United States Department of Transportation — Federal Highway Administration

Advanced High-Performance Materials for Highway Applications: A Report on the State of Technology

Chapter 2, Candidate Cementitious Materials

Performance-Specified Cements

Description

As sustainability becomes an increasingly important element in the design and construction of transportation infrastructure, approaches are continually being sought to reduce the environmental footprint of concrete, which is the most widely used construction material in the world. Although portland cement (ASTM C150) is a relatively minor constituent in concrete, it is responsible for 90 to 95 percent of the CO2 associated with concrete (Van Dam and Taylor 2009). The key to reducing the carbon footprint of concrete is therefore to reduce the amount of portland cement used, and one way of accomplishing that is through the use of alternative cement binders.

The recent adoption of ASTM C1157, Performance Specification for Hydraulic Cement (the first version of ASTM C1157 appeared in 2000), represents an important development in this area. Other portland cement specifications (both ASTM C150 and C595) are largely prescriptive, in that they are based on measured chemical and physical properties that are assumed to relate to the performance of the cement in concrete. In contrast, ASTM C1157 simply requires that the cement meet physical performance test requirements. Under this specification, six cement types are available:

- GU (general use).
- LH (low heat of hydration).
- MH (moderate heat of hydration).
- HE (high early strength).
- MS (moderate sulfate resistance).
- HS (high sulfate resistance).

For example, Type MS and HS cements use ASTM C1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution, to ensure resistance to sulfate attack. The performance classification of hydraulic cement is thus based on the concept that direct material performance is of interest and not its composition. This approach promotes innovative development of composite portland cements (for example, Portland cement blended with limestone or multiple supplementary cementitious materials) as well as opening the door to non-portland cement binders that have the potential to significantly alter the CO2 associated with concrete construction.

As it is a relatively new specification, the acceptance of ASTM C1157 cements is currently mixed. Although the majority of States allow ASTM C1157 cements in their building codes, only a few State departments of transportation (DOTs) - for example, Colorado, Montana, New Mexico, and Utah - accept their use for transportation projects. In time, the use of ASTM C1157 cements has the potential to lower the carbon footprint of concrete significantly while more effectively addressing the specific performance needs of transportation projects.

Applications

ASTM C1157, as an alternative to conventional portland cement (ASTM C150) and blended portland cement (ASTM C595), can be used in virtually any transportation application, including highway and airport pavements, bridges, port and loading facilities, and parking lots.

Benefits

The adoption of ASTM C1157, performance-specified cements will increase innovation in producing more environmentally benign cements specifically linked to performance.

Costs

Costs are comparable to ASTM C150 and ASTM C595 cements.

Current Status

The use of ASTM C1157 is being implemented on a small number of projects to evaluate its effectiveness. The Colorado DOT has been a leader in the use of performance-specified cements and has used them on a number of highway projects.

For More Information

Van Dam, T. J., B. W. Smartz, and T. S. Laker. 2010. "Use of Performance Cements (ASTM C1157) in Colorado and Utah: Laboratory Durability Testing and Case Studies," Proceedings of the International Conference on Sustainable Concrete Pavements: Practices, Challenges, and Directions (pp. 163 - 177), held in Sacramento, California, September 15 - 17, 2010.
Federal Highway Administration.

Van Dam, T., and P. Taylor. 2009. Building Sustainable Pavements with Concrete. Briefing Document, CP Road Map Track 13: Concrete Pavement Sustainability. National Concrete Pavement Technology Center, Iowa State University. Ames, IA.

Next-Generation Sustainable Cements

As sustainability becomes an increasingly important element in the design and construction of transportation infrastructure, approaches are continually being sought to reduce the environmental footprint of concrete, which is the most widely used construction material in the world. As stated earlier, although portland cement (ASTM C150) is a relatively minor constituent in concrete, it is responsible for 90 to 95 percent of the CO2 associated with concrete (Van Dam and Taylor 2009). The key to reducing the carbon footprint of concrete is therefore to reduce the amount of portland cement used, and one way of accomplishing that is through the use of next-generation cement binders that significantly reduce CO2 emissions. Additionally, some research is underway to develop cements that actually sequester CO2.

The recently constructed I-35W bridge in Minneapolis, Minnesota, is a real-life example of how innovation can result in a superior performing concrete while at the same time significantly reducing the carbon footprint of the structure. The bridge piers were constructed of a cementitious blend that was only 15 percent ASTM C150 portland cement; 85 percent of the blend was ASTM C989 slag cement, a co-product of the iron blast furnace (ACI 2009). Not only was this a durable concrete with a low heat of hydration, it was estimated to have an equivalent CO2 footprint of 85 lbs of CO2 per yd3 (50.4 kg/m3) compared to 527 lbs CO2/yd3 (312.7 kg/m3) for a typical 6-sack (564 lbs cement/yd3 [334.6 kg/m3]) concrete mixture.

Recently, the potential use of alkali-activated cements and geopolymers in concrete has been gaining popularity. Alkali-activated cements do not rely on ASTM C150 portland cement, instead using alkali-activators to stimulate hydration of fly ash, slag cements, and natural materials, with the result being a durable, environmentally friendly binder. Similarly, geopolymers use alkali solutions to dissolve and then polymerize reactive minerals rich in alumino-silcate glass (e.g,. Class F fly ash, metakoalin) in a nonhydration reaction. Both alkali-activated and geopolymer cements have been used in a number of structures, but have not seen much use in the transportation field, although they are the basis for some high-early- strength patching materials. Nevertheless, numerous studies are underway or have been recently completed evaluating the possibility of using alkali-activated and geopolymer cements in transportation infrastructure, and it is likely that broader use of these materials will occur within the next few years.

As interest grows in reducing the carbon footprint of concrete, another research area is looking into the development of cements that actually sequester CO2 from the atmosphere. A few different processes are under investigation. One focuses on passing CO2-laden exhaust gases from coal-fired power plants through seawater, brackish water, or water laden with suitable minerals, resulting in a reaction between the CO2 and calcium or magnesium ions in the water. Some companies are proposing to use this technique to produce synthetic aggregate, whereas others have proposed a process that will produce carbon-sequestering cement (Bullis 2009).

Once fully developed, next-generation sustainable cements will significantly reduce the carbon-footprint of the built environment. **This could have significant global impact as a way to mitigate the long-term effects of global climate change**.

Energetically Modified Cement

Description

Energetically modified cement (EMC) is produced through a patented process of high intensive grinding of portland cement together with pozzolans (Jonasson and Ronin 2005). By intensively grinding and activating the cement with the pozzolans, the surfaces of the pozzolans are activated, which creates a network of sub-microcracks, microdefects, and dislocations in the particles that allow deeper water penetration, thereby increasing the binding capacity of the cement (FHWA 2005). This not only helps increase the rate of strength gain (which can be a problem with traditional blended cements) but also translates into lower cement requirements, which means less energy usage and suggests improved longevity and durability.

Applications

EMC has the potential for use in nearly any type of application, including bridges, foundations, pavements, container facilities, and warehouse floors.

Benefits

EMC cement is noted to provide the following benefits (Klemens 2004):

- Reduced cement requirements.
- Increased set times.
- Increased strength.
- Improved durability.
- Improved workability, finishability, and pumpability.
- Reduced shrinkage.

Current Status

EMC has undergone over 15 years of research and development in Sweden, where it has been used in bridges, foundations, and road construction. A plant was constructed in Texas in 2004 to produce a more reactive fly ash (CemPozz®) using the same Swedish patented technology used to produce EMC (Klemens 2004). The Texas and Pennsylvania DOTs have included CemPozz® in their specifications for paving and structural concrete, allowing up to 50 percent replacement of portland cement.

For More Information

Federal Highway Administration (FHWA). 2005. Long-Term Plan for Concrete Pavement Research and Technology - The Concrete Pavement Road Map: Volume II, Tracks. HRT-05-053. Federal Highway Administration, Washington, DC.

Jonasson, J. E., and V. Ronin. 2005. High Performance Concretes with Energetically Modified Cement (EMC). Luleå University of Technology, Sweden. Available at http://www.emccement.com/Articles/01_kassel_conference_emc.pdf.

Klemens, T. 2004. "Another Mix Option: Portland Cement Substitute Yields Economic, Environmental, and Durability Benefits." The Concrete Producer, January 2004.

Pike, C. W., V. Ronin, and L. Elfgren. 2009. "Three Years of Industrial Experience in Texas with CemPozz." Concrete InFocus, Vol. 8, No. 2. National Ready-Mixed Concrete Association, Silver Springs, MD. http://www.nrmca.org/news/connections/mar_apr_09.pdf.

Ronin, V. 2010. "An Industrially Proven Solution for Sustainable Pavements of High- Volume Pozzolan Concrete - Using Eneretically Modified Cement, EMC," Proceedings of the International Conference on Sustainable Concrete Pavements: Practices, Challenges, and Directions, held in Sacramento, California, September 15 - 17, 2010, Federal Highway Administration.

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