WHITE PAPER

Building Greener, Building Better:

Blended cements deliver substantial performance and environmental benefits

Blended cements combine portland cement with one or more supplementary cementing materials (SCM), including slag cement, fly ash and silica fume. They can trace their lineage back to the volcanic pozzolans that the ancient Romans used to make cement. They've been used – and continue to be used -- in high-profile engineering projects, ranging from large dams to highly secure government buildings.

SCMs have been gaining in popularity in recent years. For example, slag cement sales in North America have tripled since 1996 and increased 15.5% in 2004 alone – nearly three times the rate of growth for portland cement. Sales of other types of SCMs are on the rise as well.

Several considerations have fueled this growth. First is performance. SCMs in combination with portland cements can make concrete stronger, more resistant to chemical and environmental attack, and more workable. They can extend the life of concrete even under the harshest conditions, such as those found in marine projects, highways and other major infrastructure projects. For example, blended cements can help extend the service life of high-performance pavements and bridge decks to as long as 100 years.

In addition, blends help engineers and architects achieve sustainability goals, such as the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) program, because they require far less energy to manufacture than 100 percent portland cement.

Engineers have more options than ever when it comes to specifying products. Ready-mix producers can create blends at their plant, or they can order "prepackaged" blends from manufacturers. Manufacturer-blended cements are especially convenient. Producers don't need to maintain separate silos for the various ingredients, and can handle the blends just as they do portland cement. They make it possible even for small producers to offer a full range of blends, and for engineers to specify precisely the blend they need to meet a project's requirements.

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Types of blends

In addition to portland cement, blends contain one or more SCMs, including:

- *Slag cement (also known as Ground Granulated Blast Furnace Slag),* which is a by-product of steel manufacturing.
- *Fly ash,* which is reclaimed from coal-burning power plants.
- *Silica fume,* a by-product of manufacturing silicon metals and ferro-silicon alloys.

There are two main categories of blends: *binary* and *ternary*. Binary is a mixture of two products: portland cement and one SCM. Ternary blends are a mixture of portland cement and two SCMs.

The type and proportion of SCMs included in the blend affect performance of the 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 can be synergistic.

Performance benefits of blends

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

Reduced permeability. 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 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.

If moisture and salts reach the steel bars in reinforced concrete, the bars corrode. Their volume expands, fracturing the concrete, allowing moisture ingress and further accelerating the damage.

In part, this reduced permeability results from improved particle packing due to the slag, fly ash or silica fume particles. Silica fume particles, for example, are 100 times smaller than cement grains, and fill in the spaces between the cement grains.

Additionally, the chemical reaction of 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” that makes up the paste of concrete.

Improved workability. In general, blended cements are easier to place, finish and consolidate. The spherical shape of fly ash particles and the glassy nature of slag particles reduce the amount of water needed to produce workable concrete. These qualities also enhance the pumpability of concrete, allowing it to pump more easily.

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 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, by converting calcium hydroxide to C-S-H, blends create stronger concrete. C-S-H gives concrete its strength, while calcium hydroxide contributes nothing to strength.

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 reaction. Alkali-silica reaction (ASR) occurs 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:

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

Resistance to thermal stress. For mass concrete pours, blends with high slag and/or fly ash content can reduce the heat of hydration, which reduces thermal stress. Thermal stresses develop as heat is generated during the hydration process. Heat dissipates slowly from mass concrete, and the resulting temperature differentials between the concrete's surface and interior can lead 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.

Environmental benefits

Unlike portland cement, SCMs do not need to be heated in a cement kiln, which is the most energy-intensive part of cement manufacturing. As a result, much less energy is required to produce blended cements than an equivalent quantity of 100 percent portland cements, and far fewer greenhouse gases are produced. Each ton of portland cement that is replaced by SCMs reduces CO_2 emissions by approximately one ton.

Considering the fact that concrete is the most widely used construction material in the world, blended cements can have a major impact on the environment. They can also help architects and engineers meet sustainable building objectives, as in the case of LEED. These environmental benefits are increasingly important to project developers and owners, especially for public-sector projects such as roads, bridges and school buildings.

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, blended cements 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.

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

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 an engineer has experience with a certain type of portland cement, a manufacturer can recommend equivalent blends that provide equal or better performance, often at a lower cost.

For further information on blends and SCMs, the following organizations can be contacted: American Coal Ash Association (www.acaa-usa.org), Portland Cement Association (www.portcement.org), Slag Cement Association (www.slagcement.org), and Silica Fume Association (www.silicafume.org).

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

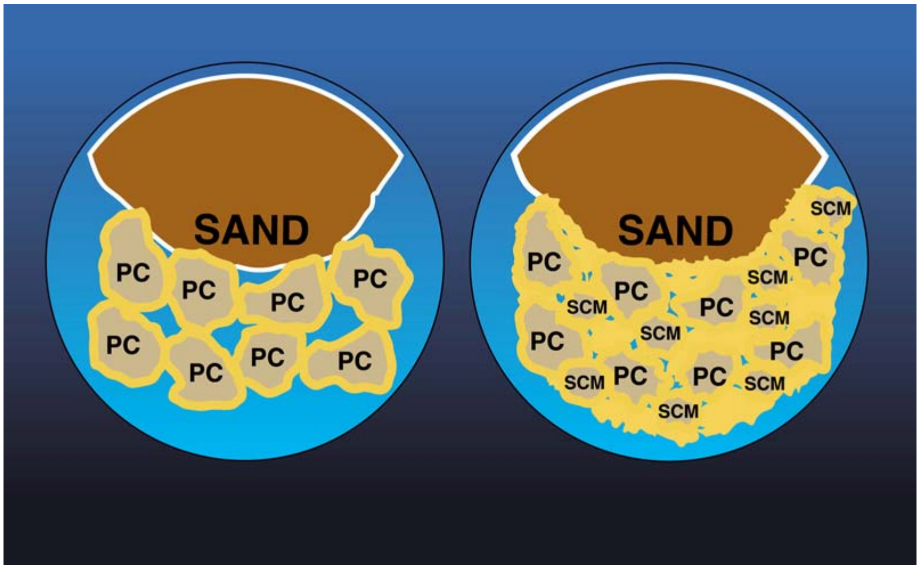

Figure 1. (Left) When ordinary portland cement (PC) hydrates, C-S-H is formed (yellow); this glue holds concrete together. However, gaps in this glue provide pathways for moisture to penetrate and reduce strength. (Right) When supplementary cementitious materials (SCM) are added, particles pack more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