University of Khartoum
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EFFECT OF CURING ON CONCRETE STRENGTH

A thesis submitted as partial fulfillment of the Master Degree of science in structural Engineering to the Department of civil Engineering
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DEDICATION

To my parents, who helped me to be,

To those, who are looking for better life,

To those, whom I love,

And

To those, who love me

I present this effort.

Faiga
ACKNOWLEDGEMENT

I would like to express my deep thanks, and gratitude, to those who helped me to conduct this work, which might be impossible without their assistance.

And I specially had to thank Dr. Abed alnabi Ali Ahmed, who did his utmost efforts to guide and supervise this work.

Also I have to extend my thanks to the staff of the concrete laboratory for their great cooperation.
**ABSTRACT**

Concrete may develop certain problems in hot weathers both in fresh and hardened states. Engineer’s have to investigate such problems.

This study is intended to investigate the effectiveness of using different curing techniques in the hot and dry environment of the Sudan, where temperature fluctuates up to 50 °C (120 °F).

The investigation included:

1. Total immersion in water.
2. Application of water through saturated burlaps.
4. Using polythene sheets.
5. Allowance to dry in air (without curing).
6. Water curing for the first 3 – days and then left dry.
7. Water curing for the first 7 – days and then left dry.
8. Water curing for the first 14 – days and then left dry.
9. Water curing after 3 – days of initial drying in air.
10. Water curing after 7–days of initial drying in air.
11. Water curing after 14 –days of initial drying in air.

This thesis includes six chapters. The first is an introduction to concrete and curing. The second deals with concrete materials and properties in both fresh and hardened states. The third presents problems of concreting in hot weather. The fourth outlines the concrete mix design and Experimental program and laboratory test results for compressive, tensile and flexural strengths. The fifth deals with result presentation and discussion of the data. The last chapter gives conclusion and recommendations.
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CHAPTER ONE

INTRODUCTION

1-1 GENERAL ABOUT CONCRETE:

Concrete in general is the most commonly used structural material and it consists essentially from mixing water, cement, aggregate and if necessary special additives with selected concrete proportions of the ingredients to produce concrete mix with specific properties. The concrete has to be satisfactory in its hardened state and also in its fresh state while being transported from the mixer and placed in the form work. The requirements in the fresh state are that the consistence of the mix is such that it can be compacted by the means desired without excessive effort, and also that the mix be cohesive enough for the method of placing used, not to produce segregation with consequent lack of the finished product. The usual primary requirements of good concrete in its hardened state are satisfactory compressive strength, density, durability, tensile strength, etc, are considered. The selection of more suitable and economical mix can be made, using mix design to give concrete with specified conditions and any defect in the mix ingredient may cause some problems in the concrete mix, such as segregation, bleeding and may cause shrinkage and creep after hardening.

In warm to hot weathers, (Fig (1), Fig (2)) in-site concrete quality will vary for many reasons other than selection of materials and design characteristics.

Concrete changes in volume when it loses or gains water. Surface cracking of fresh concrete occurs due to drying shrinkage caused by rapid
loss of water in hot and dry climates. The rate at which concrete will dry depends on air temperature, concrete temperature, relative humidity and wind velocity.

The lack of proper curing affects the quality of concrete in both fresh and hardened states. Concrete hardens and gains strength because of a chemical reaction between Portland cement and water. If concrete dries prematurely, there will be insufficient water for that reaction, i.e. no water, no hydration, no strength gain.

According to the standards, ponding is the most thorough method of water curing but it is seldom used in the field because it is difficult and cumbersome. Fog spring or sprinkling with nozzles provides excellent curing, but it requires constant vigilance. Burlap, wet sand and saw dust, usually provide good curing when fully saturated.

Sealing materials are sheets or membranes placed on the concrete to reduce the loss of mixing water. Use of plastic films is one way to protect the fresh concrete and can be applied as soon as free water has disappeared from the surface. Liquid membrane curing compounds are one of the practical methods of curing concrete. White curing compounds reflect the radiant energy of the sun and are desirable in many controlled mixes. They have been carried out in order to study the effects of the different parameters evolved, like method of curing and length of curing period (1).
1.2 HISTORICAL REVIEW OF LITERATURE:

The use of cementing materials is very old; the ancient Egyptians used calcined impure gypsum.

The Greeks and Romans used calcined lime stone and later learned to add to lime and water, sand and crushed stone or brick and broken tiles; this was the first concrete in history.

John Smeaton, commissioned in 1756 to rebuild the eddy stone light house, off the Corriush coast, found that the best mortar was produced when pozzolana was mixed with lime stone containing a high proportion of clayey matter. Then followed a development of other hydraulic cements, such as the Roman cement obtained by Joseph Pocker by calcining nodules of a argillaceous lime stone, culminating in the patent for Portland cement taken out by Joseph Asp din, Leeds builder, in 1824.

Isaac Johnson who burnt a mixture of clay and chalk until clinking made the prototype of modern cement in 1845. The name Portland cement, given originally due to the resemblance of the colour and quality of set cement to Portland stone- a limestone.

For along time the specification of concrete mixes has been carried out in a purely arbitrary way.

Certain nominal mixes were recognized such as 1:1:2,1:11/2:2, 1:3:6 and 1:4:8; the proportions being of cement, sand and coarse aggregate respectively.

In most cases the water was not measured but added to make the concrete look right.

For the last 100 years, cement and concrete have been the most common basic materials in building and civil engineering works, and the quantities consumed may be taken as a direct measure of the stage of economic development, which any country has reached (2).
Now a days, new methods in concrete technology are essential and in Sudan these have already been introduced by using admixtures, which can be defined as chemically compound fluid added to mix preferably with mixing water.

Concrete performance will be improved by the appropriate curing in the early stages. Current practice includes water curing and application of sealing materials. Among these methods, spraying liquid membrane-forming curing compound is the most common method used in pavement and other concrete structures.

Compared with its wide use, the standards to evaluate and apply curing compounds are not good. Department of Transportation (DOT) of different states used different methods to modify these standards and developed their own standards.

According to American Institute (ACI) committee 308-92, “curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early stages so that desired properties may develop”. The objectives of curing are to prevent the loss of moisture from concrete and maintain a favorable temperature in concrete for a certain time. Hydration under this condition will continue. The hydration and strength will cease when the temperature is below 140°F. The rate of reaction approximately doubles for each 10°C (3).

Curing is recognized as a very important process to achieve durable concrete. Theoretically, if the w/c ratio is 0.42 or greater, the hydration can complete without adding more water to concrete mixture (4). In this case, no curing is needed. However, in practice, the moisture may be reduced below the need for proper hydration by evaporation. Evaporation of moisture results in lower strength; the excessive evaporation from the surface of fresh concrete can also cause plastic cracking. Therefore, the
curing measure must be taken to add more water or prevent water from evaporating. Curing is taken until the desired properties are achieved.

In low w/c ratio concrete, the self-desiccation will happen in concrete. External water is needed in this case, but the permeability of low w/c ratio paste is low; it is hard to penetrate far into the paste.

As mentioned above, when the temperature is below 14°F, the hydration stops. Concrete temperatures below 50°F (10°C), are unfavorable for the development of early strength. Below 40°F the development of early strength is greatly retarded and at 32°F little strength develops.

According to ACI committee 308, there are two types of curing methods:

(1) Continuous or frequent application of water through water ponding, fogging, steam, or saturated material.

(2) The prevention of excessive loss of water from the concrete by means of sealing materials such as plastic sheets, or by application of a membrane-forming curing compound to the freshly placed concrete.

(1) Water curing:

- Ponding or immersion:
  As soon as the concrete is sufficiently hardened to withstand marring, the surface of concrete should be kept wet by ponding (5). This method is seldom used, but it is the most effective method. Sudden release of pond water should be avoided and applying time is important in ponding concrete surface.

- Fog spray or sprinkling:
  This method is really effective when adequate water is available and temperature is well above freezing. Before applying intermittent sprinkling, we must be sure that concrete does not dry out (4).
• Coverings hold water:
  As soon as the concrete is sufficiently hardened to prevent surface
damage and after the surface has been thoroughly wetted, the
surface of concrete should be protected by these coverings. These
coverings include Burlap, cotton mats, sand and sawdust, and
straw. Burlap is widely used. As these materials will dry out,
periodic moistening is required.

(2) Sealing materials:

• Plastic film:
The plastic film should be placed over the wet surface as soon as
possible, and cover all exposed surface. Plastic film can be used to cover
more complex shape because of its flexibility. The plastic film should be
continuous. Otherwise, the efficiency will be reduced.

• Reinforced paper:
  Includes two layers of Kraft paper cemented together with
bituminous adhesive and reinforced with fiber. It should comply
with American Society for Testing and Materials (6).

• Liquid membrane-forming curing compound:
  Curing compound is wildly used in the field. The membrane-
forming curing compounds should meet ASTM standards. In
addition to the ASTM standard, curing compounds should be
applied after surface water has disappeared. Membrane coating
must be maintained for the duration of the full-specified curing
period. The membrane should be protected by suitable means if
traffic is unavoidable. Any damage to the membrane during the
curing period should be immediately repaired at the original
specified rate of coverage.
1.3 OBJECT AND SCOPE:

The objective of this project is to study the behaviour of concrete under different curing conditions at hot areas, with emphasis on the strength and shrinkage.

The investigation includes the effectiveness of using different curing techniques in the hot and dry environment of Sudan where temperature fluctuates between (9-50) °C. It is also intended to study some parameters related to the properties of concrete to achieve better understanding of the behaviour of concrete.

The scope of this experimental investigation is intended to consider some of the effects of Curing on concrete strength and to deal with maintaining satisfactory moisture content in the concrete. These aims can be through ponding, sprays, saturated cover material or membrane sheeting.
CHAPTER TWO

CONCRETE MATERIALS & PROPERTIES

2.1 GENERAL:

Concrete is mainly composed of three materials, namely, cement, sand and aggregate. Additional material known, as an admixture is sometimes added to modify certain of its properties. Cement is the chemically active constituent but its reactivity is only brought into effect on mixing with water. The aggregate plays no part in chemical reactions, but it is rather a filler material with good resistance to volume changes which take place within the concrete after mixing, and it improves the durability of the concrete.

The properties of concrete in its fresh and hardened states can show large variations depending on the type, quality and proportions of the constituents.

2.2 CEMENT:

2.2.1 GENERAL:

Cement can be defined as a material with adhesive and cohesive properties, which make it capable of bonding mineral fragments into a
compact whole, useful for construction purposes. The meaning of cement is restricted to the bonding material used with stone, sand, bricks, building blocks etc….

**2.2.2 MANUFACTURE OF PORTLAND CEMENT:**

Portland cement (p.c) is made primarily from calcareous materials such as limestone and chalk and from Alumna and silica, which are found as clay or shells.

First intimately grinding and mixing the raw constituents in certain proportions, burning this mixture at a very high temperature to produce clinker, and then grinding it into powder form, produce cement. Since the clinker is formed by diffusion between the solid particles, intimate mixing of ingredients is essential if uniform cement is to be produced.

Different types of Portland cement are obtained by varying the proportions of the raw materials, the temperature of burning and the fineness of grinding. Gypsum is added to control the setting of the cement; certain additives may also be introduced for producing special cements, such as, calcium chloride, which is added in the manufacture of extra-rapid hardening cement.

**2.2.3 CHEMICAL COMPOSITION OF PORTLAND CEMENTS:**

As a result of the chemical changes which take place within the kiln, several compounds are formed in the resulting cement although only four are generally considered to be important. These are shown in Table (1).

The two silicates, $C_3S$ and $C_2S$, which are the most stable of these compounds, together form 70 to 80 percent of the constituents in the
cement and contribute most to the physical properties of concrete. When water is added to cement, C₃S begins to hydrate rapidly, making development of the early strength, particularly during the first 14 days. In contrast C₂S, which hydrates slowly, is mainly responsible for the development of strength after about 7 days.

Exceptionally low C₃A content contributes to the increased resistance to sulphate attack of sulphate-resistance cement.

C₄AF is of less importance than the other three compounds when considering the properties of hardened cement mortars or concrete (7).

In addition to the main compounds the minor compounds such as Mgo, SiO₂, Mn₂O₃, K₂O and Na₂O, they usually amount to not more than a few percentage of the weight of cement, the K₂O and Na₂O (known as the alkalis).

Table (1)

Main chemical compounds of Portland cements

<table>
<thead>
<tr>
<th>Name of Compounds</th>
<th>Chemical Composition</th>
<th>Usual Abreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tri calcium silicate</td>
<td>3CaO.SiO₂</td>
<td>C₃S</td>
</tr>
<tr>
<td>Di calcium silicate</td>
<td>2CaO.SiO₂</td>
<td>C₂S</td>
</tr>
<tr>
<td>Tri calcium alluminate</td>
<td>3CaO.Al₂O₃</td>
<td>C₃A</td>
</tr>
<tr>
<td>Tetra calcium alumino ferrite</td>
<td>4CaO.Al₂O₃.Fe₂O₃</td>
<td>C₃AF</td>
</tr>
</tbody>
</table>

2.2.4 PHYSICAL PROPERTIES OF CEMENT:

2.2.4.1 FINENESS:
The reaction between the cement and water starts on the surface of the cement particles, and in consequence the greater the surface area of a given volume of cement the greater the hydration.

A fine cement will develop strength and generate heat more quickly than a coarse cement, also it improves the cohesiveness of fresh concrete and can be effective in reducing the risk of bleeding, but it increases the tendency for shrinkage cracking (7).

An increase in fineness increases the gypsum required for proper retardation as in finer cement, more $C_3A$ is available for early hydration, also greater the finer increased the water content of a paste and improve the workability in concrete (2).

2.2.4.2 SETTING:

Used to describe the stiffening of the cement paste, and setting refers to change from a fluid to rigid state.

The beginning of a noticeable stiffening in the cement paste is known as initial set, further stiffening occurs as the volume of gel increase and the stage at which this is complete and the final hardening process, responsible for its strength are known as the final set, the time from the addition of the water to the initial and final set are known as the setting times.

In practice, when mixes have a higher water content than that used in the standard tests, the cement paste takes a longer time to set, setting time is affected by cement composition and fineness, through its influence on the rate of hydration by the ambient temperature.
Two further phenomena are flash set and false set, when cement has insufficient gypsum to control the rapid reaction of C₃A with water. This reaction generates heat and causes the cement to stiffen within a few minutes after mixing and can be overcome by adding more water and reagitating the mix. A false set also produces a rapid stiffening of the paste but is not accompanied by excessive heat and can be overcome by remixing the paste without adding water. False set is also a result of inter-grinding gypsum with very hot clinker in the final stage of the manufacture of cement (7).

2.2.4.3 Soundness:

An excessive change in volume due to expansion of cement paste after setting, indicates that the cement is unsound and not suitable for the manufacture of concrete, cement can also be unsound due to the presence of MaO.

In general, the effect of using unsound cement has not been apparent for some considerable period of time, but usually apparent in cracking and disintegration of the surface of the concrete.

2.2.4.4 Hydration of cement:

The chemical reaction of cement and water, produces a very hard and strong binding medium for the aggregate particles in concrete, and is accompanied by the liberation of heat, the rate of hydration depending on the properties of silicate and alamine compounds, the cement fineness and the ambient conditions. Table (2) shows the heat associated with the hydration of each of the principal compounds of cement. Concrete is a poor liberator of heat of hydration and can have undesirable effects as a result of micro cracking of the binding medium, which leads to loss in
durability of concrete. Also it should be noted that it is the rate at which heat is generated and not the total liberated heat, which in practice affects the rise in temperature.
Table (2)

Heat of hydration of the main chemical compounds.

<table>
<thead>
<tr>
<th>Chemical Compounds</th>
<th>Heat of hydration cal g⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_3S$</td>
<td>120</td>
</tr>
<tr>
<td>$C_2S$</td>
<td>60</td>
</tr>
<tr>
<td>$C_3A$</td>
<td>525</td>
</tr>
<tr>
<td>$C_3AF$</td>
<td>100</td>
</tr>
</tbody>
</table>

2.2.5 Test On Physical Properties Of Cement:

(1) Consistence Of Cement:

The determination of initial and final setting time is done by using Vicar apparatus, with 10mm diameter plunger fitted into the needle holder. A paste trail of cement and water is placed in the mould, the plunger is then brought into contact with the top surface of the paste and released under the action of its own weight, which penetrate the paste. The depth of penetration depends on consistence, which is (5-7) mm from the bottom of the mould.

(2) Setting time:

Setting time is measured using Vicar apparatus with penetration attachments with needle $1\text{mm}^2$ x-sectional are used to penetrate a paste of standard consistence placed in aspecial mould. When the paste stiffens sufficiently from bottom initial set have taken place.
Initial set is the time elapsed since the mixing water was added to cement (for ordinary and rapid hardening cement minimum is 45 minutes).

Final set has taken place, when the needle is gently lowered to the surface of the paste made an impression on it and the setting is determined from the moment when water way added to cement (more than 1 hours for O.P.C than R.H.C for temperature (14-18) °C and humidity 90%). Figure (3) shows the apparatus for setting.

(3) Soundness Test:

Expansion may take place due delayed or slow hydration or other reaction of some compounds present; namely in the hardened cement free lime, magnesia and calcium sulphate and presence of Mao similar to co2.

Cement is said to be unsound when there is excess of free lime with hydrates very slowly and causes expansion.

If gypsum added to prevent flash set in excess amount that can react with C₃A during setting unsoundness will result (slow expansion).

Lechatelier apparatus can be used, which consists of brass cylinder, split along its generator, two indicators, the pointed end attached to it cylinder. It is placed on a glass plate filled with cement paste of standard consistence and covered with another glass plate. The whole assembly is then immersed at (18-20) °C for 24 hours then the distance between indicators measured and the mould is immersed in the water again and brought to the boil in 30 min; after boiling for 1 hour the mould is moved and after cooling the distance between indicators is again measured, the increase in
distance represents the expansion of cement, which is limited to 10 mm for p.c.

If it exceeds 10mm further test is made after it has been aerated for 7 days, which some times may hydrate, then Lechatelier test is repeated and the expansion of aerated cement must not exceed 5mm. (cement failing to satisfy one of these test should not be used). Lechatelier test detects soundness due to free time only. Figure (4) shows apparatus for soundness.

(4) **Strength of Cement:**

The strength of hardened cement is the most required factor in structural use. The strength of mortar or concrete depends on the cohesion of the cement paste, in addition to the aggregate test indicate direct tension and compression and flexure.

Pure tension is rather difficult to apply, so that the result of such test shows a fairly large scatter. Tensile strength is less than compression strength. The tension test for one day strength of hardening p.c (1:3) cement sand mortar with a water content of 8% by weight of solid mixture moulded into a briquette shape. The briquette is moulded in a standard manner cured for 24 hours at temperature between 18-20 °C and humidity of 90% and tested in direct tension the pull being applied through special jaws one day of R.H.P.C of 2.1MN/m² An average value of briquettes.

For compression test of cement by using mortar (1:3), mortar is used with 10% of water using 70.6mm cubes. The cubes are de molded after 24 hours and further cured in water untill tested. Also the average value of strength for 3 cubes is given in the Table (3) in
BS 12:1991. Cements of class 32.5 and 42.5 are each subdivided into two subclasses, one denoted by the letter R, is rapid hardening cements, and the other denoted by N, is ordinary Portland cement (8).

### Table (3) Compressive Strength Requirements of Cement: According to BS 12:1991

<table>
<thead>
<tr>
<th>Class</th>
<th>Minimum strength, Mpa</th>
<th>Maximum strength, Mpa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At the age of:</td>
<td>At the age of 28 days</td>
</tr>
<tr>
<td></td>
<td>2 days</td>
<td>7 days</td>
</tr>
<tr>
<td>32.5N</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>32.5 R</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>42.5N</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>42.5 R</td>
<td>20</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 2.2.6 Types Of Cement:

The different types of Portland cement are as follows:

**Ordinary Portland cement**: has a medium rate of hardening, making it suitable for most concrete work; also it has a low resistance to chemical attack.

**Rapid hardening Portland cement**: produces a much higher early strength and increased rate of hydration accompanied by a high rate of heat and this is unsuitable for large masses and used to advantage in cold weather.

**Low heat Portland cement**: has a limited use but is suitable for very large structures such as concrete dams. Its slow rate of hydration is accompanied by a much slower rate of increase in strength and resistance to chemical attack.

**Sulphate resistance Portland cement**: except for high resistance to sulphate attack, calcium chloride should not be used with it as it reduces its resistance to sulphate attack.
**Extra rapid hardening Portland cement:** is used when very high early strength is required or for concreting in cold conditions. Because of its rapid setting and hardening properties; the concrete should be placed and compacted within about 30 minutes of mixing.

**Ultra high early strength Portland cement:** it is much greater in fineness and larger gypsum content. It is suitable for reinforced and prestressed concrete work.

**White and Coloured Portland cement:** White cement requires special manufacturing methods and coloured cements are produced by inter grinding a chemically inert pigment with ordinary clinker. These cements are used for architectural purposes.

**Hydrophobic Portland cement:** Owing to the presence of a water repellant film around its grain, it can be stored under unfavourable conditions of humidity for along period of time without any significant deterioration.

**Waterproof and water repellant Portland cement:** produces impermeable fully compacted concrete than Portland cement.

**Air entraining Portland cement:** produces concrete with a greater resistance to frost attack. However, in practice, it is more advantageous to add on air entraining agent during mixing since its quantity can be varied to meet particular requirements.

**2.3 AGGREGATE:**

**2.3.1 General:**

Aggregate is much cheaper than cement, and maximum economy is obtained by using as much aggregate as possible in concrete. Its use also considerably improves both the volume stability and the durability of the resulting concrete. It has physical characteristics and in some cases its chemical composition is affected in both plastic and hardened states.
2.3.2 Physical Properties:

2.3.2.1 General:

The properties of aggregate known to have a significant effect on concrete behaviour are its strength, deformation, durability, toughness, hardness, volume change, porosity, specific gravity and chemical reactivity.

2.3.2.2 Strength:

Aggregate limits the attainable strength of concrete only when its compressive strength is less than or of the same order as the design strength of concrete.

Because of the irregular size and shape of aggregate particles a direct measurement of their strength properties is not possible. These are normally assessed from compressive strength tests on cylindrical specimens taken from the parent rock and from crushing value tests on the bulk aggregate (BS812).

The results of these tests for the strength properties of aggregate are only a guide to aggregate quality. However, strength may also be assessed from intensity of aggregate fracturing in ruptured concrete specimens.

2.3.2.3 Deformation:

It’s seldom considered in assessing its stability for concrete work, although it can easily be determined from compression tests on specimens from the parent rock. The deformation also plays an important part in the creep and shrinkage of the cement paste as it depends on their relative modulei of elasticity.

2.3.2.4 Toughness:

It is the resistance to failure by impact and this is normally determined from the aggregate impact tests (BS 812).
2.3.2.5 Hardness:

It’s the resistance of an aggregate to wear, and determined by abrasion (BS812).

2.3.2.6 Volume changes:

Moisture movement in aggregate obtained from sand-stones, some results in considerable shrinkage of concrete. If concrete is restrained this produces internal tensile stresses, possible tensile cracking and subsequent deterioration of the concrete.

2.3.2.7 Porosity:

It effects on the behaviour of both freshly mixed, and hardened concrete through its effect on the strength, water absorption and permeability of aggregate.

An aggregate with high porosity will tend to produce a less durable concrete.

Direct measurement of it is difficult and in practice a related property, namely, water absorption, is measured.

The water absorption is defined as the weight of water absorbed by a dry aggregate in reaching a saturated surface-dry state and is expressed as a percentage of the weight of the dry aggregate.

Absorption can vary depending on the way in which it is measured and also on the size of the aggregate particles.

The total moisture content is defined by the absorbed moisture plus the free or surface water. The water added to the mixer must be adjusted to take account of this if the free water content is to be kept constant and the required workability and strength of concrete maintained. The mix proportions are normally based on the weight of the aggregate in their saturated surface-dry condition.

Several methods for the determination of moisture content and absorption are described in BS812.
2.3.2.8 Specific gravity:

It is the ratio of unit weight of aggregate.

For the purposes of mix design the specific gravity on saturated and surface-dry basis is used, for most natural aggregates falls within the range (2.5-3.0), as such it is an important factor affecting the density of the resulting concrete.

2.3.3 Shape and surface texture:

It can affect the properties of concrete in both its plastic and hardened states, also its classification is in accordance with Tables (4) and (5) from BS812. However, shape may also be assessed by direct measurement of the aggregate particles determining the flakiness, elongation and angularity.

Angularity is expressed in terms of the angularity number, which is the difference between the solid volume of rounded aggregate particles after compaction in a standard cylinder, expressed as a percentage of the volume of cylinder, and the solid volume of the particular aggregate being investigated when compacted in a similar manner.

The angularity number ranges from zero for a perfectly rounded aggregate to about 12.
### TABLE (3) Shape of aggregate, BS812

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounded</td>
<td>Fully water-worn or completely shaped by attrition</td>
</tr>
<tr>
<td>Irregular</td>
<td>Naturally irregular, or partly shaped by attrition and having rounded edges</td>
</tr>
<tr>
<td>Angular</td>
<td>Possessing well-defined edges formed at the intersection of roughly planar faces</td>
</tr>
<tr>
<td>Flaky</td>
<td>Material of which the thickness is small relative to the other two dimensions</td>
</tr>
<tr>
<td>Elongated</td>
<td>Material, usually angular, in which the length is considerably larger than the other two dimensions</td>
</tr>
<tr>
<td>Flaky and elongated</td>
<td>Material having the length considerably larger than width, and the width considerably larger than the thickness</td>
</tr>
</tbody>
</table>

### TABLE (4) Surface texture of aggregate, BS812

<table>
<thead>
<tr>
<th>Surface texture</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glossy</td>
<td>Conchoidal fracture</td>
</tr>
<tr>
<td>Smooth</td>
<td>Water-worn, or smooth due to fracture laminated or fine-grained rock</td>
</tr>
<tr>
<td>Granular</td>
<td>Fracture showing more or less uniform rounded grains</td>
</tr>
<tr>
<td>Rough</td>
<td>Rough fracture of fine or medium-grained rock containing no easily visible crystalline constituents</td>
</tr>
<tr>
<td>Crystalline</td>
<td>Containing easily visible crystalline constituents</td>
</tr>
<tr>
<td>Honeycombed</td>
<td>With visible pores and cavities</td>
</tr>
</tbody>
</table>
2.3.4 Grading:

It defines the proportions of different sizes of the aggregate. The size of the aggregate particles normally used in concrete varies from 37.5 to 0.15 mm.

The (BS882) places aggregates in three main categories these are fine aggregate containing particles of which are smaller than 5.00mm, coarse aggregate containing particles of which are larger than 5.00mm and all in aggregate comprising both fine and coarse aggregate.

The grading of aggregate has effects on the workability and stability of Concrete mix design.

The grading of natural aggregate is generally required to be within the limits specified in (BS882), such that the fine aggregates are required to conform to any one of four standard grading zones. Also a sieve analysis is used for determining the grading of an aggregate (BS812). The aggregate sample must be air dried and the weight of material retained on each sieve should not exceed the specified maximum values as overloading will give erroneous results, and it can be performed by hand or machine.

Convenient visual assessment of the particle size distribution can be obtained from aggrading chart Figure (3), curve A represents continuously graded aggregate and curve B represents gap graded aggregate.

2.3.5 Types of Aggregate:

2.3.5.1 Heavy weight aggregate:

It provides an effective and economical use of concrete for radiation shielding by giving the necessary protection against X-rays, gamma-rays and neutrons, its difficult in mix and making it workable and not prone to segregation, with a density from (4000 to 5500) kg m⁻³.
2.3.5.2 Normal aggregate:

This aggregate is suitable for most purposes and produces concrete with a density from (2300 to 2500) kg m\(^{-3}\).

Aggregate, in particular sands and gravels should be washed to remove impurities such as clay and silt.

The properties of rock aggregate depend on their composition, grain size and texture. For example, granites have a low resistance because of the high coefficient of expansion of its quartz content. Sandstone aggregate generally produces concrete with a high drying shrinkage because of their high porosity.

2.3.5.3 Lightweight aggregate:

It can be applied in wide variety of concrete products such as reinforced, pre cast and pre stressed concrete, and concrete can have good fire resistance properties.

They are highly porous and absorb considerably greater quantities of water than do normal aggregates. For this reason they should normally be batched by volume owing to the large variations that can occur in their moisture content.

The methods for testing lightweight aggregates are described in (BS 3681).

2.4 Water:

Water used in concrete: in addition to reacting with cement and causing it to set and harden, it also facilitates mixing, placing and compacting of the fresh concrete. It is also used for washing the aggregate and for curing purposes.

In general water fit for drinking, such as tap water, is acceptable for mixing concrete, the impurities that have adverse effect when present in appreciable quantities include silt, clay, acids, alkalis and other salts, also
when used for washing aggregate can adversely affect strength and durability.

The use of sea water does not appear to have any adverse effect on the strength and durability of Portland cement concrete but it is known to cause surface dampness, efflorescence and staining should be avoided where concrete with a good appearance is required, also it increases the risk of corrosion of steel and its use in reinforced concrete is not recommended.

Water desirable is tested for both the nature and extent of contamination as prescribed in (BS3148).

Comparing the setting time may also assess the quality of water and soundness of cement pastes made with water of known quality and the water whose quality is suspected.

Water containing appreciable amounts of acid or organic materials should be avoided.

2.5Admixtures:

2.5.1General:

They are substances introduced into concrete mixes in order to alter or improve the properties of the fresh or hardened concrete or both. These changes are effected through the influence of the admixture on hydration, liberation of heat, formation of pores and development of the gel structure and it is used when the required modifications can not be made by varying the composition and proportion of the basic constituent materials, or when the admixture can produce the required effects more economically.

Since they also have detrimental effects, their suitability for a particular concrete should be carefully evaluated before use, based on knowledge of their main active ingredients, on available performance data and on trial mixes.
The specific effects of an admixture type on cement, water-cement ratio, ambient conditions and its dosage, should also be evaluated. The quantity of admixture used is both small and critical. The required dose must be carefully determined and administered.

The air-entraining, accelerating, retarding and water-reducing admixtures are most commonly used.

2.5.2 Types of admixtures:

(1) Air-entraining agents:
They improve the durability of concrete; in particular its resistance to the effects of frost and de-icing salts. The beneficial effects of entrained air are produced in two ways, first, by disrupting the continuity of capillary pores and thus reducing the permeability of concrete, and second, by reducing the internal stresses caused by the expansion of water on freezing; also they improve the workability and cohesiveness of fresh concrete and tend to reduce bleeding and segregation and results in some reduction in concrete strength.

The amount of it depends on the type of cement; mix proportions, ambient temperature and the method for determining the amount is covered (BS1881: Part 2).

(2) Accelerating agents:
These can be divided into two groups, setting accelerators, and setting and hardening accelerators. The first are alkaline solutions, which can reduce the setting time and have adverse effect on final strength. For this reason it is not recommended to be used when the final strength is an important factor. The second calcium chloride which increases the rate of both setting and early strength development and has adverse effect such as increased
drying shrinkage, reduced resistance to sulphate attack and increased risk of corrosion of steel reinforcement.

It may usefully be employed for concreting in winter conditions, for emergency repair work or where early removal of formwork is required.

(3) Retarders:
They are used in hot areas where high temperature can reduce the normal setting and hardening time and are based on lingo sulphonic.
As slightly reduced water content with corresponding increase in final strength, also tend to increase cohesiveness and reduce bleeding although drying shrinkage may be increased.

(4) Water reducers or plasterers:
These are based on lingo sulphonic. Their effect is to increase dispersion of cement particles causing a reduction in the viscosity of the concrete and also increase the workability.

2.6 Properties of Fresh Concrete:

2.6.1 General:
Fresh concrete is a mixture of water, cement, aggregate and admixture. After mixing, operations such as mixing, transporting, placing, compacting and finishing, can considerably affect the properties of hardened concrete.

It is important that the constituent materials remain uniformly distributed within the concrete mass during the various stages of its handling and that full compaction is to be achieved. When either of these conditions is not satisfied the properties of the resulting hardened concrete, for example, strength and durability, are adversely affected.

The characteristics of fresh concrete, which affect full compaction, are its consistency, mobility and compactability.
2.6.2 Workability:

For practical purposes it generally implies the ease with which a concrete mix can be handled from the mixer to its finally compacted shape.

The three main characteristics of the property are consistence, mobility and compactability.

Consistence is a measure of wetness or fluidity. Mobility defines the ease with which a mix can flow into and completely fill the formwork or mould, and compactability is the ease with which a given mix can be fully compacted, all the trapped air being removed.

In this context the required workability of a mix depends not only on the characteristics and relative proportions of the constituent material but also on the methods employed for conveyance and compaction, the size, shape and surface roughness of formwork or mould and the quantity and spacing of reinforcement.

2.6.2.1 Measurement of Workability:

Three tests widely used for measuring workability are the slump, compacting factor and V-B consist. These tests are shown in Figure (6).

These standard tests are described in detail in (BS 1881: Part 2), also recommended in (CP 110:Part 1).

1) Slump Test:
Chapman in the United States developed this test in 1913. A 300 mm high concrete cone, prepared under standard conditions (BS 1881: Part 2) is allowed to subside and the slump or reduction in height of the cone is taken to be a measure of workability.

The test primarily measures the consistency of plastic concrete and although it is difficult to make any significant relationship between slump and workability as defined previously, it’s suitable for detecting changes in workability.
Although the test is suitable for quality-control purposes it should be remembered that it is generally considered to be unsuitable for mix design since concrete required varying amounts of work for compaction could have similar numerical values of slump.

The sensitivity and reliability of the test for detecting variation in mixes of different workabilities is largely dependent on its sensitivity to consistency.

The three types of slump usually observed are true slump, shear slump and collapse slump, as shown in Figure (7). A true slump is observed with cohesive and rich mixes, and collapse slump is usually associated with very wet mixes and generally indicative of poor quality concrete and most frequently results from segregation of its constituent materials. Shear slump occurs more often in leaner mixes than in rich ones and indicates lack of cohesion, which is generally associated with harsh mixes.

The standard slump apparatus is only suitable for concretes in which the maximum aggregate size does not exceed 37.5mm. It should be noted that the value of slump changes with time after mixing owing to normal hydration processes and evaporation of some of the free water, and it’s desirable that tests are performed within a fixed period time.

(2) Compacting Factor Test:

This test, developed in the United Kingdom by Glanville et al. (1947), measures the degree of compaction for a standard amount of work and thus offers a direct and reasonably reliable assessment of the workability and it is described in (BS1881: Part2).

The test requires measurement of the weights of the partially and fully compacted concrete and the ratio of the partially compacted weight to the fully compacted weight, which is always less than 1, is known as the compacting factor, and it range between 0.8 to 0.92.
The sensitivity of the compacting factor is reduced outside the normal range of workability and is generally unsatisfactory for compacting factors greater than 0.92.

**3) V-B Consist-o-meter Test:**
This test was developed in Sweden by Bahrner (1940). Although generally regarded as a test primarily used in research, its potential is now more widely acknowledged in industry and the test is gradually being accepted.

In this test the time taken to transform, by means of vibration, standard cone of concrete to a compacted flat cylinder mass is recorded, this is known as the V-B time, in seconds, and is stated to the nearest 0.5 s. Moreover, the test is sensitive to changes in consistency, mobility and compactiability and therefore a reasonable correlation between the test results and site assessment of workability can be expected.

The test is suitable for a wide range of mixes and, unlike the slump and compacting factor tests; it is sensitive to variations in workability of very dry and also air-entrained concretes.

It is more sensitive to variation in aggregate characteristics such as shape and surface texture.

**2.6.2.2 Factors affecting Workability:**

**1) Cement and Water:**
The change in workability for a given change in water-cement ratio is greater the water content is changed than when only the cement content is changed.

For a given mix, the workability of the concrete decreases as the fineness of the cement increases as a result of the increased specific surface, this effect being more marked in rich mixture.
It should also be noted that the finer cements improve the cohesiveness of the mix, also the variations in quality of water suitable for making concrete have no significant effect on workability.

(2) Admixtures:
The principal admixtures affecting improvement in the workability of concrete are water-reducing and air-entraining agents. The extent of the increase in workability is dependent on the type and amount of admixture used and the general characteristics of the fresh concrete.

Workability admixtures are used to increase workability while the mix proportions are kept constant or to reduce the water content while maintaining constant workability.

Air-entraining agents are by far the most commonly used workability admixtures because they also improve both the cohesiveness of the plastic concrete and the frost resistance of the resulting hardened concrete.

(3) Aggregate:

For given cement, water and aggregate contents, the total surface area of the aggregate mainly influences the workability of concrete, and the maximum size, grading and shape of the aggregate govern the surface area.

Workability decreases as the specific surface increases, since this requires a greater proportion of cement paste to wet the aggregate particles.

It follows that, all other conditions being equal, the workability will be increased when the maximum size of aggregate increases, the aggregate particles become rounded or the overall grading becomes coarser.

It can be seen that aggregate with a smooth texture results in higher workability than aggregates with a rough texture.

Absorption characteristics of aggregate also affect workability where dry or partially dry aggregates are used.
(4) Ambient Conditions:
Environmental factors that may cause a reduction in workability are temperature, humidity and wind velocity.
For a given concrete, changes in workability are governed by the rate of hydration of the cement and the rate of evaporation of water.
An increase in the temperature speeds up the rate at which water is used for hydration as well as it is loss through evaporation.
Like wise wind velocity and humidity influence the workability as they affect the rate of evaporation.
It is worth remembering that in practice these factors depend on weather conditions and cannot be controlled.

(5) Time:
The time that elapses between mixing concrete and its final compaction depends on the general conditions of work such as the distance between the mixer and the point of placing, site procedures and general management.
The associated reduction in workability is a direct result of loss of free water with time through evaporation, aggregate absorption and initial hydration of the cement.
The rate of loss of workability is affected by certain characteristics of the constituent materials, for example, hydration and heat development characteristics of the cement, initial moisture content and porosity of the aggregate.
For practical purposes, loss of workability assumes importance when concrete becomes so unworkable that it cannot be effectively compacted, with the result that its strength and other properties become adversely affected.
Corrective measures frequently taken to ensure that concrete at the time of placing has the desired workability are either an initial increase in the
water content or an increase in the water content with further mixing shortly before the concrete is discharged. When this results in water content greater than that originally intended, some reduction in strength and durability of the hardened concrete is to be expected unless the cement content is increased accordingly

2.6.3 Stability:

2.6.3.1 General:

Apart from being sufficiently workable, fresh concrete should have a composition such that its constituent materials remain uniformly distributed in the concrete during both the period between mixing and compaction and the period following compaction before the concrete stiffens. Because of differences in the particle size and specific gravities of the constituent materials there exists a natural tendency for them to separate. Concrete capable of maintaining the required uniformity is said to be stable and most cohesive mixes belong to this category.

For an unstable mix the extent to which the constituent material will separate depends on the methods of transportation, placing and compaction.

The two most common features of an unstable concrete are segregation and bleeding.

(1) Segregation:

When there is a significant tendency for the large and fine particles in a mix to become separated, segregation is said to have occurred, and the less cohesive the mix the greater the tendency for segregation to occur. Segregation is governed by the total specific surface of the solid particles including cement and the quantity of mortar in the mix.
As far as possible, conditions conducive to segregation such as jolting of concrete during transportation, dropping from excessive heights during placing and over-vibration during compaction should be avoided. These features are not only unsightly but also adversely affect strength, durability and other properties of the hardened concrete.

There are no specific rules for suspecting possible segregation but after some experience of mixing and handling concrete it’s not difficult to recognise mixes where this is likely to occur.

(2) Bleeding:
Separation of water from a mix is known bleeding.
During compaction and until the cement paste has hardened there is a natural tendency for the solid particles, depending on size and specific gravity, to exhibit a downward movement, where the consistency of a mix is such that it is unable to hold all its water some of it is gradually displaced and rises to the surface.
In general, the concrete strength tends to increase with depth below the surface; also the water, which reaches the top surface, presents the most serious practical problem. If it’s not removed, the concrete at and near the top surface will be much weaker and less durable than the remainder of the concrete.
The risk of bleeding increases when concrete is compacted by vibration although this may be minimised by using a correctly designed mix and ensuring that the concrete is not over-vibrated.
The type of cement employed is also important, the tendency for bleeding to occur is decreasing, as the fineness of cement or its alkaline and tricalcium illuminate content increases.
Air-entrainment provides another very effective means of controlling bleeding.
2.6.4 Vibration:
As reinforced concrete becomes a common construction material and thinner sections were consequently designed, constructors found it even more difficult to tamp fairly dry mixes in position. Now adays, methods of compaction other than tamping are used to consolidate the stiffened concrete. Machines are developed to impact vibratory motion to concrete. Internal surface formed tables are the most common known types of vibrators.
Vibration of fresh concrete at the time of casting is very important. Vibration has been proved to be the best means by which concrete particles are drawn into a compact mass. However it is not quite uncommon that concreting may occur near- by a source of vibration which might continue for whole or part of setting time.

2.7 Properties of Hardened Concrete:

2.7.1 General:

The important properties of hardened concrete are strength, deformation under load, durability, permeability and shrinkage.

In general, strength is considered to be the most important property and the quality of concrete is often judged by its strength.

Since the properties of concrete change with age and environment it is not possible to attribute absolute values to any of them and it is important to be able to judge the quality of concrete in site.

Laboratory tests give only an indication of the properties which concrete may have in the actual structure depending on the workmanship on site.

For these reasons it is important to be able to judge the quality of concrete in site.
2.7.2 Strength:

Is defined as the maximum load (stress) it can carry. Concrete is comparatively brittle material, which is relatively weak in tension.

2.7.2.1 Types of strength:

(1) Compressive strength:

Its taken as the maximum compressive load it can carry per unit area. Concrete structures, except for road pavements, are normally designed on the basis that concrete is capable of resisters only compression. The tension being carried by steel reinforcement.

In the united kingdom a 150 mm cube is commonly used for determining the compressive strength, the standard methods being described in (BS 1881: Part 3) which requires that the test specimen should be cured in water at $20 \pm 1^\circ c$ and tested immediately after it has been removed from the curing tank.

(2) Tensile Strength:

Its importance appears in the design of concrete roads and runways. Concrete members are also required to withstand tensile stresses resulting from any restraint to contraction due to drying or temperature variation.

(a) Of these the split cylinder test is the simplest and most widely used. This test is described in (BS 1881:Part 4) and entails diametrically loading a cylinder in compression along its entire length. This form of loading induced tensile stresses over the loaded diametrical plane and the cylinder splits along the loaded diameter.

The magnitude of the induced tensile stress $S$ at failure is given by:

$$S = \frac{2P}{\pi Ld}$$

Where $P$ is the maximum applied load, and $L$ and $d$ are the cylinder length and diameter respectively.
(b) The flexural strength of concrete is another indirect tensile value and tested for a simply supported plain concrete beam. The beam is loaded at its third points. The resulting bending moment induces compressive and tensile stresses in the top and bottom of the beam respectively. The beam fails in tension and the flexural strength (modulus of rupture) $S$ is defined by:

$$S = \frac{PL}{bd^2}$$

Where $P$ is the maximum applied load, $L$ the distance between the supports, and $b$ and $d$ are the beam breadth and depth respectively at the section at which failure occurs.

The tensile strength of concrete is usually taken to be about one-tenth of its compressive strength.

2.7.2.2 Factors influencing strength:

Influence of constituent materials:

(a) Cement:

The influence of cement on concrete strength, for given mix proportions, is determined by its fineness and chemical composition through the processes of hydration. The gain in concrete strength as the fineness of its cement particles increase is shown in Figure (8).

The role of the chemical composition of cement in the development of concrete strength can best be appreciated by studying Table (6), and Figures (9) and (10).

It is apparent that cements containing a relatively high percentage of tri calcium silicate ($\text{C}_3\text{S}$) gain strength much more rapidly than those rich in di calcium silicate ($\text{C}_2\text{S}$), as shown in Figure (9).
Table (6) Chemical composition of Various Portland cements with similar fineness

<table>
<thead>
<tr>
<th>Cement</th>
<th>Compound composition (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_3S$</td>
</tr>
<tr>
<td>A</td>
<td>55</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>43</td>
</tr>
<tr>
<td>D</td>
<td>35</td>
</tr>
</tbody>
</table>

(b) Water:
Concrete mix containing the minimum amount of water required for complete hydration of its cement, if it could be fully compacted, would develop the maximum attainable strength at any given age.

(Water – cement) ratio of approximately 0.25 (by weight) is required for full hydration of the cement but with this water content a normal concrete mix would be extremely dry and virtually impossible to compact.
A partially compacted mix will contain a large percentage of voids and the concrete strength will drop.
In practice a concrete mix is designed with a view to obtaining maximum compaction under the given conditions.
As ratio of water to cement increases the strength decreases in a manner similar to that illustrated in Figure (11).

(c) Aggregate:
Rounded aggregates will develop weaker bond between the aggregate and matrix than an angular or irregular aggregate with a rough surface texture.
Aggregate shape and surface texture affect the tensile strength more than the compressive strength.
The aggregate size also affects the strength. For given mix proportions, the concrete strength decreases as the maximum size of aggregate is increased, on the other hand, for a given cement content and workability this effect is opposed by a reduction in the water requirement for the larger aggregate.

The optimum maximum aggregate size varies with richness of the mix, being smaller for the richer mixes, and generally lies between (10 and 50) mm.

Concrete of given strength can be produced with aggregates having a variety of different grading provided due care is exercised to ensure that segregation does not occur. The suitability of a grading to some extent depends on the shape and texture of aggregate.

(d) Admixtures:

The two type of admixtures most widely used are accelerators and air-entraining agents.

Calcium chloride is the most commonly used accelerator; it increases the rate of development of concrete strength, particularly at early age and is used in concreting in winter.

Because the effectiveness varies with the type of cement, curing conditions and design strength, an accurate estimate of the increase in strength with calcium chloride is not possible.

When using an air-entraining agent, for a constant (water-cement) ratio, the greater the percentage of air entrained the greater the loss in strength; however, (water–cement) ratio can be reduced while maintaining the required workability.

(e) Influence Of The Methods Of Preparation:

When concrete materials are not adequately mixed into a consistent and homogeneous mass, some poor quality concrete is inevitable.
Even when a concrete is adequately mixed care must be taken during placing and compaction to minimise the probability of the occurrence of bleeding, segregation and honey-combing all of which can result in batches of poor quality concrete.

A properly designed concrete mix is one that does not demand the impossible from site operatives before it can be fully compacted in its final location.

(f) Influence of curing:

In order to obtain good results, curing must follow concrete casting. Curing is the procedure used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into concrete.

The object of curing is to keep concrete saturated, or as nearly saturated, Evaporation of water from concrete soon after placing depends on the temperature and relative humidity of the surrounding air and on the velocity of wind which affects a change of air over the surface of the concrete.

The partial methods of curing are:

(1) Pounding or immersion.
(2) Wet coverings (moist earth, sand, and sawdust).
(3) Springing or fogging.
(4) Water proof covering.
(5) Curing compounds (waxes, resins, chlorinated rubber and solvents of high volatility).

These are applied as coating using spray equipment immediately after disappearance of water.

For Steam curing, curing period should be as practically possible, for lean mixes long weeks and shorter periods for rich mixes, heavy constructions should be cured for minimum of 7 days. The lack of proper curing affects
the quality of concrete in both the plastic and hardened states. Concrete hardens and gains strength because of chemical relation between Portland cement and water. If concrete dries prematurely, no relation will happen between cement and water i.e. no water, no hydration, no strength gain. The temperature at which concrete is cured has an important bearing on the development of its strength with time.

The rate of gain in strength of concrete made with ordinary Portland cement increases with increase in concrete temperature at early ages Figure (12). Although at later ages the concrete made and cured at high temperature during the placing and setting of concrete can adversely affect the development of its strength.

On the other hand, when the initial temperature is lower than the subsequent curing temperature, then higher temperatures during final curing result in significantly higher strengths Figure (13).

A possible explanation for this behaviour is that a rapid initial hydration appears to form a gel structure of an inferior quality and this adversely affects concrete strength at later ages.

Figure (14) shows that both the increased hydration due to improvements in initial curing (moist or water curing at normal temperature) and the condition of the concrete at the time of testing have a significant effect on the final apparent strength of concrete.

### 2.7.3 Deformation:

#### 2.7.3.1 General:

Concrete deforms under loading and the deformation increase with the applied load is commonly known as elastic deformation, Figure (15).

Concrete continues to deform with time, under constant load; this is known as time- dependent deformation or creep, Figure (16). Finally deformation occurs due to concrete shrinkage.
(1) Elastic Deformation:
Unlike that for metals, the load-deformation relationship for concrete subjected to a continuously increasing load is non-linear in character. The non-linearity is most marked at higher loads. When the applied loads are released the concrete does not fully recover its original shape. See Figure (15).
Under repeated loading and unloading the deformation at a given load level increases, although at a decreasing rate, with each successive cycle. All these characteristics of concrete indicate that it should be considered as a quasi-elastic material when computing the elastic constants, namely, the modulus of elasticity and Poisson’s ratio.
It is only for simplicity and convenience that the elastic modulus is assumed to be constant in both concrete technology and the design of concrete structures.
(a) Crack:
When concrete dries, it contracts or shrinks, and when it is wetted again, it expands. These volume changes in moisture content are inherent characteristic of hydraulic cement concrete. It is the change in moisture content of the cement paste that causes the shrinkage or swelling of concrete, while the aggregate provides an internal restraint, which significantly reduces the magnitude of these volume changes.
Crack depends on the potential contraction and extensibility of concrete, the restraint in the form of reinforcing bars or a gradient of stress increase extensibility in that it allows concrete to develop strain well beyond that corresponding to maximum stress.
Thus time has a two-fold effects: the strength increase thereby reducing the cracking, but on the other hand the modulus of elasticity also increase, so that the stress induced by a given shrinkage become greater. Also the creep relief decreases with age so that the cracking tendency become
greater. The most important factor of cracking is the (water/cement) ratio of the mix, because its increase tends to increase shrinkage and at the same time reduce the strength of the concrete. Also increase in the cement content increases shrinkage and therefore the cracking tendency but the effect on strength is positive.

Why does concrete crack due to shrinkage? If the shrinkage of concrete caused by drying could take place without any restraint, the concrete would not crack, however, in a structure the concrete is always subject to some degree of restraint by either the foundation or another part of the structure or by the reinforcing steel embedded in the concrete. This combination of shrinkage and restraint develops tensile stress. When this tensile stress reaches the tensile strength, the concrete will crack. Another type of restraint is developed by the difference in shrinkage at the surface and interior of a concrete member, especially at early ages. Since the drying shrinkage is always larger at the exposed surface, the interior portion of the member restrains the shrinkage of the surface concrete, thus, developing tensile stresses. This may cause surface cracking, which are cracks that do not penetrate deep into the concrete. These surface cracks may with time penetrate deeper into the concrete member as the interior portion of the concrete is subject to additional drying (9).

The use of admixtures may influence the cracking tendency. Readers may allow more shrinkage to be accommodated in the form of plastic shrinkage and also probably increase the extensibility of concrete and therefore reduce cracking. On the other hand, if concrete has attained rigidity too rapidly it cannot be accommodated and there would be plastic shrinkage and having low strength, cracks.
(b) Shrinkage:

I) Introduction:

Shrinkage of concrete is caused by the settlement of solids and the loss of free water from the plastic concrete (plastic shrinkage), by the chemical combination of cement with water (autogenous shrinkage) and by the drying of concrete (drying shrinkage). Where movement of the concrete is restrained, shrinkage will produce tensile stresses within the concrete which may cause cracking. Most concrete structures experience a gradual drying out and the effects of drying shrinkage should be minimized by the provision of movement joints and careful attention at the design stage (7).

II) Plastic shrinkage:

Shrinkage, which takes place before concrete has set, is known as plastic shrinkage. This occurs as a result of the loss of free water and the settlement of solids in the mix. Since evaporation usually accounts for a large proportion of the water losses, plastic shrinkage is most common in slab construction and is characterized by the appearance of surface cracks, which can extend quite deeply into the concrete. Preventive measures are usually based on methods of reducing water loss. This can be achieved in practice by covering concrete with wet Hessian or polythene sheets or by spraying it with a membrane-curing compound (7).

III) Autogenous Shrinkage:

In a set concrete, as hydration proceeds, a net decrease in volume occurs since the hydrated cement gel has a smaller volume than the sum of the cement and water constituents. As hydration continues in an environment where the water content is constant, such as inside a large mass of concrete, this decrease in volume of the cement paste results in shrinkage of the concrete. This is known as Autogenous shrinkage because, as the name implies, it is self-produced by the hydration of
cement. However, when concrete is cured under water, the water taken up by cement during hydration is replaced from outside and furthermore the gel particles absorb more water, thus producing a net increase in volume of the cement paste and an expansion of the concrete. On the other hand if concrete is kept in dry atmosphere water is drawn out of the hydrated gel and additional shrinkage, known as drying shrinkage, occurs. Several factors influence the rate and magnitude of Autogenous shrinkage. These include the chemical composition of cement, the initial water content, temperature and time. The autogenous shrinkage can be up to 100*10^{-6} of which 75 per cent occurs within the first three months (7).

IV) Drying shrinkage:
When a hardened concrete, cured in water, is allowed to dry it first looses water from its voids and capillary pores and starts to shrink during further drying when water is drawn out of its cement gel. This is known as drying shrinkage and in some concretes it can be greater than 1500*10^{-6}, but a value in excess of 800*10^{-6} is usually considered to be undesirable for most structural applications. After an initial high rate of drying shrinkage concrete continues to shrink. For practical purposes, it may be assumed that for small sections 50 per cent of the total shrinkage occurs in the first year.

When concrete, which has been allowed to dry out, is subjected to a moist environment, it swells. However, the magnitude of this expansion is not sufficient to recover all the initial shrinkage even after prolonged immersion in water. A test procedure for determining shrinkage is described in (BS 1881:part 5).
Several factors influence the overall drying shrinkage of concrete. These include the type, content and proportion of the constituent materials of concrete, the size and shape of the concrete structure, the amount and
distribution of reinforcement and the relative humidity of the environment.

In general, drying shrinkage is directly proportional to the water-cement ratio and inversely proportional to the (aggregate-cement) ratio (see Figure (17)). Because of the interaction of the effects of aggregate-cement and water-cement ratios, it is possible to have a rich mix with a low water-cement ratio giving higher shrinkage than a leaner mix with a higher water-cement ratio.

For a given water-cement ratio shrinkage increases with increasing cement content.

Since the aggregate exerts a restraining influence on shrinkage the maximum aggregate content compatible with other required properties is desirable. When the aggregate itself is susceptible to large moisture movement, this can aggravate shrinkage (or swelling) of the concrete and my result in excessive cracking and large deflections of beams and slabs.

The composition and fineness of cement can also affect its shrinkage characteristics. In general, shrinkage increases as the specific surface area of cement increases, Table (7), although this effect is slight and is usually overshadowed by the effects of water-cement ratio and aggregate-cement ratio. Increases in diecalkium silicate (C₂S) content and ignition loss usually result in increased shrinkage. Tricalcium alminate’s (C₃A) appears to influence the expansion of concrete under moist conditions. Nevertheless, the shrinkage characteristics of concrete cannot reliably be predicted from an analysis of the chemical composition of its cement. In general, admixtures, which reduce the water requirement of concrete without affecting its other properties, will reduce it. Air-entrainment itself has no significant influence on shrinkage. Calcium chloride may considerably increase shrinkage. The size and shape of a specimen affects the rate of moisture movement in concrete and this in turn influences the
rate of volume change. Since drying begins from the surface, it follows that the greater the surface area per unit mass, the greater the rate of shrinkage. For a given shape, the initial rate of shrinkage is greater for small specimens although there will be little difference in the ultimate drying shrinkage, if this stage is ever reached for very large masses of concrete.

The shrinkage of reinforced concrete is less than of plain concrete owing to the restraint developed by the reinforcement. This restraint induces tensile stresses in the concrete, which may be large enough to cause cracking (7). The relative humidity and temperature of the environment have a significant effect on both the rate and magnitude of shrinkage in as much as they affect the movement of water in concrete. The duration of initial moist curing has little effect on ultimate shrinkage although it affects the initial rate of shrinkage (7).
TABLE (7)
Influence of the fineness of cement on drying shrinkage of concrete
(Aggregate-cement ratio) after 500 days, Bennett and Loat (1970)

<table>
<thead>
<tr>
<th>Moist curing (days)</th>
<th>Specific surface area of cement (m^2 kg^-1)</th>
<th>Drying shrinkage 10^-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>W/c ratio=0.375</td>
</tr>
<tr>
<td>1</td>
<td>280</td>
<td>460</td>
</tr>
<tr>
<td>-</td>
<td>490</td>
<td>540</td>
</tr>
<tr>
<td>-</td>
<td>740</td>
<td>540</td>
</tr>
<tr>
<td>28</td>
<td>280</td>
<td>380</td>
</tr>
<tr>
<td>-</td>
<td>490</td>
<td>460</td>
</tr>
<tr>
<td>-</td>
<td>740</td>
<td>420</td>
</tr>
</tbody>
</table>

Also the relation between the weight of water lost and shrinkage is positive, the properties of cement do not increase shrinkage of concrete made with normal or lightweight aggregate. Added calcium chloride increases shrinkage by varying amounts, generally between 10 and 50 per cent, probably because a finer gel is produced and possibly because of greater carbonation of the more mature specimens with calcium chloride. Other admixtures vary in the amount of increase in shrinkage, but the percentage influence on shrinkage is constant for a given admixture. With many plastic zing agents that allow a reduction in the water content of the mix, the net result on shrinkage is negligible.

Shrinkage takes place over long periods, some movement has been observed even after 28 years, prolonged moist curing delays the advent of shrinkage, but the effect of curing on the magnitude of shrinkage is small though rather complex. The greater the quantity of hydrated cement the smaller is the volume of unhydrated cement grains which restrain the shrinkage. Thus prolonged curing leads to greater shrinkage but the paste
becomes stronger with age and is able to attain a longer fraction of its
drink tendency without cracking. The magnitude of shrinkage is
largely independent of the rate of drying except that transferring concrete
directly from water to a very low humidity can lead to fracture. Also
shrinkage can be determined using a measuring frame fitted with a
micrometer gauge or a dial gauge reading to $10^{-5}$ strain (7).

(c) Creep:

Creep affects strains and deflections and often also stress
distribution, but the effects vary with the type of structure.
In plain concrete it does not affect the strength although under very high
stresses Creep hastens the approach of the limiting strain at which failure
takes place. This applies only when the sustained load is above 85 or 90
percent of the rapidly applied static ultimate load, but in a simply
supported reinforced concrete beam, it is not significant.
In reinforced concrete columns, creep results in a gradual transfer of load
from the concrete to the reinforcement. Once the steel yields any increase
in load is taken by the concrete, so that the full strength of both is
developed before failure takes place. In eccentrically loaded columns,
creep increases the deflection and can lead to buckling.
Another instance of the adverse effects of Creep influence on the stability
of the structure due to increase in deformation, likewise is seen in very
tall buildings, where differential Creep may cause movement and
 cracking of partitions and also structural effects in beams and slabs.
Creep relieves the compressive stress by rapid rise in temperature so that
the remaining compression disappears as soon as some cooling has taken
place. On further cooling of concrete, tensile stresses develop and since
the rate of Creep is reduced with age, cracking occur even before the
temperature has dropped to initial value. For this reasons the rise in
temperature in the interior of large concrete mass must be controlled by
the use of low heat cement. Low cement content, pre cooling of mix in gradients, limiting the height of concrete lifts, and cooling of concrete by circulating refrigerated water through a net work of pipes embedded in the concrete mass, also the influence of temperature on Creep have become of increased interest in connection with the use of concrete in the construction of pre stressed concrete nuclear pressure vessels but the problem is of significance also in other types of structures, e.g. bridges. These differences in rate persist at least for 15 months under load. Figure (18) illustrates the programs of Creep. This behaviour is believed to be due to adsorption of water from the surface of the gel so that gradually the gel itself becomes the sole phase subject to molecular diffusion shear flow, consequently the rate of Creep decreases. The behaviour over a wide range of temperatures is shown in Figure (19). Freezing produces a higher initial rate of Creep but it quickly drops to zero (2).

**2.7.4 Durability:**

**2.7.4.1 General:**

It can be defined, as resistance of concrete to deterioration resulting from external and internal causes. The external causes include the effects of environmental and service conditions to which concrete is subjected, such as weathering, chemical reactions and wear. The internal causes are the effects of interaction between the constituent materials, such as alkali-aggregate reaction, volume changes, absorption and permeability.

In order to produce a durable concrete, care should be taken to select suitable constituent materials, also the mix contains adequate quantities of materials in proportions suitable for producing a homogeneous and fully compacted concrete mass.
2.7.4.2 External Causes:

(1) Weathering:

Deterioration of concrete by weathering is usually brought about by the disruptive action of alternate freezing and thawing of free water within the concrete and expansion and contraction of the concrete, under restraint, resulting from variations in temperature and alternate wetting and drying. The resistance of concrete to freezing and thawing can be improved by lowest possible water-cement ratio compatible with sufficient workability for placing and compacting into a homogeneous mass. Durability can be further improved by using air-entrainment. The type of cement used has no effect about the rate of hydration can be beneficial. Damage to a structure resulting from the expansion and contraction of concrete should be minimised by providing joints, which permit such movement without restraint.

(2) Chemical Attack:

Concrete has a low resistance to chemical attack; there are several chemical agents, which react with concrete but two forms of attack, are most common, namely, leaching and sulphate attack. Chemical agents essentially react with certain compounds of the hardened cement paste and the resistance of concrete to it depends largely on the type of cement used. The resistance to it improves with increased Impermeability.

(a) Leaching:

Calcium hydroxide, in hardened cement paste dissolves readily in water, particularly in the presence of carbon dioxide. Thus, if concrete in service absorbs or permits the passage of water through it the calcium hydroxide in the hardened cement is removed, or leached out.
Homogenous and dense concrete with low permeability reduces the effectiveness of the leaching action; care should be taken in selecting and proportioning the constituent materials in curing the concrete to ensure that shrinkage cracking is minimized.

(b) Sulphate attack:

Most sulphate solutions react with the calcium hydroxide, and calcium sulphaaluminate compounds. The intensity and rate of sulphate attack depends on a number of factors such as type of sulphate, its concentration and the continuity of its supply to concrete. Also the type of cement is a very important factor and the resistance of various cements to sulphate attack increases in the following order: ordinary and rapid-hardening, Portland blast furnace and low-heat Portland cement, sulphate-resisting Portland and super sulphate cement and finally high alumina cement.

To protect concrete from sulphate attack every effort should be made to produce an impermeable concrete, requirements being given in (CP110: Part1).

(c) Wear:

The main causes of wear of concrete are the cavitations effects of fast-moving water, abrasive material in water, wind blasting and attrition and impact of traffic.

These cavities are usually filled with water vapour charged with extraordinarily high energy and repeated contact with the concrete surface results in the formation of pits and holes, known as cavitation erosion.

In general, the resistance of concrete to erosion and abrasion increases with increase in strength.
2.7.4.3 Internal Causes:

(a) Alkali –Aggregate Reaction:

Certain aggregates can react chemically with the alkaline content to form alkaline silica gel. When this happens these aggregates expand or swell resulting in cracking and disintegration of concrete. The minimum alkaline content of cement required to produce enough alkaline silica gel to damage concrete is 0.6 per cent of the soda equivalent. Moisture is necessary for the alkali-aggregate reaction and increased temperature accelerates this reaction.

(b) Volume Changes:

The chemical combination of water and cement and the subsequent drying of concrete, variations in temperature and alternate wetting and drying all are responsible for volume changes. When a change in volume is resisted by internal or external forces this can produce cracking, the presence of cracks in concrete reduces its resistance to the action of leaching, corrosion of reinforcement, attack by sulphates and other chemicals, alkali-aggregate reaction and freezing and thawing.

Volume changes can be minimised by using suitable constituent materials and mix proportions having due regard to size of structure. Adequate moist curing is also essential to minimise the effects of any volume changes.

(c) Permeability And Absorption:

It refers to the ease with which water can pass through the concrete. Absorption may be defined as the ability of concrete to draw water into its voids, low permeability is an important requirement for hydraulic structure, and in some cases water tightness of concrete may be considered to be more significant than strength, although, other
conditions being equal. Concrete of low permeability will also be strong and durable.
Concrete of low permeability can be obtained by suitable selection of its constituent materials and their proportions followed by careful placing, compaction and curing. In general for a fully compacted concrete, the permeability decreases with decreasing water-cement ratio. Permeability is affected by both the fineness and the chemical composition of cement; segregation of the constituent materials during placing can adversely affect the impermeability of concrete.
CHAPTER THREE

CONCRETING IN HOT WEATHER

3.1 GENERAL:

It’s pointed out in the report of ACI committee 305 (10) that once the damage is caused to the concrete by hot weather, this can ever be fully alleviated. Therefore, appropriate prevention, such as keeping the concrete temperature low, suitable wet curing etc, is the best way to obtain uniformly good concrete quality in construction in hot weather, this means also that sound engineering judgment is necessary to select the most appropriate compromise between quality, economy and practicality under the prevailing circumstances. The precautions to be observed strictly depend as much on the type of construction and the experience of the local industry in dealing with the weather as on the weather itself, namely on temperature, relative humidity and wind velocity.

The previously discussed undesirable effects of hot weather on concrete properties are summarized below following the report of A.C.I committee 305 (10).

Effects on fresh concrete:

(a) Increased water demand.

(b) Increased rate of slump loss and corresponding tendency to added water at job site.

(c) Increased rate of setting resulting in greater difference with handling, finishing and curing, and increased possibility cold joints.

(d) Increased difficulty in controlling entrained air content.

Effects on hardened concrete:

(a) Decreased strength resulting from higher water demand Increased temperature-level.
(b) Decreased uniformity of surface appearance.
(c) Decreased durability.
(d) Increased tendency for drying shrinkage and differential thermal cracking.

Additional problems to be considered in hot weather concreting:

(a) The use of finely ground cements with increased rate of hydration.
(b) The use of concrete with high compressive strength requiring higher cements content.
(c) The design of thin concrete sections with correspondingly greater percentage of steel.
(d) The increased size of concrete delivery trucks.
(e) Requirements for movement of large volumes of low slump concrete over greater horizontal and vertical distances.
(f) Increased use of concrete pumping equipment.
(g) Increased of using convey or belts.
(h) Economic necessity to continue work in extremely hot weather.
(i) The use of shrinkage –compensating cement.

3.2 EFFECTS OF TEMPERATURE ON HYDRATION AND SETTING OF CEMENT:

The aggregate particles in concrete are embedded in and held together by the matrix of fresh or hardened paste. They’re fore most of the technically important properties of concrete, such as workability, strength, shrinkage, and permeability.
The setting and hardening processes are the results of series of simultaneous and consecutive reactions between water and the constituents of Portland cement.

The measurement of heat evolution is suitable for the investigation of the early stages of hydration (11). During short period when cement and water are brought into contact at room temperature and during the time of mixing, relatively rapid chemical reactions occur primarily between the Tribalism aluminates \((\text{Ca}_3\text{A})\) of cement and water, the water rapidly becomes saturated with calcium hydroxide produced by hydrolysis of a late as well as of calcium aluminates by \(\text{CaSO}_4\cdot2\text{H}_2\text{O}\) from the gypsum and by other compounds, then the gypsum reacts with calcium aluminates to form solid calcium aluminates sulfate hydrates.

A large fraction of the \(\text{SO}_3\) in cement paste reacts in the first few minutes. The Alkalis in cement clinker also dissolve rapidly, and persist as sulfates or hydroxides; the extent of hydration of the other main constituents of Portland cement is relatively very small (12). Within five minutes, as the protective coating thickens, the rate of reaction subsides to a low level, this period during which the paste normally remains plastic is called dormant period, normally lasts (40 to 120) minutes depending on the characteristics of cement.

The fraction of cement used up in initial reactions is small, perhaps 1%, subsequently, a period of accelerating chemical Reaction sets in, again, which usually lasts about three hours, after this time the paste gradually loses its plasticity, if it’s prepared according to standard test methods, of passes through arbitrarily defined degrees of stiffness known as initial set and final set.

Another factor that can cause rapid setting is elevated temperature; the higher the curing temperature, the faster are the reactions between cement and water, and consequently the shorter becomes the setting time.
The effect of curing temperature on the rate of hydration is illustrated in Figure (20).

After final test, chemical reactions continue with diminishing rate until one or more of conditions necessary to reactions are lacking, this stage of hydration is called the hardening process, during which the predominant reaction is the continuing hydration of the calcium silicates, the decrease in rate is the result of two effects: the surface area of unhydrated cement particles decreases as the smaller particles become completely hydrated and the larger particles become smaller, secondly layer of cash gel forms on the surfaces of the cement particles, slowing down further reaction by forming a protective coating(13,14).

Measurements indicate that the kinetics of hydration are influenced by several factors, including the fineness and composition of the cement, temperature and water –cement ratios and admixtures (12).

The kinetics is important not only because it controls the quantity of the hydration products at early age but also because it influence to a certain extent the quality of hydration as well (15).

The hydration products framed, say during curing at 50 °C, do not differ greatly from those formed at 20 °C, the elevated temperature modifies somewhat the morphology of the calcium silicate hydrates, but this effect does not appear to be large enough to have a major effect on the final strength.

Thus the main reason for the relatively low final strengths of the steam-cured and other accelerated concretes seems to be mechanical the rapid hydration may produce higher final porosity and more micro cracking in the gel (16).

It is customary to talk about initial setting, which is basically the beginning of the stiffening of fresh cement paste, and final setting, which is market by the disappearance of plasticity. The setting process should
not start too early because the ready mixed concrete should remain in plastic condition for a sufficient period to permit satisfactory compaction and finishing after transporting and placing. On the other hand, a too long setting process is also undesirable because this would cause a use-less delay in the strength development after the finishing on the two concepts initial setting has far higher significance.

The standard initial set of commercial Portland cements ranges approximately from (2 to 4) hours, and final set from (5 to 8) hours. Under special conditions however, such as construction at high temperature a concrete may set early. Figure (20) demonstrates this accelerating effect of elevated temperature not only qualitatively but also quantitatively (17).

3.2.1 EFFECTS OF USING RETARDERS AND PLASTICIZERS:

One-way to counter react, the rapid setting caused by elevated temperature is to use a set retarding admixture, or retarded in concrete, the retarding delays the setting and hardening of concrete, increases workability and also the early strength development of concrete is retarded up to an age of 3 days. By retarding the setting time, concrete could be mixed away from site and transported long distances without danger of setting (2).

The effects of such admixture depend on a number of factors including temperature, certain admixtures increase the time of initial setting or reduce the amount of water needed for a given initial slump but such concrete may stiffen faster, some times too fast even with a cement and an admixture that separately meet all specifications because the readily soluble (SO₃) content in the cement is low or because its high C₃A content. Such excessive, usually called abnormal slump loss could be reduced to normal loss by:

(1) Changing or elimination the admixture.
(2) Changing the cement.
(3) The addition of extra gypsum to the cement, but this is impractical on a job site (18).

In the case of a relatively high $SO_3$ content, the cement paste or concrete containing water-reducing admixture may undergo an admixture set which is equivalent to false set caused by the precipitation of gypsum (8).

The resulting excessive slump loss may be reduced by:

- Changing or eliminating the admixture;
- Changing the cement;
- The delayed addition of the admixture;
- Increasing the dosage of the admixture;
- On site addition of the super elasticized;
- Intensive mixing or remixing of the concrete;(9)

Despite the availability of these remedial actions, its much better to check the compatibility of the job cement and the job admixture before the construction starts a simplified way for this is the use of the test method of A.S.T.M.C359 for the determination of false set in Ottawa sand mortar. A more complete answer can be obtained from concrete trial mixes with the job materials in the proper amounts as described in (A.S.T.M.C494).

Plasticizing admixture improves workability and if required reduces the amount of water required to maintain a given workability or consistency, but was negligible effect on setting properties of concrete. At early age, the Plasticzed shows a higher rate of strength development then the ordinary concrete, but at later age (after 28 days) the rate of increase is about the same in both, also it is increase the slump by about 100mm without an increase in (w/c) ratio with no decrease in strength and this can be an advantage, finally the apparent benefits of water reduction are
the improvements in concrete properties that result from a reduction in (w/c) ratio, primarily, increased strength and durability.

3.2.1.1 CHEMICAL RETARDATION OF THE SETTING:

Powders of cement clinkers, especially those of high Fe₂O₃: Al₂O₃ ratios show rapid but not flash set; yet the final set may be slow. This undesirable situation can be eliminated by the addition of gypsum (CaSO₄·2H₂O), gypsum retards the initial set properly and it speeds up the final set.

Many physical properties of hardened paste are affected by the quantity of gypsum:
(1) Compressive strength.
(2) Contraction on drying.
(3) Heat liberation.
(4) Delayed expansion.

If the gypsum is excess above the traditional “optimum” amount, it may produce unfavorable results on the cement properties when cured at standard temperature, such as slow strength and delayed expansion (19).

In any case, the basic rule appears to be that the maximum “optimum” amount of gypsum permissible in the cement should be such that just no or very little unreacted gypsum shall remain in the specimen of paste at 24 hours (19), this rule may help develop an optimum gypsum content specifically for cement to be used for concreting in hot areas.

3.2.1.2 RETEMPERING:

Another method for counter balancing the stiffening of the cement paste or concrete is to soften consistency during or after delivery by the addition of a suitable material. Such material can be water or water reducing admixture, or cement paste, or any combination of these, however, the undesirable effect of high temperature starts before that because
the quantity of mixing water needed for a specific consistency (slump) increases with an increase in temperature (20).

It’s desirable to compensate for expected slump loss by using an initial slump higher than the required final slump when prolonged delays are encountered. Experimental results (Figure 21) have shown that the retempering of a concrete will still result in a higher total (water-cement) ratio when starting with a higher initial slump value than when starting with a lower slump (21). Retempering with water is not the best practice either since it increases the original water cement ratio, thus reducing the quality of concrete. Better results have been obtained by retempering with superplastics it was reported by Remake Krishnan (22) that the slump of retempered concrete both with and without superplastics decreased about equally with time, never the less large increase in slump can be maintained for several hours by repeated retempering with superelasticized Figure (21) which does not reduce the concrete strength Figure (21).

Another form of retempering is when the appropriate water-cement ratio is added to the stiffening concrete to regain the specific slump of the decrease in the aggregate content, that is, relative increases in the paste content, increase the slump.

The opposite of excessive slump loss, that is the too slow stiffening, can also be a problem because it may result in low strengths, at least in the early ages, and in a delay in the construction (23).
3.3 EFFECTS OF CURING TEMPERATURE ON CONCRETE STRENGTH:

Curing is important factor which affect the strength of concrete, the curing is the name given to procedures used for promoting the hydration of concrete, the object of curing is to keep concrete saturated or as nearly saturated as possible. If however the water filled space in fresh concrete is greater than the volume filled by the products of hydration, greater hydration will lead to a higher strength and lower permeability.

The different means of curing will be given here as the actual products used vary widely, depending on:

1. The condition on the site.
2. The size of member.
3. The slump of the member.
4. The position of the member.

When concrete specimens are cured at various constant temperatures, this has a double effect on their strengths. On the one hand, a higher curing temperature increases the strength at early ages, which is
expected but, on the other hand, it hinders the strength development later on, which is unexpected.

In more general terms, the ultimate strength of cement paste is frequently lowered by factors that increase the early strength (24), the term 'ultimate strength' is used as the strength obtained after a very long duration of moist curing. Such an explanation offered by Verbech and Helmuth for the effect of a temperature increase states that the higher the rate of hardening, the shorter should become the time of diffusion of hydration products, that is the shorter should become the diffusion distance from the surface of the cement grain. Therefore the higher concentration of the cement gel should be in the zone immediately surrounding the hydration cement grain (25). Experimental evidence is available to demonstrate that this relatively impermeable rim around reduce significantly the ultimate degree of hydration. This, in turn, is detrimental to the final strength (22). Another line of evidence for the same argument comes from the recognition that the micro porosity of steam cured cement paste is usually lower than that of a paste of hardened at conventional temperatures for 28 days (26).

The essence of this mechanism is that a change in the rate of hardening paste affects adversely the final strength and the cause of the rate of change is secondary. At most, the specific rate of hardening increase in the (water-cement) ratio increases the early strengths relatively more than the strength at 28 days or later, the assumed mechanism for this is that the lower the (water-cement) ratio, the smaller the original capillary pore control in the paste, therefore, the more intensively the early strength develops. On the other hand, this higher rate of hardening results in a denser cement gel which in turn, is increasingly detrimental to further hydration at later ages, that is, the deceleration is intensified this hypothetical mechanism gains direct support from the
pore size versus water-cement ratio measurements by Verbech and Helmluh (25).

3.3.1 CURING TEMPERATURE AND COMPRESSIVE STRENGTH:

The size of the temperatures of curing temperature on the compressive strength of Portland cement concrete can be summarized as follows:

(1) The magnitude of the effect of temperature on the strength development depends not only on the magnitude of temperature but also on the type of cement used. When calcium chloride is added to the concrete, the adverse effect of high curing temperature on the late strengths is reduced.

(2) The primary reason for high early strengths with increasing temperatures is that the rate of chemical reactions between the cement and water, that is, hydration, increases with increasing temperature.

(3) When concrete is cast and maintained at a given temperature for several hours and then cured at 70 °F (22 °C), the higher the initial maintained temperature (within limits), the lower the 28 days strength as illustrated in Figure (23). The relative strengths at 28 days are maintained at later ages.

(4) It may be generalized from paragraph above that if the curing temperature is higher than the initial temperature of casting, the resulting 28 days strength will be higher than that for a curing temperature equal to, or lower than, the initial temperature (27).

(5) It appears that there is a curing temperature during the early life of the concrete which may be considered optimum with regard to the strength at later ages, or more strictly, at comparable degrees of hydration, this temperature is influenced some what by the cement type, for A.S.T.M.
type (I) and (II) Portland cement this temperature is 55deg.F. (13°C) For type (III) its 40 °F (4°C) (20).

(6)The 28days concrete strength can be increased by using suitable water-reducing admixtures, this beneficial effect is more pronounced when the concrete is mixed at 90 to 95 °F (22 to 25 °C) (28).

3.3.2 FLEXURAL STRENGTH OF CONCRETE:

Flexural strength at early ages increased with increase in temperature. At later ages, the effect of temperature was reversed, thus concrete made and cured at the lower temperatures showed highest flexural strength at 1 year, the optimum temperatures for flexural strength development appear to be the same as those for compressive strength (20).

3.3.4 SHRINKAGE AND CREEP AND CRACK:

Although shrinkage and creep of the hardened concrete are only indirectly related to its strength, it is worth while to say a few words about them here because both of these deformation mechanisms are based on drying and other moisture movements (29), and also because they play an important role in the cracking of concrete (30), (31).

3.3.4.1 SHRINKAGE:

Shrinkage of concrete is caused by the settlement of solids and the loss of free water from the plastic concrete (plastic shrinkage), by the chemical combination of cement with water (autogenous shrinkage) and by the drying of concrete (drying shrinkage). Where movement of the concrete is restrained, shrinkage will produce tensile stresses within the concrete which may cause cracking. Most concrete structures experience a gradual drying out and the effects of drying shrinkage should be minimized by the provision of movement joints and careful attention to detail at the design stage (7).
At higher temperature the drying process tends to be faster, therefore. The shrinkage is also likely to be more intensive. It’s not possible at present to provide more exact relationship between temperature and shrinkage of the hardened concrete because the rate as well as the extent of drying are affected not only by the temperature but also by the movement of the air (wind), relative humidity, and several other external factors (32).

3.3.4.2 CREEP:

Creep affects strains and deflections and often also stress distribution, but the effects vary with the type of structure.

In plain concrete it does not affect the strength although under very high stresses Creep hastens the approach of the limiting strain at which failure takes place. This applies only when the sustained load is above 85 or 90 percent of the rapidly applied static ultimate load, but in a simply supported reinforced concrete beam is not significant, deflection increase for case in design.

In reinforced concrete columns, Creep results in a gradual transfer of load from the concrete to the reinforcement. Once the steel yields any increase in load taken by the concrete, so that the full strength of both is developed before failure takes place. In eccentrically loaded columns, Creep increases the deflection and can lead to buckling.

Another instance of the adverse effects of Creep in the influence on the stability of the structure due to increase in deformation, like wise in very tall building differential Creep may cause movement and cracking of partitions and also structural effects in beams and slabs.

Creep relieves the compressive stress by rapid rise in temperature so that the remaining compression disappears as soon as some cooling has taken place. On further cooling of concrete, tensile stresses develop and since the rate of Creep is reduced with age, cracking occur even before
the temperature has dropped to initial value, as shown in Figure (23). For this reason the rise in temperature in the interior of large concrete mass must be controlled by the use of low head cement, low cement content, pre cooling of mix in gradients, limiting the height of concrete lifts, and cooling of concrete by circulating refrigerated water through a network of pipes embedded in the concrete mass. Also the influence of temperature on Creep has become of increased interest in connection with the use of concrete in the construction of prestressed concrete nuclear pressure vessels but the problem is of significance also in other types of structures, e. g bridges. These differences in rate persist at least for 15 months under load. Figure (24) illustrates the programs of Creep. This behavior is believed to be due to adsorption of water from the surface of the gel so that gradually the gel itself becomes the sole phase subject to molecular diffusion shear flow, consequently the rate of Creep decreases the behavior over a wide range of temperatures as shown in Figure (25).

Freezing produces a higher initial rate of Creep but it quickly drops to zero (2).

3.3.4.3 CRACK:

Cracks in concrete structures can indicated major structural problems and can mar the appearance of monolithic construction. They can expose reinforcing steel to oxygen and moisture and make the steel more susceptible to corrosion,

As subsequent drop in temperature will produce potential contraction; thus placing in hot weather means a high cracking tendency, also steep thermal or moisture gradients produce severe internal restraints and thus represent a high cracking tendency. A method to detect cracks uses strips of electro conductive paint applied to the surface of concrete. Cracking is indicated by the interruption of the circuit owing to temperature rise followed by burning of the paint. Cracks as small as
0.1µm can be detected. Also width of crack measured by alight dependent resister, which responds to the reduction in the amount of light reflected when a crack is present. Also when stated earlier, the most effective means of preventing cracking is by keeping down the rate of evaporation of water from the surface of concrete, it recommended that the value of 1Kg/m3 should not be exceeded. It should be remembered that evaporation is increased when the temperature of the concrete is much higher than the ambient temperature, also evaporation of water from concrete soon after placing depends on the relative humidity, velocity of wind, and difference between the temperature of concrete and air. The influencing of these factors can be obtained from Figures (26), (27), (28), (29). Under such case plastic cracking can occur even if the relative humidity of the air is high.

In general the actual loss of water depends on the surface and volume ratio of specimens.

3.4 Hot Weather Precautions:

The necessary precautions start at the production of the concrete, its consists essentially of the suitable proportioning of the concrete and the control of the temperature of the fresh concrete, this temperature control through the temperature of the ingredients of concrete can only be done at the point of mixing, various means to lower the temperature of concrete as mixed include (2):

(a) Using cold mixing water, even to the point of adding large quantities of ice.

(b) Avoiding, as far as practicable the use of hot cement.

(c) Insulating water supply lines and tanks, or at least painting exposed portions white to reflect heat.
(d) Cooling coarse aggregate with refrigerated water by sprinkling or in undating with cold air blasts.

(e) Insulating mixer drums or cooling then with sprays or wet burlap coverings.

(f) Shading materials and facilities not otherwise protected from the heat.

(g) Working only at night.

To obtain lower placing temperature for mass concrete, different combinations of these measures may be required; use of ice from mixing is completed. Excessively long mixing times should be avoided (23).

Where truck mixtures are used, the procedure is recommended by the U.S Bureau of Reclamation (2). The period between batching and placing, and the delivery of the concrete should be kept to an absolute minimum. One way to achieve this is to locate the batching facilities, or at least the cement batching facilities near the job site, another possibility is to coordinate the dispatching of trucks with the rate of placement to avoid waiting with concrete when elapsed time from batching to placement is so long as to result in significant slump loss, an appropriate remembering of the concrete is necessary. The proper placement of concrete in hot weather is similar to the proper placement procedure in other weathers, although there are several difference too. For instance, there are specifications that require that concrete as deposited shall have a temperature no higher than a stipulated value usually 80 deg F (27 deg C) for concrete to be placed in hot arid climate, and 90 deg .F (33 deg C) for most other concrete. For most concrete dams, temperature studies have shown the need for considerably lower maximum placing temperature. Such placing temperatures, a slow as 50 deg F at Glen Canyon Dam, are established to control cracking in the structure .On some other jobs in
desert regions, concrete placing has been prohibited by the U.S, also the concrete must be placed, compacted and finished promptly on arrival. This means that placement should be continued in batch volume of manageable size, and equipment for placing and compacting the concrete should have adequate capacity to perform its function efficiently so there will be no delays in the work, the curing of the exposed surfaces should start promptly after finishing the concrete, continuous water curing is much to be preferred for most concrete work .The need is the greatest during the first few hours, when there is to be flat walls up, or the roof on, to provide a wind break or shade or both (10). Lack of proper curing usually causes cracking in the concrete, as such cracks are difficult to close once they have occurred, although some times revibration may be helpful.

Specimens should be prepared and tests on fresh concrete samples should be conducted without delay so that they will be as representative as possible of the concrete in the structure.

Particular attention should be given to the protection and curing of molded specimens for strength tests, leaving these specimens exposed to hot sun, wind or dry air can seriously affect test results.

It’s some times desirable to conduct tests such as slump and air content more frequently than for normal conditions, other tests may also be indicated. Examples of such additional tests are temperature of the materials and the concrete, initial and final setting time, slump loss, temperature, and relative humidity at the forms.

The proper inspection of concrete placed in hot weather should be directed to insure compliance with these additional precautions and
procedures, competent inspection will anticipate the need for such things as spraying of forms and subgrad, the need for ice as a portion of the mixing water, providing sun shades, wind screens, or fogging and the like, and minimizing delays in placement and curing.
CHAPTER FOUR

MIX DESIGN AND EXPERIMENTAL PROGRAM

4.1 General:

For the past 100 years, cement and concrete have been the basic materials for building and civil engineering and the amounts used are a direct measure of the stage which any country has reached in its economic and social development (33).

Mix design can thus be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notably consistence, strength, and durability (2).

4.2 Specifications:

In the past, the specification for concrete prescribed the proportions of cement, and fine and coarse aggregate, certain traditional mixes produced but, owing to the variability of the mix ingredients, concretes having fixed cement–aggregate proportions and a given workability vary widely in strength, for this reason, the minimum compressive strength was later included in many specifications.

It may not be possible to achieve an adequate strength using the prescribed mix proportions, this is why, some times, and clauses prescribing the grading of aggregate and the shape of the particles have been added to the other requirements. However, the distributions of natural aggregates in many countries are such that these restrictions are often uneconomic. Further more, compliance with the requirements of strength, mix proportions, and aggregate shape and grading leaves no
room for economies in the mix design, and makes progress in the production of cheap and satisfactory mixes on the basis of a study of the properties of concrete impossible.

The limiting values may cover a range of properties, the more usual ones are:

(1) Minimum compressive strength necessary from structural considerations.

(2) Maximum (water/cement) ratio and or maximum cement content.

(3) Maximum cement content to avoid cracking due to the temperature cycle in mass concrete

(4) Maximum cement content to avoid shrinkage cracking.

(5) Minimum density for gravity.

(6) Workability.

(7) (aggregate/cement) ratio.

4.3 The Process of Mix Design:

4.3.1 GENERAL:

For instance, in the excellent method of the American concrete institute, the water content in kilograms per cubic metre or pounds per cubic yard of concrete is determined direct from the workability of the mix instead of being found in directly from the (water/cement) and (aggregate/cement) ratios, as is done in the method of Road Note NO.4.

It’s not surprising, therefore, that in order to obtain a satisfactory mix we not only have to calculate or estimate the proportions of the available materials but must also make trial mixes, the properties of these mixes are checked and adjustments in the mix proportions are made, further trial mixes are made until a fully satisfactory mix is obtained.

Furthermore, a laboratory trail mix does not provide the final answer even when the moisture condition of aggregate is taken into account. Only a mix made and used on the site can guarantee that all the
properties of the concrete are satisfactory in every detail for the particular job in hand.

To justify this statement two points may be mentioned, firstly the mixer used in the laboratory is generally different in type and performance from that employed on the site, secondly, the wall effect (arising from the surface to volume ratio) in laboratory test specimens is larger than in the full-size structure, so that the sand content of the mix as determined in the laboratory may be unnecessarily high.

Other factors, such as effects of handling, transporting, delay in placing, and weather conditions may also influence the properties of concrete on the site but these are generally secondary and necessitate no more than minor adjustments in the mix proportions during the progress of work (2).

4.3.2 Design of concrete mixes:

If the standard deviation of a mix design is known from earlier production in the concrete plant, the design strength i.e. mean strength of the normal distribution shall exceed the required grade strength for at least 1.64 $\beta \delta$ (\(\beta \delta\))

$$f_{cm} = f_{cg} + \beta \delta$$

where:

- $f_{cm}$: mean strength of the normal distribution in N/mm$^2$
- $f_{cg}$: grade strength i.e. nominal characteristic strength of the grade in N/mm$^2$.
- $\beta$: a constant depending upon the proportion of detective.
- $\delta$: standard deviation of the normal distribution in N/mm$^2$.

Without previous date of the standard deviation the margin between the specified grade strength and the design shall be at least
8N/mm². Special properties of mix must be tested according to standard methods of testing and evidence must be given that a satisfactory safety margin between the specified and the tested value exists (33).

Further steps can follow by other steps:

(1) Selection of (water/ cement) ratio certain strength are assumed at a (water/ cement) ratio of 0.5 and from the curve of strength at the desired age corresponding to w/c ratio of 0.5 and from the curve of strength versus w/c ratio, is selected for the desired design.

(2) The free - water content is determined from table depending on the maximum size of the aggregate to give a concrete with specified slump.

(3) The cement content is determined as follows: Cement content = (free water content) / (free water /cement) ratio.

This value must be checked against any maximum or minimum value that may be specified.

(4) The total aggregate content is determined.

This requires an estimate of the density of the fully compacted concrete.

The total aggregate content = \( T - CC - WFC \)

where:

\( T \) = the wet density of concrete (kg/m³)
\( CC \) = the cement content (kg/m³)
\( WFC \) = the free water content.

(5) Finally the fine and coarse aggregate contents are determined for the best proportion for fine aggregate (2).

4.4 EXPERIMENTAL PROGRAM AND TESTS RESULTS:

Experimental program in the laboratory consists of:

(1) Material tests.
(2) Mix design.
(3) Test specimens.
(4) Testing program.
(5) Data presentation and test results.

(1) **Material tests:**
These include the test of cement, fine aggregate and coarse aggregate.

(a) **Cement Tests:**

   Sea bulk ordinary Portland cement.

   (1) **Consistency:**
   Water content as percentage dry weight =30%.

   (2) **Soundness (Lechatelier):**
   The movement of the point=0.6mm<10mm.

   (3) **Setting time:**
   Initial setting time =1hr, 58 min>45min.
   Final setting time = 2hr, 55 min<10 hr.

   (4) **Strength:** 3 days strength=36.8>15N/mm².
   28days strength= 54.9>23 N/mm².

   The cement satisfies all conditions specified by (BS 12:1973).

(b) **Aggregate tests:**

(I) **Fine aggregate:**

*Sieve analysis:
Sieve analysis of fine aggregate when compared with British standard the sand was classified as zone no (7).
The result of sieve analysis is shown in Table (8) and Figure (30).

*Test of clay and dusty:
-Weight of sand 300g before washing.
-Weight of sand after washing and dried over 110 °C.
Dust +silt content =(4/300) ^100 =1.3%<3% the limit allowable by (BS 882).

(II) **Coarse aggregate:**

*Sieve analysis:
Using quartering method, sieve analysis of uncrushed aggregate when compared with British standard deals with the maximum size of aggregate of 20 mm, the results of sieve analysis are shown in Table (9) and Figure (31).

(2) Mix design:
Concrete mix has developed to produce 25N/mm² strength, using the basic materials described above. Mix proportions are given in Table (10).

(3) Test specimens:
(150°150°150 mm) concrete cubes have been used for uni-axial compression tests. Plain concrete beams (100°100°500 mm) have been adopted for modulus of rupture tests and (150°300 mm) concrete cylinder has been used for tensile specimens and testing was carried according to (BS 1881) for each mix batch.

(4) Testing program:
Eleven mix batches were studied, using different curing regimes. These include:

(1) Total immersion in water (Mix (A)).
(2) Application of water through saturated burlaps (Mix (B));
(3) Using liquid membrane curing compound (Mix (C));
(4) Using polythene (Mix (D)).
(5) Allowed to dry in air (without curing) (Mix (E)).
(6) Water curing for the first 3-days and then left dry (Mix (F));
(7) Water curing for the first 7-days and then left dry (Mix (G));
(8) Water curing for the first 14-days and then left dry (Mix (H));
(9) Water curing after 3-days of initial drying in air (Mix (I));
(10) Water curing after 7-days of initial drying in air (Mix (J));
(11) Water curing after 14-days of initial drying in air (Mix (K));

This is to study the effect of each of the above curing conditions on the strength of concrete. Specimens were tested at 3,7,14,28,90 days,
compressive, tensile and flexural strength have been recorded and studied.

(5) **Data presentation and Test Results:**

(a) **Compressive strength test:**

The compression specimens are cubes (150mm x 150mm x 150mm) made of steel or cast iron. The crushing strength is given by:

\[ S = \frac{P}{A} \]

where:

- S: compressive (crushing strength).
- P: load applied by testing machine.
- A: loaded area of cube face.

b) **Tensile strength test:**

In this test, a concrete cylinder 150 mm diameter and 300mm long is placed with its axis horizontal between the platens of attesting machine and the load is increased until failure by splitting along the vertical diameter takes place as shown in Figure (32) and the typical apparatus for tested shown in Figure (32).

If the load is applied along the generation, then an element on the vertical diameter of the cylinder is subjected to horizontal tensile stress.

\[ S = \frac{2P}{\pi Ld} \]

where:

- S: Tensile strength.
- P: compressive load on cylinder.
- L: length of cylinder.
- d: Diameter of cylinder.

c) **Flexural Strength Test:**
The flexural strength is measured by subjecting a plain concrete beam 100 mm by 100 mm by 500 mm to flexure shown in Figure (33). The modulus of rupture is maximum theoretical tensile stress reached in the bottom fiber of the test beam and the typical apparatus for test shown in Figure (33). The value of the modulus of rupture depends on the dimensions of the beam and arrangement of loading. Symmetrical two-point loading is used which produced a constant of bending moment distribution between the load points.

If fracture occurs with the central one-third of the beam, the modulus of rupture is given by:

$$S = \frac{PL}{bd^2}$$

where:

- $S$: modulus of rupture.
- $P$: load applied by the testing machine.
- $L$: effective length.
- $b$: width of beam.
- $d$: depth of the beam.

If fracture occurs outside the load point:

$$S = \frac{3Pa}{bd^2}$$

$a$: distance from failure point to the near support.

The results and data stemming from the above tests were showing in Tables (11), (12), (13), (14), (15), (16), (17), (18), (19), (20),(21).
Table (8) Grading of fine Aggregate:

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Weight retained (gm)</th>
<th>Weight retained %</th>
<th>Passing %</th>
<th>BS Zone 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>2.51</td>
<td>97.49</td>
<td>90-100</td>
</tr>
<tr>
<td>2.36</td>
<td>60</td>
<td>10</td>
<td>90</td>
<td>75-100</td>
</tr>
<tr>
<td>1.18</td>
<td>157.1</td>
<td>26.31</td>
<td>73.69</td>
<td>55-90</td>
</tr>
<tr>
<td>0.6</td>
<td>392.0</td>
<td>65.65</td>
<td>34.35</td>
<td>35-59</td>
</tr>
<tr>
<td>0.3</td>
<td>538.3</td>
<td>90.15</td>
<td>9.85</td>
<td>8-30</td>
</tr>
<tr>
<td>0.15</td>
<td>582.0</td>
<td>97.47</td>
<td>2.53</td>
<td>0-10</td>
</tr>
<tr>
<td>Pan</td>
<td>597.1</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Using sieve analysis the following results were found in table (8).

Compare with BS, sand is zone (2).

Table (9) Grading Of Coarse Aggregate:

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Weight retained (gm)</th>
<th>Weight retained %</th>
<th>Passing %</th>
<th>BS 882 (20 mm to 5 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>90-100</td>
</tr>
<tr>
<td>14</td>
<td>347</td>
<td>34.9</td>
<td>65.1</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>587</td>
<td>59.1</td>
<td>40.9</td>
<td>30-60</td>
</tr>
<tr>
<td>5</td>
<td>965</td>
<td>97.1</td>
<td>2.9</td>
<td>0-10</td>
</tr>
<tr>
<td>Total</td>
<td>994</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Compare with B.S, maximum size of aggregate is 20 mm.

Table (10):

Concrete mix design form

<table>
<thead>
<tr>
<th>Stage</th>
<th>Item</th>
<th>Reference or calculation</th>
<th>Values</th>
</tr>
</thead>
</table>

1.1 Chromatistic strength  Specified  
Proportion defective  5 per cent  
\[
\begin{align*}
&\text{25 N/mm}^2 \text{ at } 28 \text{ days} \\
&\text{Proportion defective } 5 \text{ per cent}
\end{align*}
\]

1.2 Standard deviation  Fig 3  
\[
\begin{align*}
&8 \text{ N/mm}^2 \text{ or no data} \\
&8 \text{ N/mm}^2
\end{align*}
\]

1.3 Margin  C1  
\[
\begin{align*}
&(k=1.64 \times 8=13) \\
&N/mm^2
\end{align*}
\]

1.4 Target mean strength  C2  
\[
\begin{align*}
&25+13=38 \text{ N/mm}^2
\end{align*}
\]

1.5 Cement type  Specified  OPC/SRPC/RHPC

1.6 Aggregate type: coarse  uncrushed
Aggregate Type: fine  uncrushed

1.7 Free-water/cement ratio  Table 2, Fig 4  0.52
Use the lower value

1.8 Maximum free-water/cement ratio  Specified

2.1 Slump or V-B  Specified  Slump 30-60 mm or V-B

2.2 Maximum aggregate size  Specified  20mm

2.3 Free-water content  Table 3  180kg/m³

3.1 Cement content  C3  
\[
\begin{align*}
&180 \div 0.52 = 346.2 \text{kg/m}^3
\end{align*}
\]

3.2 Maximum cement content  Specified

3.3 Minimum cement content  Specified  -Use if than Item 3.1
And calculate Item greater 3.4

3.4 Modified free-water/cement ratio

4.1 Relative density of aggregate (SSD)  2.6 Known/assumed.

4.2 Concrete density  Fig 5  2362.5kg/m³

4.3 Total aggregate content  C4  2362.5-360-187.2=1815.3kg/m³

5.1 Grading of fine aggregate  BS882  Zone 2

5.2 Proportion of fine aggregate  Fig 6  (42-33) say 33% per cent

5.3 Fine aggregate content  C5  
\[
\begin{align*}
&33% \times 1815.3=600\text{Kg/m}^3 \\
&1815.3-599.049=1216.251\text{Kg/m}^3
\end{align*}
\]
<table>
<thead>
<tr>
<th>Quantities</th>
<th>Cement (Kg)</th>
<th>Water (Kg or L)</th>
<th>Fine aggregate (Kg)</th>
<th>Coarse aggregate (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per m3 (to nearest 5kg)</td>
<td>360</td>
<td>190</td>
<td>600</td>
<td>1215</td>
</tr>
<tr>
<td>Per trial mix of 220 m3</td>
<td>33.5</td>
<td>17.7</td>
<td>55.9</td>
<td>113.2</td>
</tr>
</tbody>
</table>

Items in italics are optional limiting values that may be specified
1N/mm² = 1MN/m² = 1Mpa
OPC = ordinary Portland cement; SRPC = sulphate resisting Portland cement; RHP = rapid hardening Portland cement.
Relative density = specific gravity.
SSD = based a saturated surface dry basic.
Mix (A) Reference Mix:
Mix specifications:
Characteristic strength: 25N/mm²
Slump: 38mm (medium).
Curing: Total immersion in water.
Casting date 16/10/2002.
To be tested after 3-7-14-28-90 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>19/10</td>
<td>3 days</td>
<td>38</td>
<td>25.8</td>
</tr>
<tr>
<td>Cubes</td>
<td>23/10</td>
<td>7 days</td>
<td>/</td>
<td>28.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>30/10</td>
<td>14 days</td>
<td>/</td>
<td>29.2</td>
</tr>
<tr>
<td>Cubes</td>
<td>13/11</td>
<td>28 days</td>
<td>/</td>
<td>30.9</td>
</tr>
<tr>
<td>Cubes</td>
<td>15/1</td>
<td>90 days</td>
<td>/</td>
<td>34.4</td>
</tr>
<tr>
<td>Cylinder</td>
<td>13/11</td>
<td>28 days</td>
<td>/</td>
<td>3.6</td>
</tr>
<tr>
<td>Prism</td>
<td>13/11</td>
<td>28 days</td>
<td>/</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Mix (B) Mix specification:
Characteristic strength: 25N/mm².
Slump: 32 mm.
Curing: By Burlap.
Casting date 29/9/2002
To be tested after 3-7-28-90 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>2/10</td>
<td>3days</td>
<td>32</td>
<td>24.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>6/10</td>
<td>7days</td>
<td>/</td>
<td>26.5</td>
</tr>
<tr>
<td>Cubes</td>
<td>27/10</td>
<td>28days</td>
<td>/</td>
<td>30.5</td>
</tr>
<tr>
<td>Cubes</td>
<td>29/12</td>
<td>90days</td>
<td>/</td>
<td>33.5</td>
</tr>
<tr>
<td>Cylinder</td>
<td>27/10</td>
<td>28days</td>
<td>/</td>
<td>3.2</td>
</tr>
<tr>
<td>Prism</td>
<td>27/10</td>
<td>28days</td>
<td>/</td>
<td>2.4</td>
</tr>
</tbody>
</table>
**Mix (C)** Mix specification:

Characteristic strength: 25N/mm².

Slump: 31mm.

Curing: by liquid membrane compound.

Casting date 19/10/2002.

To be tested after 3-7-28-90 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>22/10</td>
<td>3days</td>
<td>31</td>
<td>24.5</td>
</tr>
<tr>
<td>Cubes</td>
<td>26/10</td>
<td>7days</td>
<td>/</td>
<td>26.0</td>
</tr>
<tr>
<td>Cubes</td>
<td>16/11</td>
<td>28days</td>
<td>/</td>
<td>28.8</td>
</tr>
<tr>
<td>Cubes</td>
<td>18/1</td>
<td>90days</td>
<td>/</td>
<td>31.4</td>
</tr>
<tr>
<td>Cylinder</td>
<td>16/11</td>
<td>28days</td>
<td>/</td>
<td>3.0</td>
</tr>
<tr>
<td>Prism</td>
<td>16/11</td>
<td>28days</td>
<td>/</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Mix (D) Mix specification:
Characteristic strength: 25N/mm².
Slump: 40 mm.
Curing: by polythene.
Casting date 21/10/2002.
To be tested after 3-7-28-90 days.

Table (14)

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>24/10</td>
<td>3 days</td>
<td>40</td>
<td>22.3</td>
</tr>
<tr>
<td>Cubes</td>
<td>28/10</td>
<td>7 days</td>
<td>/</td>
<td>25.2</td>
</tr>
<tr>
<td>Cubes</td>
<td>18/11</td>
<td>28 days</td>
<td>/</td>
<td>26.9</td>
</tr>
<tr>
<td>Cubes</td>
<td>20/1</td>
<td>90 days</td>
<td>/</td>
<td>30.5</td>
</tr>
<tr>
<td>Cylinder</td>
<td>18/11</td>
<td>28 days</td>
<td>/</td>
<td>2.9</td>
</tr>
<tr>
<td>Prism</td>
<td>18/11</td>
<td>28 days</td>
<td>/</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Mix (E) Mix specification:
Characteristic strength: 25N/mm2.
Slump: 31 mm.
Curing: left dry in air.
Casting date 1/10/2002.
To be tested after 3-7-14-28-90 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>4/10</td>
<td>3days</td>
<td>31</td>
<td>20.6</td>
</tr>
<tr>
<td>Cubes</td>
<td>8/10</td>
<td>7days</td>
<td>/</td>
<td>22.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>15/10</td>
<td>14days</td>
<td>/</td>
<td>22.9</td>
</tr>
<tr>
<td>Cubes</td>
<td>29/10</td>
<td>28days</td>
<td>/</td>
<td>23.4</td>
</tr>
<tr>
<td>Cubes</td>
<td>31/12</td>
<td>90days</td>
<td>/</td>
<td>25.1</td>
</tr>
<tr>
<td>Cylinder</td>
<td>29/10</td>
<td>28days</td>
<td>/</td>
<td>2.4</td>
</tr>
<tr>
<td>Prism</td>
<td>29/10</td>
<td>28days</td>
<td>/</td>
<td>1.7</td>
</tr>
</tbody>
</table>
**Mix (F)** Mix specification:

Characteristic strength: 25N/mm².

Slump: 37 mm.

Curing: First 14 days and then left dry.

Casting date 12/10/2002.

To be tested after 3-14-7-28days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>15/10</td>
<td>3days</td>
<td>37</td>
<td>25.8</td>
</tr>
<tr>
<td>Cubes</td>
<td>19/10</td>
<td>7days</td>
<td>/</td>
<td>28.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>26/10</td>
<td>14days</td>
<td>/</td>
<td>29.2</td>
</tr>
<tr>
<td>Cubes</td>
<td>9/11</td>
<td>28days</td>
<td>/</td>
<td>29.4</td>
</tr>
<tr>
<td>Cylinder</td>
<td>9/11</td>
<td>28days</td>
<td>/</td>
<td>3.4</td>
</tr>
<tr>
<td>Prism</td>
<td>9/11</td>
<td>28days</td>
<td>/</td>
<td>2.2</td>
</tr>
</tbody>
</table>
**Mix (G)** Mix specification:

Characteristic strength: 25N/mm².

Slump: 34 mm.

Curing: First 7 days and then left dry.

Casting date 15/10/2002.

To be tested after 3-7-14-28 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>18/10</td>
<td>3 days</td>
<td>34</td>
<td>25.8</td>
</tr>
<tr>
<td>Cubes</td>
<td>22/10</td>
<td>7 days</td>
<td>/</td>
<td>28.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>29/10</td>
<td>14 days</td>
<td>/</td>
<td>28.8</td>
</tr>
<tr>
<td>Cubes</td>
<td>12/11</td>
<td>28 days</td>
<td>/</td>
<td>28.9</td>
</tr>
<tr>
<td>Cylinder</td>
<td>12/11</td>
<td>28 days</td>
<td>/</td>
<td>3.1</td>
</tr>
<tr>
<td>Prism</td>
<td>12/11</td>
<td>28 days</td>
<td>/</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Mix (H) Mix specification:
Characteristic strength: 25N/mm2.
Slump: 40 mm.
Curing: First 3 days and left dry.
To be tested after 3-7-14-28 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>6/10</td>
<td>3 days</td>
<td>40</td>
<td>25.8</td>
</tr>
<tr>
<td>Cubes</td>
<td>10/10</td>
<td>7 days</td>
<td>/</td>
<td>27.1</td>
</tr>
<tr>
<td>Cubes</td>
<td>17/10</td>
<td>14 days</td>
<td>/</td>
<td>27.3</td>
</tr>
<tr>
<td>Cubes</td>
<td>31/10</td>
<td>28 days</td>
<td>/</td>
<td>27.6</td>
</tr>
<tr>
<td>Cylinder</td>
<td>30/10</td>
<td>28 days</td>
<td>/</td>
<td>2.9</td>
</tr>
<tr>
<td>Prism</td>
<td>30/10</td>
<td>28 days</td>
<td>/</td>
<td>1.8</td>
</tr>
</tbody>
</table>
**Mix (I)** Mix specification:

Characteristic strength: 25N/mm².

Slump: 32 mm.

Curing: After 14 days for initial dry.

Casting date 2/10/2002.

To be tested after 3-7-14-28 days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>5/10</td>
<td>3 days</td>
<td>32</td>
<td>20.6</td>
</tr>
<tr>
<td>Cubes</td>
<td>9/10</td>
<td>7 days</td>
<td>/</td>
<td>22.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>16/10</td>
<td>14 days</td>
<td>/</td>
<td>22.9</td>
</tr>
<tr>
<td>Cubes</td>
<td>30/10</td>
<td>28 days</td>
<td>/</td>
<td>24.6</td>
</tr>
<tr>
<td>Cylinder</td>
<td>30/10</td>
<td>28 days</td>
<td>/</td>
<td>2.6</td>
</tr>
<tr>
<td>Prism</td>
<td>30/10</td>
<td>28 days</td>
<td>/</td>
<td>1.8</td>
</tr>
</tbody>
</table>
**Mix (J)** Mix specification:

Characteristic strength: 25N/mm².

Slump: 30 mm.

Curing: After 7 days of initial drying in air.

Casting date 5/10/2002.

To be tested after 3-7-14-28days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>8/10</td>
<td>3days</td>
<td>30</td>
<td>20.6</td>
</tr>
<tr>
<td>Cubes</td>
<td>12/10</td>
<td>7days</td>
<td>/</td>
<td>22.7</td>
</tr>
<tr>
<td>Cubes</td>
<td>18/10</td>
<td>14days</td>
<td>/</td>
<td>24.4</td>
</tr>
<tr>
<td>Cubes</td>
<td>2/11</td>
<td>28days</td>
<td>/</td>
<td>26.5</td>
</tr>
<tr>
<td>Cylinder</td>
<td>2/11</td>
<td>28days</td>
<td>/</td>
<td>3.1</td>
</tr>
<tr>
<td>Prism</td>
<td>2/11</td>
<td>28days</td>
<td>/</td>
<td>1.9</td>
</tr>
</tbody>
</table>
**Mix (K)** Mix specification:

Characteristic strength: 25N/mm².

Slump: 42 mm.

Curing: After 3 days of initial drying in air.

Casting date 7/10/2002.

To be tested after 3-7-14-28days.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Date of cast</th>
<th>Age of Sample</th>
<th>Slump</th>
<th>Average of 3 samples strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes</td>
<td>10/10</td>
<td>3days</td>
<td>42</td>
<td>20.6</td>
</tr>
<tr>
<td>Cubes</td>
<td>14/10</td>
<td>7days</td>
<td>/</td>
<td>26.6</td>
</tr>
<tr>
<td>Cubes</td>
<td>21/10</td>
<td>14days</td>
<td>/</td>
<td>27.1</td>
</tr>
<tr>
<td>Cubes</td>
<td>4/11</td>
<td>28days</td>
<td>/</td>
<td>27.9</td>
</tr>
<tr>
<td>Cylinder</td>
<td>4/11</td>
<td>28days</td>
<td>/</td>
<td>3.2</td>
</tr>
<tr>
<td>Prism</td>
<td>4/11</td>
<td>28days</td>
<td>/</td>
<td>2.1</td>
</tr>
</tbody>
</table>
CHAPTER FIVE

RESULT PRESENTATION AND DISCUSSION

5.1 Compressive Strength:

5.1.1 Effect of Curing Method:

The average rates of concrete strength development of concrete cubes using different curing procedures were shown in Figure (34). Five cases were considered, namely: continuous water curing, covering with saturated burlaps, liquid membrane curing compound, covering with polythene and the extreme case of no curing. The results are shown in Table (22).

The results indicate that, at 28 days, concrete cured with saturated burlaps attains about 98.7 percent of the strength the fully cured concrete, concrete cured through liquid membrane compound attains about 93.2 percent, concrete cured through polythene attains about 87.1 percent and concrete with no curing attains about 75.7 percent only.
5.1.2 Effect Of Curing Period:

The effect of four different curing conditions on concrete strength were investigated: allowance dry in air, moist curing for 14-days followed by drying until tested at 90 days, moist curing for 7-days followed by drying up to the testing data, most curing for 3-days followed by drying up to the testing date, the results are shown in Table (23).

Results are presented in Figure (35). Three specimens were tested at the specified ages for each of these curing conditions and compared with the standard conditions of continuous moist curing. The rate of hydration processes is very much influenced by temperature and relative humidity.

While concrete still immature is exposed for drying and hence increase in the concrete temperature, a sharp increase in compressive strength will be produced in ages immediately following the drying, experiments show that. However, because there may be insufficient water left for proper hydration, substantial loss of ultimate strength will result. In fact its supported by data. Figure (35), that the stop of curing at ages of 3, 7 and 14 days presents lower 28- days strength than the case of continuous curing. This may be interpreted by the suggestion that the loss of strength due to wetting of compression specimens is caused by the dilation of the cement paste by adsorbed water; the forces of cohesion of the solid particles are then decreased.

5.1.3 Effect Of Delayed Curing:

After casting, the rate at which concrete will dry depends on air temperature, relative humidity and wind velocity, Figures (1), (2). If the concrete dries, rewetting will restart hydration; however maximum saturation cannot be achieved. This is probably due the braking of the continuity of flow in the capillaries. Therefore, once the concrete has
dried, it is ultimate strength cannot be achieved. The results are shown in Table (23) and Figure (36).

5.2 Tensile Strength:

Split cylinder strength tests were made on cylinders of concrete. These specimens will only develop their potential strength when properly cured. The effect of the methods of curing on concrete tensile splitting is presented in Figures (37), (38), (39). Also the compressive fall, the value for the splitting strength falls.

5.3 Modulus of Rupture:

Flexural strength tests were made on concrete cured through the five different curing techniques. The results were shown in Figures (40), (41), (42).

Table (221) Effect Of Different Curing Procedures On Strength

<table>
<thead>
<tr>
<th>Type Of Curing</th>
<th>Crushing strength N/mm²</th>
<th>Splitting N/mm²</th>
<th>Flexural N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3days</td>
<td>7days</td>
<td>28days</td>
</tr>
<tr>
<td>Total immersion in water.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.8</td>
<td>28.7</td>
<td>30.9</td>
</tr>
<tr>
<td>Application of water through saturated burlaps.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24.7</td>
<td>26.5</td>
<td>30.5</td>
</tr>
<tr>
<td>Using liquid membrane curing compound.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24.5</td>
<td>26.0</td>
<td>28.8</td>
</tr>
<tr>
<td>Using polythene.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.3</td>
<td>25.2</td>
<td>26.9</td>
</tr>
<tr>
<td>Allowed to dry in air.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.6</td>
<td>22.7</td>
<td>23.4</td>
</tr>
</tbody>
</table>
### Table (23) EFFECT OF DELAYING THE START OF CURING

<table>
<thead>
<tr>
<th>Type Of Curing</th>
<th>Crushing strength N/mm²</th>
<th>Splitting N/mm²</th>
<th>Flexural N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3days</td>
<td>7days</td>
<td>14days</td>
</tr>
<tr>
<td>Total immersion in water.</td>
<td>25.8</td>
<td>28.7</td>
<td>29.2</td>
</tr>
<tr>
<td>Water curing after 3 days of initial drying in air.</td>
<td>20.6</td>
<td>26.6</td>
<td>27.1</td>
</tr>
<tr>
<td>Water curing after 7 days of initial drying in air.</td>
<td>20.6</td>
<td>22.7</td>
<td>24.4</td>
</tr>
<tr>
<td>Water curing after 14 days of initial drying in air.</td>
<td>20.6</td>
<td>22.7</td>
<td>22.9</td>
</tr>
<tr>
<td>Allowed to dry in air.</td>
<td>20.6</td>
<td>22.7</td>
<td>22.9</td>
</tr>
</tbody>
</table>

### Table (24) EFFECT OF CURING PERIOD ON CONCRETE STRENGTH

<table>
<thead>
<tr>
<th>Type Of Curing</th>
<th>Crushing strength N/mm²</th>
<th>Splitting N/mm²</th>
<th>Flexural N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3days</td>
<td>7days</td>
<td>14days</td>
</tr>
<tr>
<td>Total immersion in water.</td>
<td>25.8</td>
<td>28.7</td>
<td>29.2</td>
</tr>
<tr>
<td>Water curing for the first 3 days and then left dry.</td>
<td>25.8</td>
<td>27.1</td>
<td>27.3</td>
</tr>
<tr>
<td>Water curing for the first 7 days and then left dry.</td>
<td>25.8</td>
<td>28.7</td>
<td>28.8</td>
</tr>
<tr>
<td>Water curing for the</td>
<td>25.8</td>
<td>28.7</td>
<td>29.2</td>
</tr>
</tbody>
</table>
first 14 days and then left dry.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowed to dry in air.</td>
<td>20.6</td>
<td>22.7</td>
<td>22.9</td>
<td>23.4</td>
</tr>
</tbody>
</table>
CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS:

Based on the tests carried out using different curing conditions and varying methods of maintaining moisture content in the concrete, the following conclusions can be drawn:

(1) Newly made concrete must be kept saturated, or nearly so, for a better degree of hydration. Concrete should be continuously cured not only to obtain its ultimate potential strength and durability but to minimize shrinkage cracking and grazing.

(2) Of the curing techniques investigated, total immersion in water is the most thorough and effective, but cumbersome. Wet burlap provides good curing and the strength developed by concrete at 28-days using
this method is about 98.5 percent of the referenced curing. Yellow-pigmented liquid membrane curing compound, when used with the manufacturer recommended application rate, at an age of 28-days and later, concrete cured by it attains about 93.0 percent of the immersion water curing.

Polythene curing may not provide adequate curing and the strength developed by concrete at 28-days using this way about 87.0 percent of referenced curing. Concrete left without curing up to the testing date at 28-days, can attain only about 75.5 percent of the strength developed by referenced curing.

(3) If the concrete is allowed to dry after a limited period of curing there may not be sufficient water left for proper hydration, and a loss of strength will result. Specimen’s water cured for the first 14 days and then allowed to dry may develop about 95.0 percent of the strength of the reference specimens at the 28 days. Specimens which are water cured for the first 7 days and then allowed to dry up to testing age of 28-daysit attains about 93.5 percent of reference specimens. Specimens which are water cured for the first 3 days and then allowed to dry may develop about 89.0 percent of the strength of the reference specimens at the 28 days.

(4) If the concrete dries initially, rewetting will restart hydration, however, ultimate strength of the concrete can not be achieved for concrete specimens cured after the first 3-days of drying, but can attain about 90.5 percent of the referenced curing. Concrete specimens cured after the first 7- days of drying can attain about 85.5 percent of referenced curing. Specimens cured after the first 14-days of drying, may develop about 79.5 percent of the strength of the reference specimens at the 28 days.
6.2 RECOMMENDATIONS:

At this stage and from the outlined scope and the previous discussions, the following investigation, may be carried out:

(1) The influence of using admixtures may be studied.
(2) The influence of using different grades of concrete (15,20,30,50).
(3) Using different types and qualities of cement.
(4) The use of different size of specimens.
(5) Further researches in concrete deformations e.g. shrinkage and Creep.
(6) Investigation of the properties of concrete as developed with age (1 year and more).
(7) More research is needed to study the strength of concrete in the different environments (high temperature–humidity–low Temperature).

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(36) BS12:1991 “Method of Testing Cement”.

(37) BS882 “Standard Specification for Aggregates From Natural Sources for concrete”.

(38) B.S. 3148 “Method of Testing Water”.
Figure (37) EFFECT OF DIFFERENT CURING PROCEDURE ON SPLITTING STRENGTH.

EFFECT OF DIFFERENT CURING PROCEDURE ON SPLITTING STRENGTH IN WATER.
Figure 38: EFFECT OF DELAYING THE START OF CURING ON SPLITTING STRENGTH
Figure (39) EFFECT OF CURING PERIOD ON CONCRETE SPLITTING STRENGTH
Figure (40) EFFECT OF DIFFERENT CURING PROCEDURE ON FLEXURAL STRENGTH