Discussion

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Pore structure and permeability of hardened cement paste*

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Dr Hughes has undertaken a permeability study on OPC, OPC/pfa and SRPC pastes.

In his introduction he mentions that many authors have suggested that the reduced permeability of OPC/pfa concretes is a major reason for their superior resistance to chemical attack. Consequently, he conducted permeability tests on pastes.

It is our opinion that one must be careful in translating the results on pastes to those for concrete and we would like to ask Dr Hughes how relevant his findings on pastes are for the concrete technologist in the field?

First, all paste-mixes were made with a fixed water/solids ratio. In concrete, the water/solids ratio of an OPC and a corresponding OPC/pfa mix (30% replacement) would certainly not be the same.

The effect of water reduction, together with some other reasons why pfa in a concrete mix can reduce permeability and therefore improve chemical resistance, was explained in my Contribution† to the

previous paper by Dr Hughes and Dr Grounds in MCR 131, *The use of beams with a single edge notch to study the sulphate resistance of OPC and OPC/pfa pastes*.

Secondly, recent research elsewhere⁽¹⁾ showed that the gas permeability of mortars is always higher than that of concretes with the same water/cement ratio. This is due to the higher content of hardened paste and therefore higher effective porosity in mortars compared to concretes.

Hence the question; how relevant are studies on pastes for the performance of concretes in the field?

REFERENCE

1. GRÄF, H. and GRUBE, H. Verfahren zur prüfung der durchlässigkeit von mörtel und beton gegenüber gasen und wasser. (Method for testing permeability of mortar and concrete against gas and water.) *Betontechnische Berichte, Beton* 5/86, p. 184. Düsseldorf, 1986.

*Pages 227 to 233 of MCR 133.

†Page 228 of this issue.

Reply by the author

The durability of concrete is a highly complex subject, regardless of the type of cement used, whether it be OPC, SRPC or a blended cement. In broad terms the useful life of a concrete structure may depend on the working environment, the ability of the aggressive media to penetrate the material, the resulting chemical reactions and the ability of the concrete to withstand subsequent physical and chemical modifications. Each of these items deserves intensive research; research which may be aimed at increasing our fundamental knowledge of the behaviour of materials. In this way the development of predictive models may be advanced so that we may describe the observed behaviour of existing materials and allow the confident introduction of new materials into a conservative market.

The ease of penetration of the aggressive environment into concrete is likely to be a function of, at least, the ability of the media to permeate through the concrete, in conjunction with its diffusion into those pores not participating in permeability. In this context permeability is taken to be the flow of fluid from one face to another *through* a porous body. The present study was confined to permeability in this sense. The sources of voids and hence *potential* flow in concrete include inadequate compaction, cracks, interfacial debonding of aggregate particles, bleed channels and entrapment of water under aggregate together with the inherently porous hardened cement paste (hcp) fraction. A knowledge of the relative contribution of each is essential so that an analysis of the whole may be attempted. It was decided to concentrate the work on the permeability of hcp, not because it was easy but since it constitutes an unresolved phenomenon from the microstructural point of view. It was always recognised that the results would not be directly applicable to "realcrete" and no attempt has been made to do so. However, in order to understand the behaviour of a multi-phase composite it is necessary to examine each

phase individually and collectively, so that an appreciation of the composite is developed which accounts for the modification to one phase by the incorporation of a second.

Care should be exercised when considering gas permeability since some drying of the sample occurs during preparation. Direct removal of the pore fluid will alter the pore size distribution and shrinkage will affect the paste/aggregate interface. Both these phenomena are likely to increase the permeability and may affect the comparison of unlike materials.

Mr Amtsbüchler appears to deny any role to the interfacial zones in his description of permeability relying totally on the relative volume of hcp. In order to produce a low permeability concrete a maximum water/cement ratio and a *minimum* cement content need to be specified, i.e. a minimum content of the porous hcp.

During the investigation reported, the water permeability of an OPC paste, $w/c = 0.47$, cured for 4 weeks at 35°C in saturated $\text{Ca}(\text{OH})_2$, was measured as 6.1×10^{-15} m/s. A concrete, of the same w/c , cured identically, and of 380 kg/m^3 cement content, yielded a water permeability of 2×10^{-13} m/s. Watson and Oyeka⁽¹⁾ have reported the oil permeability of concrete to be approximately 100 times greater than that of hcp. Nyame⁽²⁾ states that the water permeability of mortars increases as the volume fraction of aggregate increases, although it is acknowledged that, for the range of volume fractions studied, the mortars were less permeable, yet approaching that of hcp. Ruettgers et al.⁽³⁾ reported water permeability to increase with increases in the maximum size of aggregate.

These results are presented to suggest that the incorporation of aggregate within cement paste does not produce a simple dilution effect but a modified composite material. Thus, the approach of examining individual phases as well as the composite would appear well founded.

REFERENCES

1. WATSON, A. J. and OYEKA, C. C. Oil permeability of hardened cement paste and concrete. *Magazine of Concrete Research*. Vol. 33, No. 115. June 1981. pp. 85–95.
2. NYAME, B. K. Permeability of normal and lightweight mortars. *Magazine of Concrete Research*. Vol. 37, No. 130. March 1985. pp. 44–48.
3. RUETTIGERS, A., VIDAL, E. N. and WING, S. P. An investigation of the permeability of mass concrete with particular reference to Boulder Dam. *Journal of the American Concrete Institute, Proceedings*. Vol. 31, March–April 1935. pp. 382–416.