Blended Hydraulic Cements as a Sustainable Option in Precast/Prestressed Elements

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ABSTRACT

As sustainability becomes an increasingly important element in the design and construction of the built environment, approaches to reduce the environmental footprint of precast/prestressed concrete products becomes more attractive. Concrete, as the most widely used construction material on the planet, has a significant environmental impact. Although portland cement is a relatively minor constituent by volume, its presence can significantly contribute to the Carbon Dioxide (CO_2) associated with concrete. One method to reduce the carbon footprint of cement and concrete is through the use of blended cements that use limestone and/or supplementary cementitous materials (SCM) such as slag, fly ash, or natural pozzolans as a portion of their constituents. This paper investigates relevant specifications for hydraulic cements incorporating intergound limestone and pozzolans and their use in precast/prestressed applications. Furthermore, this paper introduces the potential of natural pozzolans as SCMs in hydraulic cements.

Keywords

Blended Cement, Clinker, Hydraulic Cement, Pozzolans, Supplementary Cementitious Materials, Sustainability

INTRODUCTION

Next to water, concrete is the second most used material in the world. Cement, the major binding component in concrete, is manufactured by heating sources of calcium, alumina, silica, and iron to very high temperatures to form new chemical combinations. The resulting combinations are captured in a formation called clinker which is later ground with a small portion of gypsum to produce cement powder. The manufacturing of cement worldwide accounts for approximately 5% of the manmade CO_2 production.[1]

The major source of calcium for cement manufacturing is limestone or calcium carbonate. The limestone and other chemical constituents are typically naturally occurring and are mined from large deposits. This mining has an impact on natural resources depletion. Additionally, when calcium carbonate is heated in the cement kiln, CO_2 is liberated. Liberated CO_2 from limestone accounts for approximately 60% of CO_2 generation associated with clinker production. The other 40% comes from burning fossil fuels used to heat the kiln to approximately 2400^o F (1300^oC). There is great effort by the cement industry to significantly reduce the amount of CO_2 generated in the cement making process. Technology has advanced in such a way that modern cement plants can produce clinker with much less energy and associated CO_2. Cement manufacturers are also looking at alternate fuels and raw materials to help reduce the carbon foot print of the manufacturing process.

One way to lower the CO_2 impact of cement is through the use of performance based cement specifications that help lower CO_2 production by replacing clinker with other mineral constituents. These specifications allow a manufacturer to produce hydraulic cement that performs similar to portland cement; while reducing the need for clinker by intergrinding or blending SCM's that do not need calcination (calcination is the action in clinker production when CO_2 is released from calcium carbonate forming calcium oxide.) These products can be naturally occurring or by-products from other manufacturing operations. Whatever the combination, specifications currently exist to assure the quality of performance based cements. A major issue regarding the use of these cements is the acceptance of performance based specifications by the specifying community.

CEMENT MANUFACTURING

Modern advances in cement manufacturing have reduced the amount of CO_2 emitted during the production of clinker. Dry process plants utilize preheater towers that preheat and dry material with recycled exit gases from the kiln and cooling process. This helps reduce the need for fossil fuels in the kiln. Additionally, many cement facilities utilize alternate fuel sources such as waste tires, paper, plastics, and other construction waste materials. The extreme heat of the process allows for complete combustion of these fuels and emissions are minimal. By utilizing these fuels, waste can be co-processed rather than landfilled.

Quality control is of the upmost importance in the cement industry. Through the use of X-ray technology, chemical composition can be determined in less than 90 seconds. Raw materials and finished products can now be tested at a rate unattainable by the use of wet chemistry techniques. This technology has allowed for increased sampling and measurement, assuring that specifications are met.[2]

SPECIFICATIONS

As with most products, hydraulic cements are manufactured to meet an ASTM International (ASTM) or American Association of State Highway and Transportation Officials (AASHTO) designation. These cements are to meet at least one of three specifications, ASTM C150 *Standard for Portland Cement*[3] *(AASHTO M85 Standard Specification for Portland Cement),* ASTM C595 *Standard for Blended Hydraulic Cement*[4] *(AASHTO M240 Standard Specification for Blended Hydraulic Cement),* or ASTM C1157 *Standard Performance Specification for Hydraulic Cement*[5].

The oldest and most recognized specification is ASTM C150. This specification was introduced in 1940 and is prescription based. As with other prescriptive specifications ASTM C150 provides the cement manufacturer the basic chemical requirements for traditional "Types" of cement. Type I is for general use, Type II is for moderate sulfate exposure, Type II (MH) for moderate heat of hydration, Type III is for high early strength, Type IV is for low heat of hydration, and Type V is for high sulfate exposure. Prescribed chemical compounds are within a range of maximum and minimum limits for each different Type of cement for its intended use or location. The C150 specification also incorporates optional requirements such as Low Alkali (Equivalent Alkali <0.60) for resistance to a potential Alkali Silica Reaction (ASR) with particular aggregates.

Very few changes have been made to this specification over the years and the prescriptions limit the opportunities for a producer to innovate ASTM C150 products. However in 2004, ASTM C150 was modified to allow for up to 5% high grade limestone as a constituent in the manufacturing process. This change has provided a potential reduction of CO_2 emission and reduction in raw material use per ton of cement produced while maintaining all other requirements.

ASTM C595 is an additional prescriptive cement specification that was introduced in 1967. This specification provides for the intergrinding or blending of portland cement clinker or finished portland cement with SCM's to produce hydraulic blended cement. The types of blended cements in ASTM C595 are designated by the type of supplementary material and its percentage in parentheses, i.e. Type IS (*) *portland blast-furnace slag cement* or Type IP(*) *portland-pozzolan cement,* Type IL (*) *portland-limestone cement*. There is also a ternary designation where portland cement clinker can be interground or blended with two supplementary components such as a slag and a pozzolan (IT (S25)(P15) ,for example, would include 25% slag cement and 15% pozzolan).

The recent adoption of interground limestone from 5% up to 15% replacement by weight in Type IL cement under ASTM C595 and AASHTO M240 has created and opportunity for increased usage of CO2 reducing cements. Limestone cements have been used widely in Europe for decades. More recently in the United States and Canada, limestone cements have been utilized in concrete pavements and commercial construction.[6]

Another ASTM cement standard is C1157, a performance based specification, which was introduced in 1992. This specification has no chemical requirements; instead it requires standardized test methods to determine potential performance. Types of hydraulic cement under ASTM C1157 are GU (general use), MS (moderate sulfate resistance), HE (high early strength), LH (low heat of hydration), and HS (high sulfate resistance). Performance cements can have multiple SCMs and other CO_2 reducing technologies incorporated into the manufacturing process.

Verifying the performance of hydraulic cements is the responsibility of the manufacturer and test results for certain performance characteristics can be requested by the purchaser. These tests may include sulfate resistance (ASTM C1012) and ASR resistance (ASTM C1567). Performance test results along with standard product information such as setting time, compressive strength, Blaine fineness, chemical characteristics, etc., are reported on material certification reports.

SUPPLEMENTARY CEMENTITIOUS MATERIALS

Supplementary cementitious materials are components that can be used in conjunction with portland cement. The most common SCMs are fly ash and slag cement. Fly ash is a fine powdery substance that is carried by flue gasses from the coal combustion chamber, and collected by electrostatic precipitators or bag houses prior to the gasses exiting the plant. Its composition is similar to volcanic ash with pozzolanic properties.[7] Fly ash is a by-product that can increase concrete durability by reducing permeability and calcium hydroxide in concrete. Although some ashes have cementitious characteristics, they are considered pozzolans, materials that will react in the presence of portland cement to form more of the hydration products called calcium silicate hydrates (CSH). Calcium hydroxide, a normal product of cement hydration, can provide a source of calcium for the pozzolonic reaction. Slag cement is hydraulic cement formed when granulated iron blast-furnace slag is ground to a suitable fineness.[8] Similar to fly ash, slag cement can improve concrete durability by reducing permeability and calcium hydroxide.

There are also many naturally occurring pozzolans that can be successfully incorporated into blended cements. Natural pozzolans are generally grouped into the following classifications;

calcined shales, calcined clays, diatomaceous earth, metakaolin, opaline shales, volcanic ash, volcanic materials, pumice and pumicite, trass, santorin earth tuffs and zeolites.[9] Depending on the type and amount of natural pozzolan being used, the benefit to concrete can include improvements to alkali-silica reactivity, lower heat of hydration, improved sulfate resistance and decreased permeability.[10] A description of these materials can be found in ACI 232A Use of Raw or Processed Natural Pozzolans in Concrete.[11]

CASE STUDIES

The expectation of concrete performance with blended cement products must be in line with traditional products. In the following case studies, projects across the US are presented that utilize hydraulic cements meeting ASTM C595 or ASTM C1157. These projects highlight how the use of such cements can add to the sustainability of precast/prestressed concrete construction.

Case Study #1: Owell Precast Office Building and Maintenance Shop - Draper, Utah

Owell Precast is an innovative precast concrete firm that specializes in precast wall systems, hollow-core slabs, and structural elements. In 2004, Owell Precast designed and precast a 35,000 square foot(3,250 m^2); two story office building (15,000 ft^2,1,400m^2) with an attached four-bay maintenance facility (20,000 ft^2,1900m^2). The structural framing of the building is of precast/prestressed concrete columns in-filled with precast wall panels. The precast concrete mixture included ASTM C1157 performance cement which incorporated diatomaceous earth, a natural pozzolan. Many of the interior finishes were also of precast concrete, including an exposed concrete wall which was stained and a precast concrete banister. The office building utilized approximately 1500 cubic yards (1,150 cubic meters), of concreteall of which exceed the design strength of 5000 psi(35 MPa). The Owell office building showcases the diversity of precast and the effectiveness of precast concrete containing interground pozzolans in the performance cement.

Case Study# 2: Owell Precast Fabrication Building - Draper, Utah

With the success of casting and erecting their precast office building and maintenance facility, Owell Precast initiated the design and construction of a 200 by 550 foot (110,000 ft^2)(61 by 168 meters (10,250 m^2))fabrication hall in 2006. Over a two year period Owell, precast and placed over ninety two 40 foot (12 meter) prestressed columns, and 74 column covers. The prestressed columns, spaced every twenty five feet (7.6 meters), support prestressed crane runway beams that carry four overhead cranes that service the two casting bays. The columns also support the steel roof structure which spans the 85 foot (26 meter) width of each casting bay. The exterior of the building is made of five hundred and twenty, 10by20 foot (3 by 6 meter) prestressed panels which fit between the columns. The concrete mixture for this building included ASTM C1157 performance cement which included 10%

interground limestone. All the concrete for the precast columns and panels exceeded the design strength of 5000 psi (35 MPa). Owell did not experience any casting delays during the project. In total, the casting hall utilized approximately 3,000 cubic yards (85 cubic meters) of precast concrete.

Case Study #3: Boughton Precast - Pueblo, Colorado

Boughton Precast is a long-time family owned precast concrete firm that specializes in precast concrete products such as reinforced concrete pipe (RCP), septic tanks, inlets, utility vaults and manholes. In 2008, Boughton needed to revise their mix designs to meet the new Colorado Department of Transportation (CDOT) high sulfate resistance specifications which included the requirement of fly ash in the concrete mix. A locally produced ASTM C595 IP blended with Class F fly ash provided a single silo solution to meet the strength and durability requirements of the new CDOT specification. The ASTM C595 IP me the ACI Class 3 requirements of ASTM C1012 expansion less than 0.10% at 18 months. Boughton's has supplied precast concrete products to CDOT projects on a regular basis as well as municipality and private sector work.

Case Study #4: UTA Front Runner South- Salt Lake City to Prove, Utah

Utah Block manufacturers have used ASTM C1157 performance cements for over 15 years. Their products have been used in commercial, residential and heavy civil construction. One major project recently constructed is the Utah Transportation Authority (UTA) Front Runner South - Salt Lake City to Provo, Utah commuter rail line. After the successful completion of approximately 40 miles (64 km) of a commuter rail line from Ogden to Salt Lake City, Utah in April of 2008, the UTA initiated construction on an additional 45 mile (72 km) commuter rail line from Salt Lake City to Provo, Utah in August of 2008. This southern section of the Front Runner rail line included more complex design and construction issues due to Interstate corridors and existing freight rail lines. To accommodate the congestion from existing infrastructure assets, 30 bridges and 50 other civil type structures were constructed. UTA chose to use Keystone concrete masonry units (CMU) to build mechanically stabilized walls for many of the bridges and overpasses. The CMUs that were utilized on this project incorporated ASTM C1157 cement incorporating 10% limestone with an additional 15% Class F fly ash in the block mix. The project required over 350,000 ft^2 (32,500 m^2) of retaining wall including a large overpass wall which is 37 feet (11 meter) tall and constructed with 55 block courses above grade and 10 courses of block below grade. Block on this project averages upwards of 6,500 psi (45 MPa) compressive strength with absorption of 5.3%.[12]

Along with these case studies, other project successes involving blended cements have been reported. For example, prestressed panels for a large warehouse in the Carolinas were manufactured with Type IS cement in order to help with LEED requirements regarding SCMs and recycled material. The IS cement also did not impede release times of the prestress in the panels. Other elements, such as hollow core and barrier rail, were also manufactured. Type IS has also been used in high strength vaults and drainage elements.

SUMMARY

As sustainability becomes an increasingly important element in the design and construction of the built environment, approaches to reduce the environmental footprint of concrete in precast/prestressed applications become more attractive. The following were presented in this paper:

- Concrete is the most commonly used construction material on the planet. Although portland cement is a relatively minor constituent by volume, its presence is responsible for the vast majority of CO_2 associated with concrete. In the U.S., the production of portland cement accounts for 1.5 to 2.0 percent of the nation's anthropogenic CO_2 emissions; globally, cement production accounts for approximately 5 percent of world-wide anthropogenic CO_2 emissions.

- Modern advances in cement manufacturing have reduced the amount of CO_2 emitted during the production of clinker. Alternate fuels and raw materials have also helped to decrease CO_2 associated with cement production.

- Hydraulic cements are manufactured to meet an ASTM or AASHTO designation. Standards exist that allow for CO_2 reducing technologies to be incorporated in blended cements.

- Supplementary cementitious materials including slag, fly ash, and natural pozzolans, as well as limestone have been found to enhance concrete performance as part of a blended cement.

- Case studies and examples are presented that demonstrate precast/prestressed concrete made with performance cements are readily constructible and can achieve specified requirements. Where used, these cements were not reported to have negatively affected operations.

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