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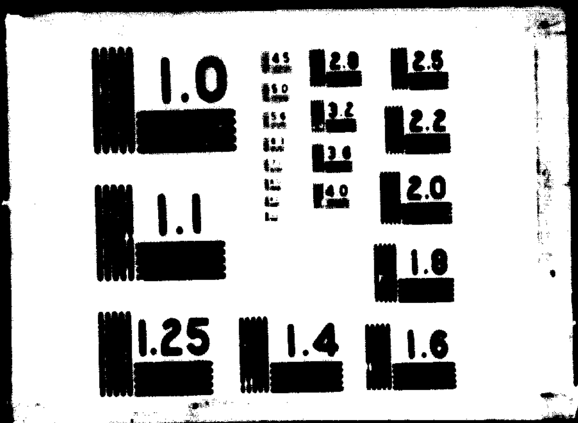

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# CONCRETE TECHNOLOGY 1/

by

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## Introduction

The words "Concrete Technology" cover a vast number of physical, chemical and technical phenomena and processes. Explaining and describing the technology of concrete, therefore, imply such scientific diciplines as physics, chemistry (inorganic as well as organic), mineralogy, and statistics.

This is the reason for the astonishing fact that in spite of its apparently simple nature concrete has attracted thousands of scientists throughout the last decades and has given work to a large number of research laboratories all over the world.

The wide field that is covered by the words "Concrete Technology" could also be illustrated by mentioning that the description of the technology of concrete comprises:

- I the properties of hardened concrete (strength, stiffness, volume-changes, permeability, durability, etc.).
- II the properties of the constituent materials (Cement, aggregates natural and artificial water, admixtures, and reinforcement).
- III the manufacturing of concrete (mix-proportioning, batching, mixing, transportation, placing of concrete in forms, compaction, curing under various conditions, etc.).
- IV the setting and hardening of concrete (structure formation, growth of strength, heat evolution, etc.).

V the control of concrete quality (causes of variation, control charts, etc.).

Obviously, therefore, the present few-page survey of the technology of concrete can only be an excursion in which a few important points are selected for further consideration.

## HISTORY

Both the Greeks and the Romans made concrete. They used a cement of calcined limestone. Roman concrete was made of broken brick embedded in a cementitious matrix consisting of lime putty mixed with brick dust or volcanic ash.

Then through a long period, concrete was so to say forgotten. The first step towards its re-introduction was in about 1790, when J. Smeaton in England found that when lime containing a certain amount of clay was burnt, it would set under water. In 1824 a dependable hydraulic cement, which was called Portland cement, was manufactured by the Englishman Joseph Aspdin. The first concrete bridge (un-reinforced) was, however, built already in 1816 in France.

Reinforced concrete was developed by such persons as Wilkinson, Lambot, Coignet and Monier. By the turn of the century fortythree patents had been taken out on reinforced concrete, and most of its basic properties and principles of design had been determined.

In this country, the first reinforced concrete bridge, designed by professor A. Ostenfeld, was erected in 1894. It is still in use.

## THE PROPERTIES OF HARDENED CONCRETE

Portland cement concrete could be characterized by:

I its appearance, such as colour (grey, white, brown, etc.), and surface texture (smooth, rough, porous, profiled, hammered, facing aggregates)

II its applications (concrete is used for a variety of purposes, such as bridges, houses, walls (slabs, facades), towers, silos, dams, quays, piers, coastal protection, floors, pavements (for roads, sidewalks, and in the garden), sewer pipes, etc.).

III concrete can be considered as a twophase material, consisting of a - usually - non-active system of discrete particles, the aggregate, and a binding agent, the cement paste, which fills the voids between the aggregate particles and ties them together to form a hard, durable material. In concrete, approximately 75% of the total volume is taken up by the aggregate, and only 25% of cement paste binder. The cement paste binder is a porous material consisting primarily of very small needle- or foil-shaped calcium silicate hydrate particles adhering to each other and comparatively much bigger calcium hydroxide crystals. The pores in cement paste may be more or less filled with water;

IV its technical properties, such as weight, strength, (compressive or tensile), stiffness, volume changes (resulting from external load (creep), drying (shrinkage), and heating), permeability, and durability (resistance to frost, aggressive solutions, alkali aggregate reaction).

In what follows, the technical properties of hardened concrete will be further elucidated.

## UNIT WEIGHT

The unit weight of concrete for structural purposes is usually about 2300 kg/m$^3$. Depending on the specific gravity of the aggregate, the unit weight of structural concrete can, however, be as low as for instance 1300 kg/m$^3$. In this case, the normal type of coarse aggregate in the concrete, such as gravel or crushed rock, is substituted by a lightweight aggregate, such as expanded clay aggregate, expanded shale aggregate, sintered fly ash, etc. In all strongly industrialized parts of the world, an ever increasing part of concrete for structural purposes is lightweight aggregate concrete, because the sources of natural aggregates are being emptied. This new technology is developing rapidly. Substituting the natural aggregate by a heavy type of aggregate, such as steel punchings, magnetite, and baryte, provides a concrete with radiation shielding properties.

Concrete for insulation purposes may have a unit weight in the range of 400-1000 kg/m$^3$. Such a type of concrete is highly porous and may be made by using a type of lightweight aggregate or by incorporating a great number of small air voids in the concrete, such as aerated concrete or foam concrete.

## STRENGTH

The compressive strength of concrete for structural purposes is usually in the range of 150 to 600 kp/cm$^2$, i.e. from 15 to 60 MN/m$^2$. The tensile strength is approximately one tenth of the compressive strength.

The factors that determine the strength level are primarily:

I the water-cement ratio, i.e. the ratio between the weight of the water and the weight of the cement added to the original concrete mix. The strength increases with decreasing water-cement ratio, that is with increasing concentration of cement in the cement paste binder.

- -

II the concentration of sand and coarse aggregate particles per volume unit; the closer the aggregate particles are packed, the higher the strength; how close these particles are packed depends among other things upon the method and degree of compaction during casting of the concrete.

III the curing conditions; see below

During the last decade much research work all over the world has aimed at methods to produce concrete with much higher strength than hitherto. These efforts have been succesful so far as it has been possible in laboratory scale to manufacture concrete specimens with compressive strengths up to about 1500 $kg/cm^2$ (150 $MN/m^2$). The methods which have been taken in use to obtain these high strength levels are primarily

a compaction methods, such as vibro-pressing

b impregnation of the hardened concrete with polymer materials, and

c use of fibre reinforcement (glass, steel or carbon fibres)

The next few years will show whether it will be possible to transfer the laboratory experience to practical conditions and to utilize economically these technical improvements.

The strength of concrete is usually tested on special test specimens (cubes, cylinders, beams) cast at the same time and with the same concrete mix as the concrete structure they are supposed to represent.

## STIFFNESS

When concrete is subjected to short-term stress, it will to a certain extent deform elastically. For uniaxial stress we have for the normal component

$$\sigma = E \cdot \varepsilon$$

where $\sigma$ is the applied stress, $\varepsilon$ the resulting strain, and E the modulus of elasticity,

Fig. 1

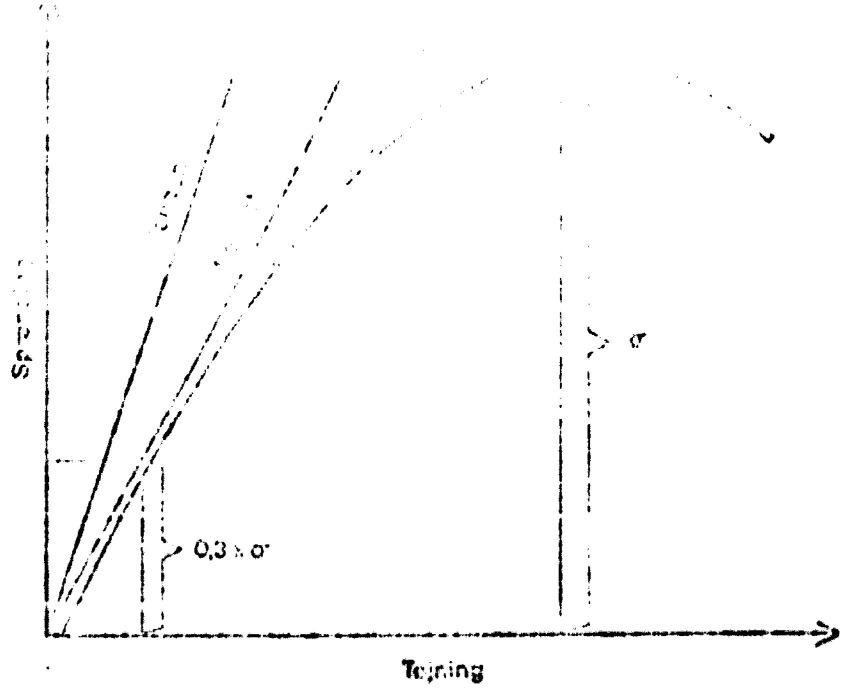


Fig. 1. Stress-strain curve for concrete

The shape of the stress-strain curve is dependent on the rate of loading.

The value of the modulus of elasticity for concrete usually lies within the range of 2 to 4 × $10^5$ kp/$cm^2$ (20,000-40,000 MN/$m^2$).

Between the modulus of elasticity of concrete and its corresponding unit weight there exists the following empirical relationship:

$$e = k \cdot \sqrt{(\text{unit weight})^3 \times \text{compressive strength}}$$

where the constant k has a value between 4,000 and 6,000 when E-modulus and strength is measured in kp/$cm^2$ and unit weight in tons/$m^3$.

## VOLUME CHANGES

**Shrinkage** When concrete dries, it shrinks. Under ordinary dry conditions (indoor) the drying shrinkage will be of the order of 0.03-0.05 per cent linearly. If concrete absorbs water again, it expands (swells). The shrinkage and swelling component in concrete is the cement paste, the apparent volume of which varies with humidity conditions. Water is present in cement paste as chemically fixed water, as adsorbed water films and as capillary water. When the relative humidity of ambient air is diminished, the thickness of the adsorbed water films will decrease. The moisture movement of cement paste and concrete can be divided into a reversible part and an irreversible one. In a dry state gel particles will be in closer contact with each other, whereby additional links within the gel structure may be formed. This explains the principal course of the moisture movement resulting from alternating moist and dry curing. The irreversible part of shrinkage amounts to 1/3-2/3 of the total drying shrinkage.

**Creep** When concrete is exposed to sustained load, time-dependent deformations will result, and these deformations will not be elastic, i.e. concrete creeps. The final creep deformation for a given load will under ordinary conditions be at least twice as great as the instantaneous elastic deformation resulting from the application of the load. The mechanism of creep may to a certain extent be explained by the mechanism which governs shrinkage. The external mechanical load causes stresses in the paste constituent and thereby also changes in the energy state of the adsorbed water as well as the capillary water. A redistribution of the relative amounts of adsorbed and capillary water results, and this is only possible by means of a slow diffusion process in analogy with the shrinkage process. The factors which determine shrinkage are, therefore, also decisive for the course and magnitude of creep.

From the moment when concrete is exposed to a mechanical stress, its deformation will develop slowly. Shrinkage may occur simultaneously and interact with creep, which will make the picture further complicated.

A constant strain may be imposed on concrete. This will cause a certain instantaneous stress, which, however, gradually decreases, because concrete creeps. This phenomenon is called relaxation, and is important for the performance of statically indeterminate concrete structures.

**Thermal expansion** Like nearly all other materials, concrete will expand as its temperature is increased. The coefficient of thermal expansion is for ordinary concrete of the order of $10^{-5}$ per degree centigrade.

## PERMEABILITY

The water permeability of concrete depends on its quality, particularly the water-cement ratio. A reduction of the water-cement ratio from 0.8 to 0.4 may have the consequense that the cement paste permeability is reduced by about 1000 times. The water impermeability of concrete is to a great extent dependent on how well the concrete has been compacted during manufacture. During the hardening of concrete its permeability is strongly reduced. If a watertight concrete is wanted, then the content of cement plus filler (fine aggregate with particle size less than 0.25 mm) should be at least 375 kgs per $m^3$ concrete.

## DURABILITY

The permeability of concrete is also to a great extent responsible for its capability to resist physical, chemical and mechanical attacks. The more impermeable the concrete is made, the more durable will it be.

Frost Resistance When a concrete surface is saturated with water and at the same time subjected to freezing and thawing it may - unless special precautions are taken - crack and disintegrate due to expansion of the pore water when freezing. This may be prevented by incorporating in the concrete a system of small air voids randomly distributed in the concrete mass and by using frost resistant aggregates. The air void system may be provided by adding an air entraining agent to the fresh concrete during mixing. A total air void content of about 4 to 6 per cent by volume is usually recommended.

Sulphate Resistance Strong acids and certain salts are aggressive towards concrete. Here are mentioned only sulphates which are quite frequently met in the nature (in sea water, in sulphate bearing earths, sometimes in the ground water, and in waste water) and which have a deteriorating effect on the cement paste binder in concrete. If the concentration of sulphate ions in water which is in contact with a concrete surface (e.g. sea structures, foundations,

...er pipes, etc.) is above approximately 1000 ppm, special precautions, such as using a sulphate resistant cement, should be taken.

Alkali Aggregate Reaction Certain minerals, such as opal, chalcedony, tridymite, phyllite and zeolite, which occur in some rock types, such as cherts, flints, siliceous limestone, rhyolites, decites, andecites, phyllite shales, etc., are reactive with alkalis. When such rock types, therefore, are used as aggregate in concrete made with high alkali cements disruptive expansions may occur because an expanding alkali silica gel is formed at the interface between the cement paste and the reactive constituents of the aggregate. Deleterious alkali-aggregate reaction would only be suspected with cement containing more than 0.6 per cent alkali.

## MATERIALS FOR CONCRETE MANUFACTURING

The materials used in the manufacture of concrete are cement, aggregate, water and admixtures.

### Cement

Cement, the manufacture and characteristics of it, is dealt with by other lecturers. It should only be mentioned here that in most countries the concrete producer has a number of types of cement which he can choose among in order to fulfill special requirements to the concrete.

### Aggregate

Aggregate materials for concrete production will also be dealt with by another lecturer. In the present context, it should only be emphasized that the type and characteristics of the aggregate material mainly influence the concrete in the following ways:

a it determines the water requirement of the fresh concrete

b it influences the strength and weight level of the concrete

c it influences the magnitude of the drying shrinkage and creep

d it influences the long-time physical and chemical durability of the concrete.

The characteristics of the aggregate particles which are of major importance in this connection are:

1 the particle size distribution

2 the weight and porosity of the particles, and

3 the mineralogical type

## Mixing Water

Water that is acceptable for drinking (except in respect of bacteriological requirements) is suitable for making concrete. Where a supply is drawn from natural sources, preliminary treatment may be required, such as settlement or filtration to remove suspended matter. The water should be free from materials that significantly affect the rate of hardening, or the strength and durability of concrete, or which promote efflorescence or the rusting of steel reinforcement. Sea water is usually not acceptable as mixing water for reinforced concrete because of its content of chlorides.

## Admixtures

An admixture for concrete is a substance which is added either in the form of a liquid or a powder, to the concrete mix before or during mixing.

Admixtures are used for the purpose of modifying some of the properties of the fresh, hardening or hardened concrete. Beneficial effects may be obtained by means of admixtures, and their use is therefore often recommended.

Admixtures may be divided into the following categories:

I Surface-active agents
  1 Air entraining agents
  2 Plastifying or water reducing agents
  3 Foaming agents
  4 Expansion agents
  5 Water-repelling agents

II Set and hardening regulating agents
  1 Accelerators
  2 Retarders

## MANUFACTURE OF CONCRETE

The manufacture of concrete comprises a number of processes ranging from mix design to curing. These are described briefly below.

### Mix Design

The design of concrete mixes is the determination of the most economical and practical combination of available aggregates, cement and water that will produce a mixture having the required degree of workability when fresh and developing the required qualitites of strength, density, durability, etc. when hardened.

Concrete mixes cannot be designed solely at the writing desk; it is necessary to make trial mixes to be adjusted in the field until the required properties of the concrete are obtained. In the first instance, the aim is to design the mix, or mixes, which are to serve as the basis for the trials.

Whereever possible, the following conditions should be investigated before selection of the initial trial mix:

Influence of the water-cement ratio on strength
Influence of aggregate gradings on the workability
Influence of aggregate grading on cement and water requirements

These conditions should, of course, be investigated for the materials to be used for the actual job. When it is impossible to conduct such tests, trial mixes for starting concrete operations can be selected by judicious application of relationships established by experience and the empiric laws known for the technology of concrete.

Proportioning by weight should always be used for work of considerable magnitude or where severe demands are made in respect of the quality of the concrete.

The six steps involved in the determination of a trial mix for initial field use are:

1. <u>Select the water-cement ratio.</u> This is done from test data, experience, or established relationships to meet the specified requirements for durability and strength.

2. <u>Estimate the workability.</u> Select the limits of slump that will permit proper handling and consolidation of a concrete under the job conditions involved.

3. <u>Determine the largest size of the aggregate available.</u> This will vary according to the nature of the work and the dimensions of the structures concerned.

4. Estimate the percentage of sand required. The desired workability will have to be taken into account.

5. Estimate the amount of water required per cubic yard of concrete. The conditions of steps (2), (3), and (4) must be fulfilled.

6. Compute the trial mix proportions. Changes in the computed mix proportions will have to be provided for after the making of trial mixes, partly in the laboratory, if any, and partly during field operations.

## Batching

It should be stressed that to-day weight-batching is considered "a must" and volume batching is used for very small jobs only. Requirements to a batching plant are that its equipment is capable of accurate measurement. The choice of equipment will depend on a) size of job, b) rate of production, and 3) required standards of performance.

The equipment types available are 1) manual, which method is accomplished by using wheelbarrows and platform scales (acceptable for small jobs up to about 5000 $m^3$ concrete); 2) cumulative, semi-automatic batching, in which case aggregate silos with manually or power-operated gates are generally used (acceptable for jobs of 5,000-30,000 $m^3$ concrete); and 3) fully-automatic batching in which case separate weigh-hoppers are used for each ingredient (used on large jobs and ready-mix concrete plants).

## Mixing

Various types of drum mixers are used, viz.:

1) Tilting. Main advantage speed of emptying.
2) Non-tilting, swing-chute discharge. Both (1) & (2) liable to give segregation.
3) Non-tilting, reversible discharge. Probably best of drum mixers.

Tilting drum mixers are used with very large - 8-10 $m^3$ - capacities. Longer mixing time, (1-1/2 to 2-1/3 min.) than with paddle mixers is required and they cannot mix very dry mixes. They must have a combination of blade arrangement and drum shape, which ensures an end-to-end exchange of material parallel to the axis of rotation, as well as a rolling, folding, or spreading movement of the mix.

Also various types of paddle mixers are used, the best having 2-3 mixing "stars" and the drum revolving counter to the stars. The advantages of this type of mixers are: a short mixing time (30-45 sec.) and the possibility of mixing very low-slump concrete. One of the disadvantages of this type of mixers is the heavy wear. Special types of this mixer are the turbine mixers and the through mixers, both of which can be excellent.

A special type of mixer is the continuous mixer. These are usually based on batching by volume, and are not acceptable for quality concrete.

## Transport and Placing

The first law regarding transport and placing of concrete is that equipment must suit the concrete and not vice-versa. All to often good concrete is spoilt by the use of unsuitable transport equipment, for example buckets incapable of dumping low-slump concrete, shutes which cause segregation, conveyor belts without protection from sun or rain, etc., etc.

Any possible step should be taken in order to minimize segregation, and it must be stressed that all points of discharge are important in this relation.

Besides the prevention of segregation, concrete must also be protected during transport against excessive loss or gain in moisture and heat. This means using proper cover and shading. In many cases it is often found advantageous to paint silos and equipment white to prevent gain in heat from direct sun.

## Compaction

Today concrete is nearly always compacted by vibration, rodding only being used in special cases.

There are various types of vibrators, e.g.:

- Immersion -
- Form -
- Table -
- Screeds -

each suited for different types of jobs, but in general the immersion type is the best, and should be used whereever possible. Vibrators are available in various sizes, from small 1" diameter to heavy two-man types , and the proper size for the job in question must be used.

## Curing

Although curing is the final phase in the production of concrete, it is by no means the least important. It involves keeping the concrete moist and if necessary protecting it from excessive loss or gain in heat, and most of the desirable properties of concrete are improved as the duration and effectiveness of the curing are increased. This applies not only to strength but also to durability, impermeability and resistance to wear, chemical attack and weathering. Ineffective curing is all too often the cause of defects such as crazing, cracking, insufficient strength development and low durability even in well designed concretes.

The strength development of concretes depends on the hydration of the cement, i.e., on the reaction of the cement with water, and if insufficient water is available the hydration process and the strength development ceases.

The curing temperature has a marked effect on the strength development of concrete. Low curing temperatures lead to decreased rate of strength development and extended moist curing is required under such conditions in order to develop a given strength. High curing temperatures lead to accelerated strength development, but also to modifications in the hydration products which may lead to lower ultimate strengths.

It should be stressed that effective moist curing is essential in order to eliminate differential shrinkage and consequent crazing and cracking. If a concrete member is not moist cured, the surfaces will dry out and shrink while the main body remains moist and constant in volume. The result will be internal stresses which will create tension in the outer layer, and cracks may form, particularly if strength development in this layer has been retarded due to the lack of moisture.

In practice, it is necessary to balance quality requirements with those of economy, and the minimum period of moist curing is generally specified as seven days for standard Portland cement concrete. Better practice would call for 10 days, and where special requirements are made for the concrete, the period should be further extended. Watertight concrete should, for example, be cured moist for at least 14 days. Rapid-hardening cements require shorter periods of moist curing (about half), and slow-hardening (e.g. pozzolanic cements) longer periods than standard cement.

The following methods of moist curing are recommended:

- covering with wet burlap or cotton mats
- covering with moist sand, sawdust, straw, etc.
- covering with waterproof paper or plastic sheets
- spraying, continuous or intermittent

- ponding, i.e. flooding the concrete within small earth dykes around the circumference of the exposed surfaces
- retaining forms in place (is applicable to beams, columns, etc., but not to floors and pavings)
- membrane curing, i.e. applying to the exposed surface a liquid curing compound designed to seal the surface and thus prevent evaporation of water

## Hot Weather Concreting and Curing

Hot weather presents special problems in the production and placing of concrete. A temperature of concrete as placed of 15°C (60°F) or even lower would be desirable, but is often difficult to attain. A maximum temperature of 35°C (90°F) should be considered a reasonable and practical upper limit, and every effort should be made to maintain lower temperatures than this maximum of 35°C. In the absence of special precautions being taken, the following effects may occur:

a) Setting is accelerated. This means that concrete stiffens faster, and the length of time used for handling becomes more critical. Inadequate consolidation and cold joints are some of the results.

b) Ultimate strength is reduced. High temperatures tend to give high early strengths, but a loss in ultimate strength.

c) Cracking tendency is increased. Plastic shrinkage may lead to cracks, and the demand for more mixing water leads to greater drying shrinkage.

d) Adequate curing is critical. Moisture for hydration _must_ be retained or strength losses develop.

## SETTING AND HARDENING

The setting and hardening of concrete is caused by chemical reaction between cement and water, whereby a solid reaction product is formed. This is glueing together the particles of sand, stone and unhydrated cement to form the solid concrete.

During the hardening, concrete changes from a liquid-like mixture of solid particles and water to a coherent solid structure and at the same time, the strength and the stiffness are changed drastically. Furthermore, the hardening is accompanied by secondary phenomena, of which heat evolution and deformations are probably the most important.

### Chemical Reactions

By the chemical reaction between water and cement, parts of the cement are dissolved in the water. The concentration of the solution increases gradually until saturation or supersaturation is obtained. Then hydration products formed by the chemical interaction between the dissolved cement and water are precipitated as solid materials, which glue together the sand, stone and unhydrated cement to the coherent solid structure of concrete.

### Strength Development

The fresh mixture of sand, stone, cement, and water behaves like a liquid with a high concentration of solid particles.

In due course, the strength gradually increases. During the first hours, the material still has a plastic behaviour. At this stage of the hardening, the strength is commonly determined by penetration measurement. Then the concrete gradually changes into a solid material. First the strength increases rapidly whereafter the rate of strength growth gradually decreases.

## Heat Evolution

The chemical reaction during the hardening is accompanied by heat evolution. The resulting rise in concrete temperature is often of importance in practical engineering. When casting in cold weather we may get the benefit of the heat evolution since the temperature rise is sometimes sufficient to prevent frost damage during the hardening. In massive structures special aids (such as cooling systems or use of special low heat cements) are sometimes necessary to avoid great thermal stresses and cracks due to the rise in temperature.

## Volume Changes

During the hardening volume change may occur. By the hydration itself a contraction may occur because the reaction products occupy a smaller volume than do the water and the cement. If, however, the concrete is supplied by additional water during the hardening the material will expand, since the hydrated cement occupies a greater volume than the cement alone does.

## Factors Affecting the Setting and Hardening

There are several ways in which the quality of the hardened concrete and the rate of hardening can be modified. Some of the methods commonly used are mentioned.

The mineral composition of cement influences the rate of hydration as well as the heat evolution. The mineral composition is a question of raw materials used and the burning of the cement slurry.

The fineness of cement can be varied. By decrease in particle size, the specific surface of the cement is increased permitting faster chemical reactions and thus a faster hardening of the concrete. Increased fineness of the cement is normally achieved at the cement plant by increased grinding.

The degree of packing of the solid particles in the concrete has as previously mentioned a great influence on the strength and stiffness and on the rate of strength and stiffness development.

The level of curing temperature effects the chemical reactions, mainly be increasing the rate of hardening with increasing temperature. Furthermore, a change in temperature may result in a somewhat different hydration product. When hot concrete is used, the heat evolution by the hydration is often of increased importance, due to the increased rate of the heat evolution.

As previously mentioned, also additives of various kinds may be used in the concrete to modify the setting and hardening.

## CONTROL OF CONCRETE QUALITY

It has been said that it is not difficult to make a good concrete. What is difficult is to make consistently a good concrete.

Consequently, the most important point in concrete manufacture is systematically to control all the materials and all the processes involved in concrete production. This, however, is dealt with by another lecturer.

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