Supplementary materials can extend concrete life and produce longer-lasting bridges

Optimizing concrete mixes with supplementary cementitious materials can make a significant contribution to meeting cost, performance and sustainability goals.

Today, more than 70,000 bridges across the country are rated structurally deficient, and engineers estimate repairing them all would take at least a generation and cost more than $188 billion. As our transportation infrastructure continues to age and deteriorate, greater attention is being given to life-cycle costs and the use of extended-life concrete to build more durable, longer-lasting bridges.

During the past 10 years, the Federal Highway Administration has encouraged the use of new materials and advanced technologies in bridge construction and maintenance projects in an effort to reduce congestion, lower life-cycle costs and enhance safety. Innovative design methods and construction practices, along with rigorous quality-management systems, have resulted in high-performance concrete (HPC) bridges that are designed to last for up to 100 years or more under the harshest of environments. One such bridge is the Confederation Bridge, which crosses the North Atlantic Ocean in Canada and was designed for a 100-year service life.

Connecting Prince Edward Island with New Brunswick, the 8-mile-long Confederation Bridge is exposed to some of the world’s most extreme weather conditions, including significant amounts of ice that are constantly moving, high winds that result in splash and spray zones on the piers and frequent cycles of freezing and thawing.

SCMs make better mix

To protect the structure against corrosion and to achieve a 100-year service life, the bridge was built with seven different concrete mix designs incorporating supplementary cementitious materials (SCMs)—including silica fume and fly ash—to achieve low permeability, high strength, low heat rise and resistance to freezing and thawing.

In almost all forms of construction, extended-life concrete offers a superior solution that should have lower service-life costs than conventional concrete. These innovative mixtures incorporating SCMs can make concrete stronger, more durable and more resistant to chemical and environmental attack. The most common SCMs are slag cement, fly ash and silica fume.

SCMs can be utilized in concrete mixes either as a separate component or as a constituent of a blended cement. Binary blends contain portland cement and one SCM; ternary blends contain portland cement and two SCMs; quaternary blends contain portland cement and three SCMs. Used in the correct proportions, fly ash, slag cement or silica fume individually improve the properties of...
concrete in both its plastic and hardened states. When used together, in ternary or quaternary blends, their effects can be synergistic. Understanding these improvements and other performance enhancements is vital to specifying concrete.

Enhanced plastic properties
SCMs generally enhance concrete’s workability. The spherical shape of fly-ash particles and the glassy nature of slag-cement particles reduce the amount of water needed to produce workable concrete. These qualities also enhance the concrete’s pumpability. Silica fume, depending on the replacement rate, can have an adverse effect on workability, and special attention should be given to concrete placing and finishing.

Concrete mixtures containing slag cement and fly ash tend to delay setting time, which can provide additional time for placement, consolidation, and finishing in warmer temperatures and climates. In cooler temperatures, the use of heated water and aggregates or the addition of an accelerating concrete admixture may be necessary to reduce setting time. Silica fume has very little effect on concrete setting times.

The development of bleed water on the concrete surface can affect finishing and durability depending on the amount and rate of bleeding, as well as the timing and finishing techniques utilized. Slag cements, which are generally ground finer than Portland cement, affect the migration of water and reduce bleeding, while slag cement ground coarser than the Portland cement particles tend to increase bleeding. Fly ash generally reduces the water demand necessary to achieve a given workability of the mixture, which in turn reduces the amount of bleeding. Silica fume can virtually eliminate bleeding, which requires special attention to concrete placing, finishing, and curing to achieve the best possible results.

Improved hardened properties
SCMs play a role in the strength-gain characteristics of concrete. Typically, the use of slag cement and fly ash will lower early strengths (one to 14 days) but can significantly improve long-term strength development (28 days and beyond), but this strength-gain curve is very dependent on the proportions and materials used. For example, Class F fly ashes tend to have a slow strength-gain curve contributing mainly to the strength beyond 28 days, whereas silica fume contributes primarily to the three- to 28-day strengths. Silica fume can greatly increase the compressive strength of hardened con-
crete by strengthening the transition zone between the aggregate and the cement paste. Compressive and flexural strengths can increase markedly at 28 days and beyond with the addition of SCMs.

Durability of concrete is largely determined by its ability to withstand harsh environmental conditions, especially freeze-thaw conditions, ingress of chlorides in the form of deicing salts or seawater and aggressive chemicals in groundwater.

SCMs can significantly extend the life of concrete by reducing the permeability of concrete to the ingress of chlorides and other aggressive agents, especially at later ages. Silica fume has a very profound effect on permeability, exhibiting as much as a five-fold reduction in permeability.

Mitigating deterioration
Concrete containing SCMs generally offer superior resistance to sulfate attack, because they lower the permeability, thus restricting the ingress of sulfate ions from groundwater and seawater.

In a number of cases, they also reduce the compounds that can react with sulfates. Typically, slag cement, silica fume and Class F fly ashes are very effective in improving sulfate resistance. The effectiveness of Class C fly ashes is very dependent on the ash chemistry and the replacement level.

When used in the correct proportions, slag cement, fly ash and silica fume can effectively prevent excessive expansion and cracking of concrete due to alkali-silica reaction (ASR).

Blends of SCMs also have been shown to be effective in controlling expansion due to ASR. Blends of slag cement and silica fume, as well as blends of fly ash and silica fume, seem to have a synergistic effect in mitigating expansion due to ASR, while producing a very workable concrete.

If the temperature differential between the concrete’s surface and interior is too high, cracking and loss of structural integrity can result. Utilizing high replacement levels of slag cement or fly ash or both in properly proportioned mixes can reduce the peak temperatures as well as the rate of heat generation. Reducing the heat of hydration of the mix can moderate the development of thermal stresses within the concrete and prevent cracking.

Green benefits
Considering that concrete is the most widely used construction material in the world, the use of SCMs in concrete mixes can have a major effect on the environment. Fly ash, slag cement and silica fume are industrial by-products that are generally destined for landfills. In addition, the use of SCMs negates the need to produce additional portland cement and beneficially uses the energy already expended in the production process of other materials. For these reasons, the EPA and other government agencies encourage the use of SCMs.

Investing in the future
For those who plan on constructing bridges, it makes good engineering, environmental and financial sense to build structures designed for long-term durability. As such, many state transportation agencies are increasingly specifying SCM mix designs. The resulting high-performance concrete yields environmental and economic dividends in terms of reduced maintenance requirements, fewer traffic delays and extended service life. Some examples follow.

Connecticut's Sikorsky Bridge
Named as one of the nation's top five bridges by ROADS & BRIDGES in 2007, the Sikorsky bridge, which crosses the Housatonic River near Stratford, Conn., used fly ash in its three HPC piers and silica fume and fly ash in its HPC deck. Because of the high traffic volumes over the bridge, longevity is critical to minimize disruptions and lane closings. According to the Connecticut DOT’s life-cycle cost analysis, projected service life for the HPC deck is 75 years, compared with 40 years for a standard concrete deck.

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astronomical compared to other ways that transportation funds are used.”

Feeling flat
In the construction equipment industry, manufacturers expect continued business declines of 8.6% in the U.S. through the end of 2008, followed by flat growth in 2009 of 0.04%, according to the annual “outlook” survey of the Association of Equipment Manufacturers (AEM).

Each year, AEM surveys its construction equipment manufacturer members about expected sales of construction machines in 72 different whole-machine product types and 19 types of attachments and components, grouped into seven broad categories: earthmoving, lifting, bituminous, concrete and aggregate, light equipment, attachments and components, and miscellaneous equipment.

“The overall slowdown of the past year or so, after record expansion, accelerated this fall with a worsening housing market and collapse of major financial institutions in the U.S.,” stated AEM President Dennis Slater.

“Our aging roads, bridges and highways need repair and upgrades,” Slater said. “Committing funds to infrastructure renewal not only provides manufacturing and construction jobs, but also helps ensure we have safe and efficient movement of goods and people. An adequate transportation network is essential to commerce and maintaining U.S. competitiveness in global markets.

“The rental market is a significant source of business for equipment manufacturers. After a few years of solid growth, this segment is undergoing a correction. Expected cuts in rental company capital spending will adversely affect equipment sales.”

With all the public resistance to increasing the federal gas tax and the immaturity of other revenue generators to take over, the transportation construction industry has a big job to convince Congress to make big increases in highway and transit funding. It should be easy to advocate saving lives, but even ATSSA could face opposition. McSwain stated:

“Even as easy as talking about safety is and saving lives is—we may have some champions in the House and Senate—but if we are not able to help in the process of finding alternative funding, our chances of success are going to be tough.”

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Maryland’s Cold Bottom Bridge

Succumbing to cracking and corrosion, the bridge deck on Maryland’s Cold Bottom Bridge, which crosses I-83 some 10 miles north of Baltimore’s I-695 Beltway, was rebuilt with HPC using a 50/50 portland-slag cement mixture. The new HPC bridge deck has a projected life of up to 75 years, according to the Maryland State Highway Administration, effectively doubling the life of the deck.

Virginia’s Pocahontas Parkway

For the Pocahontas Parkway overpass near Richmond, the Virginia Department of Transportation chose a mix containing a high proportion of slag cement because of its strength and performance characteristics and its heat of hydration. The 75% slag cement mixture reduced temperature rise in the mixture and thus the likelihood of thermal cracking in the mass concrete supports that elevate the roadway above ocean-going shipping lanes on the James River.

Michigan’s Bagley Street Pedestrian Bridge

The Michigan Department of Transportation (MDOT) specified an HPC mixture of portland cement, slag cement and silica fume for constructing a new $7 million state-of-the-art, cable-stayed pedestrian bridge in Detroit during 2008. According to MDOT’s material/engineering engineers, this ternary blend of materials works synergistically to meet the agency’s requirements for high strength, reduced permeability and long-term durability. It also offers excellent finishing qualities, as well as good freeze-thaw resistance.

Specifying for performance

Various organizations, including the American Concrete Institute, offer recommendations on how to specify SCM mixtures. As with all concrete mixtures, trial batches should be prepared 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.

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