the Construction Specifier

Specifying Blended Cements for Performance & Strength

Photo courtesy Lafarge North America

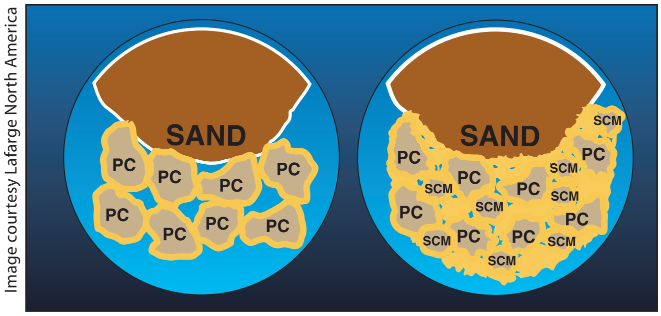
by Greg Daderko

Cement has been around a long time. It helped build the Roman Empire, then outlasted it—through monuments, temples, and vast engineering projects that stand to this day. Modern portland cement is virtually unchanged from 1824, when British stonemason Joseph Aspdin heated a mixture of limestone and clay in his kitchen stove and ground it up into powder. He named the mixture portland, because the finished cement reminded him of stone quarried on the Isle of Portland, and sparked a vast global industry. Today, his creation is everywhere: after water, concrete is the most consumed material on the planet.

Many specifiers are reluctant to change from a proven material that has performed well for them in the past, partly because they are unsure of the performance and durability of new products. Many consider portland cement the standard and are cautious about considering alternatives, such as blended cements, but they shouldn't be.

(Above) In recent years, federal buildings have been designed to better resist terrorist attack. One of the special designs in this FBI building (Washington, D.C.) is a very high-strength blast wall. The concrete producer used a mix of 50-percent slag and 50-percent portland cements.

Blends can offer significant performance advantages over portland cement. They can produce stronger and more durable concrete, and possess a long and impressive track record. Hardly the new kid on the block, the materials used in blends have been around for nearly a century, withstanding the test of time. Fly ash, for example, was used in the construction of Hoover Dam in the 1930s. Blends are also suitable for harsh environments where concrete is likely to be exposed to moisture, extreme weather, and chemicals.



(Left) When ordinary portland cement (PC) hydrates, C-S-H is formed (yellow); this glue holds concrete together. However, gaps in this glue provide pathways for moisture to penetrate and reduce strength. (Right) When supplementary cementitious materials (SCM) are added, particles pack more tightly within the voids and additional glue forms from the SCM hydration process. With fewer voids, the concrete is less permeable and stronger.

Table 1 Typical Chemical Oxides for Various Cementitious Materials

	Portland cement	Slag cement	Fly ash (Class C)	Fly ash (Class F)
CaO	65	45	25	3
SiO_2	20	33	37	58
Al_2O_3	4	10	16	20
Fe_2O_3	3	1	7	10
MgO	3	6	7	1

Source: Slag Cement Association.

Environmentally friendly blends also exist, and can help projects meet sustainable development objectives.

Specifiers who have yet to work with blended cements can find considerable technical support and documentation on its performance in published literature. In most cases, blends can be specified as a direct replacement for portland cement on a one-to-one basis.

Types of blends

As the name implies, blends are a mixture of multiple ingredients. Combined with portland cement, one or more supplemental cementitious materials (SCMs) can be added to the concrete individually at the concrete batch plant, or included as a component of blended cements. The most common SCMs are:

- Commonly known as slag cement, GGBFS (ground granulated blast furnace slag) is a by-product of the iron manufacturing process.
- Fly ash stems from the pollution-control equipment of coal-burning power plants.
- Silica fume is a by-product of manufacturing silicon metals and ferro-silicon alloys.

Blends can be divided into two main categories: binary and ternary. Binary is a mixture of two products (*i.e.* portland and one SCM), whereas the ternary blend is a mixture of three products (*i.e.* portland and two SCMs). The type and proportion of SCM included in the blend establishes the performance in concrete. Silica fume, for example, is generally specified in specialized applications requiring high strength and/or low permeability. Used in the correct proportions, fly ash, slag, or silica fume individually improves the performance of concrete. When used together in ternary blends, their effects are synergistic. While very rare, quaternary blends—those containing portland cement and three or more SCMs—do exist, and typically comprise portland cement, silica fume, slag cement, and fly ash.

Why blends perform better

Portland cement, slag, and fly ash share chemical similarities. They all contain similar oxides, though the proportions are different (Table 1). Slag particles are amorphous and glassy, and are smaller than those of portland cement. These chemical and physical properties improve performance in a number of areas:

Reduced permeability

In concrete structures, permeability is generally the critical factor affecting durability. Concrete made with portland cement is relatively porous compared to concrete containing SCMs. Since porous concrete is easier to saturate with water, freeze/thaw cycles can lead to cracking. When moisture and salts reach the rebar in reinforced concrete, deterioration can occur. As the steel corrodes, its volume expands and fractures the concrete, thereby allowing moisture ingress and accelerating damage.

Blended cements can significantly extend the life of concrete because they reduce its permeability to water, chlorides, and other aggressive agents. In part, this reduced permeability results from improved particle packing due to the physical nature of slag, fly ash, and silica fume particles. Additionally, the chemical reaction of the silica in the SCM with the calcium hydroxide produced during the hydration of portland cement produces additional calcium silicate hydrate (C-S-H), infilling voids and reducing permeability. (Calcium silicate hydrate is the 'glue' making up the paste of concrete.)

Improved workability

The spherical shape of fly ash particles and the glassy nature of slag particles reduce the amount of water needed to produce workable concrete, enhancing the pumpability and flowability of concrete. Blended cements are easier to place, finish, and consolidate.

Blended cements tend to have slower set times than portland cement, which can be a benefit during the warmer months when most construction takes place. In hot weather, for example, the slower set times allow crews more time to place and finish a slab. In cold-weather conditions, chemical admixtures or heated water and aggregates can be used to reduce set times. (These enhancements will likely increase the cost of cold-weather pours.)

Curing

As with all concretes, proper curing is essential to achieve best performance. Curing practices used with portland cement are appropriate for blends as well.

Enhanced strength
Blends can improve long-term strength development, depending on the proportions and materials used. Final concrete strength is directly influenced by the amount of water used in the mix (water-cement [w/c] ratio). By reducing the amount of water required, blends produce stronger concrete. In addition, the slag, fly ash, and silica fume in blends react with portland cement, converting calcium hydroxide ($Ca[OH]_2$) into calcium silicate hydrate, which gives cement its strength ($Ca[OH]_2$ contributes nothing to strength). By producing more calcium silicate hydrate, blends create stronger concrete.

Resistance to sulfate attack
Present in seawater, wastewater, and some soils, sulfates can react with the alumina in portland cement and cause expansion. Blends can offer superior resistance to these attacks because they contain fewer of the compounds that react with sulfates, and because their low permeability keeps out sulfate-bearing moisture.

Resistance to alkali-silica reactions
Alkali-silica reactivity (ASR) occurs between the alkalis in portland cement and certain silica aggregates. In the presence of water, they can form an expansive gel leading to cracking. As the concrete cracks, additional moisture is introduced, furthering the reaction.

Blends combat ASR three ways:

1. SCMs can reduce the alkali loading in the concrete, as they generally contain fewer alkalis than portland cement.
2. The fly ash and slag in blends react with the alkalis in portland cement, keeping them from reacting with any silica.
3. Lower permeability reduces the ingress of water.

Thermal stress resistance
For mass concrete pours, blends with high slag and/or fly ash content can minimize thermal stress by reducing the heat generated during the hydration process. Heat dissipates slowly from mass concrete, so the thicker the section, the longer it takes for the interior to cool. The resulting temperature differentials between the concrete surface and interior can result in thermal stresses leading to cracking and loss of structural integrity.

In blends containing slag cement or fly ash, heat is generated more slowly and peak temperatures are reduced. In mass concrete projects, slag and fly ash content ranging from 65–80 percent and 30–80 percent, respectively, significantly reduces heat and maintains strength.

Green benefits
Blends use industrial by-products otherwise destined for landfills. In addition, their availability negates the need to produce additional portland cement and beneficially uses the energy already expended in the manufacturing process. For these reasons, the U.S. Department of Energy (DoE), other government agencies, and organization like the U.S. Green Building Council (USGBC) encourage the use of blends containing slag cement and fly ash.

Specifying blends

Many existing specifications—especially those developed in less environmentally sensitive eras—routinely specify portland cement. In most cases, blends can be substituted to obtain superior results.

As a general rule, blends can be substituted on a one-to-one basis for portland cement. Various organizations, including the American

Standards and Nomenclature

Blended hydraulic cements conform to the requirements of ASTM International C 595, *Standard Specification for Blended Hydraulic Cements,* or ASTM C 1157, *Standard Performance Specification for Hydraulic Cement.*

ASTM C 595 cements are as follows:

- Type IS: portland/slag cement (25–70 percent slag).
- Type IP and Type P: portland-pozzolan cement (15–40 percent pozzolan).*
- Type S: slag cement (>70 percent slag).
- Type I (PM): pozzolan-modified portland cement (<15 percent pozzolan).
- Type I (SM): slag-modified portland cement (<25 percent slag).

These blended cements may also be designated as air-entraining, moderate sulfate resistance, or with moderate to low heat of hydration.

ASTM C 1157 blended hydraulic cements include the following:

- Type GU: for general construction.
- Type HE: high early strength.
- Type MS: moderate sulfate resistance.
- Type HS: high sulfate resistance.
- Type MH: moderate heat of hydration.
- Type LH: low heat of hydration.

These cements can also be designated for low reactivity (option R) with alkali-reactive aggregates. There are no restrictions as to the composition of the ASTM C 1157 cements. The manufacturer can optimize ingredients, such as pozzolans and slags, to optimize for particular concrete properties.

The most common blended cements available are Types IP and IS. (Source: Portland Cement Association.)

**ASTM defines pozzolan as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form cementitious hydrates."*

Concrete Institute (ACI) and the Slag Cement Association (SCA), offer detailed recommendations specifiers can consult to determine whether and how to specify such substitutions. Of course, as with all concrete mixtures, trial batches should be performed to verify concrete properties.

In addition, manufacturers can provide technical assistance to help develop or modify specifications, and most can provide detailed test results, quality control records, and additional support to specifiers. They can provide a general idea of costs, although the final price is be negotiated between the contractor and the ready-mix supplier.

Color

The color of concrete can be affected by the use of SCMs, but this depends on type and proportions used. Slag produces a lighter-colored concrete with high reflectivity (it is often specified for this reason). Classes C and F fly ash can produce buff, or darker gray, concrete.

Sourcing

Ready-mix plants can produce concrete with SCMs when they have sufficient silo space to handle all the ingredients. (Some will convert their portland silo to a portland-slag blend, allowing them to offer both binary and ternary blends.) Alternatively, cement manufacturers can supply blends. These blends offer a high degree of consistency, rigorous quality control measures, testing, and certification. Typically, specifications require the manufacturer to certify the quality and make-up of the blended cement, although independent testing laboratories also provide testing and certification.

Performance-based specifications

Often, the best approach for specifiers is to move from materials- to performance-based specifications for concrete, giving contractors greater control over choosing the specific blend. Concrete suppliers often have the best information for making the final materials selection, and they know the materials and the manufacturers.

Blended cements give specifiers additional options in helping them meet cost, performance, and aesthetic requirements for a variety of construction projects. SCMs' track record is long and diverse, as they have been specified for:

- the new FBI headquarters in Washington, D.C., where they provide superior strength and blast resistance.
- runways at Louis Armstrong (New Orleans, Louisiana) and Hartsfield (Atlanta, Georgia) international airports, where their high flexural strength resists the impact of hundreds of jet landings every day.
- the Chesapeake Bay Bridge Tunnel, where their resistance to sulfates helps ensure the longevity of structures exposed to seawater.
- the Pocahontas Parkway overpass near Richmond, Virginia, where were used to prevent thermal cracking in mass concrete supports elevating the roadway above oceangoing shipping lanes on the James River.
- highway pavements across North America, where Department of Transportation (DoT) specifiers select them for their long life and high strength.

Industry associations and manufacturers can assist in creating performance-based specifications offering greater flexibility for materials selection while ensuring the concrete meets performance objectives. For example, when a specifier has experience with a certain type of portland cement, a manufacturer can recommend equivalent blends providing equal or better performance, often at a lower cost.

Additional Information

Author

Greg Daderko is the product manager of specialties and blends for Lafarge North America's Cement division, and has over 25 years of experience in the construction industry. He holds a degree in geology, and can be reached at (703) 480-3763 or via e-mail at greg.daderko@lafarge-na.com.

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U.S. Green Building Council

Abstract

In this article, the author discusses the benefits to concrete work when the specifier employs supplementary cementitious materials (SCMs) such as fly ash, silica fume, and slag cement—by-products of industrial processes which are otherwise destined for landfills. SCMs lend strength and various resistances to finished concrete, and can economically replace a good deal of portland cement content in the mix.