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BINDER CONTENT INFLUENCES ON CHLORIDE INGRESS IN CONCRETE

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ABSTRACT

The reported study looked at the effect of reducing free water contents, and thereby binder contents, on the ingress of chloride in concrete. Concretes with equal water/binder ratio (and design strength), but with water contents reduced by up to 30 litres/m^3, were tested for chloride diffusion (D) and penetration. The quality of the microstructure was inferred from initial surface absorption tests (ISAT). The results show no practical difference in chloride durability between the corresponding concretes, and that reducing the binder content, (providing that the water/binder ratio is maintained) is not likely to be detrimental. However, the results reported underline the importance of binder type, in this case PFA. Implications of the results are discussed and, in light of the findings, whether specifications which demand minimum cement contents are justified. *Copyright © 1996 Elsevier Science Ltd*

Introduction

Chloride ingress into the cover zone is affected by the physical nature of the interconnected pores and the capacity for physico-chemical binding of chlorides during the absorpto-diffusive processes. Whilst the former is controlled directly by water/binder ratio and degree of hydration, chloride binding capacity is a function of binder content and type. There is therefore a risk of negating the latter effect in concrete where the free water content, and thereby the binder content are reduced. There are advantages in reducing the binder content [1], not least the reduction in heat of hydration and cost.

With this background, a test programme was devised to determine the effect of binder content reduction on the chloride durability of concrete using Portland cement (PC) and pulverized-fuel ash (PFA).

Experimental Details

Background to Test Programme. The test programme was designed to consider the requirements for concrete structures in chloride exposures. Table 1 illustrates the typical approach adopted in many standards, limiting water/binder ratio and binder content in relation to

TABLE 1

Chloride Durability Requirements of Main Standards

EXPOSURE CONDITION	NOMINAL COVER, mm	MAXIMUM WATER/BINDER RATIO	MINIMUM BINDER CONTENT, kg/m³	MINIMUM GRADE
BS 8110 [2]				
Very Severe	50	0.55	325	C40
	30	0.45	400	C50
EC2/ENV 206 [3]				
De-icing	40	0.50	300	C30/C37+
Seawater	40	0.55/0.50*	300	C35/C45+

* With Frost, + UK Annex requirement (100 mm cube strength)

nominal cover. Proportions for the control mix constituents were therefore selected, which were close to or at these limits. The free water contents of the test mixes were then reduced and the binder contents correspondingly adjusted. These mixes, whilst equal in design strength and water/binder ratio had lower binder contents than the minimum shown in Table 1 (BS 8110). In addition to these mixes, a C20 design strength was selected because of its low binder content and therefore increased sensitivity to binder reduction and reduced active phase. Likewise, PFA concretes were additionally considered at all grades, since it is generally accepted that this binder has a high capacity for chloride binding and hence may be more prone to binder content influences.

Mixes Considered. A Portland cement to BS 12, 1991 [4] and a PFA to BS 3892, Part 1, 1993 [5] were used as binders (Table 2) and a high-range, water-reducing chemical admixture to BS 5075, Part 2, 1985 [6] was used to maintain workability at a nominal slump of 75 mm. The aggregate comprised a natural gravel of 10 and 20 mm size fractions and medium grade sand to BS 882 1983 [7].

Details of the concrete mixes tested are given in Table 3.

Two curing methods were used after demoulding at 24 hours, prior to testing, viz standard water at 20°C and laboratory air at 55% RH, 20°C, for 28 days.

Test Methods. Chloride diffusion coefficients (D) were measured on 25mm thick × 150mm diameter specimens using two compartment cells (concentration difference at t_o = 5.0 N

TABLE 2

Main Properties of Portland Cement and PFA

BINDER TYPE	MAJOR OXIDE COMPOSITION, % by weight									
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	TiO_2	P_2O_5
PC	63.3	19.1	4.8	3.2	2.8	3.0	0.5	0.1	0.1	0.1
PFA*	3.7	46.8	33.3	7.5	1.6	0.9	1.0	0.1	1.5	0.6

* Fineness (45μm sieve retention) = 5.7%, LOI = 1.9%, Water demand = 95%

TABLE 3

Mix Proportions of Different Series

DESIGN STRENGTH N/mm^2	CONSTITUENT MATERIALS, kg/m^3						W/C+F	F/F+C
				Aggregate				
	Free Water	PC	PFA	sand	10mm	20mm		
Control Concrete								
PC20	185	225	-	800	375	765	0.82	-
PC40	185	335	-	745	375	745	0.55	-
PC60	185	430	-	625	375	765	0.43	-
PFA20	165	170	80	775	390	780	0.66	0.32
PFA40	165	235	130	570	420	840	0.45	0.35
PFA60	165	345	120	410	440	880	0.35	0.26
Binder-Reduced Concrete								
PC20R	165	200	-	825	395	790	0.82	-
PC40R	160	290	-	785	390	785	0.55	-
PC60R	155	355	-	710	400	785	0.43	-
PFA20R	160	165	75	795	400	800	0.66	0.32
PFA40R	155	225	120	605	450	895	0.45	0.35
PFA60R	150	315	110	450	485	970	0.35	0.26

NaCl). On achievement of steady-state conditions, D was determined using the solution to Fick's First Law described by Dhir et al [8]. In addition, water-soluble chloride profiles were measured on powder samples taken from 100 mm cubes after 12 months immersion in 5.0 N NaCl solution [9]. ISAT measurements were made to assess the near-surface permeation properties of concrete, using the method described in BS1881 [10].

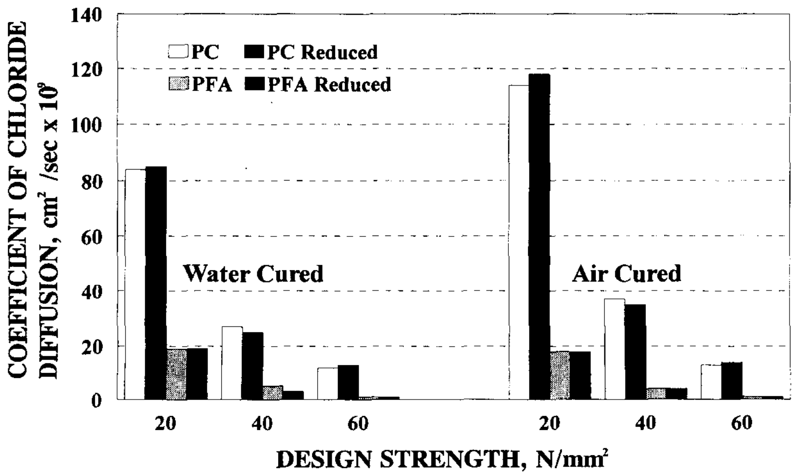

FIG. 1.
Chloride diffusion coefficients of binder reduced concrete.

Results

Figure 1 shows the chloride diffusion results for the concrete mixes under both curing conditions. As expected, D reduced with increasing concrete strength and increased with air curing. The most significant changes were observed between the 20 and 40 N/mm^2 concretes and for the 20 N/mm^2 concrete respectively. The effect of PFA in both control and binder-reduced concrete was to reduce D by 80 to 90%, depending on initial curing. A comparison between control and binder-reduced concretes, over the range of design strengths, showed, for both curings, little or no difference in D.

Figure 2 shows the results of the water-soluble (W/S) chloride content profiles on the 40 N/mm^2 concrete (water cured). The results again demonstrate the effect of PFA, with a reduction of up to 2.0% chloride content in this concrete at 12 months exposure. The results also suggest that binder content has a slight influence on the chloride level, with the binder-reduced concretes having marginally higher chloride levels for both PC and PFA concrete, but typically by only 0.1 to 0.2%.

The ISAT-10 results are given in Table 4. The results indicate a reduction in ISAT-10 value with increasing design strength. Lower values, typically 20 to 30% were obtained in PFA concrete, for both control and binder-reduced concrete compared to those of PC concrete. It is also apparent, for both concretes, that binder reduction gives a lower ISAT-10 result, by 10 to 20%, compared to control concretes, suggesting that the near-surface microstructure is improved through binder reduction.

Discussion

The control of water content is an important consideration in concrete production, not only for strength, but also for durability. When dealing with exposures which are predominantly chemical by nature, such as the highway and marine environments, this view has to balance against the effect of binder content. In such environments, these effects may in fact be contraindicated, ie there is a benefit from an improvement in microstructure, from a lower free water content, but a possible reduction in chloride binding, from the correspondingly re-

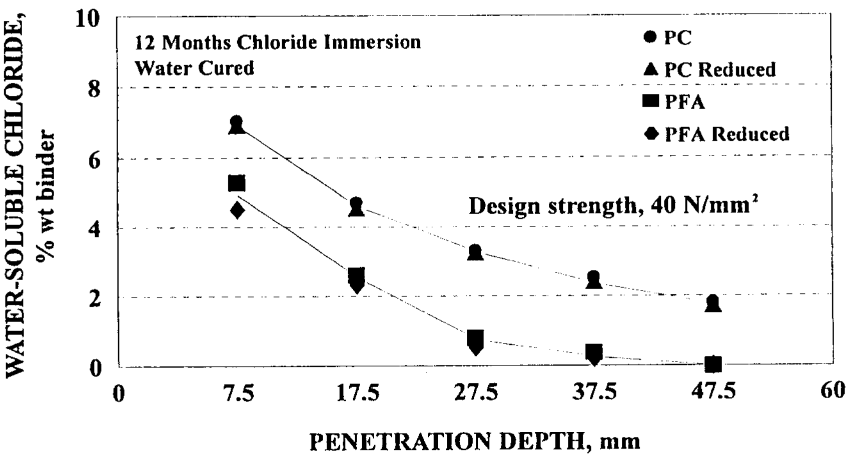

FIG. 2.

W/S chloride contents for control and binder reduced concrete.

TABLE 4

ISAT-10 Results for Control and Binder-Reduced Concretes
($40N/mm^2$, water cured)

DESIGN STRENGTH N/mm^2	10 MIN INITIAL SURFACE ABSORPTION, $ml/m^2/sec$		% Reduction wrt Control
	Control Mix	Reduced Water - Binder Mix	
PC			
20	88.9	83.7	6
40	71.1	55.7	22
60	55.7	42.9	23
PFA			
20	74.8	70.4	6
40	48.5	41.9	14
60	32.2	24.8	23

duced binder content. On a practical basis, improving durability by reducing the free water content has advantage where increasing the binder content may lead to other problems, such as heat of hydration. Figure 3 illustrates this, although if the binder used is of high chloride resistance, the benefits become markedly reduced, (eg at 350 kg/m^3 PC concrete D was reduced by 10.0×10^{-9} cm^2/sec, whereas PFA concrete was reduced by 2.0×10^{-9} cm^2/sec).

The study has, however, shown that there is an approximate equality between chloride binding and microstructure, ie any reduction in chloride binding capacity is offset by improvements in microstructure due to water reduction. This is observed both in the mixes covering the BS 8110 requirements and those of higher water/binder ratio and suggests that the binder content per se may have little influence on chloride resistance. This should, however, be contrasted with the durability performance available from alternative binders such as PFA. Whilst supporting the controlling of mix water, it is clearly important to select binders for their suitability for structures in chloride bearing environments.

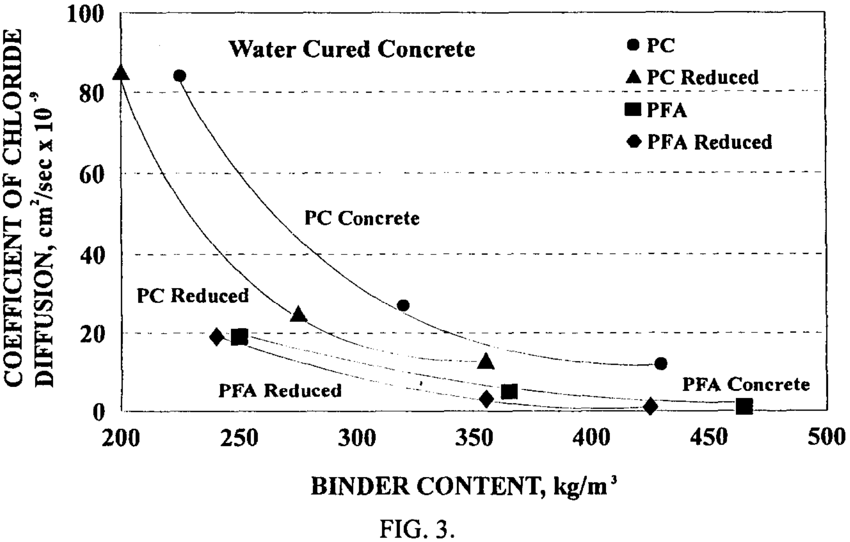

FIG. 3.
Relationship between D and binder content of PC and PFA concrete.

The results provide further evidence of the need to improve the specification methods for concrete. The use of a minimum binder content may not ensure durability and it has been shown that equal durability can be achieved with the same binder type, but with different content; some of which may not comply with commonly used national standard specifications. Clearly, a way forward for specification for durability is on the basis of performance. Whether this is achieved by controlling the water content, binder content and type and/or other measures may well be decided freely by the design engineer. Precluding such options as is the case with most specifications currently, will continue to inhibit the design of structures for durability by intent and thereby the optimisation of the use of concrete materials.

Conclusions

1. The premise of these experiments was to assess whether reducing the water content of a concrete mix and thereby the binder content for equal design strength affects chloride resistance. Within the range of parameters tested, this was found to have no significant effect for both the PC and PFA concrete.
2. Of the factors tested in this study, the binder type has the most significant effect on chloride durability, given equality in strength. Water reductions to improve chloride resistance can be usefully employed in situations where binder choice is restricted and increasing binder content could lead to other problems.
3. The reported results, which show equal performance at different binder contents, suggest that current specifications based on minimum binder content should be re-evaluated and that there is a need to develop methods to enable direct, explicit design for durability.

Acknowledgement

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