Disaster-Resilient and Self-Assessing Multifunctional Transportation Structures

Creating large dimension iron-based SMA rods that are suitable for structural and transportation applications by providing multifunctional benefits

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Shape memory alloys (SMAs) can produce large recoverable deformations triggered by stress in a response known as superelasticity. This response has been shown to limit the damage sustained by the structure from adverse events such as earthquakes. The most widespread SMA candidate for such applications is the nickel-titanium (NiTi) SMA, which is cost-prohibitive for large-scale applications. Instead, the research team proposes a low-cost and easily processed iron (Fe)-based SMA as an alternative. Furthermore, the iron-based SMA shows an interesting meta-magnetic shape memory response, where a change in induced magnetization of the material occurs from applied stress and can be easily detected using commercial magnetometers. The properties of iron-based SMA enable a new kind of structural health monitoring framework where the load-bearing and sensing elements are the same, and quantitative information could be collected in real-time with simple instruments. The goal of the proposed project is to create large dimension iron-based SMA rods and that are suitable for structural and transportation applications and determine the maximum part size. For the implementation phase of the project, the team will show that the strain in large size iron-based SMA rods and cables directly correlates with changes in its magnetic response.

Background

This study will demonstrate bulk-Fe-SMA rods and cables that are capable of sustaining high stress and elongation. Optimal configuration of rods and sensors will be computationally determined through combined magnetic-mechanical modeling and validated through experiments.

Project Summary

The objective of this research is to design and characterize multifunctional materials, in particular inexpensive shape memory alloys, for transportation structures that possess excellent mechanical properties and self-sensing capabilities for strengthening and health monitoring. The system will exploit unique properties of recently developed low-cost super elastic FeMnAlNi shape memory alloys (SMAs), which shows temperature invariant superelastic properties, high strength and self-sensing in structural health monitoring. At the conclusion of the technical part of the project, we are expected to create large dimension Fe-SMA rods and that are suitable for structural and transportation applications and determine the maximum part size. We are also expected to demonstrate bulk-Fe-SMA rods and cables that are capable of sustaining high stress and elongation. Optimal configuration of rods and sensors will be computationally determined through combined magnetic-mechanical modeling and validated through experiments. For the implementation phase of the project, we will show that the strain in large size Fe-SMA directly correlates with changes in its magnetic response. The research will address the following research tasks:

- Design topology and configuration of bulk Fe-SMA rods and cables in cementitious composites for optimal magnetic sensing capabilities;
- Determine maximum Fe-SMA component size through microstructural characterization and validation experiment; and
- Demonstration of self-assessing capabilities in a realistic infrastructure system.

Status Update

Microstructural characterization of the large sized Fe-SMA rods were done using optical microscopy and EBSD techniques. Experimental studies show large bamboo grains can be obtained in large diameter Fe-SMA rods. Through abnormal grain growth techniques, bamboo grains are obtained in rods up to 4.6 mm diameter.

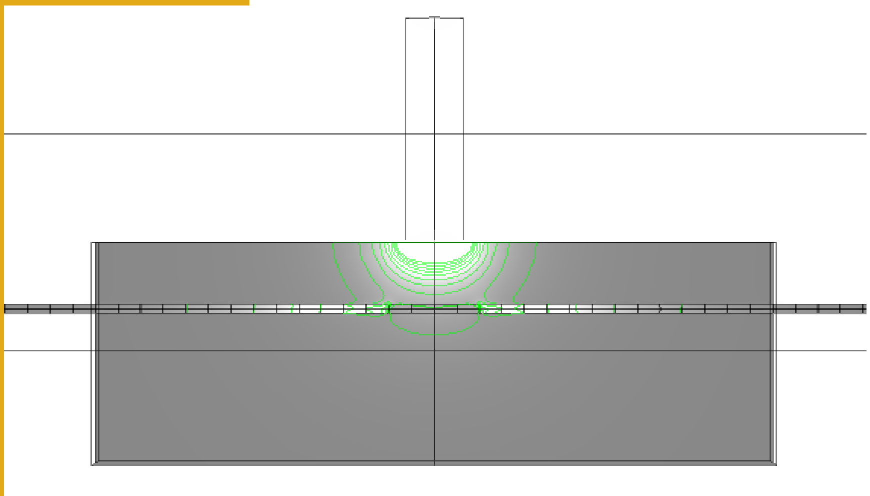

Figure 1. Simulation of large diameter Fe-SMA rods.

Computational studies have been developed to simulate the grain by grain transformation of large Fe-SMA wires and rods, and their effect on a local induced magnetic field. These changes are measured by a simulated small magnetic sensor near the wire to determine the effect of a transformed SMA on the magnetic field measured at a specific location as the Fe-SMA wire transforms grain by grain down the wire. This simulates experimental work done to characterize the change in measured magnetic field strength by a fixed sensor as an entire Fe-SMA wire undergoes phase transformation due to increased stress and strain.

Figure 2. Optical microscopy image of a large diameter Fe-Mn-Al-Ni SMA bar.

Impacts

Technology Transfer: The knowledge generated from the research study is to be disseminated and transferred to the research community, state agencies, and to the transportation and construction industries. Examples of dissemination include reporting the research findings in the form of presentations, journal articles, technical reports, design specifications, or any other medium that the authors find suitable.

Education and Workforce Development: The study provides opportunities for interdisciplinary research and educational interactions through the mutually beneficial collaborations among the different departments. The PIs will build a strong integrated research, educational and outreach collaboration focusing on mentoring and training the next generation of experts in the areas of smart materials, experimental.

Outreach Activities: The study will engage future researchers and engineers to careers in transportation, by developing activities that would encourage a higher participation from students in under-represented groups. Research opportunities will also be provided to high school students or undergraduate students in community colleges to educate future leaders on transportation related concepts.

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

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