

Assessment of Strength Development and Microstructure in Cement Mortars Incorporating Volcanic Ash and Nano-Silica

Esraa A. Al-Ali

Kuwait Institute for Scientific Research

Dana J. Dashti

Kuwait Institute for Scientific Research

Amer N. Al-Arbeed

Kuwait Institute for Scientific Research

Abstract

The development of cementitious materials with improved performance and reduced environmental impact is an important component of sustainable construction. This study investigates the influence of volcanic ash (VA) and nano-silica (NS) on the strength development and microstructural characteristics of cement mortar. Three mortar formulations were investigated, including a reference mixture containing Ordinary Portland Cement (OPC), a mixture incorporating 30% volcanic ash as a partial cement replacement, and a mixture containing 2% nano-silica. The experimental program considered the evolution of mechanical performance at different curing ages, with compressive, flexural, and tensile strengths evaluated to assess both early-age and long-term behaviour. In addition, scanning electron microscopy (SEM) was employed to examine changes in the morphology and development of hydration products within the cementitious matrix.

The results demonstrated that the incorporation of nano-silica significantly influenced the strength development of the mortar, particularly at early and intermediate curing ages. The nano-silica mixture consistently exhibited enhanced mechanical performance compared with the reference mixture, which can be associated with its fine particle size, filler effect, and contribution to the formation and densification of calcium silicate hydrate (C-S-H) phases. In contrast, the volcanic ash mixture exhibited slower strength development, particularly at early ages, although continued hydration and pozzolanic activity contributed to progressive microstructural development with extended curing. SEM observations further indicated differences in matrix morphology and the distribution of hydration products among the investigated mixtures. Overall, the findings demonstrate that the performance of sustainable cement mortars is strongly influenced by the type and characteristics of the cement-replacement material. The study highlights the potential of combining conventional supplementary cementitious materials with nano-scale modifications to develop cement-based materials with improved mechanical performance while reducing reliance on OPC.

Keywords

Sustainable cementitious materials, volcanic ash, nano-silica, cement mortar, strength development, microstructure, C-S-H, supplementary cementitious materials.