Research Interest Statement

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My research focuses on the intersection of multiple disciplines, including manufacturing science, fluid mechanics, and the collaborative use of computational and experimental methods. Currently, I am focusing on three key areas within my research: (1) Investigating the mechanical behavior of materials under various manufacturing processes to understand their properties better, (2) Applying the theory of continua, data-driven modeling, and experimental mechanics through innovative testing and constitutive models to study material behavior, and (3) Exploring the integration of additive manufacturing in fluid mechanics, aiming to revolutionize fluid systems and address fundamental challenges in the field. As additive manufacturing continues to progress, its potential for creating intricate, customized components will increasingly integrate with traditional manufacturing methods. This integration promises to boost overall flexibility and productivity, not only in manufacturing but also in the realm of mechanics by opening up new testing methods. In summary, my research intersects manufacturing science, fluid mechanics, and computational-experimental methods, focusing on material behavior, continua theory, and additive manufacturing's impact on fluid systems. As a faculty, I aim to establish a research portfolio that balances both practical and theoretical aspects of manufacturing procedures, thereby fostering interdisciplinary collaborations and contributing to the advancement of cutting-edge technologies in the field.

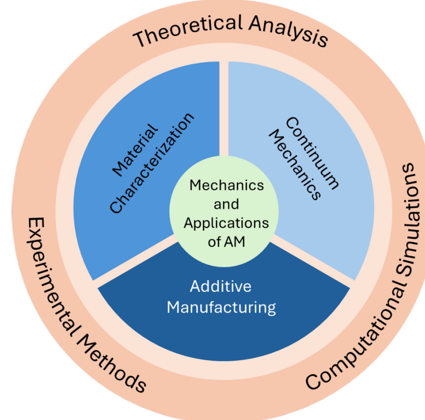


Figure 1: Research outline

Previous and ongoing research

During my doctoral studies, I extensively researched the mechanics of asphaltic materials, particularly their response to real-world loading experienced by pavements. Modeling this response is challenging due to the material's inherent inhomogeneity and its time-dependent behavior, including stress relaxation, nonlinear creep, and aging. The material's composition involves a mixture of reacting and diffusing constituents, noted in several studies [1, 2, 3]. My Ph.D. dissertation comprised four key tasks: (1) developing a multiconstituent nonlinear model using a thermodynamic continuum framework, (2) devising testing protocols for laboratory simulations of field conditions, (3) validating the model with experimental data, and (4) applying the validated model to simulate complex field conditions. The developed model was used to establish new experimental protocols to analyze permanent deformation and proposed an optimizing framework for asphaltic material.

As an Instructional Assistant Professor, I've had the chance to collaborate with multiple faculty, notably in areas of constitutive modeling, material characterizations, and additive manufacturing.

Ongoing research-Optimizing Support Structures in Metal 3D Printing

Presently, I'm serving as a CO-PI on a funded project aimed at removing or weakening supports for metal additive manufacturing parts. The current need for skilled labor proficient in CNC machining or wire EDM for the removal process imposes significant constraints on the mobility and flexibility of metal 3D printer machines. This requirement introduces several challenges and drawbacks to the additive manufacturing workflow. It adds an extra production step, increasing time and labor costs. The reliance on skilled operators for CNC milling or wire EDM reduces the automation potential of metal 3D printing, hindering streamlined production and scalability. The need for specialized equipment and expertise also limits accessibility. Addressing this reliance on manual post-processing is essential to fully realize the flexibility, scalability, and cost-effectiveness of metal 3D printing. To address this, we are developing a protocol to introduce a weak inclusion within the supports to reduce the material's shear strength while maintaining the same support for the part. This is achieved by varying the local porosity during the printing process, which alters the local density and, consequently, the local strength [7, 6].

Ongoing research-Fatigue analysis of polymers

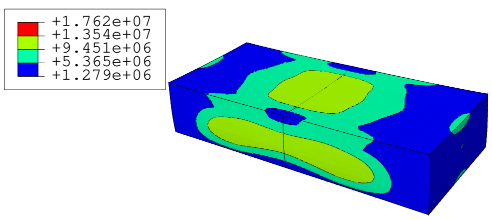
I am also currently working on addressing the challenges posed by fatigue in polymers subjected to repeated mechanical and thermal load cycles. While extensive research has been conducted on fatigue processes in metals, relatively little attention has been given to understanding these mechanisms in polymers. This knowledge gap hinders the selection of suitable polymeric materials and configurations for achieving desired load support and longevity with known reliability. My research aims to bridge this gap by establishing a framework to inform more resilient designs for machine elements, particularly in industries like medical devices and aerospace, where additive manufacturing is increasingly used but whose fatigue behavior remains under-explored.

Long term research

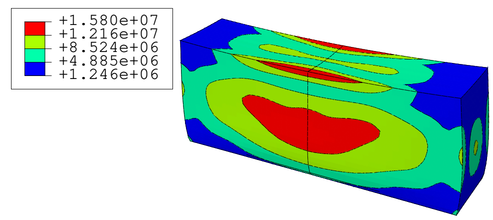
My research program will comprise three main thrusts, supplemented by several secondary projects of interest. As further opportunities arise, they will be pursued accordingly. The first and second research thrusts aim to improve the performance of additive-manufactured polymer composites and metal, while the third thrust concentrates on exploring the applications of additive manufacturing in fluid mechanics.

Smart Manufacturing of 3D Printed Polymers: Linking Process Parameters to Residual Stress Through Thermodynamic Modeling

While AM empowers the creation of complex 3D objects with design freedom and diverse material choices, accurately predicting the final assembly's strength remains a challenge. This difficulty arises from the inherent anisotropy of the materials manufactured in AM process, as shown in Figure 1, leading to a reliance on expensive and time-consuming trial-and-error approaches [4].



(a) Flat orientation.



(b) Horizontal orientation.

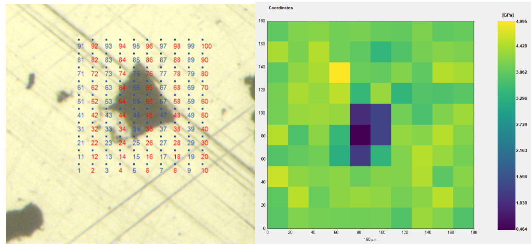
Figure 2: Contour plot of the norm of the stress on the rectangular plate. Note that the stress distribution is different in each orientation.

Numerous studies have investigated how printing parameters like orientation and pattern affect 3D printed parts. However, the underlying reasons for this behavior remain unclear. My research aims to bridge this gap by analyzing how these parameters influence residual stress during printing and its long-term impact on part behavior. To achieve this, I will leverage the thermodynamic framework proposed by [5] to model the anisotropic viscoelastic response of polymers, as shown in Figure 4. I will develop experimental protocols to acquire the necessary parameters for the constitutive models. These protocols may involve techniques like X-ray diffraction (XRD) to analyze internal stresses and micro-structural changes within the printed part. In addition, I plan to incorporate in-situ, non-destructive process monitoring techniques—such as thermal imaging evaluate layer quality and detect defects during the build process. These diagnostics will provide real time feedback for adaptive control, enhancing reliability and automation in additive manufacturing. Practical applications of this research can be in the fields of aerospace, transportation, low-cost prototyping, etc.

Fatigue Behavior and Life Cycle Assessment of Metal AM Parts: A Multiscale Perspective

Metal additive manufacturing is a revolutionary technology capable of producing complex and functional components that were once unattainable through conventional manufacturing methods. A deep understanding of material behavior under various loading conditions is essential to harness its potential fully. One critical aspect that remains relatively unexplored is the material's response to cyclic loading, which involves repeated application and removal of stress.

To understand the fatigue response of metal additively manufactured (AM) parts, I plan to analyze the effects of process parameters across different scales through a multiscale analysis. As the literature establishes, fatigue failure progresses through three stages: crack initiation, propagation, and final fracture. Although these stages have been examined at the macro scale for conventional metals, limited research exists on metal AM parts, particularly at varying scales. Each stage initiates and affects the material at distinct scales. Crack initiation, for instance, typically occurs at very small scales. A multiscale approach is essential to uncover the transitions between these stages and to develop strategies for mitigating damage at each



(a) Indentation map. (b) Hardness map

Figure 3: Nano-Indentation Images of LPBF 316L Stainless Steel(currently in progress)

stage, thereby preventing failure. Furthermore, understanding the behavior of pores and the surrounding material will be critical in addressing early-stage damage, as shown in Figure 3. Practical applications of this study can be in the aerospace industry, automobile industry, etc.

Instability-Driven Mixing of Viscoelastic Fluids in Complex Domains

This research focuses on the intricate flow behavior of viscoelastic fluids, such as asphalt, gels, and blood, as they navigate complex structures. Unlike Newtonian fluids, these materials exhibit unique instabilities even at low flow rates, a phenomenon known as elastic instabilities. This complex behavior poses significant challenges for mixing applications across industries like oil and gas, transportation, construction, and pharmaceuticals.

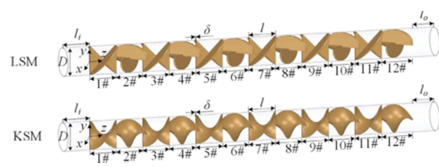


Figure 4: Static mixers.

By understanding the underlying mechanisms, including the onset of elastic turbulence, I aim to optimize mixing processes for viscoelastic fluids. To achieve this, I will leverage the efficiency and compactness of static mixers, which have gained significant attention due to their low-pressure drop and minimal moving parts. To get an in-depth understanding, I want to develop a computational model for viscoelastic fluid flow through complex geometries. This model will be based on my master's work, and by collaborating with researchers in the field, I intend to focus on this project for the next 3-5 years and provide insights into the onset of viscoelastic instability and its control. This research will also involve rigorous experimental testing. The applications of this research can be in the pharmaceuticals, food processing, chemical, and manufacturing industries.

Secondary Project 1:

Green production, encompassing sustainable and eco-friendly manufacturing, is vital for modern industry. It prioritizes minimizing environmental impact and optimizing resource use. While additive manufacturing (AM) techniques like powder bed fusion reduce material waste, recycling polymers and integrating them into AM remains a significant challenge. By re-purposing plastic waste and reducing reliance on virgin materials, we can enhance sustainability. This research investigates combining recycled and virgin polymers in AM to promote sustainable production. Key steps include developing methods to blend compatible recycled polymers and understanding how each component affects the mixture's properties. This knowledge will inform the optimization of blend designs for specific AM applications in eco-friendly AM applications.

Secondary Project 2:

Predicting drug release through mathematical modeling of drug delivery is a field gaining significant traction in academia and industry. This powerful tool has the potential to transform the future of drug development. This research involves applying mathematical and computational techniques to simulate the interactions between a Newtonian fluid (pharmaceutical drug) and non-Newtonian fluids (blood). This involves understanding drug diffusion and its effects on the surrounding material properties, etc. I aim to create a computational model that accurately simulates the mixing of these fluids and the resulting instabilities, which is crucial for optimizing and designing efficient drug delivery systems.

Potential Funding Sources

The proposed research aligns with the funding priorities of multiple agencies, including the Department of Science & Technology (DST), the Department of Defense (DOD), the Technology Development Board (TDB), the National Centre for Additive Manufacturing (NCAM), Central Manufacturing Technology Institute (CMTI) and industry partners such as Simpliforge, TATA motor. I will take a proactive approach by fostering collaborations with both internal and external stakeholders to address the interdisciplinary nature of the research.

Student Mentoring

Guided independence, structured training, and direct integration into meaningful research experiences form the core of my mentoring approach. I start by understanding each student's background and offer targeted onboarding-whether through foundational readings, hands-on training in computational tools, or supervised experimental work-on projects such as residual stress modeling in polymers, multiscale fatigue analysis of metal AM parts, or viscoelastic fluid instability. As students become more confident, I transition them toward ownership by encouraging them to design experiments, develop models, interpret data, and present findings during group meetings. I organize my research teams in such a way that graduate students mentor undergraduates, building leadership skills that facilitate collaborative progress across projects. Through this process, I emphasize open communication, professional skill-building, and a supportive environment that empowers students to grow intellectually and contribute meaningfully to the research program.

References

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