IMPACT OF NONTRADITIONAL AND NATURAL POZZOLANS (NNPS) AND NANOSILICA ON CONCRETE PERFORMANCE IN LABORATORY AND FIELD ENVIRONMENTS

ABSTRACT

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Infrastructure is one of the cornerstones of modern society. At its core, it is largely built from concrete, a material so widely used that it is second only to water. While concrete's strength, durability, and versatility make it so indispensable, its environmental impact (primarily from cement production, which is responsible for 5–7% of anthropogenic CO_2 emissions) is a growing concern. To meet carbon neutrality goals by 2050, the concrete industry is turning to supplementary cementitious materials (SCMs) to reduce cement usage and enhance durability. However, the supplies of traditional SCMs are dwindling, prompting interest in alternatives such as nontraditional and natural pozzolans (NNPs) and nanosilica (nS).

This dissertation focuses on evaluating the use of NNPs and nS in concrete mixtures, with an emphasis on their performance, durability, and practical field application. Eight NNPs, including calcined clays (CCs), volcanic ashes (VAs), ground bottom ashes (GBAs), and fluidized bed combustion (FBCs) ashes, were first evaluated in the lab at 25% replacement using both Type I and Type IL portland cement. Results demonstrated a comparable or superior performance relative to the control mixture in terms of strength. Furthermore, the mineralogy and particle size of these materials influenced their pozzolanic activity and strength development, enabling the development of a predictive model for 56-day strength.

Field trials used one CC and two VAs to conduct full-scale slabs (8' x 8' x 10") using concretes with different w/cm ratios (0.44, 0.47, and 0.50), cement contents (529 lb/yd^3, and 564 lb/yd^3), and replacement percentages (20%, and 25%). These mixtures were benchmarked against reference and fly ash concrete, under two different curing regimes (plastic sheet and sprayed curing compound). Compared to control and fly ash mixtures, natural pozzolan (NP) concretes showed equal or better performance across a range of strength and durability tests, particularly when treated with curing compound.

The synergistic role of nS was subsequently explored in lab mixtures containing the same NPs to further bolster their performance. The addition of nS to NP mixtures enhanced hydration, compressive strength, pore structure, and certain durability parameters (reduced calcium

hydroxide content, reduced degree of saturation, and improved air void systems). However, nS alone (without NPs) offered limited benefits, demonstrating the importance of synergistic effects.

Concrete mixtures with nS were then developed based on the requirements of the Indiana Department of Transportation (INDOT) for mixtures used in bridge decks at reduced cement contents (566 lb/yd^3, 580 lb/yd^3, and 610 lb/yd^3) and w/c ratios (0.42, 0.46, and 0.48). Nanosilica improved freeze-thaw resistance and air void structure but showed limited strength or gain in the transport properties, indicating the need for dosage optimization.

Two final mixes were selected for field trials: a conventional mixture (658 lb/yd^3 of cement, and w/c 0.44) and a mixture with reduced cement content and nS (580 lb/yd^3 of cement, and w/c 0.46). Both were used to cast 8' x 8' x 8" slabs. Field trials demonstrated that concrete mixtures incorporating nS can achieve acceptable durability performance, especially against freeze-thaw and chloride ingress. These field mixtures were compared to their counterpart mixtures in the lab, where differences in workability were observed and no significant improvements over baseline mixtures (i.e., same cement content and without nS) were noticed, suggesting that further investigation is needed to determine optimal use conditions.