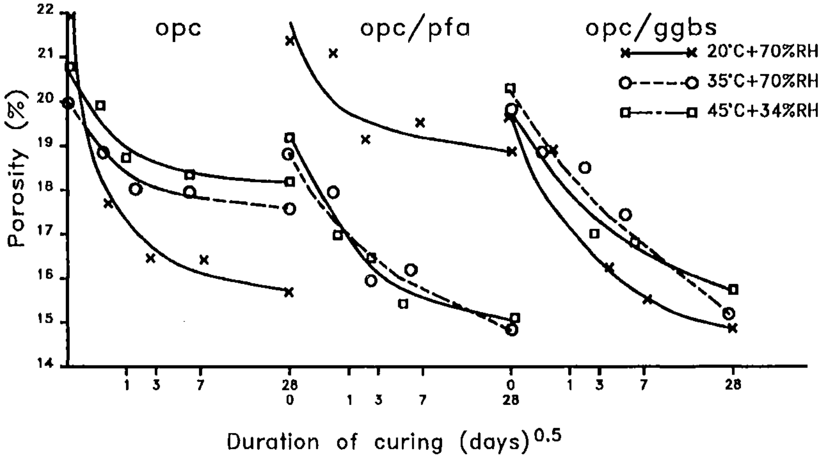

Fig. 2—Relation between total porosity and curing time

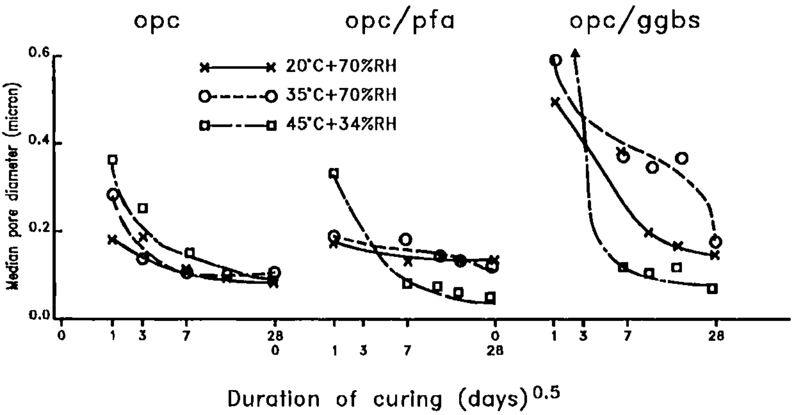

Fig. 3—Relation between MPD and curing time

SP 139-6

The Influence of Controlled Permeability Formwork Liner on the Quality of the Cover Concrete

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Synopsis: Numerous methods are available to improve the surface durability of concrete. The most commonly used techniques are improved curing practices and the application of surface treatments. Recently a new technique has been introduced in the U.K., in which a controlled permeability formwork liner (CPF) is employed. This paper describes the results of an investigation to compare the effect of the controlled permeability formwork liner with that of various curing techniques and the application of silane in relation to the air permeability, sorptivity, water permeability and strength of the cover concrete. Also, the resistance to carbonation has been studied.

The results indicate that, in general, the use of CPF improves the surface properties compared with the conventional steel formwork. Also it has been observed that the effect of variation of curing methods was marginal for concrete made with CPF.

Keywords: Carbonation; concrete durability; curing; durability; formwork (construction); permeability; sorption; strength; tests

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INTRODUCTION

The durability of concrete structures is greatly influenced by variations in curing practices. Inadequate curing results in a very weak and porous material near to the surface, leaving it vulnerable to attack from various harmful substances of the environment. In reinforced concrete structures this can lead to the corrosion of reinforcement, and subsequent cracking and spalling of the concrete.

One of the most common methods used to improve the durability of concrete after placement has been to subject it to proper curing. This involves maintaining a satisfactory moisture content in the concrete to enable adequate hydration of the cementitious materials to take place. This can be achieved by a number of methods such as supplying moisture to the concrete surface or sealing the surface in order to reduce the loss of moisture. However curing can be both expensive and time consuming, and efforts have been made to investigate alternative methods to improve durability. The most recently introduced technique is the use of a controlled permeability formwork liner (CPF). The principle of operation of the CPF is that it drains away surplus mixing water and entrapped air from the surface of the concrete. As a result it produces a relatively low water-cement ratio and hence high strength surface layer, with low permeability, and hence a more durable concrete is obtained. The CPF liner which was used in this investigation is a polypropylene fabric, which was attached to the inside of the formwork.

In this investigation the performance of CPF as a means of improving the durability of concrete was assessed. In particular the study concentrated on how its use affected some of the surface properties which are known to be related to durability. A comparison was also made with other concrete treatments, such as silane, and curing wax.

EXPERIMENTAL PROGRAMME

The experimental programme was divided into two phases in order to investigate the performance of concrete made with the CPF liner. The specific objectives of the two phases were as follows:

Phase I

To compare the durability characteristics of concrete made with conventional steel formwork, and CPF, in combination with and without silane treatment.

Phase II

To investigate the curing efficiency of CPF when kept in place for a short period of time after casting, and to compare with other curing regimes.

Variables in the Experimental Programme

Table 1 indicates the variables in the experimental programme. Concrete made with steel formwork and cured in air was used as a control specimen in both the phases. As indicated in table 1, the investigation was carried out on both low water-cement ratio and high water-cement ratio concretes.

Materials used

Ordinary portland cement, zone 2 sand (BS 812: part:2) and 20 mm Basaltic aggregate graded with 12.5 mm Basaltic aggregate (1:1 by weight) were used for the manufacture of concrete. Both fine and coarse aggregates were oven dried in order to avoid the variability due to the moisture content. The mixing was carried out according to BS1881: pt:125 . Concrete was manufactured with a mix ratio of 1:1.65:3, and water-cement ratios of 0.45 and 0.65. The compressive strength of the concrete was 60 MPa and 30 MPa respectively for the two water-cement ratios.

Details of specimens

Slabs of size 300X150X950 mm were cast vertically as shown in Fig.1 and conditioned as detailed below.

Phase I -- 24 hours after casting, the formwork and CPF liner were removed and the slabs were air cured in a conditioning room at 20±2 °C and 50 ± 5% relative humidity (R.H) until 28 days of age. The slabs were then removed to another room for conditioning at 40 °C and 22 % R.H., in order to release the surface moisture. They were kept in this environment for 10 days, following which they were allowed to cool in a constant temperature room at 20 °C and 50 % R.H. for 3 days, and then tested for permeability and sorptivity.

Silane was applied at the age of 21 days after curing, where applicable in two coats, at the rate of 0.3 l/m^2 for each coat. The interval between the two coats was two hours.

Phase II -- Curing and conditioning of phase II, was as in phase I, except where specific conditioning was required, as detailed in table 1.

TEST METHODS

Schedule of testing

Permeability and sorptivity tests were carried out at 3 different locations as shown in Fig. 1.a, at the age of 42 days, and the average reported. Pull-off testing was carried out at 6 different locations as shown in Fig. 1.b, and the average computed.. Also specimens to carry out the carbonation test were removed from the hardened concrete (Fig. 1.b), for testing at the age of 100 days. One core of 100 mm in diameter was removed from the hardened concrete to take the outer 15 mm slice for accelerated chloride tests (Fig.1.b).

Permeation Tests (Autoclam tests)

The air permeability, water permeability, and sorptivity tests were carried out using the AUTOCLAM [1] permeability system developed at the Department of Civil Engineering, the Queen's University of Belfast. It has been established [1] that the results obtained with this apparatus correlate very well with different test methods, such as the ISAT and the Figg permeability tests [2].

Air Permeability Test -- The principle of the air permeability test is that a pressure of 500 mbar is applied to the test area using the Autoclam and its decay is monitored over a period of 15 minutes. The natural logarithm of pressure bears a linear relationship with time, and the slope is reported as an air permeability index.

Sorptivity Test -- The sorptivity test is generally carried out one hour after the air permeability test at the same test location. This test involves the measurement of water penetrating into the concrete at a constant pressure of 10 mbar for a test duration of 15 minutes. A plot of the volume of water absorbed against the square root of time has been found [1] to be linear and the slope of the relationship is reported as the sorptivity index.

Water Permeability Test -- The test procedure for the Autoclam permeation test is the same as the sorptivity test, except that the pressure is 500 mbar, and the test is carried out at different location.

Accelerated Carbonation Test

The samples for carbonation testing were placed in an environment of 15 % carbon dioxide in air having a relative humidity of 70 %. Four faces of the carbonation specimens were coated with an epoxy emulsion coating, leaving the two 300x75 mm test faces free for carbon dioxide to diffuse. These samples were 100 days old when placed in this environment where they were allowed to remain for further 10 days, at which point they were tested for carbonation depth. Sprayed phenolphthalein indicator was used on fresh broken surface [3].

Pull-Off Test

The surface strength has been determined by carrying out the pull-off test [4], with a commercially available instrument, the Limpet. This test involves bonding a circular steel probe of 50 mm diameter to the surface of the concrete under test, by means of an epoxy resin adhesive as a first step. A tensile force is then slowly applied to the probe by using the Limpet, and as the tensile strength of the bond is greater than that of concrete, the later eventually fails in tension. The amount of the overbreak is usually small so that the area of failure can be taken as being equal to that of the probe. From this area and the force applied at failure the tensile strength of the concrete surface can be calculated. For ordinary portland cement concrete, it is possible to predict an equivalent compressive strength of concrete from calibration graphs [4].

RESULTS AND DISCUSSION

Phase I results

Air permeability -- The air permeability indices, in ln(pressure)/min., for phase I are shown in Fig. 2. The results in this diagram indicate that, compared with the control concrete, the use of CPF liner reduced the air permeability by 80 % for 0.45 w-c ratio concrete and 50 % for o.65 water-cement ratio concrete. However, the application of silane did not have any significant effect on both control and CPF concretes. Also it can be observed that the use of CPF for 0.65 water-cement ratio concrete resulted in an air permeability value nearly equal to that for 0.45 w-c ratio control concrete.

Sorptivity Test -- Fig. 3 presents the results of the sorptivity tests. CPF reduced the sorptivity to approximately 1/3 that of control for both w-c ratios and the application of silane on control resulted in a reduction by 50 % relative to control. The effect of silane was found to be slightly better for the high water-cement ratio concrete. Silane on CPF concrete resulted in a significant reduction of sorptivity presumably due to a high rate of absorption of silane into the dense layer formed with CPF near to the surface [5]. Also CPF concrete with 0.65 water-cement ratio exhibited a slightly less sorptivity index compared with that of 0.45 water-cement ratio control.

Water Permeability (w-p) -- Fig. 4 shows the water permeability test results of phase I. The behaviour of various types of concrete was very similar to that for the sorptivity tests. CPF reduced the water permeability by 60 % and the silane reduced it by 33 %.

Accelerated Carbonation -- Fig. 5 shows the carbonation test results for phase I, as carbonation depth in mm. It can be noted in this figure that, CPF resulted in a significant reduction in carbonation relative to the control concrete. This reduction was about 33 % for the 0.45 w-c ratio concrete and 50 % for the 0.65 w-c ratio concrete. However, silane did not have any effect on the depth of carbonation. A comparison of figures 1 and 5 would indicate similar behaviour. Therefore, it is likely that the air permeability test can be used as an indicator of the resistance to carbon dioxide.

Surface Strength -- Pull off force at failure in KN is shown in Fig. 6. Generally CPF concrete had a higher surface strength than the control concrete. As one would expect, silane did not have any effect on the surface strength.

Phase II results

For phase II the permeation test results and the surface strengths are presented.

Air permeability -- Fig. 7 reports the air permeability results of phase II. The following order of performance can be observed in this figure in relation to the air permeability for various curing regimes compared with the control, CPF28Wx, CPFH3, CPF3W, CPF (table 1 for abbreviations). In general, the CPF concrete air cured for 28 days after the removal of the formwork (24 hours after casting) has been found to be reasonably good compared with other curing regimes in reducing the air permeability. However, the control coated with Wax indicated a sharp reduction in air permeability, presumably due to the wax blocking pores, even after its removal before the test.

Sorptivity -- The sorptivity results presented in Fig. 8 would indicate the following order of performance; CPF coated with wax, CPF sprayed by water for 3 days, and CPF air cured etc. Fig. 8 would indicate that there is no curing effect in keeping CPF for 3 days on the surface of concrete after the removal of the formwork. The best curing efficiency was observed for CPF concrete sprayed with water for 3 days. However, compared with the use of CPF alone, no significant benefit was observed for other curing techniques.

Water permeability -- Fig. 9 reports the water permeability results of phase II specimens. The behaviour here was more or less similar to that of the sorptivity tests. The following is the order of performance based on the reduction in water permeability compared with control, CPF sprayed water, CPF alone, CPF coated with wax, etc.

Surface strength -- The surface strength data presented in Fig. 10 would suggest that concrete made with CPF and air cured for 28 days can result in a significant increase in strength. This is nearly the same as that due to the best curing technique , viz water spray for 3 days on CPF. Therefore, there is no additional benefit in resorting to other curing techniques while CPF is used for casting.

CONCLUSIONS

The following conclusions have been drawn based on the results reported in this paper.

(a) The use of CPF resulted in an improvement in the surface properties of concrete such as the surface tensile strength, air and the water permeabilities, and the sorptivity of the concrete. The relative improvement in these properties for CPF formed concrete surfaces compared with that made with ordinary steel formwork (non-CPF surface) was greater for a higher water-cement ratio concrete.

(b) When silane was applied to both CPF concrete and non-CPF surfaces, there was no significant change in surface strength, and air permeability values. However, the sorptivity decreased to a significant degree, especially for the CPF surface.

(c) The depth of carbonation based on an accelerated carbonation test indicated a low value for the CPF surface compared with the non-CPF surface. Also, the application of silane did not have any influence on the depth of carbonation.

(d) The comparison of various curing regimes indicated that there was no significant advantage in resorting to any such techniques for the CPF surface, with regard to the surface properties. Also there was no significant benefit in keeping CPF in place for a period after the removal of the formwork.

(e) Controlled permeability formwork resulted in a relatively smooth surface, free from any blow holes; therefore the long term benefits are generally very encouraging .

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