Transportation Consortium of South-Central States (Tran-SET)

Evaluation of Fresh and Hardened Properties of 3D-Printed Engineered Cementitious Composites (ECC) Designed for Sustainable and Resilient Infrastructure Systems

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Principal Inverstigator(s):

Maryam Hojati

University of New Mexico

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University of New Mexico

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$ 100,000

Evaluating fresh and hardened properties of sustainable 3d-printed ECCs

Additive manufacturing (AM) is revolutionizing many manufacturing fields worldwide. AM enables the fabrication of 3D-objects by extruding filaments following a designed pattern. There are some challenges in applying AM to 3D-printing of concrete structural elements. These limitations are mainly associated with the fresh properties of concrete mixtures, the possibility of cold joint formation between different layers, and the incorporation of reinforcing components (i.e., steel bars). Because of these limitations, conventional concrete mixtures cannot be used for the 3D-printing application. One of the crucial challenges against the broader adoption of concrete 3D-printing is reinforcing 3D-printed components to reach acceptable structural performance under different loading configurations. Therefore, we should design a concrete mixture that can be utilized as a rebar-free material but address both strength and ductility requirements. Recently, the development of Engineered Cementitious Composites (ECC) has neared the possibility to obtain both criteria (i.e., strength and ductility) in the concrete structures without embedding steel reinforcement. Hence, ECC can be used as an intrinsically reinforced cementitious material for the 3D-printing of concrete components. This project proposes ECC mixtures' design by mostly using the available local materials and admixtures in Region 6 and then studies the fresh and hardened properties of these 3D-printed mixtures as a function of mixture proportions. The ECC mixtures' properties, which will be evaluated in this proposal, include the extrudability and buildability as the fresh properties and compressive, flexural, and tensile strength of 3D-printed ECC elements as hardened properties.

Problem Statement

Extrusion-based 3D-printing is a novel manufacturing process, where the slurry or paste materials are extruded through a nozzle layer-wisely to make a 3D-object by using a designed digital-path. It is believed that 3D-printing will be the next industrial revolution because of the quick and cheap production of objects from simple to complex designs and geometries. Over the last few years, several 3D-printing technologies have also been developed for building and construction. Compared to conventional methods of construction, 3D-printing has the potential for automation, reduced construction cost (in terms of labor and formwork), time, material waste, and energy; and fabrication of geometrically complex structures. One of the critical limitations for broader adoption of concrete 3D-printing in the civil infrastructures is the difficulty of providing reinforcement to achieve sound structural performance under different loading conditions. Therefore, the application of intrinsically reinforced cementitious materials has the potential to address this barrier and yield significant benefits such as enhanced structural capacity, durability and resiliency. For this reason, the unique mechanical properties of ECC positions this composite as a suitable candidate for the 3D-printing of civil infrastructure. However, the inclusion of high quantity fibers, as a suitable reinforcement method for 3D-printable cementitious materials, has an adverse impact on fresh properties of material behavior. According to previous studies, the fiber incorporation would decrease the flowability and extrudability of 3D-printed concrete. Optimizing the mix design of ECC is required to engineer the fresh properties of ECC for 3D-printing. Additionally, with no vibrator employed for further compaction of 3D-printed elements, small linear voids are possible to form among extruded filaments owing to the layer-by-layer extrusion method, resulting in anisotropic behavior. These voids would be defects in the 3D-printed structures and adversely influence the hardened properties of the 3D-printed component. Furthermore, because of the inherent layered structures of the 3D-printed material, special attention shall be paid to the interface development across different concrete layers.

Objectives

This project will advance the application of novel manufacturing techniques, including 3Dprinting, autonomous equipment, and advanced construction materials, such as ECC, in the transportation infrastructure project of Region 6, such as prefabrication of different segments of bridges by using the 3D-printing technique. In the first phase of this study, ECC mixtures would be developed by using different content of chemical and mineral admixtures, fine local aggregates, and different types and contents of fibers. The fresh characterization of the designed mixtures will be measured and the viability of the developed mixtures in terms of required water content for 3D-printing, extrudability, and buildability will be evaluated. Then in the hardened phase of 3D-printed ECC elements, the mechanical properties of the 3D-printed elements such as compressive strength, flexural strength, tensile strength and ductility of 3Dprinted specimens will be measured.

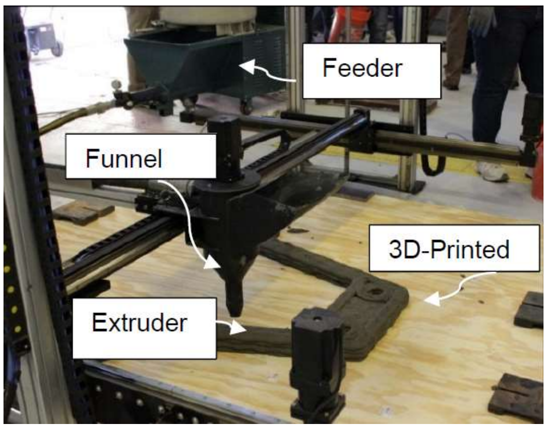

Figure 1. UNM Dana C. Wood Materials and Structures Lab 3D-Printing Systems

Intended Implementation of Research

The knowledge generated from this research study will be disseminated and transferred to the stakeholders who might be interested in the study outcomes. This research project will provide funding to one graduate student at University of New Mexico (UNM). This will help recruit and train future leaders in the Transportation Sector specializing in development of new materials for transportation infrastructure. The research team will also prepare educational material on ECCs to be incorporated in courses at UNM and share it with other universities. Results of this work will be also disseminated at national conferences such as Tran Set, TRB and ASCE.

Anticipated Impacts/Benefits of Implementation

The outcome of this research project will be several characterized 3D-printed ECC materials that will be readily available for implementation in local infrastructure as well as 3D-printing technology.

Web links

- Tran-SET's website https://transet.lsu.edu/research-in-progress/

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 Dr. Momen Mousa (Tran-SET Program Manager) directly at transet@lsu.edu.