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Curing of Concrete Surfaces

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Abstract

Curing of concrete is mainly understood to be measures to maintain a satisfactory moisture content in concrete during its early stages so that desired properties may develop. This paper gives an overview on basic aspects and principles of curing. The effects of curing on the structure of concrete are summarized on the basis of a literature review. Various commonly accepted methods of curing arè listed and their effectiveness is delt with. Furthermore, relevant recommendations and codes on curing and in particular on the estimate of the duration of curing are concisely presented and compared with each other. Finally, some comments are given on test methods to be applied on the construction site to determine the effectiveness and required duration of curing.

1 General considerations

After placing and compaction of the concrete, adequate measures have to be taken in order to obtain the expected properties from hardened concrete, in particular strength, impermeability and durability. In that context curing of concrete is understood to be measures to avoid premature drying of the concrete and to provide the cement paste in the concrete with a sufficient amount of water over a sufficiently long period of time to achieve a high degree of hydration within its mass and particularly in its surface layers. In addition, curing includes measures against environmental effects such as direct sunshine or wind and comprises also measures to prevent cracking due to early shrinkage.

In contrast to curing protection is understood to be a measure against other external effects which may harm the young concrete such as leaching due to rain or flowing water, rapid cooling or freezing, thermal stresses due to heat of hydration, vibration or impact [1].

Carefully curing is an important contribution to obtain a high quality concrete and durable concrete structures. This results from the fact that the durability of concrete members is primarily controlled by the properties of the surface layers. If concrete is adequately composed, sufficiently curing results in an impermeable and strong surface layer with a high resistance to the ingress of aggressive media which may exert an attack to the concrete and/or to the embedded steel. While insufficient curing strongly impairs the surface layers,

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it often has only a minor effect on the strength development of the concrete in the structure with the exception of thin sections because the core of a thicker concrete section maintains a sufficiently high moisture content for a prolonged period of time even without curing. It is essential that curing and protection start immediately after compaction of the fresh concrete.

2 Effect of curing on the structure of concrete

The hardening of the concrete is the consequence of the hydration of the cement, i.e. the reaction between the cement and the mixing water forming solid hydration products. To achieve a complete hydration of the cement and an impermeable structure of the concrete a certain amount of mixing water is necessary but the water-cement ratio has to be sufficiently low. An early loss of water from a young concrete may prevent further hydration. This may occur, e.g. in the surface region of a structural member if early drying is possible due to insufficient curing. As a consequence this region obtains a low strength and a high permeability. This results from the pronounced effect of the prevented hydration on the pore structure of concrete. The relations between the pore structure of concrete surfaces and the duration of moist curing have been investigated in [2]. Some of the test results of this study are shown in Fig. 1.

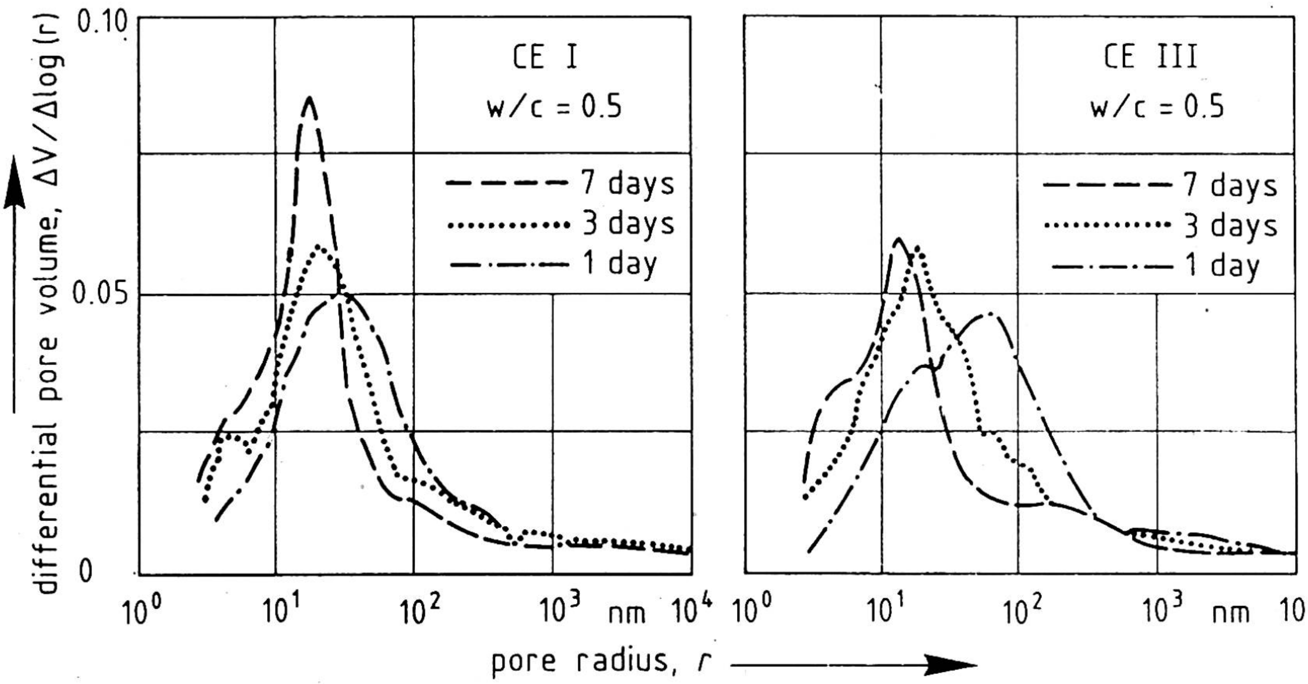

Fig. 1: Effect of the duration of curing on the pore size distribution of concretes made with Portland cement (CE I) and blast furnace slag cement (CE III) [2]

The diagrams represent pore size distributions which were obtained by differentiating the curves of the cumulative pore volume measured by mercury intrusion porosimetry. The investigated concretes have been made with an ordinary Portland cement (CE I) and a blast furnace slag cement (CE III), respectively. Both concretes have a water-cement ratio of w/c = 0.5. The specimens have been moist cured for 1, 3 and 7 days and afterwards stored at 20°C and 65% relative humidity. The tests have been carried out at the concrete age of 28 days. It is apparent from Fig. 1 that for both concretes the pore size distribution is shifted to smaller pore radii if the duration of curing increases. The pore volume measured by the mercury intrusion porosimetry is only little affect by the duration of curing for both concretes (mean value: 0.070 cm^3/g). From the diagrams it is also evident, that the concrete made with the cement type CE III is more sensitive to curing. The peak of the pore size distribution for 1 day of curing is found to be at a significantly larger pore radius for a concrete made with a CE III cement than for a concrete made with a CE I cement. However, after 7 days of curing the structure is found to be slightly more dense for the concrete made with the CE III cement.

These findings agree very well with the results of permeability tests (Fig. 2) conducted in [3]. The storage of the investigated concrete specimens corresponds to that reported above for the experiments of [2]. The air permeability tests have been carried out at the concrete age of 56 days. It is apparent from Fig. 2 that the air permeability decreases with decreasing water-cement ratio and increasing duration of curing. Also in these tests the curing sensitivity of a concrete made with a CE III cement is very pronounced compared to a concrete made with a CE I cement both having a water-cement ratio of 0.45. The results found for the air permeability can easily be understood in view of the pore size distributions obtained for different durations of curing shown in Fig. 1.

Furthermore, the strength class of the cement and in particular its hardening behavior have a significant effect on the development of the pore structure and therefore on the curing sensitivity of corresponding concretes. Fig. 2 shows that the air permeability of concretes after a duration of curing of 1 day is considerably lower if the concrete is made with a rapid hardening cement of a high strength class (CE I, 42.5 R) compared to a concrete having also a w/c ratio of 0.45 but made with a cement of a lower strength class (CE I, 32.5 R). This difference vanishes if the duration of curing increases. These test results are confirmed by a similar investigation in [4]. In summing up, Figs. 1 and 2 clearly indicate the pronounced effect of the duration of curing on the porosity and permeability of surface regions of concretes.

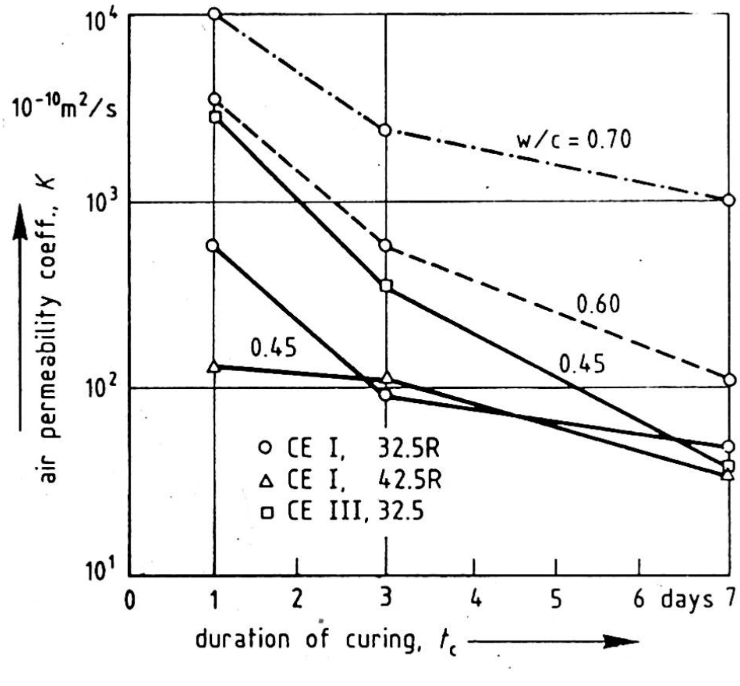

Fig. 2: Effect of the duration of curing on the air permeability coefficient of various concretes [3]

3 Parameters affecting the duration of curing

The required duration of curing of concrete depends on various parameters. First of all, the *composition of concrete* itself is of major importance in that context. As has been shown in the preceding section, the water-cement ratio and the type and strength class of the cement exert a tremendous effect on the hydration rate, i.e. the pore structure and its development, respectively, and thus on required curing durations of concretes. Furthermore, additions such as e.g. fly ash may lead to prolonged curing periods if a sufficient impermeable surface of concrete shall be achieved. Another parameter affecting the duration of curing is the *concrete temperature*. The heat of hydration increases the concrete temperature and thus accelerates hydration. Hence, thin concrete sections exposed to low ambient temperatures during curing where the concrete is made of cements with a low heat of hydration need a very careful curing. The *ambient conditions during and after curing* have a relevant effect on the required duration of curing. Under the conditions of low relative humidity of the ambient air, sunshine and high wind velocity prolonged curing is required. Finally the *exposure conditions of the finished structure in service* have to be taken into consideration. The more severe the exposure conditions are, e.g. chemical aggressive environment, the longer is the required duration of curing. Some of the mentioned parameters are interrelated particular with regard to the concrete temperature. This interrelation also contributes to the complexity of the problem of estimating required durations of curing. Some detailed guidelines on the estimation of the duration of curing will be presented in section 5.

4 Methods of curing and their effectiveness

The various methods of curing may be subdivided into two principal groups. The first group includes those methods of curing which decelerate drying of the concrete, such as:

- keeping the formwork in place
- covering the concrete surfaces with plastic films
- application of curing compounds which form protective membranes.

In contrast, the second group of curing methods includes those procedures where the concrete surface is kept moist by the application of water:

- placing of wet coverings on the free concrete surface
- storage of the concrete under water
- sprinkling the concrete surface with water.

The individual curing methods can be applied either separately or in combination. They are not equally effective; in particular the methods where water is applied are more effective than other methods provided that thermal shocks, e. g. by using cold water on a concrete surface which is warm due to the heat of hydration, are avoided. However, the effectiveness of curing methods is significantly affected by the composition of the concrete, see e. g. [4], [5].

Besides the test methods mentioned in section 2, the effectiveness of curing methods has also been evaluated on the basis of strength tests and from testing the rate of carbonation. However, it has been repeatedly observed that the standard compressive strength is not a suitable measure of curing effects, whereas the rate of carbonation has proved to be more sensitive.

Fig. 3 shows the influence of various curing methods on the depth of carbonation observed at an age of concrete of 6 months. The investigation has been carried out on structural concretes, having a water-cement ratio w/c = 0.55 and made of different types of cement. After demoulding at the age of 1 day, some of the specimens have been water or wet cured for 6 days before being stored in the air at 23 °C and 50 % relative humidity. Comparing the effects of the curing methods "wet covering" and "air", there is only a minor difference between the measured depths of carbonation if concretes made with rapid hardening cements (CE I, 32.5 and CE I, 52.5) are under consideration. This is not observed for the concrete made with a CE III cement. Obviously the curing compound No. 4 strongly reduced the diffusion of CO_2 by sealing the concrete surface. The experimental results indicate that the effectiveness of curing methods, i.e. the progress of carbonation clearly depends on the composition of concrete.

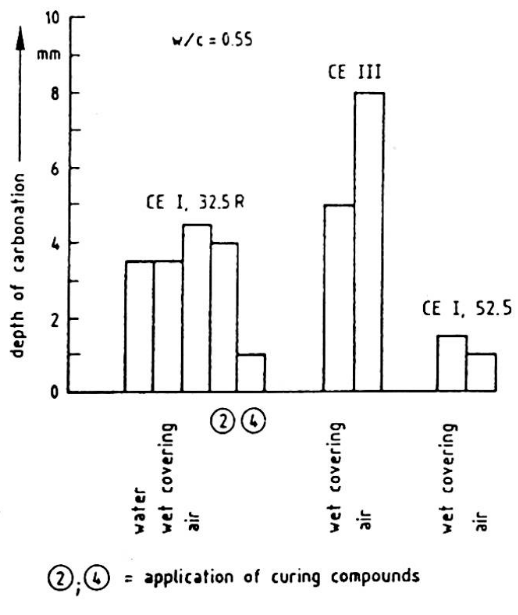

Fig. 3: Effect of various curing methods on the depth of carbonation at a concrete age of 6 months [5]

In practice the choice of a particular curing method often depends on the facilities given on the site. With respect to the effectiveness and practical aspects the following general guidelines on curing methods are given [7]:

The storage under water may be regarded as the most effective curing method. It has mainly a positive effect on concretes with a low water-cement ratio as well as on concretes made with a rapid hardening cement. However, on the construction site this method is hardly feasable for practical reasons.

Covering the concrete surface with wet burlap in combination with plastic films is considered to be as effective as curing under water. This curing method may often be applied on the construction site. For architectural concrete surfaces attention has to be paid to the fact that efflorescences may occur.

Keeping the formwork in place is a favourable method of curing because it starts working just after compaction of the concrete. A wooden formwork which may suck water has to be kept moist.

The covering with plastic films is a simple, practicable and in many cases sufficient curing method; however, they should be so placed, weighted or fastened that the wind is prevented from getting under the film and removing it.

The application of membrane-forming curing compounds has been proved for curing of horizontal concrete surfaces; in addition, they may be of advantage for structural components which can be cured only for a short time period, e.g. due to the construction process [6].
The curing compounds may have an adverse effect on the bond behavior of a coating which is applied on the concrete surface; hence the chemical compatibility of curing compound and coating material has to be checked. At temperatures below the freezing point it is recommended to apply dissolved curing agents instead of emulsions.

Curing by sprinkling with water may result in cracking of the concrete surface due to differences in temperature between the concrete and the water. Generally, temperature differences of more than 15 K between the concrete core and the surface have to be avoided.

It is essential that curing commences not later than the time the concrete surface looses its sheen. Any delay or interruption of the curing can hardly be compensated by an extension of the duration of curing. Additional information on commonly accepted curing methods and materials may be found in [11].

5 Estimates of the duration of curing

The required duration of curing depends on the time needed of the surface zone to reach a sufficient resistance to the penetration of gases or liquids into the hardened concrete.

According to [8] the duration of curing shall be determined from the following criteria:

- parameters which determine the maturity of concrete
- local requirements
- minimum standard curing periods.

The standard curing times as required by various recommendations or building codes are based on the following parameters which influence the rate of hydration essentially:

- concrete composition, in particular the strength class of cement and the water-cement ratio
- ambient conditions during and after curing
- temperature of concrete.

Table 1: Minimum duration of curing in days for T > 10 °C according to [1]

Rate of development of impermeability of concrete		Very rapid	Rapid	Medium	Slow
Expected ambient conditions during and after curing	I No direct sunshine, rel. humidity of surrounding air RH > 80 %	1	2	3	4
	II Exposed to medium sunshine or medium wind velocity or rel. humidity RH: 50 % < RH < 80 %	2	3	4	5
	III Exposed to strong sunshine or high wind velocity or rel. humidity RH < 50 %	3	4	6	8

Table 2: Rate of development of impermeability according to [1]

Rate of development of impermeability	w / c	Class of cement
Very rapid	0.5 - 0.6 < 0.5	RS RS; R
Rapid	0.5 - 0.6 < 0.5	R N
Medium	0.5 - 0.6 < 0.5	N SL
Slow	All other cases	

Table 1 gives in combination with Table 2 the minimum durations of curing for concrete temperatures T > 10 °C as proposed in the CEB-FIP Model Code 1990 [1]. The values are valid for concretes made with Portland cements (CE I), where the cements are subdivided into the classes RS = rapid hardening high strength cement, R = rapid hardening cement, N = normally hardening cement, and SL = slowly hardening cement. In ENV 206 [8] a very similar approach to estimate the duration of curing is chosen. However, with respect to the concrete temperature there is a more detailed classification into three different temperature ranges.

The recommended standard curing times have to be extended in certain cases. According to [8], the curing times should be substantially increased if the concrete is exposed to severe abrasion or to severe environmental conditions. It is also mentioned that longer curing times may be appropriate for other types of cement than CE I. More detailed information is given in [1] and [9]. For example, the curing time has to be extended in the following cases:

for concretes made of cements containing high amounts of constituents other than Portland cement clinker and concretes containing latent hydraulic and pozzolana additions in high amounts, for 1 to 2 days beyond the values given in Table 1 if concrete is exposed to conditions II and III [1];

where concrete is exposed to severe abrasion or to severe environmental conditions, for 3 to 5 days [1];

- when the temperature of the concrete surface drops below 0 °C, for at least by the number of days with $T < 0$ °C [9];

- for concretes containing set retarding admixtures, for the time of retardation [9];

- for concretes containing fly ash in combination with reduced cement contents, for 2 days [9].

With respect to the concrete temperature, the duration of curing may be determined more accurately on the basis of the maturity concept given in the CEB Model Code 1990 [1]. The temperature adjusted concrete age may be calculated from eq. 1:

$$t_T = \sum_{i=1}^{n} \Delta t_i \cdot \exp\left[13.65 - \frac{4000}{273 + T(\Delta t_i)/T_0}\right] \qquad (1)$$

where: t_T = temperature adjusted concrete age [days] if the concrete temperature deviates from $T = 20$ °C;

$T(\Delta t_i)$ = concrete temperature [°C] during the time period Δt_i;

T_0 = 1 °C;

Δt_i = number of days where a concrete temperature T prevails.

Eq. 1 is valid for temperatures $T > 0$ °C. If the required duration of curing is calculated from eq. 1, then t_T has to be considered as the duration of curing at $T = 20$ °C and $\Sigma\,\Delta t_i$ is the required duration of curing if the temperature T deviates from 20 °C.

Presently, a working group within CEN TC 104 is preparing a revised approach to estimate the duration of curing [12]. According to this approach the following relations have to be used to estimate the duration of curing:

$$t_c = \Sigma\,\Delta t_i \qquad (2)$$

$$\Sigma\,\Delta t_i \cdot T_i = k \cdot 20 \cdot MH \qquad (3)$$

where: t_c = actual curing time for an applied curing method;

Δt_i = time interval [hours] during which a temperature T_i [°C] prevails;

T_i = concrete temperature [°C];

k = coefficient which depends on the method of curing;

MH = required maturity hours [hours · °C].

The required maturity hours MH are defined as the required curing time for a constant concrete temperature of 20 °C. Values of MH are given in a table for the exposure conditions indoor, outdoor and severe abrasion and for various curing sensitivity classes of the concrete. The curing sensitivity of the concrete depends on the type of cement, the strength class of cement, the water-cement ratio of the mix and the type of additions. This approach [12] which is still under discussion allows a considerably more precise and comprehensive estimation of a required duration of curing than [8]. In particular, the effects of curing methods, types of cement and additions as well as variable concrete temperatures are taken into consideration.

6 Test methods for the application on the construction site

Generally the estimation of the effectiveness of a curing method is possible only indirectly, i.e. through testing such concrete properties which are affected by curing.

In various studies the compressive strength of companion specimens has been used as a parameter to evaluate the effectiveness of curing methods. The experimental investigations showed that the compressive strength often undergoes only a little reduction when curing is deficient. Sufficient curing results in an impermeable and strong surface zone of the concrete which contributes only minor to the compressive strength of concrete measured on standard specimens. However, the porosity and thus the permeability of the surface zone of concrete is significantly affect by the curing procedure (see section 2). Hence, test methods which determine the resistance to the penetration of gases or liquids into the surface zone of the concrete in view of the evaluating the efficiency of curing but also with respect to durability considerations became an important subject of the recent research.

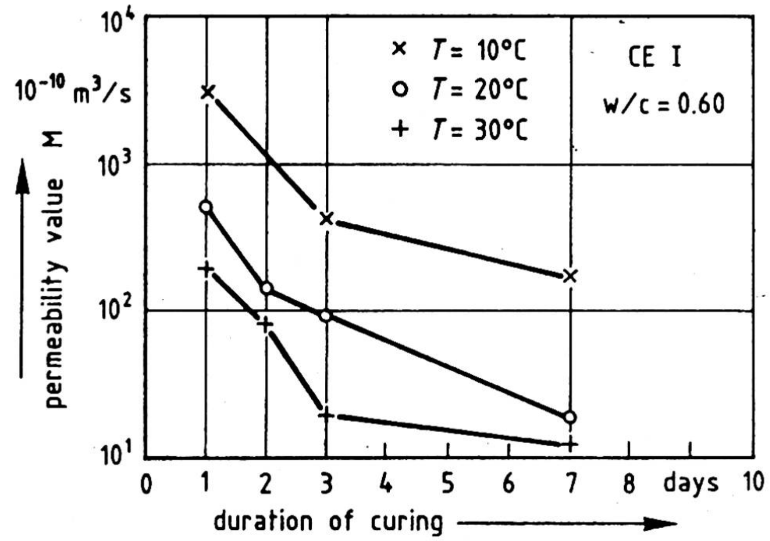

Fig. 4: Effect of the duration of curing on the permeability value at various concrete temperatures [3]

Suitable test methods to be used in the laboratory for a characterization of the structure and permeability of concrete are the mercury porosimetry and the methods of measuring the gas permeability and the water penetration. In contrast, for the time being there are no generally accepted methods for a rapid determination of concrete porosity and permeability which may be used on the construction site. In particular, the aim of the research in this area is to develop a non-destructive test method in order to assess the effectiveness of curing and to determine the end of curing time on the construction site. A promising test procedure has been developed e.g. by Schönlin [3].

He uses a suction device which is placed directly on the concrete surface. This instrument allows to exert an underpressure generated by a connected vacuum pump on a circular surface area of 50 mm in diameter. After the pump is removed, the air pressure inside the vacuum chamber of the suction device will rise to a certain amount within a fixed time period depending on the porosity and air permeability of the concrete, respectively. As the penetrated area and the path of the penetrating air cannot be determined exactly a permeability value M is defined and obtained from corresponding tests. However, this permeability value M may be correlated to the permeability coefficient K. As it is apparent from Fig. 4 the permeability value M of concrete surfaces depends pronouncedly on the duration of curing and concrete temperature. However, also the moisture content and the moisture history of surface regions tremendously affect the measured values. Hence it is difficult to obtain reliable test values on site. For further details and test methods see [10].

Further research work is mendatory to arrive at a test procedure being reliable and operational for application on the construction site. In summing up it has to be stated that presently there is no commonly accepted rapid test method to determine the effectiveness and duration of curing on the construction site.

7 Concluding remarks

The significance of curing on the impermeability of concrete surfaces and thus on the durability of concrete structures has been demonstrated in numerous experimental investigations. As a consequence, nowadays many efforts are undertaken to give more detailed and more substantiated proposals for curing requirements in recommendations and codes on the basis of these findings. In view of the connection between curing and durability the measures for curing and protection should be a separate item of the construction contract to be agreed upon prior to the commencement of the construction work.

8 References

[1] CEB-Bulletin d'Information No. 203/204/205:
CEB-FIP Model Code 1990, Final Draft 1991. Comité Euro-International du Beton (CEB), Lausanne, Switzerland, 1991

[2] Bier, T.:
Karbonatisierung und Realkalisierung von Zementstein und Beton (Carbonation and re-alkalization of hardened cement paste and concrete). Institute for Concrete Structures and Building Materials Technology, University of Karlsruhe, Series IfMB, Vol. 4, Karlsruhe, Germany, 1988

[3] Schonlin, K. F.:
Permeabilität als Kennwert der Dauerhaftigkeit von Beton. (Permeability as a parameter of durability of concrete). Institute for Concrete Structures and Building Materials Technology, University of Karlsruhe, Series IfMB, Vol. 8, Karlsruhe, Germany, 1989; see also: Schonlin, K.F.; Hilsdorf, H.K.: Evaluation of the Effectiveness of Curing of Concrete Structures. Concrete Durability, Katharine and Bryant Mather International Conference, American Concrete Institute, ACI-SP 100, 1987

[4] Gräf, H.; Grube, H.:
Einfluß der Zusammensetzung und der Nachbehandlung des Betons auf seine Gasdurchlässigkeit (Effect of composition and curing of concrete on its gas permeability). Beton, Vol. 11, 1986, pp. 426-429, Vol. 12, 1986, pp. 473-476

[5] Kern, E.:
Zur Nachbehandlung von Beton (On the curing of concrete). Beton- und Stahlbetonbau, Vol. 12, 1983, pp. 336-341

[6] Wierig, H.-J.; Kurz, M.:
Einfluß von sehr kurzen Nachbehandlungszeiten und von Nachbehandlungsmitteln auf den Carbonatisierungsfortschritt im Beton (Effect of very short durations of curing and curing compounds on the carbonation progress in concrete). VGB Kraftwerkstechnik, Vol. 1, 1988, pp. 89-94

[7] Deutscher Beton-Verein E. V.:
Annual report 1988, Wiesbaden, Germany, 1988

[8] ENV 206:
Beton - Eigenschaften, Herstellung, Verarbeitung und Gütenachweis (Concrete - performance, production, placing and compliance criteria). March 1990, German Institute for Standardisation (DIN), Berlin, Germany, 1990

[9] Deutscher Ausschuß für Stahlbeton (DAfStb):
Richtlinie zur Nachbehandlung von Beton (Recommendation for curing of concrete). Edition 2/1984, Beton-Kalender 1986, Teil II, Ernst & Sohn, Berlin, Germany, pp. 154-156

[10] Hilsdorf, H. K.:
In-situ permeability testing of concrete. RILEM International Workshop on Testing during Concrete Construction, Mainz, Germany, 1990

[11] ACI 308-81:
Standard practice for curing concrete. Reported by ACI Committee 308, ACI Manual of concrete practice 1983, Part 2 - Construction Practices and Inspection Pavements, American Concrete Institute (ACI), Detroit, U.S.A., 1983

[12] CEN Technical Committee 104:
Curing and protection. Working Group 1, Task Group 7, 2nd draft, 1991