Bond strength in steel-fibre-reinforced concrete*

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Dr Tattersall and Mr Urbanowicz are to be commended on their comprehensive examination of the influence of a wide range of variables upon the pull-out resistance of a steel fibre embedded in a cement paste or mortar matrix. However, whilst we note that the embedded length of fibre is constant throughout their study and therefore does not affect the conclusions drawn from their results regarding the comparative influence of chemical or mechanical surface treatments, age, etc., we disagree with their statement that "The pull-out load is not proportional to the length of the fibre embedded and at present it is not meaningful to quote anything other than the load under particular conditions; there is no point in dividing by the nominal area of contact to calculate a notional bond shear stress". As no supporting evidence for this statement is given in the paper, we assume that it is based upon limited experimental data previously reported by one of the authors for a different fibre-matrix combination⁽¹⁾.

The substance of this statement is contrary to both elementary composite materials theory and experimental results for various fibre-matrix systems^(2,3), which show that pull-out load is proportional to embedded fibre length. Accordingly, we have carried out a series of pull-out tests on specimens with different lengths of fibre embedded in a cement-mortar matrix. As the method of test may have some influence upon the results obtained, two testing arrangements have been used, one that we have employed for some time in our own continuing work on bond strength, and the other similar to that used by the authors.

The fibre used in these tests was a high-tensile, brass-coated carbon steel wire, 0.38 mm in diameter, with a tensile strength of 2584 N/mm². The wire was cleaned with trichloroethylene before use. The mortar matrix had a sand/cement ratio of 3.0 and a water/cement ratio of 0.5; ordinary Portland cement and a local sand were used. Two batches (numbered A-15 and A-16) of 16 specimens each were cast with the

wires in a horizontal position. The specimens consisted of mortar blocks of 25.4 × 25.4 mm cross-section, eight per batch with an embedded fibre length of 25.4 mm and eight with an embedded length of 76.2 mm. All specimens were demoulded after 24 h and cured for six more days at 22°C and 100% relative humidity.

The pull-out tests were performed under water by means of the two specimen-gripping arrangements shown diagrammatically in Figure I. Diagram I represents the arrangement being used in our own work, whilst diagram II represents an arrangement corresponding to that used by the authors. The second

Figure I: Variation of pull-out load with length of fibre embedded. Inset shows two methods of gripping specimens.

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arrangement is not as suitable as the first for concentric bond tests, as it produces a confining compressive stress in the region of the specimen where bond is most critical, i.e. at the point where the wire enters the mortar block, and a strain incompatibility between the wire and the mortar.

The results in Figure I clearly show that the measured pull-out load is proportional to the embedded fibre length, the pull-out load increasing as the embedded length is increased for both testing arrangements. Owing to the large variation in the measured pull-out loads for a given embedded length, it was not possible to determine whether the difference between the results obtained for the two arrangements is statistically significant and they have therefore been combined in the calculation of the mean and 95% con-

fidence limits shown. The authors' results for trichloroethylene-cleaned wire in a mortar matrix are also shown in Figure I, and it can be seen that they are in agreement with the general pattern of increasing pull-out load with increasing embedded length.

In view of these results, one can only conclude that the pull-out load is, in fact, almost directly proportional to embedded length. It is therefore valid and meaningful to define bond between a given steel fibre and cement-mortar matrix in terms of average shear bond strength, which remains essentially constant for all embedded lengths. Knowledge of this shear bond strength then permits the application of composite materials theories in the assessment or prediction of material properties and failure mechanisms for this fibre-matrix system.

Reply by G. H. Tattersall

Our statement that pull-out load is not proportional to embedded length was based partly on previous work by Urbanowicz, as Mr Gray and Professor Johnston suggest, and partly on unreported experiments carried out as a preliminary to our main programme. However, it does receive support from other sources.

According to Lawrence⁽⁴⁾, pull-out load is a hyperbolic function of l which reduces to a straight line through the origin only when the whole of the load is due to friction. Kelly⁽²⁾, who is one of the two authors cited by Mr Gray and Professor Johnston, proposes a linear relationship between pull-out load and length but specifically states that there is a non-zero intercept. Cooper⁽³⁾, on his plot of pull-out load against embedded length, draws a straight line with a very small intercept on the load axis, but a critical examination suggests that the four or five points in the region of the origin properly belong to the 'friction only' case and should therefore not be considered when deciding the best line. If this is so, Cooper's intercept is no longer negligible.

However, the clearest support for our statement comes from the results now given by Gray and

Johnston themselves. For their results to "show that the measured pull-out load is proportional to the embedded fibre length" as they claim, it would be necessary, of course, for the relationship between the two variables to be a straight line passing through the origin, and that is clearly not so. (Note that the 95% confidence limits shown on their graph relate to individual values; these must be divided by 4 to obtain the corresponding limits for the means.) Linearity cannot be established by the results for only two values of the independent variable, but if linearity is assumed, it is evident that the line intersects the load axis at about 20 N, a value equal to about 50% of the mean value for the 25.4 mm length.

An alternative, and equally valid, assumption would be that the points fit a smooth curve that passes through the origin, of the type proposed by Lawrence. The best relationship cannot be deduced from these limited results but, in any case, the mean bond stresses for the two lengths are proportional to the (different) slopes of the lines from the origin to the appropriate mean points. For the 25.4 mm and 76.2 mm lengths, they are respectively 11.2 and 7.9 N/mm².

REFERENCES

1. BAILEY, J. E., BAKER, H. A. and URBANOWICZ, C. Alumina filament reinforced cement paste. *Transactions of the British Ceramic Society*. Vol. 71, Part 1. 1972. pp. 203-210.
2. KELLY, A. *Strong solids*. Second edition. Oxford, The Clarendon Press, 1973. pp. 202, 203.
3. COOPER, G. A. The fracture toughness of composites reinforced with weakened fibres. *Journal of Materials Science*. Vol. 5, No. 8. August 1970. pp. 645-654.
4. LAWRENCE, P. Some theoretical considerations of fibre pull-out from an elastic matrix. *Journal of Materials Science*. Vol. 7, No. 1. January 1972. pp. 1-6.