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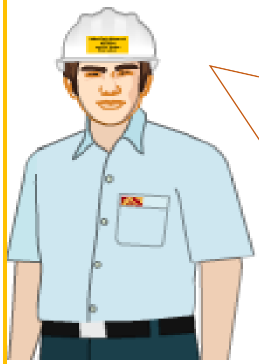
UltraTech



Dear Reader,

The strength of concrete is the property most valued by designers and quality control engineers. Uniaxial strength in compression is commonly accepted as a general index of the concrete strength. Strength gives an overall indication of quality of concrete as it is directly related to the lifelong performance of the concrete structure. The response of concrete to applied stress depends not only on the stress type but also on combination of various factors from raw materials to testing methods. This mailer, ***Factors affecting compressive strength of concrete*** *attempts to provide the reader information on Compressive Strength and Factors affecting it.*

We hope you find the mailer informative and useful. Happy Reading!!

Issue Highlights

- *Concrete*
- *Importance of Compressive Strength*
- *Test for Compressive Strength*
- *Factors affecting strength*

Concrete:

Concrete is the most widely used building material in the construction world. Concrete is made up of various ingredients and of course all of them have their role. The properties of concrete generally depend on the mix proportion of concrete ingredients i.e. cement, coarse aggregates, fine aggregates (sand), and water.

Everyone wishes their structure to be strong and durable and for that, they always aim towards making all elements of their structure to attain the desired strength and durability. Strength gives an overall indication of quality of concrete and it is directly related to the lifelong performance of the concrete structure. The strength of the concrete indicates the ability of the structure to withstand various loads (i.e. Dead Load, Live Load, Earthquake Load, Wind Load, etc..).

Compressive Strength of concrete:

The strength of a material is defined as the ability to resist stress without failure. Microstructural investigations of ordinary concrete show that unlike most structural materials concrete contains many fine cracks even before it is subjected to external stresses. Hence it is even more important to evaluate the stress handling capacity or strength of concrete after it has hardened and has become strong.

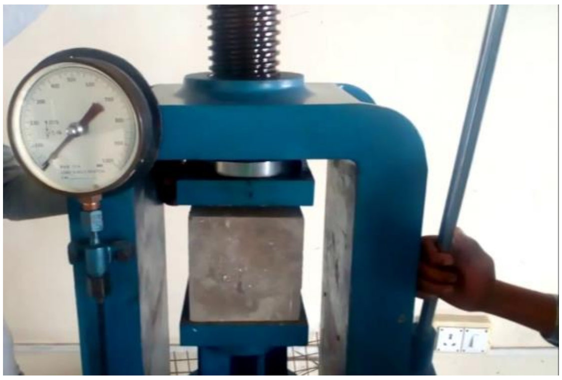
Many properties of concrete, such as elastic modulus, water tightness or impermeability, and resistance to weathering agents including aggressive waters, are believed to be dependent denseness and hence on strength. Compressive strength of concrete is several times greater than other types of strength (tensile, flexural, shear and bond), therefore a majority of concrete elements are designed to take advantage of the compressive strength of the material. The strengths like tensile, bending, shear strengths are related to the compressive strength and hence if the compressive strength is known, the other strengths can be estimated.

The compressive strength of concrete determined by a standard compression test is accepted universally as a general index of the concrete strength.

Test for Compressive Strength of Concrete Specimen:

In concretes made with Ordinary Portland Cement, it is found that more than 90% of the strength is achieved at 28 days. Compressive loads are applied on cubes made with concrete till they fail to take further loads. In other words, the cubes are tested to failure. In some countries, the test is carried out on cylinders. Tests are carried out on the test specimens at desired ages, the most usual being 7 and 28 days. The age of the specimen is calculated from the time of the addition of water to the dry ingredients to make concrete. At least three specimens each shall be made for testing at each selected age. The cubes are cast in standard cube moulds of side 150mm with proper compaction, demoulded the next day and cured for required number of days in a tank of water.

A Compressive Testing Machine (CTM) is used to apply the load on the specimens. The specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cube as cast.



The measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area of the cube. The compressive strength is expressed in terms of Newtons/sq.mm (N/mm^2) or Mega Pascals (MPa). It is to be noted that Indian Standard Code (IS 516) permits use of cubes of 100mm sides if max. size of coarse aggregate is 20mm. Cylinders can also be used for estimating compressive strength.

Factors Affecting Compressive Strength:

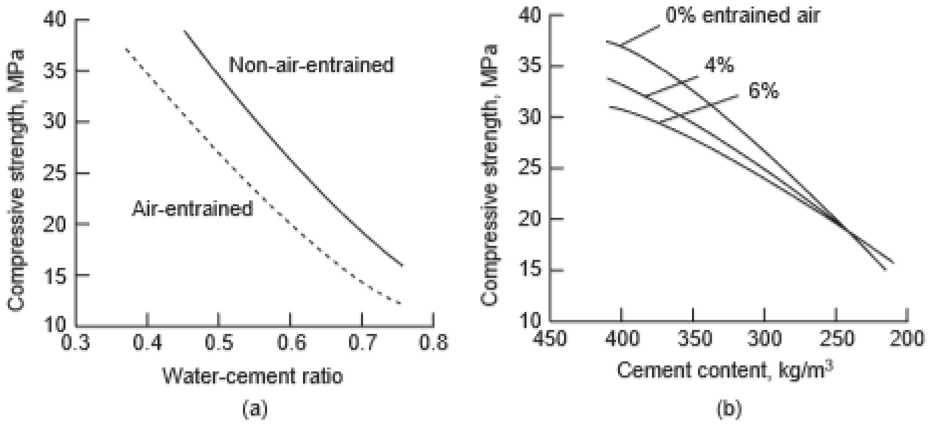
- **Water-cement ratio**

The ratio of the weight of water to the weight of cement is called Water/Cement ratio. W/c ratio is the notation used to represent the water-cement ratio of the concrete mixture. It is the most important factor for the strength gain of concrete. Generally, w/c ratio of 0.45 to 0.60 is used. Although a w/c of 0.3 is generally sufficient for complete hydration of cement, little higher ratio would become necessary to make the concrete “workable”. Too much water leads to segregation, voids and capillaries in concrete. W/c ratio is inversely proportional to the strength of concrete. As shown in the graph (a) below, when the w/c ratio is increased the strength of concrete gets decreased and when w/c ratio is decreased then the strength of concrete increases.

- **Air entrainment**

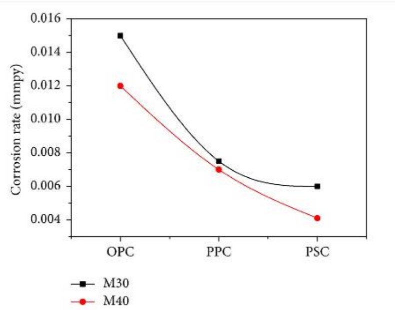
Sometimes a chemical called Air Entraining Agent is used while mixing concrete to get higher workability. Generally water-cement ratio determines the porosity of the cement paste in a hardened concrete; however, when air voids are incorporated into the system, either as a result of inadequate compaction or through the use of an air-entraining admixture, they have the effect of increasing the porosity and decreasing the strength of concrete.

Loss of strength as a result of entrained air depends on w/c ratio and cement content of the concrete mixture. As can be seen in graph (b), at a given w/c ratio, concretes with high cement content suffer considerable strength loss with increasing amounts of entrained air, whereas those with low cement content tend to suffer only a small strength loss.



- ## Cement Type

Degree of cement hydration has a direct effect on porosity and consequently on strength. At ordinary temperature, cement which has a higher fineness, hydrates more rapidly than other types; therefore, at early ages of hydration (e.g., 1, 3, and 7 days) and a given w/c, a concrete containing cement of higher fineness will have a lower porosity and correspondingly a higher early strength. If a blended cement like Portland Pozzolana Cement (PPC) containing fly ash or Portland Slag Cement (PSC) containing slag is used, the initial strength gain may be a bit slower. However, cement type (OPC/PPC/PSC) doesn't affect the ultimate strength as they achieve similar degree of hydration. It is also observed that blended cements continue to gain strength beyond 28 days and sometimes concretes made with blended cement exhibit higher compressive strength (at later ages) than concretes made with OPC due to pozzolanic (or secondary) reaction. It is also worth noting that the rate of corrosion of rebar is much lesser with blended cements.



- ## Aggregates

Although aggregates are most commonly known to be inert fillers in concrete, their characteristics such as the size, shape, surface texture, grading (particle size distribution), and mineralogy, are known to affect concrete strength. The characteristics of the aggregate affect the characteristics of the interface between the aggregate and cement paste (interfacial transition zone – ITZ) and hence concrete strength.

a) **Size** - A change in the maximum size of well-graded coarse aggregate can have two opposing effects on the strength of concrete - With the same cement content and consistency, concrete mixtures containing larger aggregate particles require less mixing water than those containing smaller aggregate. On the contrary, larger aggregates tend to form weaker interfacial transition zone containing more micro cracks. Also, the smaller size aggregates give larger surface area for bonding with the mortar matrix. In general, the compressive strength of concrete increases when the maximum size of aggregate decreases and the maximum aggregate size strongly influences the concrete strength.

b) **Grading** - The grading or size distribution of aggregate is an important characteristic because it determines the paste requirement for workable concrete. It is desirable to minimize the amount of paste consistent with the production of concrete that can be handled, compacted, and finished while providing the necessary strength and durability. The required amount of cement paste is dependent upon the amount of void space that must be filled and the total surface area that must be covered. When the particles are of uniform size, the spacing between them is the greatest, but when a range of sizes is used (i.e., proper gradation), the void spaces are filled and the paste requirement is lowered. A change in the aggregate grading influences consistency and bleeding characteristics of concrete, which can influence the concrete strength.

c) **Surface Texture** - A concrete mixture containing a rough-textured or crushed aggregate would show higher strength (especially tensile strength) at early ages than a corresponding concrete containing smooth or naturally weathered aggregate. A stronger physical bond between the aggregate and the hydrated cement paste is assumed to be responsible for this.

d) **Moisture Content**: The moisture content of an aggregate is an important factor when developing the proper water/cementitious material ratio. All aggregates contain some moisture based on the porosity of the particles and the moisture condition of the storage area. Aggregate can be found in four different moisture states viz. oven-dry (OD), air-dry (AD), saturated-surface dry (SSD) and wet. Of these four states, only OD and SSD correspond to a specific moisture state and can be used as reference states for calculating moisture content. In order to calculate the quantity of water that aggregate will either add to or subtract from the paste, the following three quantities must be calculated: absorption capacity, effective absorption, and surface moisture. Most stockpiled coarse aggregate is in the AD state with an absorption of less than one percent, but most fine aggregate is often in the wet state with surface moisture up to five percent. This surface moisture on the fine aggregate particles creates a film over the surface of the particles pushing them apart and increasing the apparent volume. This is commonly known as "bulking" and can cause significant errors in proportioning volume.

e) **Crushed Stone Sand vs River Sand:** River Sand is becoming scarce and as an alternate, crushed stone sand – CSS (also called manufactured sand colloquially) is being manufactured in many cities and towns. Crushed stone sand made using Vertical Shaft Impact (VSI) crusher is found superior to river sand since CSS has cubical particles, no deleterious materials like clay and organic impurities and also conforms to zone requirements of IS: 383. This results in improved cohesion and compression strength of concrete.

- **Mixing water**

Excessive impurities in water used for mixing concrete may affect concrete strength, setting time and induce corrosion of reinforcement. Indian standards suggest drinkable quality water for mixing concrete but because of shortage recycled water can be safely used as mixing water after testing to ensure that the requirements of Cl 5.4 of IS:456 – 2000 are satisfied. The best way to determine the suitability of a water of unproven performance for making concrete is to compare the setting time of cement and the strength of mortar cubes made with the unproven water with reference water that is clean. Unproven water under question is allowed to be used when compressive strength is at least 90% of that achieved using clean water.

- **Admixtures**

Admixtures are classified as mineral admixtures (fly ash, slag etc.,) and Chemical Admixtures. Water reducing admixtures (plasticizers) - with their ability to reduce water content of concrete mixture, can enhance both the early and the ultimate strength of concrete.

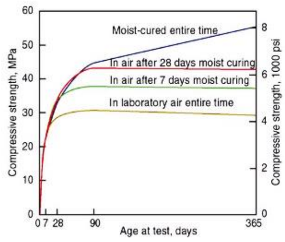
Admixtures capable of accelerating or retarding cement hydration obviously would have a great influence on the rate of strength gain; however, the ultimate strengths may not be significantly affected. It is important to choose chemical admixtures with care since some of them may not be compatible with the type of cement used.

For ecological reasons to reduce the carbon emission, the use of pozzolanic and cementitious by-products as mineral admixtures in concrete is gradually increasing which has retarding effect on early age strength. Their ability to form additional calcium silicate hydrate can lead to significant reduction in porosity of both the matrix and the interfacial transition zone and improvement in ultimate strength and water tightness of concrete.

- **Curing Parameters**

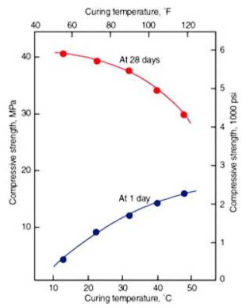
Curing plays an important role on strength development and durability of concrete. Curing is the process of preventing the loss of moisture from the concrete and maintaining a satisfactory temperature regime while it is hardening and gaining strength. Effects of curing depend on a combination of conditions namely time, humidity and temperature.

a) **Time** - Longer curing time improves the hydration process resulting in higher compressive strength. If the concrete is allowed to dry out, the hydration reaction will stop as the hydration reaction cannot proceed without moisture. If water is lost by evaporation from the capillaries, air-curing conditions prevail, and strength of concrete will not increase with time. The figure shows the strength development of similar concretes exposed to different conditions.



b) **Humidity** – For a constant water-cement ratio, the ultimate strength of the moist cured concrete would be much higher than the strength of the continuously air-cured concrete. The duration of curing depends on mixture proportions, specified strength, size and shape of concrete member and ambient weather conditions. A minimum period of 7 days of moist curing is generally recommended if OPC is used and in case of use of blended cement, the curing should be for a period of at least 10 days.

c) **Temperature -** Strength depends on the time-temperature history of casting and curing. It is generally observed that up to 28 days, the higher the temperature the more rapid the cement hydration and higher would be the early strength gain. At later ages, when the differences in the degree of cement hydration disappear, so do the differences in the concrete strength. Higher the casting and curing temperature, the lower will be the ultimate strength. The ultimate strengths of the concrete cast at lower temperatures are higher than those cast at higher temperatures. In low temperature casting, relatively more uniform microstructure of the hydrated cement paste accounts for the higher strength. Lower the curing temperature, the lower would be the strength up to 28 days. Since the hydration reactions are slow, it is essential that adequate temperature levels must be maintained for a sufficient time to provide the needed activation energy for the reactions to begin and continue.



- **Testing Parameters**

Results of concrete strength tests are significantly affected by parameters involving the test specimen and loading conditions. Specimen parameters include the way they are cast, cured, dimensional accuracy and the moisture state of concrete. Loading parameters include stress level and duration and the rate at which stress is applied.

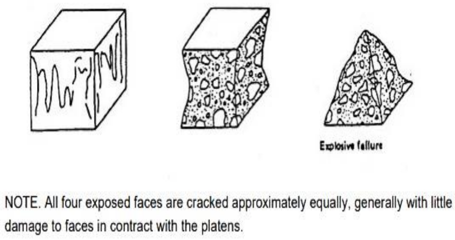
Specimen parameters –

- **Size:** Standard specimen used in India is a cube of 150mm sides. The code (IS 516) permits use of cubes of 100mm sides if the size of coarse aggregate does not exceed 20mm. The code also permits use of 150mm dia cylinders of 300mm height. The dimensions shall not deviate by more than 0.5mm
- **Casting procedure:** The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance. The concrete shall be filled into the mould in layers approximately 50 mm deep. Each layer shall be compacted either by hand (applying min. 35 strokes to each layer with a tamping rod) or by vibration. After the top layer bas been compacted. surface of the concrete shall be finished level with the top of the mould, using a trowel, and covered with a glass or metal plate to prevent evaporation.
- **Curing procedure:** The specimens inside the mould which are kept covered with a wet hessian cloth, are demoulded after 24 hours and immediately transferred to a curing tank till the time of testing. In the curing tank water is kept at a temperature of $27^0 \pm 2^0$.
- **Moisture State:** The In compression tests it has been observed that air-dried specimens show 20 to 25 percent higher strength than corresponding specimens tested in saturated surface dry condition. Hence if the cubes are in air dried condition, it is advisable to immerse the cubes in water for 24 hours before testing.

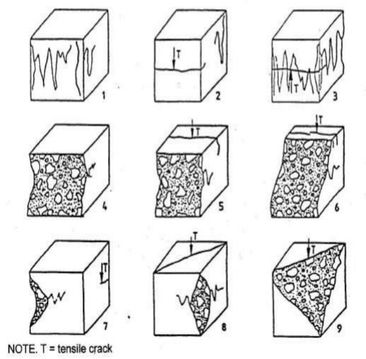
Loading parameters - Loading condition has an important influence on the strength. It is very important that the cube specimen should be placed in the CTM with the “as cast top surface” facing sideways as shown in the photo The central axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated loading platen. The surfaces of the top and bottom platens shall be truly parallel. The load shall be applied without shock and increased continuously at a constant rate of approximately 140 kg/cm^2/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. It is generally agreed that the more rapid the rate of loading, the higher would be the observed strength. The maximum load applied to the specimen shall then be recorded.

- **Failure Mode**

The mode of failure of the cube and the fractured surface should be closely observed as it indicates major issues if any. The typical failures are as shown in figure. The unsatisfactory failures could be due to insufficient attention to the detail of various procedures to be followed in making and testing of specimens like inadequate compaction, improper geometry, misalignment of loading axis, machine issues etc.



Satisfactory failures



Unsatisfactory failures

Conclusion

Compressive Strength gives an overall indication of quality of concrete. Compressive strength is related to the other strengths like tensile, flexural, bond strengths. There are several factors responsible for achieving desired strength starting from raw materials to the process of making and casting of concrete. It is also important to know that several factor affect the accuracy of estimating this crucial parameter called compressive strength.

References:

- **IS 516 : 1959 (Reaffirmed 2004) – Indian Standard Methods of test for strength of Concrete**
- **IS 456 : 2000 (Reaffirmed 2005) – Indian Standard Plain and Reinforced Concrete – Code of Practice**
- **IS 383 : 2016 Indian Standard Coarse and Fine Aggregate for Concrete - Specification**
- **Concrete Microstructure, properties and materials by P. Kumar Mehta, Paulo J M Monteiro.**
- **Advanced Concrete Technology, Concrete Properties by John Newman.**
- **www.constructor.org; civilsnapshot.com; engr.psu.edu; cement.org and other sites on internet**

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