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The effect of paste volume and of water content on the strength and water absorption of concrete

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Abstract

The W/C ratio is generally considered to be the governing parameter, which affects the strength and durability of concrete. In this paper, the effect of paste volume and of water content on capillary absorption and strength is investigated on concrete mixes having the same W_{ef}/C ratio. Four W_{ef}/C ratios (0.3, 0.4, 0.5, 0.6) were used and for each W_{ef}/C ratio four mixes were prepared with effective water contents 140, 180, 220 and 260 l/m^3. It is found that although the W_{ef}/C ratio is kept constant, strength increases and capillary absorption decreases when the volume of the water or the volume of the paste decreases. The effect of the paste or water content by volume on strength is stronger for lower W/C ratios and for water contents at the lower or upper values (140 l/m^3, 260 l/m^3) used in the investigation. Similarly capillary absorption is higher the higher is the value of W_{ef}/C ratio and, with constant W_{ef}/C ratio, increases approximately linearly as the paste content increases. The rate of increase is lower for lower values of W_{ef}/C ratios.

Keywords: Concrete strength; Capillary absorption; Paste content; Water content

1. Introduction

A fundamental assumption of most codes, standards and practices is that concretes having the same paste characteristics, that is the same W_{ef}/C ratio and cement type, with similar aggregates will have the same behaviour as far as strength and durability are concerned. This is true for most practical applications where conventional mixes are produced with moderate use of admixtures and moderate cement contents.

However, with the advent of modern admixtures, the increasing requirements for higher strengths, the development of new types of concrete and the increasing use of additions of "fines" (with or without cementing action) it becomes sometimes possible, even necessary to use higher cement contents in the concrete mix. In these cases the amount of cement and/or other cementing materials may be increased considerably, while the amount of aggregates is proportionally decreased. Therefore, these concrete mixes may not have the conventional range of constituents.

A number of research works have studied the effect of increased paste contents on strength [1–5] and transport properties of concrete [5]. The strength changes are attributed to the interaction of paste thickness, bond strength and modulus of elasticity of paste and aggregates. The effect on transport properties and therefore on durability is attributed to the fact that the paste is the main factor of porosity in the concrete, and if the volume of the aggregates is replaced by paste, the volume of the porous material per volume of concrete is increased and thus the new concrete becomes more porous.

This paper presents the first results of a continuing investigation aiming at studying these parameters in more detail.

2. Mixes investigated—specimen preparation and testing

Concrete mixes with four W_{ef}/C ratios (0.3, 0.4, 0.5, 0.6) were studied. For each W_{ef}/C ratio four mixes were prepared with water contents 140, 180, 220 and 260 l/m^3, as shown in Table 1. Cement CEM I 42.5 (EN197-1) and crushed limestone aggregates, (sand 0/4 with 14%

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Table 1
Composition and properties of the mixes investigated

W_{ef}/C	W_{ef} (l/m^3)	$W_{ef\,cor.}$ [a] (l/m^3)	C (kg/m^3)	W_{total} [b] (l/m^3)	Aggregates		Water reducing agent		Slump[c] (mm)	Strength (MPa)		
					Sand 0/4mm (kg/m^3)	Coarse 4/8mm (kg/m^3)	N%	P%		2d	7d	28d
0.6	140	148	233	163	1489	608		3.37	24	21.7	35.0	40.6
0.6	180	185	300	201	1288	592	1.60		27	21.3	33.7	39.6
0.6	220	221	367	239	1126	593	0.33		32	15.5	32.5	42.3
0.6	260	260	433	277	986	579			52	12.2	27.3	39.0
0.5	140	145	280	162	1383	621		1.76	40	36.1	50.8	57.6
0.5	180	185	360	200	1211	624	1.39		20	28.5	44.4	51.9
0.5	220	222	440	238	1038	623	0.37		22	21.0	39.1	51.2
0.5	260	261	520	276	889	605	0.12		42	19.8	36.0	50.2
0.4	140	147	350	161	1292	651		2.00	52	42.0	63.4	71.7
0.4	180	188	450	199	1087	666	1.67		56	38.3	57.3	64.6
0.4	220	224	550	236	910	659	0.76		45	33.7	55.8	66.4
0.4	260	261	650	274	750	639	0.20		37	31.3	50.1	63.5
0.3	140	148	467	160	1135	710		1.73	62	68.7	82.7	91.3
0.3	180	184	600	197	915	719		0.73	20	58.1	71.3	81.1
0.3	220	231	733	234	717	703	1.54		29	52.2	68.4	78.9
0.3	260	265	867	271	540	659	0.59		25	49.5	65.8	74.5

[a] $W_{ef\,cor}$ = Effective water corrected = W_{ef} + amount of water in the superplasticiser.
[b] W_{total} = Total water = W_{ef} + Water absorbed by aggregates.
[c] Measured by special cone.

passing the 63 μm sieve and coarse aggregates 4/8) were used. It should be noted that in an effort to produce the most workable mixes possible for practical applications, the proportion of sand was reduced as the cement content was increased. The overall grading of the aggregates was kept within zone D of the Greek Code (similar to the pertinent zone of DIN 1045). Fig. 1 shows the range of aggregate gradings used for each W/C ratio in conjunction with the grading zone D. For mixes for which the desired workability could not be achieved, superplasticiser of naphthalene (N) or polycarboxylate (P) type (where a stronger reduction in water content made it necessary) was used as shown in Table 1 (expressed as % b.m. of cement). The workability of each mix was measured with a small 90 mm high cone with top and bottom diameter 30 and 70 mm respectively. No segregation was observed in all the mixes prepared and this was shown in a preliminary investigation by sawing specimens in half and observing the concrete surfaces.

2.1. Compressive strength

The compressive strength was measured on 70 mm cubes, at 2, 7 and 28 days after moist curing at 20 °C and RH >98%.

2.2. Water absorption

The water absorption was measured on cylindrical specimens of 120 mm diameter and 50 mm height. The specimens were cured in water (22 °C) for 21 days after which were taken out from the water tank, wiped and allowed to dry superficially for about 2 h in the laboratory. Their cylindrical surface was subsequently coated with epoxy adhesive paint and the next day they were put in a well-ventilated oven at 45 °C for 5 days. At the end of this period the specimens were taken out from the oven, were wrapped with thin plastic foil and stored in the laboratory for 2 days. Water capillary absorption measurements were started at 29 days. The specimens were put in a water tank with the bottom-as-cast surface immersed up to 2 mm in the water for a period of 48 h. The water level in the tank was kept constant during this period. The specimens were taken out from the water tank at intervals of 15, 30, 60, 90, 150, 300, 1440, and 2880 min and were weighed on a 0.01 g balance, after being wiped with a dry paper towel. It is pointed out that the preconditioning procedure recommended in [6] was not strictly followed and this is further discussed in Section 3.2.

3. Discussion of the results

3.1. Compressive strength

The results are shown in Fig. 2, in terms of strength versus W_{ef}/C and in Fig. 3 in terms of strength against paste content by volume (m^3 of paste/m^3 of concrete). It should be noted that the water content of the super-

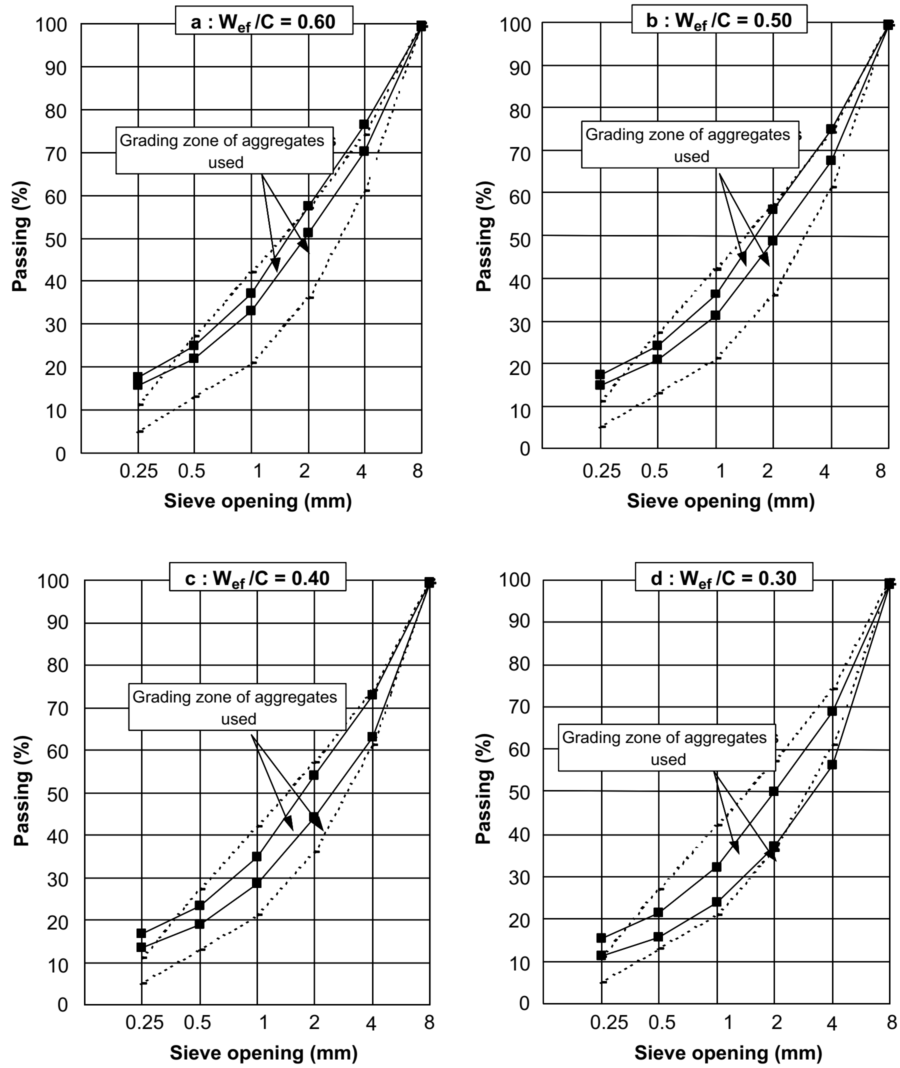

Fig. 1. Grading zone of aggregates used.

plasticiser used was taken into consideration in the calculation of the total and the effective water of the mix (Table 1).

It can be seen in Fig. 2 that, for water content changes within the usual range for conventional concrete mixes range, no significant differences in strength are observed. However, for much higher or lower water contents (∼260 l/m^3 or ∼140 l/m^3), significant strength changes are observed, which become more pronounced at lower W/C ratios.

The scatter of results, which is observed in certain cases for the 1-day and 2-day strength results could be attributed to the effect of different amount and type of superplasticiser used.

It can be seen in Fig. 3 that, for constant paste content, the strength significantly increases as the W/C ratio decreases but for constant W/C ratio the strength decreases as the paste content in the mix increases. The effect of paste content is more pronounced for low values of W/C ratio for which the rate of strength change is higher. The increase of strength as the volume of the paste in the mix decreases has been also observed in other research works [1–5] but more work is needed in order to clarify the reasons for this effect. It is usually attributed to the longer path the crack needs to follow when the aggregate volume in the concrete is higher, thus having to move around greater number of aggregates, a fact which makes the energy absorbed higher. When the volume of the paste is higher and the volume of the aggregates is smaller, the length of the path becomes straighter, thus smaller, and the amount of energy absorbed becomes smaller.

De Larrard and Belloc [2] presented a comprehensive theory attributing this effect to a characteristic called maximum paste thickness which is defined as the mean distance between adjacent coarse aggregates.

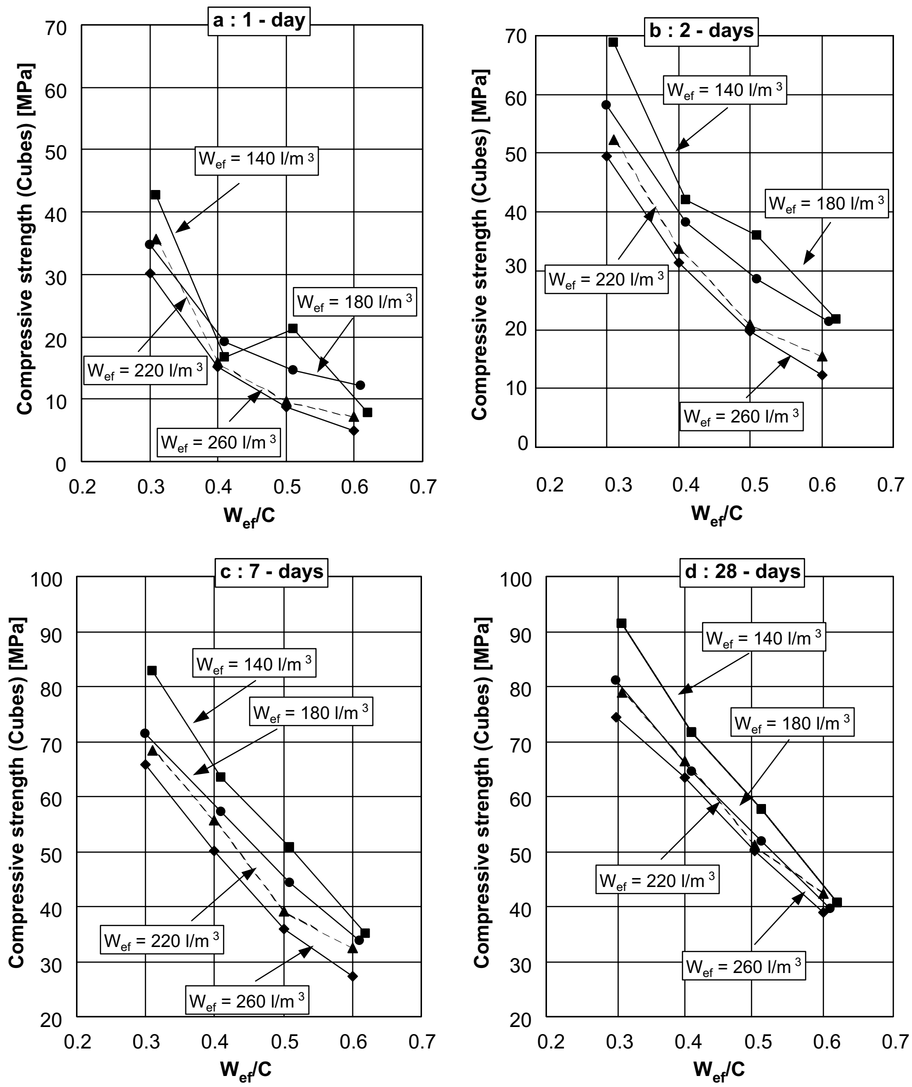

Fig. 2. Relationship between compressive strength (cubes) and W_{ef}/C ratio.

3.2. Water absorption

The results are shown in Fig. 4 as capillary absorption in g/mm^2 versus paste content of the concrete mix by volume (m^3 of paste/m^3 of concrete). Each point on the figures is the mean value of measurements of four specimens.

It can be seen in Fig. 4 that the absorption (in 1, 5, 24 and 48 h) is higher the higher is the value of the effective water/cement ratio. For each W_{ef}/C ratio, the absorption increases approximately linearly as the paste content in the mix increases reflecting the fact that the paste, being more porous than the limestone aggregates, absorbs more water. The results are consistent with those published by Bueneld and al [3].

The rate of absorption change for a given change of paste content is lower for lower values of W_{ef}/C ratios, as a result of the decrease of paste porosity as the W/C ratio decreases. It should be also noted that as it can be seen from Fig. 4 in some cases the same absorption may be obtained with different W_{ef}/C ratios (i.e. about 100 g/m^2 capillary absorption in 1 h can have the following mixes a) $W_{ef}/C = 0.5$ with approximately 21% paste content b) $W_{ef}/C = 0.4$ with approximately 29% paste content and c) $W_{ef}/C = 0.3$ with 38% paste content by volume). Obviously these concrete mixes will have the same behaviour for environmental actions which are governed by capillary absorption characteristics, although their W/C ratios are different.

It should be noted that the transport properties in general and capillary absorption in particular are very much influenced by the moisture content of the concrete specimens at testing. It is therefore very important to precondition the specimens before testing to a pre-set internal average relative humidity, which normally is lower than the original after the curing period.

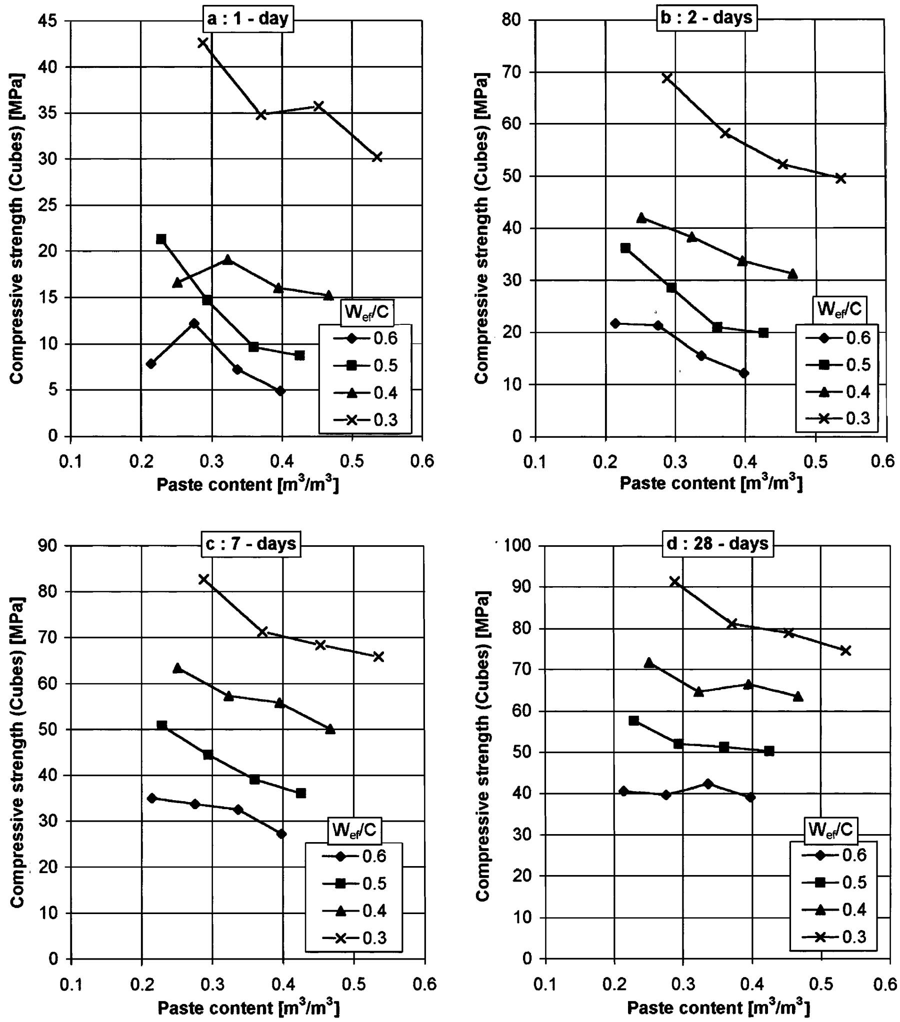

Fig. 3. Relationship between compressive strength (cubes) and paste content by volume.

This requires drying the specimens at slightly elevated temperatures ($\leqslant 50$ °C) to avoid internal micro-cracking. However, drying at these temperatures creates moisture profiles within the mass of the specimens and allowance for moisture redistribution should be provided by keeping the specimens under the appropriate moisture conditions for a sufficient time interval [6]. Both drying at a pre-set moisture content and allowing for moisture redistribution are time consuming procedures and for paste rich mixes it could require several weeks.

In the case of this work the above procedure was not strictly followed, because of time restrictions and the results are reported with these reservations. It should also be noted that preliminary drying measurements at 45 °C in well-ventilated oven had shown that 5 days were sufficient to dry cylindrical specimens ($h = 50$ mm, $\varnothing = 120$ mm) of normal concrete mixes to constant weight. However, the comparison includes mixes with high cement content ($C = 867$ kg/m^3) and low water cement ratio ($W/C = 0.3$) that would require considerably longer drying and moisture redistribution periods than very lean mixes. Since the aim of the work was not to report absolute sorptivity values but only to compare the various mixes, it can be said with certainty that the conclusions drawn would not change if the correct preconditioning procedures were strictly followed. The high paste content mixes would show higher absorption values and therefore, the slightly concave curve of absorption versus paste content shown in Fig. 4 for low W/C ratios (0.4 and 0.3) and paste contents higher than 0.3 m^3/m^3 may be linear.

4. Conclusions

Taking into account the limitations of the work concerning primarily the max aggregate size used (8 mm) and the limited preconditioning procedure applied

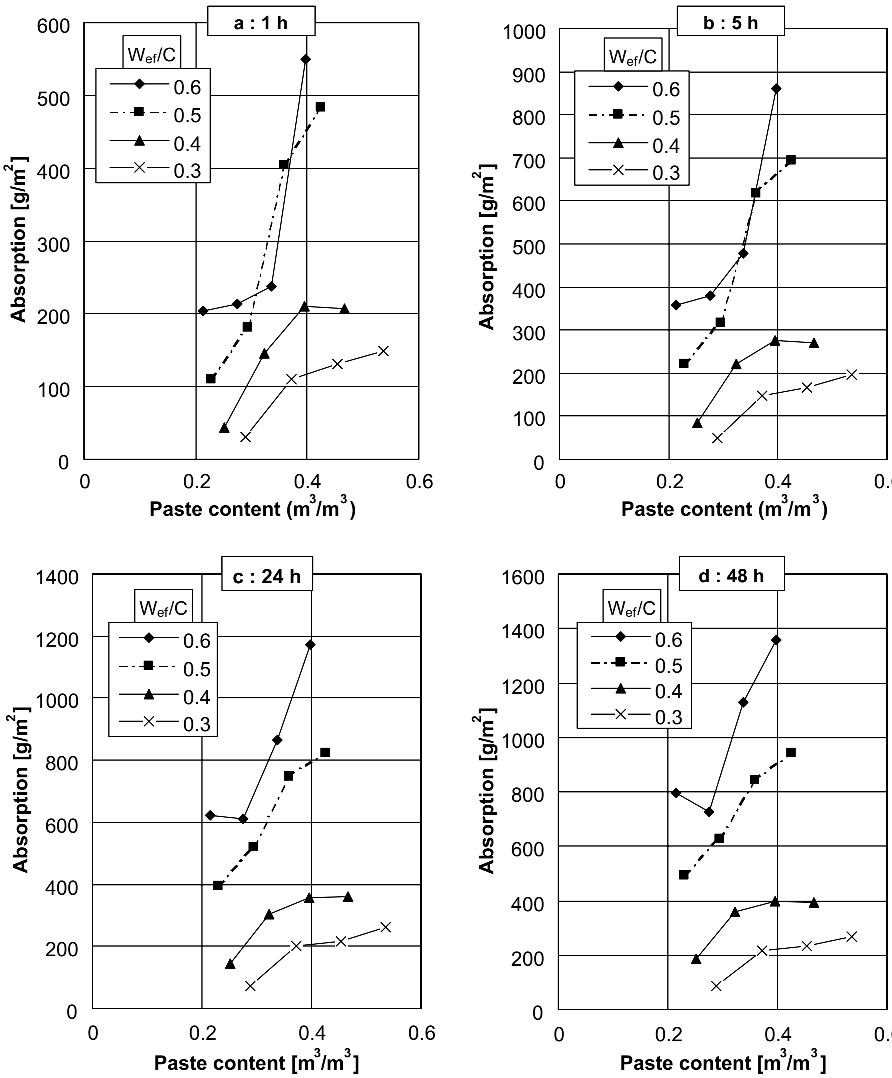

Fig. 4. Relationship between absorption and paste content.

to the capillary absorption specimens, the following conclusions may be drawn:

Strength depends not only on the W_{ef}/C ratio but also on the paste volume. As the paste volume in the mix increases the strength decreases the decrease being more intense for low values of W/C ratios.

Capillary absorption is not only affected by the W_{ef}/C ratio but also by the paste content in the mix. As the paste content increases the absorption also increases and the effect is more pronounced for higher W_{ef}/C ratios.

In cases where the mix proportions of the concrete are different from the usual ones then the effect of paste content on the strength and durability should be carefully studied.

References

[1] Stock FS, Hannant DJ, Williams RIT. The effect of aggregate concentration upon the strength and modulus of elasticity of concrete. Magazine Concr Res 1979;31(109):225–34.

[2] De Larrard F, Belloc A. The influence of aggregate on the compressive strength of normal and high-strength concrete. ACI Mater J 1997;(September–October):417–26.

[3] Buenfeld NR, Okundi E. Effect of cement content on transport in concrete. Magazine of Concrete Research 1998;50(4):339–50.

[4] Johnston CD. Strength and deformation of concrete in uniaxial tension and compression. Magazine Concr Res 1970;22(70):5–16.

[5] Popovics S. Analysis of the concrete strength versus water/cement ratio relationship. ACI Mater J 1990;87:517–29.

[6] RILEM TC 116-PCD: Permeability of Concrete as a Criterion of its Durability. Final Report. Concrete durability—An Approach towards performance testing. Mater Struct 1999;32:163–73.