Discussion

on articles published in the
Magazine of Concrete Research

Volume 9, Number 26 : August 1957

The relation between bond strength and maturity for ordinary Portland cement concrete*

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**Contribution by K. R. Peattie, B.Sc., Ph.D.,
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I have read with considerable interest Dr Plowman's paper on bond strength and maturity. A series of experiments on bond was carried out some years ago at the University of Nottingham^(1, 2) and I have examined the results of these experiments in the light of Dr Plowman's theory.

If the compressive strengths of the concretes used are plotted against the $\log_{10}$ (maturity in $^{\circ}\text{F hr}$), a sensibly linear plot results. When, however, the various factors expressing the bond resistance are so plotted, it is found that this linear relation no longer holds. The one exception to this appears to be the strain at which rupture of the adhesion was found to occur in bond specimens subjected to a torque. Here quite a reasonably linear plot results and it is perhaps significant that at the time these papers were written it was considered that this effect in bond action was some function of the modulus of the concrete and would presumably follow laws similar to those followed by the increase of the crushing strength.

The other factors in bond action which have been considered are all predominantly "frictional" phenomena—that is, they become operative after the steel has moved relative to the concrete. These factors will be affected mainly by the condition of the concrete adjacent to the steel but the maturities which I used in checking Dr Plowman's suggestions were based on the temperature of the air in the curing chamber. This temperature may well have been different from that in the concrete at the centre of the specimen and this difference between the actual and the assumed maturities might contribute to the failure of the results from these experiments to support Dr Plowman's law.

Some of the lack of agreement may be due to the use of bars with machined surfaces in the tests at Nottingham,

but it is important to consider which component of bond resistance is being measured.

I believe that it is not possible to disregard the effect of the value of the ratio of the embedded length to bar diameter of the specimens. It was pointed out⁽¹⁾ that one of the reasons for the very rapid growth of bond resistance which we observed was probably the accelerated effects occurring in the concrete adjacent to the bar and insulated from the air by the remainder of the concrete of the specimen. We found a more rapid growth of bond resistance in specimens having greater values for the embedded-length/diameter ratio, although most of our work was done with specimens for which the value was 17.5. In addition, there will always be some relative movement between the steel and the concrete before the ultimate resistance is reached.

It would be interesting to know why the low-strength concretes give a more linear bond-maturity relation than the stronger concretes (Figures 1, 2 and 3 of the paper), and why the scatter in Figure 2 appears to be less than that in Figure 3.

Reply by the author

Dr Peattie's remarks are of considerable interest with regard to the relation between the pull-out and torsion tests as measures of bond resistance. It is unlikely that the difference in temperature between the surface and centre of small specimens would be more than a fraction of 1°F . Hence the maturity would be constant throughout the block. The need for measuring internal temperatures occurs:

- (1) when specimens are cooled or heated;
- (2) with specimens of large bulk where the heat of hydration causes an internal temperature gradient.

All tests carried out by the author were upon short embedded lengths, being 8 diameters. Those of Abrams were of 8 and 12 diameters, whereas Dr Peattie worked with 17.5 diameter embedment. It has been shown⁽³⁾ that bars with embedded lengths of approximately seven diameters

*Pages 83-88.

do not build up any frictional resistance after the partial breakdown of the adhesion in pull-out tests. Thus the results of Abrams and the author are for bars failing mainly if not totally by adhesion breakdown, whilst Peattie's contain the friction element.

Concerning the scatter of points on Figures 1, 2 and 3 of the original paper, it appears to be a fact that lower grades of concrete tend to deviate from the mean, both in bond and compressive tests, less than higher grades. This may be because yielding of concrete with a low modulus of elasticity gives a more uniform stress distribution. This fact, when considering tests where the average of only four specimens is taken, can result in less regularity than if averages of, say, twenty specimens are used.

Abrams's results plotted in Figure 3 of my paper have increased scatter, probably because 1 in. bars were used instead of $\frac{3}{4}$ in. bars as in the tests illustrated by Figure 2, in specimens of the same size. This frequently results in specimens cracking⁽⁴⁾, although no mention of cracking

is made in the text. In the experience of the author, this tendency to split is greatly increased with an increase in bar roughness.

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