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Effect of conditioning temperature on the strength and permeability of normal- and high-strength concrete

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Abstract

In order to evaluate the effect of the conditioning temperature on strength and permeability properties of concrete a series of compressive, indirect tensile and permeability tests were performed on concretes (designed to have 28-day compressive strengths of 40 and 100 N/mm^2) conditioned at temperatures of 85 and 105 °C. The results show that, for both the normal- (NSC) and the high-strength concrete (HSC), comparable 28-day test results were obtained from strength tests performed on concrete conditioned at 85 and 105 °C. The permeability results were also somewhat similar for the two conditioning temperatures, although greater differences than previously reported were observed. Conditioning at both 85 and 105 °C was identified as adequate, with the preferred temperature of conditioning being 105 °C.

Keywords: Concrete; Conditioning; Compressive strength; Tensile properties; Permeability

1. Introduction

Fundamental to measuring permeability is the preparation and conditioning of the specimen prior to testing. The primary role of conditioning can be described as the preparation of the sample prior to testing to ensure that a standard moisture distribution across the specimen is obtained. In sample preparation and conditioning, it is important that the drying phase is strictly regulated as drying not only empties pore space but also may induce cracking in the microstructure. When extensive drying occurs, the measured permeability coefficients may not be a true representation of the permeability of the concrete in question. Drying induces a high number of cracks, developing a more accessible pore structure and thus easier ingress of the permeating medium.

It has been reported that gas permeability varies significantly with the distribution and the amount of moisture present in the porous network. This effect is more pronounced when the concrete is nearly dry [1,2]. Various preconditioning methods, which have achieved varied success, exist to achieve a standardised state with respect to the amount of moisture inside the pores. However, these procedures do have some associated disadvantages. They try to achieve an almost dry condition and, therefore, failure to comply with the standardised conditioning methods may result in inconsistent results.

Moisture content within concrete is known to play a major role in controlling the cement hydration and therefore influencing the pore structure. It also has a decisive effect on transport properties and encourages many of the deterioration processes [3]. Furthermore, moisture content has been noted repeatedly in the literature [4,5] as having a primary role in determining the relative permeability value of concrete.

Recent investigations [6] have tried to optimise the preconditioning procedure for gas permeability measurement, and a draft standard detailing preconditioning

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regimes has been proposed by a RILEM committee for preparation of specimens for testing in the CEMBUREAU gas permeability test [7]. Both recommendations use a combination of conditioning temperatures for varying amounts of time to achieve constant mass and moisture distribution. Further methods of preconditioning specimens include drying the specimens so that they have a predetermined level of evaporation rate of water. This involves consecutive periods of drying the specimens and performing permeability tests so that gas permeabilities at different degrees of saturation including the totally dry state are achieved. This procedure may extend over a significant period of time if the concrete has a slow drying rate, leading to questions about its relevance to permeability tests on high-performance concrete.

The work reported here set out to determine the effect of two conditioning temperatures on the strength and permeability of a normal- (NSC) and a high-strength concrete (HSC). The permeability test used was the Nitrogen Gas Relative Permeability Test designed by Martin [8] and modified by Lydon [9].

2. Relative gas permeability test

The permeability test used in this study was a relative gas permeability test and certain parameters from the test provide an index of the permeability of the concrete. These parameters are shown schematically in Fig. 1(a) and (b). The three parameters, which can be determined from a pressure–time decay curve, are (a) the half time (expressed in minutes), or the time taken for the pressure inside the reservoir to decrease from 10 to 5 bar; (b) the gradient of the line of the plot of log pressure against time, referred to as m; and (c) the area under the graph of pressure against time.

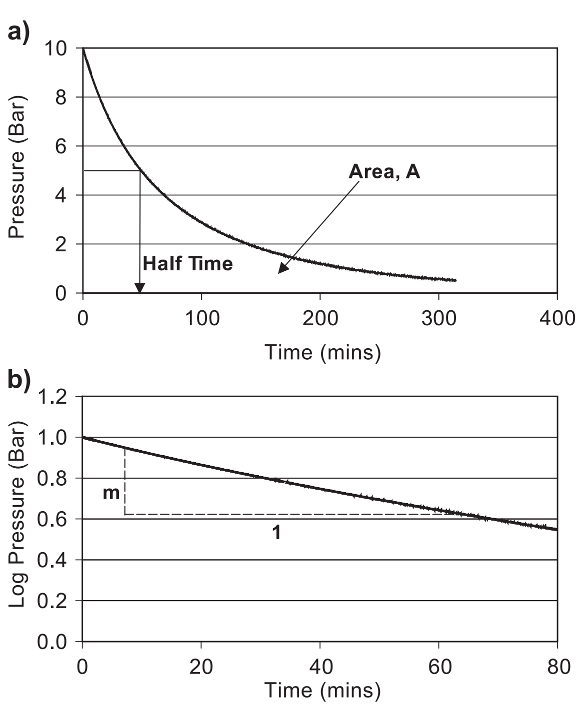

Fig. 1. Schematic view of the permeability parameters. (a) Graph of pressure against time showing half time and area a, under the pressure-time curve. (b) Graph of log pressure against time, the gradient of which is m.

In a previous investigation by Gardner [10], it was shown that full permeability tests performed on high-strength concrete lasted for more than 2 weeks and this time scale was considered too long. Therefore, the two parameters recommended for use were the half time and the gradient of the graph of log pressure against time. The data required to identify these parameters are obtained from the decrease of pressure from 10 to 5 bar and, therefore, the experiments did not have to be continued beyond 5 bar resulting in much reduced testing times.

3. Experimental programme

3.1. Materials and mix proportions

In this study, the 40 N/mm^2 (C40) concrete was considered to be normal-strength concrete (NSC), consisting of the basic constituents of cement, aggregate and water. The 100 N/mm^2 (C100) concrete was considered to be high-strength concrete (HSC). In producing this high-strength mix, silica fume and superplasticiser were used to achieve the desired workability and 28-day compressive strength. The mix proportions used are reported in Table 1.

3.2. Specimen preparation

For each mix, a breakdown of the specimens used is given in Table 2. Twenty-two 100-mm cubes, along with ten 200×100 mm diameter cylinders were cast. Control cylinders were cast for each mix and were tested at an age of 28 days to determine the Modulus of Elasticity, E, and tensile strength, f_t, of the concrete via a torsion test [11]. The torsion test is a simple arrangement whereby cylinders are subject to a torque. The torque–twist relationship provides a measurement of the shear modulus and, hence, E can be determined by assuming ν=0.2. The maximum torque provides an indirect measure of tensile strength. Control cubes were made to test the 28-day compressive strength. For each mix, four cubes were also made for permeability testing.

Following demoulding, the cubes that were cast in order to perform control tests were placed in a 20 °C water curing tank from which they were removed 1 h before testing. The cylinders were removed from the curing tank 4 h before they were subjected to torsion testing. The cubes used for the conditioning study and relative permeability tests were placed in the water curing tank to cure for a period of 7 days, following which they were removed to start the conditioning procedure.

Table 1
Mix proportions for C40 and C100 concrete

Mix reference	Cement	Silica fume	Fine aggregate	Coarse aggregate	Water	Superplasticiser (ml/kg)
C40	1	–	1.94	2.42	0.52	–
C100	1	0.11	1.52	2.55	0.32	29.5

All of the cubes used to determine the relative permeability were drilled on the fifth day of curing prior to conditioning. A central 6-mm hole was drilled through each cube. From one face, the hole was drilled to a depth of approximately half of the cube. The cube was then turned over to the opposite face and the same procedure was followed. The drilling was performed in this manner to avoid damaging the surface of the concrete by drilling through the entire depth of the cube from one side of the specimen. The surfaces of the cubes were cleaned prior to testing by blowing pressurised air through the drilled hole and over the sides of the specimen.

3.3. Details of the conditioning regime

The conditioning regime was performed after 7 days of curing. The conditioning procedures were performed at two temperatures, 105 and 85 °C, and were carried out until a 0.02% weight change was recorded between consecutive readings in any 24-h period; this condition was assumed to give the specimen's maximum percentage weight loss. As shown in Table 2, for each mix, three cubes were made for testing immediately after the conditioning regime at the two temperatures had been completed. These cubes were taken out of the oven, placed in the dessicator to cool down and tested 24 h later. Furthermore, three cubes were made to test after being placed in the dessicator until their lower temperature counterparts had achieved their minimum percentage weight loss. This was done because it was originally thought that the specimens conditioned at the temperature of 105 °C would reach the maximum percentage weight loss before those conditioned at 85 °C, and it was desirable, for comparison purposes, to test the specimens conditioned at 105 and 85 °C after the same period of time after casting. This resulted in compressive strength tests being performed after a period of 18 days after the last specimens were placed in the dessicator in the case of normal-strength concrete and 10 days in the case of high-strength concrete.

Table 2
The number of specimens cast for each mix and their use

No. of cubes	No. of cylinders	Use
3	–	7-day compressive strength tests
3	2	28-day compressive strength and torsion tests
3	2	Dried at 85 °C, tested immediately (c and t)[a]
3	2	Dried at 85 °C, placed in dessicator, then tested (c and t)
2	–	Dried at 85 °C, then tested for relative permeability
3	2	Dried at 105 °C, tested immediately (c and t)
3	2	Dried at 105 °C, placed in dessicator, then tested (c and t)
2	–	Dried at 105 °C, then tested for relative permeability

[a] c=compression, t=torsion.

3.4. Gas relative permeability test details

The experimental set up is illustrated in Fig. 2. Nitrogen gas was stored in a pressurised cylinder which was isolated from the reservoir by a regulator valve 'A'. This valve was opened and the pressure inside the reservoir was increased to 10 bar. Another valve separated the reservoir from the pressure cell and, when this valve was opened, the pressurised gas rapidly entered the cell causing a decrease in the pressure recorded in the reservoir. This procedure was then repeated until the pressure in the reservoir stabilised at 10 bar, at which point it was sealed from the pressurised gas cylinder by closing valve 'A'. The test was then commenced. A computer, which logged the pressure decay via a pressure transducer in each of the reservoirs, was used to record the data as a text file. The test equipment was duplicated to allow two specimens to be tested simultaneously. The pressure gauge and other recording equipment were checked and calibrated at the beginning of every test. Gas leakage was regularly checked by observing the cells and checking for air bubbles in the petroleum jelly around the sealed lids.

For each test, two cubes were removed from the dessicator and their weight was recorded. Aluminium tape was placed over the bottom hole of the cube and a thin film of petroleum jelly was spread over the bottom face, including the aluminium tape, and the top face of the cubes. A circular pad of rubberised cork was placed on the base of the permeability cell, followed by the test specimen, carefully aligning the hole in the top of the specimen with the hole in the lid of the cell. A further circular pad of rubberised cork was then placed on top of the specimen; this pad contained a hole in the centre to coincide with the hole on the top face of the cube. A further layer of petroleum jelly was applied around the cork pad in order to ensure a perfect seal when the lid of the cell was fitted. The lid was then placed on the cell and was sealed using a systematic procedure of tightening 12 bolts to ensure a uniform gas-tight seal and that, throughout the test, there was no loss of

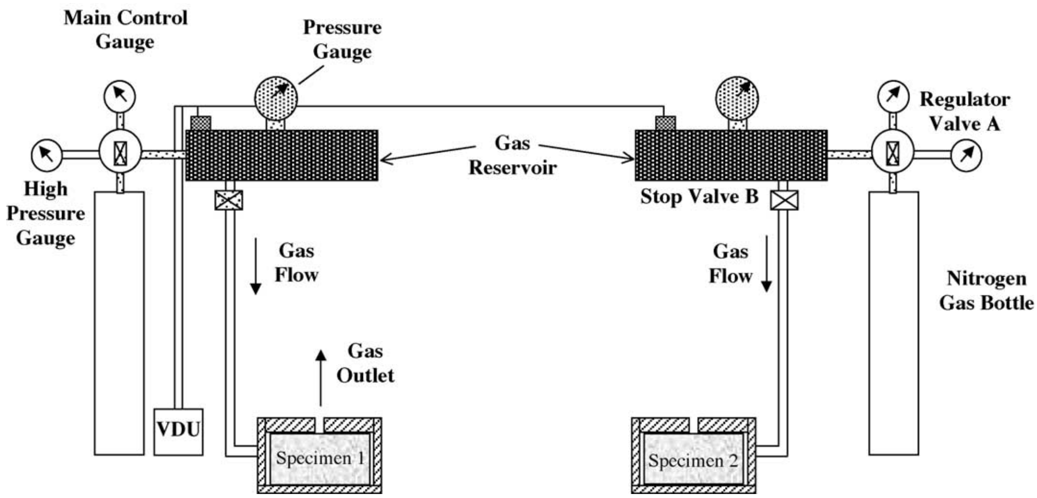

Fig. 2. Experiment arrangement for the relative permeability test.

gas from the interface between the concrete and the rubberised cork pads.

4. Test results and discussion

4.1. Strength properties

4.1.1. Compressive strength

The mean compressive strength results, f_{cu}, are presented in Table 3, along with the coefficients of variation (V%). The control tests, the results of which are given in the first two rows of Table 3, were performed after 28 days of water curing and (with one exception) had the lowest coefficients of variation of all of the test results. The remaining results are from the conditioning tests performed at the two temperatures of 85 and 105 °C. The second and fourth columns provide details of the number of days of curing, conditioning and dessicator storage. However, care is needed when considering the test results in Table 3, as the number of days after the curing period until the test date varied, especially for the C40 concrete.

The compressive strength of the cubes conditioned at 85 °C is slightly higher than that of the control cubes. There are a number of reasons that may explain this. It is known that, at temperatures greater than those normally experienced in the laboratory, the rate of the pozzolanic reaction occurring in the concrete is increased and this in turn leads to a greater degree of hydration and to the production of concrete with a higher compressive strength. This can effectively be considered as subsequent high-temperature curing. Furthermore, in comparison to the concrete conditioned at 105 °C, the specimens remained in the oven for a longer period of time, so that the maximum percentage weight loss was achieved, and were therefore subject to curing at this temperature for a longer duration. It should be noted that the "immediate" tests were performed approximately 10 days before the 28-day compressive strengths were carried out.

There are several possible reasons that can be given to explain why the "immediate" compressive strength of the C40 concrete conditioned at 105 °C is lower than that of both the control concrete and the concrete conditioned at 85 °C. Firstly, at higher temperatures, a large amount of water, which would have been used in the hydration of concrete, is rapidly lost and further hydration of the concrete and therefore gain in strength is inhibited. Secondly, high pressures may be caused inside the specimens as steam is generated. This pressure may damage the internal structure of the concrete, in the form of microcracking, and result in a weakened concrete structure and therefore a decrease in compressive strength. Moreover, the test was performed only 17 days after the

Table 3
C40 and C100 concrete compressive strength results

	Immediate mean f_{cu}, N/mm^2 (V(%))	No. of days until test from casting date (total days)	Dessicator mean f_{cu}, N/mm^2 (V(%))	No. of days until test from casting date (total days)
C40 28-day control	48.0 (0.3)	28+0+0 (28)	–	–
C100 28-day control	106.5 (2.0)	28+0+0 (28)	–	–
C40 concrete conditioned at 85 °C	48.6 (2.4)	7+11+0[a] (18)	45.8 (5.8)	7+11+17 (35)
C40 concrete conditioned at 105 °C	46.7 (3.5)	7+10+0 (17)	44.5 (1.6)	7+10+18 (35)
C100 concrete conditioned at 85 °C	115.1 (3.8)	7+21+0 (28)	104.1 (7.3)	7+21+7 (35)
C100 concrete conditioned at 105 °C	114.4 (5.8)	7+21+0 (28)	112.8 (3.0)	7+21+7 (35)

[a] This indicates 7 days of curing followed by 11 days of conditioning and 0 days in the dessicator.

concrete was made, and therefore, given the curing conditions of only 1 week and an elevated temperature of conditioning of 105 °C for only 10 days, then it is quite feasible that the 28-day strength is not achieved.

The concrete conditioned at 85 °C and tested immediately had the highest compressive strength of all the C40 test specimens. This can be attributed to a higher degree of hydration caused by curing at elevated temperatures. Nevertheless, at 85 °C, there is uncertainty regarding the temperature distribution within the specimens and regarding whether a range of temperatures exists.

The control mix achieved a compressive strength similar to that of the "immediate" results. It is known that testing a specimen that has recently been removed from water will always produce higher compressive strength values than those produced by so-called dry test specimens [12]. This emphasises the fact that conditioning at high temperatures can be partly considered as a period of curing at elevated temperatures and hence results in higher compressive strength values. The coefficient of variation for the control mix is the lowest of all those obtained, as might be expected; as of all the curing and conditioning procedures used, the procedure adopted for the control mix ensured the highest degree of uniformity by curing in water at a temperature of 20±2 °C for 28 days.

The "immediate" results are, in all cases, greater than those of the cubes that were left in the dessicator. The reason for this is not clear as it is normally assumed that the longer the time until testing, the higher the compressive strength. Further research is required before drawing firm conclusions in this area.

When considering the "immediate" compressive strength mean values, the same trend as observed in the normal-strength concrete was observed in the high-strength concrete. However, the magnitude of the difference between the "immediate" mean compressive strength values of the concrete conditioned at 85 and 105 °C is notably less than the difference observed between the "immediate" mean compressive strength values of the normal-strength concrete. Furthermore, both values are greater than the mean 28-day compressive strength of the control tests, although all tests were performed on the same day. However, when comparing the "dessicator" compressive strength values, the trend is reversed and the concrete conditioned at 105 °C actually had a higher compressive strength than the concrete conditioned at 85 °C and the control concrete. These "dessicator" compressive strength tests were performed 1 week after the control 28-day compressive strength tests, and the results can be explained in the following way. Although the HSC was conditioned at 105 °C until a weight change of no more than 0.02% was observed, it is known that to draw water out of HSC is a very lengthy process and, therefore, the minimum weight may not have been achieved. The HSC will therefore continue to lose water at this slow rate over a further period of time. However, it appears that the mean compressive strength values for those specimens kept in the dessicator are closer in magnitude to the mean compressive strength values of the control mix than the mean compressive strength values of the specimens tested immediately after conditioning.

As previously mentioned, the same trends and explanations that have been given for NSC can be applied to HSC. However, a larger increase was observed in the "immediate" results for the concrete conditioned at 85 and 105 °C in relation to the control mix compressive strength results. Again, the lowest coefficient of variation belonged to the control mix cubes.

It should be noted that, in a similar way to the NSC results, the mean compressive strength results of the specimens tested immediately are always higher than the specimens tested after being placed in the dessicator.

4.1.2. Tensile strength and torsion test

The mean tensile strength (mean f_t) and Young's modulus (E) results are presented in Table 4, along with the coefficients of variation (V%). The first two rows in Table 4 show the control test results. Although these test specimens were cured in water for 28 days under controlled conditions, the spread of results for the C40 concrete was higher than expected. The remaining results are from the conditioning tests performed at the two temperatures of 85 and 105 °C. The third column again provides details of the number of days of curing, conditioning and dessicator storage.

The C40 concrete conditioned at 105 °C gave a mean E value of 42.7 kN/mm^2. However, the coefficient of variation for this mean E value was 11.8%, indicating a larger spread of results in comparison to the concrete conditioned at 85 °C, whose mean E value was very similar at 40.3 kN/mm^2 but with only a coefficient of variation of 2.2%. The C40 concretes, conditioned at 105 and 85 °C, were removed from the oven on the same day. The mean values of E for both concretes may have been lower than the mean E value of the control mix because the drying procedure may have reduced the stiffness of the concrete and/or the tests on the

Table 4
Tensile strength and young's modulus results for C40 and C100 concrete

	Mean f_t, N/mm^2 (V(%))	Mean E kN/mm^2 (V(%))	No. of days until test from casting date (total days)
C40 28-day control	4.0 (1.3)	48.2 (10.8)	28+0+0 (28)
C100 28-day control	7.1 (6.4)	63.2 (3.0)	28+0+0 (28)
C40 concrete conditioned at 85 °C	6.1 (6.7)	40.4 (2.2)	7+11+4[a] (22)
C40 concrete conditioned at 105 °C	5.6 (3.2)	42.7 (11.8)	7+8+7 (22)
C100 concrete conditioned at 85 °C	9.6 (7.4)	49.9 (7.6)	7+38+57 (102)
C100 concrete conditioned at 105 °C	9.6 (3.4)	49.0 (11.5)	7+38+57 (102)

[a] This indicates 7 days of curing followed by 11 days of conditioning and 4 days in the dessicator.

conditioned concrete were performed only 3 weeks after the casting date.

The concrete conditioned at 85 °C had the highest tensile strength of all of the concretes, although it also had the highest coefficient of variation. When considering the concrete conditioned at 105 °C, the tensile strength is lower than that of the concrete conditioned at 85 °C and this may be attributed to either the reduction in hydration due to the removal of water or to damage in the concrete resulting from conditioning at a temperature of 105 °C. However, both concretes conditioned at 85 and 105 °C have tensile strengths higher than that of the control mix and this may again signify a greater degree of hydration during conditioning.

As hydration of the concrete continues, it is known that the structure of the concrete becomes more rigid due to the formation of the products of hydration which "infill" the concrete structure. This effect is more pronounced in the C100 concrete. Therefore, as time increases, the stiffness of the concrete also increases and the Young's Modulus of the concrete increases. This was observed in the HSC mixes. The control concrete achieved a mean 28-day Young's Modulus of 63.2 kN/mm^2.

The mean values of E for the C100 concrete conditioned at 105 and 85 °C were 49.0 and 49.9 kN/mm^2, respectively, and although these tests were performed approximately 10 weeks after the 28-day torsion tests were completed, this is a considerable reduction in the E value. This may be due to the conditioning regime. However, as all specimens undergo the conditioning regime as a part of permeability testing, this is not relevant to the final decision as to which temperature at which to condition. The factor that needs to be examined is the difference between the mean values of E for the concretes conditioned at 105 and 85 °C. For the high-strength concrete these values are almost identical, and, therefore, in this context, it can be stated that conditioning at either temperature is satisfactory.

As is evident in Table 4, the mean tensile strengths for the C100 concrete conditioned at 85 and 105 °C are equal and higher than that of the control mix. The coefficient of variation for the concrete conditioned at 85 °C is the highest of all of the values obtained for tensile strength and highlights the level of variation that is inherent when specimens are conditioned at temperatures lower than 100 °C, where water may exist in either liquid or vapour form depending on the temperature achieved inside the specimens.

It must be noted that there was a distinct difference in the fracture surface of the concrete conditioned at 85 °C, compared to the concrete conditioned at 105 °C. On close examination, a dark circle in the centre of the specimen, surrounded by a lighter ring of concrete, was observed in the case of the C100 test specimens conditioned at 85 °C. This may signify that when the concrete was conditioned at a temperature of 85 °C, there was a slow movement of water, via evaporation, away from the outer surface of the concrete and following this is a gradual movement of water from the centre of the concrete, causing a moisture gradient across the cylinder. With a conditioning temperature of 105 °C, no moisture gradient is observed. This may explain why the failure of the concrete conditioned at 105 °C was very brittle, and, in all cases, the specimens broke into two pieces, along an initial fracture plane at 45° to the longitudinal axis. In the concrete conditioned at 85 °C, cracks appeared on the surface of the concrete at 45° to the horizontal. However, some of the specimens did not break in two because the cracks spread into the area confined by the supporting rings.

4.2. Permeability properties

Relative gas permeability tests were carried out to complete the experimental programme. The mean gradient (m) of the graph of the log of Pressure against time, along with the values of the half time ($t1/2$) are reported in Table 5, for both concretes and conditioning temperatures.

From the results in Table 5, it can be seen that the $t1/2$ results for the C100 concrete are two orders of magnitude greater than the corresponding results for the C40 concrete. This conclusion applies for both conditioning temperatures. On the other hand, the variation in the $t1/2$ results due to a change in conditioning temperature is significantly less. Indeed, it should be noted that the mean value of $t1/2$ presented in Table 5 is the mean of only two values and the variation in the results of the concrete conditioned at 85 °C was 15% and that of the concrete conditioned at 105 °C was 49%. Therefore, caution must be exercised when interpreting these results as the difference in the C40 values due to conditioning at 85 and 105 °C is within these coefficients of variation. There could be several explanations as to why there is a difference in $t1/2$ values for the C40 concrete. At the higher temperature, hydration is rapidly reduced, until it completely ceases as all of the water is driven out of the specimens. Therefore, there may be a lower quantity of hydration products present in the structure resulting in a more open pore structure in comparison to the concrete conditioned at 85 °C. Moreover, it is evident that a greater quantity of water was removed from the concrete conditioned at 105 °C and, as previously reported, moisture content has an important role in determining the relative permeability of concrete, as the lower the moisture content within the specimen, the higher the permeability due to the

Table 5
C40 and C100 concrete mean permeability parameters

	Temperature of conditioning (°C)	Maximum mean percent (%) weight loss	Mean value of m ($\times10^{-5}$)	Mean $t1/2$ (min)
C40	85	6.1	−561	49.7
concrete	105	6.5	−959	29.0
C100	85	2.5	−6.4	5982.0
concrete	105	3.1	−17.4	1975.9

greater accessibility of the pore structure. The difference between the mean values of the half times of normal-strength concrete conditioned at 105 C and 85 °C, as reported in Table 5, is of the same order as that obtained by Al-Otaibi [13] who, working in the same laboratory and using the same apparatus, reported differences of up to 15% in the relative permeability of concrete conditioned at temperatures of 50 and 105 °C and a combination of the two temperatures.

It can be seen that the difference between the mean values of the parameters measured in the permeability test on C100 concrete conditioned at 105 and 85 °C follow a similar pattern to that observed for the C40 concrete. The permeability is increased by conditioning at 105 °C, but the main difference observed in the results shown in Table 5 is the major influence of concrete grade rather than the more marginal influence of conditioning temperature. Again, the concrete conditioned at the higher temperature exhibited a higher-percentage loss of water and this may explain the difference in the permeability parameters between the two conditioning temperatures. Moreover, as previously reported for the compressive strength results, C100 concrete may continue to lose water at a slow rate over a long period of time and, although the criteria outlined in the conditioning procedure may suggest that the maximum weight loss has been achieved, this may not be the case with high-strength concrete. Similar variations were obtained by Al-Otaibi [13] when examining the differences in the relative permeability parameters of HSC (77 N/mm^2) conditioned at 50 and 105 °C and a combination of these two temperatures.

5. Conclusions

The majority of the work published on the permeability of concrete gives details of permeability tests and reports values of permeability based on a conditioning regime which uses a temperature of 105 °C for part, if not for the whole, duration of the conditioning procedure. When comparing the permeability parameters of the normal- and the high-strength concrete used in this study, the latter is less permeable due to the presence of Silica Fume. Although differences have been observed in the permeability results obtained after conditioning at 105 and 85 °C, it is believed that the differences can generally be explained.

The coefficients of variation for the results, although used as a statistical measure, cannot be used as a stand-alone justification for the choices made in determining the temperature of conditioning. This is because concrete has a heterogeneous nature which dictates that a significant variation can be expected in its properties. This is obvious from the control tests, which were produced from the same mix, were subject to the same procedures and experienced the same conditions, yet still had coefficients of variation of 0.3% and 2.0% for 28-day compressive strength values of NSC and HSC, respectively, and 10.8% and 3.0% for 28-day E values of NSC and HSC, respectively.

In conclusion, it can be stated that similar strength results are obtained irrespective of the conditioning temperatures used for both normal- and high-strength concrete. However, in the case of permeability results, the effect of concrete grade is significantly greater than the influence of conditioning temperature. In view of this conclusion, regarding the importance of the nature of the concrete, there is no apparent advantage in conditioning at 85 °C rather than at 105 °C, especially because conditioning at 85 °C takes longer. Moreover, it is thought that any differences between the permeability parameters can be attributed to the moisture contents and the effect of the conditioning temperatures on the hydration process. Although a small degree of damage may exist within the specimens conditioned at the higher temperature, it is not thought to be of great significance as the permeability parameters are still comparable. A study performed by Al-Otaibi [13] supports this view. Although the latter examined the conditioning procedure using temperatures of 50 and 105 °C and a combination of the two temperatures, the results reported are similar to those obtained in this study. This leads to the conclusion that, at temperatures higher than 50 °C, the variation that exists in the mean permeability coefficients decreases and, therefore, conditioning at 105 °C not only produces results similar to those of a concrete conditioned at 85 °C but they can also be obtained much more quickly.

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