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An Innovative Reinforcement Approach for Rebar-Free 3D Printing of Transportation Infrastructure

A research team at Louisiana State University (LSU) developed an innovative, rebar-free Construction 3D Printing (C3DP) process to encourage efficient and resilient transportation infrastructure development. LSU is the lead university at the Region 6 University Transportation Center, (UTC) Transportation Consortium of South Central States, or Tran-SET. Tran-SET is a collaborative partnership comprised of 11 institutions across five states, focusing on “Improving the durability and extending the life of transportation infrastructure.” A major challenge addressed by Trans-SET researchers is in the widespread application of C3DP, which currently lacks seamless integration of reinforcement into the automated layering process using conventional concrete reinforcement techniques.

An integrated and automated reinforcement approach enables the automated construction of structures and bridges, and can reduce the construction time and cost. This project developed a fully characterized printable self-reinforced mixture and provided comprehensive experimental data on the performance of an alternative reinforcement technique under different loading conditions. This is an important first step towards the automated construction of structural elements without the need for manual insertion of conventional steel rebars.

Reinforcement integration techniques in C3DP have been explored by multiple researchers in the past. However, most methods required manual installation, were tedious and inefficient, or needed further investigation on account of various technical issues such as very slow process speed or unknown behavior of the reinforced element at different scales. The proposed configuration uses Steel Fiber Reinforced Concrete (SFRC) as a self-reinforced printing material and as an additional strengthening technique using discontinuous vertical reinforcement elements. The vertical reinforcement technique includes the insertion of mini-rods during the layer deposition process, which can be fully automated and integrated into the 3D printing process.

The experimental program was designed to develop printable mixes with varying steel fiber reinforcement amounts. Different proportions of limestone and silica sand to substitute cement were used to prepare environmentally friendly and low-cost mixes. Figure 1 shows a lab-scale concrete printer used to prepare the specimens. The printer can print elements with maximum dimensions of 2.1m (L) x 0.9 m (H). The equipment is also equipped with a touchscreen user interface that controls the printing parameters such as extrusion rate and nozzle traveling speed. Specimens were printed with both four and 14 layers, with different interlayer time gaps of 1 and 3 minutes, respectively. Figure 2 shows a printed 4-layer sample.

The research team created specialized nozzles to improve the surface quality of printed layers. Multiple designs were tested and studied to enable the printing of wide layers. A screw insertion device was also designed to enable additional reinforcement of 3D printed specimens. The device was mounted to provide swift insertion of

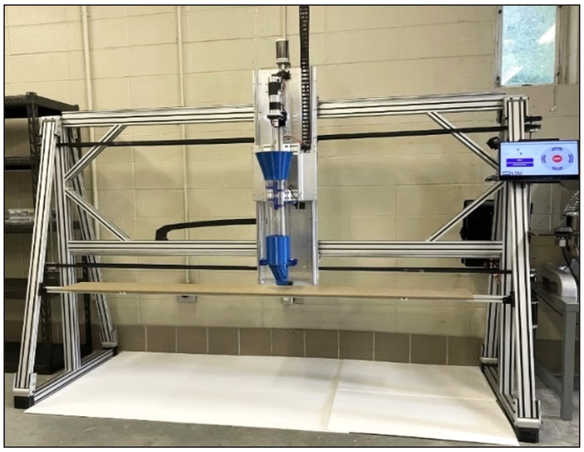

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Figure 1. The lab-scale 3D concrete printing platform at the recast lab at LSU

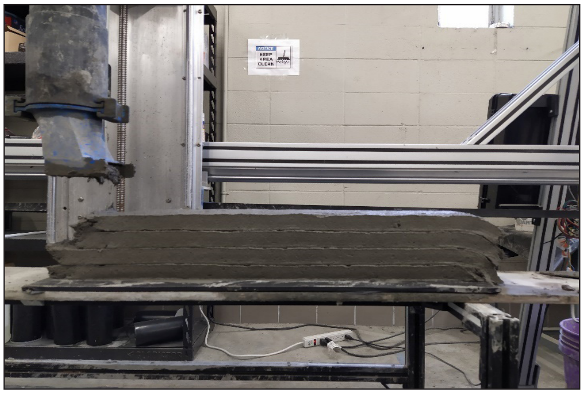

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Figure 2. Printing of specimens at 2.5% steel fiber dosage

discontinuous reinforcement elements (mini-rebars) during printing. A motor and microcontroller were used to regulate the speed and direction of the process.

To study the reinforcement process, different types of reinforcement such as threaded screws of various configurations were studied. Manual reinforcement insertion created large voids and deformation in the printed layer, which can cause weak bonding between the concrete and reinforcement. Steel screws were used as an additional strengthening mechanism in the printed specimens. Figure 3 shows the reinforcement insertion in progress with the rebar insertion device.

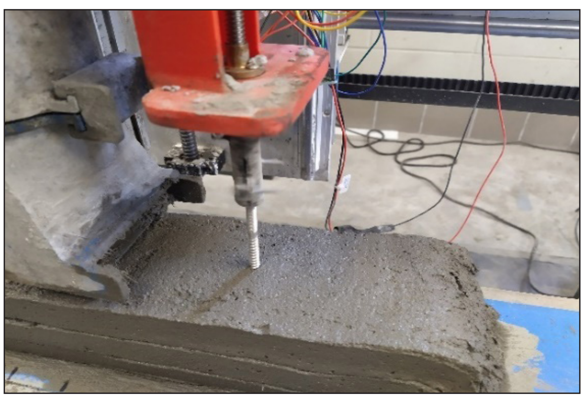

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Figure 3. Design of beams in Z-directions with screw reinforcement insertion in progress with the rebar insertion device

From the different tests conducted to determine the mixture performance of concrete specimens, it was found that limestone powder with low steel fiber content helped to reduce the amount of cement in the mixture to produce a sustainable product and improved the surface quality of the printed layers and showed a comparable or higher mechanical performance. High steel fiber dosages resulted in a significant increase in mechanical strength. Moreover, beams with reinforcement showed a better flexural strength than the beams without any reinforcement.

To further study the contribution of fiber reinforcement on mixture performance, micro-Computed Tomography (CT) scans were conducted to evaluate the orientation and distribution of steel fibers relative to the printing direction. Figure 4 shows a 3D image obtained from one of the scans. Based on the scans, conclusions were made about the applicability of nozzles, fiber content, sand content etc. It was also observed that for a specific orientation (30°-60°) of fibers in a mixture, the resistance to fiber pullout was the highest. It was concluded that due to the uniform alignment of fibers possible due to the printing process, flexural strength of the 3D printed samples was higher than traditionally prepared concrete samples.

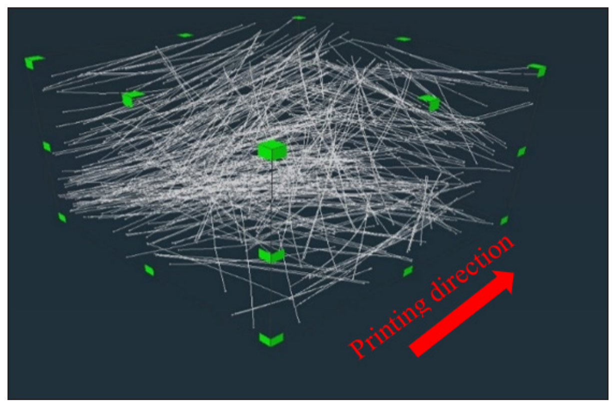

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Figure 4. 3D view of traced fiber centerlines

To reduce the dependency on fiber usage and develop superior performing concrete mixes, another project funded by Tran-SET explored the possibility of using Ultra High Performance Engineered Cementitious Composites (UHP-ECC) in the C3DP process. UHP-ECCs are novel concrete materials exhibiting excellent mechanical strength. Locally-sourced, sustainable materials will be used in the future to develop low-cost concrete mixes.

About This Project

The project "Rebar-Free 3D Printing of Transportation Infrastructure" was led by the Principal Investigator Dr. Ali Kazemian, and Co-Principal Investigators Dr. Marwa Hassan, and Dr. Hassan Noorvand. Dr. Marwa Hassan is the director of Tran-SET UTC and the CETF Distinguished Professor in the Department of Construction Management, College of Engineering, at Louisiana State University. For additional information, please send inquiries to kazemian1@lsu.edu, marwa@lsu.edu or hnoorv1@lsu.edu.