Theoretical-Experimental Aspects of Determining Concrete Strength

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Abstract

Concrete strength is the property most valued by designers and quality control engineers. In rigid bodies, there is an inverse relationship between porosity (volume fraction of voids) and strength. Consequently, in multi-stage materials such as concrete, the porosity of each microstructure component can become limiting in durability. Natural aggregates are generally dense and strong; hence, it is the porosity of the hydrated cement paste and the interface transition zone between the matrix and the hard aggregate that usually determines the characteristic strength of normal weight concrete. Although the water-cement ratio is important in determining the porosity of the matrix composition and the interface transition zone and the strength of the concrete, factors such as compaction and curing conditions (degree of hydration of the cement), aggregate size and mineralogy, types of admixtures of mixtures, geometry and humidity conditions, types of stresses and load rate can have an impact on strength. In this paper will be explained in detail, the impact of several factors on the strength of concrete. While uniaxial compressive strength is generally accepted as the general concrete strength index, the relationships between compressive uniaxial strength and other strengths such as tensile, bending, shear, and biaxial strength are discussed.

Keywords: *Theoretical-Experimental Aspects, Concrete Strength*

1. Introduction

1.1 Strength-Porosity Relationship

In general, there is a fundamental inverse relationship between the porosity and the strength of rigid bodies. For simple homogeneous materials, it can be described by the expression

$$S = S_0\, e^{-kp} \quad (1)$$

Where S = strength of the material having porosity p
S_0 = internal strength at porosity 0
k = constant

For many materials the schematic S/S_0 ratio against porosity follows the same curve. For example, the data in fig 1a show normally mature cements, autoclaved cements and various types of aggregates. Currently, the same strength-porosity relationship is applicable to a wide variety of materials such as iron, Paris plaster, sintered alumina and zirconia (Fig. 1b).

Powers found that the compressive strength of day 28 f_c in three different samples of mortar compositions was related to the gel/space ratio or the ratio between the hydrated solid products in the system and the total space:

$$f_c = ax^3 \qquad (2)$$

where a is the internal stability of the material at 0 porosity and x is the solid/space ratio or the amount of solid fraction in the system, equal to 1-p. Powers data are shown in fig. 1c; he found the value of 234 MPa. The similarity of the three curves in Figure 1 confirms the overall validity of the strength-porosity relationship in rigid bodies.

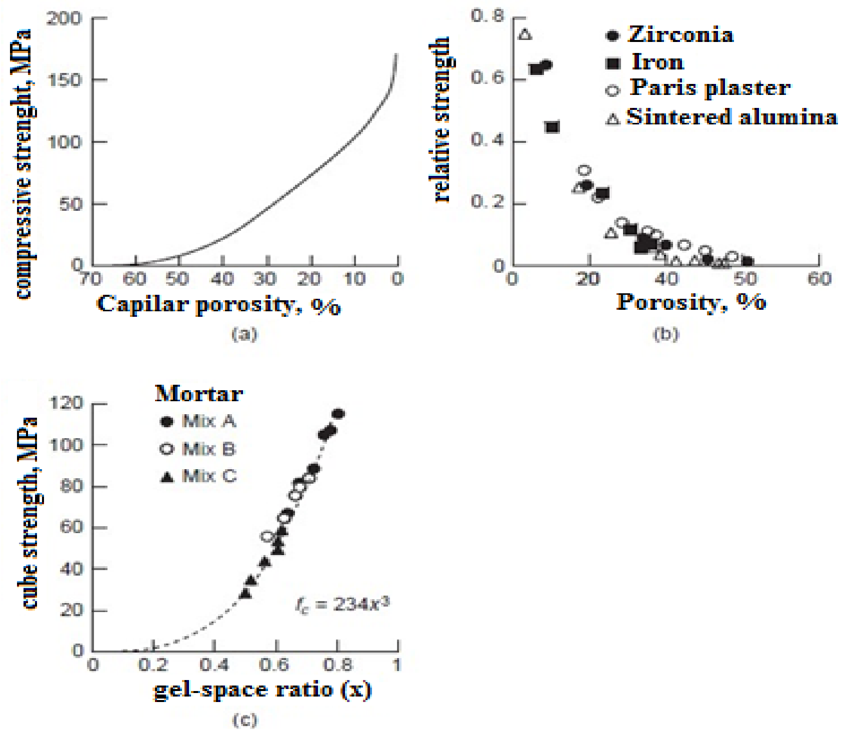

Figure 1 Strength-porosity relationship in solids: (a) baked cement norm wool, autoclaved cement and aggregates; (b) iron, Paris plaster, sintered alumina and zirconia; (c) Portland cement mortar with different mix ratios.

While in reinforced cement paste or in mortar porosity can be related to strength, with concrete the situation changes. The presence of microcracks in the interface transit zone between the hard aggregate and the matrix makes concrete a very complex material for predicting strength through accurate strength-porosity relationships. The overall validity of the strength-porosity relationship must be respected because the porosities of the constituent phases of the concrete, including the interfacial transit area, actually become constraints of strength.

1.2 Ways Of Breaking Concrete

With a material like concrete, which contains empty spaces of different sizes and shapes in the matrix and microcracks in the interfacial transit area, the fracture modes under the stress feed are very complex and vary with the types of stress. A brief overview of fracture modalities would be helpful in understanding and controlling the factors that affect the strength of concrete. Under uniaxial load, relatively less energy is needed to start and increase cracks in the matrix. The rapid proliferation and interconnections of the crack system consist of pre-existing cracks in the interface transit zone and the formation of new cracks in the matrix, leading to brittle fracture. In compression, the breaking mode is a bit more fragile because more energy is needed to form and expand the cracks in the matrix. It is generally accepted that in the test of uniaxial compaction in concrete of medium or low strength, no cracks are initiated in the matrix up to about 50% fracture strain; at this stage a stable cracking system, called the cutting crack belt, already exists in the vicinity of the hard aggregate. The cracks in the matrix and in the interface transit zone join and create a surface fracture of about 20° to 30° from the direction of the load, as shown in fig 2.

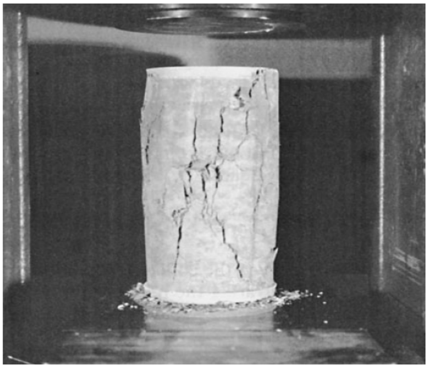

Figure 2 Common failure of compacted concrete

2. Test Parameters

It is not always estimated that the results of concrete strength tests are influenced by parameters that include here the test sample and the load conditions. Sample parameters include the influence of size, geometry and moisture state of the concrete; load parameters include the level and duration of strain and the degree to which the load is applied.

2.1 Sample Parameters

In the United States, the standard specimen for testing the compressive strength of concrete is a 15 by 30 cm cylinder. When maintaining the height/diameter ratio equal to 2, if a concrete mix has been tested in compaction with a variable diameter cylindrical sample; the larger the diameter the smaller the strength will be. The data in fig 3 show that, compared to the standard sample, the average strength of the 5 by 10 cm and 7.5 by 15 cm cylindrical specimens were 106 and 108%, respectively. When the diameter increases beyond 45 cm a very small reduction in strength is observed.

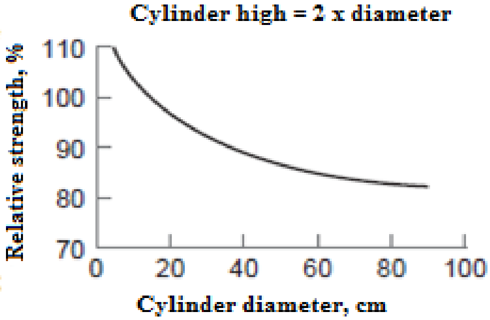

Figure 3 Influence of sample diameter on concrete strength when height/diameter ratio is equal to 2

The effect of changing the sample geometry on the compressive strength of the concrete is shown in Fig. 4. In general, the larger the height / diameter ratio of the sample, the lower the strength. For example, compared to the durability of standard specimens, specimens with a height / diameter ratio of 1 show about 15% more robustness. It may be of interest to note that the strength of concrete based on the standard 15 cm3 sample was reported to have yielded 10-15% more strength than the same concrete mix tested to U.S. standards.

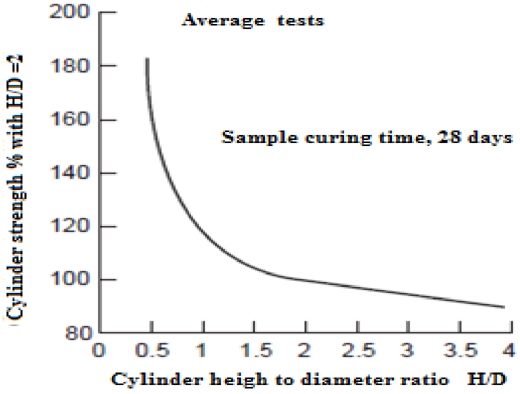

Figure 4 Impact of heigh/diameter ratio change on concrete strength

Due to the effect of the state of moisture on the strength of the concrete, the standard procedure requires that the sample continue to be in humid conditions at the time of testing. In compression tests it has been observed that air-dried samples show 20-25% higher strength than the corresponding samples tested under saturation conditions. The low strength of saturated concrete is due to the separation pressure inside the cement paste.

2.2 Load conditions

The compressive strength of concrete is measured in laboratories through the uniaxial compression test (ASTM C 469) in which the load is progressively increased to break the sample within 2-3 min. In practice, most structural elements are subject to dead loads for an indefinite period of time and repeated loads or shock loads. So it is necessary to know the relationship between the strength of concrete under laboratory test conditions and actual load conditions. The behavior of concrete under different stress conditions is described in the following paragraphs. From this description it can be concluded that the load condition has a large impact on strength.

To evaluate the perspective of the multivariate complex network affecting the strength of concrete, a summary is shown in fig 5.

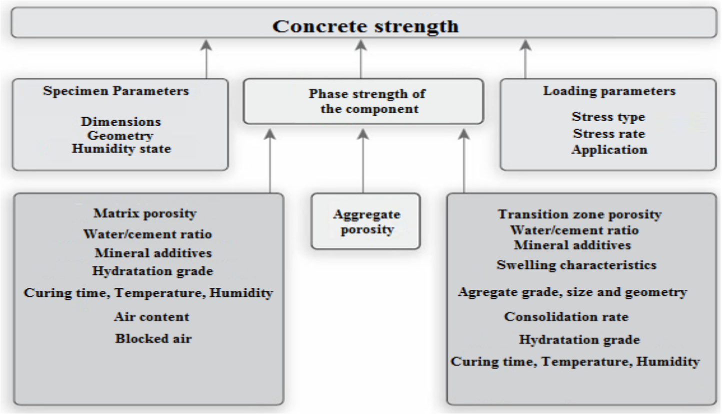

Figure 5 Presentation of factors affecting concrete strength

3. Concrete Behavior Under Uniaxial Compression

The stress-strain behavior of concrete subjected to uniaxial compression will be shown here. The stress-strain curve (fig. 6a) shows linear elastic behavior up to about 30% of the final strength f'_c, because under short load the microcracks in the interface transit zone remain unaffected. For stresses above this point, the curve shows a gradual increase to about 0.75 - 0.9 f'_c, then bends strongly and as a result the sample suffers a fracture.

From the form of the stress-strain curve it appears that with a stress level between 30-50% of f'_c, the microcracks in the interfacial transition zone show some extensions due to the stress concentration at the cracks, however no cracks occur in the mortar matrix. Up to this point, the crack propagation is assumed to be stable in the sense that the crack lengths quickly reach the maximum value if the applied strain is kept constant. With a strain level of 50-75% of f'_c, the crack system tends to be unstable just as cracks in the interface transition area start to grow again. When the existing internal energy exceeds the energy required for the crack, the crack propagation rate will increase and the system will become unstable. This occurs at compressive strain levels above 75% of f'_c, where complete rupture of the test specimen can occur by rupture bridges between the matrix and the interfacial transit area.

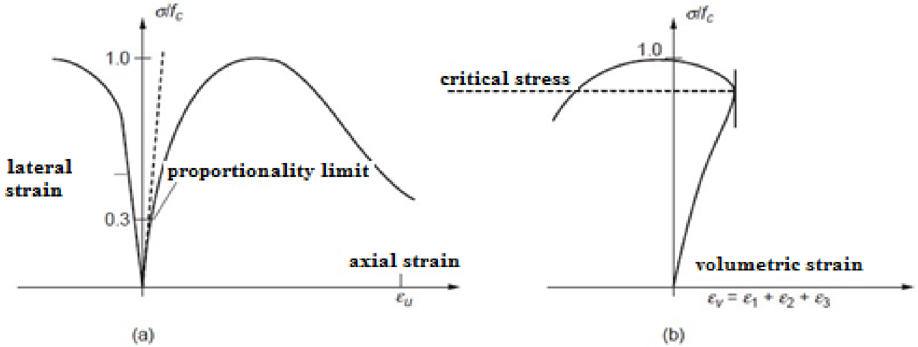

Figure 6 Compressive stress schematics vs (a) axial and lateral deformations and (b) lateral deformations

The strain level at 75% of f'_c, which indicates the propagation of unstable cracks is called critical strain: it corresponds to the maximum value of the volumetric deformation (fig. 6b). From the figure it can be seen that when the volumetric deformation $\varepsilon_v = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$ is plotted against strain; the initial change in volume is reversed resulting in a volumetric increase near or at f'_c.

Above the critical stress level, concrete exhibits time-dependent fractures; thus, under steady-state conditions the cracks bonded between the interface transit zone and the matrix will lead to breakdown in a strain that is lower than the short-term load stability f'_c. In Price studies conducted when sustained strain was 90% of the short-term final strain, fracture occurred in 1 hour, however, when sustained strain was about 75% of the short-term strain, the fracture occurred after 30 years. As the value of the steady strain approaches that of the steady state short-term strain, the fracture time decreases. Rusch has confirmed through his tests during the 56th day, in champions with compressive strength of 34 MPa. The long-term fracture limit is about 80% of the final short-term strain (Fig. 7).

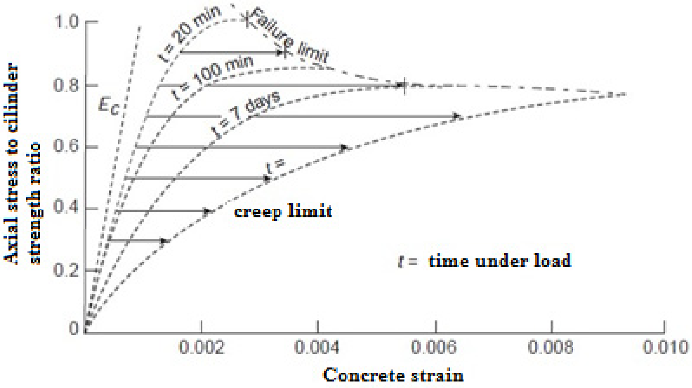

Figure 7 Relationship between short-term and long-term load resistance

However Jones and Richart found that within the scale of evidence, the effect of the loading degree on stability is not large. For example, compared to data from ASTMC 469 standard test, which requires a single-axis compressive load rate of 0.25 MPa / s, the load rate of 0.007 MPa / s reduced the shown concrete cylinder strength by about 12%, to on the other hand, a charge rate of 6.9 MPa / s increased the strength by the same amount.

It is interesting to note that the impact strength of concrete increases greatly with the degree to which impact stress is applied. It is generally assumed that impact strength is directly related to compressive strength, and both are affected by the presence of microcracks and voids. This assumption is not entirely correct; for the same compressive strength. Green found that the compressive strength increased greatly with the angle and surface roughness sv of the hard aggregate and decreased with increasing aggregate size. It seems that shock resistance is influenced more by the characteristics of the interfacial transit area than by the compressive strength. Impact strength is therefore more related to tensile strength.

4. Concrete Behavior Under Uniaxial Stress

The shape of the stress-strain curve, the modulus of elasticity and the Poisson ratio of concrete under uniaxial stress are similar to those of uniaxial compression. However, there are some important changes in behavior. While the uniaxial stress state tends to stop crack propagation less than the compressive stress state, the stable crack propagation interval is expected to be short.

The direction of propagation of cracks at the uniaxial stress is perpendicular to the direction of strain. The onset and increase of any new cracks will reduce the load-bearing area, and this reduction will cause an increase in stresses at the critical peaks of the cracks. The reduced frequency of crack rupture means that the voltage damage is caused by several rupture bonds and not by many ruptures, as is the case for stress compression states. Due to the increase in crack propagation, it is difficult to follow the descending part of the strain-deformation curve in an experimental test.

The ratio between uniaxial tensile strength and compressive strength is usually in the range of 0.07 - 0.11. Because of the ease with which cracks can spread under an attractive strain, this is not surprising. Most concrete elements are designed under the assumption that the concrete must withstand compressive but attractive stresses. However tensile stresses caused by residual shrinkage, shrinkage usually occurs either due to lowering of the concrete temperature or drying of the concrete moisture. Also, the combination of tensile, compressive, and shear stresses usually determines the strength when concrete is subjected to torsional or bending loads, such as on highway floors.

In the previous discussion regarding the factors that affect the compressive strength of concrete, it was assumed that the compressive strength is a suitable indicator for all types of strengths and thus a direct relationship exists between the compressive strength and that of tensile or torsional strength for a given concrete.

As a first rough estimate, the assumption is valid; however it is not always the case. It has been observed that the relationship between different types of strength is influenced by factors such as the methods by which it is measured, the quality of the concrete, the characteristics of the aggregate and the admixtures.

5. Tensile Strength Test Methods

Direct concrete stress tests are seldom performed, mainly because the sample bearing machines exert secondary stresses that cannot be ignored. The tests used to evaluate the tensile strength of concrete are ASTM C 469 stress separation test and ASTM C 78 three-point torsional load test.

In the stress separation test a 15 x 30 cm cylinder is subjected to compressive loads along two axial lines that are diametrically opposed. The load is applied continuously in constant ratio with the stress separation strain ranging from 0.7-1.3 MPa until the sample breaks. Compressive strain produces tensile perpendicular strain that is uniform in vertical diameter. Voltage separation stability is calculated from the formula:

$$T = \frac{TP}{\pi l d}$$

Where T = tensile strength
P = breakdown load
l = length
d = sample diameter

Compared to direct stress, the stress separation test is known to overestimate the tensile strength of concrete by 10 - 15%.

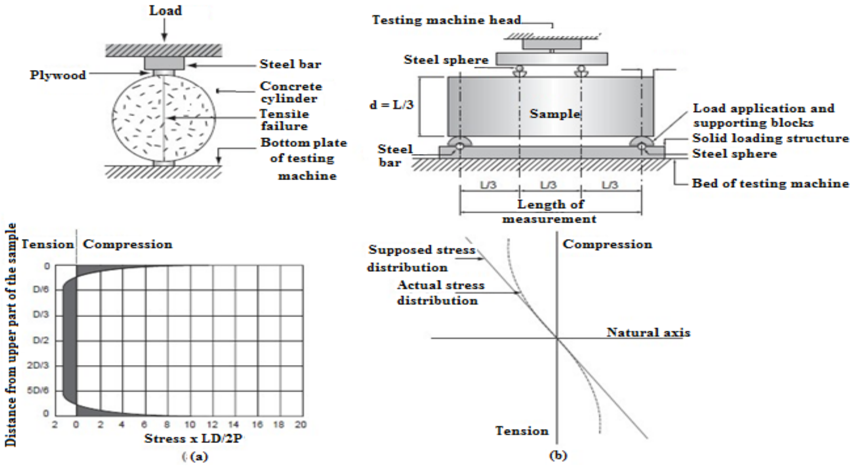

Figure 8 (a) Tension separation test, up, plotted test, down, stress distribution through the loaded diameter of a compression cylinder between two plates, (b) Tensile load test with three points: up, plotted representation of the test, below: stress distribution through the depth of a concrete profile under torsion.

6. Conclusions

For designers, compressive strength is one of the most important engineering properties of concrete. It is a well-known industrial practice for concrete to be classified according to brands. The mark indicates the compressive strength of the concrete cube or cylinder. Cubic or cylindrical specimens are usually subjected to tests with the compression tester to obtain the strength of the concrete. Test requirements vary from country to country based on the design code. One way to determine compressive strength is:

The compressive strength of concrete is given in terms of the compressive strength characteristic of 150 mm cubes tested after 28 days (fck). The characteristic strength is defined as the strength of the concrete below which no more than 5% of the test results are expected to fail.

For design purposes, this value of compressive strength is limited by dividing it by a safety factor, the value of which depends on the design philosophy used.

Given the results obtained from the measurements of the physical-mechanical properties of concrete produced by cement mixed with additives in different quantitative ratios of slag and ash, we can say that the latter can be used in mixing up to 15 % preserving within the required parameters the properties of the concretes produced with them.

Increasing the content of additional components that we experimented for the production of mixed Cement over 15%, prolongs the hardening time and reduces the mechanical strength, even for longer maturation times of concrete, so it is recommended not to exceed this limit.

Regarding the porosity of concretes obtained from Cement without additives and from Cement mixed with slag and fly ash to the extent of 15% that we optimized above we can say that:

For concretes with a curing period of 12 days, the additives lead to a reduction in pore volume and the greatest reduction is achieved by the presence of fly ash. With the extension of the curing period up to 28 days, a new porosity modification is obtained. For concretes prepared with Cement with fly ash content, the structure with small pores is preserved, while for others we have a reduction in the volume of pores. The presence of the structure with small pores nëon increases the resistance of concrete to climatic agents.

With the increase of the curing time, for all produced concretes, the time of the first crack (tkp) increases, which varies from 4 days for 12-day curing periods to 26 days for 90-day curing periods.

The best parameters are achieved in cements prepared with Cement containing fly ash additives, which in the first 12 days of curing shows a first cracking time of 13 days, which is higher compared to the other two types. of Cement (standard and with slag). Consequently, the corrosion resistance, evaluated with this parameter, is higher.

Referring to the half-cell potential test, it results that the greatest resistance is presented by the samples prepared with standard cement for which the tendencies for corrosion appear after 7 cycles.

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