CHAPTER 1
COMPONENTS OF CONCRETE

Concrete is made up of two components, aggregates and paste. Aggregates are generally classified into two groups, fine and coarse, and occupy about 60 to 80 percent of the volume of concrete. The paste is composed of cement, water, and entrained air and ordinarily constitutes 20 to 40 percent of the total volume.

In properly made concrete, the aggregate should consist of particles having adequate strength and weather resistance and should not contain materials having injurious effects. A well graded aggregate with low void content is desired for efficient use of paste. Each aggregate particle is completely coated with paste, and the space between the aggregate particles is completely filled with paste. The quality of the concrete is greatly dependent upon the quality of paste, which in turn, is dependent upon the ratio of water to cement content used, and the extent of curing. The cement and water combine chemically in a reaction, called hydration, which takes place very rapidly at first and then more and more slowly for a long period of time in favorable moisture conditions. More water is used in mixing concrete than is required for complete hydration of the cement. This is required to make the concrete plastic and more workable; however, as the paste is thinned with water, its quality is lowered, it has less strength, and it is less resistant to weather. For quality concrete, a proper proportion of water to cement is essential.

Desirable Properties of Concrete

Durability: Ability of hardened concrete to resist deterioration caused by weathering, chemicals, and abrasion

Workability: Ease of placing, handling, and finishing

Weather Resistance: Resistance to deterioration caused by freezing and thawing, wetting and drying, and heating and cooling

Erosion Resistance: Resistance to deterioration caused by water flow, traffic, and wind blasting

Chemical Resistance: Resistance to deterioration caused by de-icing salts, salt water, sulfate salts

Water Tightness: Resistance to water infiltration.

Strength

Economy

Ingredients in Concrete

Hydraulic Cement

Portland Cements and Blended Cements are hydraulic, since they set and harden to form a stone-like mass by reacting with water. The term Hydraulic Cement is all inclusive and is the newer term to be used for both Portland Cement and Blended Cement.

The invention of Portland Cement is credited to Joseph Aspdin, an English mason, in 1824. He named his product Portland Cement, because it produced a concrete which resembled a natural limestone quarried on the Isle of Portland.

The raw materials used in the manufacturing of cement consist of combinations of limestone, marl or oyster shells, shale, clay and iron ore. The raw materials must contain appropriate proportions of lime, silica, alumina, and iron components. Selected raw materials are pulverized and proportioned in such a way that the resulting mixture has the desired chemical composition. This is done in a dry process by grinding and blending dry materials, or in a wet process by utilizing a wet slurry. In the manufacturing process, analyses of the materials are made frequently to ensure a uniform high quality Portland Cement.

After blending, the prepared mix is fed into the upper end of a kiln while burning fuel, producing temperatures of 2600 °F to 3000 °F (1425 °C to 1650 °C), is forced into the lower end of the kiln. During the process, several reactions occur which result in the formation of Portland Cement clinker. The clinker is cooled and then pulverized. During this operation gypsum is added as needed to control the setting time of the cement. The pulverized finished product is Portland Cement. It is ground so fine that nearly all of it passes a sieve having 40,000 openings per sq. inch (1.6 openings per $mm^{2)}$.

There are five types of Portland Cement (Types I, II, III, IV, V) and two types of Blended Cement (Types I-P, I-S). Each type is manufactured to meet certain physical and chemical requirements for specific purposes.

Type I is a general-purpose cement. It is suitable for all uses when the special properties of the other types are not required.

Type II cement is used when sulfate concentrations in ground water are higher than normal. Type II will usually generate less heat at a slower rate than Type I or Normal cement. Therefore, it may be used in structures of considerable mass, such as large piers, heavy abutments, and heavy retaining walls. Its use will minimize temperature rise, which is especially important in warm weather pours.

Type III is a high-early-strength cement which will develop higher strength at an earlier age. It is used when early form removal is desired. Richer mixes (higher cement content) of Types I and II may be used to gain early strength

Type IV cement is used in massive structures, such as dams. This type of cement is used where the heat generated during hardening is critical

Type V cement is used in concrete exposed to severe sulfate action, and is used mainly in the western section of the United States

Type I-P blended cement is a combination of Portland Cement and a pozzolan. A pozzolan, such as fly ash, by itself has no cementing qualities, but when combined with moisture and calcium hydroxide (in the Portland Cement) it produces a cementing effect

Type I-S blended cement is a combination of Portland Cement and blast-furnace slag. The slag constitutes between 25 and 65 percent of the weight of the blended cement

Basically, Hydraulic Cements may be considered as being composed of the following compounds:

Tricalcium Silicate $3\ CaO.S_1O_2 = C_3S$
Dicalcium Silicate $2\ CaO.S_1O_2 = C_2S$
Tricalcium Aluminate $3\ CaO.Al_2O_3 = C_3A$
Tetracalcium Aluminoferrite $4\ CaO.Al_2O_3.Fe_2O_3 = C_4AF$

It is not necessary to memorize these chemical formulas; however, do become familiar with the contribution each compound makes to the concrete.

Tricalcium Silicate hydrates and hardens rapidly and is largely responsible for initial set and early strength.

Dicalcium Silicate hydrates and hardens slowly and contributes to strength increases at ages beyond one week.

Tricalcium Aluminate causes the concrete to liberate heat during the first few days of hardening and it contributes slightly to early strength. Cement with low percentages of this compound are especially resistant to sulfates (Types II and Type V).

Tetracalcium Aluminoferrite formation reduces the clinkering temperature, thereby assisting in the manufacture of cement. It hydrates rapidly but contributes very little to strength.

Table 1. Chemical and Compound Composition and Fineness of Some Typical Cements

Types of Portland Cement		Potential Compound Composition %*				Blaine Fineness m^2/kg
ASTM	CSA	C_3S	C_2S	C_3A	C_4AF	
I	Normal	55	19	10	7	370
II		51	24	6	11	370
III	High-Early Strength	56	19	10	7	540
IV		28	49	4	12	380
V	Sulfate-Resisting	38	43	4	9	380

* "Potential Compound Composition" refers to the maximum compound composition allowable by ASTM C150 calculations using the chemical composition of the cement. The actual compound composition may be less due to incomplete or altered chemical reactions.

Properties of Hydraulic Cement

Fineness: Fineness of cement affects heat released and the rate of hydration. Greater cement fineness increases the rate at which cement hydrates and thus accelerates strength development.

Setting Time: Initial set of cement paste must not occur too early; final set must not occur too late. The setting times indicate that the paste is or is not undergoing normal hydration reactions. Setting time is also affected by cement fineness, water-cement ratio, admixtures and Gypsum. Setting times of concrete do not correlate directly with setting times of pastes because of water loss to air or substrate and because of temperature differences in the field as contrasted with the controlled temperature in the testing lab.

False Set: False set is evidenced by a significant loss of plasticity without the evolution of much heat shortly after mixing. Further mixing without the addition of water or mixing for a longer time than usual can restore plasticity.

Heat of Hydration: Heat of hydration is the heat generated when cement and water react. The amount of heat generated is dependent chiefly upon the chemical composition of the cement. The water-cement ratio, fineness of the cement, and temperature of curing also are factors.

Specific Gravity: Specific gravity of portland cement is generally about 3.15. The specific gravity of a cement is not an indication of the cement's quality; its principal use is in mixture proportioning calculations.

Shipping and Storage of Cement

Cement shall be measured by weight. Cement in standard packages need not have its weight determined, but bulk cement and fractional packages shall have their weight determined within an accuracy of 1 percent.

Mixing Water for Concrete

Almost any natural water that is drinkable is satisfactory as mixing water for making or curing concrete. However, water suitable for making concrete may not necessarily be fit for drinking.

The acceptance of acidic or alkaline waters is based on the pH scale which ranges from 0 to 14. The pH of neutral water is 7.0. A pH below 7.0 indicates acidity, and a pH above 7.0 indicates alkalinity. The pH of mixing water should be between 4.5 and 8.5.

Unless approved by tests, water from the following sources should not be used:

1. Water containing inorganic salts such as manganese, tin, zinc, copper, or lead;
2. Industrial waste waters from tanneries, paint and paper factories, coke plants, chemical and galvanizing plants, etc.;
3. Waters carrying sanitary sewage or organic silt; and
4. Waters containing small amounts of sugar, oil, or algae.

Wash water can be reused in the concrete mixture provided it is metered and is 25 percent or less of the total water. A uniform amount of wash water must be used in consecutive batches, with subsequent admixture rates adjusted accordingly to produce a workable concrete that conforms to the specifications. The total water must conform to the acceptance criteria of ASTM C1602, Tables 1 and 2.

Aggregates for Concrete

Aggregates must conform to certain requirements and should consist of clean, hard, strong, and durable particles free of chemicals, coatings of clay, or other fine materials that may affect the hydration and bond of the cement paste. The characteristics of the aggregates influence the properties of the concrete.

Weak, friable, or laminated aggregate particles are undesirable. Aggregates containing natural shale or shale like particles, soft and porous particles, and certain types of chert should be especially avoided since they have poor resistance to weathering.

Characteristics of Aggregates

Resistance to Freeze-Thaw: (Important in structures subjected to weathering) - The freeze-thaw resistance of an aggregate is related to its porosity, absorption, and pore structure. Specifications require that resistance to weathering be demonstrated by the magnesium sulfate test.

Abrasion Resistance: (Important in pavements, loading plat-forms, floors, etc.) - Abrasion resistance is the ability to withstand loads without excessive wear or deterioration of the aggregate.

Chemical Stability: (Important to strength and durability of all types of structures) - Aggregates must not be reactive with cement alkalies. This reaction may cause abnormal expansion and map-cracking of concrete.

Particle Shape and Surface Texture: (Important to the workability of fresh concrete) - Rough textured or flat and elongated particles, due to their high surface area, require more water to produce workable concrete than do rounded or cubical aggregates.

Grading: (Important to the workability of fresh concrete) - The grading or particle size distribution of an aggregate is determined by sieve analysis.

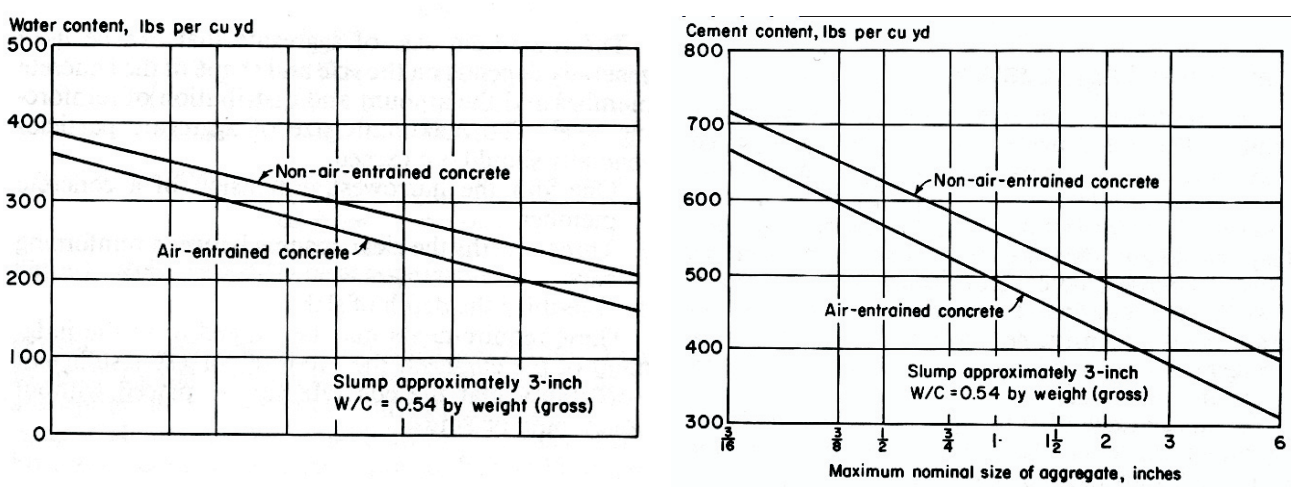

Fig. 1. Cement and water contents in relation to maximum size of aggregates, for air-entrained and non-air-entrained concrete. Less cement and water are required in mixes having large, coarse aggregate.

Specific Gravity (Density):

The specific gravity of an aggregate is the ratio of its weight to the weight of an equal volume of water at a given temperature. Most normal weight aggregates have a specific gravity ranging from 2.4 to 2.9. It is not a measure of aggregate quality. It is used for certain computations in a mix design.

Absorption and Surface Moisture:

The moisture conditions of aggregates are shown in Fig. 2. They are designated as:

a. **Oven-Dry:** fully absorbent
b. **Air-Dry:** dry at the surface but containing some interior moisture, thus somewhat absorbent
c. **Saturated Surface-Dry:** neither absorbing water from, nor contributing water to, the concrete mix
d. **Wet with Free Moisture:** containing an excess of moisture on the surface

Batch weights of materials must be adjusted for moisture conditions of the aggregates.

Dry-rodded Unit Weight:

Dry-rodded unit weight is the mass (weight) of one cubic meter (foot) of dry coarse aggregate that is compacted, by rodding in three equal layers, in a standard container. For any one aggregate, the dry-rodded unit weight varies with the size and gradation.

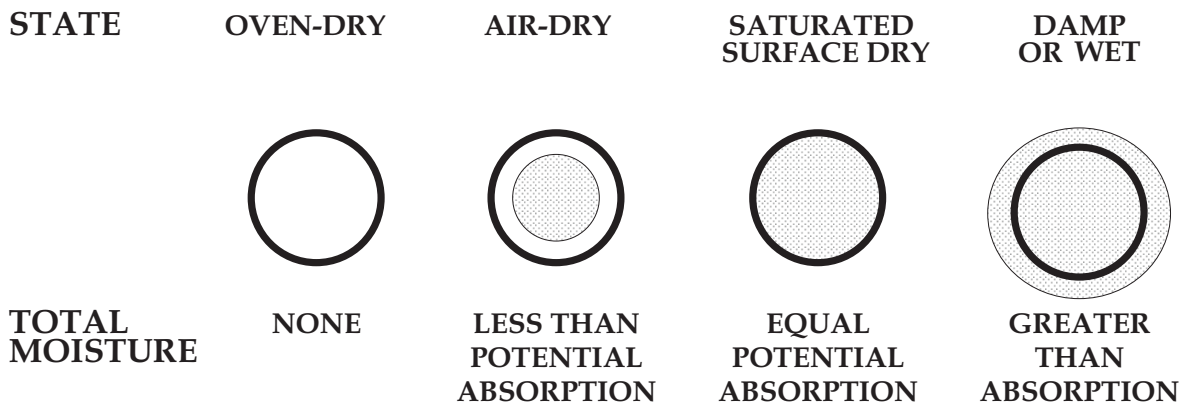

Fig. 2. Moisture conditions of aggregates

Deleterious Substances in Aggregates

Harmful substances and their effect on concrete include the following:

1. **Organic Impurities:** affect setting time and hardening, and may cause deterioration
2. **Material finer than the #200 (75μm) sieve:** affect bond and increases water demand
3. **Lightweight Materials** (coal, lignite)**:** affect durability, and may cause popouts and stains
4. **Soft Particles:** affect durability and wear resistance
5. **Friable Particles:** affect workability and durability, break up in mixing, and increase water demand
6. **Clay Lumps:** absorb mixing water or cause popouts

Admixtures for Concrete

Admixtures include all materials other than cement, water and aggregates that are added to concrete. Admixtures can be broadly classified as follows:

1. Air-entraining admixtures
2. Retarding admixtures
3. Water-reducing admixtures
4. Accelerating admixtures (Used only in special circum-stances)
5. Pozzolans
6. Workability agents
7. Miscellaneous, such as permeability-reducing agents, gas forming agents, and grouting agents
8. Water reducing and retarding admixtures
9. Water reducing and accelerating admixtures (Used only in special circumstances)

Concrete should be workable, finishable, strong, durable, watertight, and wear-resistant. These qualities can often be obtained by proper design of the mix using suitable materials without resorting to admixtures (except air-entraining admixtures). There may be instances, however, when special properties such as extended time of set, acceleration of strength, or a reduction in shrinkage may be desired. These may be obtained by the use of admixtures. However, no admixture of any type or amount should be considered as a substitute for good concreting practices.

The effectiveness of an admixture depends upon such factors as the type and amount of cement, water content, aggregate shape, gradation and proportions, mixing time, slump, and the temperature of the concrete and air. Trial mixes should be made to observe the compatibility of the admixture with other admixtures and job materials as well as the properties of the fresh or hardened concrete.

Air-Entraining Admixtures

An air-entrained concrete contains microscopic air bubbles that are distributed, but not interconnected, through the cement paste. The air bubbles are small and invisible to the naked eye. Visible entrapped air voids occur in all concrete and the amount of entrapped air is largely a function of aggregate characteristics. Variations in air content can be expected with variations in aggregate proportion and gradation, mixing time, temperature and slump. Adequate control is required to ensure the proper air content at all times. Since the amount of air-entraining agent per batch is small [3 to 8 oz. (110 to 300 ml) per cubic yard (meter) of concrete], it is important to disperse the agent in the plastic concrete to insure proper spacing and size of air voids, which are significant factors contributing to the effectiveness of air-entrainment in concrete.

Effect of Entrained Air on Concrete

Workability: Air-entrainment improves workability. Sand and water contents are reduced. The plastic mass is more cohesive and looks and feels "fatty" or "workable". Segregation and bleeding of the mix are reduced.

Freeze-Thaw Resistance: Freeze-thaw resistance is improved as the air voids act as reservoirs to relieve the pressure as water freezes. This prevents damage to the concrete.

Resistance to De-icing: Surface scaling is reduced.

Sulfate Resistance: Air-entrainment improves sulfate resistance.

Strength: Reduction in strength is minimized because the improved workability allows a lower water-cement ratio. Strength depends upon the voids-cement ratio. "Voids" is defined as the total volume of water plus air (entrained and entrapped).

Abrasion Resistance: About the same as non-air-entrained concrete of the same compressive strength.

Watertightness: Watertightness of air-entrained concrete is superior to that of non-air-entrained concrete. Low water-cement ratio makes the concrete more impermeable.

Factors Affecting Air Content

Coarse Aggregate Gradation: There is little change in air content when the maximum size of aggregate is increased above 1½ in. (37.5 mm). For aggregate sizes smaller than 1½ in. (37.5 mm), the air content increases sharply as the size decreases because of the increase in mortar volume. (See Fig. 3.)

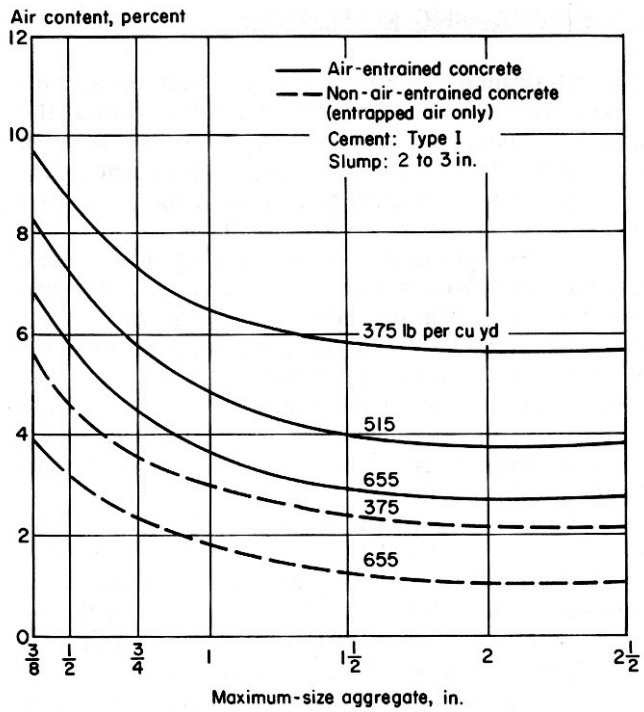

Fig. 3. Relationship between aggregate size, cement content, and air content of concrete. The air-entraining admixture dosage per unit of cement was constant for air-entrained concrete.

Fine Aggregate Content: An increase in the amount of fine aggregate causes an increase in air content with a given amount of air-entraining agent. (See Fig. 4.)

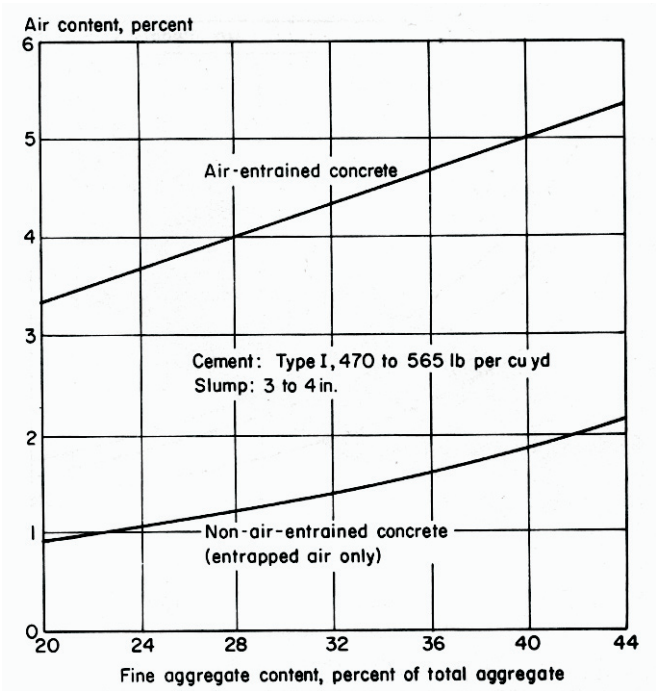

Fig. 4. Relationship between percentage of fine aggregate and air content of concrete.

Cement Content: As the cement content increases, the air content decreases.

Consistency: The air content increases as the slump increases up to about 7" (175 mm), and decreases with further increases in slump.

Vibration: Prolonged vibration should be avoided. Regardless of the slump, 15 seconds of vibration causes a considerable reduction in air content. If vibration is properly applied, little of the intentionally entrained air is lost. Air lost during handling and vibration consists mostly of large bubbles (entrapped air) which are usually undesirable from a standpoint of strength and durability.

Temperature: Less air is entrained as the temperature of the concrete increases. (See Fig. 5)

Mixing Action: The amount of entrained air varies with the type and condition of the mixer, the amount of concrete being mixed, and the rate of mixing. Fig. 6 shows the affect of mixing speed and mixing time in a transit mixer. Fig. 7 shows the affect on air content as agitating time is increased.

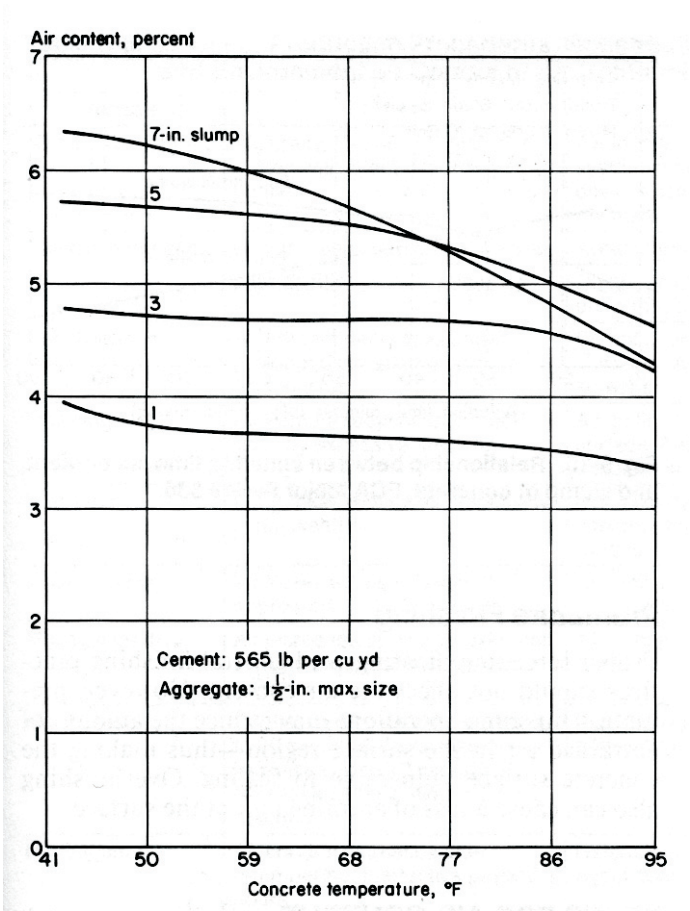

Fig. 5 Relationship between temperature, slump, and air content of concrete.

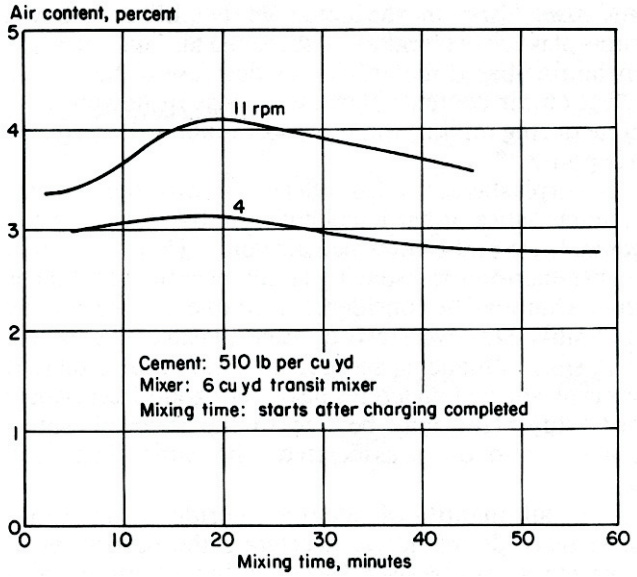

Fig. 6. Relationship between mixing time and air content of concrete.

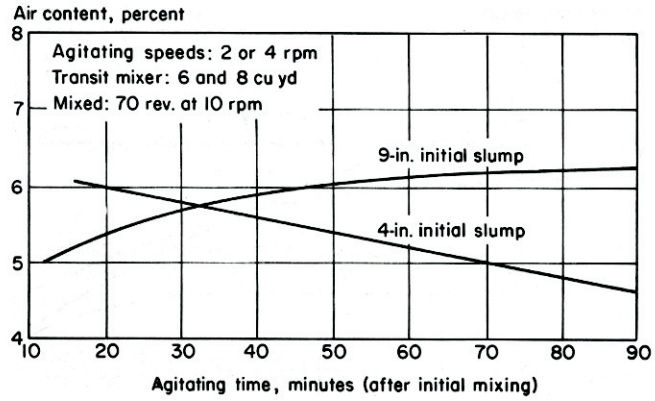

Fig. 7. Typical relationship between agitating time, air content and slump of concrete.

The amount of air specified in air-entrained concrete depends on the type of structure and the extent of exposure to de-icing chemicals, freeze-thaw cycles, and chemically reactive soil or water.

Retarding Admixtures

A retarding admixture is a material that is used for the purpose of delaying the setting time of concrete. Retarders are used in concrete to:

1. Offset the accelerating affect of hot weather on the setting of concrete.
2. Provide time for difficult placing or finishing in such items as bridge decks or large piers.

Most retarders also function as water reducers. They are frequently called "water-reducing retarders." Some retarders also entrain air in concrete. A retarded concrete may lose slump faster than a non-retarded concrete. Because some retarders react with certain air-entraining agents, they are introduced into the mixing water separately.

Acceptance tests of retarders with cements for each design mix and cement content are necessary to determine whether the materials are compatible.

Water Reducing Admixtures

A water-reducing admixture is a material used for the purpose of reducing the quantity of mixing water required to produce concrete of a given consistency. These materials increase the slump of concrete for a given water content. For a given slump, the water reduction possibly amounts to about 5%.

Many water-reducing admixtures may also retard the setting time of concrete. Some also entrain air in concrete. An increase in strength can generally be obtained with water-reducing admixtures if the water content is reduced and if the cement content and slump are kept the same. A rapid loss in slump and a significant increase in drying shrinkage can result from the use of some of these admixtures. Therefore, trial batch tests should be made with job materials.

Accelerating Admixtures

An accelerating admixture is used to accelerate the setting and the strength development of concrete. The development of strength of concrete can also be accelerated by:

1. Using Type III Cement (high-early-strength cement);
2. Lowering the water cement ratio, or increasing the cement content; and
3. Curing at higher temperatures.

Most of the commonly used accelerators cause an increase in the drying shrinkage of concrete. Calcium chloride is the most commonly used accelerating admixture. Calcium chloride and other materials used as accelerators are not antifreeze agents. When used in normal amounts, they will not reduce the freezing point of concrete by more than a few degrees.

Calcium chloride should be added in solution form as part of the mixing water in amounts not to exceed two percent by weight of cement. A greater amount can result in placement problems and can be detrimental to concrete, since it may cause rapid stiffening, increase drying shrinkage, and corrode reinforcement steel. The addition of no more than two percent of calcium chloride has no significant corrosive effect on ordinary steel reinforcement provided the concrete is of high quality.

Most commercial admixtures contain calcium chloride and are not recommended for use in items such as:

1. Prestressed concrete,
2. Concrete with steel reinforcement, or
3. Concrete subject to alkali-aggregate reaction.

However, there are more and more admixtures available without calcium chloride, which overcome the concerns with these items.

Virginia Specifications do not allow the use of an accelerator except in special circumstances.

Mineral Admixtures

Fly Ash and Granulated Iron Blast-Furnace Slag are two of the mineral admixtures available for use in concrete.

They may be used to replace a portion of the cement in a concrete mix. This replacement is usually made for economic reasons, but the quality of the mix can be maintained if certain precautions are taken. Actually, some properties such as sulfate resistance and cement-alkali reactions may be improved when mineral admixtures are used.

The fly ash approved for use as an admixture for concrete must meet certain chemical and physical requirements. The type of fly ash available in this area has pozzolanic properties. Pozzolans are siliceous materials which themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds having cementitious properties. Fly ash is a residue collected from the exhaust gases of a coal burning boiler (usually from an electrical power plant). Coal has in it certain minerals which cannot be burned, and the very fine ash that goes up the exhaust stack is termed fly ash.

A portion of the residue is unburnt carbon, which tends to filter out the air entraining agent. This reduction in air content can be further increased because of the fineness of fly ash when compared to cement, and it is not uncommon for the air content to be very low if the air entraining admixture dosage is not increased. The properties listed above and the effect on air content make it necessary to monitor air contents more frequently.

Granulated iron blast-furnace slag is a glassy, granular material formed when molten blast-furnace slag is rapidly chilled. The slag is composed of various silicates and oxides similar to those in portland cement, and as such it has some cementitious properties of its own. It also has the finely divided silica, associated with pozzolans, thereby functioning similar to the fly ash. It is permitted to replace a much higher percentage of cement.

High Range Water Reducers

High range water reducing and retarding admixtures are water reducers which permit large reductions in the water cement ratio, or provide large increases in the consistency. This can be accomplished with relatively small dosages of the admixture. It is possible to make no-slump concrete and produce a workable concrete. It is also possible to take a normal specification concrete and increase the consistency to the flowable range of greater than 8 inches (200 mm) of a slump. Because the slump cone is limited in its ability to measure high slumps, the maximum slump should be about 7 inches (175 mm).

These admixtures have a very limited time duration before the benefits of increased consistency have been lost, which can create finishing problems. Caution should be exercised in the use of these admixtures and the selection of applications where they will provide a benefit. Trial batching is recommended prior to use.

Chapter 1
Study Questions

1. _____ is the chemical reaction between water and cement.

2. _____ is the property of freshly mixed concrete which is the ease of difficulty in the placing and finishing of concrete.

3. A chemical, such as calcium chloride used to "speed up" the setting time of concrete is _____.

4. _____ is a significant loss of plasticity shortly after the concrete is mixed.

5. The time it takes a cement paste to begin hardening is known as ____.

6. A condition at which an aggregate will neither absorb moisture from concrete nor contribute moisture to the mix is _____.

7. _____ is a material used for the purpose of delaying the setting time of concrete.

8. _____ is a condition of plastic concrete which relates to its cohesion, wetness, or to flow.

9. _____ is the bonding agent used in a concrete mix.

10. The ability of hardened concrete to resist the deterioration caused by weathering, chemicals, and abrasion is known as _____.

11. The pH value of water used with cement shall be between _____ and _____ _____.

12. Gypsum is added to cement to control _____.

13. List two desirable qualities of hardened concrete: _____ and _____.

14. The primary effect of air entrainment in concrete is to improve _____.

15. List two desirable properties of an aggregate: _____ and _____.

16. How should admixtures be dispensed?

17. List two principal raw components in the manufacture of cement _____ and _____

18. The type of cement which has the highest fineness reading and the highest tricalcium silicate (C_3S) composition, both factors in accelerated strength, is _____.

19. The void content of identically graded fine aggregates will vary with _____.

20. _____ is the specific gravity of Portland Cement.

21. _____ has the greatest affect on the strength, durability and water tightness of concrete.

22. If the amount of admixture is constant and the concrete temperature is increased, the entrained air content will _____.

23. A pH value of 6.0 indicates _____ and a pH value of 7.5 indicates ____ _____.

24. The strength requirements for High Early Strength Portland Cement Concrete shall be obtained in ____ days as stated in Section _____.

25. In no case shall a vibrator be operated longer than ____ seconds in any one location as stated in Section _____.

26. The specification requirements for the approval to use admixtures in Hydraulic Cement Concrete are found in Section _____.

27. Each batch of concrete shall be delivered to the site of work and discharged withi n _____ of the time the cement is introduced into the mixture unless otherwise approved by the Engineer as found in Section _____.