LAFARGE NORTH AMERICA

WHITE PAPER

Specifying Blended Cements for Performance and Strength

Cement has been around a long time. It helped to build the Roman Empire and then outlasted it, in 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.

They shouldn't be. Blends can offer significant performance advantages over portland cement. They can produce stronger and more durable concrete. And they have 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 and have withstood the test of time. Fly ash, for example, was used in the construction of the 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. And they are environmentally friendly products that can help projects meet sustainable development objectives.

Specifiers who haven't worked with blended cements can find considerable technical support and documentation on 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

Blends, as the names implies, are a mixture of multiple ingredients. They combine portland cement with one or more supplemental cementitious material (SCM). SCM's can be added to the concrete individually at the concrete batch plant or included as a component of blended cements. The most common SCM's are:

- *GGBFS (Ground Granulated Blast Furnace Slag),* commonly known as slag cement, which is a byproduct of the iron manufacturing process.
- *Fly ash,* which comes from pollution-control equipment of coal-burning power plants.
- *Silica fume*, a byproduct of manufacturing silicon metals and ferro-silicon alloys.

There are two main categories of blends: b*inary* and t*ernary*. Binary, as the name implies is a mixture of two products, portland and one SCM. Whereas the ternary blend is a mixture of three products, portland and two SCM's. The type and proportion of SCM included in the blend establishes the performance in concrete. Silica fume, as an 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 improve the performance of concrete. When used together, in ternary blends, their effects are synergistic.

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, glassy particles that are smaller than those of portland cement. The round shape of fly ash is also beneficial. 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 ordinary portland cement is relatively porous compared to concrete containing SCM's. Since porous concrete is easier to saturate with water, freeze/thaw cycles can lead to cracking.

If moisture and salts reach the steel bars in reinforced concrete, deterioration can occur . As the steel corrodes, its volume expands, fracturing the concrete, allowing moisture ingress and accelerating the damage.

Blended cements can significantly extend the life of concrete because they can reduce the permeability of concrete to water, chlorides and other aggressive agents.

In part, this reduced permeability results from improved particle packing due to the slag, fly ash or 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 C-S-H, infilling voids and reducing permeability. C-S-H is the "glue" that makes 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. This also enhances the pumpability of concrete, allowing it to flow more easily. 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 give 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.

Curing. As with all concretes, proper curing is essential to achieve the 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 strength of concrete is directly related to the amount of water used in the mix (water-cement ratio). By reducing the amount of water required, blends produce stronger concrete. In addition, the slag, fly ash and silica fume in blends reacts with portland cement, converting calcium hydroxide $Ca(OH)_2$ into calcium silicate hydrate (C-S-H). C-S-H gives cement its strength, while calcium hydroxide contributes nothing to strength. By producing more C-S-H, blends create stronger concrete.

Resistance to sulfate attack. Sulfates, which are present in seawater, wastewater and some soils, can react with the alumina in portland cement, causing 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 sulfate-bearing waters out.

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

Blends combat ASR in three ways:

1. SCMs can reduce the alkali loading in the concrete, as generally SCMs contain fewer alkalis than portland cement.
2. The fly ash and slag in blends also react with the alkalis in portland cement, making them unavailable for the reaction.
3. Lower permeability reduces the ingress of water.

Resistance to thermal stress. For mass concrete pours, blends with high slag and/or fly ash contents can reduce the heat of hydration, which reduces thermal stress. Thermal stresses develop as heat is generated during the hydration process. Because heat dissipates slowly from mass concrete, 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 content ranging from 65 to 80 percent and fly ash from 30 to 80 % provides significant heat reduction while maintaining strength.

Green benefits. Blends use industrial by-products that would otherwise be destined for landfills. In addition, their availability negates the need to produce additional portland cement and beneficially uses the energy already expended in their manufacturing process. For these reasons, the U.S. Department of Energy and other government agencies 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 ACI (American Concrete Institute) and the SCA (Slag Cement Association), offer detailed recommendations that 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.

Color. The color of the concrete can be effected by the use of SCMs but this is dependent on the type and proportions used. Slag produces a lighter concrete with high reflectivity and is often specified for this reason. Class C and Class F fly ash can produce buff or darker gray concrete.

Sourcing. Ready-mix plants can produce concrete with SCM's if they have sufficient silo space to handle all of 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.

Performance-based specifications

Often, the best approach for specifiers is to move from materials-based specifications for concrete to a performance-based specification, allowing contractors greater control over choosing the specific blend.

Concrete suppliers often have the best information for making the final materials selection. They know the materials and the manufacturers; they are well attuned to the seasonal fluctuations in supply and costs; they know what their customers are comfortable with, and they are responsible for the quality of the product.

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

Standards and nomenclature

Blended hydraulic cements conform to the requirements of ASTM C595 or C1157.

ASTM C595 cements are as follows:

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

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

ASTM C1157 blended hydraulic cements include the following:

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

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 C1157 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.

Table 1: Typical chemical oxides for various cementitious materials. *(Source: Slag Cement Association.)*

	Portland Cement	Slag Cement	Fly Ash C	Fly Ash 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

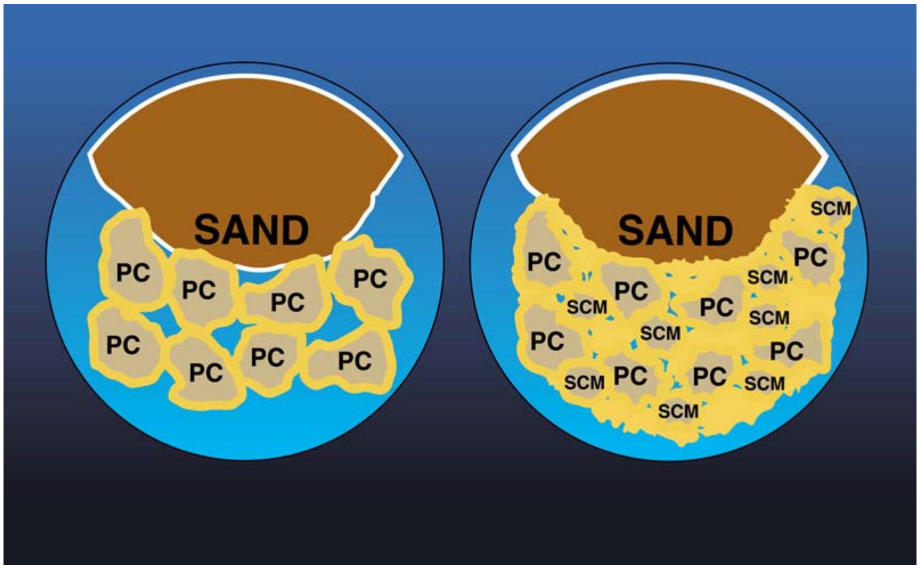

Figure 1. (Left) When ordinary portland cement (PC) hydrates, C-S-H is formed (yellow); this glue holds concrete together. However, gaps in this glue provide pathways for moisture to penetrate and reduce strength. (Right) When supplementary cementitious materials (SCM) are added, particles pack more tightly within the voids and additional glue forms from the SCM hydration process. With fewer voids, the concrete is less permeable and stronger.

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