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LOAD RELAXATION IN LEVEL II THREE-POINT BEND TESTS

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Abstract

In this paper, the procedures involved in the Three Point Bending Test of plain concrete notched beams are reviewed. Special attention is given to the loading, unloading and reloading procedures involved in the Level II fracture toughness test. A vertical drop of the load level, at the peak load of each cycle, under a constant CMOD condition has been observed. This drop presents a quasi-exponential variation with time, tending asymptotically to a level of equilibrium.

The load drop, observed in a closed loop in which the load level is controlled by the clip on gage response, was understood initially as a necessary condition for the maintenance of the CMOD at the level where the holding takes place, within a relaxation process. The load decline may lead to a first assumptions that the cohesive interface is opening with a simultaneous reduction in the cohesive tractions. It was observed that each new ascendant branch crosses the descendant one practically at the previous point of equilibrium, and that these interception points form a new envelop, internal to the one corresponding to the maximum loads of each cycle.

Key words: Load relaxation, fracture toughness, level II three-point bending test.

1 Introduction

The fracture toughness of concrete and mortar is usually determined through Level I and Level II tests. As it is well known, three point bending Level I tests require basically the maximum load, $\mathbf{P_{max}}$, the Young Modulus, **E**, resultant or not from the fracture test, accompanied by the load line deflection at the maximum load, $\boldsymbol{\delta_{max}}$, or the initial and the unload compliances, $\mathbf{C_I}$ and $\mathbf{C_U}$. These models are known as the Effective Crack Model by Karihaloo and Nalathambi (1989) and the Two Parameters Crack Model, by Jenq and Shah (1985), respectively.

In a Level I test, the nonlinear response of the specimen due to the material inelastic behavior is treated iteratively through the determination of an effective crack length, $\underline{\mathbf{a}}$, because a satisfactory value of the real crack length at the maximum load, $\mathbf{P_{max}}$, cannot be experimentally determined due to the cohesive interface, present in the cracking process.

Proposed initially by Barker (1979), Level II fracture toughness test, usually performed under CMOD control conditions, deals with the inelastic behavior of the material by considering the change in the compliance of the specimen within two or more complete loading cycles. The unloading starts at $\mathbf{P_{max}}$ and reloading takes place from a certain minimum value of the applied force. This procedure allows the determination of a correction factor, **p**, named "inelastic correction factor". This factor, conveniently applied to a fracture toughness obtained from the linear elastic fracture mechanics concepts, $\mathbf{K_{IQ}}$, usually conducts to valid results of fracture toughness. Hence, the applicability of Level II tests seems to be suitable to specimens in which the crack length, $\mathbf{a_C}$, at maximum load, is known *a priori*, what apparently occurs with short rods, short bars and other chevron notched specimens.

On the other hand, the applicability of Level II tests to the determination of fracture toughness from notched-through concrete beams in bending requires a knowledge of the apparent crack length at the maximum load. To measure this crack length, within a CMOD controlled test, a "holding phase" at the maximum load is necessary. At this time of the test, that is, at the load of instability, the CMOD is kept constant by the clip on gage response.

Catalano (1983), measuring the apparent crack length in three point bending beam tests, observed a decrease in the applied load under constant CMOD, indicating that the crack propagated during the holding phase. This phenomenon, according to authors' best knowledge, was exclusively reported by Catalano, even considering the substantial number of beams tested in bending until the present day. An initial discussion of the phenomenon is presented as the main objective of this paper.

According to Catalano, the amount of crack propagation was small and the load loss and crack propagation were negligible beyond the first two minutes of the holding phase. Here, it is understood that the decrease of load, occurring in a closed loop where the load is controlled by the clip on gage response, may be interpreted as a necessary condition for the maintenance of the CMOD, within a relaxation process. So, the ceasing of the force decline after a few minutes under sustained CMOD (represented by point B_1 in Fig. 1) leads to the first assumption that the load drop originates from the cohesive interface.

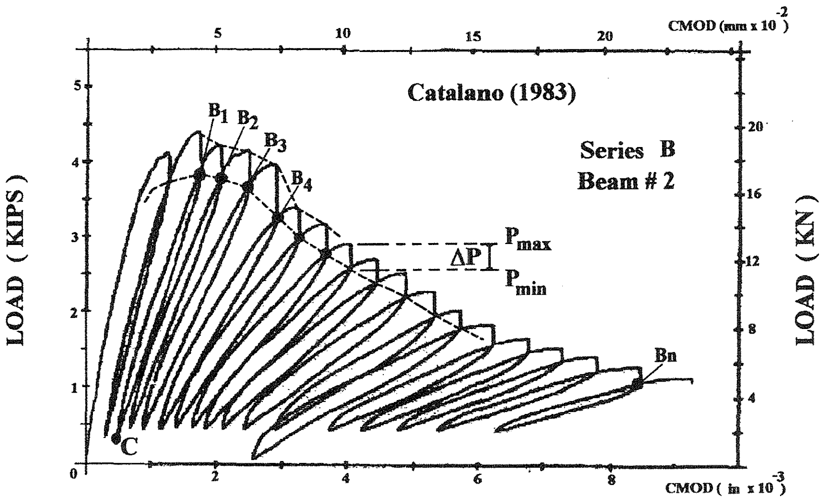

Fig. 1. Points of stabilization of the load after the relaxation process

It was observed that, after unloading from point $\mathbf{B_1}$ and reloading from point **C**, a new crack extension takes place and the ascendant branch on the P x CMOD path crosses the previous descendent one, practically at point $\mathbf{B_1}$. This is true if the first holding takes place at or after the peak load. From successive complete cycles of loading, holding and unloading, it is possible to obtain the $\mathbf{B_i}$ points shown in Fig. 1. These points clearly forms a new envelop, internal to the one due to the maximum loads from each cycle. The maximum load of the any cycle is always on the external envelop, that would be obtained if the specimen was taken to the rupture in a monotonic way. This fact, was studied in details by Yankelevsky and Reinhardt (1989). In this paper the relaxation phenomenon briefly described is analyzed, first through the interpretation of Catalano's experiments and after, through the authors' results.

2 Analysis of previous experiment

From Catalano's experimental results it was possible to identify the values of the load drop, **ΔP**, in each cycle, as well as to correlate the minimum loads, **P_{min}**, with the maximum ones, **P_{max}**, in these cycles. These load values were obtained, with satisfactory precision, through the graphical coordinates from tests diagrams images, for the 6 beams of series B and C tested by Catalano in 1983 (Fig. 1).

Using this procedure, it was observed that, within each cycle of relaxation, the relation **P_{min} / P_{max}** remained somewhat constant. For the 12 complete cycles performed in each test, low values of standard deviation were observed.

As in each of the series (B and C) **3** beams were tested, a mean value per series was computed and, again, presenting low values of standard deviation (Table 1).

Table 1 - Relations between Minimum and Maximum Loads in the relaxation phases

Series/Beam		$(P_{min}/P_{max}).100$	S.D.
	Beam #1	86.35	2.40
B	Beam #2	87.85	1.05
	Beam #3	83.90	1.71
Mean Value		**86.03**	**1.63**
	Beam #1	83.14	0.89
C	Beam #2	84.44	1.34
	Beam #3	81.84	1.76
Mean Value		**83.14**	**1.06**

3 Experimental Investigations

Within a more recent research program, Ferreira and Sousa (1997) tested beam (60 mm x 90 mm x 405 mm, span 360 mm) made of a micro-concrete resultant from an ideal aggregate granulometric distribution curve, to confirm Catalano's observations. The maximum aggregate size used was 9.5 mm and the water/cement ratio 0.55. The compressive strength of the mix was 31.26 MPa and the tensile strength, 3.00 MPa, both at age 28 days. Five complete loading cycles were performed and the relaxation process was observed by monitoring the load level through time, every 15 seconds. The relaxation time was verified to be 7 minutes, approximately $1.5T_P$, where $\mathbf{T_p}$ is the time to the peak load. The results are shown in Table 2 and Fig. 2.

Table 2 - Relations between Minimum and Maximum Loads in the relaxation phases

Cycle	1	2	3	4	5	Mean	S.D.
$(P_{MIN}/P_{MAX}).100$	91.14	91.45	88.09	90.41	90.85	**90.39**	**1.20**

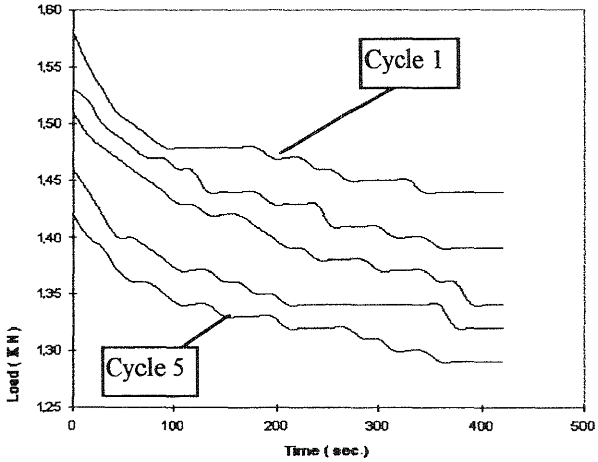

Fig. 2 Relaxation of the load in time

Similarly, other two beams (60 mm x 120 mm x 540 mm, span 480mm) of the same material were tested. The results are shown on Table 3 and Fig. 3.

Table 3- Relations between Minimum and Maximum Loads, in the relaxation phases

Beam	N. Cycles	$(P_{min}/P_{max}).100$	Standard Dev.
1	5	91.884	0.837
2	4	86.550	2.259

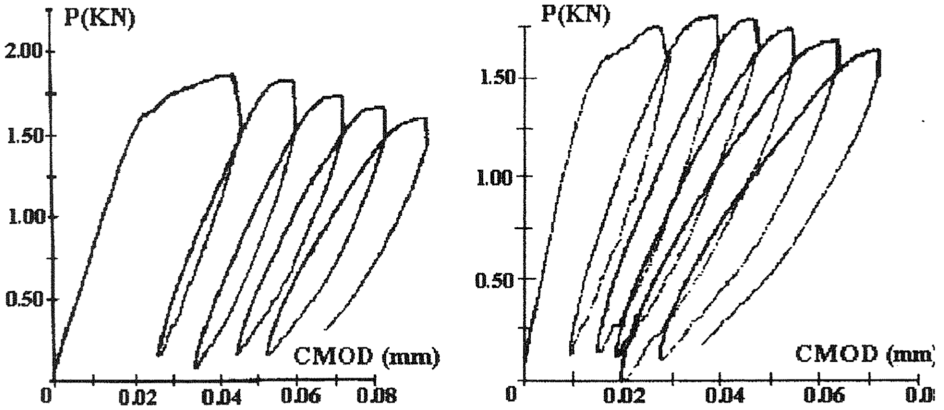

Fig. 3 Plots of P x CMOD tests (note different scales).

To better evaluate the relaxation phenomenon, Ferreira and Bittencourt (1997) tested a concrete beam in three point bending under CMOD control using the extensometric arrangement displayed in Fig. 4. In order to observe the cohesive interface behavior during the relaxation phase, 4 extensometers equally spaced were placed along the beam depth, sufficiently close to the expected crack path and down to the neutral axis.

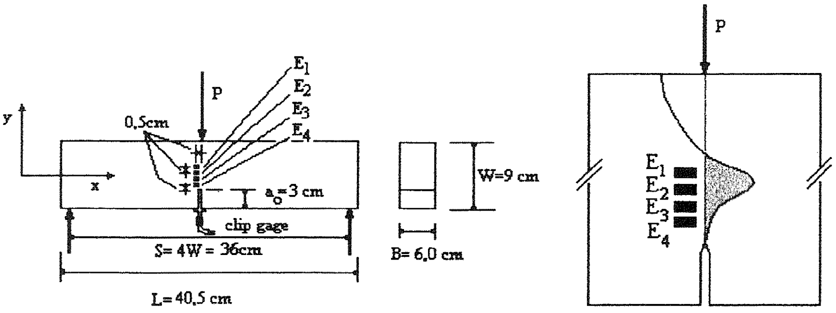

Fig. 4 Extensometric arrangement in a three point bending beam and expected stress distribution

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To prevent any distortion due to aggregate size and strain gage length, a micro-concrete close to a mortar mix was used, with maximum aggregate size 4.5mm, proportion in mass 1:2:3 (cement, sand, gravel) and water/cement ratio 0.6. The beam was cast with an insertion plate, removed $3^1/_2$ days latter, submerged into water and tested at age 130 days.

The results of the extensometric tests, as well as the load line displacement along several loading, holding and unloading phases, starting on cycle two to show repeatability, are presented in Fig.5 through 7.

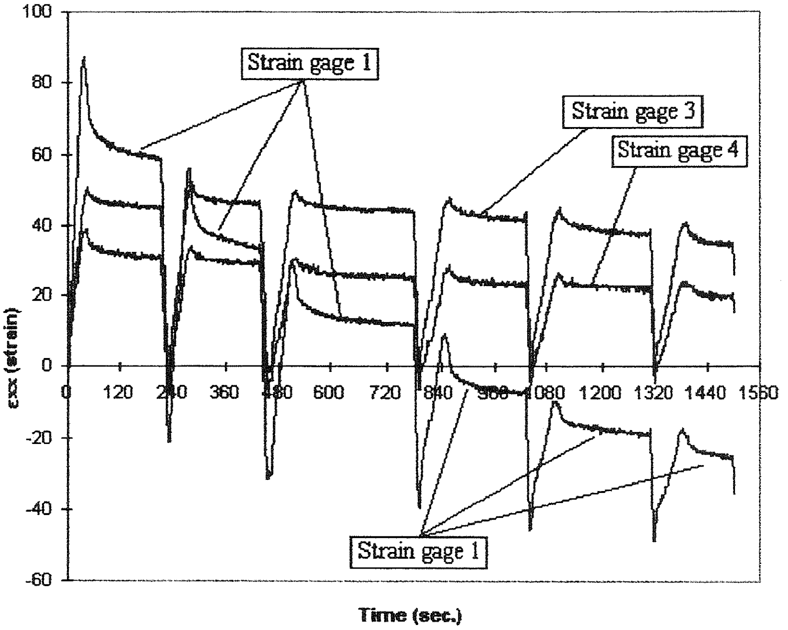

Fig. 5 Plots of ε_{xx} strains, in time . Strain gages 1,3 and 4.

4 Analysis of results

The tests proceeded under CMOD control (*viz.* Fig. 2) showed a quasi-exponential behavior of the load decay, as well as the stabilizing path tending, in time, asymptotically and rapidly to a conservative level. This leads to the understanding that, even within a relaxation process, the phenomenon takes place in a localized manner. The load line displacement plots shows that, during the holding phase, the vertical displacement decreases. This fact, in a purely geometric sense, suggests that this displacement occurs as a mechanism antagonic to the tendency of increasing the horizontal displacement due to the opening of the cohesive interface, in such a way that the CMOD is kept constant, apparently justifying the applied load decay.

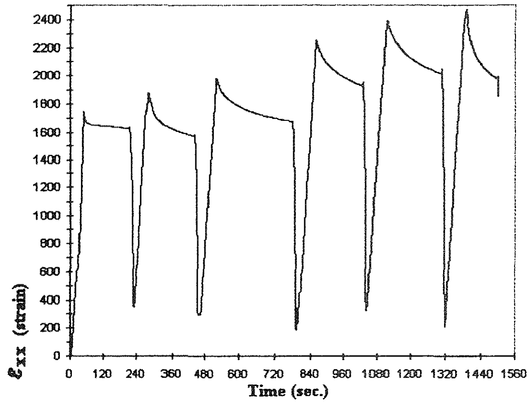

Fig.6 Plots of ε_{xx} strain in time . Strain gage 2.

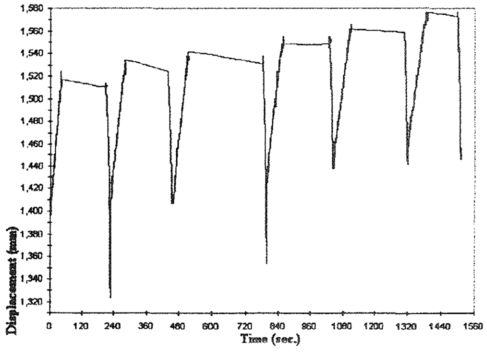

Fig.7 Plot of the load line displacement.

Therefore, the cohesive interface is believed to be ineffective, in terms of transmission of stress between the crack faces, when the applied load reaches the stabilization level, what also occurs quasi-exponentially. The reversal of this process may be observed by the increasing in stiffness at the end of any descendant path when the interface is closing, and again at the beginning of any ascendant path when it is reopening.

Also, the extensometric results for the lower strain gages (3 and 4) seems to confirm the frictional behavior of the interface. The successive loading phases conducted to almost constant levels of tensile strain. On the other hand, the unloading phases produced at their end, even small, almost constant compressive strains, along the performed cycles.

The behavior presented by strain gage 2, the most stressed in tension, seems to indicate a microcracking zone increase. Also shows the quasi-exponential relief, in the holding phases, of tensile strains, and consequently stresses and applied loads. Strain gage 1, the upper one, suggests a progressive movement of the neutral axis, downwards, apparently due to the increase of tensile stresses in the downer regions, motivated by crack growth.

5 Conclusions

A brief description of fracture toughness tests on concrete specimens, obtained by the authors and by others, was presented. The focus was the phenomenon of relaxation at maximum load(load drop) of several load cycles, observed under constant CMOD conditions. From the reported results, the following observations are considered relevant:

1) The phenomenon of relaxation at maximum load in fracture toughness tests from notch-through three point bending specimens, showed that a constant CMOD applied at the maximum load (as a prescribed boundary condition), is not a sufficient condition to keep the equilibrium of the system, after strain localization has occurred.

2) The relation between the minimum loads, $\mathbf{P_{min}}$, and the maximum ones, $\mathbf{P_{max}}$, obtained in the softening branch remained almost constant, presenting low values of standard deviation. Moreover, the time necessary for the relaxation process stabilization, within each cycle performed, showed to be almost uniform, through the softening branch.

3) Once the ratio $\mathbf{P_{min}}/\ \mathbf{P_{max}}$ observed in the cycle performed showed an almost constant behavior, it is possible that the ratio itself may keep a relationship with other fracture properties of the material.

4) As a consequence, the load drop, **ΔP**, may keep a relation with the behavior of the cohesive interface at each cycle and indirectly, with the fracture resistance of the material.

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