Chemistry of Cement and Concrete

Cement is simply something that sticks things together, but we usually think of cement as the basis for mortar for sticking bricks together and for synthetic rock - concrete. Cements which bind natural rocks together are oxides of iron, calcium and/or silicon. Builders have used natural clay and burnt lime for thousands of years to cement structures together, but 200 years ago we began to need something better. Pressure on space caused by populations moving into cities created the need for bigger, higher, stronger buildings – see *The Rise and Rise of Concrete*.

Concrete, whether made in a wheelbarrow or a giant machine, is a semi-fluid mixture of cement, sand, gravel and water with perhaps some other additives. It is designed to be poured into a mould of any shape where, after a few hours, is sets to a rigid solid. Then, over days and weeks it hardens to a mass of great strength, hardness and durability.

Even after hundred of millions of years, natural cements remain excellent binders of rocks which have been subjected to the severest of natural stresses. It took about 2000 years for engineers and architects to agree on one type of cement suitable for a wide range of constructions. This is ***portland cement*** whose optimum proportions are –

70% calcium oxide CaO
20% silica SiO_2
5% alumina Al_2O_3
3% ferric oxide Fe_2O_3
2% gypsum $CaSO_4.2H_2O$

Picking rocks which, together, will make the best portland cement is both an art and a science. Not only do geologists and managers have to assemble rocks with the right combinations of elements, but it is also critical to choose rocks which are low in certain other elements, particularly sodium, potassium, magnesium and phosphorus.

Cement plants are usually built close to limestone mines because that is the main mineral needed. Other common minerals – sand, a clay called kaolinite, and one of several iron-rich minerals – are used to provide the alumina, silica and iron oxide needed. When this mixture is roasted, it drives off carbon dioxide, leaving behind the required oxides plus a small amount of gypsum.

Besides being close to a large source of limestone, the siting of cement works are determined by the economic combination of transport, energy and raw materials, and that usually means being close to a coal mine and to rail or sea transport. There is no doubt that production of cement is one of the most energy intensive industries, and it produces a large amount of greenhouse gas. Berryessa is involved with industrial research aiming to achieve major reductions in energy consumption and envirnmental damage by substitution of materials and processes yielding concrete structures of uncompromising strength and durability.

Adding water to dry cement immediately starts a series of chemical reactions which bind the whole mass together, but the mass is too brittle. However, the combination of cement and water with sand, or with sand and gravel, makes the mixture extremely useful. Calcium oxide immediately reacts with water forming a strongly alkaline solution of hydrated lime. This hydrated lime then reacts with silica both within the cement and on the surface of the sand and gravel to form silica gel which gives fresh concrete its early stiffness. This gel slowly rearranges to form a complex matrix of crystalline silicates surrounding the particles of sand and aggregate, yielding a composite of great strength. The optimum composition of that matrix contains –

51% tricalcium silicate Ca_3SiO_5
26% dicalcium silicate Ca_2SiO_4
11% tricalcium aluminate $Ca_3Al_2O_6$
1% complex ferric salt $Ca_4Al_2Fe_2O_{10}$
some calcium sulfate $CaSO_4$