Research about::

(Concrete Components)

Prepared By : Sairan A. Muhammad

Card No: 1280

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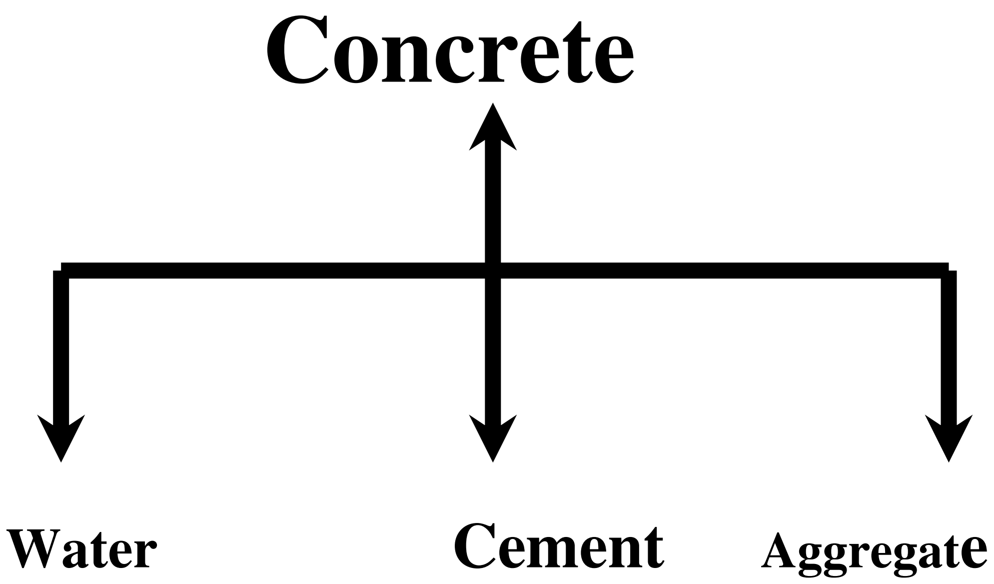
Introduction

The importance of concrete in modern society cannot be underestimated. Look around you and you will find concrete structures everywhere such as buildings, roads, bridges, and dams. There is no escaping the impact concrete makes on your everyday life. So what is it? Concrete is a composite material which is made up of a filler and a binder. The binder (cement paste) "glues" the filler together to form a synthetic conglomerate. The constituents used for the binder are cement and water, while the filler can be fine or coarse aggregate. The role of these constituents will be discussed in this section.

Cement, as it is commonly known, is a mixture of compounds made by burning limestone and clay together at very high temperatures ranging from 1400 to 1600 ˚C. ………………



Cement +water = cement past

APPLICATIONS OF CONCRETE

Past, Present, and Future

Roads
Bricks/blocks
Beams
Sewer pipes
Canals
Dams
Caskets
Tombs
Swimming pools
Canoes
Tunnels
Holding tanks
Flower pots & planters
Ballast
Bank vaults
Telephone poles
Headstones
Business/credit cards **
Insulating tiles/bricks
Parking stones
Water tanks
Artificial rocks
Railroad ties
Picnic table's
Wharves & piers
Stadium seats

sidewalks
bridges
foundations
water mains
missile silos
churches
monuments
indoor furniture
airport runways
barges
parking garages
cement "overshoes"
chimneys
bath tubs
basements
electric light poles
steps
fertilizer
corn silos
roof tiles
curb & gutters
office buildings
airports
swimming pools
bird baths
fountains

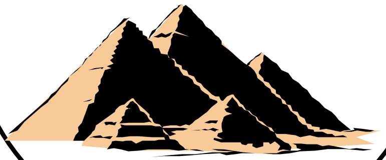
houses
walls
floors
computer chip backing **
containment of nuclear waste
automobile brake lining **
solidification of hazardous wastes
garden ornaments
sailing boats
subways
patio bricks
sculptures
mantels
grave vaults
lamp posts
Frisbees
fence posts
bone replacement **
park benches
water troughs
nuclear reactor containment structures
parking lots
monorails
break waters
barbecue pits
lunar bases **

**** Denotes future applications.**

CONCRETE HISTORICAL TIMELINE

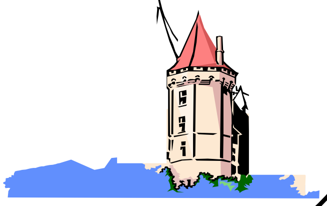
3000 B.C.- PRESENT

3000 B.C.
Egyptians used mud mixed with straw to bind bricks. They used gypsum and lime mortars in the pyramids.

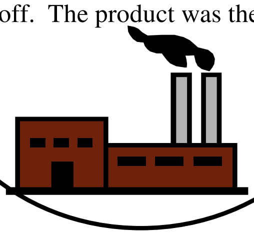


300 BC- 476 AD
Applian Way, Roman baths, the Colosseum and Pantheon used Pozzalana cement. Animal fat, milk and blood were used as admixtures.

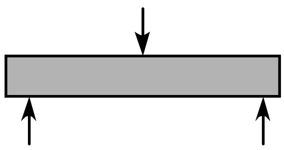
1793
John Smeaton used hydraulic lime to rebuild Eddystone Lighthouse in Cornwall, England



1824
Joseph Aspdin of England invented portland cement by burning ground chalk with finely divided clay in a lime kiln until carbon dioxide is driven off. The product was then ground.



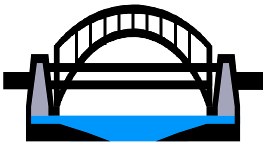
1836
The first systematic test of tensile and compressive strength took place in Germany



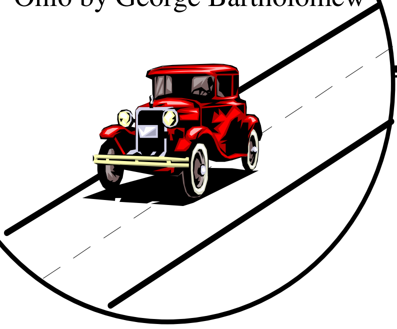
1867
Joseph Monier of France reinforced flower pots with wire ushering in theidea of iron reinforcing bars.

1886
First rotary kiln was introduced
in England, which allowed for
continuous production of cement.

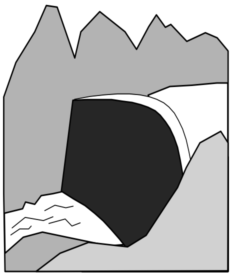
1889
First concrete reinforced
bridge was built.



1891
First concrete street in the
USA was placed in Bellefontaine,
Ohio by George Bartholomew

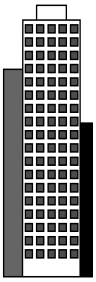


1936
First major concrete dams,
the Hoover Dam and Grand
Cooley Dam, were built.



1967
First concrete dome sport
structure constructed at the
University of Illinois, Assembly Hall.

1992
Tallest reinforced building
(946 ft) constructed in
Chicago, IL



The History of Concrete:
A Timeline

Cement has been around for at least 12 million years. When the earth itself was undergoing intense geologic changes natural, cement was being created. It was this natural cement that humans first put to use. Eventually, they discovered how to make cement from other materials.

**12,000,000 BC Reactions between limestone and oil shale during spontaneous
Combustion occurred in Israel to form a natural deposit of cement
Compounds. The deposits were characterized by Israeli geologists in the
1960's and 70's.**

**3000 BC Used mud mixed with straw to bind dried bricks. They also used gypsum
Egyptians mortars and mortars of lime in the pyramids.**

**Chinese Used cementations materials to hold bamboo together in their boats and in
The Great Wall.**

**800 BC Used lime mortars which were much harder than later Roman mortars.
Greeks, Crete
& Cyprus**

**300 BC Used bitumen to bind stones and bricks.
Babylonians
& As Syrians**

**300 BC - 476 AD Used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius to build the
Romans Appian Way, Roman baths, the Coliseum and Pantheon in Rome, and
The Pont du Gard aqueduct in south France. They used lime as a**

	Cementations material. Pliny reported a mortar mixture of 1 part lime to 4 Parts sand. Vitruvius reported a 2 parts pozzolana to 1 part lime. Animal fat, milk, and blood were used as admixtures (substances added to cement to increase the properties.) ***These structures still exist today!***
1200 - 1500 The Middle Ages	**The quality of cementing materials deteriorated. The use of burning lime and pozzolan (admixture) was lost, but reintroduced in the 1300's.**
1678	**Joseph Moxon wrote about a hidden fire in heated lime that appears upon the addition of water.**
1779	**Bry Higgins was issued a patent for hydraulic cement (stucco) for exterior plastering use.**
1780	**Bry Higgins published "Experiments and Observations Made With the View of Improving the Art of Composing and Applying Calcereous Cements and of Preparing Quicklime."**
1793	**John Smeaton found that the calcination of limestone containing clay gave a lime which hardened under water (hydraulic lime). He used hydraulic lime to rebuild Eddystone Lighthouse in Cornwall, England which he had been commissioned to build in 1756, but had to first invent a material that would not be affected by water. He wrote a book about his work.**
1796	**James Parker from England patented a natural hydraulic cement by calcining nodules of impure limestone containing clay, called Parker's Cement or Roman Cement.**

1802 In France, a similar Roman Cement process was used.

1810 Edgar Dobbs received a patent for hydraulic mortars, stucco, and plaster, although they were of poor quality due to lack of kiln precautions.

1812 -1813 Louis Vicat of France prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay.

1818 Maurice St. Leger was issued patents for hydraulic cement.

Natural Cement was produced in the USA. Natural cement is limestone that naturally has the appropriate amounts of clay to make the same type of concrete as John Smeaton discovered.

1820 - 1821 John Tickell and Abraham Chambers were issued more hydraulic cement patents.

1822 James Frost of England prepared artificial hydraulic lime like Vicat's and called it British Cement.

1824 Joseph Aspdin of England invented portland cement by burning finely ground chalk with finely divided clay in a lime kiln until carbon dioxide was driven off. The sintered product was then ground and he called it portland cement named after the high quality building stones quarried at Portland, England.

1828 I. K. Brunel is credited with the first engineering application of portland cement, which was used to fill a breach in the Thames Tunnel.

1830 The first production of lime and hydraulic cement took place in Canada.

1836 The first systematic tests of tensile and compressive strength took place in Germany.

1843 J. M. Mauder, Son & Co. were licensed to produce patented portland cement.

1845 Isaac Johnson claims to have burned the raw materials of portland cement to clinkering temperatures.

1849 Pettenkofer & Fuches performed the first accurate chemical analysis of portland cement.

1860 The beginning of the era of portland cements of modern composition.

1862 Blake Stonebreaker of England introduced the jaw breakers to crush clinkers.

1867 Joseph Monier of France reinforced William Wand's (USA) flower pots with wire ushering in the idea of iron reinforcing bars (re-bar).

1871 David Saylor was issued the first American patent for portland cement. He showed the importance of true clinkering.

1880 J. Grant of England show the importance of using the hardest and densest portions of the clinker. Key ingredients were being chemically analyzed.

1886 The first rotary kiln was introduced in England to replace the vertical shaft kilns.

1887 Henri Le Chatelier of France established oxide ratios to prepare the proper amount of lime to produce portland cement. He named the

components: Alite (tricalcium silicate), Belite (dicalcium silicate), and Celite (tetracalcium aluminoferrite). He proposed that hardening is caused by the formation of crystalline products of the reaction between cement and water.

1889 **The first concrete reinforced bridge is built.**

1890 **The addition of gypsum when grinding clinker to act as a retardant to the setting of concrete was introduced in the USA. Vertical shaft kilns were replaced with rotary kilns and ball mills were used for grinding cement.**

1891 **George Bartholomew placed the first concrete street in the USA in Bellefontaine, OH.** *It still exists today!*

1893 **William Michaelis claimed that hydrated metasilicates form a gelatinous mass (gel) that dehydrates over time to harden.**

1900 **Basic cement tests were standardized.**

1903 **The first concrete high rise was built in Cincinnati, OH.**

1908 **Thomas Edison built cheap, cozy concrete houses in Union, NJ.** *They still exist today!*

1909 **Thomas Edison was issued a patent for rotary kilns.**

1929 **Dr. Linus Pauling of the USA formulated a set of principles for the structures of complex silicates.**

1930 **Air entraining agents were introduced to improve concrete's resistance to freeze/thaw damage.**

1936 **The first major concrete dams, Hoover Dam and Grand Coulee Dam, were built.** *They still exist today!*

1956 **U.S. Congress annexed the Federal Interstate Highway Act.**

1967 First concrete domed sport structure, the Assembly Hall, was constructed at The University of Illinois, at Urbana-Champaign.

1970's Fiber reinforcement in concrete was introduced.

1975 CN Tower in Toronto, Canada, the tallest slip-form building, was constructed.

Water Tower Place in Chicago, Illinois, the tallest building was constructed.

1980's Superplasticizers were introduced as admixtures.

1985 Silica fume was introduced as a pozzolanic additive.

The "highest strength" concrete was used in building the Union Plaza constructed in Seattle, Washington.

1992 The tallest reinforced concrete building in the world was constructed at 311 S. Wacker Dr., Chicago, Illinois.

Scientific Principles

****

Component of concrete:

1. Cement:

The properties of concrete depend on the quantities and qualities of its components. Because cement is the most active component of concrete and usually has the greatest unit cost, its selection and proper use are important in obtaining most economically the balance of properties desired for any particular concrete mixture.

Cement, as it is commonly known, is a mixture of compounds made by burning limestone and clay together at very high temperatures ranging from 1400 to 1600 ˚C.

Although there are other cements for special purposes, this module will focus solely on portland cement and its properties. The production of portland cement begins with the quarrying of limestone, $CaCO_3$. Huge

crushers break the blasted limestone into small pieces. The crushed limestone is then mixed with clay (or shale), sand, and iron ore and ground together to form a homogeneous powder. However, this powder is microscopically heterogeneous. (See flowchart.)

PRODUCTION OF PORTLAND CEMENT

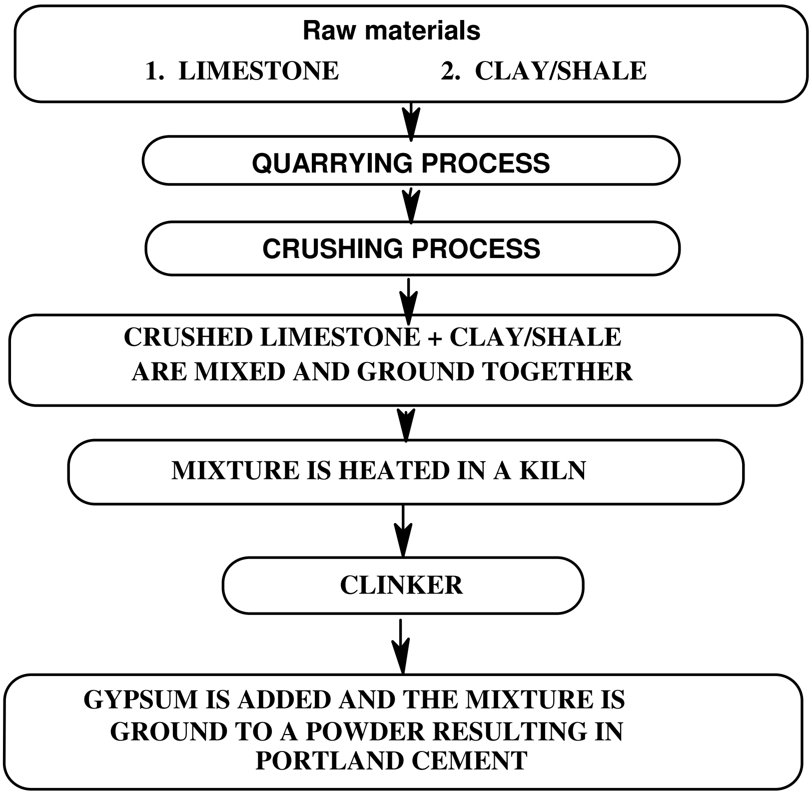


Figure 1: A flow diagram of Portland Cement production.

The mixture is heated in kilns that are long rotating steel cylinders on an incline. The kilns may be up to 6 meters in diameter and 180 meters in length. The mixture of raw materials enters at the high end of the cylinder and slowly moves along the length of the kiln due to the constant rotation and inclination. At the low end of the kiln, a fuel is injected and burned, thus providing the heat necessary to make the materials react. It can take up to 2 hours for the mixture to pass through the kiln, depending upon the length of the cylinder.

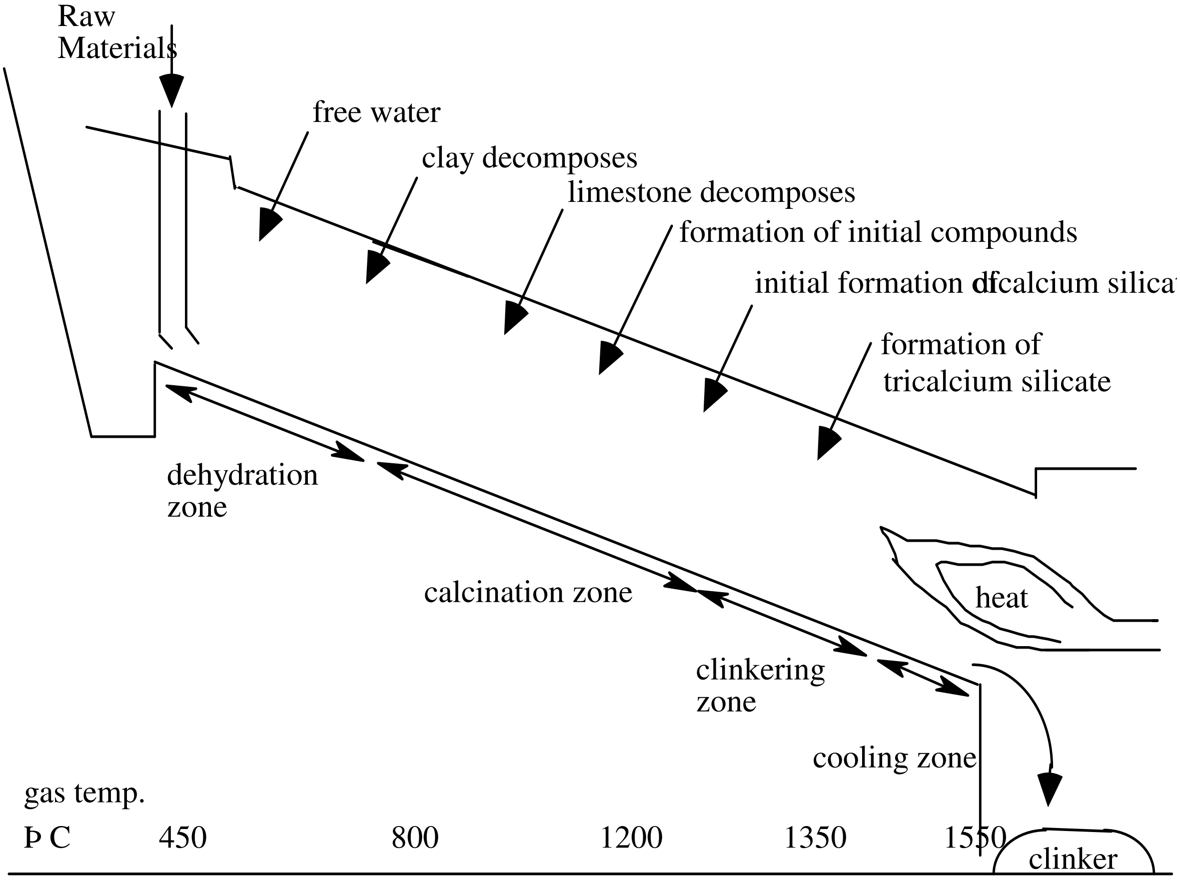


Figure 2: Schematic diagram of rotary kiln.

As the mixture moves down the cylinder, it progresses through four stages of transformation. Initially, any free water in the powder is lost by evaporation. Next, decomposition occurs from the loss of bound water and carbon dioxide. This is called calcination. The third stage is called clinkering. During this stage, the calcium silicates are formed. The final stage is the cooling stage.

The marble-sized pieces produced by the kiln are referred to as clinker. Clinker is actually a mixture of four compounds which will be discussed later. The clinker is cooled, ground, and mixed with a small amount of gypsum (which regulates setting) to produce the general-purpose portland cement.

Hydration of Portland Cement

Concrete is prepared by mixing cement, water, and aggregate together to make a workable paste. It is molded or placed as desired, consolidated,

and then left to harden. Concrete does not need to dry out in order to harden as commonly thought.

The concrete (or specifically, the cement in it) needs moisture to hydrate and cure (harden). When concrete dries, it actually stops getting stronger. Concrete with too little water may be dry but is not fully reacted. The properties of such a concrete would be less than that of a wet concrete. The reaction of water with the cement in concrete is extremely important to its properties and reactions may continue for many years. This very important reaction will be discussed in detail in this section.

Portland cement consists of five major compounds and a few minor compounds. The composition of a typical portland cement is listed by weight percentage in Table 2.

Cement Compound	**Weight Percentage**	**Chemical Formula**
Tricalcium silicate	**50 %**	**Ca_3SiO_5 or $3CaO{\cdot}SiO_2$**
Dicalcium silicate	**25 %**	**Ca_2SiO_4 or $2CaO{\cdot}SiO_2$**
Tricalcium aluminate	**10 %**	**$Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$**
Tetracalcium aluminoferrite	**10 %**	**$Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$**
Gypsum	**5 %**	**$CaSO_4{\cdot}2H_2O$**

Table 2: Composition of portland cement with chemical composition and weight percent.

When water is added to cement, each of the compounds undergoes hydration and contributes to the final concrete product. Only the calcium silicates contribute to strength. Tricalcium silicate is responsible for most of the early strength (first 7 days). Dicalcium silicate, which reacts more slowly, contributes only to the strength at later times. Tricalcium silicate will be discussed in the greatest detail.

The equation for the hydration of tricalcium silicate is given by:

Tricalcium silicate + Water--->Calcium silicate hydrate+Calcium hydroxide + heat

$$2\,Ca_3SiO_5 + 7\,H_2O \text{ ---> } 3\,CaO{\cdot}2SiO_2{\cdot}4H_2O + 3\,Ca(OH)_2 + 173.6\,kJ$$

Upon the addition of water, tricalcium silicate rapidly reacts to release calcium ions, hydroxide ions, and a large amount of heat. The pH quickly rises to over 12 because of the release of alkaline hydroxide (OH^-) ions. This initial hydrolysis slows down quickly after it starts resulting in a decrease in heat evolved.

The reaction slowly continues producing calcium and hydroxide ions until the system becomes saturated. Once this occurs, the calcium hydroxide starts to crystallize. Simultaneously, calcium silicate hydrate begins to form. Ions precipitate out of solution accelerating the reaction of tricalcium silicate to calcium and hydroxide ions. (Le Chatlier's principle). The evolution of heat is then dramatically increased.

The formation of the calcium hydroxide and calcium silicate hydrate crystals provide "seeds" upon which more calcium silicate hydrate can form. The calcium silicate hydrate crystals grow thicker making it more difficult for water molecules to reach the unhydrated tricalcium silicate. The speed of the reaction is now controlled by the rate at which water molecules diffuse through the calcium silicate hydrate coating. This coating thickens over time causing the production of calcium silicate hydrate to become slower and slower.

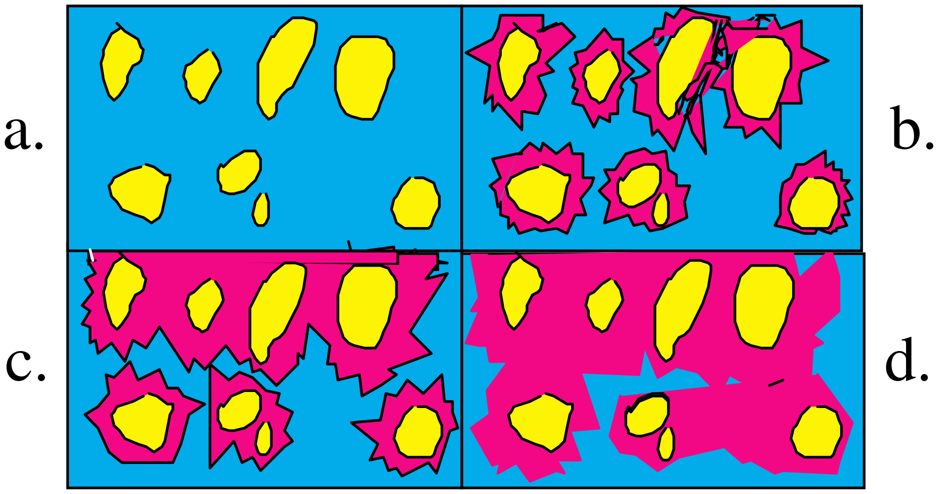


Figure 3: Schematic illustration of the pores in calcium silicate through different stages of hydration.

The above diagrams represent the formation of pores as calcium silicate hydrate is formed. Note in diagram (a) that hydration has not yet

occurred and the pores (empty spaces between grains) are filled with water. Diagram (b) represents the beginning of hydration. In diagram (c), the hydration continues. Although empty spaces still exist, they are filled with water and calcium hydroxide. Diagram (d) shows nearly hardened cement paste. Note that the majority of space is filled with calcium silicate hydrate. That which is not filled with the hardened hydrate is primarily calcium hydroxide solution. The hydration will continue as long as water is present and there are still unhydrated compounds in the cement paste.

Dicalcium silicate also affects the strength of concrete through its hydration. Dicalcium silicate reacts with water in a similar manner compared to tricalcium silicate, but much more slowly. The heat released is less than that by the hydration of tricalcium silicate because the dicalcium silicate is much less reactive. The products from the hydration of dicalcium silicate are the same as those for tricalcium silicate:

Dicalcium silicate + Water--->Calcium silicate hydrate + Calcium hydroxide +heat

$$2\,Ca_2SiO_4 + 5\,H_2O \text{--->} 3\,CaO\cdot 2SiO_2\cdot 4H_2O + Ca(OH)_2 + 58.6\ \text{kJ}$$

The other major components of portland cement, tricalcium aluminate and tetracalcium aluminoferrite also react with water. Their hydration chemistry is more complicated as they involve reactions with the gypsum as well. Because these reactions do not contribute significantly to strength, they will be neglected in this discussion. Although we have treated the hydration of each cement compound independently, this is not completely accurate. The rate of hydration of a compound may be affected by varying the concentration of another. In general, the rates of hydration during the first few days ranked from fastest to slowest are:
tricalcium aluminate > tricalcium silicate > tetracalcium aluminoferrite > dicalcium silicate.

Heat is evolved with cement hydration. This is due to the breaking and making of chemical bonds during hydration. The heat generated is shown below as a function of time.

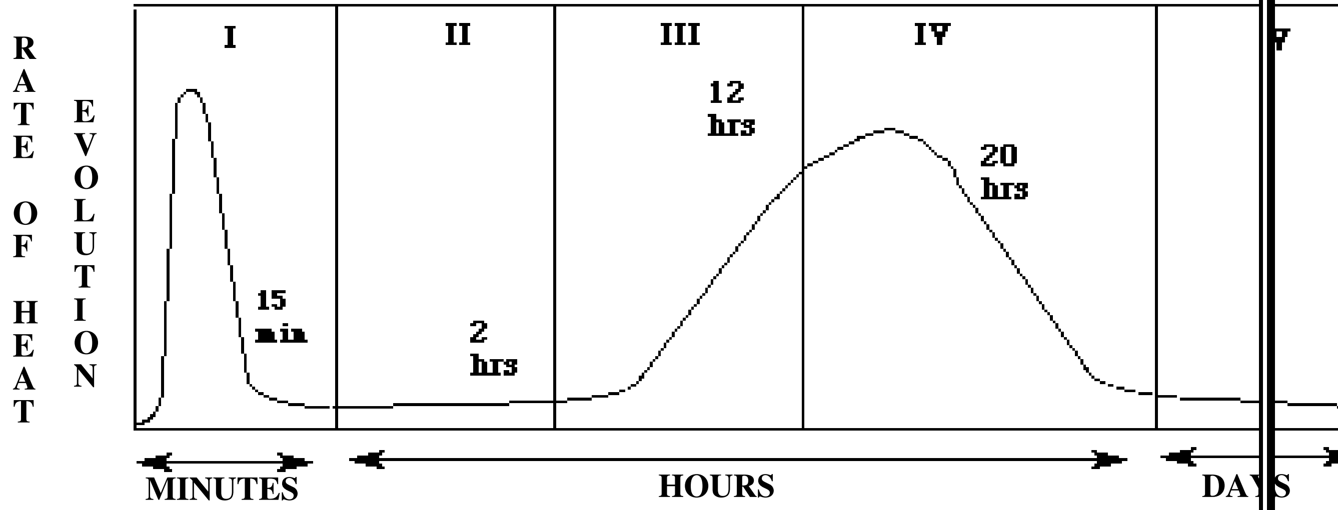


Figure 4: Rate of heat evolution during the hydration of portland cement

The stage I hydrolysis of the cement compounds occurs rapidly with a temperature increase of several degrees. Stage II is known as the dormancy period. The evolution of heat slows dramatically in this stage. The dormancy period can last from one to three hours. During this period, the concrete is in a plastic state which allows the concrete to be transported and placed without any major difficulty. This is particularly important for the construction trade who must transport concrete to the job site. It is at the end of this stage that initial setting begins. In stages III and IV, the concrete starts to harden and the heat evolution increases due primarily to the hydration of tricalcium silicate. Stage V is reached after 36 hours. The slow formation of hydrate products occurs and continues as long as water and unhydrated silicates are present.

Types of Portland Cement.

Different types of portland cement are manufactured to meet different physical and chemical requirements for specific purposes, such as durability and high-early strength. Eight types of cement are covered in ASTM C 150 and AASHTO M 85. These types and brief descriptions of their uses are listed in Table 2.1.

More than 92% of portland cement produced in the United States is Type I and II (or Type I/II); Type III accounts for about 3.5% of cement production (U.S. Dept. Int. 1989). Type IV cement is only available on

special request, and Type V may also be difficult to obtain (less than 0.5% of production).

Although IA, IIA, and IIIA (air-entraining cements) are available as options, concrete producers prefer to use an air-entraining admixture during concrete manufacture, where they can get better control in obtaining the desired air content. However, this kind of cements can be useful under conditions in which quality control is poor, particularly when no means of measuring the air content of fresh concrete is available (ACI Comm. 225R 1985; Nat. Mat. Ad. Board 1987).

If a given type of cement is not available, comparable results can frequently be obtained by using modifications of available types. High-early strength concrete, for example, can be made by using a higher content of Type I when Type III cement is not available (Nat. Mat. Ad. Board 1987), or by using admixtures such as chemical accelerators or high-range water reducers (HRWR). The availability of portland cements will be affected for years to come by energy and pollution requirements. In fact, the increased attention to pollution abatement and energy conservation has already greatly influenced the cement industry, especially in the production of low-alkali cements. Using high-alkali raw materials in the manufacture of low-alkali cement requires bypass systems to avoid concentrating alkali in the clinkers, which consumes more energy (Energetics, Inc. 1988). It is estimated that 4% of energy used by the cement industry could be saved by relaxing alkali specifications. Limiting use of low-alkali cement to cases in which alkali-reactive aggregates are used could lead to significant improvement in energy efficiency (Energetics, Inc. 1988).

Table 1.1 Portland cement types and their uses.

Cement type	Use
I[1]	General purpose cement, when there are no extenuating conditions
II[2]	Aids in providing moderate resistance to sulfate attack
III	When high-early strength is required
IV[3]	When a low heat of hydration is desired (in massive structures)
V[4]	When high sulfate resistance is required

IA[4]	**A type I cement containing an integral air-entraining agent**
IIA[4]	**A type II cement containing an integral air-entraining agent**
IIIA[4]	**A type III cement containing an integral air-entraining agent**

1 Cements that simultaneously meet requirements of Type I and Type II are also widely available.
2 Type II low alkali (total alkali as Na2O < 0.6%) is often specified in regions where aggregates susceptible to alkali-silica reactivity are employed.
3 Type IV cements are only available on special request.
4 These cements are in limited production and not widely available.

Cement Composition. The composition of portland cements is what distinguishes one type of cement from another. ASTM C 150 and AASHTO M 85 present the standard chemical requirements for each type. The phase compositions in portland cement are denoted by ASTM as tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF). However, it should be noted that these compositions would occur at a phase equilibrium of all components in the mix and do not reflect effects of burn temperatures, quenching, oxygen availability, and other real-world kiln conditions. The actual components are often complex chemical crystalline and amorphous structures, denoted by cement chemists as "elite" (C_3S), "belite" (C_2S), and various forms of aluminates. The behavior of each type of cement depends on the content of these components. Characterization of these compounds, their hydration, and their influence on the behavior of cements are presented in full detail in many texts. Some of the most complete references dealing with the chemistry of cement include those written by Bogue (1955), Taylor (1964), and Lea (1970). Different analytical techniques such as x-ray diffraction and analytical electron microscopy are used by researchers in order to understand fully the reaction of cement with water (hydration process) and to improve its properties.

In simplest terms, results of these studies have shown that early hydration of cement is principally controlled by the amount and activity of C_3A, balanced by the amount and type of sulfate interground with the cement. C_3A hydrates very rapidly and will influence early bonding characteristics. Abnormal hydration of (C_3A) and poor control of this hydration by sulfate

can lead to such problems as flash set, false set, slump loss, and cement-admixture incompatibility (Previte 1977; Whiting 1981; Meyer and Perenchio 1979).

Development of the internal structure of hydrated cement (referred to by many researchers as the microstructure) occurs after the concrete has set and continues for months (and even years) after placement. The microstructure of the cement hydrates will determine the mechanical behavior and durability of the concrete. In terms of cement composition, the C_3S and C_2S will have the primary influence on long term development of structure, although aluminates may contribute to formation of compounds such as ettringite (sulfoaluminate hydrate), which can cause expansive disruption of concrete. Cements high in C_3S (especially those that are finely ground) will hydrate more rapidly and lead to higher early strength. However, the hydration products formed will, in effect, make it more difficult for hydration to proceed at later ages, leading to an ultimate strength lower than desired in some cases. Cements high in C_2S will hydrate much more slowly, leading to a denser ultimate structure and a higher long-term strength. The relative ratio of C_3S to C_2S, and the overall fineness of cements, has been steadily increasing over the past few decades. Indeed, Pomeroy (1989) notes that early strengths achievable today in concrete could not have been achieved in the past except at very low water-to-cement ratios (w/c's), which would have rendered concretes unworkable in the absence of HRWR. This ability to achieve desired strengths at a higher workability (and hence a higher w/c) may account for many durability problems, as it is now established that higher w/c invariably leads to higher permeability in the concrete (Ruettgers, Vidal, and Wing 1935; Whiting, 1988).

One of the major aspects of cement chemistry that concern cement users is the influence of chemical admixtures on portland cement. Since the early 1960s most states have permitted or required the use of water-reducing and other admixtures in highway pavements and structures (Mielenz 1984). A wide variety of chemical admixtures have been introduced to the concrete industry over the last three decades, and engineers are increasingly concerned about the positive and negative effects of these admixtures on cement and concrete performance.

Considerable research dealing with admixtures has been conducted in the United States. Air-entraining agents are widely used in the highway industry in North America, where concrete will be subjected to repeated freeze-thaw cycles. Air-entraining agents have no appreciable effect on the rate of hydration of cement or on the chemical composition of hydration products (Ramachandran and Feldman 1984). However, an increase in cement fineness or a decrease in cement alkali content generally increases the amount of an admixture required for a given air content (ACI Comm.

225R 1985). Water reducers or retarders influence cement compounds and their hydration. Lignosulfonate-based admixtures affect the hydration of C_3A, which controls the setting and early hydration of cement. C_3S and C_4AF hydration is also influenced by water reducers (Ramachandran and Feldman 1984).

Test results presented by Polivka and Klein (1960) showed that alkali and C_3A contents influence the required admixtures to achieve the desired mix. It appears that set retarders, for example, are more effective with cement of low alkali and low C_3A content, and that water reducers seem to improve the compressive strength of concrete containing cements of low alkali content more than that of the concrete containing cements of high alkali content.

Physical Properties of Portland Cements. ASTM C 150 and AASHTO M 85 have specified certain physical requirements for each type of cement. These properties include 1) fineness, 2) soundness, 3) consistency, 4) setting time, 5) compressive strength, 6) heat of hydration, 7) specific gravity, and 8) loss of ignition. Each one of these properties has an influence on the performance of cement in concrete. The fineness of the cement, for example, affects the rate of hydration. Greater fineness increases the surface available for hydration, causing greater early strength and more rapid generation of heat (the fineness of Type III is higher than that of Type I cement) (U.S. Dept. Trans. 1990).

ASTM C 150 and AASHTO M 85 specifications are similar except with regard to fineness of cement. AASHTO M 85 requires coarser cement, which will result in higher ultimate strengths and lower early-strength gain. The Wagner Turbidimeter and the Blaine air permeability test for measuring cement fineness are both required by the American Society for Testing Materials (ASTM) and the American Association for State Highway Transportation Officials (AASHTO). Average Blaine fineness of modern cement ranges from 3,000 to 5,000 cm^2/g (300 to 500 m^2/kg).

Soundness, which is the ability of hardened cement paste to retain its volume after setting, can be characterized by measuring the expansion of mortar bars in an autoclave (ASTM C 191, AASHTO T 130). The compressive strength of 2-inch (50-mm) mortar cubes after 7 days (as measured by ASTM C 109) should not be less than 2,800 psi (19.3 MPa) for Type I cement. Other physical properties included in both ASTM C 150 and AASHTO M 95 are specific gravity and false set. False set is a significant loss of plasticity shortly after mixing due to the formation of gypsum or the formation of ettringite after mixing. In many cases, workability can be restored by remixing concrete before it is cast.

Influence of Portland Cement on Concrete Properties.

Effects of cement on the most important concrete properties are presented in Table 1.2.

Cement composition and fineness play a major role in controlling concrete properties. Fineness of cement affects the placeability, workability, and water content of a concrete mixture much like the amount of cement used in concrete does.

Cement composition affects the permeability of concrete by controlling the rate of hydration. However, the ultimate porosity and permeability are unaffected (ACI Comm. 225R 1985; Powers et al. 1954). The coarse cement tends to produce pastes with higher porosity than that produced by finer cement (Powers et al. 1954). Cement composition has only a minor effect on freeze-thaw resistance. Corrosion of embedded steel has been related to C_3A content (Verbeck 1968). The higher the C_3A, the more chloride can be tied into chloroaluminate complexes—and thereby be unavailable for catalysis of the corrosion process.

Table 1.2. Effects of cements on concrete properties.

Cement Property	Cement Effects
Placeability	Cement amount, fineness, setting characteristics
Strength	Cement composition (C_3S, C_2S and C_3A), loss on ignition, fineness
Drying Shrinkage	SO_3content, cement composition
Permeability	Cement composition, fineness
Resistance to sulfate	C_3A content
Alkali Silica Reactivity	Alkali content
Corrosion of embedded steel	Cement Composition (esp. C_3A content)

Storage of Cement. Portland cement is a moisture-sensitive material; if kept dry, it will retain its quality indefinitely. When stored in contact with damp air or moisture, portland cement will set more slowly and has less strength than portland cement that is kept dry. When storing bagged cement, a shaded area or warehouse is preferred. Cracks and openings in

storehouses should be closed. When storing bagged cement outdoors, it should be stacked on pallets and covered with a waterproof covering.

Storage of bulk cement should be in a watertight bin or silo. Transportation should be in vehicles with watertight, properly sealed lids. Cement stored for long periods of time should be tested for strength and loss on ignition.

Cement Certification. The current trend in state transportation departments is to accept certification by the cement producer that the cement complies with specifications. Verifications tests are taken by the state DOT to continually monitor specification compliance. The cement producer has a variety of information available from production records and quality control records that may permit certification of conformance without much, if any, additional testing of the product as it is shipped (ACI Comm. 225R 1985).

Blended Portland Cements

Blended cement, as defined in ASTM C 595, is a mixture of portland cement and blast furnace slag (BFS) or a "mixture of portland cement and a pozzolan (most commonly fly ash)."

The use of blended cements in concrete reduces mixing water and bleeding, improves finishability and workability, enhances sulfate resistance, inhibits the alkali-aggregate reaction, and lessens heat evolution during hydration, thus moderating the chances for thermal cracking on cooling.

Blended cement types and blended ratios are presented in Table 1.3.

Table 1.3 Blended cement types and blended ratios.

Type	Blended Ingredients
IP	15-40% by weight of pozzolan (fly ash)
I(PM)	0-15% by weight of Pozzolan (fly ash) (modified)
P	15-40% by weitht of pozzolan (fly ash)
IS	25-70% by weight of blast furnace slag
I(SM)	0-25% by weight of blast furnace slag (modified)

S	**70-100% by weight of blast furnace slag**

2.Water :

Water is a key reactant in cement hydration. The incorporation of water into a substance is known as hydration. Water and cement initially form a cement paste that begins to react and harden (set). This paste binds the aggregate particles through the chemical process of hydration. In the hydration of cement, chemical changes occur slowly, eventually creating new crystalline products, heat evolution, and other measurable signs.

cement + water = hardened cement paste

Remember that water is the key ingredient. Too much water results in weak concrete. Too little water results in a concrete that is unworkable.
Water is the key ingredient, which when mixed with cement, forms a paste that binds the
aggregate together. The water causes the hardening of concrete through a process called hydration. Hydration is a chemical reaction in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products. Details of the hydration process are explored in the next section. The water needs to be pure in order to prevent side reactions from occurring which may weaken the concrete or otherwise interfere with the hydration process. The role of water is important because the water to cement ratio is the most critical factor in the production of "perfect" concrete. Too much water reduces concrete strength, while too little will make the concrete unworkable. Concrete needs to be workable so that it may be consolidated and shaped into different forms (i.e.. walls, domes, etc.). Because concrete must be both strong and workable, a careful balance of the cement to water ratio is required when making concrete.

Portland cement concrete has a number of voids that are usually filled with water.

Depending on the type of voids and the degree of firmness with which the water is held in these voids, water can be classified as capillary water, adsorbed water, and interlayer water. Capillary voids are spaces in PCC that are not filled by the products of hydration. The water in these voids, called capillary water, can be further subdivided into free and bound water. Free water is the water present in voids greater than 50 nm in size, while the water in voids in the 5-50 nm range constitutes bound water. As will be explained later, bound water is crucial from the point of view of shrinkage. Free water, on the other hand is responsible for the electrical conductivity of PCC.
Adsorbed water is the water bonded to the surface of the CSH gel. The water present between the layers of the CSH gel is called interlayer or zeolitic water. Adsorbed water and interlayer water do not have an impact on the conductivity.

The properties of this hardened cement paste, called binder, control the properties of the concrete. It is the inclusion of water (hydration) into the product that causes concrete to set, stiffen, and become hard. Once set, concrete continues to harden (cure) and become stronger for a long period of time, often up to several years.

3.Aggregates

We have many dfininition for aggregates…
First-----
Aggregates are chemically inert, solid bodies held together by the cement. Aggregates come in various shapes, sizes, and materials ranging from fine particles of sand to large, coarse rocks. Because cement is the most expensive ingredient in making concrete, it is desirable to minimize the amount of cement used. 70 to 80% of the volume of concrete is aggregate keeping the cost of the concrete low. The selection of an aggregate is determined, in part, by the desired characteristics of the concrete. For example, the density of concrete is determined by the density of the aggregate. Soft, porous aggregates can result in weak concrete with low

wear resistance, while using hard aggregates can make strong concrete with a high resistance to abrasion.
{{{{{{{Aggregate is the solid particles that are bound together by the cement paste to create the synthetic rock known as concrete. Aggregates can be fine, such as sand, or coarse, such as gravel. The relative amounts of each type and the sizes of each type of aggregate determines the physical properties of the concrete.

sand + cement paste = mortar

mortar + gravel = concrete

Sometimes other materials are incorporated into the batch of concrete to create specific characteristics. These additives are called admixtures. Admixtures are used to: alter the fluidity (plasticity) of the cement paste; increase (accelerate) or decrease (retard) the setting time; increase strength (both bending and compression); or to extend the life of a structure. The making of concrete is a very complex process involving both chemical and physical changes. It is a material of great importance in our lives.}}}}}}}}}}}}}}}

Aggregates should be clean, hard, and strong. The aggregate is usually washed to remove any dust, silt, clay, organic matter, or other impurities that would interfere with the bonding reaction with the cement paste. It is then separated into various sizes by passing the material through a series of screens with different size openings.

Table 1: Classes of Aggregates

class	examples of aggregates used	uses
ultra-lightweight	vermiculite	lightweight concrete which

	ceramic spheres	**can be sawed or nailed, also**
	perlite	**for its insulating properties**
lightweight	**expanded clay** **shale or slate** **crushed brick**	**used primarily for making lightweight concrete for structures, also used for its insulating properties.**
normal weight	**crushed limestone** **sand** **river gravel** **crushed recycled concrete**	**used for normal concrete projects**
heavyweight	**steel or iron shot** **steel or iron pellets**	**used for making high density concrete for shielding against nuclear radiation**

Second---

Aggregates generally occupy 70 to 80 % of the volume of concrete and therefore have a significant effect on its properties. Strength of concrete and mix design are independent of the composition of aggregate, but durability may be affected. Aggregates are classified based on specific gravity as heavyweight, normal-weight, and lightweight. Normal weight aggregates make-up 9 0% of concrete used in the United States.

The Role of Aggregate

in PCC is as a filler. Aggregates can be classified on the basis of their size. Aggregates greater than 4.75 mm are called coarse aggregate and those smaller than 4.75 mm are called fine aggregate.
Aggregates play a significant role in the physical properties of PCC. They affect the
unit weight, elastic modulus, absorption, and the durability of PCC. The properties of PCC are also affected by the shape, texture and gradation of the aggregate. Aggregates are usually stronger than cement paste and therefore do not play a significant role in the strength of PCC.
Aggregate reaction with cement may be detrimental such as alkali-silica reaction.

Third----

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and portland cement, are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories-fine and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch (9.5-mm) sieve. Coarse aggregates are any particles greater than 0.19 inch (4.75 mm), but generally range between 3/8 and 1.5 inches (9.5 mm to 37.5 mm) in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Recycled concrete is a viable source of aggregate and has been satisfactorily used in granular subbases, soil-cement, and in new concrete. Aggregate processing consists of crushing, screening, and washing the aggregate to obtain proper cleanliness and gradation. If necessary, a benefaction process such as jigging or heavy media separation can be used to upgrade the quality. Once processed, the aggregates are handled and stored in a way that minimizes segregation and degradation and prevents contamination. Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include:

I. **grading**
II. **durability**
III. **particle shape and surface texture**
IV. **abrasion and skid resistance**
V. **unit weights and voids**
VI. **absorption and surface moisture**

Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because grading and size affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength. When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. Close control of mix proportions is necessary to avoid segregation.

Shape and Size Matter

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio. Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate. Unit-weight measures the volume that graded aggregate and the voids between them will occupy in concrete. The void content between particles affects the amount of cement paste required for the mix. Angular aggregate increase the void content. Larger sizes of well-graded aggregate and improved grading decrease the void content. Absorption and surface moisture of aggregate are measured when selecting aggregate because the internal structure of aggregate is made up of solid material and voids that may or may not contain water. The amount of water in the concrete mixture must be adjusted to include the moisture conditions of the aggregate. Abrasion and skid resistance of an aggregate are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements. Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

Shape and texture affect workability of fresh concrete.

The ideal aggregate would be spherical and smooth allowing good mixing

and decreasing interaction between particles. Natural sands are close to this shape. However, crushed stone is much more angular and requires more paste to coat the increased surface area. Long, flat aggregate should be avoided due to increased interaction with other particles and the tendency toward segregation during handling.

Shape and texture of coarse aggregates affects the strength of the concrete mix. Increased surface area provides more opportunity for bonding and increases strength. However, excessive surface area in an aggregate can lead to internal stress concentrations and potential bond failure.

Size Gradation:

Grading or aggregate size distribution is a major characteristic in concrete mix design. Cement is the most expensive material in concrete. Therefore, by minimizing the amount of cement, the cost of concrete can be reduced.

Sieve Analysis -- determines the grading of an aggregate. Coarse aggregate is that retained on the #4 sieve and fine aggregate is that passing a #4 sieve. In a sieve analysis a series of sieve are used with smaller and smaller openings. Coarse aggregates are analyzed with standard sieves and fine aggregates with half-sized sieves

Maximum Aggregate Size -- Smallest sieve in which the entire sample will pass through. The maximum nominal size is the smallest sieve in which at least 95%, by weight, of the sample will pass. Maximum size should not be larger than 1/5 the minimum dimension of a structural member, 1/3 the thickness of a slab, or 3/4 the clearance between reinforcing rods and forms. These restrictions limit maximum aggregate size to 1 1/2 inches, except in mass applications

Higher maximum aggregate size lowers paste requirements, increases strength and reduces *w/c* ratios. However, excessively large aggregate tends to lower strength by reducing available bonding area. ASTM has imits for grading of concrete aggregates.

Gap Grading -- **An aggregate where one or more of the intermediate-sized fractions is omitted. Advantages of gap grading are more economical concrete, use of less cement, and lower *w/c* ratios. The resulting concrete is very stiff and has low workability. An extreme case is no-fines concrete. This concrete is difficult to handle and compact; developing low strength and high permeability.**

Fineness Modulus -- **a parameter for checking the uniformity of grading. Generally calculated for fine aggregates but also for coarse aggregates assuming 100% is retained on #8 - #100 sieves. Therefore, for fine and coarse aggregates respectively, the fineness modulus is:**

F.M. = (Cumulative percent retained on half-sized sieves)/100

F.M. = (Cumulative percent retained on standard sieves including #4 + 500)/ 100

A fineness modulus for fine aggregates should be 2.3 - 3.1. Two aggregates with the same fineness modulus can have different grading curves. A low fineness modulus requires more cement paste to maintain workability. Variations from mix design requirements for fineness modulus should not exceed 0.2 (ASTM standards). ASTM allows for an increase in fine aggregates (% passing #50 and #100) if smoother surface finishing is required. However, there are solid restrictions on very fine particles to prevent increased water demand and volume instability.

Moisture Content:

Aggregate can contain water, both internal, based on porosity, and external, surface moisture. This gives aggregate the ability to absorb water. This will effectively reduce the amount of water available for hydration; or conversely, if the aggregate is very wet, add excess water to a cement mix.

There are four moisture states:

1. **Oven-dry (OD); all moisture removed.**

2. **Air-dry (AD); surface moisture removed, internal pores partially full**
3. **Saturated-surface-dry (SSD); surface moisture removed, all internal pores full.**
4. **Wet; pores full with surface film.**

Of these four states, SSD, saturated-surface-dry, is considered the best reference state. It is an equilibrium state, where the aggregate will not absorb or give water to the cement paste, simulates actual field conditions more closely, and used to determine bulk specific gravity. However, this moisture state is not easy to obtain.

Absorption and Surface Moisture

To determine the amount of water an aggregate will add or subtract from a cement paste, the following three quantities are used:

1. **Absorption capacity (*AC*) -- maximum amount of water the aggregate will absorb. The range for most normal-weight aggregates is 1 - 2%.**

$$AC = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100\%$$

2. **Effective Absorption (*EA*) -- amount of water required to bring an aggregate from the *AD* state to the *SSD* state.**

$$EA = \frac{W_{SSD} - W_{AD}}{W_{SSD}} \times 100\%$$

The weight of water absorbed by the aggregate *Wabs* is calculated from the weigh of the aggregate *Wagg* in a concrete mix using effective absorption (*EA*).

$$W_{abs} = (EA)W_{agg}$$

3. **Surface Moisture (SM) -- amount of water in excess of *SSD***

$$SM = \frac{W_{wet} - W_{SSD}}{W_{SSD}} \times 100\%$$

It is used to calculate the additional water W_{add} of the concrete mix

$$W_{add} = (SM)W_{agg}$$

The moisture content (*MC*) of aggregate is given by:

$$MC = \frac{W_{stock} - W_{SSD}}{W_{SSD}} \times 100\%$$

If the moisture content (*MC*) is positive, there is surface moisture. If the *MC* is negative, it has the potential for absorption. Therefore, the total moisture associated with an aggregate is:

$$W_{MC} = (MC)W_{agg}$$

Stockpiled fine aggregate is often in a wet state with a surface moisture of 0 to 5%. More water can be held in the interspace between particles than in coarse aggregates. This also leads to thicker films of water which in turn push the aggregate apart and increase the apparent volume. This is called bulking.

Specific Gravity

A dimensionless ratio of density of the material in question to the density of water.

SG = [density of solid] / [density of water]

Absolute specific gravity (ASG) considers the weight and volume of the solid part of the aggregate. Whereas, bulk specific gravity (BSG) is a measure of the weight/volume of solids and pores of a material.

ASG > BSG*SSD* > BSG*OD*

However, since the porosity of most rocks used in concrete is 1 to 2%, the values of all specific gravities are approximately the same; in the range of 2.5 to 2.8.

some common term in concrete &aggregates::

Unit Weight

Unit weight (UW) or bulk density is the weight of a given volume of material. Basically, unit weight is measured by filling a container of known volume with a material and weighing it. The degree of moisture and compaction will affect the unit weight measurement. Therefore, ASTM has set a standard oven-dry moisture content and a rodding method for compaction. The maximum unit weight of a blend of two aggregates is about 40% fine aggregate by weight. Therefore, this is the most economical concrete aggregate since it will require the least amount of cement.

Durability of Aggregates

Aggregates makeup the largest part of concrete mixes and are responsible for the durability of the mix. Durability is a measure of how well concrete will handle freezing and thawing, wetting and drying, and physical wear. Chemical reactions also can contribute to problems with durability.

Soundness -- rocks that undergo volume changes due to wetting and drying are rare. However, aggregate is susceptible to volume change during freezing and thawing cycles. Freezing can cause internal stresses to build up as water inside the aggregate freezes and expands. A critical size can be calculated below which freeze-thaw stress is not a problem; however, for most rock it is greater than normal sizes.

Wear Resistance -- a good aggregate will be hard, dense, strong, and free of porous material. The abrasion resistance of aggregate can be tested by the Los Angeles abrasion test; however, this test does not match well with concrete wear in the field.

Alkali-Aggregate Reaction -- An expansive reaction between some reactive forms of silica with the aggregate and alkalis in the cement paste. The result is overall cracking in the structure, manifesting itself in map or pattern cracking at the surface. This reaction can be controlled most easily by using low-alkali cements. However, due to changes in manufacturing, low-alkali cements may not be feasible. A better approach is to avoid aggregate with the potential or proven record of reactivity. A low *w/c* ratio is very impermeable and will slow down the reaction but not

stop it. No adverse reactions will occur without external water.

Other Alkali-Silica Reactions -- sand-gravels found in river systems of Kansas and Nebraska are highly reactive and cause map cracking. Replacement of 30% of the aggregate with crushed limestone is effective in reducing the damage. Basically, it results in the separation of flat clay minerals causing very slow expansion.

Alkali-Carbonate Reactions -- an expansive reaction involving clayey carbonate rock. Reaction can be controlled by using low-alkali cements or blending aggregate with other less reactive material. ASTM has set standards for deleterious substances in aggregates, which depend on application. This can be divided into two categories:

Solid materials - particles passing a 200-mesh sieve. These fine particles may increase water requirements and interfere with surface bonding between cement and coarse aggregates

Soluble substances - organic matter may interfere chemically with alkaline cement pastes affecting setting time. Aggregates obtained from the sea should be thoroughly cleaned to avoid problems from salt contamination.

Unsound particles -- Soft particles such as clay lumps, wood, and coal will cause pitting and scaling at the surface. Organic compounds can be released which interfere with setting and hardening. Weak material of low density which have low wear resistance should also be avoided.

Evaluation of Aggregates

It should be noted that tests on aggregates alone are not an effective means of predicting aggregate performance in the field. Tests for aggregate properties for mix design are straightforward. However, tests for durability and performance have limitations.

Physical Tests for aggregate:

Abrasion resistance -- The Los Angeles test for abrasion involves ball milling an aggregate sample for a given time and measuring how the sample particles are reduced in size.

Scratch hardness test -- assumes a relationship between hardness and abrasion. Neither of this tests are an accurate or reliable measure of the concrete hardness. An indication would be to test the concrete itself.

Soundness test -- This test is a simulation of ice formation in an aggregate sample. The sample is saturated with a solution of sodium or magnesium salt and dried in an oven. The salt crystals which form in the pores simulate ice. Correlation between this test and field tests are not good. Again, a better approach is testing aggregate in concrete.

Chemical Tests for aggregate:

Alkali-silica Reaction -- A rapid reliable test for alkali-aggregate reactivity has not yet been developed. Most acceptable tests require long curing times of about 6 months. In this test, the aggregate is ground into a fine sand and used to make a variety of mortar bars. The mortars are stored in hot, moist conditions to accelerate the reaction. Expansion of the sample is measured and compared to ASTM specifications.

Aggregate Beneficiation -- If an aggregate does not pass the ASTM tests, an engineer may choose to try to upgrade the material. Beneficiation may be useful in areas where aggregate is scarce. There are several possible ways of treatment:

Crushing -- Soft, porous rock may be removed by crushing

Heavy-media separation -- Lightweight particles may be separated by floating them to the top of a liquid.

Reverse water flow or air flow -- used to remove lightweight particles like wood.

Hydraulic jigging -- Stratification of aggregate in a vertical pulsation of water. Lightweight particles separate to the top.

Elastic fractionation -- Aggregate is dropped on an incline steel plate. Hard particles bounce higher off the plate than do softer particles. Appropriate placement of collection bins can provide good separation.

Washing and scrubbing -- Removes fine surface particles

Waste Materials as Aggregate

The use of waste materials as aggregate in concrete is gaining increased attention, especially in view of our escalating solid-waste problems. A wide variety of materials are being considered as aggregates: garbage, building rubble, industrial waste products, and mine tailings. All of these potential aggregates are evaluated on their

1) economy

2) compatibility with other materials, and

3) concrete properties. Successful utilization of waste material as aggregate depends on anticipating potential problems and ensuring that the properties of concrete will remain unchanged.

Aggregates are classified by their specific gravities into three categories;

1) lightweight,

2) normal-weight,

3) heavy-weight; each with different applications.

Lightweight Aggregates -- A general characteristic of lightweight aggregate is high internal porosity. Most of these materials are synthetic, however, some natural materials can be treated to provide low specific gravity. Clays, shale, or slates will bloat at high temperatures resulting in an expansion in volume. Other synthetic materials are produced using pyroprocessing techniques, such as volcanic glass, slags, or waste glass. Lightweight aggregates have high absorption capacity associated with their high porosity. However, some materials have a coating resulting from the fusion process and water cannot penetrate. This coating can be damaged during handling resulting in an abrupt increase in absorption.

Heavyweight Aggregates -- A material with a high specific gravity.These types of materials are mostly used for radiation shielding and,Abrasion and Skid-Resistant Aggregates -- Hard, dense aggregates used in heavy-industry applications where high resistance to abrasion is required. The strength of the cement paste and the cement-aggregate bond are more important than the aggregate hardness.

Marginal Aggregates -- Use of this type of aggregate will require more care and thought in design, and generally more cost. In considering marginal aggregates, there are four areas of interest:
1) concrete properties,
2) weaknesses of aggregate,
3) beneficiation, and
4) use of protective measures.

Properties of Concrete

Concrete has many properties that make it a popular construction material. The correct proportion of ingredients, placement, and curing are needed in order for these properties to be optimal.

Good-quality concrete has many advantages that add to its popularity. First, it is economical when ingredients are readily available. Concrete's long life and relatively low maintenance requirements increase its economic benefits. Concrete is not as likely to rot, corrode, or decay as other building materials. Concrete has the ability to be molded or cast into almost any desired shape. Building of the molds and casting can occur on the work-site which reduces costs.

Concrete is a non-combustible material which makes it fire-safe and able withstand high temperatures. It is resistant to wind, water, rodents, and insects. Hence, concrete is often used for storm shelters.

Concrete does have some limitations despite its numerous advantages. Concrete has a relatively low tensile strength (compared to other building materials), low ductility, low strength-to-weight ratio, and is susceptible to cracking. Concrete remains the material of choice for many applications regardless of these limitations.

Strength of Concrete

The strength of concrete is very much dependent upon the hydration reaction just discussed. Water plays a critical role, particularly the amount used. The strength of concrete increases when less water is used to make concrete. The hydration reaction itself consumes a specific amount of water. Concrete is actually mixed with more water than is needed for the hydration reactions. This extra water is added to give concrete sufficient workability. Flowing concrete is desired to achieve proper filling and composition of the forms. The water not consumed in the hydration reaction will remain in the microstructure pore space. These pores make the concrete weaker due to the lack of strength-forming calcium silicate hydrate bonds. Some pores will remain no matter how well the concrete has been compacted.

The strength of the concrete is related to the water to cement mass ratio and the curing conditions. A high water to cement mass ratio yields a low strength concrete. This is due to the increase in porosity (space between particles) that is created with the hydration process. Most concrete is made with a water to cement mass ratio ranging from 0.35 to 0.6.

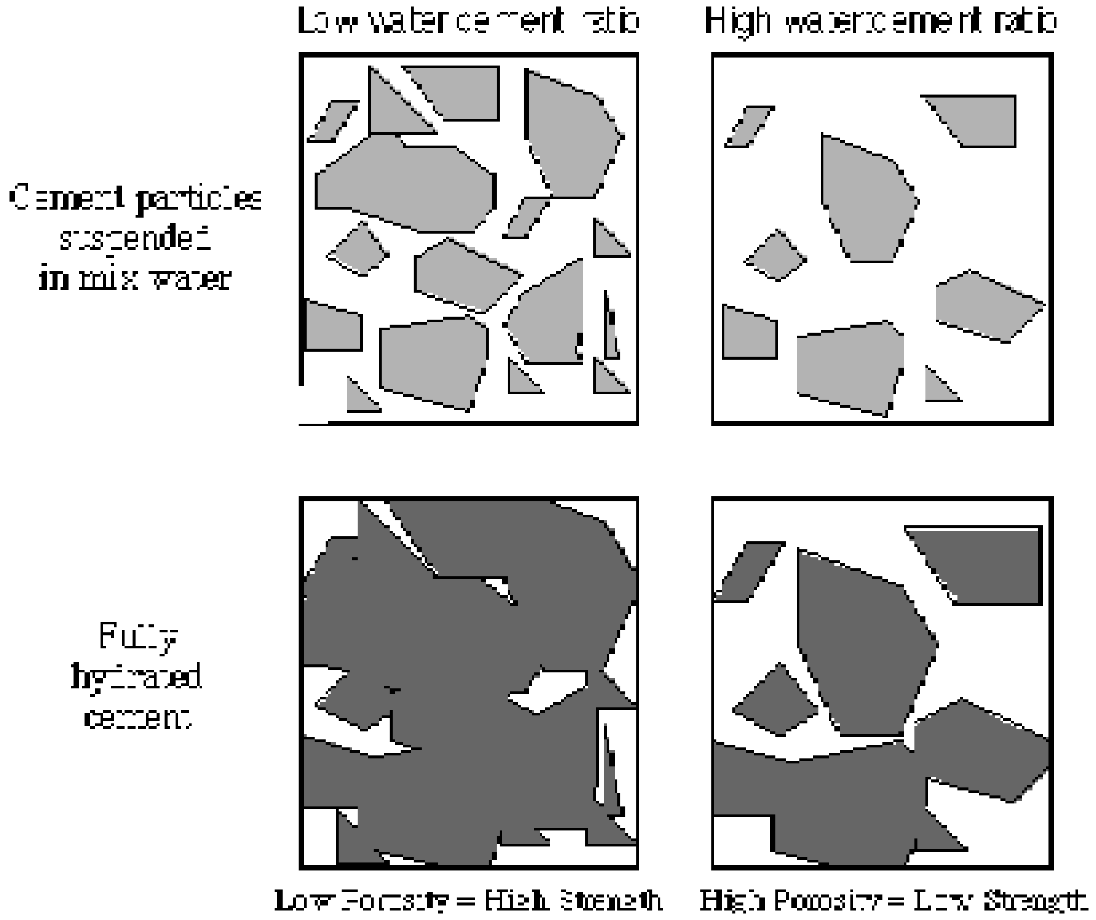


Figure 5: **Schematic drawings to demonstrate the relationship between the water/cement ratio and porosity.**

The empty space (porosity) is determined by the water to cement ratio. The relationship between the water to cement ratio and strength is shown in the graph that follows.

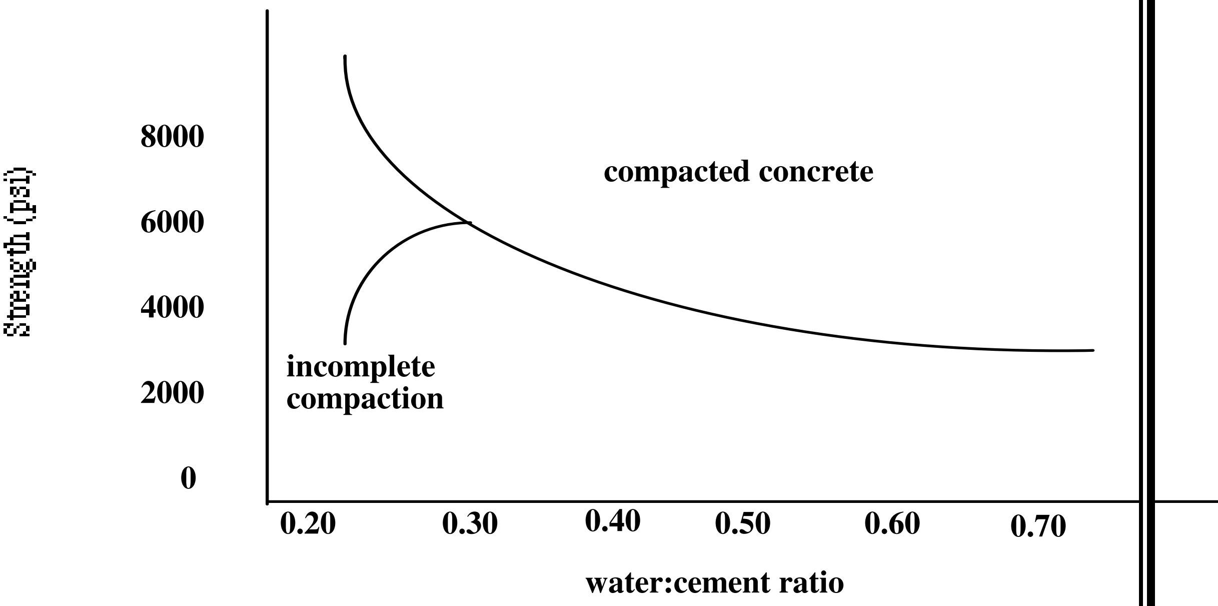


Figure 6: A plot of concrete strength as a function of the water to cement ratio.

Low water to cement ratio leads to high strength but low workability. High water to cement ratio leads to low strength, but good workability.

The physical characteristics of aggregates are shape, texture, and size. These can <u>indirectly affect strength because they affect the workability of the concrete</u>. If the aggregate makes the concrete unworkable, the contractor is likely to add more water which will weaken the concrete by increasing the water to cement mass ratio.

<u>Time is also an important factor in determining concrete strength</u>. Concrete hardens as time passes. Why? Remember the hydration reactions get slower and slower as the tricalcium silicate hydrate forms. It takes a great deal of time (even years!) for all of the bonds to form which determine concrete's strength. It is common to use a 28-day test to determine the relative strength of concrete.

<u>Concrete's strength may also be affected by the addition of admixtures</u>. Admixtures are substances other than the key ingredients or reinforcements which are added during the mixing process. Some admixtures add fluidity to concrete while requiring less water to be used. An example of an admixture which affects strength is superplasticizer. This makes concrete more workable or fluid without adding excess water. A list of some other admixtures and their functions is given below. Note that not all admixtures increase concrete strength. The

selection and use of an admixture are based on the need of the concrete user.

***Note* <u>Concrete's strength may also be affected by the addition of admixtures</u>**

<u>SOME ADMIXTURES AND FUNCTIONS</u>

TYPE	**FUNCTION**
AIR ENTRAINING	**improves durability, workability, reduces bleeding, reduces freezing/thawing problems (e.g. special detergents)**
SUPERPLASTICIZERS	**increase strength by decreasing water needed for workable concrete (e.g. special polymers)**
RETARDING	**delays setting time, more long term strength, offsets adverse high temp. weather (e.g. sugar)**
ACCELERATING	**speeds setting time, more early strength, offsets adverse low temp. weather (e.g. calcium chloride)**
MINERAL ADMIXTURES	**improves workability, plasticity, strength (e.g. fly ash)**
PIGMENT	**adds color (e.g. metal oxides)**

Table 3: A table of admixtures and their functions.

Durability is a very important concern in using concrete for a given application. Concrete provides good performance through the service life of the structure when concrete is mixed properly and care is taken in curing it. Good concrete can have an infinite life span under the right conditions. Water, although important for concrete hydration and

hardening, can also play a role in decreased durability once the structure is built. This is because water can transport harmful chemicals to the interior of the concrete leading to various forms of deterioration. Such deterioration ultimately adds costs due to maintenance and repair of the concrete structure. The contractor should be able to account for environmental factors and produce a durable concrete structure if these factors are considered when building concrete structures.

Placing & Finishing Concrete

Concrete placed in an environment where it begins to dry and lose moisture will begin to shrink. The amount of drying shrinkage that occurs in concrete depends on the characteristics of the materials, mixture proportions, and placing methods. When pavements or other structural members are restrained by subgrade friction, reinforcement, or other portions of the structure, drying shrinkage will induce tensile stresses. These drying shrinkage stresses usually exceed the concrete tensile strengths, causing cracking. The advantage of using expansive cements is to induce stresses large enough to compensate for drying shrinkage stresses and minimize cracking (ACI Comm. 223 1983; Hoff et al. 1977).

Mixing, transporting, and handling of concrete should be carefully coordinated with placing and finishing operations. Concrete should not be deposited more rapidly than it can be spread, struck off, consolidated, and bullfloated. Concrete should be deposited continuously as near as possible to its final position. In slab construction, placing should be started along the perimeter at one end of the work with each batch placed against previously dispatched concrete. Concrete should not be dumped in separate piles and then leveled and worked together; nor should the concrete be deposited in large piles and moved horizontally into final position.

Consolidation

In some types of construction, the concrete is placed in forms, then consolidated. Consolidation compacts fresh concrete to mold it within the forms and around embedded items and reinforcement and to eliminate stone pockets, honeycomb, and entrapped air. It should not remove significant amounts of intentionally entrained air. Vibration, either

internal or external, is the most widely used method for consolidating concrete. When concrete is vibrated, the internal friction between the aggregate particles is temporarily destroyed and the concrete behaves like a liquid; it settles in the forms under the action of gravity and the large entrapped air voids rise more easily to the surface. Internal friction is reestablished as soon as vibration stops.

Finishing

Concrete that will be visible, such as slabs like driveways, highways, or patios, often needs finishing. Concrete slabs can be finished in many ways, depending on the intended service use. Options include various colors and textures, such as exposed aggregate or a patterned-stamped surface. Some surfaces may require only strikeoff and screeding to proper contour and elevation, while for other surfaces a broomed, floated, or troweled finish may be specified. In slab construction, screeding or strikeoff is the process of cutting off excess concrete to bring the top surface of the slab to proper grade. A straight edge is moved across the concrete with a sawing motion and advanced forward a short distance with each movement.

Bullfloating eliminates high and low spots and embeds large aggregate particles immediately after strikeoff. This looks like a long-handled straight edge pulled across the concrete. Jointing is required to eliminate unsightly random cracks. Contraction joints are made with a hand groover or by inserting strips of plastic, wood, metal, or preformed joint material into the unhardened concrete. Sawcut joints can be made after the concrete is sufficiently hard or strong enough to prevent raveling. After the concrete has been jointed, it should be floated with a wood or metal hand float or with a finishing machine using float blades. This embeds aggregate particles just beneath the surface; removes slight imperfections, humps, and voids; and compacts the mortar at the surface in preparation for additional finishing operations. Where a smooth, hard, dense surface is desired, floating should be followed by steel troweling. Troweling should not be done on a surface that has not been floated; troweling after only bullfloating is not an adequate finish procedure. A slip-resistant surface can be produced by brooming before the concrete has thoroughly hardened, but it should be sufficiently hard to retain the scoring impression.

*********End************

Reference

1. Internet **2.Engineering book** **3. Own information**