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Concrete Options for Water-retaining Structures

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ABSTRACT:

The water-retaining properties of 18 different concrete mixes were assessed using permeability and sorptivity tests. Grade 30 and 35 concrete mixes were cast and either wet-cured or moist-cured before testing. Grade 35 concretes made with high quality aggregates, were found to have low permeability and sorptivity when well cured.

Such concretes should provide satisfactory performance in water-retaining structures provided good construction practice is ensured. Findings also suggest that slag and fly ash concretes have improved longer-term transport properties compared with similar portland cement or silica fume concretes.

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TECHNICAL PAPER

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ABSTRACT

The water-retaining properties of 18 different concrete mixes were assessed using permeability and sorptivity tests. Grade 30 and 35 concrete mixes were cast and either wet or moist cured before testing. Grade 35 concretes, made with high quality aggregates were found to have low permeability and sorptivity when well cured. Such concretes should provide satisfactory performance in water-retaining structures provided good construction practice is ensured. Findings also suggest that slag and fly ash concretes have improved longer-term transport properties compared with similar portland cement or silica fume concretes.

INTRODUCTION

Permeability of concrete is a crucial material property for water-retaining structures, influencing serviceability and durability. Impermeability is generally considered to improve with good compaction, active moist curing, higher concrete strengths and the use of cement replacement materials. Poor site performance of some blended concretes has however raised concerns about the effect of certain cementitious materials in water-retaining applications.

A comparative testing programme was undertaken to assess the water-retaining properties of a range of concrete mixes. Standard concrete materials from the Durban area were used and a special focus of the work was the performance of slag concrete compared with other concrete types.

MATERIALS AND CONCRETE MIXES

Concrete materials from the Durban area were used, being a blend of Coedmore quartzite stone (13 and 19 mm) and river and crusher sand. Two sources of slag were used from Vanderbijlpark, standard GGBS and a fine slag (Blaine 5000 cm^2/g), denoted SL and SLF respectively. Cement used was NPC Cem I, fly ash was Lethabo classified (denoted FA) and condensed silica fume was densified CSF-90 (denoted CSF). A water content of 180 L/m^3 was maintained for all mixes with the use of a super-plasticizer. Grade 30 and 35 MPa concretes were cast. Details of grade 35 concrete mixes are shown in Table 1.

Concrete with a moderate workability (nominal slump of 50 mm) was cast into steel cube moulds and compacted on a vibrating table. The concrete was demoulded after 24 hours and cured either in water at 23°C (denoted wet curing) or damp cured under hessian until 7 days at 90% R.H. and 23°C followed by laboratory curing at 60% R.H. and 23°C (denoted moist curing).

LABORATORY TESTING

A range of laboratory tests was done at 28 and 90 days to characterize the water-retaining qualities of the concrete. Apart from standard tests such as the slump and compressive strength test, the following specialized testing was done.

a) DIN water permeability test

The DIN 1048 permeability test was chosen due to the direct nature of the testing, in that concrete is exposed to water under pressure 1. Concrete cubes of size 150 mm were initially wet cured before being exposed to a water pressure of 6 bar at 28 days. After 72 hours of testing, the concrete cubes were split and the depth of water penetration measured. Depths of water penetration less than 25 mm generally indicate relatively impermeable concrete.

b) Oxygen permeability test

The oxygen permeability test is a rapid durability index test that characterizes the micro-structural resistance of concrete to gas permeation. Core samples, 68 mm in diameter and 25 mm thick were extracted from the sides of concrete cubes and oven-dried at 50°C for seven days. Permeability testing was done using falling-head permeameters pressurized with oxygen 2. The oxygen permeability index (OPI) was determined from the negative log of the coefficient of permeability. An oxygen permeability index greater than 10.0 is required for low permeability while values greater than 10.5 indicate exceptional impermeability characteristics.

c) Water sorptivity test

Core samples from the oxygen permeability test were redried for 24 hours before being tested for water sorptivity 2. The sides of the core sample were coated with epoxy to ensure uniaxial water movement when the test surface is exposed to water. Absorption of water by capillary suction was monitored at intervals by weighing the core sample. The rate of movement of the wetting front through the concrete, defined as sorptivity, was then determined by plotting mass gain versus the square root of time. High quality concrete with low absorption characteristics generally has sorptivity values below 6.0 mm/√hr.

TABLE 1: Concrete mix designs (kg per cubic metre of concrete)

Binder Type	w/b	Water	Cement	Pozz./ Slag	Stone	Sand	S-P (%)	Slump (mm)
100% PC	0.68	180	265	0	1 200	786	0.79	65
15% SL	0.65	180	235	42	1 200	772	0.54	65
30% SL	0.62	180	203	87	1 200	757	0.43	65
50% SL	0.61	180	147	148	1 200	748	0.41	40
15% FA	0.60	180	255	45	1 200	744	0.28	50
22% FA	0.51	180	275	78	1 200	688	0.21	55
30% FA	0.48	180	263	113	1 200	658	0.10	50
9% CSF	0.74	180	221	22	1 200	797	0.23	65
50% SLF	0.63	180	143	143	1 200	756	0.38	55

Notes: S-P denotes super-plasticizer with dosage as a percentage of total binder content w/b denotes water/binder ratio

RESULTS AND DISCUSSION

Experimental results for the grade 35 concrete are shown in Table 2. Grade 30 concrete was found to have slightly poorer results but had the same general trends.

TABLE 2: Experimental results recorded at 28 days for grade 35 concrete

Binder Type	Curing regime	f_{cu} (MPa)	DIN 1048 (mm)	OPI	Sorptivity (mm/hr)	Effective porosity (%)
100% PC	Wet	41.0	15.5	10.52	7.2	8.9
	Moist			9.97	9.9	9.4
15% Slag	Wet	40.5	20.0	10.56	5.5	9.3
	Moist			9.78	9.6	10.2
30% Slag	Wet	43.5	21.5	10.25	4.5	9.4
	Moist			9.84	8.2	10.0
50% Slag	Wet	40.5	12.5	10.08	3.7	9.3
	Moist			9.89	8.1	10.2
15% FA	Wet	40.5	15.5	10.32	7.5	9.8
	Moist			9.89	8.8	9.7
22% FA	Wet	45.0	16.5	10.43	6.5	9.3
	Moist			9.84	9.1	9.3
30% FA	Wet	41.5	16.5	10.46	5.5	10.0
	Moist			9.85	9.1	11.4
9% CSF	Wet	40.0	15.0	10.30	6.3	11.1
	Moist			9.96	8.3	10.1
50% SLF	Wet	42.0	20.0	10.12	3.9	8.4
	Moist			9.46	7.8	10.2

a) DIN permeability results

Results for grade 35 concrete fell within the range of 12 - 22 mm and even grade 30 concretes had penetration depth less than 30 mm. An increase in water penetration was found for higher replacement levels of both fly ash and slag although 50% replacement with SL had lowest penetration depths. Overall the differences in penetration depths between the different concretes at 28 days were relatively small, without major practical significance (see Figure 1). All grade 35 concretes had good resistance to water penetration needed for water-retaining structures.

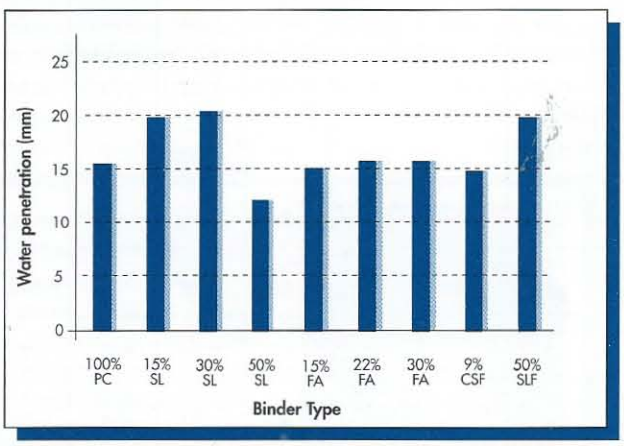

Figure 1: DIN permeability results at 28 days

b) Oxygen permeability results

Wet cured concrete had considerably higher OPI values (indicating lower permeability) than moist cured concrete for all concrete types as shown in Figure 2. OPC concrete was found to have highest impermeability for both wet and moist curing. All wet cured concretes had OPI values in excess of 10.0 whilst when moist cured OPI results all fell below 10.0. It should be noted however that that these oxygen permeability results were measured on near-surface concrete (i.e. within 30 mm of surface).

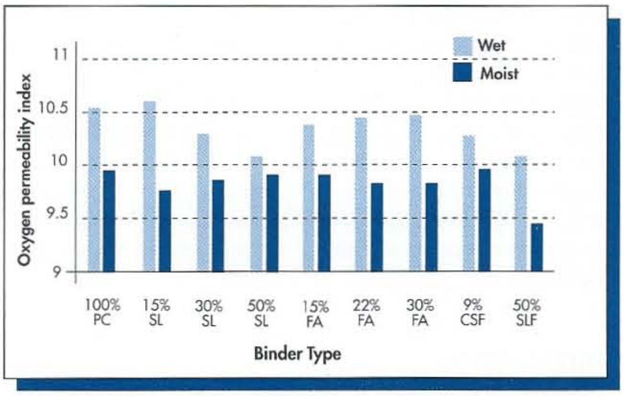

Figure 2: Oxygen permeability results at 28 days

Comparative testing of concretes at 28 days may unfairly bias slower maturing concretes such as fly ash and slag concrete. A better indication of long-term permeability may be gained by comparing 90 day OPI results shown in Figure 3. PC and CSF concretes were found to have no consistent improvement in impermeability between 28 and 90 days despite continued wet curing. Slag concrete was found to achieve slightly higher impermeability by 90 days whilst fly ash concrete became significantly less permeable. The improvements measured at 90 days for fly ash and slag concrete may be attributed to long-term cementing reactions and pozzolanic reactions of these materials.

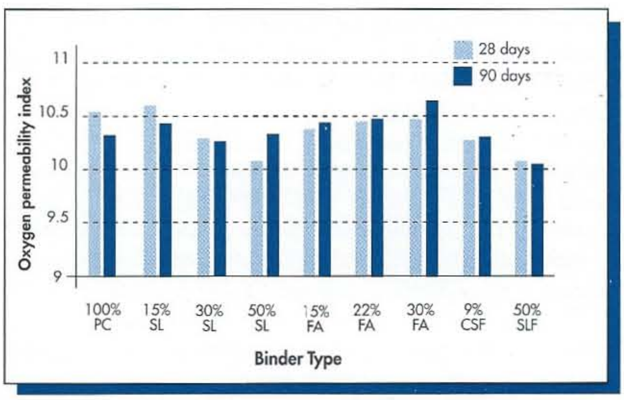

Figure 3: Oxygen permeability results - wet cured concrete

c) Water sorptivity results

Water sorptivity results measured at 28 days are shown in Figure 4. Wet curing and increasing replacement levels of slag or fly ash promoted low rates of absorption suitable for water-retaining structures. Virtually all moist cured concrete had sorptivity values above 8.0 mm/√hr with little difference between concrete types. Slag concrete with 50% replacement of either SL or SLF produced the lowest sorptivity levels for both wet and moist curing. Effective porosity levels (defined as the total water penetrable void volume) for grade 35 concretes were generally below 10.0% which indicates good aggregate packing and a dense microstructure.

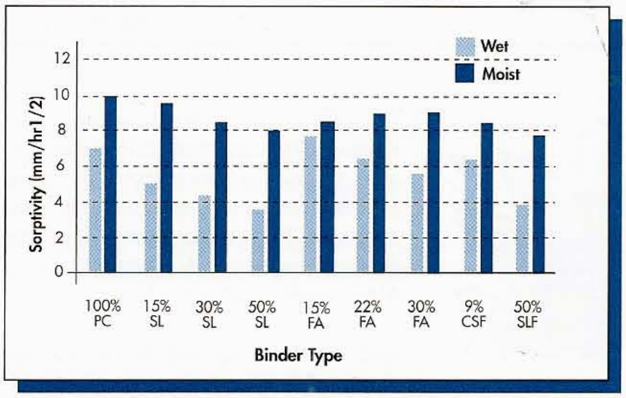

Figure 4: Water sorptivity results at 28 days

CONCLUSIONS

Results measured at 28 days for grade 35 concrete were fairly consistent and indicated good to excellent quality. This was partly due to the selection of high quality aggregates that allowed dense packing of the concrete. Using these materials a number of different binder options will provide satisfactory water-retaining properties, including the use of a PC concrete without supplementary materials. Experience has shown however that when using poorer quality aggregates supplementary materials, particularly fly ash and silica fume, significantly reduce permeability 4,5.

Active wet curing is essential for promoting a low permeability concrete in near-surface regions. When dealing with thick sections the central core may be relied on for impermeability and poor surface curing may not be detrimental to water-tightness. Such a policy may however be dangerous for thin wall sections where the curing affected zone may constitute a major portion of the wall section. Poor curing may also be detrimental to durability, increasing the risk of reinforcement corrosion.

Comparisons of 28 day test results across a range of binder types may be misleading since concretes do not mature at similar rates. Slag and fly ash concrete properties generally continue to improve at ages later than 28 days due to long-term pozzolanic and cementing reactions. This was confirmed by the 90 day oxygen permeability results, particularly for fly ash concrete.

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