Factors affecting strength of concrete:

1. Water/cement ratio:

In engineering practice, the strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors only:

(a) Water/cement ratio.
(b) Degree of compaction.

When considering fully compacted concrete only: for mix proportioning purposes this is taken to mean that the hardened concrete contains about 1 % t of air voids. When concrete is fully compacted, its strength is taken to be inversely proportional to the water/cement ratio as shown in the following equation:

$$f_c = \frac{K_1}{K_2^{w/c}}$$

Where:
w/c : represents the water/cement ratio of the mix (originally taken by volume),
K_1 and K_2 : are empirical constants.

The general form of the strength versus water/cement ratio curve is shown in Fig. 6.1.

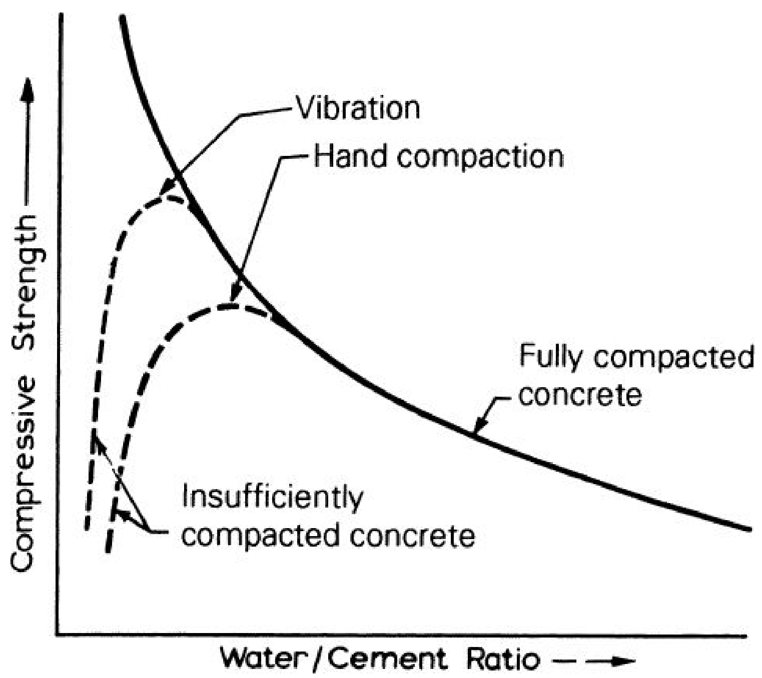

Fig. 6.1. The relation between strength and water/cement ratio of concrete

2. Effective water in the mix

- We consider as effective that water which occupies space outside the aggregate particles when the gross volume of concrete becomes stabilized, i.e. approximately at the time of setting. Hence the terms *effective*, *free*, or *net* water/cement ratio.
- *Generally, water in concrete consists:*
  (1) Added water to the mix.
  (2) Water that held by the aggregate at the time when it enters the mixers.

- A part of the latter water is absorbed within the pore structure of the aggregate while some exists as free water on the surface of the aggregate and is therefore no different from the water added direct into the mixer.
- Conversely, when the aggregate is not saturated and some of its pores are therefore air-filled, a part of the water added to the mix will be absorbed by the aggregate during the first half-hour or so after mixing. Under such circumstances the demarcation between absorbed and free water is a little difficult.

3. Gel/space ratio

In particular, strength at any water/cement ratio depends on:

(1) Degree of hydration of cement.
(2) Chemical and physical properties of cement;
(3) Temperature at which hydration takes place;
(4) Air content of the concrete;
(5) Formation of cracks due to bleeding

It is more correct, therefore, to relate strength to the concentration of the solid products of hydration of cement in the space available for these products.

4. Influence of aggregate/cement ratio on strength

- There is no doubt that the aggregate/ cement ratio, is only a secondary factor in the strength of concrete but it has been found that, for a constant water/cement ratio, a leaner mix leads to a higher strength.
- In certain cases, some water may be absorbed by the aggregate: a larger amount of aggregate absorbs a greater quantity of water, the effective water/ cement ratio being thus reduced.
- In other cases, a higher aggregate content would lead to lower shrinkage and lower bleeding, and therefore to less damage to the bond between the aggregate and the cement paste; likewise, the thermal changes caused by the heat of hydration of cement would be smaller.
- The total water content per cubic meter of concrete is lower in a leaner mix than in a rich one. As a result, in a leaner mix, the voids form a smaller fraction of the total volume of concrete, and it is these voids that have an adverse effect on strength.

5. Influence of properties of coarse aggregate:

- The properties of aggregate affect the cracking load, as distinct from ultimate load, in compression and the flexural strength in the same manner that the relation between the two quantities is independent of the type of aggregate used.

- On the other hand, the relation between the flexural and compressive strengths depends on the type of coarse aggregate because (except in high strength concrete) the properties of aggregate, especially its shape and surface texture, affect the ultimate strength in compression very much less than the strength in tension or the cracking load in compression.

- In experimental concrete, entirely smooth coarse aggregate led to a lower compressive strength, typically by 10 % than when roughened.

- The influence of **the type of coarse aggregate on the strength of concrete** varies in magnitude and depends on the **water/cement ratio of the mix**.:

  a) For water/cement ratios below 0.4, the use of crushed aggregate has resulted in strengths up to 38 % higher than when gravel is used.

  b) With an increase in the water/cement ratio to 0.5, the influence of aggregate falls off, presumably because the strength of the hydrated cement paste itself becomes paramount.

  c) at a water/cement ratio of 0.65, no difference in the strengths of concretes made with crushed rock and gravel has observed.

6. Effect of age on strength:

The relation between the water/cement ratio and the strength of concrete applies to one type of cement and one age only, and also assumes wet curing conditions.

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

In concrete practice, the strength of concrete is traditionally characterized by the 28-day value, and some other properties of concrete are often referred to the 28-day strength. If, for some reason, the 28-day strength is to be estimated from the strength determined at an earlier age, say 7 days, then the relation between the 28-day and the 7-day strengths has to be established experimentally for the given mix.

7- Effect of temperature on strength

- The rise in the curing temperature speeds up the chemical reactions of hydration and thus affects beneficially the early strength of concrete without any ill-effects on the later strength.

- Higher temperature during and following the initial contact between cement and water reduces the length of the dormant period so that the *overall* structure of the hydrated cement paste becomes established very early.

- Although a higher temperature during placing and setting increases the very early strength, it may adversely affect the strength from about 7 days onwards. The explanation is that:

  1. a rapid initial hydration appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled. It follows from the gel/space ratio rule, that this will lead to a lower strength compared with a less porous, though slowly hydrating, cement paste in which a high gel/space ratio will eventually be reached.

  2. at the high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space (as is the case at lower temperatures). As a result, a high concentration of the products of hydration is built up in the vicinity of the hydrating particles, and this retards the subsequent hydration and adversely affects the long-term strength.

- For laboratory-made concrete, using ordinary or modified Portland cement, the optimum temperature is approximately 13 °C ; for rapid-hardening Portland cement it is about 4 °C .

- Beyond the initial period of setting and hardening the influence of temperature (within limits) accords with the maturity rule: a higher temperature accelerates the development of strength.

- The tests described so far were all made in the laboratory or under known conditions, but the behavior on site in a hot climate may not be the same. There are some additional factors acting:

  - ✓ Ambient humidity,
  - ✓ Direct radiation of the sun,
  - ✓ Wind velocity,
  - ✓ Method of curing.
  - ✓ Temperature of concrete.
  - ✓ Size of the member.