



CHAPTER TWO

CONCRETE MATERIALS & PROPERTIES

2.1 Introduction

This chapter deals with the basic characteristics of NSC materials, properties of concrete and the factors affecting strength of concrete.

2.2 Concrete Component Materials

Concrete is a mixture of coarse (stone or brick chips) and fine (generally sand or crushed stone) aggregates with a paste of binder material (usually portland cement and water). Selection of proper materials and their proportions are the most important steps in producing a concrete meeting the requirements of strength and durability. Composition and properties of materials used for making concrete are discussed under the following heads:

2.2.1 Cement

Cement, in the general sense of the word, can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact whole (Neville, 2002). This definition embraces a large variety of cementing materials. For constructional purposes, the meaning of the term 'cement' is restricted to the bonding materials used with stones, sand, bricks, building blocks, etc. The principal constituents of this type of cement are compounds of lime, so that in building and civil engineering we are concerned with calcareous cement. The cements is essential for making the concrete have the



property of setting and hardening under water by virtue of a chemical reaction with it and are, therefore, called hydraulic cements.

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina, and iron oxide. These compounds interact with one another in the kiln at high temperature to form the cement clinker.

This clinker is composed of four compounds – each playing a different part in the hydration reaction. These four compounds are shown in table (2.1).

Table (2.1):- Cement Major Compounds (SHETTY, 2005).

Name of compound	Oxide compositions	Abbreviation
Tricalcium silicate	3CaO.SiO ₂	C ₃ S
Dicalcium silicate	2CaO.SiO ₂	C ₂ S
Tricalcium aluminate	3CaO.AL ₂ O ₃	C ₃ A
Tetra calcium aluminoferrite	4CaO.AL ₂ O ₃ .Fe ₂ O ₃	C ₄ AF

In addition to the main compounds listed in table (2.1) there exist minor compounds, such as (MgO, TiO₂, Mn₂O₃, K₂O and Na₂O₃). The two calcium silicates, namely C₃S and C₂S, together constitute 70 to 80 percent of the cement. Upon the hydration both C₃S and C₂S give the same product called calcium silicate hydrate C₃S₂H₃ and calcium hydroxide. The Tricalcium Silicate C₃S hydrates and hardens rapidly provides most of the early strength in the first three to four weeks. In general, the early strength of Portland cement concrete is higher with increased percentage of C₃S. Dicalcium Silicate C₂S hydrates and hardens slowly and contributes largely to strength increase at ages beyond one week (Neville, 2002). The compound Tricalcium aluminate C₃A is characteristically fast react with water and may lead to an immediate stiffening of the paste and this process is termed flash set. The role of



gypsum added in the manufacture of cement is to prevent such a fast reaction. C_4AF is present in cement in small quantities, and compared with the other three compounds, it does not affect the behavior significantly; however, it reacts with gypsum to form calcium sulfoferrite and its presence may accelerate the hydration of the silicates.

2.2.1.1 Physical Properties of Cement

Because the quality of cement is vital for the production of good concrete, the manufacture of cement requires stringent control. A number of tests are performed in the cement plants laboratory to ensure that the cement should be to desired quality and that it conforms to the requirements of the relevant national standard. Hence, it is desirable to examine the physical properties of cement used for some special purpose. consistency, fineness test, setting, soundness and strength test, will now be briefly discussed as follows:

(a) Consistency: - refers to the relative mobility of a freshly mixed cement paste or mortar, to its ability to flow. Consistency is measured by the vicat apparatus, which measures the depth of penetration of 10 mm diameter plunger under its own weight. When depth of penetration reaches a certain value, the water content required gives the standard consistence of between 26 and 33 percent (expressed as a percentage by mass of dry cement) (Neville, 2002).

(b) Fineness of Cement: - has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Because hydration starts at the surface of the cement particles, it is the total surface area of the cement that represents material available for hydration. Thus, the rate of hydration depends on the fineness of cement particles, and for a rapid development of strength, high fineness is necessary. However, the cost of grinding and the effect of



fineness on other properties, e.g., gypsum requirement, workability of fresh concrete and long term behavior, must be taken into account. (Neville, 2002).

(c) Setting: - is a term used to describe the stiffening of the cement paste. Broadly speaking setting refers to change from fluid to rigid state. Setting is mainly caused by selective hydration of C_3A and C_3S and is accompanied by temperature rise (speeds up the chemical reactions of hydration) and final set corresponds to the peak temperature. Initial and final setting should be distinguished from false set which sometimes occurs with few minutes of mixing with water. No heat is evolved in false set and concrete can be remixed without adding water. Flash set is characterized by the liberation of heat. The setting times of cement are measured using the vicat apparatus with different penetrating attachments. A minimum time of 45 minute is prescribed by BS12-1978 for initial set, and 10 hours for final set (Neville, 2002).

(d) Soundness: - refers to the ability of a hardened paste to retain its volume. Lack of soundness or delayed destructive expansion can be caused by excessive amount of hard burned free lime or magnesia and calcium sulphate. Cement exhibiting this type of expansion is classified as unsoundness. The chief test for soundness are the (Le Chatelier accelerated test, and autoclaved tests) the expansion carried out in the manner described in (BS812) should not be more than (10 mm) in the Le Chatelier tests and (0.8 percent) in autoclaved test (Neville, 2002).

2.2.1.2 Types of Portland Cement

Different types of Portland cement are manufactured to meet various normal physical and chemical requirements for specific purposes. These are:



- **Ordinary Portland Cement Type (I):-** the common all-purpose cement used for general construction work (Neville, 2002).
- **Moderate Sulfate Resistance Type (II):-** for general use, especially when moderate sulfate resistance is desired (SHETTY, 2005).
- **Rapid Hardening Portland Cement Type (III):-** for use when high early strength is desired. Strength of this cement develops rapidly because of higher C_3S content (up to 70 percent) and a higher fineness (Neville, 2002).
- **Low Heat Portland Cement Type (IV):-** for use when low heat of hydration is required. It is used for very large concrete construction (Neville, 2002).
- **Sulphate Resisting Cement Type (V):-** Has a low C_3A content so as to avoid sulphate attack from outside the concrete (Neville, 2002).
- **Portland Pozzolan Cement Type (IP):-** Are blends of Portland cement and a pozzolanic material. The role of the pozzolan is to react slowly with the calcium hydroxide that is liberated during cement hydration. This tends increase the ultimate strength of the material (SHETTY, 2005).

2.2.2 Aggregates

Since at least three-quarter of the volume of concrete is occupied by aggregate, it is not surprising that its quality is of considerable importance. Not only may the aggregate limit the strength of concrete, but the aggregate properties greatly affect the performance of concrete (Neville, 2002). Aggregate was originally viewed as an inert, inexpensive material dispersed throughout the cement paste for economic reasons. In fact, aggregate is not truly inert and its physical, thermal, and sometimes also chemical properties influence the performance of concrete.



2.2.2.1 Classification of Aggregates

The classification of aggregate is generally based on their (size, bulk density, source, surface texture ...etc.).

Aggregates can be classified according to size:-

(a) Fine Aggregate: - smaller than (5 or 4.75 mm) in diameter.

(b) Coarse Aggregate: - larger than (5 or 4.75 mm) in diameter.

Aggregate can be classified on the basis of bulk density:-

(a) Normal-Weight Aggregate: - aggregate with bulk density of 1520 to 1680 kg/m³.

(b) Light-weight Aggregate: - aggregate with bulk density less than 1120 kg/m³.

(c) Heavy Weight Aggregate: - aggregate with bulk density more than 2080 kg/m³.

According to surface texture, aggregate is classified as into: Glassy, Smooth, granular, rough, crystalline or honeycombed particles (SHETTY, 2005).

2.2.2.2 Properties of Aggregate

As mentioned earlier, the properties and performance of concrete are dependent to a large extent on the characteristic and properties of the aggregate themselves.

The properties of aggregate for concrete are discussed under the:

(a) Mechanical Properties

Several mechanical properties of aggregate are interest. These properties include: Strength, Toughness and Hardness.

Toughness can be defined as resistance of the aggregate to failure by impact and it is usual to determine the aggregate impact value of bulk aggregate. Full details of the prescribed tests are given in (BS 812 part 112:1990) (Neville, 2002).



Hardness of aggregate can be defined as its resistance to wear obtained in the term of aggregate abrasion value is determined by using Los Angeles machine as described in (BS 812: part 113: 1990). The method combines the test for attrition and abrasion. A satisfactory aggregate should have an abrasion value of not more than 30 percent for aggregate used for wearing surface (Neville, 2002).

(b) Physical Properties

The physical properties of aggregate includes: specific gravity, bulk density, soundness, absorption, porosity, permeability, and particles size distribution.

Specific gravity can be defined as ratio of mass (or weight in air) of a unit volume of material to the mass of the same volume of a water as the stated temperature. In concrete technology, specific gravity of aggregate is used in design calculations of concrete mixes. With the specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated (SHETTY, 2005).

The Bulk density or unit weight of an aggregate is the mass or weight of the aggregate required to fill a container of a specified unit volume. The volume referred to here is that occupied by both aggregate and voids between particles. The bulk density depends on how densely the aggregate is packed and consequently, on the size distribution and the shape of particles. The higher the bulk density, the lower is the void content to be filled by sand and cement (Kosmatka, 2003).

The soundness of an aggregate is a measure of its durability which is defined as the ability of individual particles to retain integrity and not suffer physical, mechanical or chemical changes to extents which could adversely affect the properties of concrete (Neville, 2002).



Absorption relates to the particle's ability to take in a liquid. Porosity is a ratio of the volume of the pores to the total volume of the particle. Permeability refers to the particle's ability to allow liquids to pass through.

The particle-size distribution is a sample of aggregate, referred to as the grading is generally expressed in terms of the cumulative percentage of particles passing (or retained on) a specific series of sieves. The particles size distribution is extremely important in the design of any concrete mix. For most practical concrete, it is desirable to have the particle sizes evenly distributed from the maximum size of coarse aggregate down to the smallest sand particles. This will enable the aggregate to compact in the densest form leaving the minimum number of voids to be filled by the more expensive cement paste (choo, 2003).

2.2.3 Water

Water is an important constituent in concrete. It chemically reacts with cement (hydration) to produce the desired properties of concrete. Mixing water is the quantity of water that comes in contact with cement, impacts slump of concrete and is used to determine the water to cementitious materials ratio w/cm of the concrete mixture. Strength and durability of concrete is controlled to a large extent by its w/cm . Mixing water in concrete includes batch water measured and added to the mixer at the batch plant, ice, free moisture on aggregates, water included in any significant quantity with chemical admixtures, and water added after batching during delivery or at the jobsite. Water absorbed by aggregates is excluded from mixing water. Besides its quantity, the quality of mixing water used in concrete has important effects on fresh concrete properties, such as setting time and workability; it also has important effects on the strength and durability of hardened concrete.



In general, water that is fit for human consumption (potable) is acceptable for use as mixing water. However, non-potable sources of water can also be used provided the source does not negatively impact the properties of concrete (SHETTY, 2005).

2.3 Properties of Concrete

Concrete will go through two states: “fresh state” and “Hardened state”. Good concrete has to satisfy performance requirements in fresh & hardened state. In fresh states the concrete should be placed and compacted without occurring of segregation. In hardened state, concrete should be strong, durable and impermeable and it should have minimum dimensional changes. Properties of concrete in both, Fresh & Hardened states are discussed below:-

2.3.1 Properties of Fresh Concrete

Concrete remains in its fresh state from the time it is mixed until it sets. During this time the concrete is handled, transported, placed and compacted. The fresh concrete has the following properties, consistency, workability, bleeding, plastic shrinkage and loss of consistency.

(a) Consistency: - consistency of a concrete mix is a measure of the stiffness or sloppiness of the mix. For effective handling, placing and compacting the concrete, consistency must be the same for each batch. It is therefore necessary to measure consistency of concrete at regular intervals. Slump test is commonly used to measure consistency of concrete (Neville, 2002).

(b) Workability: - the workability of a concrete mix is the relative ease with which concrete can be placed, compacted and finished without separation or segregation of the individual materials (Neville, 2002).

(c) Bleeding: - cement and aggregate particles have densities about three times that of water. In fresh concrete they consequently tend to settle and



displace mixing water which migrates upward and may collect on the top surface of the concrete. This upward movement of mixing water is known as bleeding (Neville, 2002).

(d) Plastic Shrinkage: - if water is removed from the compacted concrete before it sets, the volume of the concrete is reduced by the amount of water removed. This volume reduction is called plastic shrinkage.

Water may be removed from the plastic concrete by evaporation or by being absorbed by dry surfaces such as soil or old concrete or by the dry wooden form work (Neville, 2002).

(e) Slump Loss: - from the time of mixing, fresh concrete gradually loses consistency. This gives rise to the problems only if the concrete becomes too stiff to handle, place and compact properly.

Slump loss in concrete is due to the following reasons: hydration of cement (generating more heat), loss of water by evaporation, absorption of water by dry aggregates and absorption of water by surfaces in contact with the concrete (Neville, 2002).

2.3.2 Properties of Hardened Concrete

Fully cured, hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. If concrete is made with high-quality materials and is properly proportioned, mixed, handled, placed and finished, it will be the strong and durable building material. The most important properties of hardened concrete are strength and durability.

Strength of concrete is commonly considered its most valuable property. Strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hardened



cement paste. Moreover, the strength of concrete is almost invariably a vital element of structural design and is specified for compliance purposes.

Durability might be defined as the ability to maintain satisfactory performance over an extended service life. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years. Most concrete buildings are demolished due to obsolescence rather than deterioration.

Different concrete require different degrees of durability depending on the exposure environment and properties desired. Appropriate concrete ingredients, mix proportions, finishes and curing practices can be adjusted on the basis of required durability of concrete (Neville, 2002).

2.3.2.1 The Factors Affecting Strength of Concrete

The important factors that affecting strength of concrete are: water/cement ratio, gel/space ratio, properties of coarse aggregate, age of concrete and temperature.

2.3.2.1.1 Water/cement Ratio

In engineering practice, the strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors: the water/cement ratio and the degree of compaction. When concrete is fully compacted, its strength is taken to be inversely proportional to the water/cement ratio. The general form of the strength versus water/cement ratio curve is shown in Figure (2.1). It may be recalled that the water/cement ratio determines the porosity of the hardened cement paste at any stage of hydration. Thus the water/cement ratio and the degree of compaction both affect the volume of voids in concrete. Figure (2.1) shows that the range of the validity of the water/cement ratio rule is limited. At very low values of the water/cement



ratio, the curve ceases to be followed when full compaction is no longer possible. Thus the increase of the water/cement ratio would improve workability and enhance the ability to decrease entrapped air.

From time to time, the water/cement ratio rule has been criticized as not being sufficiently fundamental. Nevertheless in, practice the water/cement ratio is the largest single factor in the strength of fully compacted concrete.

The quantity of water in the mix needs a more careful definition. It is considered to be as effective water, which occupies space outside the aggregate particles when the gross volume of concrete becomes stabilized, i.e. approximately at the time of setting. Hence the terms effective, free, or net water/cement ratio.

Generally, water in concrete consists of that added to the mix and that held by the aggregate at the time when it enters the mixers. A part of the latter water is absorbed within the pore structure of the aggregate while some exists as free water on the surface of the aggregate and is therefore not different from the water added direct into the mixer. Conversely, when the aggregate is not saturated and some of its pores are therefore air-filled, a part of the water added to the mix will be absorbed by the aggregate during the first half-hour or so after mixing. Under such circumstances the demarcation between absorbed and free water is a little difficult (Neville, 2002).

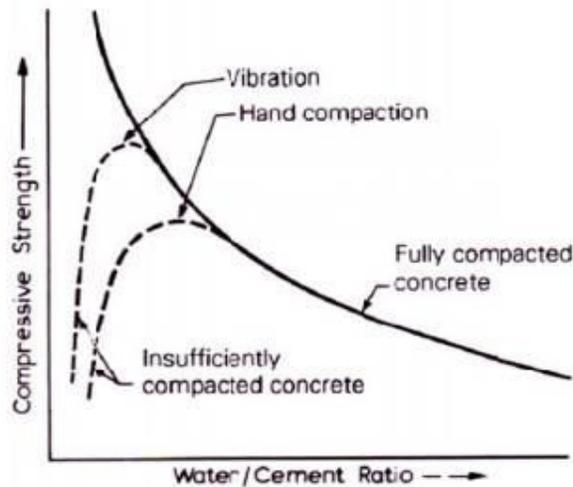


Figure (2.1):- Related between Strength, and Water/Cement Ratio (Neville, 2002).

2.3.2.1.2 Gel/Space Ratio

The influence of the water/cement ratio on strength does not truly constitute a law because the water/cement ratio rule does not include many qualifications necessary for its validity. In particular, strength at any water/cement ratio depends on: degree of hydration of cement, chemical and physical properties of cement, temperature at which hydration takes place, Air content of the concrete, change in the effective water/cement ratio, formation of cracks due to bleeding and the cement content of the mix and the properties of the aggregate-cement paste interface are also relevant.

It is more correct, therefore to relate strength to the concentration of the solid products of hydration of cement in the space available for these products. "Powers" has determined the relation between the strength development and the gel/space ratio. This ratio is defined as the ratio of the volume of the hydration cement paste to the sum of the volumes of



the hydration cement and of the capillary pores. See figure (2.2)

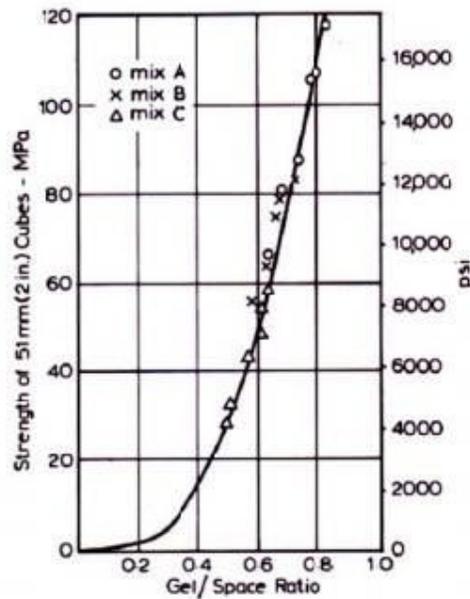


Figure (2.2):- Relation between Strength, and Gel/Space Ratio (Neville, 2002).

2.3.2.1.3 Properties of Coarse Aggregate:

The properties of aggregate affect the cracking load, as distinct from ultimate load, in compression and the flexural strength in the same manner that the relation between the two quantities is independent of the type of aggregate used. On the other hand, the relation between the flexural and compressive strengths depends on the type of coarse aggregate because (except in High Strength Concrete) the properties of aggregate, especially its shape and surface texture, affect the ultimate strength in compression very much less than the strength in tension or the cracking load in compression. In experimental concrete, entirely smooth coarse aggregate led to a lower compressive strength, typically by 10 per cent, than when roughened.



The influence of the type of coarse aggregate on the strength of concrete varies in magnitude and depends on the water/cement ratio of the mix. For water/cement ratios below 0.4, the use of crushed aggregate has resulted in strengths up to 38 per cent higher than when gravel is used. With an increase in the water/cement ratio to 0.5, the influence of aggregate falls off, presumably because the strength of the hydrated cement paste itself becomes paramount and, at a water/cement ratio of 0.65, no difference in the strengths of concretes made with crushed rock and gravel has been observed (Neville, 2002).

2.3.2.1.4 Age of Concrete

The relation between the water/cement ratio and the strength of concrete applies to one type of cement and one age only, and also assumes wet-curing conditions. On the other hand, the strength versus gel/space ratio relationship has a more general application because the amount of gel present in the cement paste at any time is itself a function of age and type of cement. The latter relation thus allows for the fact that different cements require a different length of time to produce the same quantity of gel.

In concrete practice, the strength of concrete is traditionally characterized by the 28-day value, and some other properties of concrete are often referred to the 28-day strength. If, for some reason, the 28-day strength is to be estimated from the strength determined at an earlier age, say 7 days, then the relation between the 28-day and the 7-day strengths has to be established experimentally for the given mix. The following relations could be used as rough estimations only: (Neville, 2002).

$$S_{28} \text{ (Mpa)} = 1.4 S_7 + 1.0$$

$$S_{28} \text{ (Mpa)} = 1.7 S_7 + 5.9$$



2.3.2.1.5 Temperature

The rise in the curing temperature speeds up the chemical reactions of hydration and thus affects beneficially the early strength of concrete without any ill-effects on the later strength. Higher temperature during and, following the initial contact between cement and water reduces the length of the dormant periods so that the overall structure of the hydrated cement paste becomes established very early.

Although a higher temperature during placing and setting increases the very early strength, it may adversely affect the strength from about 7 days onwards. The explanation is that a rapid initial hydration appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled. It follows from the gel/space ratio rule this will lead to a lower strength compared with a less porous. Though slowly hydrating, cement paste in which a high gel/space ratio will eventually be reached.

The adverse effects of a high early temperature on later strength could be explained by that the rapid initial rate of hydration and produced a non-uniform distribution of products of hydration within the paste. The reason for this is that, at the high initial rate of hydration, there is time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space (as in the case at lower temperatures). As a result, a high concentration of the products of hydration is built up in the vicinity of the hydration particles, and this retards the subsequent hydration and adversely affects the long-term strength (Neville, 2002).