Transportation Consortium of South Central States

Key Points

Project Number:
17STTAM04

Start Date:
05/08/2017

End Date:
11/08/2018

Principal Investigator(s):
Dr. Ibrahim Karaman
Texas A&M University
Email: ikaraman@tamu.edu

Dr. Darren Hartl
Texas A&M University
Email: Darren.hartl@tamu.edu

Lead Institution:
Texas A&M University

Funds Requested to UTC:
$94,000

Funding Source(s):
Tran-SET
Texas A&M University

Total Project Cost:
$188,000

Integrated Health Monitoring and Reinforcement of Transportation Structures with Optimized Low-Cost Multifunctional Braided Cables

Brief Project Description

Shape memory alloy (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 an adverse event such as earthquakes, and have been considered in a range of civil engineering applications. Through a combined approach of structural optimization and materials design, this research aims to simultaneously achieving advantageous mechanical properties and self-monitoring capabilities in a single material for transportation structures.

Problem Statement

To enhance the longevity and performance of next generation structures, high performance material and systems should be integrated with health monitoring systems that can obtain real-time data on the condition of structures and identify defects in a timely fashion. Smart materials that can serve multiple functions enables simplified designs, reduced material use, and less manufacturing complexity. A particularly appealing and interesting class of smart materials is shape memory alloys (SMAs). Superelastic SMAs can produce large recoverable deformations triggered by change in stress, and have been considered in a range of civil engineering applications such as bracing systems, connectors, and concrete reinforcement due to their superelastic response, which provides a restoring force to the structure after deformation. This response has been shown to limit the damage sustained by the structure from adverse event such as earthquakes by controlling the deformation and crack growth. Currently, the most widespread SMA candidate for such applications is the NiTi-based alloy also known as "Nitinol". While it shows excellent superelastic properties, the high cost due to inherent materials cost, difficulty in processing and fabrication, and limited in supply severely limit its application in large-scale applications in transportation projects. Thus, there exists a need for an alternative to NiTi that is cost effective, easily processed, and show comparable superelastic response.

Objective

The objective of this collaborative research is to design, fabricate, and characterize multifunctional high strength and self-sensing braided cables structures using novel Fe-based SMAs. The system will exploit unique properties of recently developed low-cost superelastic FeMnAlNi shape memory alloys (SMAs), which enables excellent superelastic properties, high strength, and self-sensing in structural health monitoring.

Intended Implementation of Research

Technology Transfer

It is the goal of the proposed project to identify and develop a pathway for continued commercial development of the Fe-SMA cables. The proposed project will seek to reduce the risk of commercial development in two ways: first, the proposed demonstration study will be conducted on a completed prototype braided cable created using conventional braiding techniques and coupling types. The Fe-SMA cables would not differ in appearance or targeted function compared to conventional steel cables and can be subjected to similar standardized testing protocols such as ASTM A586, which means the cost of translation is reduced. Further, the PIs will work with Dyalloy and Fort Wayne Metals to develop and scale up the commercial wire production, both in terms of raw materials processing and cable fabrication. It is our goal to achieve small-scale wire production at the end of the implementation period such that Fe-SMA wires or cables become commercially available. The PIs will work with the Office of Technology Commercialization at Texas A&M University on intellectual property and negotiate potential licensing agreements with commercial partners.

Education, Workforce Development, and Outreach

Workforce Development: The successful transition of the novel technologies considered herein into widespread acceptance and adopting will require a nationwide workforce that is comfortable with the material approaches considered. To that end, our team will leverage several industry training and outreach programs that have been successful at Texas A&M University (TAMU). Karaman and Hartl have previously given short courses on shape memory alloys to engineers from numerous Texas companies (oil and gas focused), as well as teaching versions of these courses in Seattle and Bristol, UK. This course can be updated to consider the specific application case study considered in the proposed research and development effort and offered more specifically to engineers in the civil infrastructure sector. For an even more in-depth understanding of the material design principles and methods employed herein, interested TRAN-SET industrial partners are invited to attend the Summer School on Computational Materials Science held annually at Texas A&M (e.g., July 23-August 4, 2017). The 10-day course provides a platform for thoroughly overviewing of some of the most important tools currently in use to investigate materials phenomena at multiple scales, ranging from the continuum to the electronic structure level. The School is organized in thematic sessions (modules) focused on different computational techniques, starting the continuum level. A new module on Materials Informatics has been included in the 2017 edition of the school. Industrial rates have been established on a per module basis.

Additionally, a series of live web-based seminars will be organized on topics related to the proposed research to further demonstrate its impact. The seminar will be transmitted over using video conferencing software (e.g., WebEx) with the ability to give, receive, and discussion information in real time. A website will be developed to host the webcasts for on-demand viewing. The proposed seminars will be held during the implementation phase of the project.

Education: The proposed program provides opportunities for interdisciplinary research and educational interactions through the mutually beneficial collaborations among the different departments. The training of graduate students will be coordinated with the recently awarded NSF-NRT-DESE program at TAMU on the design and discovery of smart materials. The graduate student at TAMU working on the project will follow the new NRT curriculum on materials design and materials informatics. Each year, support for two undergraduates will be sought through the Summer Research Experience for Undergraduate Students Program and recently awarded NSF-REU site on multifunctional. The graduate and undergraduate students working on this project will have unique opportunity to develop their multidisciplinary expertise and experience through the summer student exchanges among other members of the TranSET institutions. Beyond directly mentoring students, this project will be integrated into graduate teaching at collaborating universities. Research findings will be used to develop experimental learning modules for graduate-level courses MSEN 640: Multifunctional Materials, taught by Dr. Karaman with a special emphasis on SMAs. In addition, elements of the application of active and smart materials will be incorporated into the introductory level undergraduate materials science course taught by Dr. Ma (senior personnel) at TAMU.

Outreach Activities to K-12 Students: The outcomes of the project will be promoted amongst K-12 students on various occasions to attract them to pursue a degree in one of the STEM disciplines at college level. The graduate students of the PIs at TAMU have been heavily involved in both STEMFest to mentor Girl Scouts and the Women in Mathematics and Sciences (WIMS) community and will continue these activities. The PI at UA and her students will actively participate in various outreach activities such as "Kids Career Day" Camp and "Summer Experience in Engineering" (SEE) for middle and high school female students.

Anticipated Impacts/Benefits of Implementation

The developed multifunctional composites will transform the design, construction, and rehabilitation of infrastructure systems. The proposed Fe-SMA material will be cost-effective when compared to traditional SMAs. In addition, the proposed technology will enable a new kind of structural health monitoring framework where the structural and sensing elements are integrated and quantitative information could be collected in real-time with simple instruments.

Weblinks:

- Tran-SET's website (http://transet.lsu.edu/completed-research/)
- TRB's Research in Progress (RIP) database (https://rip.trb.org/view/1467520)