



**INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS**

Name of the Student : Dhrutiman Dey
Roll Number : 206103110
Programme of Study : Ph.D.
Thesis Title: Printability, mechanical and thermal performance study of sustainable concrete lattice structures
Name of Thesis Supervisor(s) : Dr. Biranchi Panda
Thesis Submitted to the Department/ Center : Department of Mechanical Engineering
Date of completion of Thesis Viva-Voce Exam : 06/06/2025
Key words for description of Thesis Work : Concrete 3D Printing, Digital Construction, Lattice structure, Thermal and mechanical performance,

SHORT ABSTRACT

Concrete 3D printing (3DCP) is an advanced construction technology that uses additive manufacturing technique to build structures layer by layer, offering greater precision, reduced waste, and design flexibility compared to traditional methods using formwork. Despite these advantages, 3DCP faces significant challenges that must be addressed to enhance its sustainability and functionality. 3D printable concrete typically requires no coarse aggregate, higher cement paste volume and induce significant embodied carbon. The usage of fine aggregates, often sourced from natural river sand causes ecological damage, including habitat destruction and biodiversity loss. Consequently, there is an urgent need for the development of low carbon 3DCP mixes by utilizing local materials and industrial wastes. The material as well as 3D printed structure design can be tailored for improving fresh, hardened and functional properties such as thermal conductivity, which perfectly align with the growing demand for sustainable and functional structures in the built environment. The main objective of this research is three-fold: (1) development and characterization of 3D printable sustainable mortar mixes using two steel industry by-products such as Portland slag cement and slag sand (2) exploring flexural response of 3D printed concrete structures with different lattice configurations and (3) an accurate steady-state approach for comprehension of thermal performance of lattice infilled 3D printed concrete walls.

First, the development of sustainable 3D printable thixotropic mortar is explored, aiming to uncover the influence of Portland slag cement (PSC) and slag sand (SS) on fresh, hardened and thermal properties. The results of printing trials revealed smooth extrusion of fresh concrete, characterized by the excellent dynamic yield stress and plastic viscosity, affected by the PSC and SS content. The angular morphology of SS enhanced inter-particle friction, while PSC's finer particles and high reactivity contributed to better cohesion and print stability. The synergetic effect of PSC and SS resulted highest buildability but reduced the open time to 20 minutes, compared to the control (OPC and river sand) mix having 40 minutes' open time. In the hardened state, SS improved thermal resistance by reducing crystallinity and increasing phonon scattering but directional compressive strength was slightly reduced due to the higher porosity. It was also found that PSC resulted in improved carbon sequestration capacity by decalcifying

secondary hydration products. These findings were substantiated by microstructural analyses, including X-ray diffraction (XRD), thermo-gravimetric analysis (TGA/DTG), and mercury intrusion porosimetry (MIP). Despite the higher cost associated with SS, the sustainability analysis highlights lowest equivalent CO₂ emissions (327 kg/m³) for mixes containing both SS and PSC. These results show potential of direct utilization of the steel industry by-products to formulate printable mortar mixes, while addressing both material performance and ecological sustainability.

Second, flexural performance of 3D-printed concrete beams with extant lattice infilled configurations was experimentally tested in two different loading (vertical/transverse) directions. A multi-scale finite element (FE) simulation was developed to model the mechanical behavior, and the proposed FE model was calibrated through experimental testing. The comparative analysis of simulation and experimental results proves the reliability of the numerical model, which correctly estimated the peak load and damage patterns. Leveraging this validated model, parametric studies were conducted by varying the ratio of horizontal-to-triangular pattern lengths to optimize the infill design. These studies led to the development of lattice infill-optimized simply supported beam, achieving a substantial improvement in peak load (60%) and maximum midpoint displacement (12%). These findings underscore the critical role of infill configuration optimization in enhancing structural performance, offering a pathway for design of light weight 3D-printed concrete components.

Third, thermal performance of 3D-printed concrete walls with different lattice infill configurations was explored through a combination of experimental testing and steady state CFD numerical modelling, aiming to uncover the underlying mechanism, direction and magnitude of heat flow affecting thermal transmittance. A calibrated numerical model accurately predicted the thermal performance, underscoring reliability of the proposed model. Based on the model suggested heat transfer mechanism, we expand the lattice design space, aiming to uncover configurations that exhibit superior performance with insulation material. The results indicate lowest U-value (0.79 W/m²K) of modified partially insulated lattice infill wall, surpassing the studied configurations. This study offers a critical evaluation of infill configurations to develop thermally efficient cost-effective concrete wall, that align with the growing demand for lightweight, functional structures in built environment. In summary, the present work advances the research in 3DCP by developing printable sustainable mixes along with model driven strategies to design infill lattice configurations for lightweight structures, where both mechanical and thermal performance are essential.