Discussion on papers published in the *Magazine of Concrete Research* Volume 24, Number 81: December 1972

Measuring the fracture toughness of cement paste and mortar*

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With reference to Mr Brown's interesting paper, I would like to refer to a recent paper[1] in which I called attention to the need to consider absolute size in the design of fracture tests. It was shown that, for reliable fracture tests on notched concrete beams, a specimen depth of 150 mm is required. More generally, this requirement can be expressed as

$$(K_c/f_t)^2 > 50 \text{ mm} \quad \text{(I)}$$

where f_t is the nominal stress at failure (computed from a linear stress distribution).

For very much smaller specimens, the fracture becomes virtually notch-insensitive and the failure load can be found from the modulus of rupture and the net section. For intermediate sizes, such as the 38 mm depth, $(K_c/f_t)^2 = 10$ mm, for Mr Brown's notched beams, transitional behaviour can be expected. This gives rise to the behaviour shown in Figure 5, which reflects the reduced influence of f_t upon the failure at intermediate crack lengths. Also the difficulties associated with slow crack growth can be attributed to the small size of specimen. With large specimens which satisfy equation I, simple fracture tests are possible. Slow crack growth, although present, is not of any significance for the larger crack lengths used.

The results of the variable-width DCB tests similarly suffer from small size, $(K_c/f_t)^2$ being in the range of 5 to 50 mm. Moreover the applicability of a two-dimensional equation such as equation 3 to the highly three-dimensional stress situation in the tapered web specimen seems very doubtful.

Reply by the author

I thank Dr Walsh for his contribution and would like to offer the following observations in reply. The mortar used in the tests had been found to be notch-sensitive, although the slow crack growth observed, and attributed in part to pseudo-plastic behaviour of the crack tip, meant that the mortar could not behave as an ideal brittle material. The slow crack growth will become negligible if the specimen is large enough and, as Dr Walsh points out, can be ignored when the classical fracture mechanics analysis is applied. However, in the technique described, the slow crack growth is taken into account in the analysis; it is included as part of the whole crack and so the fracture toughness approach can be extended to specimens smaller than the minimum suggested by Dr Walsh. The alternative criterion of crack instability, that the crack extends when the net section stress (f_t) exceeds the tensile

*Pages 185 to 196 of *Magazine* No. 81.

Magazine of Concrete Research 1973.25:220-221.

strength, has been convincingly demonstrated by Shah and McGarry[2] for initial crack growth from a notch, but their observation seems inadequate to explain the present results. The results of Figure 5 referred to by Dr Walsh show that the increase of K_c with crack growth is about 13%. The corresponding values of f_t increase by about 40% so that, whilst neither parameter is ideal, as a crack instability criterion K_c is less dependent upon crack growth than is f_t.

The satisfactory performance of the DCB specimens with cement paste suggest that the equation 3 is not seriously in error, despite the depth of the crack-guiding grooves. Reservations about the absolute accuracy of the effective toughness values were noted in the paper.

REFERENCES

1. WALSH, P. F. Fracture of plain concrete. *The Indian Concrete Journal*. Vol. 46, No. 11. November 1972. pp. 469–470, 476.
2. SHAH, S. P. and McGARRY, F. J. Griffith fracture criterion and concrete. *Proceedings of the American Society of Civil Engineers*. Vol. 97, No. EM6. December 1971. pp. 1663–1676.

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