

Ph.D. DISSERTATION DEFENSE

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Date:	Friday, May 1 st , 2026
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Title:	Carbonation Engineering and CNC-Assisted Nano-Engineering of Waste-Derived Materials for Low-Carbon Concrete
Chairperson:	Dr. Weina Meng, SES/Department of Civil, Environmental and Ocean Engineering
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ABSTRACT

This dissertation develops engineering strategies to transform waste-derived materials and CO₂-derived nano-materials into functional constituents for low-carbon concrete. The work is organized around two complementary approaches: carbonation engineering and cellulose nanocrystal (CNC)-assisted nano-engineering. Through five interrelated studies, it addresses major barriers that limit the direct use of recycled concrete aggregate (RCA), blast furnace slag, produced water (PW), nano-CaCO₃, and nano-silica in cementitious systems, including weak microstructure, low reactivity, poor interfacial bonding, agglomeration, and environmental risk. Multi-scale characterization was combined with fresh, mechanical, and durability testing to establish structure-property relationships and practical treatment pathways.

Under carbonation engineering, a slag-coated carbonation treatment was developed for RCA to supply external calcium and silica during carbonation, reducing water absorption by up to 40% and increasing bond strength with new cement paste by up to 65%. Carbonation was also applied to slag for low-carbon ultra-high-performance concrete, where slag mineral composition was shown to control carbonation degree and CaCO₃ polymorph formation; carbonated slag improved compressive strength by up to 20%, flexural strength by 30%, toughness by 45%, and reduced strength-normalized carbon footprint. In addition, carbonation enabled the use of 100% PW in cementitious systems by refining microstructure and mitigating durability and environmental concerns, increasing compressive strength by 15%, lowering chloride penetrability, reducing alkali-

silica reaction expansion by 25%, immobilizing heavy metals, and producing strong thermal-insulation potential.

Under CNC-assisted nano-engineering, CNC was used as a bio-based dispersant and interfacial modifier to improve the effectiveness of CO₂-derived and pozzolanic nanoparticles. For nano-CaCO₃ synthesized through carbonation, CNC improved dispersion, altered polymorph formation and crystallinity, and increased compressive and flexural strengths by up to 52% and 30%, respectively. For RCA treatment, CNC-assisted nano-silica coating improved nanoparticle dispersion and retention on old adhered mortar, reducing RCA water absorption by up to 30% and enhancing concrete performance, including 77% higher slant shear bond strength, 25% higher compressive strength, lower drying shrinkage, and better chloride resistance.

This dissertation establishes a unified framework in which carbonation engineering upgrades waste-derived materials and CNC-assisted nano-engineering stabilizes nano-material functions, enabling more sustainable, durable, and mechanically reliable low-carbon concrete for structural and infrastructure applications under practical material constraints.