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Influence of early curing on the sub-surface permeability and strength of silica fume concrete

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The authors are to be congratulated on their attempt to test realistic concrete in simulated realistic conditions of environment and curing regime. The various conditions used may well be appropriate for the two regions selected (Algeria and Iraq) but are not necessarily appropriate to other hot and arid environments such as the Gulf region, where the quantity of concrete exposed to risk is somewhat higher and certain aspects of the environment are more aggressive.

Selection of mix designs based on realistic and equivalent characteristics is, of course, a prerequisite for any investigation that is intended to simulate actual construction concrete. However, as in any investigation, the various parameters used to achieve these characteristics must also be representative of current practice:

(*a*) In the Gulf region, durability is the prime consideration, and it is rare to use a free water/cementitious ratio (FW/CR) $> 0{\cdot}40$ for durable concrete. Calculation of FW/CR includes water from all sources (added, natural moisture content of aggregates and water in admixtures) and typically allows for 100% water absorption by the aggregates. Values of FW/CR of the order of 0·36–0·42 (occasionally increasing to 0·45) are representative of current requirements. It is not entirely clear from the data presented what the actual FW/CRs were for these concretes, but they were most certainly considerably in excess of those which are normally used in such environments.

(*b*) Likewise, the range of total cementitious contents used could not be considered as being representative of well-specified, durable structural concrete in the Gulf region. Typically, a range of 340–380 $\mathrm{kg/m^3}$ would be normal, occasionally increasing to 420 $\mathrm{kg/m^3}$ in special circumstances. When microsilica (CSF) is specified as a constituent of the mix for increased durability, then this is normally within a range of 7–10% of the total cementitious content, and the microsilica would be added as a replacement for the same weight of cement. On this basis, only the CSF: C55 mix would be anywhere near being representative of current practice.

(*c*) In hot, dry conditions, the ability to discharge, place and compact the concrete as quickly as practicable is considered to be essential. To this end, placement slump values (even with microsilica concrete) of the order of 100–160 mm are normal in the region, although reductions to 75 mm could be used for massive pours. The slump values of 10–55 mm used in the investigation do not represent actual conditions.

(*d*) A further factor of some relevance is the temperature of the fresh concrete. In winter conditions, placing temperatures down to 15°C are quite normal, but in high summer, even at night with the maximum practicable amount of ice, it can be difficult to keep much below 30°C in some areas. In general, a casting temperature in the range 25–30°C would be representative of concrete in the region. The temperature of the fresh concrete used in the investigation was not reported, but it would be reasonable to assume that it was a normal UK laboratory temperature of around 20°C. The difference might be expected to exert a significant influence on the test results and conclusions.

(*e*) Naturally, using low FW/CRs, high workability and relatively high concrete temperatures, the use of fairly large amounts of superplasticizers is absolutely standard practice. Indeed, it is solely due to the development of these admixtures that the possibility of making durable concrete can even be contemplated in the region. It is recognized that this introduces considerable complexities in the variables to be investigated, but without the inclusion of superplasticizers, no concrete which is representative of Gulf practice can be made.

Turning to the curing method used, this too must be representative of current practice if the results are to be relevant:

(*a*) Polythene sheeting (on its own) would not be considered to represent normal practice. On occasions, the use of a sealed polythene enclosure, with added water to ensure full development of humidity, is required for precast units, but the standard regional practice is, almost invariably, 7–10 day wet curing with saturated hessian which is fully protected from evaporation by closely tied or weighted-down polythene sheeting. Best curing practice requires this to be rewetted at least twice a day in the winter and as much as 4–6 times every 24 h in high summer. Occasionally, the application of a curing compound might be required after completion of wet curing.

(*b*) Initial protection of fresh concrete in horizontal surfaces is, of course, absolutely critical (especially with microsilica) and the use of heavy duty polythene sheeting laid over the rough screeded surface within minutes of completion would be normal best practice. This is left in place until final finishing operations are commenced, after which it is immediately replaced by the wet curing system.

(*c*) The use of a system which provides an external source of water to concrete in the critical cover zone during the early stages of hydration is considered to be particularly beneficial in all concretes that have a low FW/CR and, possibly, essential for concretes containing microsilica or slag as part of the cementitious system. The differences between the method used in the investigation and actual practice might be expected to have a considerable effect on the results.

As regards the results themselves, whilst certain trends are impressively distinct (within the system of variables used) they may nevertheless not be representative of actual concrete and construction conditions; at least those currently used in the hot and arid climate of the Gulf region. For this reason alone, extreme caution should be exercised in direct application of this data to specifications or construction work.

Reduced curing periods for microsilica concrete in hot, dry environments – and without water! – flies in the face of received opinion in the region as regards the absolute necessity for adequate curing. Which is not to say that reduced curing periods may not be appropriate; merely that this cannot be taken as proven on the present data. Any further work which could lead to a more rational understanding of the curing process using representative materials and conditions would be of the greatest benefit.

There are several additional factors that could be considered:

(*a*) Whilst the two Figg tests clearly provide good assessments of relative permeabilities, their use has been limited to the 20–40 mm depth in the curing-affected zone. Typical cover values are 60–75 mm in the most critical external environments, and information on concrete in the 40–60 mm depth increment could be of some significance. Is this curing affected under these conditions, or is it not? Larger test specimens would clearly be needed.

(*b*) Despite many real criticisms, the rapid chloride permeability test can still be expected to yield pertinent relative information which may (or may not) support the Figg data.

(*c*) When dealing with concretes designed principally for durability, strength (per se) is of very limited interest. The FW/CR is presently considered to be the prime mix design factor affecting durability and is a more appropriate variable upon which to base experimental data.

(*d*) Finally, and possibly contentiously, the use of microsilica in a laboratory-based concrete may present some unexpected problems. To become

> fully effective, densified microsilica has to be broken down in the mixing process into as near as possible to its constituent particles. Whilst laboratory mixing may (just) be able to simulate mixing conditions for non-microsilica concrete, it is doubtful whether it is sufficently aggressive to simulate what actually happens with 0·5–2·0 m^3 of concrete churning around for 30–40 s in a full-scale pan mixer (preferably including reverse agitation) followed by 10–60 min of transport in a slowly revolving agitator truck. The difference between the two (otherwise identical) products is possibly significant.

Reply by the authors

The authors thank Mr Burfitt for his detailed comments and observations, particularly as they come from a practitioner of hot-weather concreting. Naturally there are limits to which a laboratory-based programme can reflect site practice (which itself is highly variable) and hence caution should always be taken when attempting to apply the results to practice. Clearly research focused on one climatic region may not be directly applicable to another, such as the Gulf.

With regard to the comments on the mix designs, we make the following observations. The free-water/cementitious ratios, allowing for absorption by the dry aggregates, were 0·72, 0·55 and 0·41 for C25, C40 and C55 ordinary Portland cement (OPC) mixes. The latter two grades are typical of the specification limits (based on cement content and water/cement ratio) for low- and high-risk exposure conditions, as recommended by CIRIA for the Gulf region.[1] Whilst this document is currently under review, it was considered good practice at the time of the research programme. The C25 was tested in order to investigate the performance of a relatively low-quality concrete and was never intended to represent good practice. With regard to the silica fume content, a straight weight-for-weight replacement was not chosen because this would alter the 28 day strength – as stated in the paper, the mixes were designed for equal 28 day strength and workability.

At the workability levels and cement contents quoted as being typical of good practice, the resulting free-water/cement ratio would be around 0·6–0·7. Clearly to achieve significantly lower ratios (0·36–0·42) without substantial increases in cement content requires a water-reducing admixture. Whilst superplasticized mixes are increasingly common, they are by no means always used in countries with a hot climate. This research programme did investigate a C40 silica fume mix in which workability was controlled by a superplasticizer, rather than the addition of water, and the results are published elsewhere.[2]

Turning to the curing methods, there are a wide range of techniques reported. Water addition methods, if carefully administered, are generally acknowledged to be the best; sealing methods, such as polythene or a curing membrane, may not be as effective but are often considered to be more practical or realistically achievable. The duration and intensity of the wet curing quoted by the writer does indeed sound like excellent practice and is to be commended. Unfortunately, however, even good practice is not always used, and exposed, dry hessian is not a rare sight in hot climate construction. There is some evidence that hessian that is allowed to dry can even remove water from the surfaces of the concrete by wicking action.[3]

With regard to the temperature of the fresh concrete, we were unable to preheat the mix constituents but did transfer all fresh moulded specimens directly to the climatic room immediately after casting.

Clearly the contribution of this research programme is one small piece of a large and as yet incomplete jigsaw. As such, the results should be considered to be part of an increasing body of knowledge, and it is clearly not appropriate to apply them directly and exclusively to practice. We are continuing to do research in this area and are currently investigating the effects of curing and microclimates on the durability of OPC and slag concretes cured in temperate (in UK) and hot (in Oman) climates.[3, 4] This programme is concentrating on looking at depth profile effects on sorptivity and permeability of concrete blocks subjected to a range of curing regimes (including hessian) and surface orientations. Results to date suggest that the curing affected zone is of the order of 30 mm deep, that is, significantly less than the 60–75 mm cover values quoted by the writer for critical environments.

References

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