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# Effect of Curing on the Compressive Strength, Resistance to Chloride-Ion Penetration and Porosity of Concretes Incorporating Slag, Fly Ash or Silica Fume

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***Abstract***

*This paper reports an investigation in which the performance of slag, fly ash, and silica fume concretes were studied under four different curing regimes. The water–cementitious materials ratio of all the concrete mixtures was kept constant at 0·50, except for the high-volume fly ash concrete mixture, for which the ratio was 0·35. The concrete specimens were subjected to moist curing, curing at room temperature after demoulding, curing at room temperature after two days of moist curing, and curing at 38°C and 65% relative humidity.*

*The compressive strength was determined at various ages, and the resistance to chloride-ion penetration was measured according to ASTM C 1202 at different ages up to 180 days. Mercury intrusion porosimetry tests were performed on the 28-day old mortar specimens for comparison purposes.*

*The results indicate that the reduction in the moist-curing period results in lower strengths, higher porosity and more permeable concretes. The strength of the concretes containing fly ash or slag appears to be more sensitive to poor curing that the control concrete, with the sensitivity increasing with the increasing amounts of fly ash or slag in the mixtures. The incorporation of slag or silica fume, or high volumes of fly ash in the concrete mixtures, increased the resistance to chloride ions and produced concretes with very low permeability.*

*Keywords:* Compressive strength, curing, fly ash, slag, silica fume, concrete durability, chloride penetration, porosity, pore volume, pore size distribution, permeability.

## INTRODUCTION

If the potential of concrete with regards to strength and durability is to be fully realized, it is most essential that it be cured adequately. The curing becomes even more important if the concrete contains supplementary cementing materials such as fly ash or ground, granulated blast-furnace slag or silica fume, and is subjected to hot and dry environments immediately after casting.

This paper reports the results of an investigation in which the performance of concrete containing supplementary cementing materials was studied after four curing regimes. These included moist curing, curing at room temperature immediately after demoulding and after two days of moist curing, and curing at 38°C and 65% relative humidity.

## SCOPE

Six concrete mixtures were made in this investigation. These included a control mixture, mixtures containing 25 and 50% slag as cement replacement, mixtures with 25 and 58% fly ash as replacement for cement, and a mixture with 10% silica fume as cement replacement. The water–cementitious materials ratio was kept constant at 0·50 for all mixtures, except that the mixture containing 58% fly ash had a water–cementitious materials ratio (W/C) of 0·35. A large number of cylinders were cast and subjected to moist curing, curing at room temperature after demoulding, curing at room temperature after two days of moist curing, and curing at 38°C and 65% relative humidity. The compressive strength was determined at various ages, and the resistance to chloride-ion penetration was measured. Mercury intrusion porosimetry tests were performed on the 28-day old mortar specimens.

## CONCRETE MATERIALS

### Materials used

The concrete mixtures were made in the CANMET laboratory during 1993 using the following materials:

*Cement*

Normal Portland cement (ASTM Type I) was used, the physical properties and chemical analysis of which are given in Table 1.

*Fly ash*

Low-calcium fly ash (ASTM Class F) from a source of Eastern Canada was used in this investigation. The physical properties and the chemical composition of the fly ash are shown in Table 1.

*Silica fume*

Uncompacted silica fume from a Canadian source was incorporated in this study. The chemical analysis of the silica fume is presented in Table 1.

*Ground, granulated blast-furnace slag*

Blast-furnace slag from a commercial producer in Canada was used. The physical properties and chemical composition of the slag are also shown in Table 1.

*Aggregates*

The fine and coarse aggregates were local natural sand and crushed limestone, respectively. The fine and coarse aggregates were sieved into different size fractions that were then recombined to a specific grading. The grading and the physical properties of both aggregates are given in Tables 2 and 3.

**Table 1.** Physical properties and chemical analysis of cementitious materials

| *Description of test* | *ASTM Type I Portland cement* | *Blast-furnace slag* | *Fly ash ASTM class F* | *Silica fume* |
|---|---|---|---|---|
| *Physical tests* | | | | |
| Specific gravity | 3·17 | 2·92 | 2·68 | — |
| Fineness — passing 45 $\mu$l (%) | 94·1 | — | 81·7 | — |
| — surface area, Blaine ($m^2$ $kg^{-1}$) | 351 | 470 | 306 | — |
| Compressive strength of 51-mm cubes (MPa) | | | | |
| — 3-day | 25·2 | — | — | — |
| — 7-day | 30·3 | — | — | — |
| — 28-day | 38·2 | — | — | — |
| *Chemical analysis* | | | | |
| Silicon dioxide ($SiO_2$) | 20·32 | 38·0 | 40·9 | 93·5 |
| Aluminium oxide ($Al_2O_3$) | 4·94 | 6·63 | 18·6 | 0·06 |
| Ferric oxide ($Fe_2O_3$) | 2·55 | 0·40 | 28·9 | 0·45 |
| Calcium oxide (CaO) | 62·58 | 35·7 | 1·87 | 0·50 |
| Magnesium oxide (MgO) | 2·23 | 13·6 | 1·01 | 0·67 |
| Sulphur trioxide ($SO_2$) | 3·46 | — | 0·87 | 0·10 |
| Sodium oxide ($Na_2O$) | 0·19 | 0·36 | 0·56 | 0·32 |
| Potassium oxide ($K_2O$) | 0·86 | 0·40 | 1·44 | 0·85 |
| Loss on ignition (LOI) | 2·15 | 0·76 | 1·87 | 2·26 |
| *Bogue potential compound (%)* | | | | |
| Tricalcium silicate ($C_3S$) | 54·0 | | | |
| Dicalcium silicate ($C_2S$) | 18·0 | | | |
| Tricalcium aluminate ($C_3A$) | 9·0 | | | |
| Tetracalcium aluminoferrite ($C_4AF$) | 8·0 | | | |

*Superplasticizer*
A sulphonated, naphthalene-formaldehyde condensate superplasticizer of Japanese origin was used. This superplasticizer is available as a dark brown aqueous solution with 42% solids and a density of 1200 kg $m^{-3}$.

*Air-entraining admixture*
A synthetic resin type air-entraining admixture was used to produce an air content of $6 \pm 1\%$ in one of the mixtures.

## MIXTURE PROPORTIONS

The concrete mixture proportions are given in Table 4. The mixture RA1 is the control concrete with 372 kg $m^{-3}$ Portland cement and a $W/C$ of 0·50. The mixtures RA2 and RA3 were made with 25 and 50% of cement being replaced by slag. In the mixture RA4, fly ash was used at 25% level of cement. The mixture RA5 is a high-volume fly ash concrete mixture (HVFA) in which fly ash content was 58% of the total cementitious materials. Finally, mixture RA6 was made in which 10% of the cement was replaced by silica fume. The $W/C$ ratio was kept constant at 0·50 for all the concrete mixtures except for mixture RA5 which was made with a $W/C$ ratio of 0·35. All Portland cement replacements were on weight basis.

**Table 2.** Grading of aggregates

| *Sieve size (mm)* | *Cumulative percentage retained* | *Sieve size (mm)* | *Cumulative percentage retained* |
|---|---|---|---|
| 19·0 | 0·0 | 4·75 | 0·0 |
| 12·7 | 40·0 | 2·36 | 10·0 |
| 9·5 | 65·0 | 1·18 | 32·5 |
| 4·75 | 100·0 | 0·600 | 57·5 |
| | | 0·300 | 80·0 |
| | | 0·150 | 94·0 |
| | | pan | 100·0 |

**Table 3.** Physical properties of aggregate

| | *Coarse aggregate* | *Fine aggregate* |
|---|---|---|
| Specific gravity | 2·69 | 2·70 |
| Absorption (%) | 0·82 | 1·10 |

### Casting and curing of test specimens

In general, 56 102 × 203-mm cylinders were cast from each batch of concrete. Two 50-mm mortar cubes were made from the same batch by sieving concrete to remove the coarse aggregate. The cylinders were cast in two equal layers and each layer was compacted using a vibrating table. After casting, the moulded specimens were covered with water-saturated burlap and left in the casting room at $23 \pm 1{\cdot}7$°C for 24 h. They were then demoulded and transferred to different rooms for curing under predetermined curing regimes (Table 5).

**Table 5.** Curing regimes for concrete mixtures

| *No.* | *Curing regime* |
|---|---|
| 1 | Standard moist curing following demoulding |
| 2 | Curing at room temperature after demoulding |
| 3 | Curing at room temperature after two days of moist curing |
| 4 | Curing at 38°C and 65% RH |

**Table 4.** Proportioning of concrete mixtures

| *Mixture no.* | *W/C+SCM* | *Water* | *Cement* | *Quantities (kg $m^{-3}$)* Slag | Fly ash | Silica fume | CA SSD | FA SSD | SP | *AEA ($l\,m^{-3}$)* |
|---|---|---|---|---|---|---|---|---|---|---|
| RA1 | 0·50 | 186 | 372 | — | — | — | 1165 | 655 | — | — |
| RA2 | 0·50 | 186 | 280 | 92 | — | — | 1165 | 655 | — | — |
| RA3 | 0·50 | 186 | 186 | 186 | — | — | 1165 | 655 | — | — |
| RA4 | 0·50 | 186 | 280 | — | 92 | — | 1165 | 655 | — | — |
| RA5 | 0·35 | 130 | 156 | — | 216 | — | 1209 | 681 | 3·6 | 0·22 |
| RA6 | 0·50 | 186 | 335 | — | — | 37·2 | 1165 | 655 | — | — |

Note: CA = coarse aggregate; FA = fine aggregate; SSD = saturated, surface dry; SP = superplasticizer; AEA = air-entraining admixture; SCM = supplementary cementing material.

The first curing condition was the standard moist curing. In the second curing condition, the specimens, immediately after demoulding were left in a room for curing at ambient conditions. The third curing regime consisted of two days of moist curing followed by curing at room temperature. Finally, the fourth curing condition represents the condition of concretes in hot-weather countries, i.e. after demoulding, the concrete is left to cure under ambient conditions of temperature and humidity (38°C and 65% relative humidity).

## TESTING OF SPECIMENS

The concrete cylinders were tested in compression at 1, 3, 7, 28 and 180 days. All specimens for compression testing were capped with a sulfur compound before testing.

The tests for resistance to chloride-ion penetration were carried out on 102 × 50-mm discs cut from the 102 × 203-mm cylinders at 7, 28 and 180 days. This test was performed in accordance with ASTM C 1202 test method.

The porosity and pore size distribution were measured using mercury porosimetry on samples cut from the 50-mm mortar cubes.

## PROPERTIES OF FRESH CONCRETE

The properties of the freshly mixed concrete, i.e., temperature, slump, unit weight, and air content are given in Table 6. The entrapped air content of the non-air entrained concrete mixtures was between 1 and 2%. The use of the air-entraining admixtures in the high-volume fly ash concrete resulted in 6·2% air. The slump of all concrete mixtures was greater than 120 mm except for the silica fume concrete for which the slump was 65 mm.

## TEST RESULTS AND DISCUSSION

### Compressive strength

*Curing condition 1 — moist curing*

The strength development characteristics of the various concretes under moist-curing conditions are shown in Fig. 1. At one day, the highest strength of 19·6 MPa is obtained for concrete incorporating 10% silica fume, and the lowest value of 4·2 MPa is for concrete with 50% slag. The strength values for the control concrete, concrete incorporating 25% slag, concrete made with 25% fly ash and HVFA concrete were 16·9, 11·6, 9·6 and 7·4 MPa, respectively.

At 28 days, silica fume concrete still had the highest strength with a value of 48·4 MPa. This was followed by 25% slag concrete, control concrete, 50% slag concrete, HVFA concrete, and 25% fly ash concrete, respectively. The lowest compressive strength value at 28 days was 31·5 MPa for 25% fly ash concrete. Between 28 and 180 days, silica fume concrete showed almost no strength gain whereas all other concretes showed a continuous gain in strength, and reached strength values between 44·3 and 51·1 MPa, the highest value being for concrete with 25% slag. The high-strength gains for the slag and fly ash concrete are due to the inherent cementitious

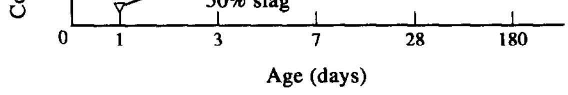


**Fig. 1.** Compressive strength development of moist-cured concrete — curing condition 1.

**Table 6.** Properties of fresh concrete

| *Mixture type* | *Mixture no.* | *Temperature (°C)* | *Slump (mm)* | *Unit weight (kg m$^{-3}$)* | *Air content (%)* |
|---|---|---|---|---|---|
| Control concrete | RA1 | 16 | 130 | 2410 | 1·4 |
| 25% Slag concrete | RA2 | 19 | 140 | 2405 | 1·5 |
| 50% Slag concrete | RA3 | 21 | 165 | 2380 | 1·2 |
| 25% Fly ash concrete | RA4 | 23 | 215 | 2418 | 1·3 |
| HVFA Concrete | RA5 | 23 | 120 | 2320 | 6·2 |
| 10% Silica fume concrete | RA6 | 21 | 65 | 2405 | 1·4 |

properties of the slag and the pozzolanic reactivity of fly ash. If allowance is made for the air content of 6·1% in HVFA, the strength of this concrete should have approached or exceeded the strength of 25% slag concrete.

*Curing condition 2 — curing at room temperature after demoulding*

This curing condition was selected to develop data for the worst scenario when there is absolutely no curing after demoulding of formwork, a situation not uncommon in a number of countries, especially in the developing countries. The rate of strength gain between 1 and 180 days is somewhat similar for all concretes except that the silica fume and HVFA concretes show a slight drop in strength between 28 and 180 days (Fig. 2). The highest strength values of 36·2 and 35·8 MPa at 180 days are reached by the silica fume and the control concretes, respectively. This is a drop of about 28% from the corresponding strengths achieved in curing condition 1, i.e. moist curing. The concretes incorporating supplementary cementing material are more sensitive to the lack of supply of moisture, and show significant loss of strength at 180 days compared with the strength values obtained after moist curing. This ranges from about 38% for concrete containing 25% slag to about 50% for concretes made with 25% fly ash, 50% slag or HVFA.

The drop in the strength of silica-fume and high-volume fly ash concretes is due probably to the development of microcracks due to drying, and this has been reported previously for silica fume concretes.[4]

*Curing condition 3 — curing at room temperature after two days of moist curing*

This curing condition consists of two days of moist curing following demoulding, and then exposure at room temperature, i.e. 23 ± 2°C and 50% relative humidity. This curing regime was selected to simulate the current ongoing practice in construction industry in most countries. There is a steady increase in the strength of all concretes between 1 and 28 days (Fig. 3). This rate slows down between 28 and 180 days, except for the silica fume concrete which maintains its rate of strength gain until it reaches a strength of 44·3 MPa. This reflects a drop of about 9% in the strength at 180 days as compared with that reached under moist-curing conditions; the corresponding loss in the strength of the control concrete was about 20%. The concretes incorporating 25% slag or 25% fly ash or 50% slag or HVFA concrete showed significantly higher losses in strength than the two concretes discussed above, although these were not as serious as those in curing regime 2. Nevertheless, the additional moist curing is essential if the concretes are to achieve their full strength potential, and this is especially so for the concretes incorporating high percentages of slag or fly ash.

*Curing condition 4 — 38°C and 65% relative humidity*

This curing regime consisted of transferring the specimens after demoulding to a temperature and humidity controlled chamber maintained at 38°C and 65% relative humidity, and keeping the specimen there until required for testing. This curing condition was selected to simulate climatic conditions in warm countries where the concrete not only receives little or no curing after the first 24 h, but also is exposed to elevated temperatures, and where humidity is somewhat higher than 50%.

The increased curing temperature accelerates the hydration reaction in the control and the slag concretes; also, the pozzolanic reactions are

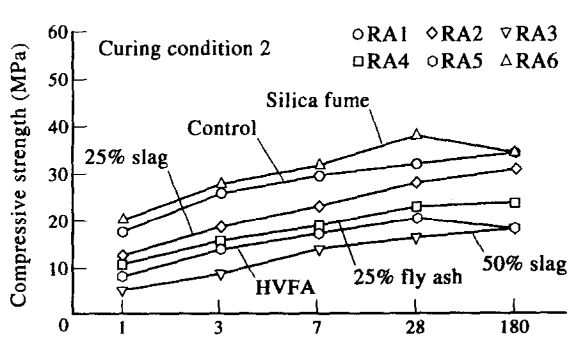


**Fig. 2.** Compressive strength development of concrete cured at room temperature after demoulding — curing condition 2.

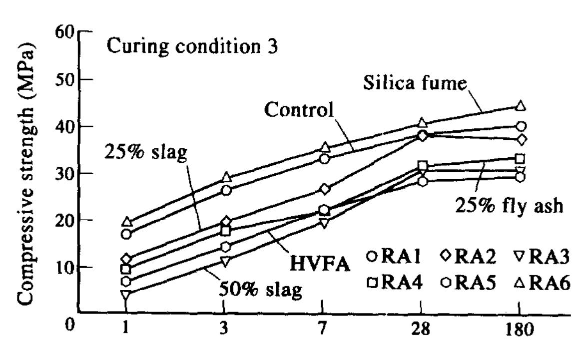


**Fig. 3.** Compressive strength development of concrete cured at room temperature after two days of moist curing — curing condition 3.

accelerated in the silica fume and fly ash concretes. This is reflected in higher strengths at three days for all the concretes under investigation compared with the corresponding strengths achieved under the moist-curing conditions. However, this increase is not sustained beyond five days (Fig. 4). At seven days and beyond, the rate of strength gain is lower than that for the concrete cured under moist-curing conditions. At 180 days, the strength of the silica fume concrete, HVFA concrete, control concrete, 25% slag concrete, 50% slag concrete and 25% fly ash concrete were 40·3, 36·8, 36·7, 33·7, 27·7 and 26·4 MPa, respectively. These are considerably lower than the corresponding strengths reached under the moist-curing conditions. The lower strengths at 180 days are due to the lack of sufficient moisture for the hydration and pozzolanic reactions. Between the ages of 3 and 28 days, the rate of strength development for the HVFA concrete is much higher than all the other concretes investigated, and is probably due to the availability of the large amount of $SiO_2$.

**Resistance to the penetration of chloride ions**

The resistance of the concretes to the penetration of chloride ions was determined by ASTM C 1202. Briefly, this test consists of monitoring the amount of electrical current passed through a 102-mm diameter × 51-mm thick concrete disc, when a potential difference of 60 V DC is maintained across the specimen for a period of 6 h. Chloride ions are forced to migrate out of a NaCl solution subjected to a negative charge through the concrete into a NaOH solution maintained at a positive potential.

It is generally agreed that for low-permeability concretes, the value of the charge in coulombs passed through the specimens should not exceed 1000, and for the very low-permeability concretes, this value should preferably be less than 600.[4] The test results obtained for the various curing conditions are discussed below:

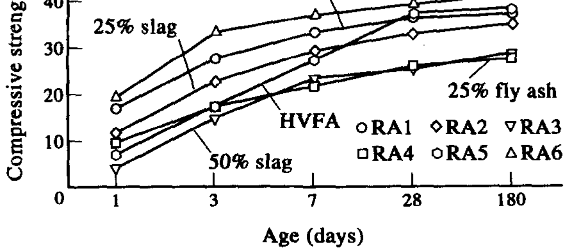


**Fig. 4.** Compressive strength development of concrete cured at 38°C and 65% RH — curing condition 4.

*Curing condition 1 — moist curing*

The charge in coulombs, a measure of the resistance of the concrete to the penetration of chloride ions is very high at one day for all the concretes investigated, and decreases with time. The control concrete and the 25% slag concrete show very high values for the charge, i.e. > 1500 even at 180 days, including relatively high permeability of the concrete. However, the HVFA concrete and the concretes containing 50% slag or 25% fly ash or 10% silica fume show sharply reduced values of the charge at both 28 and 180 days. At 180 days, the values range from 375 C for the HVFA concrete to 734 C for the silica fume concrete, indicating very low permeability of the concretes. The large decrease in the permeability with time in the above concretes is due to the change in the pore structure of the hydrated cementitious system due to the use of supplementary cementing materials.[5,6]

*Curing conditions — 2, 3, and 4*

Irrespective of the curing conditions and regardless of the age, the concretes investigated show very high values of the charge at 180 days. The only exception was the HVFA concrete for which the charge at 180 days was 973 C (curing condition 4). For the other concretes, the values of the charge ranged from 1722 C for the 10% silica fume concrete (curing condition 4) to 11 268 C for control concrete (curing condition 2), indicating very high permeability.

The high permeability of the concretes indicated by the test results is directly due to the lack of the moisture availability for the hydration of the cementitious system, thus the need for moist curing cannot be overemphasized.

**Porosity and pore-size distribution in mortars**

The pore size distribution and total porosity of the mortars cured under the four curing conditions are shown in Figs 5–8, and are discussed below. It is to be noted that due to laboratory constraints, pore-size distribution tests were performed at 28 days rather than 180 days, a more desirable age especially when supplementary cementing materials are being used.

*Curing condition 1 — moist curing*

Under this curing condition, the control mortar shows the lowest total porosity. This is followed

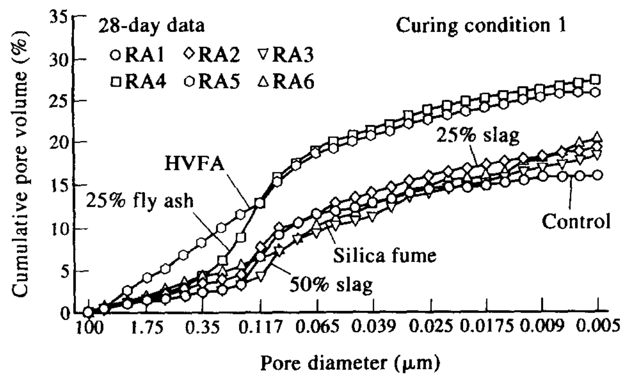


**Fig. 5.** Pore size distribution of moist-cured mortars — curing condition 1.

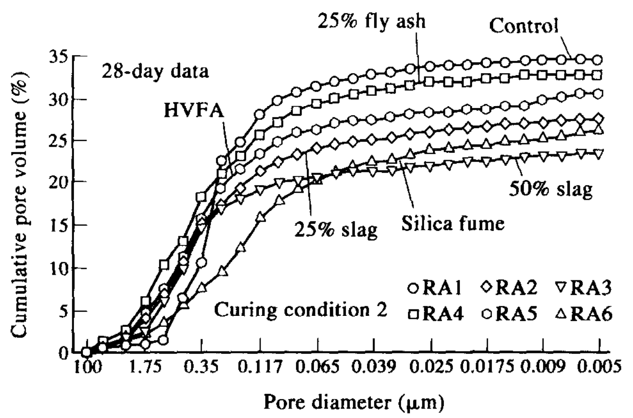


**Fig. 6.** Pore size distribution of mortars cured at room temperature after demoulding — curing condition 2.

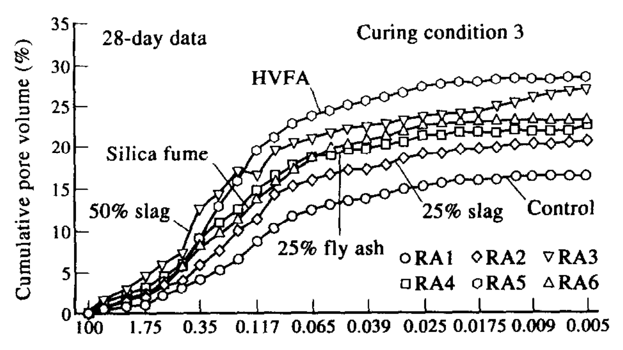


**Fig. 7.** Pore size distribution of mortars at room temperature after two days of moist curing — curing condition 3.

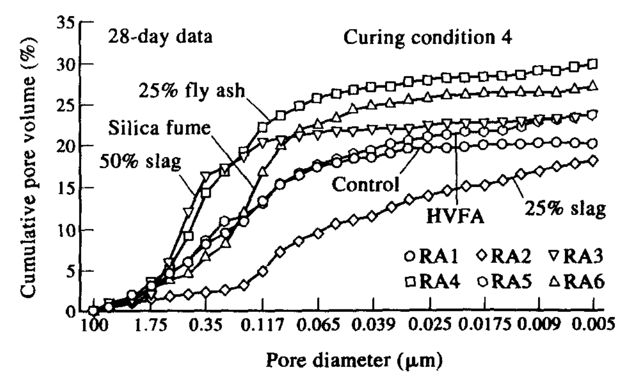


**Fig. 8.** Pore size distribution of mortars cured at 38°C and 65% RH — curing condition 4.

by 50% slag mortar, 25% slag mortar, silica fume mortar, HVFA mortar and 25% fly ash mortar, in that order. The beneficial effects of the use of slag, fly ash, and silica fume are not being reflected in the above results because the hydration reactions in the case of slag concrete, and the pozzolanic reactions in the case of fly ash and silica fume concrete proceed at a relatively slow rate (Fig. 5).

*Curing condition 2 — curing at room temperature after demoulding*

As expected, all mortars show significantly higher total porosities as compared with the values obtained for the moist-curing condition. The control mortars show the poorest performance, i.e. the highest cumulative pore volume percentage of about 35%. The other mortars also perform poorly, with cumulative total porosity in excess of 20% (Fig. 6).

*Curing condition 3 — curing at room temperature after two days of moist curing*

This curing condition, i.e. subjecting the mortars two days of moist curing, improves significantly the performance of the control mortar, and the total porosity values approach those obtained for curing condition 1. This curing condition does not significantly affect the performance of the other mortars (Fig. 7).

*Curing condition 4 — 38°C and 65% relative humidity*

The curing at 38°C and 65% relative humidity affects favourably the porosity and pore size distribution of HVFA mortars, and results in the lowest total porosity as compared with the porosity values obtained for HVFA subjected to the other curing conditions. As mentioned earlier, this is due to the acceleration of the pozzolanic reactions. On the other hand, this curing condition affects adversely the porosity of the silica fume mortar with a total porosity value of approximately 27%. This is contrary to the strength values which were the highest as compared with the other concretes (Fig. 8).

## CONCLUDING REMARKS

For the concrete mixtures investigated and the curing conditions employed, the following conclusions may be drawn.

(1) The continuous moist curing of concrete is essential to achieve the highest strength,

**Table 7.** Properties of hardened concretes

| *Mixture no.* | *Curing condition* | *1-day density ($kg\,m^{-3}$)* | *Compressive strength (MPa)* | | | | | *Resistance to chloride-ion penetration (C)* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *1-d* | *3-d* | *7-d* | *28-d* | *180-d* | *1-d* | *28-d* | *180-d* |
| RA1 | 1 | 2420 | 16·9 | 26·0 | 31·6 | 39·3 | 49·3 | 6606 | 4251 | 3767 |
| RA2 | 1 | 2410 | 11·6 | 19·5 | 27·1 | 41·1 | 51·1 | 6240 | 2343 | 1555 |
| RA3 | 1 | 2400 | 4·20 | 11·3 | 20·7 | 35·3 | 46·1 | 4846 | 1083 | 656 |
| RA4 | 1 | 2420 | 9·60 | 17·9 | 22·7 | 31·5 | 44·3 | 6570 | 3963 | 725 |
| RA5 | 1 | 2370 | 7·40 | 14·7 | 20·0 | 32·1 | 44·3 | 6843 | 1030 | 375 |
| RA6 | 1 | 2400 | 19·6 | 28·9 | 37·8 | 48·4 | 48·9 | 3145 | 823 | 734 |
| RA1 | 2 | 2420 | 16·9 | 25·6 | 29·6 | 32·6 | 35·8 | — | 12066 | 11268 |
| RA2 | 2 | 2410 | 11·6 | 18·6 | 23·1 | 28·7 | 32·3 | — | 10029 | 6954 |
| RA3 | 2 | 2400 | 4·20 | 8·30 | 13·8 | 16·4 | 19·3 | — | — | 10466 |
| RA4 | 2 | 2420 | 9·60 | 15·3 | 18·6 | 23·0 | 25·0 | — | — | 9452 |
| RA5 | 2 | 2370 | 7·40 | 13·7 | 17·4 | 21·0 | 19·4 | 11831 | 8218 | 7230 |
| RA6 | 2 | 2400 | 19·6 | 27·6 | 32·2 | 38·7 | 36·2 | 5815 | 3250 | 2421 |
| RA1 | 3 | 2420 | 16·9 | 26·0 | 32·7 | 37·3 | 39·8 | 8902 | 7860 | 7068 |
| RA2 | 3 | 2410 | 11·6 | 19·5 | 26·2 | 36·5 | 37·2 | 8394 | 5698 | 5524 |
| RA3 | 3 | 2400 | 4·20 | 11·3 | 19·4 | 29·7 | 30·2 | 6920 | 5651 | 4985 |
| RA4 | 3 | 2420 | 9·60 | 17·9 | 21·5 | 29·9 | 33·1 | 8652 | — | 7697 |
| RA5 | 3 | 2370 | 7·40 | 14·7 | 22·1 | 27·7 | 29·3 | 9213 | 5265 | 5113 |
| RA6 | 3 | 2400 | 19·6 | 28·9 | 34·9 | 39·6 | 44·3 | 4433 | 2768 | 2043 |
| RA1 | 4 | 2420 | 16·9 | 27·8 | 32·7 | 35·2 | 36·7 | 9200 | 8811 | 7582 |
| RA2 | 4 | 2410 | 11·6 | 22·8 | 28·7 | 31·8 | 33·7 | 9239 | 8227 | 6265 |
| RA3 | 4 | 2400 | 4·20 | 15·2 | 22·7 | 24·4 | 27·3 | 8878 | 6351 | 6110 |
| RA4 | 4 | 2420 | 9·60 | 16·8 | 21·0 | 25·1 | 26·4 | — | — | 10325 |
| RA5 | 4 | 2370 | 7·40 | 17·4 | 26·7 | 36·1 | 36·8 | 2466 | 1391 | 973 |
| RA6 | 4 | 2400 | 19·6 | 33·7 | 36·4 | 38·6 | 40·3 | 3057 | 2507 | 1722 |

Notes: *W/C* for RA1, RA2, RA3, RA4, RA6 = 0·50; *W/(cement + fly ash)* for RA5 = 0·35; mixture RA5, air content = 6·2%; mixture RA1, RA2, RA3, RA4, and RA6 = non-air entrained.
Mixture: RA1: control concrete;
RA2: 25% slag concrete;
RA3: 50% slag concrete;
RA4: 25% fly ash concrete;
RA5: HVFA concrete;
RA6: 10% silica fume concrete.

lowest porosity and highest resistance to the penetration of chloride ions.

(2) The concretes which received no curing after demouling show the poorest performance in terms of the strength development, porosity, and resistance to the chloride-ion penetration. However, the concretes moist cured for only two days show significant improvement in strength, and other characteristics, as compared with the concretes without any curing.

(3) The early-strength gains achieved by the concretes cured at 38°C and 65% relative humidity in comparison to the moist-cured concretes are not maintained at later ages; the compressive strengths at 180 days are significantly lower than the strength of the corresponding moist-cured concrete. The lack of moist curing of concrete affects more adversely its resistance to the chloride-ion penetration than it affects its compressive strength.

(4) The later-age performance of the HVFA and 10% silica-fume concrete cured at 38°C and 65% relative humidity is equal to or superior than the control concrete both as regards to strength development and the resistance to chloride-ion penetration.

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