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# Effect of Concrete Parameters on Local Fracture Energy of Concrete

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**Abstract**
Experimental observations and numerical simulations are compared with theoretical results based on RILEM recommendation [1].

The intention of this paper is to determine the influence of concrete parameters on local fracture energy and failure mode of concrete beams. Three-point-bending test on notched concrete beams have been performed using two most known methods available in literature for determining the failure mode dependent on fracture energy of concrete beams, taking in consideration the relationship between the applied load and the crack opening displacement during different loading stages. The existing fracture models for concrete and the testing methods for fracture energy are reviewed, some new results on relationship between failure mode from one side and fracture energy and size effect from the other side are presented, the value of critical fracture load has been checked during the crack propagation process, also it has been noticed that in both test and analytical model results, the critical fracture load disappears as the notch length increases and finally the results obtained were confronted with other results [2].

**Keywords:** Fracture Energy, Concrete Parameters, Cohesive Crack, Size effect.

## INTRODUCTION

The fracture energy of concrete $G_f$ is the amount of energy necessary to create one unit area of a crack, defined as the projected area on a plane parallel to the main crack direction and it is one of the important parameters that characterize concrete fracture. The nonlinear behavior of concrete has been taken in consideration and the direct iterative method has been considered as shown in (Fig.1). The equilibrium equation at an instant t is given by:

$$\{R(t)\}-\{F(t)\}=0 \tag{1}$$

Where $\{R(t)\}$ is the external Load vector at an instant t and $\{F(t)\}$ is the internal force vector, given by:

$$\{F(t)\} = \tag{2}$$

The equilibrium equation could be written as a secant stiffness matrix $[K_S(\Delta)]$ :

$$[K_S(\Delta)]\ \{\Delta\} = \{R\} \tag{3}$$

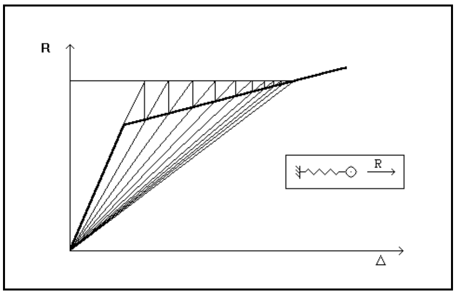


**Figure 1.** Secant Iterative Method

Thus the fracture Mechanics introduced here as the science which deals with the study of how a crack or flow in a structure propagates under applied load involving correlating analytical predictions of crack propagation and failure with experimental results. In many experiments on three point pending beams it was found that the maximum load increases by increasing $G_f$ [3], showing brittle behavior with lower value of $G_f$ and ductile behavior for higher values, where the area under which represents the work of fracture $W_f$

$$W_f = W_o + mg\delta_o; \tag{4}$$

Relating the work of fracture with the fracture energy we get:

$$W_f = \frac{G_f}{A_{lig}} \tag{5}$$

The most extended procedure for it to be obtained is the three point bending test [1 - 3], whose guidelines are collected in RILEM draft recommendation (50-FMC). The wedge-splitting test [4] represents some advantages compared to the three point bending test and it is also often used. From any of those tests, the load-displacement or Load-CMOD (crack mouth open displacement) curve is obtained as shown in (Fig.2), Where:

$W_o$ is the area under load displacement Diagram

m = Mass of beam between supports plus the double weight of the loading arrangement, g is the acceleration due to gravity, $\delta_o$ is the deformation at the beam failure and

$A_{lig}$ is the area of the ligament

According to LEFM the strength of a structure is proportional to the critical stress

Intensity factor $K_c$, and in its turn proportional to the fracture energy as follows:

$$k^2_{c/E} = G_f \tag{6}$$

In non-linear fracture mechanics the strength of a structure is proportional to the tensile strength $f_t$ and a function of $\frac{d}{I_{ch}}$, where d is a typical dimension of the structure and

$$I_{ch} f_t^2 = E G_f \tag{7}$$

$I_{ch}$, is the characteristic length, which describes the brittleness of the concrete [5]

So as a result, one single value alone is not enough to describe the fracture properties of the concrete. More accurate value is possible if it is correlated to modulus of elasticity, tensile strength $f_t$ and the shape of the descending branch of the tensile stress-deformation diagram are known.

**Test Setup**

As a rule the displacement velocity must be constant or nearly constant to reach the maximum load value after 30 to 60 second at least. Figure (3) shows the test setup.

The concrete compressive strength, obtained by 7 cubic specimens with a side equal to 100 mm, presents a mean value equal to 48.2 Mpa, concrete elastic modulus, obtained by 4 specimens of 100x100x300 mm, presents a mean value equal to 35000 Mpa The geometrical characteristics of the tested beams are reassumed in table 1; water cement ratio used was 0.52 and the maximum aggregate size is 20 mm.

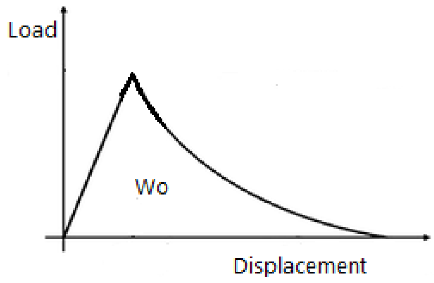


**Figure 2.** Load Displacement (CMO) Diagram

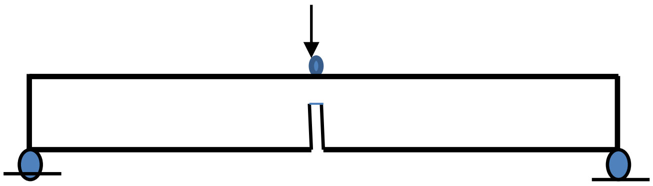

**Figure 3.** Test setup

**Table1.** Beams characteristic

| Beam N. | M1 (Kg) | M2 (Kg) | Length (mm) | Depth (mm) | Width (mm) | Span (mm) | Notch Depth (mm) | Notch Width (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.460 | 1.406 | 859 | 100 | 102 | 800 | 49 | 3.2 |
| 2 | 20.090 | 1.406 | 857 | 100 | 104 | 800 | 49 | 3.2 |
| 3 | 20.380 | 1.406 | 855 | 102 | 100 | 800 | 48.5 | 3.2 |
| 4 | 20.035 | 1.406 | 855 | 100 | 100 | 800 | 48.5 | 3.2 |
| 5 | 20.810 | 1.406 | 857 | 100 | 105 | 800 | 51.5 | 3.2 |
| 6 | 20.280 | 1.406 | 857 | 100 | 100 | 800 | 51 | 3.2 |
| 7 | 20.615 | 1.406 | 860 | 101 | 107 | 800 | 49.5 | 3.2 |
| 8 | 20.190 | 1.406 | 857 | 101 | 101 | 800 | 51.9 | 3.2 |

**Test Results**

Table 2 reports the experimental results

Table 3 reports values with different W/C ratio while table 4 with different beam depths both tables represented by others.

Figure 3 shows the load displacement Diagrams for all tested beams

Concrete fracture energy, determined according to RILEM (RILEM TC50-FMC) on 8 specimens, is characterized by a mean value of 0.118 N/mm.

**Table2.** Fracture energy values

| **wo (N.m)** | **(M1+M2) Kg** | **δ (m)** | **g m/s2** | **Area Lig.(m2)** | **$G_f$ (N/m)** |
|---|---|---|---|---|---|
| 0.4492 | 23.272 | 0.001116 | 9.81 | 0.005202 | 135.3288976 |
| 0.3435 | 22.902 | 0.000901 | 9.81 | 0.005304 | 102.9273052 |
| 0.4013 | 23.192 | 0.000883 | 9.81 | 0.00515 | 116.9309589 |
| 0.3904 | 22.847 | 0.000886 | 9.81 | 0.00515 | 114.3647293 |
| 0.3378 | 23.622 | 0.000844 | 9.81 | 0.0050925 | 104.7386659 |
| 0.3734 | 22.517 | 0.001114 | 9.81 | 0.0049 | 126.4231493 |
| 0.3925 | 23.427 | 0.000958 | 9.81 | 0.0054035 | 113.3832659 |
| 0.3912 | 22.712 | 0.00117 | 9.81 | 0.0048581 | 134.1844594 |

**Table 3.** D max = 16mm by others

| W/C | B (mm) | H (mm) | L (mm) | $G_f$ (N/m) |
|---|---|---|---|---|
| 0.33 | 100 | 100 | 800 | 77 |
| 0.35 | 100 | 100 | 800 | 102 |
| 0.48 | 100 | 100 | 800 | 174 |

**Table 4.** D max = 30 mm changing beam depth and length by others.

| W/C | b (mm) | h (mm) | L (mm) | $G_f$ (N/m) |
|---|---|---|---|---|
| 0.4 | 100 | 100 | 800 | 130 |
| 0.4 | 100 | 200 | 1148 | 167 |
| 0.4 | 100 | 300 | 1415 | 234 |

Figures 4 to 9 indicate the Load Displacement Diagrams for all 8 tested beams.

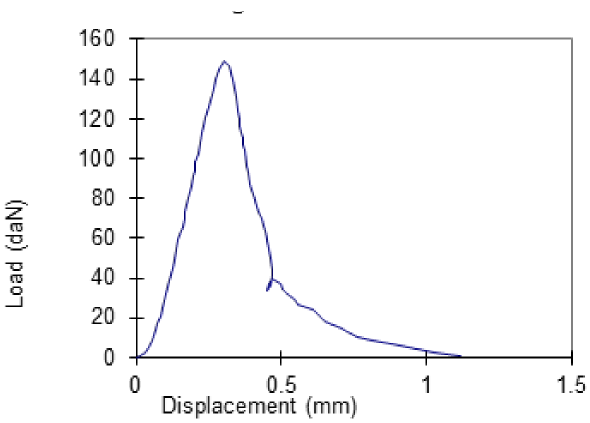


**Figure 4**

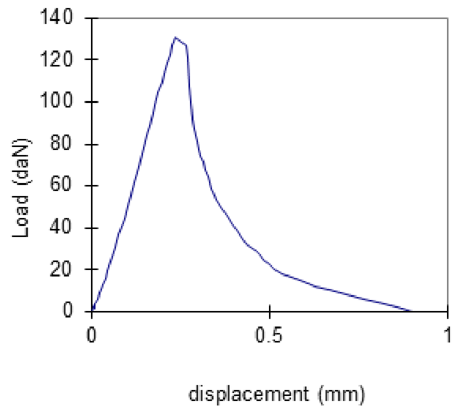


**Figure 5**

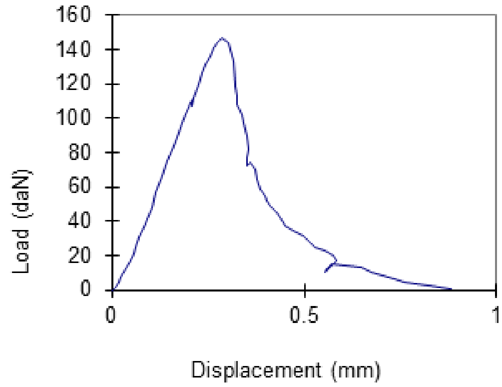


**Figure 6**

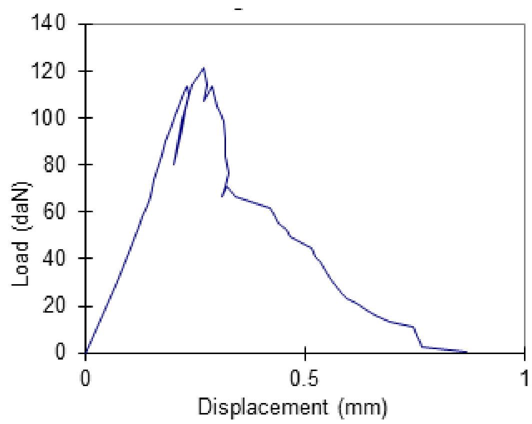


**Figure 7**

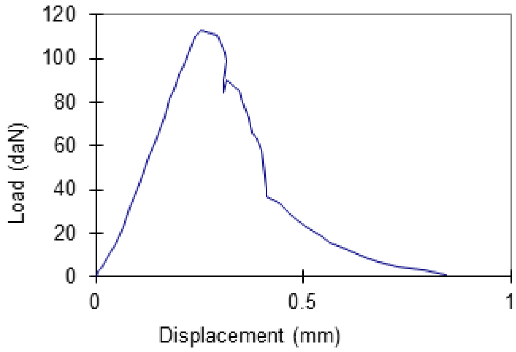


**Figure 8**

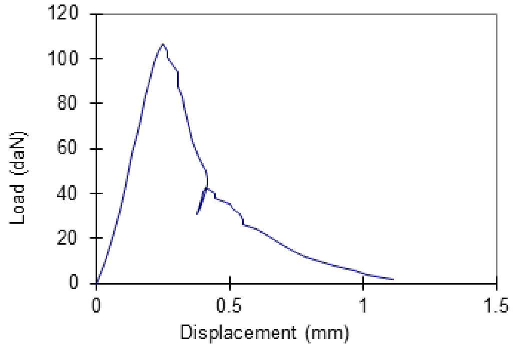


**Figure 9**

## CONCLUSION

As shown in table 3 and 4, the value of $G_f$ increases by increasing W/C ratio which reflect the increasing in concrete strength as known, also increasing beam depth and/or aggregate size show a considerable increasing in $G_f$ value, this is a confirmation of what has been discussed by many other authors in the past.

The representation of the micro crack is being considered as a part of crack and is governing by the transfer law of cohesive stress, which is decreased with increasing the crack opening.

The cohesive crack model [6], which models the development of the fracture process zone (FPZ) by the stress vs. crack-opening relationship at the crack tip is widely believed to be the best performing fracture model for concrete and is widely used in the fracture analysis of concrete. The model is also very useful in experimental studies since only the characteristics at the original crack tip, whose geometric location is precisely known, need to be studied.

## REFERENCES

[1] RILEM 50-FMC, Determination of the Fracture Energy of Mortar and Concrete by Means of Three Point Bend Test on Notched Beams, Materials and Structures, Vol. 18, No. 106, pp. 285-290. (1985).

[2] C. Bosco, A. Carpinteri, M.El-Khatieb, G. Ferro: "Ductile-brittle transition for reinforced concrete beams: Experimental and numerical investigation", in *Mechanisms and Mechanics of Damage and Failure* (Proceedings of the 11th European Conference on Fracture, Poitiers, France, 1996), Ed. J. Petit, EMAS, West Midlands (1996), Vol. 3, 1865-1870.

[3] Z.P. Bazant, in SEM / RI LEM International Conference on Fracture oj" Concrete and Rock, Society for Experimental Mechanics (1987) 390-402; also Fracture o/, Concrete and Rock, S.P. Shah and S.E. Swartz (eds.), Springer Verlag, N.Y. (1989) 229-241.

[4] Korte, S., Boel, V., De Corte, W., De Schutter, G., Static and fatigue fracture mechanics properties of self-compacting concrete using three-point bending tests and wedge-splitting tests, Construction and Buildings Materials, 57 (2014) 1– 8.

[5] Minimum Reinforcement in Concrete Members" *European Structural Integrity Society*, *Volume 24*, *1999*, *Pages 1-30* Elsevier A. Carpinteri, G. Ferro, C. Bosco, M. Elkatieb

[6] Failure mode transitions in RC beams: a cohesive/overlapping crack model application Carpinteri · M. El-Khatieb · E. Cadamuro "Meccanica December 2013", Volume 48, Issue 10, pp 2349-2366