DETERMINATION OF THE PENETRATION DEPTH OF VOLATILE FLUIDS IN CONCRETE USING THERMOGRAPHY

FESTSTELLUNG DER EINDRINGTIEFE LEICHTFLÜCHTIGER FLÜSSIGKEITEN IN BETON MIT HILFE DER THERMOGRAPHIE

DÉTERMINATION DE LA PROFONDEUR DE PÉNÉTRATION DE LIQUIDES VOLATILES DANS LE BÉTON À L'AIDE DE LA THERMOGRAPHIE

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SUMMARY

A simple testing method which allows to determine the penetration depth of volatile fluids in concrete is presented. Different fluids which were absorbed in concrete specimens with different degrees of water saturation by capillary suction were investigated. The results obtained were compared with the penetration depths determined visually.

ZUSAMMENFASSUNG

Es wird eine einfache Untersuchungsmethode vorgestellt, mit der es möglich ist die Eindringtiefe von leichtflüchtigen Flüssigkeiten in Beton zu ermitteln. Es wurden unterschiedliche Flüssigkeiten untersucht, die in Probekörper aus Beton mit unterschiedlicher Wassersättigung kapillar eingedrungen waren. Die erhaltenen Ergebnisse wurden mit den visuell feststellbaren Eindringtiefen verglichen.

RÉSUMÉ

Une méthode simple pour déterminer la profondeur de pénétration de liquides dans le béton est présentée. Des liquides différentes absorbées d'une manière capillaire des éprouvettes de béton d'un degrée de saturation en eau différente ont été examinées. Les résultats obtenus ont été comparés avec la profondeur de pénétration déterminée visuellement.

KEYWORDS: thermography, infrared image, volatile fluids, fluid detection, penetration depth, concrete.

1 INTRODUCTION

Concrete structures for environmental protection, like catching basins in chemical production facilities, need to be impervious to organic fluids. The function of a catching basin is to prevent hazardous organic fluids to get into the soil and the ground water. Although concrete is not absolutly impervious to organic fluids a catching basin has to retain a fluid in a hazard situation for a certain period of time until the fluid is removed completely. The point of interest is to know how deep a fluid will penetrate into a concrete structure during the time of exposure and to consider this depth during the design of catching basins (e. g. determination of wall thickness) for a certain fluid.

It is easy to determine the penetration depth of a non volatile fluid visually after splitting the specimen. Unfortunately this is not possible for a volatile fluid as it evaporates quickly and the wetting front disappears. The temperature of the region of the specimen saturated with the volatile fluid is lowered by the heat of vaporization which the fluid needs to evaporate. It is becoming possible to determine the penetration depth with the aid of an infrared camera. In addition the fluid distribution can be visualized.

2 EXPERIMENTAL

2.1 Specimen preparation

Concrete cylinders with a diameter of 100 mm and a height of 300 mm were cut into halves. The resulting two cylinders had each a height of 150 mm. These cylinders were coated with a dense epoxy resin along the perimeter in order to get an one-dimensional inflow and to avoid evaporation of fluid through the surface of the specimens. The cut surfaces of the specimens were exposed to the testing fluids. The concrete used had a water cement ratio of 0.58 and a maximum aggregate size of 16 mm.

Different degrees of moisture content of the specimens were obtained by first drying the specimens in an oven and then exposing them to a defined amount of water. Afterwards the specimens were sealed in airtight plastic bags and stored for several weeks. This procedure was necessarry to obtain an uniform degree of moisture distribution throughout the specimen.

2.2 Testing fluids

The lowering of the temperature of the region which is saturated with the testing fluid depends on different parameters of the fluid and the test specimens. The most important parameters are the heat of vaporization and the vapour pressure of the fluid and the degree of fluid saturation of the specimen. The degree of saturation decreases with increasing moisture content of the specimen because of reduced available pore volume. Table 1 shows the vapour pressure of the fluids investigated. The heat of vaporization is about 360 J/g for the organic fluids of Table 1 at 20°C [1]. The heat of vaporization for water is about 2600 J/g at the same temperature.

Table 1. Vapour pressure of the fluids at 20°C

Testing fluid	Vapour pressure [1] [kPa]
n-pentane	57.3
cyclohexane	10.4
n-decane	0.19
water	2.34

2.3 Determination of the fluid inflow

During the test the specimens were immersed with the cut surface 1 cm deep into the testing fluid. The epoxy resin chosen as coating for the test specimens was transparent and therefore the penetration depth could be determined visually from outside for all investigated fluids. It is not always possible to use a transparent epoxy resin coating because of its reaction with some fluids and in that case a non transparent special coating must be used. If a drilled core is

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[1] calculated from data in: Lide DR, editor-in-chief. Handbook of Chemistry and Physics. 72nd ed. Boca Raton, Ann Arbor, Boston: CRC press; 1991.

used as a test specimen, it is also not possible to determine the penetration depth visually from outside, even with a tranparent epoxy resin coating, because of the roughness of the drilled surface. This is the reason why splitting of concrete specimens is required in order to determine the penetration depth of a fluid.

At the end of the exposure time the specimens were split perpendicular to the exposed surface in two halves and the penetration depth, measured visually from outside, was compared to the penetration depth determined inside the specimen. For volatile fluids the penetration depth was determined using an infrared camera.

3 RESULTS AND DISCUSSION

The penetration depth of n-Pentane visible from outside the specimen through the transparent epoxy resin coating is shown in Figure 1. The degree of water saturation of the specimen was about 20 %. The penetration depth was traced at different times of exposure. The top line corresponds to the maximum time of exposure. The thermo-image of the split surface and the temperature profile across the central axis of this specimen are shown in Figure 2. The cool regions are dark and denote a high amount of n-Pentane. It can be seen that the penetration depth is the same as shown in Figure 1. Since n-Pentane has a very high vapour pressure and the degree of water saturation of the specimen was low, the temperature difference is very high (about 1.7°C) and therefore the penetration depth is easy to determine.

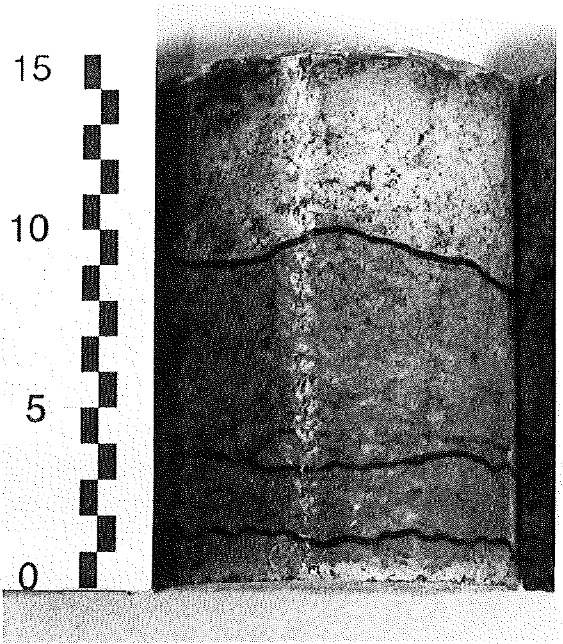

Figure 1. Penetration depth of n-Pentane as seen from outside.

With increasing moisture content of the specimen, a smaller amount of test fluid will be absorbed and thus the temperature difference between the region saturated with test fluid and the non saturated region will be smaller. In Figure 3 the thermo-image and the temperature profile of the split surface of a specimen with a degree of water saturation of 70 % can be seen. The test fluid is again n-Pentane. Here the penetration depth cannot be determined easily as in Figure 2 because only a small amount of the test fluid could penetrate. The temperature difference is about 0.4°C. The penetration depth of test fluids in

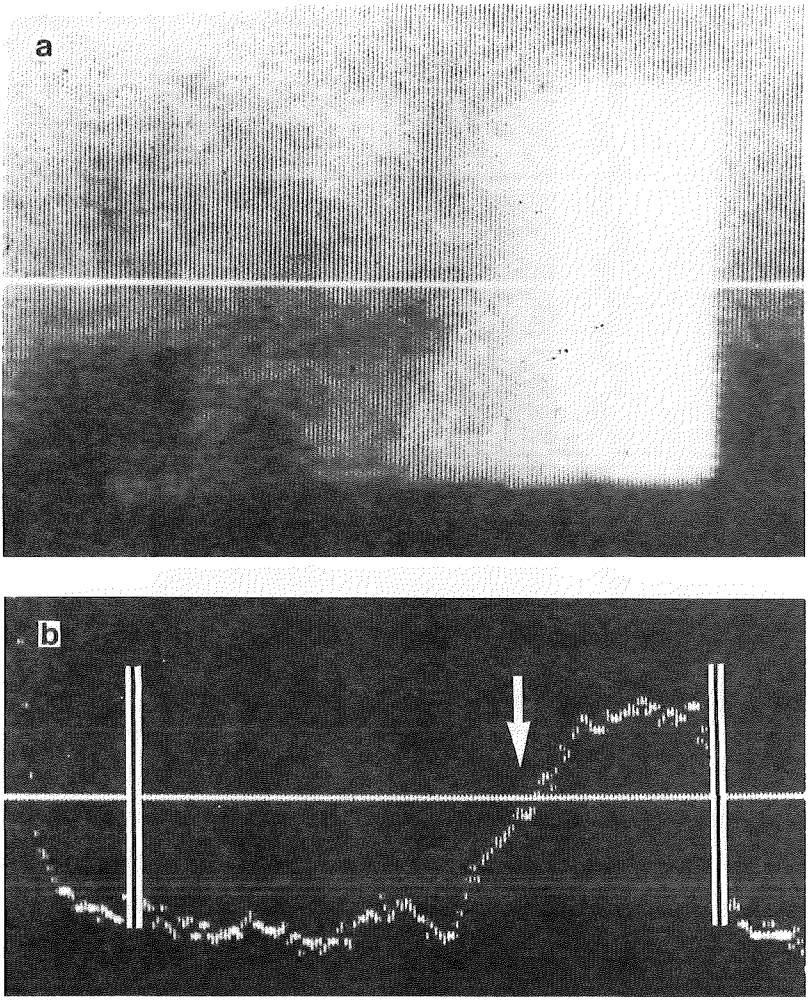

Figure 2. Thermo-image (a) and temperature profile (b) of the split surface of a specimen with 20 % water saturation which was exposed 24 hours to n-Pentane before splitting.

specimens with a higher degree of water saturation than 70 % could not be determined, because the amount of penetrating test fluid and therefore the temperature differences were too small.

Investigations with test fluids with a lower vapour pressure than n-Pentane were also possible. The penetration depth of Cyclohexane (Figure 4) and Water (Figure 5) in specimens with a degree of water saturation of 20 % can easily be determined. The temperature differences were 1 °C for Cyclohexane and 0.6°C for water.

Using a testing fluid with a very low vapour pressure like n-Decane, the penetration depth can be determined visually after splitting (Figure 6). With an infrared camera this is nearly impossible, even using a test specimen with 0 % water saturation, because of the small temperature difference (Figure 7).

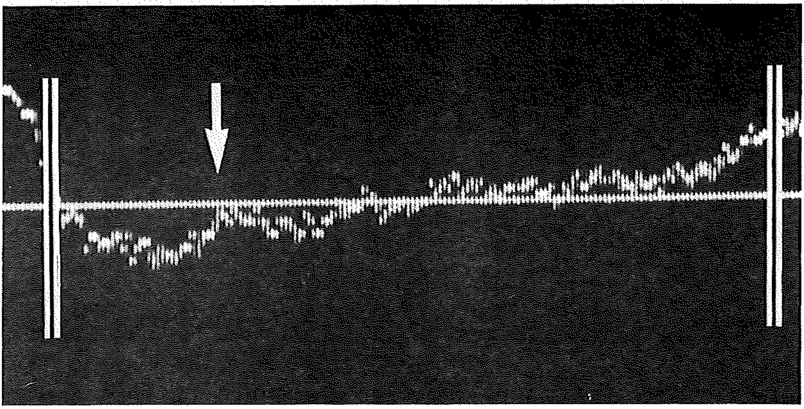

Figure 3. Temperature profile of the split surface of a specimen with 70 % water saturation which was exposed 24 hours to n-Pentane before splitting.

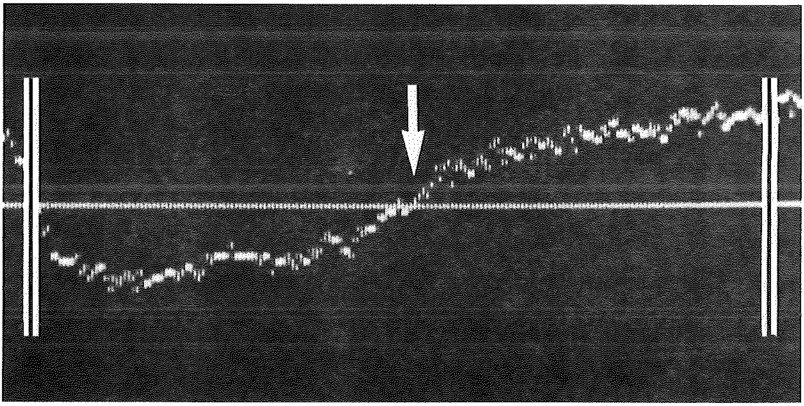

Figure 4. Temperature profile of the split surface of a specimen with 20 % water saturation which was exposed 72 hours to Cyclohexane before splitting.

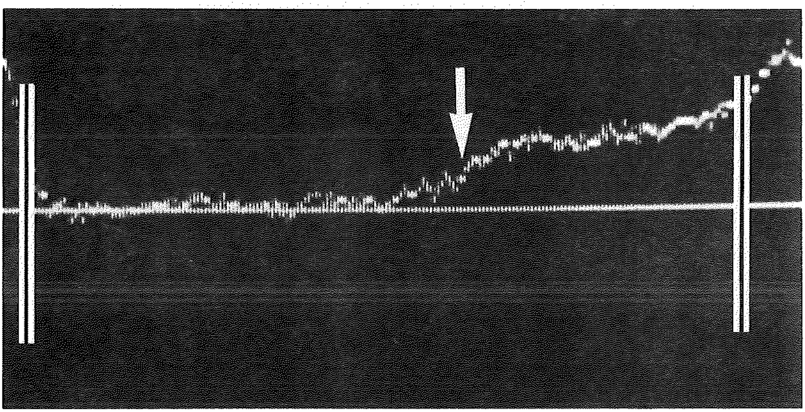

Figure 5. Temperature profile of the split surface of a specimen with 20 % water saturation which was exposed 72 hours to water before splitting.

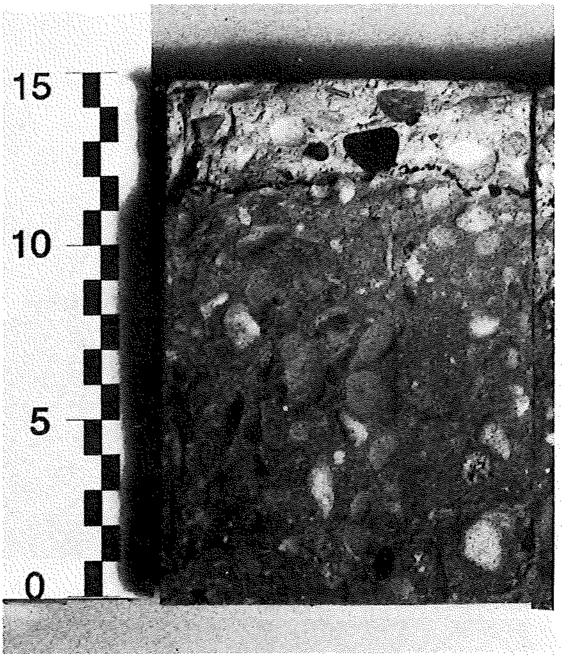

Figure 6. Penetration depth of n-Decane as seen inside the specimen after splitting.

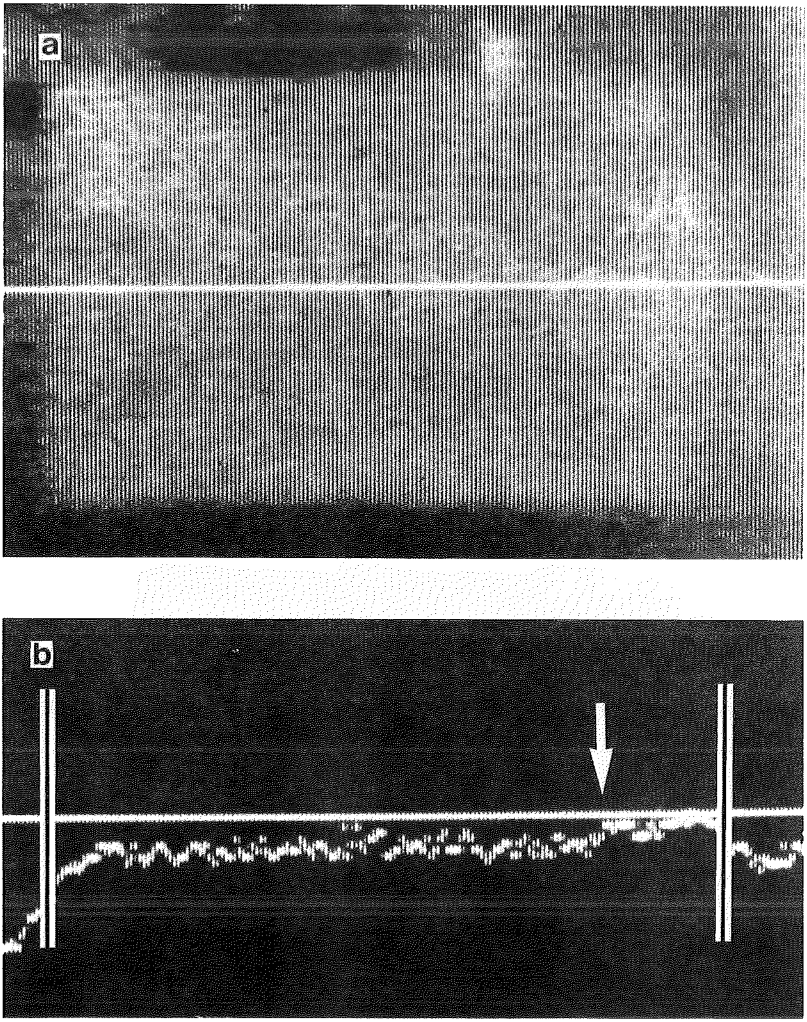

Figure 7. Thermo-image (a) and temperature profile (b) of the split surface of a completely dried specimen (0 % water saturation) which was exposed 72 hours to n-Decane before splitting.

4 CONCLUSIONS

The results show that thermography is a suitable test method to determine the penetration depth and fluid distribution in concrete. However the effectiveness of this method depends on the degree of water saturation of the specimen and the vapour pressure of the fluid. If the degree of water saturation of the specimens is too high or the vapour pressure of the fluid too low, then it is not possible to measure the penetration depth and visualize the fluid distribution using thermography.

The penetration depth of a fluid in a dry concrete specimen can always be determined after splitting the specimen, either visually or by means of an infrared camera. For some special fluids, like water, the penetration depth can be determined with both methods.

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