**Project Title:** Multiphysics Characterization of Printed Smart Materials and Systems

**Project Period:** 07/01/2021 – 06/30/2022

**Reporting Period:** 07/01/2021 – 06/30/2021

**PI**: Zhangxian (Dan) Deng

**Institute**: Department of Mechanical and Biomedical Engineering, Boise State University

1. **Summary of project accomplishments for the period just completed and plans for the coming reporting period.**

Global supply chain disruption and labor shortage caused by the COVID pandemic have significantly affected the project progress. The research lab for the proposed MTS load frame was flooded on May 23, 2022. This incident further disrupted the project schedule. To remedy the negative impact of logistics issues on Task 4 (magnetostrictive material characterization), the PI adjusted the budget to acquire another MTI fotonic probe that can work independently or along with the proposed frame. This probe is able to measure the magnetically-activated material deformation in sub-nanometer resolution. Achievements and future plans associated with each proposed task are presented in detail below.

***Task 1: Acquire and install the MTS test system.***

The proposed MTS load frame system was delivered on May 25, 2022. Load frame installation, on-site calibration, and user training were eventually completed on July 11-13, 2022. In addition, the new MTI fotonic probe system was delivered on May 14, 2022.

***Task 2: Provide instrument training and increase visibility.***

Students from the PI’s lab were trained by MTS technicians on July 13, 2022. Training sessions were recorded and standard testing templates (e.g., tensile or cyclic testing) were prepared for future users.

***Task 3: Characterize thermomechanical loops of printed shape memory polymers.***

Achievements: Using a Geeetech A30M fused filament printer, the PI’s lab has fabricated shape memory polymer (SMP) dogbone samples by mix printing polylactic acid (PLA) and thermoplastic polyurethane (TPU) filaments. The PI’s lab has also customized SMP filaments by extruding PLA and TPU pellets in a 50:50 volume fraction. On a Hyrel Engine SR printer, the PI printed the first-ever morphing electrical circuit by innovatively merging direct ink writing and fused filament deposition. The PI’s lab has completed the tensile testing of printed SMP dogbone samples at room temperature.

Collaborations:In collaboration with Dr. Brian Jaques from the Micron School of Materials Science and Engineering at Boise State University, the PI has preliminarily measured the thermomechanical loops of printed SMPs. The PI has identified the required force and temperature ranges for this type of tests. The PI has initiated collaboration with Dr. Harish Subbaraman from the Department of Electrical and Computer Engineering at Boise State and completed dielectric constant measurement of the printed SMPs.

Publications: Adam Train, an undergraduate student from the PI’s lab, published a paper entitled “All printed flexible and morphing electronics” in the conference proceeding of SPIE Smart Structures + Nondestructive Evaluation, 2022.

Plans after the Project Period: (a) Once the cooling water installation is completed in the PI’s lab, the PI will continue characterizing SMP samples up to 80 Celsius. (b) The PI will publish their achievements on SMP-based morphing electronics on *Additive Manufacturing* in the next 6 months.

***Task 4: Characterize the Young’s modulus of magnetostrictive iron-gallium alloys.***

Achievement: Since the domestic Galfenol provider (TdVib llc.) went out of business in Oct 2021, the PI selected magnetostrictive terbium-iron-dysprosium (Terfenol-D) for this task instead. The PI has printed the first-ever magnetostrictive composites using direct ink writing.

Collaborations: In collaboration with Dr. David Estrada at Boise State, the PI for the first time customized Terfenol-D nanoparticles using high energy ball milling. Together with Dr. Chien-hong Lin from National Cheng Kung University, Taiwan, the PI has developed a micromechanics model for Terfenol-D composites. Using the MTI fotonic system acquired in this project, the PI’s lab collected a series of material property data for model validation.

Plans after the Project Period: (a) The PI will publish their recent achievements on Terfenol-D composite printing on *Additive Manufacturing*. (b) The PI has drafted a journal paper titled “Constitutive modeling of particulate magnetostrictive polymer composites” that is ready to be submitted to *Composite Structures*.

***Task 5: Seek for long-term funding sources to support sustainable research and product commercialization.***

Awarded Proposals: (a) In collaboration with researchers from NASA Ames, NASA MSFC, and NASA JSC, the PI was awarded a NASA EPSCoR proposal ($750,000 over 3 years) entitled “On-demand Manufacturing of Smart Systems for Structural Health Monitoring.” In this project, the PI will use the MTS load frame to characterize the structural health monitoring capabilities of printed piezoelectric and magnetostrictive sensors. This project will also provide $60K funding to acquire a Correlated Solution digital image correlation (DIC) system that will be integrated with the MTS load frame to enable contactless strain measurements. (b) The PI received $1,800 from the CAES Senior Design Grant Program to purchase magnetostrictive iron-gallium alloys (Galfenol) samples.

Pending Proposals: (a) In collaboration with Dr. Joshua Daw from the High Temperature Test Laboratory at Idaho National Laboratory and Dr. Dylan Mikesell from the Department of Geosciences at Boise State University, the PI has submitted a proposal titled “Multiphysics mechanics of magnetostrictive materials” to NSF Program of Mechanics of Materials and Structures (MoMS). This proposal is currently under review. The PI plans to use the proposed MTS load frame to characterize the temperature- and magnetic-dependent Young’s modulus of Galfenol.

Declined Proposals: The PI submitted a proposal entitled “Guided Wave Ultrasonic Testing for Structural Health Monitoring in Extreme Environments” to Department of Energy. The PI plans to use the MTS load frame to characterize the printed magnetostrictive materials at elevated temperatures to verify their feasibility. This proposal passed the competitive pre-proposal phase but was declined in the full proposal review. The PI will work closely with researchers from Boise State and Idaho National Lab and target a resubmission next year.

1. **Summary of budget expenditures for the period just completed**

A total of $85,358.82 has been spent to purchase the MTS system. An additional $11,514.90 was used to acquired the MTI fotonic probe system. This results in a $3126.28 remaining budget. More details of the budget expenditures can be found in the spreadsheet included in this submission.

1. **Numbers of faculty and student participation resulting from the funding**

Faculty Participation (4): Zhangxian Deng, David Estrada, Brian Jaques, and Harish Subbaraman

Student Participation (6): Adam Tran, Braden Robinson, Drew Keller, Joy Morin, Amanda White, and Nick McKibben.

1. **Patents, copyrights, and Plant Variety Protection Certificates received or pending**

Nothing to report

1. **Technology licenses signed and start-up businesses created**

Nothing to report

1. **Status of private part/industry partnerships**

Nothing to report

1. **Additional funding received and financial burn rate**

Nothing to report

1. **Any other pertinent information**

Nothing to report