Benefits of Metakaolin in HPC

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Metakaolin
Photo: Portland Cement Association

Self-consolidating concrete using metakaolin

Metakaolin is produced by heat-treating kaolin, a natural, finely divided, aluminosiliceous mineral, which is found in abundance in North America in Georgia, South Carolina, and Saskatchewan. Heating to 1200 to 1650°F (650-900°C) alters its structure, producing a highly reactive supplementary cementitious material (SCM) that is widely available for use in concrete construction. ASTM C618 and AASHTO M 295 classify metakaolin as a Class N (or natural) pozzolan.

Because it is produced under controlled conditions, its composition (typically 50 to 55% SiO_2 and 40 to 45% Al_2O_3), white appearance, and performance are relatively consistent. Due to its high surface area and high reactivity, relatively small addition rates of metakaolin—typically 10% or less by weight of cement—produce relatively large increases in strength, impermeability, and durability, while its light color gives it an aesthetic advantage over other SCMs.

Improved Strength

Metakaolin's reaction rate is rapid, significantly increasing compressive strength, even at early ages, which can allow for earlier release of formwork. Mixes with metakaolin at 8% of the total cementitious materials have produced concrete compressive strength increases of more than 20% at 1 day and 40% at 28 days.(1) Early age flexural strengths can also be increased by as much as 60%, potentially allowing for early opening of concrete pavements to traffic. Strengths of up to 35,000 psi (240 MPa) have been achieved in ultra-high strength concrete, formulated with 25% metakaolin and a water-to-binder ratio of 0.22.(2)

Improved Durability

In addition to increasing strength, the densification of the microstructure that results from the pozzolanic and hydraulic reactions of metakaolin also leads to greater impermeability. Very low and low 28-day rapid chloride permeability test (RCPT) results per AASHTO T 277 have been reported for concretes containing 8% metakaolin at water-to-binder ratios of 0.40 and 0.50, with the metakaolin concrete achieving remarkably lower RCPT values than other comparable mixes.(3) In concretes containing metakaolin at 8 to 12% of the total cementitious materials, 50-60% decreases in chloride diffusion coefficient suggest that significant improvements in service life can be achieved through metakaolin utilization in chloride environments.(4) In addition, metakaolin has been shown to be highly effective in mitigating expansion due to alkali-silica reaction (ASR) and sulfate attack.(5,6)

Improved Early Age Behavior

The relative fineness of metakaolin can result in decreased slump, but the use of water reducing admixtures or use in combination with fly ash in ternary mixes can compensate for this.(7) Slumps of 5 to 7 in. (125 to 180 mm) have been achieved with metakaolin at water-cementitious materials ratio (w/cm) of 0.36 to 0.38, using 25-35% less high-range water-reducing admixture than comparable mixes.(8)

Metakaolin concrete tends to exhibit a creamy texture, resulting in better finishability compared to other finely divided SCMs. This quality also improves pumpability and can be used to impart detailed surface textures to cast surfaces. In addition, the cohesiveness provided by the metakaolin allows for relatively simple formulation of self-consolidating concrete, when using an appropriate dosage of polycarboxylate water reducer as shown in the photograph at the beginning of this article.

Data on the potential contributions of metakaolin to chemical, autogenous, and drying shrinkage are inconsistent, with authors reporting both decreases and increases in each form at various ages and at various addition rates. For applications with restrictions on shrinkage, additional testing, including the assessment of shrinkage-reducing admixtures and fiber reinforcement, may be advised.

Contributions to Sustainability

Because of the lower processing temperature compared to cement clinker, use of metakaolin can contribute to sustainability through energy savings, as well as reductions in greenhouse gas emissions. After examining various SCMs alone and in combination and considering performance, economic, and environmental criteria, metakaolin concrete was identified as a "very promising solution" for the precast industry for reducing clinker content in concrete.[(9)]

In ternary blends with 25% fly ash and 8% metakaolin, concrete achieved equivalent strength to other concrete at just 3 days, while reducing cementitious materials content by more than 350 lb/yd^3 (208 kg/m^3). Combinations of 25% fly ash and 3% metakaolin achieved strength equivalence by 28 days, at a w/cm of 0.30.[(7)]

Alkali-activation of metakaolin, alone and in combination with slag or fly ash, has produced good quality geopolymers. Compressive strengths exceeding those of comparable portland cement concrete have been demonstrated, suggesting that metakaolin may be commercially viable as an alternative binder, in addition to its currently more common use as an SCM.

References

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