Development of Low-Cost Multifunctional Materials for Near-Surface-Mounted (NSM) Strengthening of RC Bridge Beams and Columns

Design, fabrication and characterizion of multifunctional, low-cost and large scale Cu-based and Fe-based shape memory alloy (SMA)

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Due to their excellent passive re-centering and energy absorbing capabilities, superelastic shape memory alloys (SMAs) have been considered in the development of seismic protection systems. Among various SMA compositions, nickel-titanium (NiTi) alloys have been the most widely studied and commercially available material. Low-cost SMAs such as Cu-based or Fe-based SMAs have recently emerged as strong candidates to replace NiTi SMAs especially in the civil applications, primarily due to the need of larger scales and associated costs, and secondarily but equally importantly, their superior mechanical and shape memory properties, easy machinability and weldability. Specific Fe-based SMA compositions in particular, show intriguingly wide temperature ranges where superelasticity can be observed. These Fe-based SMA compositions also exhibits magnetic properties enabling the monitoring of stresses and strains on structural systems remotely using commercial magnetometers. Within this study, low-cost superelastic Fe-based and Cu-based SMA rods will be fabricated. Initial efforts will be towards the scale-up process of the rods, to enable their use as rebars in structural applications. These efforts will include specific thermomechanical processing and heat treatments to induce a unique microstructure that will result in the superelastic effect. The fabricated SMA bars will subsequently be used in the nearsurface-mounted (NSM) reinforcement of prototype reinforced concrete (RC) structural elements to investigate their effectiveness compared to other common reinforcement materials such as fiber-reinforced polymers. RC structures NSM strengthened via low-cost SMA will transform the design, construction, and rehabilitation of infrastructure systems.

Problem Statement

Over their service life, reinforced concrete (RC) bridge structures need to be strengthened due to different factors. Corrosion is a leading cause of bridge deterioration. Rebar corrosion in reinforced concrete structures may lead to major retrofit. Impact of vehicles with bridge component may also result in significant damage and loss of capacity in a bridge structure. Many bridges in the United States were constructed before 1970 without adequate consideration for resistance to extreme events; therefore, they are in need of seismic upgrade to make them less vulnerable to future earthquakes. Furthermore, as extreme weather events such as hurricanes, tornadoes, tropical storms, and prolonged intense temperatures occur more frequently, they are expected to considerably impact the health of civil infrastructure systems. Therefore, state transportation agencies are in need of strategies to avoid, minimize or mitigate potential consequences. Replacement of all aging and structurally deficient bridges may require significant resources and time. Strengthening can be a more economical and sustainable alternative to extend the intended lifespans of concrete bridges. There is also a need for innovative strategies to assess structural integrity throughput the life of a part, to avoid or mitigate potential consequences, and to obtain more accurate and quantitative data on the damage evolution in such structures. To enhance longevity and structural performance, next generation concrete infrastructure must integrate high performance structural systems that have health monitoring capability in order to obtain real-time data on the condition of structures and timely detect anomalies in the structural performance. One potential solution to this need includes multifunctional materials systems: structural materials that provide simultaneous sensing capabilities that can be easily assessed.

Objectives

The objective of this collaborative research is to design, fabricate and characterize multifunctional, low-cost and large scale Cu-based and Fe-based shape memory alloy (SMA) rods to be used as strengthening elements for reinforced concrete structural elements. Therefore, this research addresses the following tasks:(1) Design and characterization of low-cost multifunctional materials, in particular iron and/or copper based SMAs. (2) Demonstration of the use of these low cost SMAs as NSM strengthening systems to

enhance the capacity of RC bridges; (3) Demonstration of self-assessing capabilities of these NSM strengthening systems in a realistic infrastructure system.

Intended Implementation of Research

Education and Workforce Development: 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 mechanics, and structural engineering. The training of graduate students will also 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. Beyond directly mentoring students, this project will be integrated in 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.

Our team will leverage a number of industry training and outreach programs that have been successful at Texas A&M. Karaman and Hartl have previously given short courses on shape memory alloys to engineers from numerous Texas companies, 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. Interested TRAN-SET industrial partners are invited to attend the Summer School on Computational Materials Science held annually at Texas A&M. A new module on Materials Informatics has been included in the 2018 edition of the school. Industrial rates have been established on a per module basis. Knowledge generated from the research study is to be incorporated into educational and training activities.

Outreach: The proposed research study will engage future researchers and engineers to careers in transportation, by developing activities that would encourage a hig her 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. 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 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 woman students..

Anticipated Impacts/Benefits of Implementation

To be reported at the conclusion of the project.

Web Links

- TranSET’s website (https://transet.lsu.edu/research-in-progress/)
- TRB's Research in Progress (RIP) database (https://rip.trb.org/View/1644242)

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”.

Learn More

For more information about Tran-SET, please visit Our Website, LinkedIn, Twitter, Facebook, and YouTube pages. Also, please feel free to contact Mr. Christopher Melson (Tran-SET Program Manager) directly at transet@lsu.edu.