Plain & Reinforced Concrete-1

CE-313

Compressive Strength of Concrete

- Strength of concrete is its most valuable property that determines the amount of resistance it can offer against the applied loading.
- Further, it indirectly gives indication about other important characteristics, such as, durability, impermeability and stability against volume changes.
- Strength of concrete is more related to physical structure of the hardened concrete compared with the actual chemical composition.
- It basically depends upon factors that are difficult to study directly including presence of flaws, discontinuities and pores.
- To control the quality of concrete, there is a need to concentrate on aspects that may reduce the flaws, discontinuities and pores.

- For better strength of concrete, a minimum amount of cement is required to coat the aggregate particles and bind them together.
- The concept that greater amount of cement increases the strength directly is not always correct.
- Greater cement increases workability and compaction and reduces W/C ratio, which increase the strength.
- The strength of concrete mainly depends on two factors:

  1. Degree of compaction and   2. W / C ratio.

- If more compaction is achieved at a lower W / C ratio, using lesser content of cement with addition of plasticizers, etc., the strength of concrete may be higher.

- In general, compressive strength of concrete is measured by performing tests on concrete cylinders or cubes.
- The strength against other actions, like tensile and shear strengths, are determined indirectly.
- However, even the compressive strength also depends upon the tensile strength.
- A compression test specimen fails by crushing that may also be considered as the splitting in the perpendicular direction due to Poisson’s effect and slenderness effect.

- The concrete strength is indeed controlled by limiting strain rather than a maximum stress level.
- In pure tension, concrete fails at a strain value within the range 0.0001 to 0.0002.
- The compressive strain causing failure is approximately 0.002 for a 70 MPa concrete to 0.004 for a 14 MPa concrete.

Mechanism Of Concrete Failure In Compression

- Very fine cracks are present in hardened concrete at the surface of coarse aggregate before the application of load and are called ***bond cracks***.
- These cracks appear due to differential volume changes between the aggregate and the cement paste.
- The differential volume changes are caused by different stress-strain behavior, coefficient of thermal expansion and moisture movement patterns.

- The bond cracks do not open up to approximately 30 per cent of the ultimate strength.
- At a stress level of approximately 30 to 70 per cent of the ultimate strength, bond cracks grow in number, length and width.
- At this stage, the stress-strain curve becomes somewhat nonlinear due to development of more strain.
- In this range of applied stress, the cracks are not usually interconnected with each other and are termed ***micro-cracks***.
- At stress levels of 70 to 90 per cent, cracks through the mortar appear that connect the bond cracks to form longer interconnected cracks.

Factors Affecting Strength Of Concrete

1. Porosity

- The reduction in concrete strength with the amount of voids is given in Table 22.1.
- This is the main factor that influences strength, but by itself this is mainly controlled by the W / C ratio of the mix.
- Pores are produced in the hardened concrete due to two main reasons.
  - The first reason is the presence of entrapped air in concrete due to compaction less than 100 per cent (***air voids*** are produced).
  - The second reason is the evaporation of water from the hardened concrete (may be called ***water pores***).

Table 22.1. Average Reduction of Concrete Strength due to Presence of Voids.

Voids Percentage	**Strength Reduced**
2%	10%
5%	30%
10%	55%
20%	85%

- The water added to a concrete mix remains as combined water, gel water and capillary water in the hardened moist cured concretes.
- The ***combined water*** is the water that is chemically combined or permanently held within crystals as water of hydration.
- This water does not evaporate upon drying up to 105° C, and amounts to approximately 23 per cent of the mass of dry cement.
- The ***gel pores*** are very small pores of about 2×10^{-6} mm diameter formed by the crystals of hydrates containing gel water.

- The gel water is approximately 28 per cent of the cement gel volume.
- ***Capillary pores*** are relatively larger pores, approximately 0.001mm in diameter, formed within the gel due to the fact that the hydrate-crystals occupy less volume than the original unhydrated constituents (water and cement).
- The volume of these pores is approximately 18.5 per cent of the dry volume of cement provided that full hydration takes place and there is no excess water added.
- Capillary pores may be filled with ***capillary water*** during moist curing.

- At a water / cement ratio of 0.6, all types of pores for fully compacted concrete may occupy 47 to 60 per cent volume of the cement paste.
- Strength of concrete not only depends upon the total volume of pores but also upon the other features such as whether these pores are interconnected or they are separate.
- As already stated, the exact effect of porosity of cement gel is indirectly determined based on the W / C ratio.

2. Degree of compaction

- Compaction is related with the removal of air-voids from the concrete, whereas, porosity deals with the presence of both air and water pores.
- If full compaction is not carried out, air-voids are left in concrete. These large voids significantly reduce the strength as discussed in the topic of workability.

3. Water-cement ratio

- After the degree of compaction, W / C ratio is the single largest factor affecting the strength.
- Larger W / C ratio from a basic value required for full hydration, reduces the strength drastically by increasing the porosity of the cement gel.
- Effective water-cement ratio is to be used for the comparison, which is based on water added for saturated surface dry aggregate.

4. Age of concrete

- The strength of concrete increases with age and this effect is caused by more hydration of cement and reduction of capillary pores.
- The effect is more pronounced at early ages and becomes slow at higher ages.
- After an age of one year, the effect is insignificant.

5. Improper curing and temperature changes

- Improper curing and larger temperature changes produce shrinkage and thermal cracks.
- These cracks further reduce the strength of concrete.

6. Aggregate / cement ratio

- For a constant W / C ratio and full compaction, a leaner mix with larger aggregate / cement ratio develops a higher strength.
- This effect is produced due to lesser porosity of the resulting concrete.

7. Aggregate properties

- The factors like grading, surface texture, shape, strength and maximum size of aggregate also influence the concrete strength.
- For example, the bond cracks may easily develop and propagate for smooth gravel than for rough and angular crushed aggregate.
- Hence, crushed aggregate may develop larger strengths.
- For high strength concretes, failure planes may pass through the larger size aggregate particles and their individual strength also becomes significantly important.

8. Effect of additives and admixtures

- The presence of various additives and admixtures may influence the strength of concrete.
- Usually strengths at ages lesser than 28 days are affected the most.
- However, the final strengths may also vary with the type of cement and presence of any additional chemical in it.

Concluded