the Construction Specifier

Better, Brighter, Whiter Concrete

Using metakaolin to improve appearance and performance

by Michael Chusid, RA, FCSI, CCS, and Anthony Reed


Photo Shepard Hall courtesy Engelhard Corp.

Photo Alwyn Court courtesy Walter B. Melvin Architects LLC.

The light color of portland cement concrete has always been one of the material's most important attributes. Even its name conjures an image of whiteness since its inventor named it after the white, fine-grained limestone mined near the coastal city of Portland, England.

While portland cement ranges from light to dark gray, annual consumption of its white-colored variation appears to be increasing. Several recent international projects demonstrate the continuing allure of light-colored concrete.

For example, *Auditorio de Tenerife* in the Canary Islands (designed by Santiago Calatrava) and Rome, Italy's *Dives in Misericordia Church* (designed by Richard Meier) are both expressive, white portland cement concrete buildings. The integrally colored concrete of the new Cathedral of Our Lady of the Angels in Los Angeles, California (designed by Jose Rafael Moneo), relies on white portland cement for its vibrant coloration.

However, white cement is not only being used for building facades—it is also finding growing acceptance in countertops, flooring, pavement, concrete masonry units (CMUs), mortar, grout, and site furnishings. While aesthetics are the primary factor driving the use of white concrete, its brilliance/reflectivity also contributes to energy efficiency, safety, and other functional considerations. In addition, metakaolin, a new type of pozzolanic admixture, now makes it possible to obtain high performance white concrete with improved strength, durability, and handling characteristics.

Current work on Shepard Hall at the City College of New York City (above) benefits from the improved properties and whitening aesthetics of metakolin. The Alwyn Court renovation (left) on the city's upper West Side relies on the admixture to resist pollution and freeze-thaw conditions, as well as create a surface visually similar to the original terra cotta.

The arrows point to white portland cement and white concrete without additives. The circled samples illustrate the color of high reactivity metakaolin and the effect once high reactivity metakaolin is added as an admixture. The darker samples show the effects of fly ash and silica fume.

Photo courtesy Engelhard Corp.

Energy and safety

The enhanced reflectivity of white concrete can be used to conserve energy and meet criteria for sustainable construction established by the U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design™ (LEED) program. A building can qualify for LEED points when at least 30 percent of its impervious landscaping and hardscape surfaces have an albedo (solar reflectance) of 0.3 or greater. (Aged asphalt has about 0.1 albedo.)

Albedo for ordinary gray concrete can be as high as 0.38 or fall below the 0.3 criterion with age. In contrast, using white portland cement concrete can result in albedos as high as 0.8 or 0.9. By reflecting a significant amount of solar energy, white concrete helps keep cities cooler and prevents urban heat islands.[1]

White concrete can also create floors that reflect more light, reducing the energy required for interior lighting by approximately 20 percent when compared to ordinary gray concrete floors.[2] Besides lowering energy consumption, white flooring can reduce lighting fixtures and the ongoing expense of re-lamping. Brighter floors are specified for a more attractive merchandising ambiance in retail environments, and for accident reduction and the appearance of better 'housekeeping' in industrial buildings.

Light-colored concrete's inherent reflectivity also improves visibility and safety on roadways. For example, the Port Authority of New York and New Jersey used white concrete in the George Washington Bridge's vertical traffic barriers to increase night visibility. The reflectivity is particularly striking in wet weather because gray concrete tends to darken when damp. For many state departments of transportation, white concrete reduces the ongoing expense of repainting highway barriers, bridge piers/parapets, median strips, and other structures, which are required to be white for safety reasons.[3]

Concrete whitening methods

Many factors contribute to concrete's final appearance and brightness. For example, the material's shade depends on the color of the portland cement and aggregates, the water-to-cementitious material content, the curing conditions, and the use of pigments and other additives. White sand and coarse aggregates brighten concrete, especially when the concrete's surface is abraded to expose the light-colored aggregates. The pigment titanium dioxide can also be used to lighten concrete, but is generally not cost-effective and lacks the tinting strength needed to overcome gray concrete's inherent darkness.

Recently, a new type of white pozzolanic additive has been found to be an effective means of brightening concrete. Pozzolans are supplemental cementitious materials that act synergistically with portland cement to improve properties affecting concrete strength and durability. The most widely used pozzolans, fly ash and silica fume, are industrial by-products and typically dark, with uncontrolled color consistency. When used with white portland cement, they can darken the concrete and mute intended brightness. High-reactivity metakaolin (HRM), on the other hand, is a pozzolanic material equaling or exceeding the performance of its counterparts, but bright white in color. It perceptively lightens ordinary gray concrete, and even enhances the brilliance of concrete made with white portland cement.

HRM's pozzolanic properties were recognized only in the past decade and have been extensively researched and proven since then. Metakaolin is amorphous aluminate silicate refined from naturally occurring kaolin clays found in large deposits in the southeastern United States, China, and other parts of the world. It is purified to eliminate discoloring minerals, ground to a controlled size, and calcined at a high temperature to make it pozzolanic.

Originally, HRM was more expensive than fly ash and silica fume, so its use was limited to situations where whiteness was required or where a specifier desired its specific properties. However, this has changed dramatically as the cost of silica fume has escalated while the metakaolin supply increased. Still, certain specific mix designs may favor one type of pozzolan over another, depending on the other concrete ingredients, exposure conditions, project requirements, or personal preference.

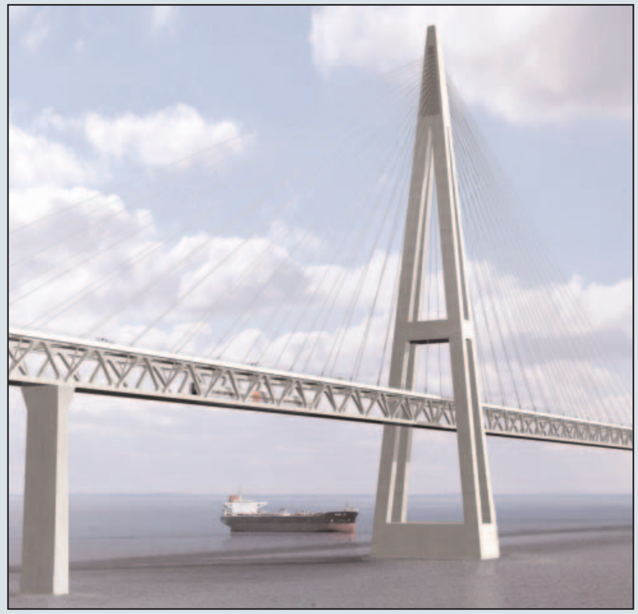
Perhaps the biggest hindrance to the use of metakaolin is simply its comparative newness on the market. For example, one of the authors has spoken with a concrete researcher from a major university who used silica fume in his demonstration project because he was unaware HRM was available in his state. The irony is the project was in Georgia—where almost all the HRM in the country is produced.

Pozzolanic chemistry 101

Portland cement undergoes a chemical reaction called 'hydration'—this produces calcium silicate hydrate (CSH), which then crystallizes into interlocking crystals creating concrete's inherent strength. However, hydration also produces calcium hydroxide (lime), with the average 0.8 m^3

Photo courtesy Wausau Tile

By mitigating alkali-silica reaction (ASR), metakaolin has made it practical to use recycled glass as a decorative aggregate in various white portland cement products.



Rendering courtesy Dissing + Weitling Ltd. Architects

The proposed Fehrman Bridge, linking Denmark and Germany, could benefit from the safety and aesthetic values of white concrete.

(1 cy) of concrete containing as much as 63.5 kg (140 lb). Rather than contributing to concrete's strength, lime does not form cementitious bonds like CSH and can be very detrimental. Lime can leach out of the concrete, creating efflorescence and increasing porosity (a primary mechanism promoting water penetration and corrosion). Additionally, lime is a factor in the alkali-silica reaction (ASR) that can lead to concrete deterioration. Pozzolans, such as metakaolin, convert lime into additional CSH, forming additional cementitious bonds to strengthen the concrete. By consuming free lime, pozzolans mitigate against efflorescence and alkali-silica reaction.

Pozzolans also improve concrete durability by plugging the capillary pores that allow water penetration. Portland cement concrete mixtures generally include far more water than required for cement hydration. Some of this excess water evaporates as the concrete cures, creating microscopic channels through which water can later penetrate into the concrete. However, CSH formed by the reaction of pozzolans and lime creates more cementitious bonds, yielding less porous concrete that is more resistant to chloride ion penetration (a significant factor contributing to the corrosion of reinforcing steel in concrete).

During ASR, alkaline cement chemically reacts with the silica found in certain types of concrete aggregates. This forms a gel, which expands in the presence of water to create internal forces that can crack and tear apart concrete. Pozzolans mitigate the alkali-silica reaction in two ways:

1. They reduce the penetration of moisture necessary to the expansion of ASR.
2. They consume the lime (*i.e.* the primary alkaline component in concrete).

Controlling ASR has allowed the use of crushed, recycled glass as concrete aggregate. Many manufacturers now produce attractive concrete and site-amenities that use colorful glass as a decorative aggregate, also increasing their products' recycled materials content.

While silica fume is the pozzolan most commonly used when high strength concrete is required, it generally not suitable for use in light-colored concrete. However, similar dosage rates of metakaolin equal or outperform silica fume's contribution to concrete strength.[4] Silica fume also has an extremely small particle size, which requires more water in a mixture to coat each of the microscopic particles. This added demand makes silica fume concrete mixtures very sticky, and can require the expense of adding superplasticizers to make a mixture workable. On the other hand, contractors report mixtures containing metakaolin are 'creamy' and compare working with them to 'spreading butter'.[5] As a result of these characteristics, metakaolin also tends to reduce the mottling that can disfigure a troweled concrete surface.

This improved workability has made metakaolin a common additive in portland cement-based swimming pool plasters where smooth, white, durable finishes are required. Metakaolin manufacturers have documented improved resistance to pool chemicals in concrete using proprietary-brand HRM products, as well as increased durability under the freeze-thaw conditions to which outdoor pools are often exposed.

Benefits add up

As metakaolin's performance has become better understood, the whitener is being incorporated into a growing number of light-colored architectural concrete projects. Projects such as the Shepard Hall renovation at the City College of New York City demonstrate metakaolin's effect on concrete durability. For this historic building, Stein White Nelligan Architects LLC designed the replacement of a failing terra cotta facade. During a warm winter day in New York City, temperatures can reach 21 C (70 F) on a building's south elevation, and then drop to below freezing in just 20 minutes when a storm front arrives. The architect developed a rigorous testing regimen to determine which materials would withstand these climatic extremes.

The selected material needed to be bright enough to match the off-white facade and retain its appearance despite accelerated aging that simulated an aggressive coastal and urban environment. Of the 11 materials tested, glass-fiber reinforced concrete (GFRC) with high reactivity metakaolin was one of just two products that survived. Of the two, GFRC with metakaolin proved more economical, and has been used to replace more than 40,000 pieces of terra cotta in an ongoing renovation. According to Carl Stein, one of the firm's principals, the whitener produced a dense architectural surface much less affected by environmental factors.

Designers and material scientists worldwide continue their quest to improve the aesthetics and performance of concrete. For example, the proposed Fehrman Bridge, which would cross the Baltic Sea between Denmark and Germany, may use white concrete—to foil a dark coastal sky—and a mixture formulated to provide service for over a century despite an extremely severe environment. Present trends suggest the future of white concrete and concrete whiteners is very bright indeed.

Notes

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Additional Information

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Abstract

While aesthetics is the primary factor driving the popularity of white cement, the material's reflectivity also contributes to functional advantages such as energy efficiency and safety at night. By understanding pozzolanic admixture chemistry, specifiers can use additives such as high reactivity metakaolin (HRM) to achieve brighter concrete surfaces, along with improved workability and durability.