MEASUREMENTS OF THE FRACTURE TOUGHNESS K_{IC} OF CONCRETE

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ABSTRACT

The mechanical behavior of the fracture toughness of concrete, has been computed by a 2D and 3D finite element analysis. This allows analysis of the tests results obtained through a K_{IC} value varying between 2 and 2,3 MPa$\sqrt{m}$.

KEYWORDS

Concrete, fracture toughness, DCB specimen, finite element analysis.

INTRODUCTION

For about twenty years several authors have attempted to measure the fracture toughness of concrete (Kaplan, 1961 ; Nauss and Lott, 1969 ; Walsh, 1972 ; Entov and Yagust, 1975 ; Carpinteri, 1981). A critical review showed some important features for a valid use of linear elastic fracture mechanics :

The need for large enough specimens and for a crack size larger than the aggregates.

In order to meet these requirements Laboratoire Central des Ponts et Chaussées (LCPC) has used since 1976 a large DCB specimen with prestressed arms. In the first tests (Chhuy Sok, 1978 ; Benkirane 1982), the prestressing was not centered and the loading sequence included hold times introducing some viscous behavior which hampered the analysis. Some improvements were thus introduced to the experiment and there are reported together with results obtained on three specimens made of the same concrete with various prestressing loads in the arms.

EXPERIMENTAL METHOD

Concrete Used

The composition is given in table 1.

Table 1 : Concrete Composition for 1 m3

Ciment CPA 400	400 kg
Sand (0/5)	700 kg
Gravel (5/12)	1 105 kg
Water	190 kg

After setting a resin protective layer was applied on the whole surface of the specimens. They were tested after 28 days, 27 days and 42 days respectively.

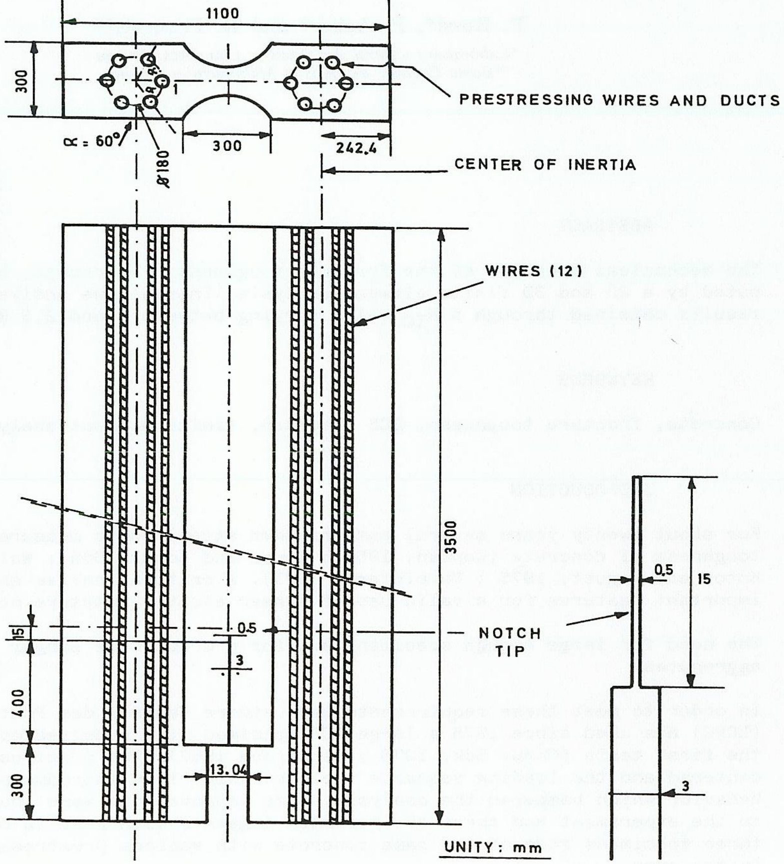

Fig. 1 : Geometric configuration of the DCB specimen

Specimen Used

It is shown on fig. 1. With respect to the previous specimen modifications were introduced on the notch shape so as to center the prestressing in both arms. The prestressing loads were respectively : 1 230 kN, 683 kN, 0 kN.

Experimental Procedure

The crack opening displacement V_1 on the load line at 0.175 m of the specimen end, was measured with an extensometer. It was controlled with an automatic regulator. The crack length was measured on the surface with a magnifying glass. The specimen hanging vertically with the notch at the lower end was loaded at a constant opening rate of 25 µm/mn. After each V_1 increment of 200 µm the specimen was partially unloaded so as to measure its compliance for crack length determination.

FINITE ELEMENTS CALCULATION OF THE DCB SPECIMEN

Calculations were undertaken to allow a correct analysis of the experimental results.

2D Calculation

The program used is Rosalie group 5 of LCPC on IBM 370. It is carried out in plane stress and linear elasticity. It takes a unit constant thickness. The specimen narrowing in the center part was represented by a change in the modulus of elasticity (Benkirane, 1982). The crack length was held constant for each calculation. Four independent calculations were carried out corresponding to four different crack lengths. The upper end of the specimen was considered fixed and the prestressing was represented by local forces applied on the lower end. The compliance C (a) was obtained and K_I (a) was deduced from an energy balance. The results could be represented by polynomial expressions :

$$C\ (a) = \frac{1}{E}\ (219.62\ a^3 + 266.46\ a^2 + 72.20\ a + 16.45) \qquad (1)$$

$$K_I\ (a) = \frac{10^{-5}}{B}\ (1.831\ a + 0.688)\ P \qquad (2)$$

where a is the crack length, E Youngs'modulus, B the thickness, P the load, all in SI units but for K_I (a) in MPa$\sqrt{m}$.

3D Calculation

A 3D calculation was carried out in one instance to check the validity of the 2D calculations, especially considering the way the specimen narrowing was introduced. The stresses σ_{22} and σ_{11} obtained at various distances r from the crack tip are compared on fig. 2. Its shows that the 2D calculation gives results which are not too much in error and which are reasonable for the experimental analysis.

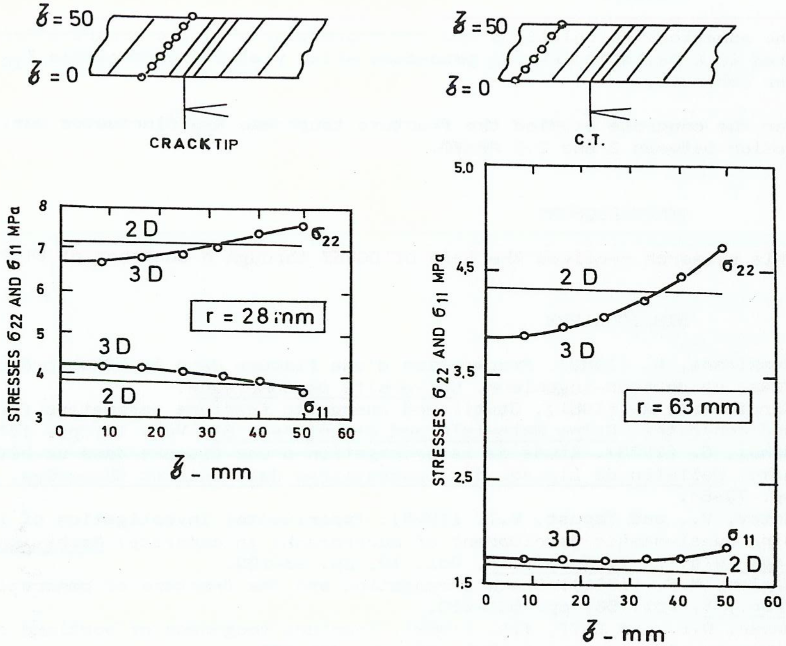

Fig. 2 : Comparison of the stresses σ_{22} and σ_{11} for various distances r from the crack tip obtained by 3D and 2D finite element calculations

EXPERIMENTAL RESULTS

Figure 3 shows the load displacement curves recorded for the three specimens. The compliance yields an effective crack length a_e by equating the experimental compliance (on loading) and the theoretical compliance from the finite element calculation for the crack length a_e.

This effective crack length includes the effect of the inelastic zone ahead of the crack tip due to microcracking. From the expression 2 where the load is set equal to the critical load P_c at crack propagation and $a = a_e$, the fracture toughness K_{IC} plotted on fig. 4 is obtained.

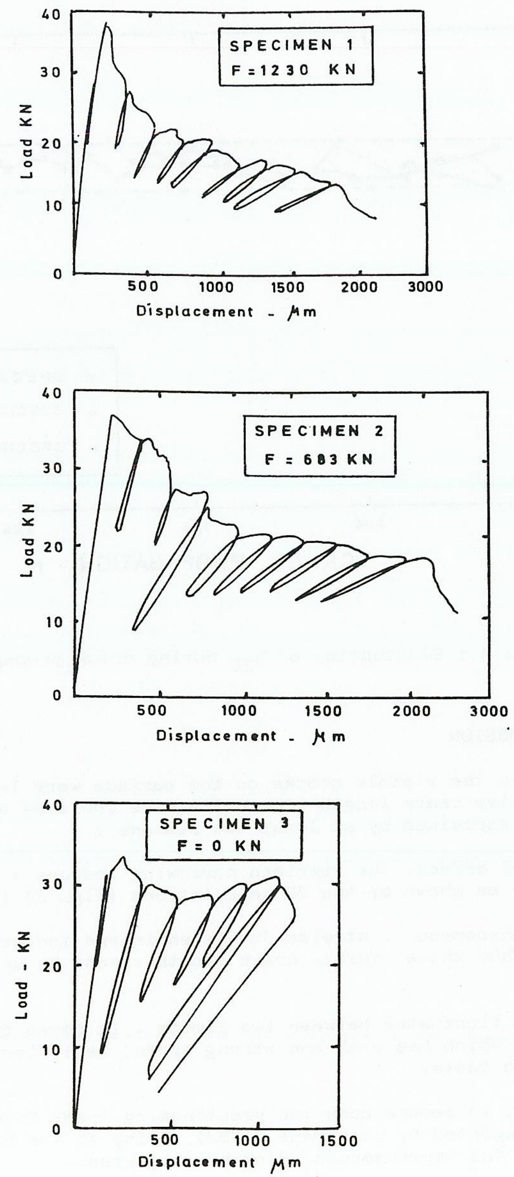

Fig. 3 : Load displacement curves for the three specimens

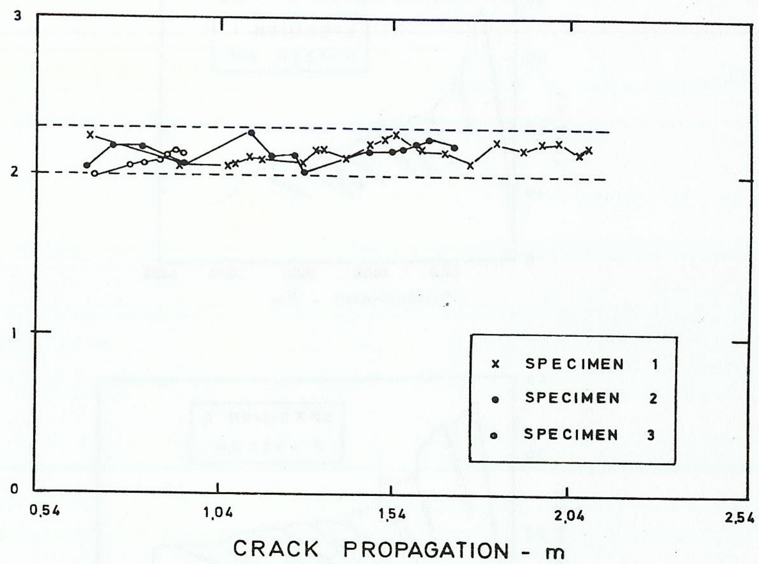

Fig. 4 : Fluctuation of K_{IC} during crack propagation

DISCUSSION

For the 3 tests the visible cracks on the surface were larger than the calculated effective crack length (the difference could be as high as 20 cm). This could be explained by at least two reasons :

- a geometrical effect. The specimen narrowing induces a stress concentration on the surface as shown by the 3D calculations (fig. 2) ;

- a physical phenomenon : strains due to shrinkage induce microcracking on the surface. Thus those visible crack length cannot be used for K_{IC} measurements.

The K_{IC} curves fluctuates between two limits . It comes from the heterogeneity of concrete which has weak and strong spots, reflected also in the dispersion of tensile tests.

K_{IC} appears not to depend upon the prestressing load. This is not in keeping with results reported by Benkirane (1982), owing to the better precision obtained through the improvements which he suggested.

CONCLUSION

The numerical calculations and the improvements in the experimental set up lead to a reliable testing procedure which yields reproductible K_{IC} results for concrete.

For the concrete studied the fracture toughness K_{IC} fluctuates during propagation between 2 and 2.3 MPa$\sqrt{m}$.

AKNOWLEDGMENT

This research received the help of DGRST through a contract n° 81.P.0713.

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