

Assessment of Mechanical Concrete Properties: An Overview

Najlaa Zaidan Kazem^{1*}, Mohammed Mosleh Salman² and Husain Khalaf Jarallah³

1, 2, 3) Al-Mustansiriyah University, College of Engineering, Civil Engineering Department, Baghdad, Iraq

Abstract: *In recent years, there has been covering or affecting a large area to enhance and improving the concrete mechanical properties by adopting different ways. These improvements adopted by many researchers that tested different concrete types with and without additives materials. Conventional, high strength, high performance, reactive powder, modified reactive powder and ultra-high performance concrete are the main types of concrete that used in the buildings and infrastructures construction by selecting best concrete type to reduce the cross sectional of structural elements that lead to less weight and smaller sizes. In the current study, reviewed different concrete type with corresponding tests that adopted to investigated, evaluate and assessment the mechanical properties such as compressive, modulus of rupture and tensile strength in addition to modulus of elasticity by destructive and nondestructive tests are provided based on the reviewed literature. According to that, the best-recommended properties of different concrete types are summarized and discussed.*

Keywords: *Compressive strength, Modulus of rupture, Tensile Strength; Modulus of elasticity of concrete, Concrete type, Steel fiber, Destructive and nondestructive concrete tests.*

I. Introduction

All concrete structural members mostly used steel reinforcements along with concrete to resists tension stress that developed in tension zone of concrete member due to applied loadings. The developments of concrete mechanical properties over the past years has led to the production of different concrete types have higher mechanical properties such as high strength concrete, high performance concrete, moderate reactive powder concrete and reactive powder concrete that named as ultra-high performance concrete. two tests methodologies that adopted by researchers to evaluate the behavior of concrete strength such as destructive and nondestructive tests.

Aim and significant of research

The aim and significant of present study are to review the assessments of mechanical properties of different concrete types by adopted destructive and nondestructive tests. The mechanical properties that founded by other researchers are evaluates, discusses and giving recommendations.

Reviewed tests and studied

Kausay and Simon, 2019 [1], investigated the acceptance of concrete compressive strength that designed based on the mix design for concrete members. Roles for evaluated and acceptance or rejection of compressive strength were presented and discussed. The time period of concrete tests was longer three months but not more than one year. All specimen's tests were calculating the standard deviation for at least 15 tested specimens as follow:

$$S_n = \sqrt{\frac{\sum_{i=1}^n (f_{ci} - f_{cm, test})^2}{n-1}} \quad 1$$

In which $n \geq 35$, f_{ci} and f_{cm} , test is the compressive and mean compressive strength of tested specimens. The authors recommended that in case of normal concrete with strength class $\leq C50/60$ is 3 MPa and in case of high strength concrete with class $\geq C55/67$ is 5 MPa. To apply this phenomena, the recommended number of samples that must be adopted one sample for 25 m^3 . The acceptance compressive strength must be satisfying the following formula:

$$f_{cm, test} \geq f_{cm} = f_{ck} + 1.48\sigma \quad 2$$

Where, f_{ck} characteristic compressive strength and σ is the standard deviation according to the calculations of initial production of test results at least 35 samples. Obtained results from study concluded that the reliability of the conformity was important for evaluation of the compressive strength.

Tijani et al., 2019 [2], investigated the influence of aggregate size on the concrete mechanical properties. Three dimensional applied loading was used to evaluated the impact of size aggregate of confined concrete as shown in Figure 1.



Figure 1: Setup specimen procedure (a) Uniaxial loading, (b) Biaxial loading, (c) Adjustment of plate and (d) Three dimensional setup [2]

Cube mold was used to examine the stress-strain behavior of the tested specimens under the effects of static loading and the test results were compared with the specimens that were unconfined. The concrete cube dimensions were 150x150x150 mm while the aggregate sizes are 5, 10 and 20 mm. Two different mixtures were adopted that are listed in Table 1.

Table 1: Specimen mixtures

Mix ID	Specific weight (kg/m ³)				Water/cement ratio
	Cement	Fine aggregate	Coarse aggregate	water	
A	395	800	850	256.75	0.65
B	275	900	920	233.75	0.85

The FRP bars that were adopted to confine some specimens with different ply such as 0.5, 1 and 2 ply. FRP properties with modulus of elasticity 245 GPa, thickness of 0.165 mm. Obtained test results of the specimens in case of unconfined and confined subjected to uniform and non-uniform lateral confinement showed that the main failure of the specimens was longitudinal splitting was obvious on the axial loading surface. Mode of failure in case of confinement by FRP was shear sliding. Based on test results, the confinement efficiency increased with increased aggregate size.

Gomaa et al, 2020 [3], pointed out on the mechanical properties of alkali activated concrete by adopted alkali activators such as Sodium hydroxide and sodium silicate in which the specimens were cured at 70 °C for one day. Traditional concrete with compressive strength 34.5 MPa was adopted as reference. Different tests were adopted to evaluate the compressive strength, splitting tensile strength and modulus of rupture tested at different ages as 1, 7 and 28 days. Compressive strengths of the alkali activated concrete tested results for 1 day lie in the range of 25.1-37.8 MPa rely on the calcium content of the fly ash and the corresponding surface area. These values represented 88-99% of the compressive strength of conventional concrete that tested at 28 days. Splitting tensile strength and modulus of rupture tested specimens showed that the values 1.9-2.9 MPa for alkali activated concrete while for conventional concrete ranged 2.4-3.1 MPa. Modulus of rupture ranged 3.2-4.5 MPa and 4-4.5 MPa for alkali activated and conventional concrete respectively. Based on the compared test results concluded that the alkali activated concrete can be adopted in applications where rapid strength gain is required.

Basa et al., 2020 [4], explored the mechanical properties of new concrete by replaced fine aggregate by sustainable material such as fly ash. Different tests were adopted to evaluate the presence of fly ash in the concrete mixture such as compressive strength, flexural strength and splitting tensile strength in which for all concrete mixes, the silica fume was added as binder material. The designed concrete strength was 38.25 MPa by used 438 kg of cement, 610 kg fine aggregate, 1206 kg coarse aggregate and 197 liter of water for 1 cubic meter. Different percentages of fly ash from fine aggregate such as 10% 20% 30% 40% 50 and 100% by weight. The specimens were cured at different ages as 7, 28 and 56 days. Compressive strength founded by tested cube with 150 mm side, splitting tensile strength tested by cylinder with 100 mm diameter and 200

mm height, flexural strength obtained by tested prism with 500x100x100 mm. test results indicated that with natural fine aggregate 90%, fly ash 10% and silica fume 20% that gave 52, 69 and 75 MPa, splitting tensile strength gave 5, 6.2 and 5.9 MPa, flexural strength gave 4.3, 5.4 and 7 MPa at 7, 28 and 56 cured days respectively.

Tiwari et al., 2019 [5], evaluated the concrete pavement by used using Ekosoil in the concrete mixture to enhance the concrete workability and concrete mechanical properties such as compressive strength and modulus of rupture as flexural strength by adopted different percentages of Ekosoil. The Ekosoil was classified as produced fermented from organic materials. Water to cement ratio for all mixed concrete but differe in Ekosoil percentages such as 1, 2 and 3% by volume. All concrete specimens cured inside water and then tested at 28 days. Slump test was carried out to investigat the concrete workability, also the ultra-sonic velocity was calculated by recorded the time interval rquired to travel the pulse from one sie to the other and then divided the distance to the interval time to find out the velocity. Based on test results, the slump increased as the percentages of Ekosoil increased in which the slump for reference was 27 mm that increased to 28, 31 and 34 mm for 1, 2 and 3% presences of Ekosoil respectively. The presence of Ekosoil decreased the compressive strength and increased in Ekosoil percentages lead to reduced in compressive strengths for all cured ages as compared with reference specimen. Decred in compressive strength was (53.36, 51.52 and 51.77%) in case of Ekosoil with 3% tested at 7, 14 and 28 days respectively as compared with reference specimens. The flexural strength was 4.62 MPa that represents 8.62 and 15.23% lower than reference specimens in case of 3% Ekosoil. Concluded by test results and by observed, the compressive and flexural strength of concrete contained of Ekosoil there was a slight increased in case of 1 to 2% addited of Ekosoil and decrease in the values from 2-3% but the results indicated that there are less than as compared with reference specimens.

Amen et al., 2016 [6], investigated the concrete properties by nondestructive test used hammar and ultrasonic velocity tests. Total of 150 cunes were casted with compressive strength ranged 3-55 MPa and then tested by hammar and ultrasonic test and then crusheds. The recorded tests data were adopted to draived an emperical equation that descibed the relationship between ultrasonic velocity, hammar rebound number and compressive strength. The peosed equation suggested as follow:

$$C(R, V) = 0.0002781 R^{3.198} + 0.0001426 V^{7.333} \quad 3$$

in which, C is the compressive strength, R is the rebound number and V is the ultrasonic velocity. Test and analysis results indicated that the rebound number by used hammar test gives reliable results than ultrasonic velocity test to estinated the compressive strength.

Mulik et al., 2019 [7], assessmented the concrete quility by nondestructive tests such as rebound hammerand and impact energy. Test results were compared with previous tests by other

researchers from literature and with practice results collected from existing structures showed that the adopted two tested methodologies gave the accuracy of the estimations of the in site compressive strength.

Nwidi 2019 [8], suggested a relationship of compressive strength of normal concrete as a function of ultrasonic velocity as nondestructive cube test. Different parameters were adopted in the tested specimens such as water to cement ratio, aggregate size and concrete mix. Three different proposals were suggested based on the regression analysis of tested results. The concrete mix that adopted as 1:1.5:3, 1:2:4 and 1:3:6 with aggregate size as 10-20 mm and water to cement ratio of 0.6-0.6. the proposed models as follow:

$$f_c = 5.76e0.0004V \quad 4$$

$$f_c = 0.000044 V^{1.6807} \quad 5$$

$$f_c = 0.0117V - 18.693 \quad 6$$

All suggested models were verified with test results that showed close.

Koespiadi et al, 2018 [9], investigated the quality of concrete that used in foundations as precast concrete. mix design of the precast concrete trapezoidal model was 1:2:3 in which the precast model reinforced by 6 mm bar diameter and the models classified as A and B that differ in presence of stiffness at base or without stiffness, the model shown in Figure 2



Figure 2: Precast design models A and B [9]

Test results showed that the foundation type A gave stronger resistance capacity and quality of the concrete than the design B.

Haavisto et al., 2020 [10], evaluated the compressive strength of concrete by core test. Total of 650 specimens with different core dimensions such as 50x50, 80x80, 100x100 and 150x300 mm were tested under same cured conditions and drilled from casted cylinders as shown in Figure 3. Also, with side dimensions 100 and 150 mm, cylinder diameter and height 150 and 300 mm respectively. Four different concrete types were adopted with slump range as 130/70, 180/180,

180/200 and 180/160. Compressive strength of tested specimens ranged between 43.7-72.7 MPa and density 2310-2390 kg/m³. Test results showed that the compressive strength depended on the specimen size and concrete mix.

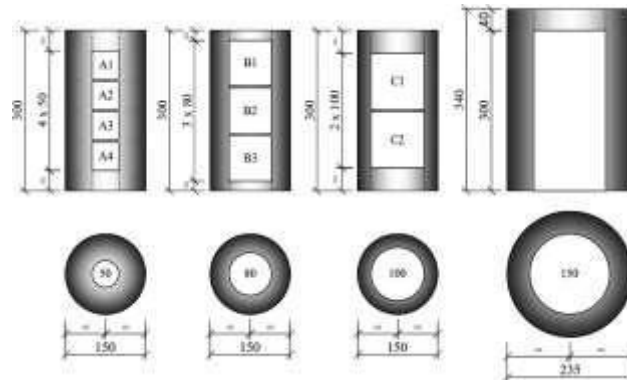


Figure 3: Core samples [10]

Al-Ghamdi, 2020 [11], assessed the concrete quality by adopted tested mechanism and estimated the failure concrete type. Different main factors were considered classified as the contributed to the buildings that made from concrete such as used poor and not quality materials, the inaccurate machines test and wrongs in mixing methodology. The investigated of the reasons that adopted in the study indicated that the compressive strength of concrete were tested by old machine. The case studied that adopted as concrete building showed that there were some structural members failed due to low compressive strength of these members because of inaccurate mixing procedure of concrete in addition to the poor in quality of mixed materials.

Zhou et al., 2019 [12], studied the influence and impacts of coal gangue content as coarse aggregate on the concrete mechanical properties. Two types of coal gangue were adopted as 25, 50, 75 and 100% partial replaced of coarse aggregate such as spontaneous (S) or rock gangue (R). the specimens that tested have dimensions as 100x100x100 mm cube, and prismatic specimens of 100x100x300 mm and 100x100x400 mm in which all specimens were tested at 28 days. Obtained test results showed that the failure modes for all percentages replacements are same and the compressive and flexural strength decreased as compared with the reference specimen.

Buller et al., 2019 [13], presented the relationship between cubic and cylinder tests in case of recycled aggregate. Total of 200 specimens were casted with 50% replacement of aggregate as recycled aggregate gat it from demolished concrete. The mix design for all samples was 1:2:4 with water to cement ratio 0.54 was adopted. All samples were tested after 28 cured days in which by test results the obtained factor was 0.7 to convert the compressive strength of concrete from cube to cylinder.

Mishra et al., 2007 [14], studied the ability to produce a desired and intended result standard division of compressive concrete strength. Mix design to produced 32 samples to reach 30 MPa as compressive strength by used ordinary Partaken cement. The main goal was to find out the standard division to obtained the best water to cement ratio. Trail assumed standard division was 5 MPa for

compressive strength and at the end of the tested specimens, the standard deviation was founded to be 2.43 MPa that lead to conclude that the best water to cement ratio was 0.4723.

Rao and Ibrahim, 2017 [15], investigated the influence of replaced sand by quarry and fly ash as fine aggregate. The self-compacted concrete was adopted with concrete grade 40 MPa in which the fine aggregate was replaced by 35% quarry dust powder with size of 600-300 micron. Four different mix design were used with different water to cement such as 0.54, 0.609, 0.7308 and 0.9135 for mix1, mix2, mix3 and mix4 respectively. the specimens were casted by cube mold with size of 150x150x150 and cylinder with 150 mm in diameter and 300 mm in high. Obtained test results gave the average compressive strength of 58.03MPa, and standard deviation as 7.485MPa for mix1, mix 2 the compressive strength of 55.4 MPa and standard deviation 7.41 MPa, mix 3 gave compressive strength of 52.58 MPa, and standard deviation as 2.52 MPa, mix 4 indicated that the compressive strength of 45.74 MPa, and standard deviation as 3.08 MPa.

Neville, 1960 [16], studied the relationship between the mean compressive strength and the standard deviation of concrete. concrete mix design with compressive strength 3000 lb/in², water to cement ratio was 0.71, with assumed standard deviation 600 lb/in², so that the required compressive strength based on these data was 4400 3000 lb/in² and water to cement ratio 0.57. concluded by the study that the value of the compressive strength at the time of tested specimen.

Neville, 1957 [17], studied the influence of cube tested size on the standard deviation and on mean compressive strength of concrete. Recommended the maximum size of aggregate for mass concrete ranged 3-6 inches, so that it require a special mold cube or cylinder for test as compressive strength larger than the usual molds so that it not necessary to remove the large aggregate size because in standard mold, the mold, size of aggregate is ¾ inch. Suggested that in case of maximum aggregate size 3 inch, the mixed rock ratio limited to 1:8.5-1:12by weight and water to cement ratio is 0.52-0.58 with 10 inches' cube gave compressive strength same as 6-inch mold with rock ratio ranged 3-1.5-inch removal bit 12-20% lower than cube 6 inches.

Ramadoss, 2012 [18], suggested a model to evaluated the toughness and of strength high performance fiber reinforced concrete HPFC. The model evaluated different concrete properties such as compressive strength, splitting tensile strength flexural strength and toughness in addition to the ratio of steel fiber. Different parameters were considered such as mix design and percentages of steel fiber as 0, 0.5, 1 and 1.5%. the adapted steel fiber with aspect ratio 80 in which the mix designed with different water to cement ratio such as 0.25, 0.3, 0.35 and 0.4 depend on the percentages of steel fiber, silica fume content and super stabilizer. Compressive strength of samples was tested based on ASTM C 39-05 [19] with 150 mm diameter cylinder while the splitting strength test and flexural test based on ASTM C 496-1990 [20] used 150 mm diameter and 300 mm height of cylinder and ASTM C 78-1994 [21] used 100×100×500 mm prisms for flexural and splitting tests respectively. The proposed models as follow:

$$\begin{aligned} \text{compressive strength} = & -35562.4 x_1 - 14.979 x_2 - 7.853 x_3 - 19.211 x_4 \\ & - 14.81 x_5 - 308.847 x_6 + 3.7253 x_7 - 6.1708 x_8 \end{aligned} \quad 7$$

$$\text{Modulus of rupture} = -30.0628 x_1 - 0.00354 x_2 + 0.01592 x_3 + 0.1074 x_6 + 0.011944 x_8 \quad 8$$

$$\text{Splitting tensile strength} = -12.0588 x_1 + 0.00103 x_2 + 0.01763 x_5 + 0.02101 x_8 \quad 9$$

in which x1, x2, x3.....x8 are the independent variable, the proposed models were validated with experimental results and the absolute variations are 1.09, 2.36, and 3.36% for compressive strength, flexural strength and

splitting tensile strengths, respectively.

Hong et al., 2020 [22], evaluated the concrete structural conditions by nondestructive test by ultrasonic pulse velocity tests. The main function of nondestructive test was estimated the compressive strength of the structural members by ultrasonic test based on the age of structure. Total of 123 specimens were tested based on the compressive strength such as 24, 30 and 40 MPa tested at 16, 20, 24, 48, 72, 120, 168, 360 and 672 hours. The calculated of the average ultrasonic velocity based on to the age of concrete by adapted ASTM C597 [23] and ACI 228-2R [24] while the compressive strength was based on KS F 2405 [25]. The correlation between the two test methods as ultrasonic pulse velocity and compressive strength was applied and analyzed the test results. Suggested the equation to find out the compressive strength that related to ultrasonic pulse velocity. The proposed equation as follow:

$$Pulse\ Velocity = 832.75 \ln \left(\frac{f'}{c} \right) + 844.9 \quad 10$$

Wang and Jiang, 2015 [26], evaluated of concrete quality and the methodology that adopted to control and the reliability analysis of concrete tests. Different nondestructive methods were adapted such as ultrasonic pulse velocity and rebound hammer. Rogation analysis was used to find out the relationship between the two methods and the concrete compressive strength that tested in situ for structural members. Suggested method to evaluate the collapse failure of structural member by determined the reliability index of the structure. Recommended for engineering designer was in many practical applications constraints on maximum displacements must be enforced in order to guarantee an appropriate use of the construction.

Ammad et al., 2018 [27], assessment the mechanical concrete properties in case of low strength by destructive and nondestructive methods. Core and compressive strength tests as destructive methods while ultrasonic pulse velocity and hammer tests as nondestructive tests were adapted to investigated the concrete have low strength. Low concrete compressive strength in the range of 1500-1700 psi was evaluated. Different mix design was considered such as 1:2:3, 1:1.5:2.5 and 1:1.5:3, as cement: fine aggregate: coarse aggregate respectively. The basis mix design for comparison was 1:1.5:3 that tested after 14 cured days. Obtained test results indicated that the hammer gave higher values while core test founded mostly accurate values. Hammer tests gave around 30% higher as compared with standard results.

Arioz et al., 2008 [28], investigated the compressive strength of normal weight concrete by core test. Beams with dimensions of 250x300x650 mm and cubes with 150 mm as side length were prepared and casted and then after cured up to 90 days by adapted different concentrations of sodium sulphate solutions while the samples as cubes was under the effect of frost at different ages. Different core samples were considered such as 94, 69, 46 mm as diameter with length to diameter ratio as ranged 0.75-2 that drilled from beams while in case of drilled core from cube was 69 mm in diameter. Different water to cement ratio such as 0.6, 0.54, 0.47, 0.44 and 0.4 were considered. According to experimental investigation results the type of aggregate, diameter and length to diameter ratio of the tested core affect the compressive strength of cores, concentration of sulphate impacts on the strength of concrete even when the time period of exposure was very short.

Soutsos et al., 2009 [29], pointed out on tests of scale reinforced concrete frame building. Statistical analysis of test results was tacked into account and then after make interpolation to find out the uncertainties that existed of concrete strength. Methodology of the assessment the test results based on the BS EN 13791-2007 [30] that deal with the procedure of how to find the compressive strength in situ. Test results showed that the use of standard statistical procedures that considered different parameters such as quality control, number of tests and the required confidence level in the predictions gave best methodology to find out the compressive strength of concrete.

Kirchhof et al., 2015 [31], evaluated the residual compressive strength of ordinary concrete after the specimens was exposure to high temperature used nondestructive test by ultrasonic pulse velocity tests. Different mix

design was adapted with water to cement ratio of 0.25, 0.3 and 0.5 and the cylinder samples were subjected to temperature in the ranged of 200-600 C°. Test results showed that the adopted ultrasonic pulse velocity test gave accurate and can be trustworthy analysis to predict the concrete compressive strength under the effect of high temperature.

Olusola et al., 2012 [32], investigated the influence of batching method on the concrete properties for both fresh as slump test and hardening concrete as compressive strength. different mix design was adapted such as 1:1:2, 1:1½:3 as rich mix, 1:2:4 as ordinary mix, 1:3:6, 1:4:8 as nonstructural mix with water to cement ratios ranged as 0.35-0.95 in which all samples are cured in water up to 28 days. The results showed that a higher workability's for concrete batched by mass as compared with concrete batched by volume for all water to cement ratios. Noted that the workability was increased as increased in water to cement ratios in both methodologies. Compressive strength results indicated that in case of 1:1:2 and 1:1.5:3 concrete mix batched by mass gave 20 and 6% strength increases respectively over the concrete batched by volume. In case of concrete mix 1:2:4 had 14 % increase while non-structural mixes 1:3:6 and 1:4:8 gave 8% and 6% increases respectively.

Kabashi et al., 2015 [33], evaluated the compressive strength of concrete structural member in situ. Nondestructive tests were adapted to examined the compressive strength of concrete such as rebound hammer based on EN12504-2 [34], ultrasonic pulse velocity based on EN 12504-4 [35] and Core test based on EN12504-1 [36]. Different structural elements were considered such as slab, beam, column and wall that tested in situ in which all concrete members with structural building. Concluded based on the investigation, more than one method to evaluate the concrete strength lead to more promising of the concrete in construction.

Ju et al., 2017 [37], assessment the compressive strength by ultrasonic pulse velocity in addition to hammer test and core tests for high strength concrete. different compressive strength was considered such as 40, 60 and 100 MPa with different core diameter as 30, 50 and 100 mm in which for each compressive strength there is ultrasonic pulse velocity test. Regression analysis for tested data to develop an equation that represent the relationship between compressive strength and nondestructive magnitude. According to the 61 samples that tested to find out the compressive strengths of core specimens, a correction factor was investigated to estimate the relationship between core test and compressive strength. Test results showed that the compressive strength of a concrete core samples decreases when the core diameter reduces.

Nepomuceno and Bernardo, 2019 [38], assessment the structural concrete members that casted by self-weight concrete by nondestructive methods. Different test methodologies were adapted such as ultrasonic pulse velocity, rebound hammer, pull-out and the concrete maturity tests. The samples tested at different ages such as 1, 2, 3, 7, 14, 28, and 94 days. Test results showed that the compressive strength ranged 45-97 MPa. Correlations and regression analysis were established to find out the relationship between the nondestructive test and concrete compressive strength by adopted 95% confidence limits computed. Test results indicated good correlations.

Michalek, 2019 [39], investigated the variation of compressive strength in concrete layers when placed as more than one layer. Core sample from 350 mm slab thickness was tested by ultrasonic and find out the compressive strength to check out the variation in compressive strength in layers. Test results showed that there was no different in compressive strength between the layers and should be not taking into account from engineering designer.

Bora, [40], studied the criteria that depended for acceptance of concrete according to compressive strength. Different tests were studied to find out the concrete compressive strength such as core, cube, ultrasonic pulse velocity and hammer. The acceptance criteria for destructive test as cube was accepted as average of three samples and the individual variation should not greater than $\pm 15\%$, core test shall be at least 85% from the tested cube and the ultrasonic pulse velocity have variation $\pm 20\%$ by compressive strength.

Standard codes and specifications

Many codes considered the specifications of testing of concrete samples such as compressive strength, flexural strength, splitting tensile strength and in addition to nondestructive tests like ultrasonic pulse velocity and hammer test.

ASTM Standard C 39 – 05 [19] explained and discussed the standard test method for compressive strength of cylindrical and drilled cores in which is limited to concrete having a unit weight in excess of 800 kg/m³ to evaluating the concrete how strong. The standard cylinder with diameter 150 mm and height 300 mm was adopted and the breaking load after 28 days curing of the sample divided by the surface area of the cylinder gave the compressive strength of concrete in which the compressive strength must be within 15-55 MPa. Test results can be adopted as a basis for concrete quality control, mixing, and placing. The maximum difference of individual diameter of a cylinder sample from other diameter of the same cylinder not greater than 2 %. The type of fracture evaluating based on Figure 4.

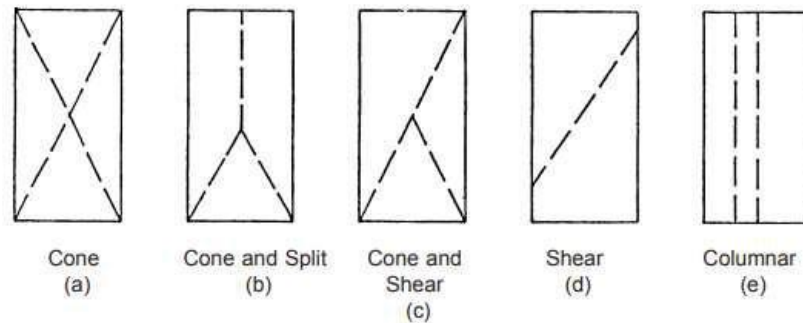


Figure 4: Types of fracture [19]

ASTM Standard C 496–90 [20], gave details how to find out the splitting tensile strength of concrete. the cylinder sample of concrete with 150x300 mm as diameter and height was considered. Calculation of the splitting tensile strength by applied as follows:

$$T = \frac{2P}{\pi dl} \tag{11}$$

In which, T is the splitting tensile strength (MPa), P is the maximum applied load indicated by the testing machine (N), l is the length of sample (mm) and d is the diameter of sample (mm). Based on this specification, the coefficient of variation was 5 % for sample dimensions of cylinder 152x305 mm with test results (average have same property) of 2.8 MPa, the differ not greater than 14 %.

ASTM C 78–94 [21], this standard test method explained the determination of the flexural strength of concrete by the use of a simple beam with third-point loading in which the sample is prism with symbols dimensions as Lxbxd and the modulus of rupture calculations as follows:

$$R = \frac{PL}{bd^2} \tag{12}$$

Where, R is the modulus of rupture (MPa), P is the maximum applied load indicated by the testing machine (N), L is the span length (mm), b is the average width of specimen (mm) at the fracture and d is the average depth of specimen (mm) at the fracture. The standard division for flexural test up to 5.5 MPa for good concrete quality and the standard division over 0.7 MPa indicate there is problem in test or the sample in dry condition that lead to reduce strength.

ASTM C 597 – 16 [23], determined the ultrasonic pulse velocity of in a concrete mass is related to its elastic properties and density according to the following relationship: as follows:

$$V = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}} \quad 13$$

where, E is the dynamic modulus of elasticity, μ is the Poisson's ratio and ρ is the density. When the span path that required for test ranged between 0.3-6 m, the test results of velocity within difference of 2%.

ACI 228-2R [24], this code adopting to find out the hardened concrete properties and to assessment evaluate the condition of concrete that including the methodology for each sample test.

BS EN 13791: 2007 [30], this specification related to evaluation of concrete compressive strength in situ in which the minimum number of samples is one core per location. The compressive strength of core has length and diameter 100 mm same as compressive strength of cube with 150

mm in side that treated under same conditions. In case of core with length in the range of 100-150 mm with length to diameter ratio equal to 2 give compressive strength equivalent to 150 mm diameter and 300 mm in length of cylinder. In case of core diameter in the range of 50-150 mm with other length to diameter ratio, the shall be assessment based on the factor conversions. The assessment the compressive strength in situ based on the lower value of:

$$f_{ck, is} = f_m(n)_{is}^{-k_2} \cdot S \quad 14$$

$$f_{ck, is} = f_{is, lowest}^{+4} \quad 15$$

In which, $f_{ck, is}$ is the characteristic compressive strength in situ, $f_m(n)_{is}$ is the mean compressive strength in situ, $f_{is, lowest}$ is the lowest compressive strength in situ, S is the standard deviation of test results or 2 MPa whichever highest value, k_2 equal to 1.48.

BS EN 12504-2:2012 [34], adopting this specification for testing concrete in structures. Non-destructive testing to determination of rebound number in which this method can be used to assessing the uniformity of concrete in situ. If more than 20 % of all the readings differ from the median by more than 6 units, the entire set of readings shall be discarded.

BS EN 12504-4:2004 [35], can be adopting for testing concrete by ultrasonic pulse velocity. The arrangement is shown in Figure 5 in which T is the transmitter and R receiver transducer respectively.

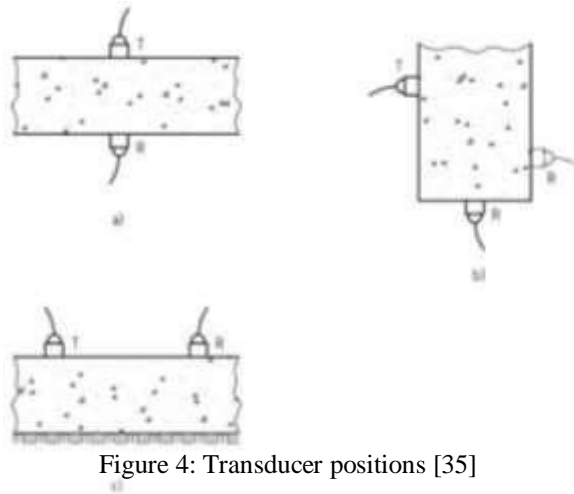


Figure 4: Transducer positions [35]

The pulse velocity calculated as follow:

$$V = \frac{L}{T} \quad 16$$

Where, V is the pulse velocity, L is the path length and T is the time that the pulse requires to transverse the path length., the velocity expressed in km/sec.

BS EN 12504-1:2019 [36], for testing concrete in structures, cored specimens taking, examining and testing in compression. Length to diameter ratio for core sample in case of the test results compared with cylinder or cube 2 or 1 respectively.

Based on ACI-318-2019 [41] that classified the concrete compressive strength as the important parameter for evaluating the concrete members that effect on the design. The arithmetic average of three tested samples shall be greater or equal to the specified compressive strength, in additions, in case of specified compressive strength less or equal to 35 MPa, the samples fall below this required strength should be not greater than by 3.5 MPa, wgen the required compressive strength less than 35 MPa, the fall sample should be not more than 10% of specified strength. ACI-318-2011 [42] specified the required average compressive strength by adopted samples as cylinder 150 diameter by 300 mm height as follows:

Specified compressive strength $f_c' \leq 35$ MPa

$$\text{Larger of } f_{cr}' = f_c' + 1.34 S_s \quad \text{and} \quad f_{cr}' = f_c' + 2.33 S_s - 3.5 \quad 17$$

Specified compressive strength $f_c' > 35$ MPa

$$\text{Larger of } f_{cr}' = f_c' + 1.34 S_s \quad \text{and} \quad f_{cr}' = 0.9 f_c' + 2.33 S_s \quad 18$$

Where, f_{cr}' is the required average compressive strength (MPa), S_s is the sample standard deviation that calculated based on the at least 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests (same as equation (1)).

Based on the criteria of BS 5328 Part 4-1990 [43], the compressive strength of tested sample (cube) was classified as criteria A and B. Group A when the mean of the exceeds 1, 2 or 3 MPa for first 2, 3 or 4 group of test results, then the compressive strength as follows:

$$f_{cui} \geq f_{cu} + 2 \quad 19$$

Group B, when the mean of the exceeds 2,32 or 3 MPa for first 2, 3 or 4 group of test results, then the compressive strength as follows:

$$f_{cui} \geq f_{cu}^{-3} \quad 20$$

Where, f_{cui} and f_{cu} is the specified and required compressive strength respectively.

According to BS EN 206-1: 2013 [44], the criteria for compressive strength divided as criteria 1 and 2. Criteria 1 based on the mean of n test results of compressive strength f_{cm} individual criteria 2 based on the individual test results f_{ci} . The two criteria list in Table 2:

Table 2: Criteria for compressive strength [44]

Number n of test results	Criteria 1	Criteria 2
	f_{cm}	f_{ci}
1	Not applicable	$\geq f_{ck} - 4$
2 to 4	$\geq f_{ck} + 1$	$\geq f_{ck} - 4$
5 to 6	$\geq f_{ck} + 2$	$\geq f_{ck} - 4$

f_{ck} is the characteristic compressive strength.

Based on IS 516:1959 [45], the compressive strength of cube with dimensions of 150x150x150 mm that tested at 28 days 95% of tested cubes should not have a value less than this value. Shown in Figure 5.

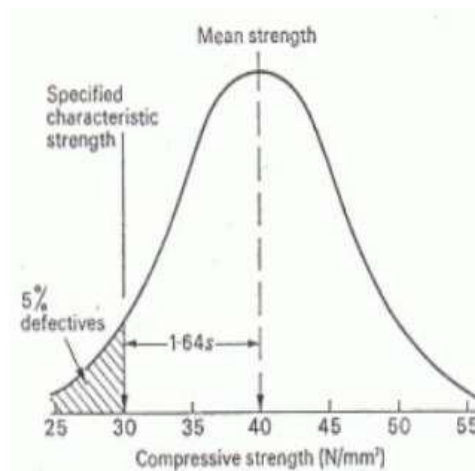


Figure 5: Normal Distribution curve on test specimens for determining compressive strength [45]

Iraq building code 1-1987 [46], the quality of concrete that measure as compressive strength in which the average of four consecutive strength tests, the compressive characteristic compressive strength shall exceed at least 3 MPa in addition to no individual compressive strength results by more than 3 MPa. The Iraq specification relies on BS and ASTM that deals with same subject that is mean the compressive strength and other concrete mechanical properties of concrete.

Egyptian code of practice, ECP 203-2018 [47], specified the minimum requirements of compressive strength for cub with dimensions of 150x150x150 mm that using in structural reinforce concrete members 20 MPa and should be not greater than 60 MPa.

Based on PCA [48], the design compressive strength f'_{cr} must be greater than the specified strength f'_c in which the standard deviation must be greater than 30 consecutive strength tests have similar materials and conditions. In case of the samples less than 30 but more than 15 tests, the standard deviation multiply by modification factor that lists in Table 3 as follows:

Table 3: modification factor [48]

Number of Tests	Modification Factor
15	1.16
20	1.08
25	1.03
>30	1.00

In case of the tests less than 15, Table 4 lists the formula to calculate the compressive strength as follows:

Table 4: Required strength [48]

Specified Strength (MPa)	Required Average Strength (MPa)
< 21	$f'_c + 7.0$
21-35	$f'_c + 8.5$
> 35	$1.1 f'_c + 5.0$

The normal distribution with standard deviation shown in Figure 6 that represents the specified and average design strength limit.

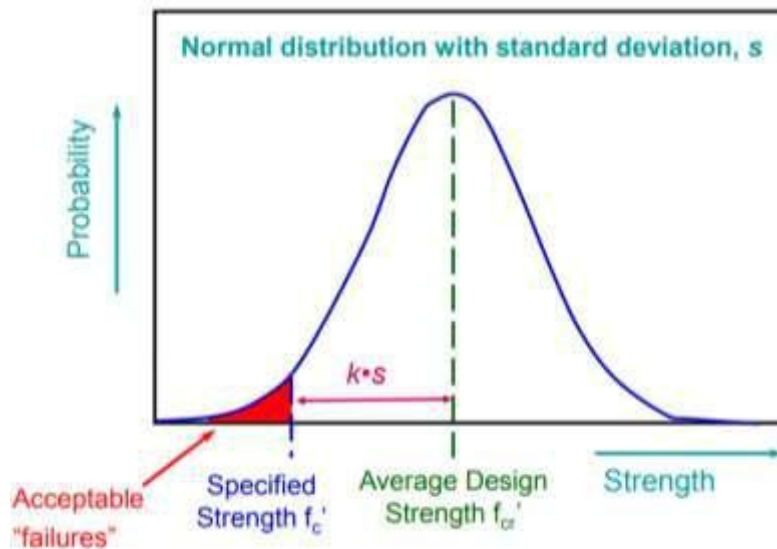


Figure 6: Normal distribution and standard deviation of the specified and average design strength limit [48]

BS (1881): Part 203 (BS, 1881, 1986) [49], described the time required for pulse to travel through concrete to find out the velocity. The ultrasonic pulse velocity can be adopting to evaluation of concrete quality based on test results so that the pulse velocity is a function of uniformity, incidence, internal flaws, cracks and segregation. Table 5 lists the concrete quality according to pulse velocity.

Table 5: Concrete quality [49]

Concrete quality	Pulse velocity (km/sec)
Excellent	> 4.5
Good	3.5-4.5
Medium	3.0-3.5
Poor	< 3

According to ACI-214R-11 [50], the required compressive strength f'_{cr} as a function of specified compressive strength f'_c as follow:

$$f'_{cr} = f'_c + z s \quad 21$$

where s is the sample standard deviation and z is the constant multiplier that depend on the number of tests. The equation to determine the minimum required strength lists in Table 6.

Table 6: Equations to determine minimum required average strength [50]

Criterion 1	Criterion 2	Criterion 3	Criterion 4
Maximum percent of individual tests < f_c	Maximum percent of moving average of n consecutive tests < f_c	Maximum percent of individual tests < ($f_c' - k$)	Maximum percent of individual tests < ($k\%$ of f_c')
$f_{cr}' = f_c' + z s$	$f_{cr}' = f_c' + (z s / n^{0.5})$	$f_{cr}' = (f_c' - k) + z s$	$f_{cr}' = k f_c' + z s$

The Probabilities associated with values of z lists in Table 7 Table 7: Probabilities associated with values of z [50]

Percentages of tests within $\pm z\sigma$	40	50	60	68.27	70	80*	90	95	95.45	98*	99	99.73
Chances of falling below $f_c' - z\sigma$	3 in 10 (30%)	2.5 in 10 (25%)	2 in 10 (20%)	1 in 6.3 (15.9%)	1.5 in 10 (15%)	1 in 10 (10%)*	1 in 20 (5%)	1 in 40 (2.5%)	1 in 44 (2.3%)	1 in 100 (1%)*	1 in 200 (0.5%)	1 in 744 (0.13%)
z	0.52	0.67	0.84	1.00	1.04	1.28*	1.65	1.96	2.00	2.53*	2.58	3.00

* Commonly used values.

Conclusions

This study reviewed on the assessment methodologies tests of concrete samples as destructive and nondestructive, the following conclusions can be drawn from this study:

- The reliability of the conformity very important for compressive strength assessment.
- Undestructive test as hammer test gives reliable results as compared with ultrasonic velocity test.
- The compressive strength mainly rely on concrete mix.
- Some structural members failed due to low compressive strength of these members because of inaccurate mixing procedure of concrete in addition to the poor in quality of mixed materials.
- The hammer test gave higher values as compared with distractible compression test while core test founded mostly accurate values.
- Length to diameter ratio of the tested core effect on the compressive strength of cores.
- Ultrasonic pulse velocity test gave accurate and can be trustworthy analysis to predict the concrete compressive strength under the effect of high temperature.
- The investigation, more than one method to evaluate the concrete strength lead to more promising of the concrete in construction.
- No different in compressive strength between the layers and should be not taking into account from engineering designer.

References

- [1.] Kausay and Simon, "Acceptance of concrete compressive strength", Research gate, July 2019, pp. 1-19.
- [2.] Tijani, Wu and Lim, "Aggregate size effects and general static loading response on mechanical behavior of passively confined concrete", Construction and Building Materials 205, 2019, pp. 61–72.
- [3.] Gomaa, Sargon, Kashosi, Gheni, and ElGawady, "Mechanical Properties of High Early Strength Class C Fly Ash-Based Alkali Activated Concrete", Transportation Research Record Journal of the Transportation Research Board, March 2020, pp.430-443.
- [4.] Basa, Pradhan and Parhi, "Mechanical Properties of Concrete with Sintered Fly Ash Aggregate as Substitute of Natural Fine Aggregate", Bidyadhar Basa et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 970 012013, pp. 1-7.
- [5.] Tiwari, Shrivastava, Singh³ and Kishan, "Evaluation of Strength Characteristics of Pavement Quality Concrete Mixes using Ekosoil", International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 01 | Jan 2019, pp.1746-1751.
- [6.] Amen, Abdulmajeed and Hassan,"comparative analysis of the rebound hammer & ultrasonic pulse velocity in testing concrete with multi – variation equation", International Review of Civil Engineering (I.R.E.C.E.), Vol. 7, n. 6 (2016), pp. 1-7.
- [7.] Mulik, Deo, Dhumal and Ghaywat, "Concrete Quality Assessment by Using Non-Destructive Test", International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 03 | Mar 2019, pp. 5202-5204.
- [8.] Nwidi, "Modeling of compressive strength of concrete using pulse velocity values from a non-destructive testing of concrete", Journal of Civil Engineering and Construction Technology, 12 March, 2019, pp.13-19.

- [9.] Koespiadi et al, "The Concrete Quality Testing for Trapezoidal Model of the Prefabricated Foundation", *International Journal of Engineering & Technology*, 7 (3.25) (2018), pp. 311-315.
- [10.] Haavisto, Husso and Laaksonen, "Compressive strength of core specimens drilled from concrete test cylinders", *TECHNICAL PAPER Fib WILEY*, 24 September 2020, pp.1-13.
- [11.] Al-Ghamdi, "An Assessment of Quality Compliance Using Concrete Test Mechanism: A Case Study with a Construction Company in Saudi Arabia", *Journal of Global Scientific Research (ISSN: 2523-9376)* 3 (2020), pp.429-433.
- [12.] Zhou, Dou, Zhang, Zhang and Zhang, "Effects of the variety and content of coal gangue coarse aggregate on the mechanical properties of concrete", *Construction and Building Materials* 220, 2019, pp. 386–395.
- [13.] Buller, Oad and Memon, "Relationship between Cubical and Cylindrical Compressive Strength of Recycled Aggregate Concrete", *IJRMPS Volume 7, Issue 2*, 2019, pp.14-19.
- [14.] Mishra, Kenna-o, Sonam, Pamtheid and Taram, "Efficacy of Established Standard Deviation on M30 Grade Concrete", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 4, Issue 1, January 2015, pp.19127-19134.
- [15.] Rao, Ibrahim, "The standard deviation in cube strength results of self-compacting concrete of m40 grade using quarry dust as fine aggregate and fly ash powder as filler", *International Journal of Civil Engineering and Technology*, Volume 8, Issue 10, October 2017, pp.1695–1703.
- [16.] Neville, "The relation between standard deviation and mean strength of concrete test cubes", *Magazine of Concrete Research: Vol. 12, No. 34: March 1960*, pp.44-49.
- [17.] Neville, "The influence of size of concrete test cubes on mean strength and standard deviation", *Magazine of Concrete Research: March 1957*, pp.52-55.
- [18.] Ramadoss, "Modeling for the evaluation of strength and toughness of high-performance fiber reinforced concrete", *Journal of Engineering Science and Technology* Vol. 7, No. 3 (2012), pp. 280 – 291.
- [19.] ASTM Standard C 39 – 05, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens".
- [20.] ASTM Standard C 496–90, "Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA, 1990.
- [21.] ASTM Standard C 78–94, "Test Method for Flexural Strength of Concrete Using Simple Beam with Third-Point Loading" *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA, 1994.
- [22.] Hong, Yoon, Kim, Lee, Kim and Lee, "Evaluation of Condition of Concrete Structures Using Ultrasonic Pulse Velocity Method", *Appl. Sci.*, January 2020, PP.13-19.
- [23.] ASTM C597 – 16, "Standard Test Method for Pulse Velocity Through Concrete"
- [24.] ACI 228-2R, "Nondestructive Test Methods for Evaluation of Concrete in Structures".
- [25.] KS F 2405-2010, "Standard test method for compressive strength of concrete".
- [26.] Wang and Jiang, "Quality Control and Evaluation Methods of Concrete Engineering and Its Reliability Analysis", *The Open Civil Engineering Journal*, 2015, 9, PP.639-643.
- [27.] Ammad, Rehman, Saad and Abbas, "Assessment of low strength concrete with destructive & nondestructive testing method's", *3rd International Conference on Emerging Trends in Engineering, Management and Sciences* October 2018, pp.393-402.
- [28.] Arioz, Tuncan, Ramyar, Karasu, Tuncan and Kilinc, "Determination of Concrete Strength by Core Test; Effects of Sodium Sulphate and Frost Action", *8th International Congress on Advances in Civil Engineering*, September 2008, pp.77-89.
- [29.] Soutsos, Bungey, Long and Tickell, "Interpretation of in-situ concrete strength test results", *NDTCE'09, Non-Destructive Testing in Civil Engineering* Nantes, France, June 30th – July 3rd, 2009, pp.1-6.
- [30.] BS EN 13791: 2007 "Assessment of in-situ compressive strength in structures and precast concrete components", ISBN 978-0-580-50271-2, BSI, London, 2007, p. 29.

- [31.] Kirchof, Lorenzi and Silva filho, "Assessment of Concrete Residual Strength at High Temperatures using Ultrasonic Pulse Velocity", Vol.20 No.7 (July 2015) - The e-Journal of Nondestructive Testing - ISSN 1435-4934, pp.1-9.
- [32.] Olusola, Babafemi, Umoh and Olawuyi, "Effect of batching methods on the fresh and hardened properties of concrete", IJRRAS 13 (3), December 2012, pp.773-779.
- [33.] Kabashi, Krasniqi and Dautaj, "Evaluation the Compressive Strength in Concrete Structures Using the In-situ Test Methods", Journal of Civil Engineering and Environmental Sciences, 2015, pp. 1-5.
- [34.] BS EN 12504-2:2012, Testing concrete in structures. Non-destructive testing. Determination of rebound number
- [35.] BS EN 12504-4:2004, Testing concrete. Determination of ultrasonic pulse velocity
- [36.] BS EN 12504-1:2019, Testing concrete in structures. Cored specimens. Taking, examining and testing in compression
- [37.] Ju, Park and Oh, "Estimation of Compressive Strength of High Strength Concrete Using Non-Destructive Technique and Concrete Core Strength", Appl. Sci. 2017, pp.2-16.
- [38.] Nepomuceno and Bernardo, "Evaluation of Self-Compacting Concrete Strength with Non-Destructive Tests for Concrete Structures", Applied sciences, 2019, pp. 1-18.
- [39.] Michalek, "Variation in Compressive Strength of Concrete across Thickness of Placed Layer", Materials 2019, pp.2-14.
- [40.] Bora, "Tests and Acceptance Criteria for Concrete Based on Compressive Strength", National Technical Seminar on Innovation in Infrastructure Technology for Sustainable Development, Project Delivery and Management, pp.133-141.
- [41.] ACI 318-2019, "Building Code Requirements for Structural Concrete and Commentary:
- [42.] ACI 318-2011, "Building Code Requirements for Structural Concrete and Commentary:
- [43.] BS 5328 Part 4-1990. Specification for the procedures to be used in sampling, testing and assessing compliance of concrete.
- [44.] BS EN 206-1: 2013, Concrete - Specification, performance, production and conformity (incorporating corrigendum May 2014)
- [45.] IS 516:1959 Methods of Tests for Strength of Concrete (Eighteenth revision). Reaffirmed-May 2013/
- [46.] Code 1-1987, Iraq building code requirements for reinforced concrete.
- [47.] Egyptian code of practice, ECP 203-2018 for concrete construction.
- [48.] Portland Cement Association PCA, concrete technology and codes.
- [49.] BS 1881: Part 203, 1986. Recommendations for Measurement of Velocity of Ultrasonic Pulses in Concrete. British Standards Institution, London.
- [50.] ACI-214R-11, Guide to Evaluation of Strength Test Results of Concrete.