

# **Title: Design of thermally Adaptive Concrete Incorporating Phase Change Materials for Climate-Resilient Infrastructure (OLP 2602)**

## **Abstract:**

The proposed research is motivated by the limited performance of conventional cement-based concretes under low-temperature conditions, particularly below 5°C and sub-zero environments, where hydration kinetics slow significantly, internal thermal gradients increase, and susceptibility to freeze-thaw damage becomes critical. In cold and high-altitude regions of India, such as the Himalayan belt, concrete infrastructure frequently experiences premature deterioration due to repeated freeze-thaw cycling, despite the use of conventional mitigation strategies such as air-entrainment or supplementary cementitious materials.

The novelty of this research lies in advancing the role of Phase Change Materials (PCMs) in concrete from conventional thermal energy storage in buildings to multi-functional applications in climate-resilient infrastructure. Unlike traditional additives such as fly ash, silica fume, or air-entraining agents, which primarily modify pore structure or accommodate ice expansion, PCM integration provides an active thermal regulation mechanism. Through latent heat absorption and release, PCMs can buffer rapid temperature variations, delay ice nucleation, and mitigate freeze-thaw damage, a functionality absent in conventional approaches.

Building on this principle, the proposed work aims to develop a multifunctional PCM-concrete system that enhances both thermal energy efficiency and material durability under extreme cold-weather conditions. The focus is on developing thermally adaptive concrete composites capable of moderating internal temperature fluctuations to improve indoor thermal comfort, while simultaneously mitigating freeze-thaw-induced microcracking and extending service life through latent heat exchange. This approach directly addresses the challenges prevalent in India's high-altitude and Himalayan regions, where prolonged sub-zero exposure and steep thermal gradients are critical, necessitating both effective thermal regulation and protection against freeze-thaw damage. Beyond building energy applications, the research extends the potential of PCM-concrete to strategic infrastructure sectors including border defence facilities, hydropower structures, mountain highways, tunnels, and cold-chain systems, where thermal regulation and material durability are critical. By integrating thermal regulation with durability enhancement, this work aligns material innovation with national priorities in sustainable infrastructure, energy security, and climate resilience.

Ordinary Portland Cement (OPC) will be used as the primary binder system in the proposed study to establish a clear baseline for evaluating the influence of MPCMs on concrete performance under low-temperature conditions. OPC-based systems are widely used in Indian infrastructure and are known to exhibit reduced hydration rates, delayed strength development, and increased vulnerability to frost damage when exposed to temperatures below 5°C.

At low temperatures, the release of latent heat from MPCMs during phase transition is expected to locally elevate and stabilize the internal temperature of concrete, thereby promoting continued cement hydration, delaying ice crystallization within capillary pores, and reducing thermally induced stresses. This targeted thermal regulation near the critical freezing threshold provides a mechanistic basis for improved freeze-thaw resistance and enhanced durability, which will be systematically evaluated in the proposed work. The outcomes are expected to contribute to sustainable infrastructure development, offering a cost-effective alternative to high-carbon, high-cost advanced materials such as ultra-high-

performance concrete (UHPC), particularly for strategic and remote applications. Simultaneously, the proposed project will serve as a foundation for follow-up studies focusing on hybrid PCM systems combined with fibers or nano-modifiers, extension to higher-strength and specialty concretes, and long-term field validation under real climatic conditions. Such studies will support the translation of laboratory findings into commercially viable, climate-resilient construction materials.

**Objectives:**

To design and develop a thermally adaptive OPC-based concrete (target strength 30 MPa) incorporating microencapsulated phase change materials (MPCMs) for improved thermal regulation, early-age performance, and freeze-thaw durability under low-temperature conditions, with potential applications in climate-resilient and cold-region infrastructure.

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