Exhibit D

Research Project Requirement Template

Durability Assessment of Binders with Interlayer Reinforcement for 3D Printed Elements

Recipient/Grant (Contract) Number: 69A3552348306 (CY1-OU-03)

Center Name: Southern Plains Transportation Center (SPTC)

Research Priority: Improving the Durability and Extending the Life of Transportation

Principal Investigator(s): Shreya Vemuganti, University of Oklahoma

Project Partners: University of Oklahoma, University of New Mexico (consulting collaborators)

Research Project Funding: University of Oklahoma: $46,622 (Match)

Proposed Start and End Date: 10/1/2023 to 09/30/2024

Project Description: 3D Concrete Printing (3DCP) is one of the fastest emerging technologies and involves layer-by-layer building of a binder material with additives without the use of formworks while enabling the design freedom to produce complex structural geometries. To enable this technology to reach end-use applications in construction such as printing large-scale, fail-safe concrete structural elements, the low tensile strength of concrete is to be overcome. Incorporating reinforcement such as steel between printed layers to carry tensile stress is at the risk of exposure to environmental degradation mechanisms such as chloride ingress and freeze-thaw which affect their durability due to lack of formwork and the weak morphology of the interface.

In this study, it is hypothesized that intrusion of chlorides and exposure to freeze-thaw will decrease the flexural strength and interlayer strength of reinforced 3DCP elements. In addition, 3DCP elements with fiber-reinforced polymers may show increased resistance to deterioration mechanisms while improving flexural and interlayer strength. This project aims to assess the durability properties of cementitious binders with interlayer reinforcement to aid in the design and development of 3DCP elements for transportation systems. The objectives of the proposed study are to answer two issues: the effect of deterioration mechanisms such as chloride ingress and freeze and thaw on the mechanical performance, and flexural strength capacities of (a) cementitious binders with successive layers representing 3D printed elements and (b) cementitious binders with different types of reinforcement incorporated at the interface between successive layers.

The following tasks will be pursued to achieve the aforementioned objectives: (1) developing a database of mix design for 3D printed concrete by targeting the specific workability requirements; (2) preparing specimens with steel, glass fiber (GF), and carbon fiber (CF); (3) subjecting specimens to deterioration mechanisms including freeze-thaw and chemical ingress; (4) testing specimens without exposure, with freeze-thaw exposure and chemical ingress exposure in flexure and obtain a database with graphs of load vs displacement behavior; (5) investigating failure interfaces using microscopic analysis; (6) performing a training session for rural STEM high school teachers; and (7) identifying large-scale structures for 3D printing durable elements.

US DOT Priorities: This project will address the USDOT Strategic Goal of Climate and Sustainability, particularly focused on the following: (a) infrastructure resilience by developing the database necessary to design durable and fit-for-purpose 3D printed elements for transportation systems; (b) net zero emissions vision by using natural, novel, and durable materials; (c) use of materials for reinforcement that can extend infrastructure life and improve durability. It will also address the transformational research through the following: (a) advancing breakthroughs in 3D printing concrete with reinforcement for transportation systems; (b) advancing innovation to meet challenges in current 3D printing and lead towards the pathway to promote end-use applications; (c) modernizing transportation systems through flexibility and adaptability by using 3D printing; (d) pursuing purpose-driven research to strengthen the current and future of transportation systems.

Outputs: The outputs of this project include: (1) mix designs based on the existing literature review of 3D printed concrete by targeting the specific workability requirements, fresh properties, and hardened properties; (2) load vs displacement graphs, average strengths, and failure mechanisms from flexural testing of 3DCP elements with three types of interlayer reinforcement and two types of deterioration mechanisms. At least one journal paper, one poster presentation, and a 3–5-minute video summarizing the findings of this project are expected from this study.

Outcomes/Impacts: This work offers solutions to using 3DCP with reinforcement for large-scale structural and non-structural elements that could save 35% to 60% of the total monetary expense of concrete construction since no formwork is needed and can reduce global energy usage by 25% by 2050, in terms of the carbon footprint generated by materials, process energy, and transportation. The outputs from this project address the knowledge gap about 3DCP for strength and durability-demanding applications.

Final Research Report: