MODE III TYPE OF FRACTURE IN CONCRETE

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The application of Fracture Mechanics to concrete has concentrated on Mode I fracture and more recently on Mixed-Mode fracture in which Mode II is significant. This paper reports on recent attempts at proposing Mode III type of test specimen geometries. The paper presents Mode III fracture results for a range of concretes. The tests were carried out on circumferentially notched cylinders subjected to torsional loading. A range of test specimen diameters together with varying notch depth ratios have been studied. Finally, the paper presents an attempt at applying the Size Effect Law to Mode III fracture.

INTRODUCTION

Most of the early fracture tests developed for concrete concentrated on the Mode I fracture mode. In recent years, shear fracture (Mode II) and, in particular, Mixed-Mode fracture (Mode I/II) have received greater attention. This paper is aimed at stimulating greater interest in the Mode III type of fracture in concrete materials.

Bazant and Prat (1) appear to be the first to show that a Mode III type of failure is produced in notched cylinders subjected to torsional loading. More recently Xu and Reinhardt (2) and Yacoub-Tokatly and Barr (3) have also reported on Mode III or torsional tests on concretes. The main objective of the work reported here is to attempt to apply the Size Effect Law to Mode III fracture results obtained using the testing arrangements described in (3).

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EXPERIMENTAL DETAILS

The initial tests were carried out using a standard concrete mix with a cement: fine aggregate: coarse aggregate ratio of 1:1.8:2.8 and a water/cement ratio of 0.5. Fibre reinforced concrete (FRC) mixes were also used - four concentrations of polypropylene and steel fibres were investigated as detailed in Table 1. Lightweight concrete mixes and mortar mixes were also investigated as reported in Table 1. The lightweight concrete mixes had cement:fine aggregate:Lytag aggregate ratio of 1:1.8:1.67 with a water/cement ratio of 0.45 whereas the mortar mixes had a cement:sand ratio of 1:3 with a water/cement ratio of 0.5.

The testing arrangement used in the study is illustrated in Figure 1. The system of loading shows two supports providing upward reactions, a third support providing a downward reaction, and the fourth support being the location of the applied load. Split-collars are attached to the two ends of the centrally circumferentially notched concrete cylinders to transfer the torque into the test specimens. A range of specimen diameters (from 80mm to 200mm) and varying notch depth values (from D/4 to D/6) were used as detailed in Table 2.

Figure 2 shows a typical load-deflection curve for a plain concrete specimen. The graph is linear up to the cracking load, P_c, at which point the test specimen shows signs of softening. Once the maximum load, P_m, is reached the test specimen shows a rapid reduction in the load. The cracking load is used to determine the K_{IIIc} results (by means of the stress intensity expression developed by Tada et al (4)) and the maximum load is used to determine the torques used in the Size Effect study.

RESULTS AND CONCLUSIONS

Table 1 presents the K_{IIIc} results for the various FRC mixes investigated in this study. The fracture toughness results are relatively independent of the fibre type and concentration. The fracture toughness of lightweight concrete and mortar is approximately 60% that of the normal density concrete - this is a similar ratio to that of their respective compressive strengths.

Table 2 shows the maximum torque results obtained for the four specimen diameters and three notch depth ratios used in the study. In the case of the tests carried out where the notch depth was only D/6, a large number of the specimens failed in a typical torsion manner rather than in Mode III. The twelve maximum torque results obtained with a notch depth value of D/4 have been used to investigate the Size Effect Law.

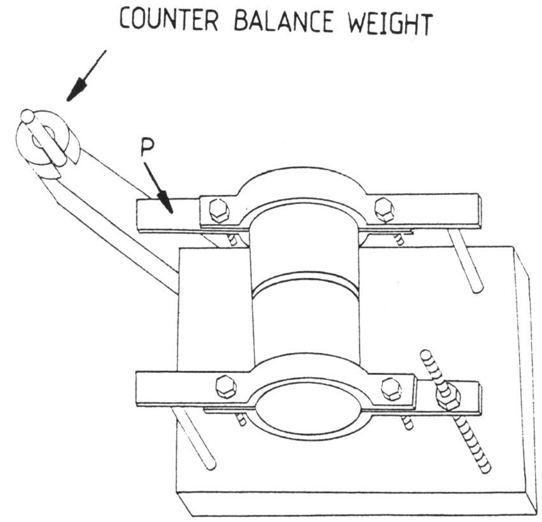

Figure 1 Illustration of Torsion Rig

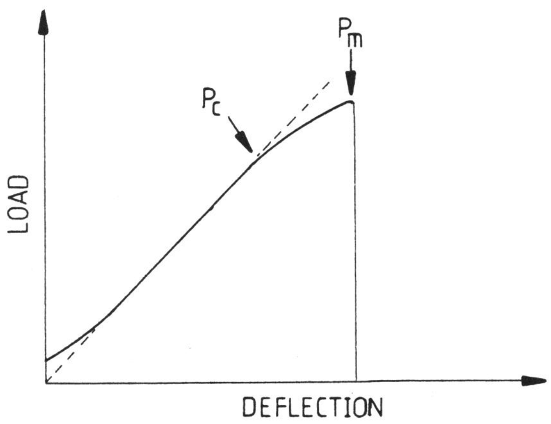

Figure 2 Typical Load - Deflection Curve for Concrete

TABLE 1 - Mode III Fracture Toughness Results for Various Concretes

Fibre Content (%wt)	K_{IIIc} ($N/mm^{3/2}$)		
	Normal Density	Lightweight Aggregate	Mortar
0.0	33.2	19.6	18.7
0.1 Poly.	32.8	21.6	17.5
0.2 "	33.9	21.1	16.1
0.3 "	32.0	21.1	18.1
0.4 "	24.2	19.7	18.8
1.0 Steel	33.3	21.1	20.6
2.0 "	31.1	20.1	20.5
3.0 "	29.0	23.1	18.9
4.0 "	30.4	26.2	-

TABLE 2 - Maximum Torque Results for Three Notch Depth Ratios

Cylinder Diameter (mm)	Notch Depth (mm)	Maximum Torque (N.m) T_1	T_2	T_3	Average Torque (N.m)	Coeff. of var. (%)
Maximum Torque Results - Notch Depth = D/4						
80	20	130.3	154.8	145.8	143.6	8.6
100	25	235.8	227.0	249.3	237.4	4.7
150	37.5	906.0	867.5	896.8	896.8	2.9
200	50	1782.0	1432.2	1628.0	1628.0	10.8
Maximum Torque Results - Notch Depth = D/5						
80	16	263.8	225.8	258.0	249.2	8.2
100	20	411.8	389.3	408.3	403.1	3.0
150	30	1170.0	1332.0	1231.2	1244.4	6.6
200	40	2857.8	2996.4	2871.0	2908.4	2.6
Maximum Torque Results - Notch Depth = D/6						
80	13.3	356.0	328.3	303.8	329.4	7.9
100	16.7	569.5	*	*		
130	25.0	*	*	*		
200	33.3	*	*	*		

*Failure mode other than Mode III fracture

Note: 1. All the specimens had length/diameter ratio = 2

2. Concrete mix proportion is 1 cement:1.8 sand:2.8 coarse aggregate with a maximum size of 10mm, with 0.5 water/cement ratio.

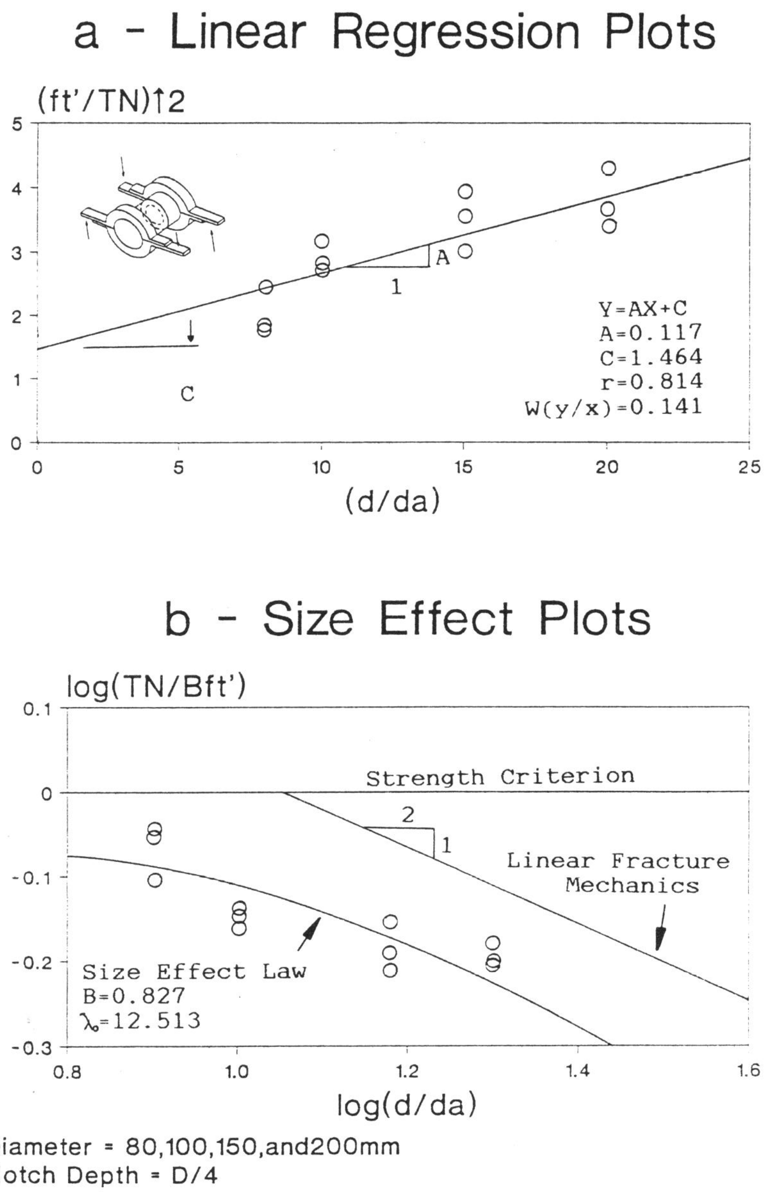

Figure 3 Linear Regression and
Size Effects Plots

The Size Effect Law and its application to Mode III fracture have been reported by Bazant and Prat (1) and will not be repeated here. The linear regression plots for the twelve results identified above are shown in Figure 3(a) and the corresponding Size Effect plots in Figure 3(b). The results shown in Figure 3(b) suggests that the Size Effect Law is applicable but could be better.

This work is still in progress at Cardiff. In particular, a detailed study is being carried out wherein various groups of three out of the four results are being investigated and compared with the actual fourth result. Work is also in progress on a numerical study of the test specimen geometries together with a detailed study of the fracture surfaces produced during the failure of the test specimens.

REFERENCES

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