Reduction of Structural Damage from the Thermal Expansion of Concrete Using Multifunctional Materials

Analyzing and designing shape memory components to address the issue of thermal expansion in concrete structures

Highlight | Jan. 2019

Project No. 18STTAM01

PI: Dr. Darren Hartl (TAMU)

POP: March 2018 – November 2019

This study will leverage past successes in the analysis and design of shape memory components to address the issue of thermal expansion in concrete structures. It is hoped that the results of this work could help to design smarter civil infrastructures incorporating multifunctional materials into the old civil engineering material. Since the SMA used in the current work is relatively cheaper than other common SMAs (less than $50/lb compared to NiTi which is about $200/lb due to difficulties in processing), it is anticipated that the findings of the current research could be implemented in real infrastructures made of concrete, asphalt concrete, and other complex large infrastructures. For the applications considered, low-cost Fe-SMAs and other multifunctional materials can be considered as a replacement for components made of steel (e.g., in reinforced or plain jointed concrete pavements) to control distresses resulting from thermal expansion during seasonal/daily temperature change. Through a combined approach of structural optimization, mechanics, and materials design, this research aims at simultaneously achieving advantageous mechanical properties and passive actuation behavior in a single material for concrete infrastructures.

Background

Control of thermal expansion is a critical goal of engineering design in a wide range of applications, particularly in cases where system components are small, are subject to large changes (gradients) in temperatures, or require extreme dimensional stability over a wide range of temperatures. Thermal expansion causes thermal stresses in structures and structural failure can happen as a result of excessive thermal strains. In structures made of brittle materials (e.g., concrete), stresses induced by the thermal expansion would lead to the catastrophic structural failure. Thermal expansion compensation often requires materials with either negative or (close to) zero thermal expansion. Because of the thermomechanical coupling behavior, shape memory alloys are one of the best candidates for this purpose. The most common SMA candidate for such applications is the NiTi SMA, which is expensive for civil infrastructures due to large scale applications. For such reasons, we can replace NiTi SMA with iron-based SMA which is low-cost and can be processed easily, compared to NiTi SMA, to address the issue of thermal expansion. However, integrating such high performance materials into next generation designs is challenging since systems and materials that address the problem of thermal expansion must not significantly increase the overall complexity of the current infrastructure and must be scalable so that they may be implemented in a variety of structural configurations. Materials with passive actuation based on changes in temperature could be used to counter the damage caused by thermal expansion. Solutions that incorporate design optimization and adaptive, durable materials are of particular interest.

Project Summary

This study will address the following research tasks:

- Design and characterization of multifunctional materials for reduction of structural damage from the thermal expansion;
- Optimization of the topology and configuration of these materials in infrastructures to improve the structural performance against thermally induced distresses; and
- Demonstration of capabilities of the approach in a realistic infrastructure system.

Status Update

Shape memory alloys (SMAs), through their ability to recover strains through thermal loading-induced phase transformations, offer a distinct advantage in achieving this design goal as such strain recovery in embedded components could be used to oppose thermal expansion in a surrounding matrix (e.g. concrete). Studies have been developed to characterize the thermal expansion of system, comprised of an SMA rod embedded in a concrete block undergoing a thermal loading cycle. Characterization is produced through a full factorial analysis, wherein evaluation is performed through the Abaqus unified finite element analysis suite. This preliminary analysis indicates that, while iron-based SMAs show promise in this field due to their low manufacturing costs, their large thermal hysteresis may lead to limited phase transformation in this application.

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.

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".

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.