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A Discussion of the Paper "CEMENT-SATURATION AND ITS EFFECTS ON THE COMPRESSIVE STRENGTH AND STIFFNESS OF CONCRETE" by B.J. Addis and M.G. Alexander*

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In the interesting above-mentioned paper, the authors present some experimental results dealing with compressive strength and elastic modulus measurements obtained for various concrete mixtures. When plotting these mechanical properties versus the cement-water ratio, they observe a non-linear behavior for c/w higher than 2.4-2.8. To explain this non-linear behavior, Addis and Alexander indroduced the "cement-saturation" concept. According to this concept, there exists a certain critical cement concentration beyond which the hydrated cement paste capillary porosity is virtually zero, and the intrinsic strength does no longer increase with an increment of the cement/water ratio. The additional increase of strength for higher c/w is attributed to an enhancement of the paste/aggregate interface. The fact that E-modulus seems to level off at the same time supports this thesis.

We have however some recent experimental results which are in contradiction with the authors theory. In a first series of tests, Marchand [1] made cement pastes of various water-cement ratios. A superplasticizer has been added in order to have comparable fluidity for each paste. Great care was taken to limit segregation in the specimens, which were cured at 20°C under an aluminium foil, in order to avoid any significant humidity exchange with the environment. The faces of the 38x76 mm cylinders have been ground prior crushing of the specimens. Results of compressive strength at 28 days and one year are given in Fig. 1. As can be seen, no signs of cement saturation are visible. The relationship between strength and c/w is fairly linear (especially at 28 d.), for a wide range of cement-water ratio variation, including authors one. These results are in good agreement with those previously reported by Jambor [2] for water-cured pastes of similar cement-water ratios.

However, Kheirbeck [3] tested at LCPC a series of mortar mixes with the same cement, keeping the same paste volume for all their mixes, and adjusting the superplasticizer content in order to have a constant flow time. Compressive strength was measured at 28 days on 40x40x160 mm prisms. Here, a non-linearity of (f'c, c/w) relationship is found (see Fig. 2), comparable to the one obtained by the authors in their Fig. 6.

The discrepancy between these two series of tests clearly emphasizes the fact that the cement-water ratio/compressive strength relationship obtained for cement paste mixtures can be quite

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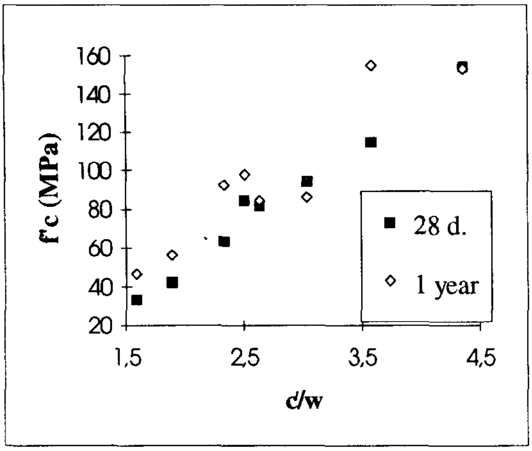

Fig. 1. Compressive strength of cement pastes vs. cement-water ratio [1].

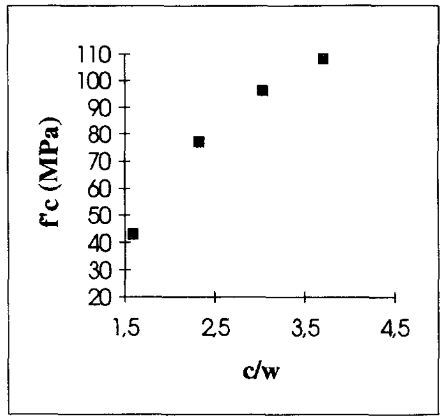

Fig. 2. Compressive strength of mortars vs. cement-water ratio [3].

different to that obtained for mortar (and presumably concrete) mixtures. On the other hand, the results obtained by Marchand question the basis of the cement saturation concept.

In the model proposed by Addis and Alexander, it is supposed that the cement is fully hydrated in mature concrete, whatever the value of c/w. However, as recognized elsewhere by the authors, anhydrous cement can be found in any concrete. Moreover, the final degree of hydration is a decreasing function of c/w, as shown by Sellevold and Justnes [4]. Following these authors, at w/c = 0.30 (c/w = 3.3), only about 60% of the clinker is hydrated in a 28 days-old paste (a much lower value that the one given in authors Fig. 2). Therefore, there is not any critical threshold in the microstructure of pastes of decreasing w/c: the reduction of capillary porosity is a continuous process. Even if some tests made by mercury porosimetry support the idea of a lack of capillary porosity in low w/c paste, this is due to the fact that this technique measures the size of the 'doors', not the mean diameter of the pores [5].

Now, the question remains to know why the increase in strength is less in presence of aggregate than in a neat paste. A part of the answer probably lies in the fact that cube strength results are less and less reliable when the strength increases, especially when the test faces have not been ground prior crushing of the specimens [6]. Also, the nature of hydrates and the degree of hydration could be different in concrete, as compared to a paste having the same water-cement ratio. A third reason could be related with the transition zone (increasing effect of this part of the composite, as the strength of matrix increases). Finally, the aggregate could exert in some cases a "ceiling" effect on the strength (due to its intrinsic strength). More research is needed to clarify these questions.

The levelling-off of the E-modulus, on the other hand, is less surprising. Following the modified Hashin's model [7], the paste modulus increases linearly with the *concrete* strength. As, at the same time, the paste volume increases, there are two contradictory effects when concrete becomes richer. With very stiff aggregates, as the ones used by Addis and Alexander, it is expectable that for high cement dosages, the two phenomenons balance each other, so that E-modulus is approximately constant (like in authors' Fig. 5).

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