, edge surfaces. In order to extend the model to address edges placed in tension, flaw parameters are required to model the effect of edge-lines on load resistance. Historically, edge-lines have been stressed either by either a 4-point bending test or a vertical 4-point bending test. Both of the test procedures stresses either the face or the edge-face along with the edge-lines officiating whether the critical flaw was on an edge-line or edge-face. A novel angled four-point bending test is used that places a single edge-line in tension by holding the glass beam specimen at a slight angle where the adjacent edge-line (opposite side across the edge-face) is on the neutral axis and thus unstressed. Thus the flaws in each edge-line can be stressed independently. Float glass beams of size 6"x 1"x 1/8" were used to obtain the edge-line flaw parameters using the angled 4-point bending test. Heat treated glass (heat strengthened or fully tempered glass) is often used in structural elements because of the relatively higher tensile strength compared to float glass. Heat treated glass beams samples should be generally bigger in size for the ease of the heat treatment process. Ratios for length to depth was maintained at 6:1 for float glass to reduce shear-deformation induced stress and the same ratio was maintained for the HT samples. The depth to thickness ratio was maintained at 10:1 in the float glass to have a sample large enough to be tested. The HT samples didn't have the limitation of large samples, but the d/t ratio for HT samples were driven by torsion for which the ratio was reduced from 10:1 to 6:1. Keeping the ratios in consideration, the HT samples were in the order of 18" x 3" x ½". Initial estimation of the samples suggested the breaking load for the FT samples were near 4800 lbf. To carry the load, supports was built with the help of steel plates connected to a vertical rotary table which allowed us to load the specimen at required angles. The presentation will go through the modified glass failure prediction model followed by the angled 4-point bending test setup for obtaining edge-line flaw parameters. The design steps for the HT sample angled 4-point bending test and the validation of the model with experimental data will be discussed too.

Characterization of Interphase zone using elastic instabilities in soft composites

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Abstract

Polymer based multi-material 3D printing – such as UV-assisted layer-by-layer polymerization techniques – is widely used for the fabrication of soft microstructured materials. However, the properties of materials fabricated employing these methods requires proper characterization. In this work, we focus on characterizing the new interphase zone which is formed at the boundary between two different constituents. These interphasial layers are generally mechanically invisible, i.e, they cannot be detected using simple tensile and compression tests. We show that the development of elastic instabilities in soft composites are highly sensitive to the specifications of the interphasial layers. Thus, we propose using elastic instabilities parameters to analyze the interphasial layer characteristics. We perform a numerical study to investigate the influence of interphasial zone on the onset of elastic instabilities and associated buckling modes, which can be reversely used to characterize the interphasial layers. Finally, a qualitative validation of the numerical study is presented for 3D-printed deformable composites.

2020 Midwest Graduate Student Society for Experimental Mechanics (SEM) Symposium

<u>March 8, 2020 (Sunday)</u>

Morning Session II

1. **Amir Niaraki**
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   <u>Abstract Title</u>: 3D Printed Graphene Biosensors for Measuring Electrochemical Properties of Neuronal Cells

3D Printed graphene biosensors for measuring electrochemical properties of neuronal cells

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INTRODUCTION

Parkinson's disease (PD) is the second most common neurodegenerative disease in the United States. PD is caused by the death of dopaminergic neurons in the substantia nigra pars compacta region of the brain. Hence, investigating such neurons and measuring the change in their properties during the exposure to damage is essential for prevention of neuronal loss. Rat dopaminergic N27 cells are one of the commonly reported *in-vitro* models for PD studies.[2] Presented here is a graphene-based platform for the growth of N27 neuronal cells, which can be used continually for electrical and optical measurements.

It is shown in numerous electrophysiological studies that, excitable cells grow compatibly in presence of graphene which is a one-atom-thick, two-dimensional, honey-combed arrangement of hybridized carbon atoms. In this study, we combined the shear force of low speed wet ball milling with stabling characteristics of an edible (BSA) protein to exfoliate highly concentrated graphene ($5.1\ mgml^{-1}$) from pristine graphite in water (Figure 1A). Next, the graphene solution was formulized as a conductive ink, 3D printed into a flexible substrate and consolidated via applying a strong electrostatic field. Finally, the N27 cells were cultured in the biosensor and their viability was measured along with the resistance of the lines.

High concentration ($5.1\ mgml^{-1}$) of defect-free FLG in water was produced using BSA and wet ball milling. The quality of the shear-exfoliated graphene is demonstrated through TEM and AFM imaging (Figure 1B-D). The lateral dimension of most graphene sheets reaches to hundreds of nanometers and the measured normal thickness is 7.6 ± 2.3 nm, providing a large aspect ratio. The electrical conductivity of the printed lines changed from 370 Sm^{-1} to 6800 Sm^{-1} subsequent to the thermal annealing, which can pave the way for capturing membrane potential in the course of cell-cell communication (Figure 1E). Additionally, N27 neurons could adhere to graphene lines and proliferate for several days *in-vitro*. The live-dead assay for the cells cultured on the chip was measured to be as high as 96.5% of the cells counted in control after 3 DIV (Figure 1 F-G). The high resultant live cell count suggests applicability of this biosensor for studying electrical properties of neuronal cells.

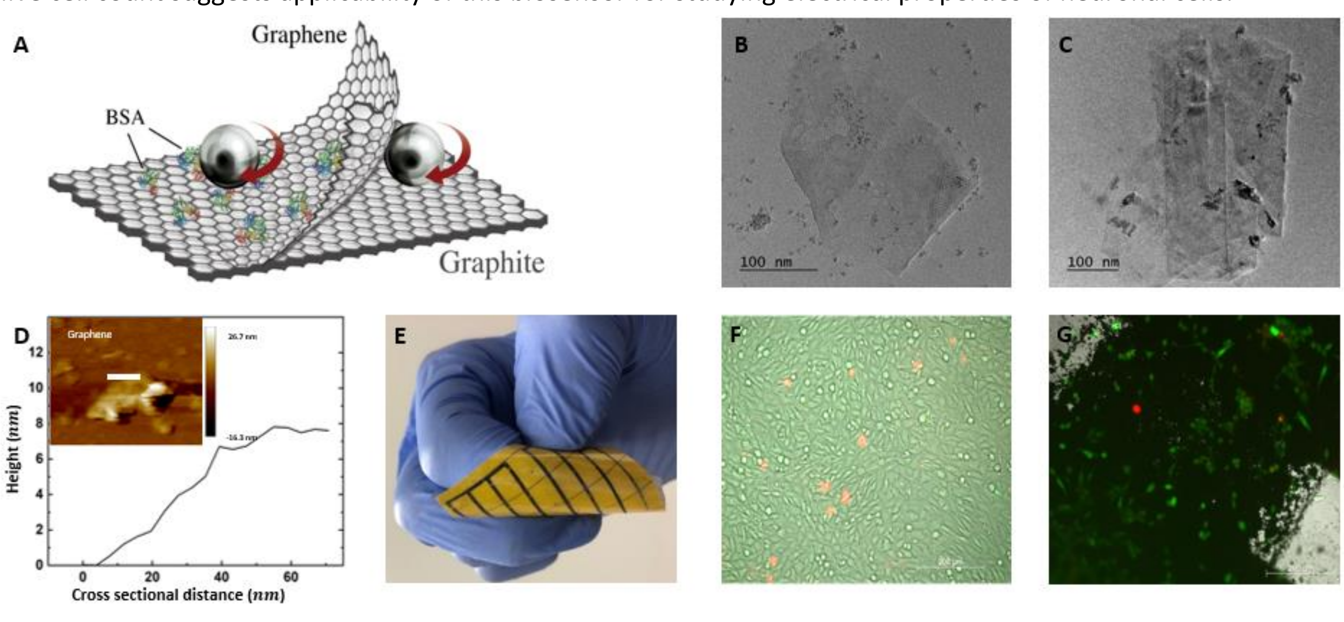

Figure 1. (A) Inkjet printing of shear-exfoliated graphene and the adhesion of neuronal cells.