How to use Fracture mechanics in concrete design

Sabr Fnir

***Abstract*—**Fracture mechanics is applied to concrete design to offer a good understanding that how the size of a structural element may affect the ultimate load capacity, also; crack propagation can be predicted by fracture mechanics.

According to British standard (BS) there are many tests to obtain the mechanical properties of concrete, some of them for fresh concrete and the reminder for hard concrete. This report will be mentioned to five tests, slump test for fresh concrete, and compression test, splitting tensile test, three point test and ultrasonic pulse velocity are used for hard concrete ,those testes has applied on tow grades of concrete according to its strength, normal strength concrete (C30) and high strength concrete (C70).

***Keywords*—** Fracture, mechanics, concrete, design.

I. Introduction

CONCRETE'S tests can be made for different purposes but the main two objectives of testing are quality control and compliance with specifications. Five tests has been done in the laboratory for each grade of concrete (C30,C70), the first test, for fresh concrete is slump test to measure the consistency of concrete. Six moulds of cubes and three beams have used to do the testes of each grade of hard concrete. The compression test to obtain the compressive strength, splitting tensile test to obtain tensile strength, three point test to obtain the fracture energy and the fracture toughness and ultrasonic pulse velocity to obtain the modulus of elastic. All hard concrete tests have done 14 days after filed moulds. the testes have provided a results which have used to polt graphs which showing the evolution of each property, and the relation between the properties was compared and discussed. moulds. the testes have provided a results which have used to polt graphs which showing the evolution of each property, and the relation between the properties was compared and discussed.

II. Experimental work

A. Specimen preparation/mix proportions

According to (BS) the concrete mix has been designed for each grade of concrete, and the following table is shown a specific of each Grades.

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TABLE I
IN TOW TYPES OF CONCRETE (C30, C70) THE FOLLOWING ARE MAIN INGREDIENTS:

Grades	Free Water/ cement ratio	Cement	Water	Finer aggregate	Corse aggregate (20mm)	Slump
		Kg/ m³	ml /m³	Kg /m³	Kg/ m³	Mm
C30	0.58	310	1800	752	1128	30-60
C70	0.31	615	1900	535	1090	30-60

Cement is ordinary Portland.
Coarse aggregate is 20mm, uncrushed and gravel in C30, and crushed granite in C70.
Fine aggregate is natural river sand uncrushed in both C30 andC70.
The water is tap water.

The contents have mixed by drum (concrete mixer) as the procedure to get homogeneous mixture in the laboratory. The super-plasticizer has added in C70, before it is added noted that the mixture became hard to mix because the amount of water was little but when added the super-plasticizer the mixture became easier to mix. The reason to use the super-plasticizer, to decrease the water cement ratio and modify the properties of concrete.

Six cubes moulds which dimensions of each cube according to BS 1881-108:1983 is (100*100*100 mm) have used for each grade (C30, C70), the cubes filled according to BS 1881:part 108 in three layers, and compacted by using the vibration table to make the sample homogeneous, compacted and to eliminate the air voids. Then the samples have left 24hours in conditions of chamber according to BS 1881:Part11 (temperature 20±2C and humidity 90%), later than removed the samples from the moulds and flooded them in water for 7days (temperature 20±2C) and additional 7days in air.

At the same time, it has been done that use three beams (moulds) which dimensions (100*100*500mm) for each Grade of concrete, they filled and used the vibrating table to compact the samples, and in same conditions chamber and same time, put all beams in water and air as same as the cubes. And it has notched for each beam by used diamond saw one week before testing.

B. Workability

Workability is the amount of mechanical work required to make full compaction of the concrete without segregation. It is desirable depends on two factors, minimum size of the section to be concreted and the amount and spacing of reinforcement. The appropriate value of slump and of means of compaction for various types of construction is given in BS 5328: Part 1:1991.

C. Slump Test

The explanation for slump test In BS 1881: part 102:1983; the mould for slump test is a frustum of a cone, (300 mm) high. The mould placed on a smooth surface with the smaller opening at the top. The procedure to fill the cone with concrete in three layers, each layer is tamped 25 times with a standard (16 mm) diameter steel rod. After filling, the cone is bit by bit lifted, and the unsupported concrete will now slump. The decrease in the height of the slumped concrete is a slump, and is measured to the nearest 5mm from the top and that what has done in the laboratory

D. Compressive Strength

Three cubes have tested to obtain the compressive strength by using the compression test for each grade (C30, C70). The samples have crushed under the applied load during the compression test at rate constant of 6KN/sec.
The compressive strength is calculated by following formula:

$$f_c = \frac{P}{A}$$

Where : P = maximum load (kN)
A = Area of cross section of beam (base x height) in mm².

E. Tensile Strength

The other three cubes have tested to obtain tensile strength by using the splitting tensile test for each grade (C30, C70). The tensile strength is calculated by following formula:
Note: The rate of speed of displacement was 1mm/min.

$$f_t' = \frac{2P}{\pi a^2}$$

Where : P = Compressive load.
a = Side of the cube.

F. Density

The samples have been used to obtain the density as well; The Density is calculated by following formula:

$$\rho = \frac{W_{in\_air}}{W_{in\_ar} - W_{in\_water}}$$

Where: w_{air} is the mass of cube in air (kg),
W_{water} is the mass of cube in water (kg),
ρ is the density of water(kg/m³).

G. Young Modulus of Elasticity

The modulus of elasticity has been obtained by using Ultrasonic pulse velocity (UPV) test, this determination consists of measurement of the time taken by a pulse - so the name of the method to travel measured distance. The apparatus includes transducers which are placed in contact with the concrete, a pulse generator with a frequency of between 10 and 150 Hz, an amplifier, a time measuring circuit, and a digital display of the time taken by the pulse of longitudinal waves to travel between the transducers.. The test method is prescribed by ASTM C 597-83 (Reapproved 1991) and by BS 1881: Part 203:1986. And it is calculated by following formulas:
Note: The soap has used to make good contact.

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

Where: V = velocity (m/s)
L=Distance
T=poissonic pulse time in sec

$$Ed = \rho * V^2$$

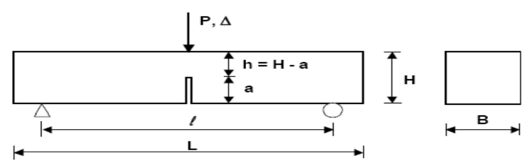
Where : ρ = density of concrete (g/ m^3)
Ed = modulus of elasticity (GPa)

H. Fracture Energy

Three point bending test has done for beams to obtain the total energy dissipated over a unit area of the cracked ligament (fracture energy) and Fracture toughness for concrete (C30 and C70) as following:
Note: The rate of speed of displacement 0.01 mm/min for three-point bending test. The ball in machine used to make sure the load applied on the centre of sample.
Calculation of Fracture Energy;

$$G_F = \frac{\int_0^{\Delta_0} P d\Delta + mg\Delta_0}{b(h-a)}$$

Where :
P = the applied load;
m = the mass of the concrete beam between the supports in kg;
g = the acceleration due to gravity and g = 9.81 m/s2;
b = the breadth of the beam;
h = the height of the beam;
a = the notch depth of the beam and normally a = 0.5 h.



The beam in three-point bending test

I. Fracture Toughness

Fracture toughness is an indication of the amount of stress required to propagate a pre existing flaw. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof.
Calculation of Fracture Toughness as the following:

$$G_c = \frac{K_c^2}{E_d}$$

$$K_c = \sqrt{G_F E_d}$$

Where: GF = Fracture mechanics (Gpa)
E = modulus of elasticity (KPa)

III. Results/Data of Properties Measured and Discussion of Results

A. Workability and Slump Test

The table below show the average of values of slump which have got from the test.

TABLE II

Grades	The average of slump(mm)
C30	11.334
C70	256

It is clear from the table above, the value that has been determined from slump test for (C30) is (11.334mm) , that means it is not acceptable compared with the limitation of slump value of mix design form which is (30-60mm), that means the test has failed because of the lack of the amount of concrete water.

The result of slump for (C70) is (256mm) it has been collapsed that because of the super-plasticizer and the moisture content of aggregate has suddenly increased.

B. Compressive Strength, Tensile strength and Density

The table below show the values of results of the Compressive Strength, Tensile strength and Density of C30 and C70:

TABLE III

Grades	Compressive Strength *(MPa)*	Tensile strength *(MPa)*	Density *Kg/m^3*
C30	42.676	3.19	2.373
C70	73.271	*4.42*	2.382

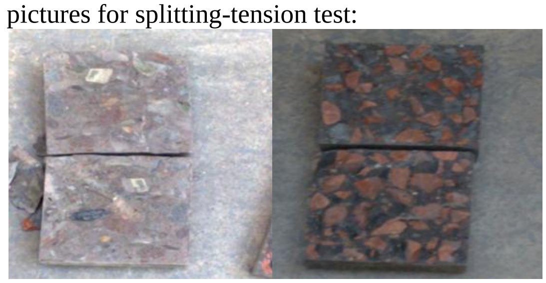
As can be seen from the table above the results prove that the compressive strength of concrete greater than the tensile strength. Also it is clear, the differences in compressive strength and tensile strength between two grades (C30 and C70) where the values for high strength concrete higher than the values for normal strength concrete, that due to used super-plasticizer which provide the concrete high strength. Furthermore, the type of aggregate has influence on the strength of concrete. So the crushed coarse aggregate made the concrete more strength than uncrushed coarse aggregate. It might be because of an increasing the surface roughness of crushed coarse aggregate which improve the bonding matrix between the aggregates and cement. Therefore, the bonding matrix between the coarse aggregate and cement paste in high strength concrete higher than in normal strength concrete that made the high strength concrete more resistance under the applied load. Also it is noted that, the value of density of each Grades has been increase when the Compressive Strength increase.

Following pictures shows the Compression test for both C30 & C70:

(C70) (C30)

Fig. 1 compression test Figure

Some pictures for splitting-tension test:



(C70 (C30)

Fig. 2 Splitting-tension test

It is clear from the figures above that, the failure in splitting-tensile test for (C30) in cement paste and between the aggregates but the failure in (C70) through the aggregates and cement paste that prove the good bonding between the aggregate and cement paste in high strength concrete. Also it can be seen that there is separation between the aggregate and cement paste in normal strength concrete (C30). However, there is consistence between the aggregate and cement paste in high strength concrete that because the structure for higher strength concrete more homogeneous than the structure for normal strength concrete.

C. Young Modulus of Elasticity

The table below show the values of Young Modulus of Elasticity of C30 and C70:

TABLE IV

Grades	Young Modulus of Elasticity(*Gpa)*
C30	44.131
C70	58.349

As can be seen that, the value of Young Modulus of Elasticity of C70 higher than the value of Young Modulus of Elasticity of C30 due to the difference of the coarse aggregate which crushed for C70 and uncrushed for C30 which have an effect on the modulus of elasticity of aggregate.

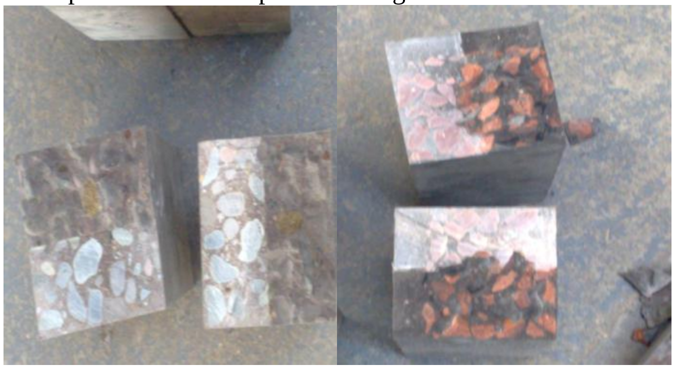
D. Fracture Energy and Fracture Toughness

The table below show the values Fracture Energy and Fracture Toughness of C30 and C70.

TABLE V

Grades	Fracture Energy (GF) Gpa	Fracture Toughness *(KC)* Gpa
C30	174.997	3.051
C70	186.953	2.997

Some pictures for three-point bending test.



(C70) (C30)

Fig. 3 Three-point bending test

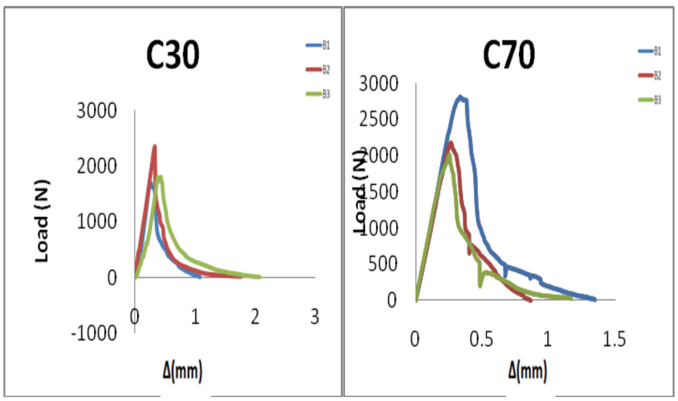


Fig. 4 Load-displacement curves for three-point bending test

As a result from the calculation of fracture energy and Fracture Toughness that the characteristic length and fracture energy increase when brittleness decrease. the failure of normal strength concrete is more brittle than the failure of high strength concrete that relating to the compressed high strength concrete matrix and interfaces, which reduce the toughening that can occur during crack propagation.

IV. Conclusion

To sum up, the value of slump test of C30 and C70 was not acceptable due to use little amount of water for C30 and used amount of super-plasticizer for C70.

The compressive strength of concrete greater than the tensile strength, Also the differences in compressive strength and tensile strength between two grades where the values for high strength concrete higher than the values for normal strength concrete, due to using super-plasticizer and the type of aggregate. Also it can be seen that the difference in elastic-linear behaviour between two Grades that influence on the values for modulus of elasticity and the properties of concrete, the high strength concrete more brittle than normal strength concrete and as a results for fracture energy, characteristic length and brittleness illustrate that when the strength increase the brittleness increase.

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