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Ph.D. DISSERTATION DEFENSE

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Title:	Ultra-High-Performance Concrete for Marine Infrastructure: Strategies to Optimize Strength, Sustainability, and Durability
Chairperson:	Dr. Yi Bao, Department of Civil, Environmental & Ocean Engineering
Committee Members:	Dr. Weina Meng, Department of Civil, Environmental & Ocean Engineering Dr. Ronghuan Xu, Department of Civil, Environmental & Ocean Engineering Dr. Benjamin Paren, Department of Chemical Engineering and Materials Science

ABSTRACT

Ultra-high-performance concrete (UHPC) offers superior strength and durability for marine infrastructure while its widespread adoption is limited by high cement content, reliance on natural sand, and the lack of structural-scale life-cycle data that represent actual service behavior and maintenance needs in marine environments. This dissertation addresses these challenges through three integrated studies. First, cellulose nanocrystals (CNCs) are investigated as a renewable nanoreinforcement to enhance sustainability and mechanical performance. However, their use is hindered by severe agglomeration in the highly alkaline, multivalent-ion-rich cementitious environment. By clarifying why CNCs agglomerate in cementitious systems and systematically assessing five dispersants, this study identifies the PCE–PAA combination as the most effective dispersant, providing stable CNC suspensions and up to 20% higher 28-day compressive strength in cementitious composites. Second, microplastics (MPs) are evaluated as a sustainable fine aggregate replacement to reduce reliance on natural sand and divert plastic waste, but their weak interfacial transition zone (ITZ) lowers UHPC's mechanical performance and limits structural capacity. To resolve this, two approaches—nanomaterial coating of MPs to densify the ITZ and direct nanomaterial incorporation to enhance matrix packing—are developed and validated across ten UHPC mixtures, both improving mechanical performance at MP replacement levels up to 50%. Third, to quantify long-term performance in marine environments, a cradle-to-grave life-cycle assessment (LCA) framework is established that integrates real-time crack-width data from digital image correlation and distributed fiber optic sensors to determine maintenance scheduling. Application of this framework to conventional and UHPC beams demonstrates that UHPC materials reduced life-cycle cost and carbon emission by up to 55% and 58%, respectively, with additional savings of 64% and 76% achieved when shear reinforcement is removed.