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Cement and concrete—production and use in New Mexico

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Abstract

Modern portland cement, discovered in 1824 by an English bricklayer, has become one of the world's favorite building materials. As a cement that will harden in water (a hydraulic cement), it is used in many ways under many conditions with varying degrees of success. Understanding the cement-making process, the different concrete aggregates, and the affect of the environment on the hardened concrete are all essential to understanding the durability of concrete structures and highways.

Four dominant chemical components are contributed by the raw materials of portland cement: lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). The combined weight of these four oxides is about 90 wt% of cement, so they are referred to as the "major oxides." Portland cement consists of a mixture of chemical compounds rather than a precise chemical formula. Each compound also contains appreciable dissolved impurities. Tricalcium silicate (C_3S) and dicalcium silicate (C_2S) account for about 75% of portland cement. The other two cement "minerals" are tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF). Each of the four cement minerals contributes its own characteristics to hardening cement. The proportions of these compounds are carefully controlled, along with the temperature and speed of the burning (clinkering) process, to produce six major types of portland cement and their many modifications.

Some geologic materials are deleterious to making cement and can be tolerated only in small amounts. Some, such as porous, weak, or reactive materials, are deleterious when mixed with cement as aggregate. In particular, alkali-bearing minerals or materials are carefully regulated both in cement raw materials and aggregate. In concrete, aggregates containing strained quartz, volcanic glass, and amorphous or microcrystalline silica (chert, flint, opal, chalcedony, and agate) produce alkali-silica reactions (ASR). These materials can hydrate, producing expansive forces that cause the concrete to crack or spall. Acidic igneous rocks also are potentially reactive, but although fine-grained volcanic varieties will react quickly, little change is apparent in coarsely crystalline varieties even after 20 years. One way to reduce ASR in concrete aggregate is to add pozzolans, limestones, or marble.

New Mexico's one cement plant, operated by the Rio Grande Portland Cement Corporation in Tijeras east of Albuquerque, produces only low-alkali cement (0.6% alkali oxides or less). Ready-mix plants and contractors must pick and choose to select suitable aggregate for concrete in the state's sand and gravel pits, particularly along the Rio Grande. Light-colored volcanic rocks and amorphous or microcrystalline silica are highly reactive as aggregate. For durable concrete, geologists must be aware of potential problems and solutions for both cement and aggregate.

Introduction

Although cement as a construction material has been known for thousands of years, modern "portland cement" was first patented by an English bricklayer, Joseph Aspdin, in 1824 (Soroka, 1979). He produced the new cement material by burning limestone and clay together in his kitchen stove. When ground to a fine powder and mixed with water to form a paste, it would harden to a stone-like material even in water, forming a hydraulic cement. Aspdin named his discovery after the well-known dimension stone, which it resembled, that was quarried on the Isle of Portland off England's southern coast. Although Englishman John Smeaton had already developed a "hydraulic cement" in 1756, it was Aspdin's "portland cement" that revolutionized construction.

The Romans, and before them the ancient Egyptians, used pozzolanic cement that was composed of volcanic ash and lime (CaO) and is called a hydraulic lime. A pozzolan is composed of siliceous or siliceous and aluminous material, which in itself possesses little or no cementing value but will, in finely ground form and in the presence of moisture, chemically react with calcium hydroxide at ordinary construction temperatures to form compounds possessing cementing properties. Pozzolans include diatomaceous earth, opaline chert and shale, volcanic tuff and ash, and fly ash.

Masonry cement, also hydraulic, is a finely ground mixture with portland cement as the major constituent. Secondary constituents provide the water retention and plasticity required for use as mortar. The essential characteristic of any of these cements is that they harden into a stone-like mass when calcined, ground to a powder, then mixed with water to form a paste and allowed to react or "hydrate."

Non-hydraulic cements include "plaster of Paris" or calcined gypsum ($CaSO_4 \cdot \frac{1}{2}H_2O$), which rehydrate after being mixed with water. They harden into stone-like but soft gypsum ($CaSO_4 \cdot 2H_2O$) that further softens and breaks apart in water.

Concrete is essentially a mixture of portland cement, water, fine aggregate (sand), and coarse (large-size) aggregate. Portland cement may amount to as little as 10% of this mixture, but it is the most costly major constituent.

Cement composition

Raw materials

The raw materials of portland cement contribute four dominant chemical components: lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). The combined weight of the four "major oxides" is about 90% of the cement. Table 1 lists these oxides, their common percentage in cement, and typical rock or mineral sources (Soroka, 1979; Ames et al., 1994; Austin and Barker, in press). The common source of CaO is limestone, which is composed of calcium carbonate ($CaCO_3$). Calcining drives off CO_2, leaving lime (CaO). Silica and alumina are the dominant components of shale. Iron-bearing materials may be pre-

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