Hardened Concrete

General

- The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. In those cases where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties.
- Therefore, the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength.
- The compressive strength of concrete is generally determined by testing cubes or cylinders made in laboratory or field or cores drilled from hardened concrete at site or from the non-destructive testing of the specimen or actual structures.

- Strength of concrete is its resistance to rupture. It may be measured in a number of ways, such as, strength in compression, in tension, in shear or in flexure. All these indicate strength with reference to a particular method of testing. When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure.

Factors affecting strength of concrete:

(a) Ratio of cement to mixing water;

(b) Ratio of cement to aggregate;

(c) Grading, surface texture, shape, strength and stiffness of aggregate particles;

(d) Maximum size of aggregate.

- **Water/Cement Ratio**
- Strength of concrete primarily depends upon the strength of cement paste. The strength of cement paste depends upon the dilution of paste or in other words, the strength of paste increases with cement content and decreases with air and water content.
- Abrams water/cement ratio law states that the strength of concrete is only dependent upon water/cement ratio provided the mix is workable.
- From the Fig. It can be seen that lower water/cement ratio could be used when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand compacted.
- In both cases when the water/cement ratio is below the practical limit the strength of the concrete falls rapidly due to introduction of air voids.

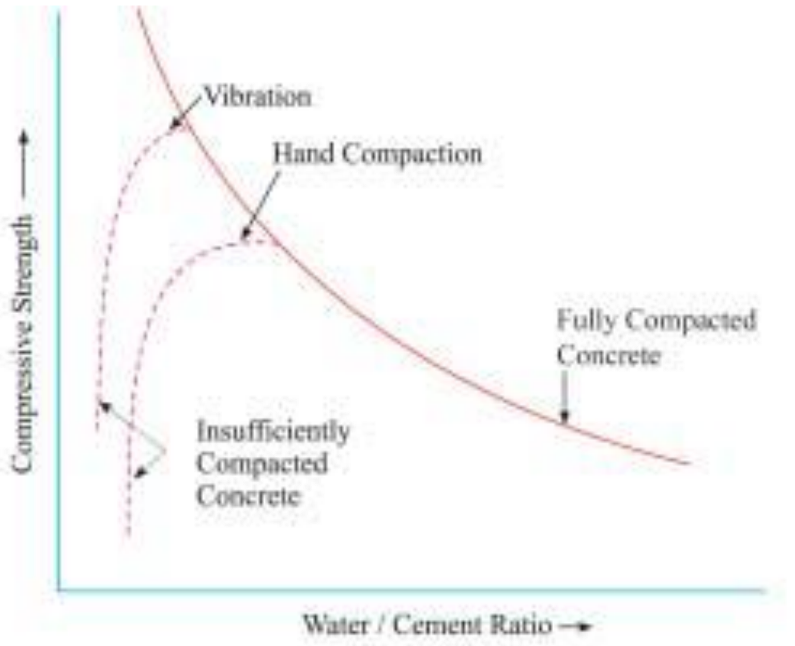


Fig. 7.1. The relation between strength and water/cement ratio of concrete.

- **Gel/Space Ratio**
- Some of the limitations are that the strength at any water/cement ratio depends on the degree of hydration of cement and its chemical and physical properties, the temperature at which the hydration takes place, the air content in case of air entrained concrete, the change in the effective water/cement ratio and the formation of fissures and cracks due to bleeding or shrinkage.
- Instead of relating the strength to water/cement ratio, the strength can be more correctly related to the solid products of hydration of cement to the space available for formation of this product.
- Powers and Brownyard have established the relationship between the strength and gel/space ratio. This ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of volumes of the hydrated cement and of the capillary pores.

Calculation of gel/space ratio for complete hydration

Let C = weight of cement in gm.

V_C = specific volume of cement = 0.319 ml/gm.

W_O = volume of mixing water in ml.

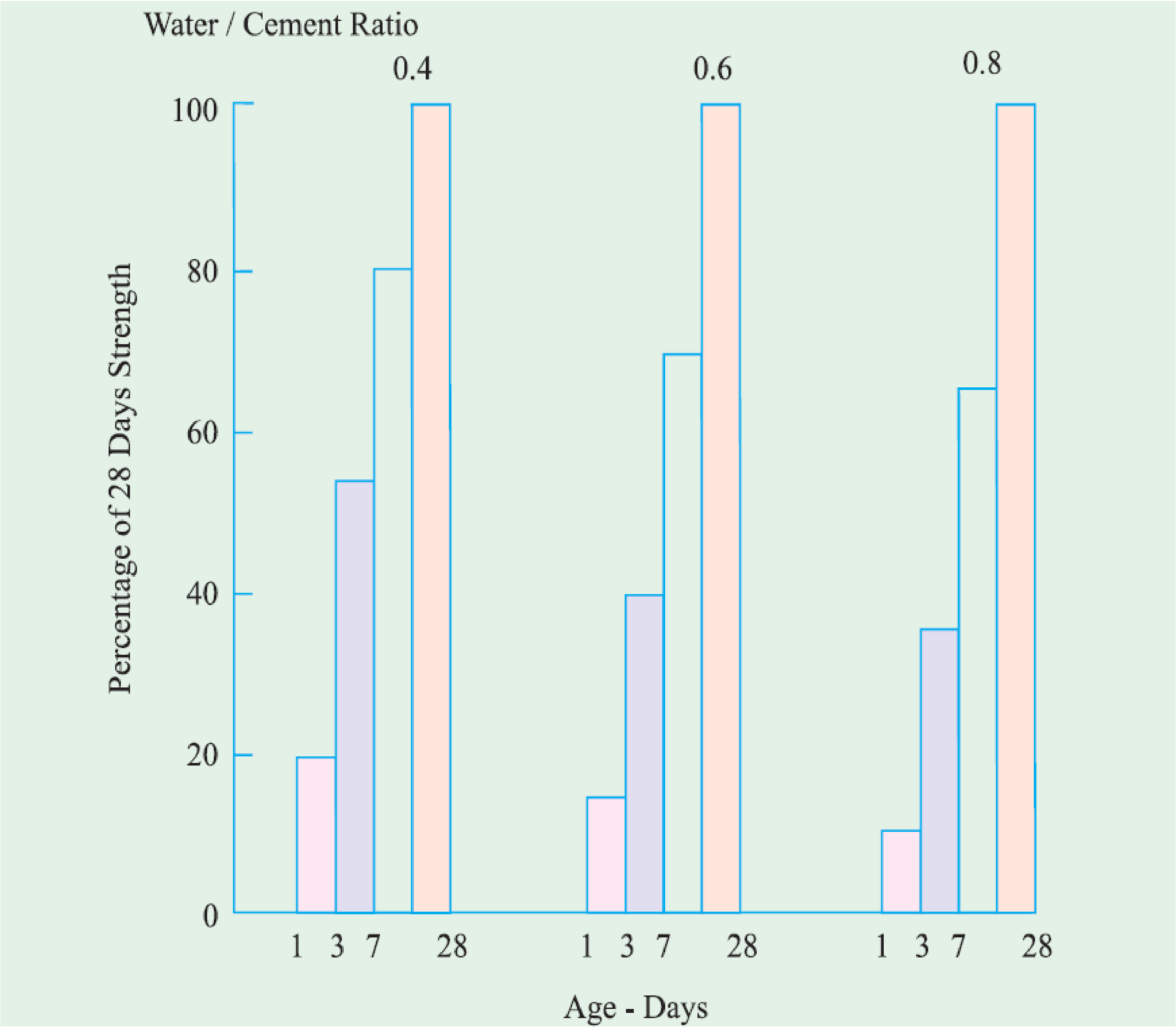
Assuming that 1 ml. of cement on hydration will produce 2.06 ml of gel,

Volume of gel = $C \times 0.319 \times 2.06$

Space available = $C \times 0.319 + W_O$

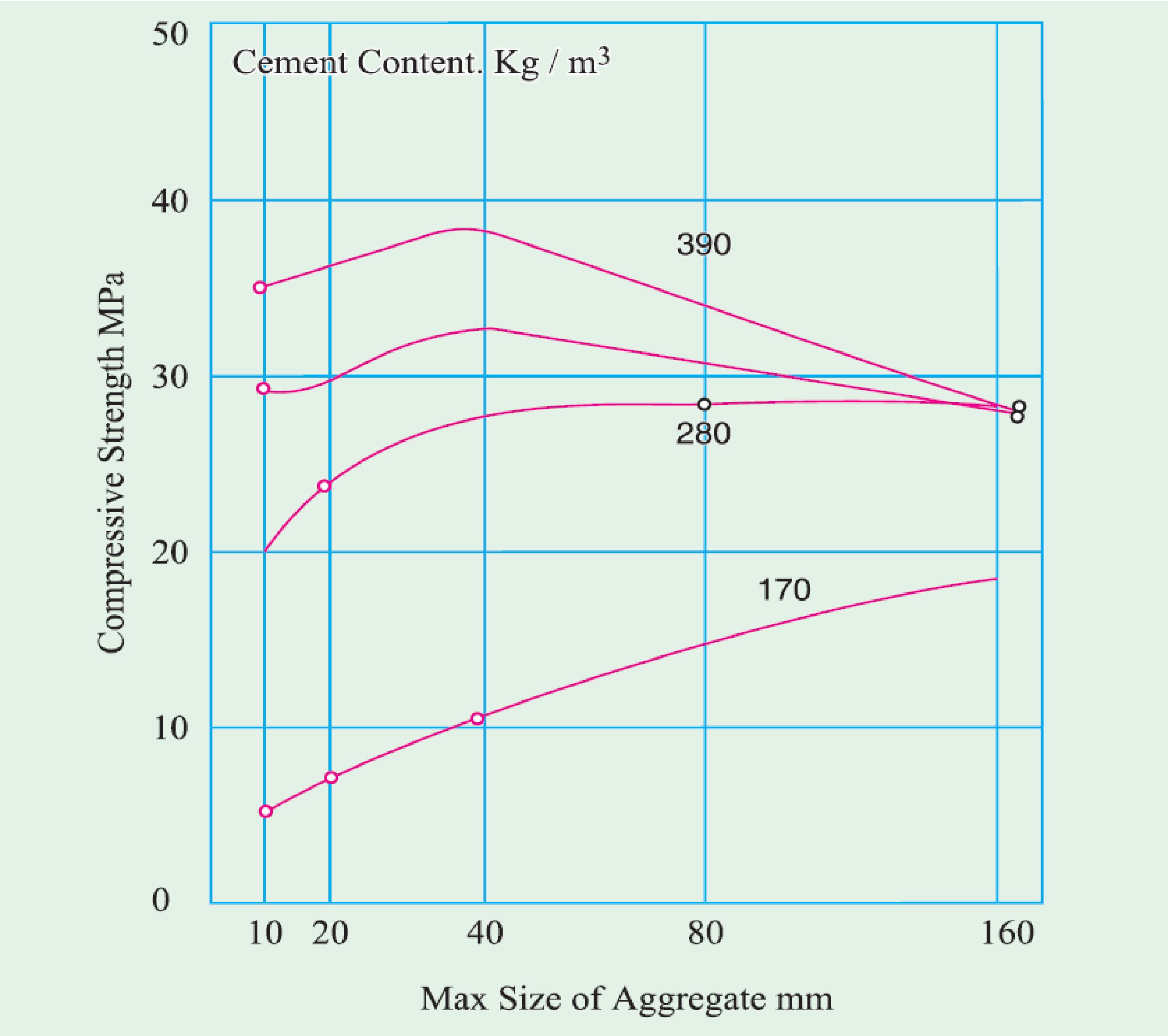
$$\therefore \quad \text{Gel/Space ratio} = x = \frac{\text{Volume of gel}}{\text{Space available}} = \frac{0.657\,C}{0.319\,C + W_O}$$

- **Gain of Strength with Age**
- The concrete develops strength with continued hydration. The rate of gain of strength is faster to start with and the rate gets reduced with age. It is customary to assume the 28 days strength as the full strength of concrete. Actually concrete develops strength beyond 28 days also. Earlier codes have not been permitting to consider this increase of strength beyond 28 days for design purposes.
- The increase in strength beyond 28 days used to get immersed with the factor of safety. With better understanding of the material, progressive designers have been trying to reduce the factor of safety and make the structure more economical. In this direction, the increase in strength beyond 28 days is taken into consideration in design of structures.

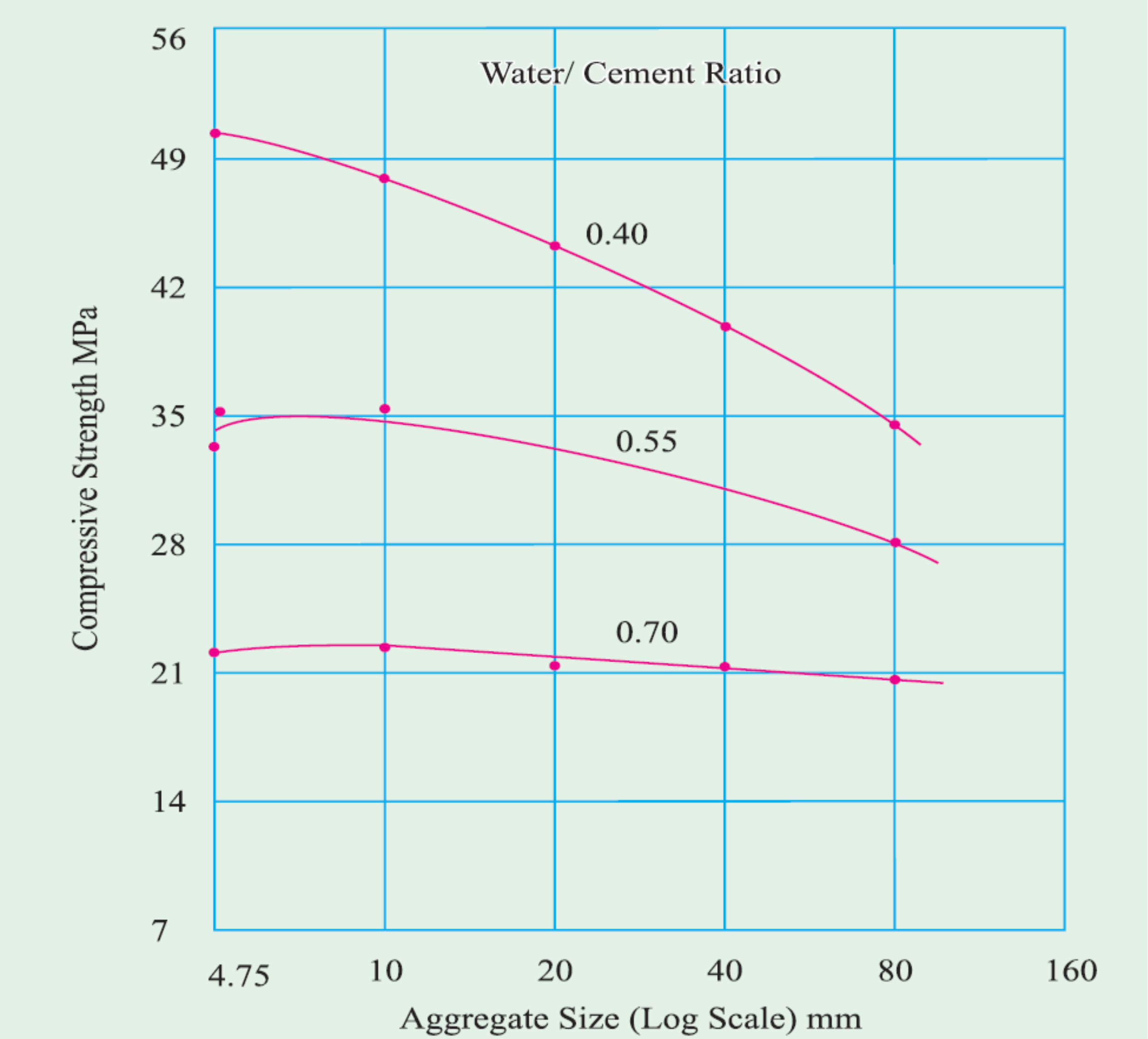


Water / Cement Ratio
0.4
0.6
0.8
100
80
60
40
20
0
Percentage of 28 Days Strength
1 3 7 28
1 3 7 28
1 3 7 28
Age - Days

- **Effect of Maximum size of Aggregate on Strength**
- At one time it was thought that the use of larger size aggregate leads to higher strength. This was due to the fact that the larger the aggregate the lower is the total surface area and, therefore, the lower is the requirement of water for the given workability. For this reason, a lower water/cement ratio can be used which will result in higher strength.
- However, later it was found that the use of larger size aggregate did not contribute to higher strength as expected from the theoretical considerations due to the following reasons.
- The larger maximum size aggregate gives lower surface area for developments of gel bonds which is responsible for the lower strength of the concrete. Secondly bigger aggregate size causes a more heterogeneity in the concrete which will prevent the uniform distribution of load when stressed.
- When large size aggregate is used, due to internal bleeding, the transition zone will become much weaker due to the development of microcracks which result in lower compressive strength.
- Generally, high strength concrete or rich concrete is adversely affected by the use of large size aggregate. But in lean mixes or weaker concrete the influence of size of the aggregate gets reduced. It is interesting to note that in lean mixes larger aggregate gives highest strength while in rich mixes it is the smaller aggregate which yields higher strength.



50
40
30
20
10
0
Cement Content. Kg / m3
390
280
170
Compressive Strength MPa
10
20
40
80
160
Max Size of Aggregate mm



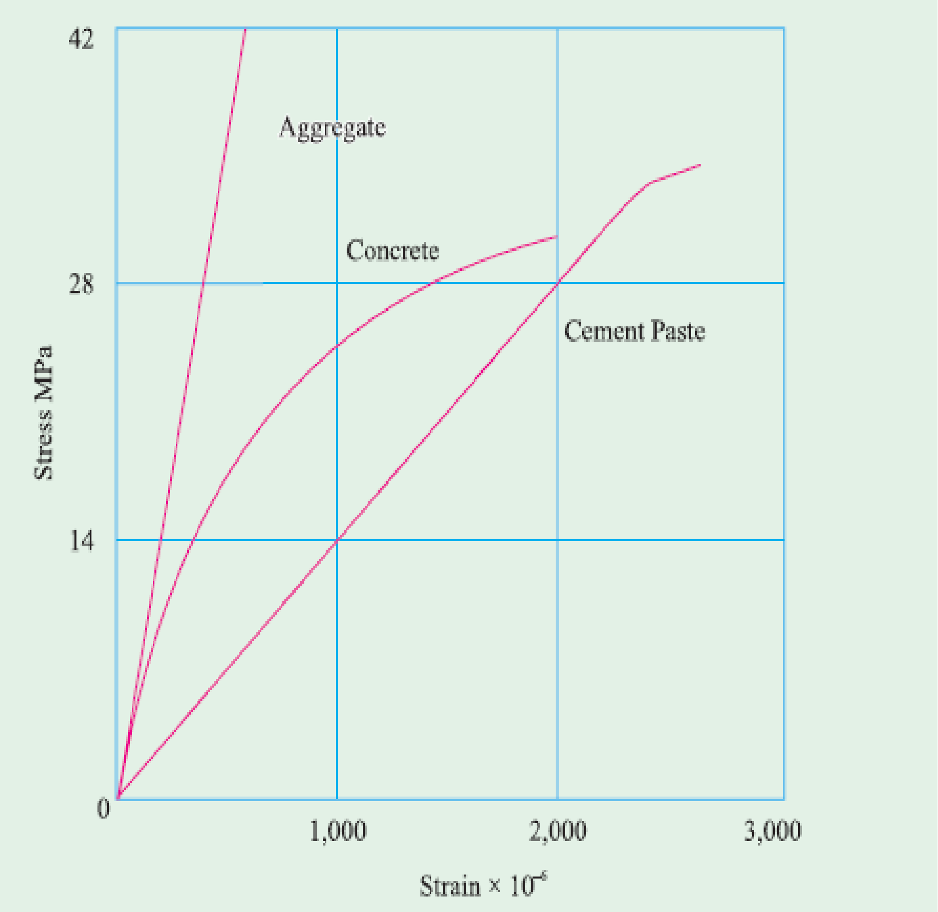
Water/ Cement Ratio
0.40
0.55
0.70
56
49
42
35
28
21
14
7
Compressive Strength MPa
4.75
10
20
40
80
160
Aggregate Size (Log Scale) mm

- **Bond Strength**
- We can consider the bond strength from two different angles; one is the bond strength between paste and steel reinforcement and the other is the bond strength between paste and aggregate. Firstly, let us consider the bond strength between paste and steel reinforcement.
- Bond strength between paste and steel reinforcement is of considerable importance. A perfect bond, existing between concrete and steel reinforcement is one of the fundamental assumptions of reinforced concrete. Bond strength arises primarily from the friction and adhesion between concrete and steel.
- The roughness of the steel surface is also one of the factors affecting bond strength. The bond strength of concrete is a function of compressive strength and is approximately proportional to the compressive strength upto about 20 MPa. For higher strength, increase in bond strength becomes progressively smaller.

- **Elastic Properties of Concrete**
- theory of reinforced concrete, it is assumed that concrete is elastic, isotropic, homogenous and that it conforms to Hooke's law. Actually none of these assumptions are strictly true and concrete is not a perfectly elastic material. Concrete deforms when load is applied but this deformation does not follow any simple set rule.
- The deformation depends upon the magnitude of the load, the rate at which the load is applied and the elapsed time after which the observation is made. In other words, the rheological behaviour of concrete i.e., the response of concrete to applied load is quite complex.

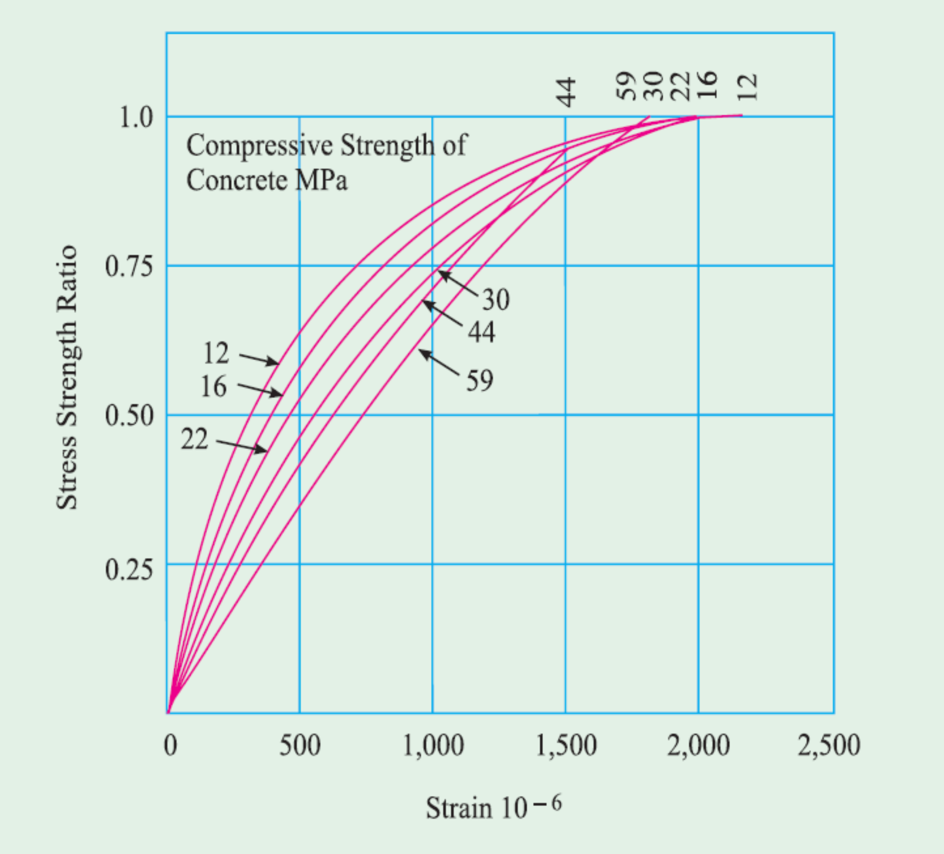
- When reinforced concrete is designed by elastic theory it is assumed that a perfect bond exists between concrete and steel. The stress in steel is “m” times the stress in concrete where “m” is the ratio between modulus of elasticity of steel and concrete, known as modular ratio.
- The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxial compression and measuring the deformations by means of dial gauges fixed between certain gauge length. Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross section will give the stress. A series of readings are taken and the stress-strain relationship is established.

- The stress-strain relationship of aggregate alone shows a fairly good straight line. Similarly, stress-strain relationship of cement paste alone also shows a fairly good straight line. But the stress-strain relationship of concrete which is combination of aggregate and paste together shows a curved relationship.
- Perhaps this is due to the development of micro cracks at the interface of the aggregate and paste. Because of the failure of bond at the interface increases at a faster rate than that of the applied stress, the stress-strain curve continues to bend faster than increase of stress.

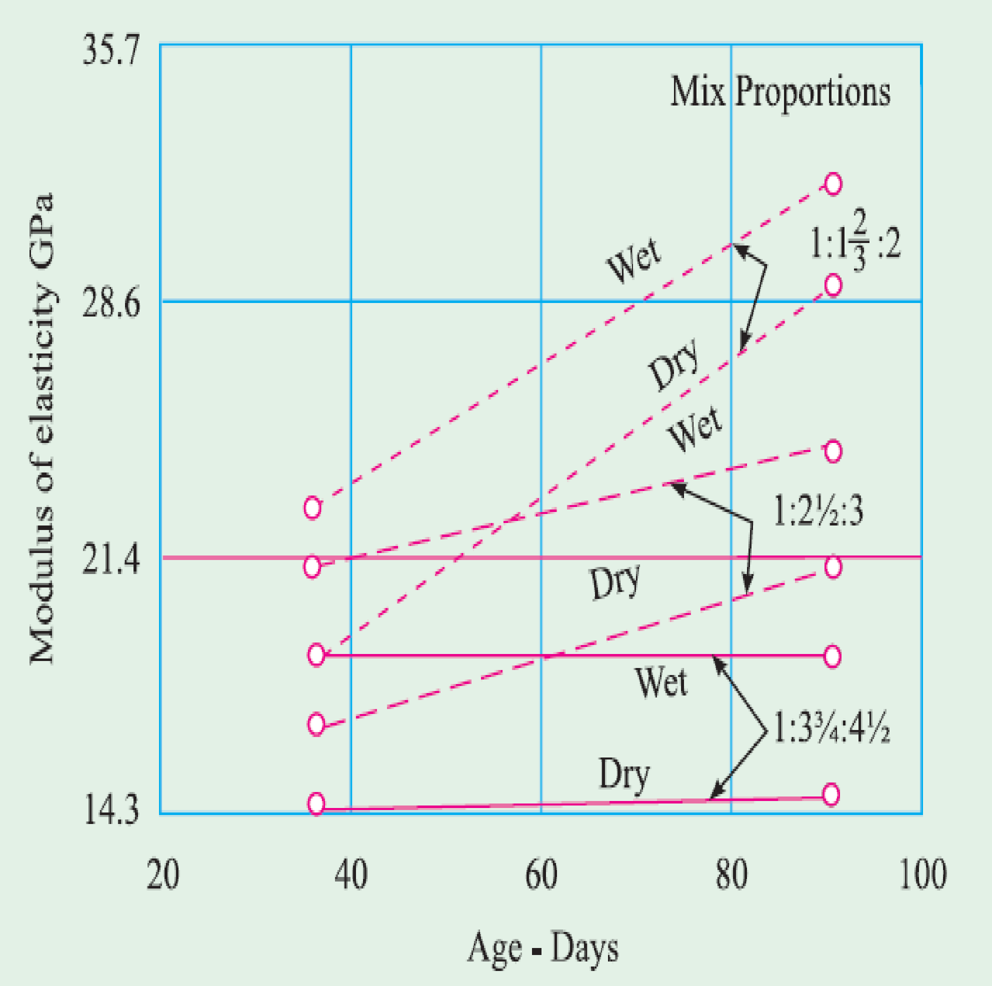


- **Relation between Modulus of Elasticity and Strength**
- Figure shows the strain in concrete of different strengths plotted against the stress strain ratio. At the same stress-strength ratio, stronger concrete has higher strain.
- On the contrary, stronger the concrete higher the modulus of elasticity. This can be explained that stronger the concrete the stronger is the gel and hence less is the strain for a given load.
- Because of lower strain, higher is the modulus of elasticity. Modulus of elasticity of concrete increases approximately with the square root of the strength. The IS 456 of 2000 gives the Modulus of elasticity as EC = 5000 √*fck* ,

  where EC is the short term static modulus of elasticity in N/mm2.



- **Factors Affecting Modulus of Elasticity**
- As explained earlier, one of the important factors affecting the modulus of elasticity of concrete is the strength of concrete. This can be represented in many ways such as the relationship between ratio of mix or water/cement ratio.
- The modulus of elasticity also depends upon the state of wetness of concrete when other conditions being the same. Wet concrete will show higher modulus of elasticity than dry concrete. This is in contrast to the strength property that dry concrete has higher strength than wet concrete.
- The possible reason is that wet concrete being saturated with water, experiences less strain for a given stress and, therefore, gives higher modulus of elasticity, whereas dry concrete shows higher strain for given stress on account of less gel water and inter-crystal adsorbed water.



- **Creep**
- Creep can be defined as "the time-dependent" part of the strain resulting from stress. The stress-strain relationship of concrete is not a straight line relationship but a curved one.
- The degree of curvature of the stress-strain relationship depends upon many factors amongst which the intensity of stress and time for which the load is acting are of significant interest.
- Therefore, it clearly shows that the relation between stress and strain for concrete is a function of time. The gradual increase in strain, without increase in stress, with the time is due to creep. From this explanation creep can also be defined as the increase in strain under sustained stress.
- Creep takes place only under stress. Under sustained stress, with time, the gel, the adsorbed water layer, the water held in the gel pores and capillary pores yields, flows and readjust themselves, which behavior is termed as creep in concrete.

- **Factors Affecting Creep**

(1) Influence of Aggregate:

- Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep.
- The grading, the shape, the maximum size of aggregate have been suggested as factors affecting creep. But it is later shown that the effect of aggregate and their properties mentioned above per se do not effect the creep.

(2) Influence of Mix Proportions:

- The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio.

(3) Influence of Age:

- Age at which a concrete members is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more.

Effects of Creep:

- The magnitude of creep is dependent on many factors, the main factors being time and level of stress. In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In reinforced concrete columns, creep property of concrete is useful. Under load immediately elastic deformation takes place. Concrete creeps and deforms. It can not deform independent of steel reinforcement. There will be gradual transfer of stress from concrete to steel.

- **Shrinkage**
- Concrete is subjected to changes in volume either autogenously or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete.
- Effect of volume change due to thermal properties of aggregate and concrete, due to alkali/aggregate reaction, due to sulphate action etc. Presently we shall discuss the volume change on account of inherent properties of concrete “shrinkage”.

- The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons. To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage ; (b) Drying Shrinkage;

(c) Autogeneous Shrinkage; (d) Carbonation Shrinkage.

(1) Plastic Shrinkage

- Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade, is believed to be the reasons of plastic shrinkage.
- The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.

(2) Drying Shrinkage

- Just as the hydration of cement is an ever lasting process, the drying shrinkage is also an ever lasting process when concrete is subjected to drying conditions. The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen.
- The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume.

- **Factors Affecting Shrinkage**
- One of the most important factors that affects shrinkage is the drying condition or in other words, the relative humidity of the atmosphere at which the concrete specimen is kept.
- If the concrete is placed in 100 per cent relative humidity for any length of time, there will not be any shrinkage, instead there will be a slight swelling.
- Another important factor which influences the magnitude of shrinkage is water/cement ratio of the concrete. As mentioned earlier, the richness of the concrete also has a significant influence on shrinkage.