Construction CANADA

Blended Cements

An option for Canadian construction

All photos and figures courtesy Lafarge North America

By Greg Daderko and Brent Smith

When the design team for Winnipeg International Airport was building a new runway apron last year, it needed concrete that would stand up to some of the most extreme weather conditions in the world. Temperatures in Manitoba's capital can swing from –35 C (–29 F) in the winter to 35 C (95 F) in summer, capable of causing heavy damage to regular concrete. Mindful of this challenge, specifiers instead chose an 85/15 blend of portland cement and fly ash. This blended material provided strength and durability, with greater resistance to cracking from freeze-thaw cycles. As an added benefit, the blended cement was easier to place and finish—an important advantage given the project's tight timeframe and Winnipeg's short construction season. The project—providing an apron where airport workers can de-ice planes with liquid antifreeze before takeoff—was completed in less than two months, and the concrete exceeded flexural strength specifications.

The Winnipeg airport project is an example of why blended cements can be a good choice for many Canadian construction projects. They offer a combination of performance characteristics able to extend the life of concrete under harsh conditions, such as those found in marine projects, highways and other major infrastructure projects. At the same time, they can help projects meet sustainable development objectives and are cost-competitive with portland cement.

Blended cements can be sourced in two ways: Concrete producers can blend them on-site, or cement manufacturers can provide blended materials to meet a variety of specifications. (When the manufacturer does the blending, there is no need for additional silos or blending equipment on-site.) The materials are also highly consistent, through testing to such standards as Canadian Standards Association (CSA) A 3001, *Cementitious Materials for Use in Concrete,* and ASTM International C 595, *Standard Specification for Blended Hydraulic Cements.*

Types of blends

As their name implies, blended cements combine portland cement with one or more supplemental cementing materials (SCMs). The most common SCMs are:

- ground-granulated blast furnace slag (GGBFS) (commonly known as 'slag cement,' this is a by-product of steel manufacturing);
- fly ash (derived from pollution-control equipment of coal-burning power plants); and
- silica fume (a by-product of manufacturing silicon metals and ferro-silicon alloys).

There are two main categories of blends: binary and ternary. The former is a mixture of two products (*i.e.* portland cement and one SCM), while the latter is portland cement and two SCMs. The type and proportion of SCM included in the blend affects performance of

The use of blended cements can yield credits under the Canada Green Building Council's (CaGBC's) Leadership in Energy and Environmental Design® (LEED®) Canada program, for reasons ranging from recycled content to heat island reduction.

the concrete. For example, silica fume is generally specified in specialized applications requiring high strength and/or low permeability. Used in the correct proportions, fly ash, slag or silica fume can individually improve concrete performance. When used together, in ternary blends, their effects are synergistic.

The advantages of blends

Portland cement, slag and fly ash all contain comparable oxides, though the proportions are different (see Table 1). They also 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, as described below.

Reduced permeability

Blended cements can extend the life of concrete by reducing its permeability to water, chlorides and other aggressive agents. In concrete structures, permeability is generally the critical factor affecting durability.

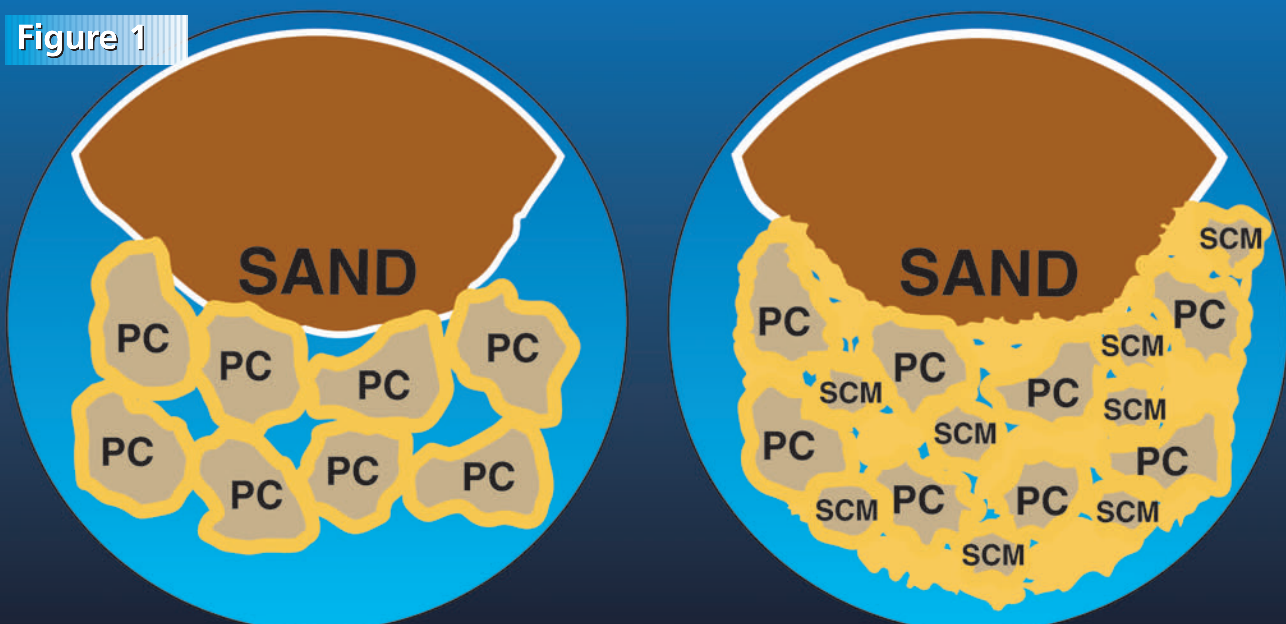
Concrete made with portland cement is relatively porous compared to concrete containing SCMs. Since porous concrete is easier to saturate with water, it is more vulnerable to freeze-thaw cycles that can lead to cracking. Should moisture and salts reach the steel bars in reinforced concrete, the bars can corrode. The rebar's volume can also expand, allowing moisture ingress and further accelerating damage.

Blended cements' reduced permeability results in part from improved particle-packing, made possible by the presence of the SCMs. For example, silica-fume particles are one-hundredth the size of cement grains, and able to fill in the spaces between them. Additionally, the chemical reaction of silica with the calcium hydroxide produced during the hydration of portland cement produces additional calcium silicate hydrate (CSH), infilling voids and reducing permeability. (Calcium silicate hydrate is the 'glue' making up the paste of concrete.)

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—these qualities also enhance the concrete's pumpability,

Figure 1



When ordinary portland cement hydrates, calcium silicate hydrate (CSH) is formed (shown in yellow), and serves as the glue holding concrete together. However, gaps provide pathways for moisture to penetrate and reduce strength.

When supplementary cementitious materials (SCMs) are added, particles pack more tightly within the voids and additional glue forms from the hydration process. With fewer voids, the concrete is less permeable and stronger.

The near 13-km (8-mi) long Confederation Bridge connecting Prince Edward Island to New Brunswick required seven types of concrete, incorporating various supplementary cementitious materials (SCMs)—including silica fume and fly ash—to achieve low permeability, high early-strength, low heat-rise and freeze-thaw resistance.

allowing it to flow 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. (Blending on-site will, of course, add an extra step.) In cold-weather conditions, chemical admixtures or heated water and aggregates can be used to reduce blended-cement set-times. However, these additives increase cost of the mix, and add more potential variables to the process, making it more complex. Portland cement sets more quickly in cold weather, and is less likely to require such additives.

Curing

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

Strength development

Blends can improve long-term strength development, depending on the specified proportions and materials. The material's final strength is directly related to the amount of water used in the mix (*i.e.* water-cement ratio). By requiring less water, and converting calcium hydroxide to CSH, blends create stronger concrete.[1]

Resistance to sulphate attack

Present in seawater, wastewater and some soils, sulphates can react with the alumina in portland cement, causing expansion. Blends better resist these attacks as they contain fewer of the compounds that react with sulphates, and because their low permeability keeps sulphate-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 ASRs in three ways:

1. SCMs can reduce the alkali loading in the concrete, as they generally contain fewer alkalis than portland cement.
2. Fly ash and slag 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 content can reduce the heat of hydration, which reduces thermal stress. These 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 considerations

Blended cements can benefit the environment as well as performance requirements. 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-per cent portland cement and far fewer greenhouse gases are produced. One tonne (1 ton) of portland cement replaced by SCMs reduces carbon dioxide (CO_2) emissions by approximately the same amount.

Blended cements can also help architects and builders meet the goals of sustainable building initiatives such as Leadership in Energy and Environmental Design® (LEED®) Canada, sponsored by the Canada Green Building Council (CaGBC). Blended cements can help projects earn up to five points toward LEED Canada certification.

Materials and resources

1. Projects earn one point for a minimum of 7.5-per cent recycled content (Materials & Resources [MR] Credit 4.1) and another point for a minimum of 15-per cent recycled content (MR Credit 4.2). LEED Canada–New Construction (NC) makes special provisions for SCMs due to their low weight—instead of the concrete's weight being used to determine recycled content, the

Data courtesy Slag Cement Association

Table 1
Typical chemical oxides for various cementitious materials

	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

*The designations 'C' and 'F' refer to the chemical make-up of the fly-ash. 'F' is low in calcium oxides (< eight per cent), while 'C' contains higher quantities.

weight of the SCMs is divided by the weight of the total cementitious material, then multiplied by two, and that number is multiplied by the cost of the concrete and formwork. As a result, a concrete building with 25 per cent of the portland cement replaced with fly ash should be able to achieve one LEED Canada point, while a concrete building with 40-per cent replacement of portland cement with fly ash should be able to achieve two points. (Using fly-ash replacement levels for portland cement greater than 25 per cent are not routine. Actual limits are based on experience and concrete performance in the field or laboratory.)

2. Depending on location, blended cements may qualify as regional materials under MR Credits 5.1 and 5.2. Credit 5.1 awards one point for using a minimum of 10-per cent regional building materials (*i.e.* materials for which 80 per cent of the mass is produced, extracted or manufactured within 800 km (500 miles) of the project, or 2400 km [1500 miles] if shipped by rail or water. Credit 5.2 awards an additional point if the regional material content is 20 per cent.

Sustainable sites

Certain blends can help projects earn one LEED Canada point for reducing heat-island effect (Sustainable Sites [SS] Credit 7.1). Slag blends have a higher albedo (reflectance) than many materials, including grey portland cement and asphalt. The heat-island credit calls for the use of high-albedo materials (reflectance of at least 0.3) for non-roof impervious surfaces, including parking lots, walkway, plazas, etc. According to research from the American Concrete Paving Association (ACPA), field measurements of new, cured grey-cement concrete pavement show an albedo of 0.35 to 0.40, while aged concrete has albedos in the range of 0.20 to 0.30. These values are close to the threshold for the LEED-Canada credits. Concrete made with slag blends have a significantly higher albedo, ensuring the requirement can be met.

The Canadian government, in partnership with cement manufacturers, has encouraged the use of blended cements through its EcoSmart initiative (since most of the products used to produce the blends are by-products from other industries). The program helps connect concrete suppliers, owners and developers, structural designers and concrete contractors to use sustainable concrete in construction projects.

Specifying blends

Many existing specifications routinely specify portland cement—as a general rule, blended cements can be substituted on a one-to-one basis. Various organizations, including the American Concrete Institute (ACI) and the Slag Cement Association (SCA), offer detailed recommendations that specifiers can consult to determine whether (and how) to specify such substitutions.[2]

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 for design professionals is to move from materials-based specifications for concrete to performance-based ones, allowing contractors greater control over choosing the specific blend.

Concrete producers often have the best information for making the final materials selection. They are well-attuned to seasonal fluctuations in supply and costs, and tend to be aware of what their customers are comfortable with. Industry associations and manufacturers can assist in creating performance-based specifications offering greater flexibility for materials selection while ensuring the concrete meets performance objectives. ✍

Notes

1. Calcium silicate hydrate gives cement its strength, while calcium hydroxide does not contribute to this.
2. Specifiers can visit www.aci-int.org and www.slagcement.org, respectively. For further information on supplementary cementing materials, one can contact the American Coal Ash Association (ACAA) at www.acaa-usa.org, the Portland Cement Association (PCA) at www.portcement.org and the Silica Fume Association (SFA) at www.silicafume.org.

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