EFFECT OF DRYING AT AN EARLY AGE ON MOISTURE DISTRIBUTIONS IN CONCRETE SPECIMENS USED FOR AIR PERMEABILITY TEST

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ABSTRACT

The concrete discs with water-cement ratios 0.4 and 0.7 were preconditioned at their early age by drying at 50 °C for 2 to 4 days, followed by storage in a laboratory atmosphere till an age of 28 or 56 days. The moisture distributions in the specimens were determined by measuring relative humidity and capillary saturation degree, and the air permeability was determined according to the Cembureau method. The results show that drying at an early age, although it reduced the total moisture content, eventually increased the moisture gradients which might introduce new cracks in the specimens. The relationships between relative humidity and capillary saturation degree at different depths are used to indicate the heterogeneity originating from the preconditioning.

Key words: capillary suction, concrete, drying, moisture, moisture distribution, permeability.

1. INTRODUCTION

It is well known that gas permeability of concrete is rather sensitive to the moisture conditions in the specimens. The Cembureau method /1/ recommended two approaches to the standard moisture conditions: 1) to store the specimens in a laboratory atmosphere at 20 ± 2 °C and RH 65 ± 5% for a period of 28 days; and 2) to dry the specimens in a ventilated laboratory cabinet at 105 ± 5 °C for a period of 7 days, followed by storage in a desiccator for 3 days at a temperature of 20 ± 2 °C. The second approach is far from the natural moisture conditions. The first approach seems closer to normally encountered exposure, but the storage of the specimens in air at 20 °C for only 28 days is in most instances insufficient to reach the moisture equilibrium with the surrounding environment. Costa et at /2/ preconditioned the specimen by drying at 60 °C for 10 days up to constant weight. In order to evaluate the possibilities for accelerating the moisture equilibrium, RILEM Technical Committee TC 116-PCD, working on permeability of concrete as a criterion of its durability, made a pilot test including the preconditioning of the specimens by drying at 50 °C for 2 to 4 days, followed by storage in a laboratory atmosphere till an age of 28 or 56 days. The work reported in this paper is a part of the pilot test carried out at the Chalmers University of Technology.

2. EXPERIMENTAL

Preparation and Preconditioning of Specimens

The cementitious material used in this work was Swedish standard Portland cement. The fine aggregate was natural sand, and the coarse aggregate was granite gravel of size 8-12 mm. The mix proportions of concrete are listed in Table 1.

Table 1—Mix Proportions of Concrete, kg/m³

	OPC	Sand	Gravel	Water	Super-plasticizer Mighty 100	Water-Cement Ratio	Compressive Strength 28 days, MPa
Mix A	380	771	1157	152	2.5	0.4	69.4
Mix B	270	769	1153	189	0	0.7	37.8

Concrete was mixed in a 30 litres forced mixer, and cast into ∅150×50 mm moulds. The top surface was covered with plastic film to prevent water from evaporating. All the concrete discs were cured at room temperature for one day before being demoulded. After their surfaces were cleaned with a brush, the specimens were covered with wet burlap and stored in a sealed plastic box for additional 6 days, i.e. the initial moisture curing age is 7 days. After one day of drying at 20 °C, RH 55%, the control specimens were stored in a climate room at 20 °C, RH 55%, for the specified ages (28 and 56 days). The rest of the specimens were put into a computer-controlled oven and were heated at a rate of 5 °C/h up to a temperature of 50 °C, and then they were kept at 50 °C for 2 or 4 days (including the period of temperature rising from 20 °C to 50 °C). These specimens were transferred from the oven to a heat-insulated box for slowly cooling. One day after cooling, they were stored in the same climate room as mentioned above for the specified ages.

From the age of 7 days on, the weight loss of each disc was recorded. At the specified age, three discs from each composition and heating duration were used for each test.

Determination of Air Permeability

The Cembureau apparatus was used for determining air permeability. High-pressure air from the laboratory was directly used as the fluid. Two stages of relative inlet pressure, 1.0 and 1.5 $\times 10^5$ N/m^2, were selected in succession. Other measurement procedures followed the Cembureau recommendation /1/.

Determination of Humidity Profile

The specimens for moisture determination were quickly sampled by splitting and crushing at the positions shown in Fig. 1. The crushed samples of about 20 g from each position were put into a test tube for RH measurement by using the hygrometric method /3/.

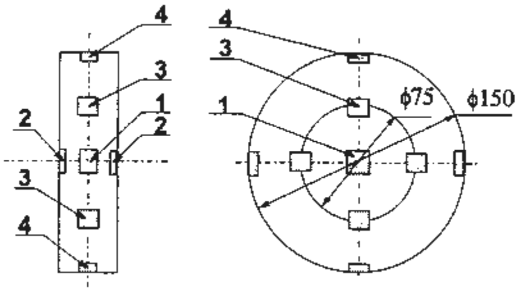

Fig. 1—Positions of sampling.

Determination of Capillary Saturation Degree

A concrete lump of about 30 g was quickly sampled at the positions 1, 3 and 4 shown in Fig. 1 for determining the degree of capillary saturation. The initial weight of the sample, W_0, from each position was recorded with a precision of 0.01 g before the sample was placed in a suction box, as shown in Fig. 2. After a few days when the sample was capillary filled, the weight, W_1, was recorded again. Later the sample was dried at 105 °C and the dry weight, W_2, was recorded. The degree of capillary saturation, S_{cap}, is defined as /4/:

$$S_{cap} = \frac{W_0 - W_2}{W_1 - W_2} \tag{1}$$

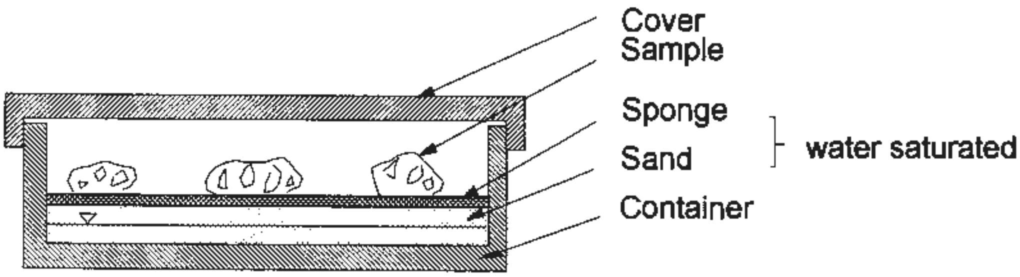

Fig. 2—Sketch of capillary suction test.

3. RESULTS AND DISCUSSION

Weight Loss of the Specimens

The average values of the weight loss of the specimens under different preconditioning are plotted in Fig. 3. It is clear that drying at 50 °C greatly removed water from the specimens and consequently resulted in a lower total moisture content. Without heating at 50 °C, the specimens were still far away from reaching a constant moisture content after the storage of 56 days at 20 °C, RH55%. Four days' drying at 50 °C, on the other hand, is enough to accelerate the specimens with a high water-cement ratio (Mix B) to reach a constant moisture content, but it seems to overdry the specimens with a low water-cement ratio (Mix A), which even absorbed moisture from the environment during the storage.

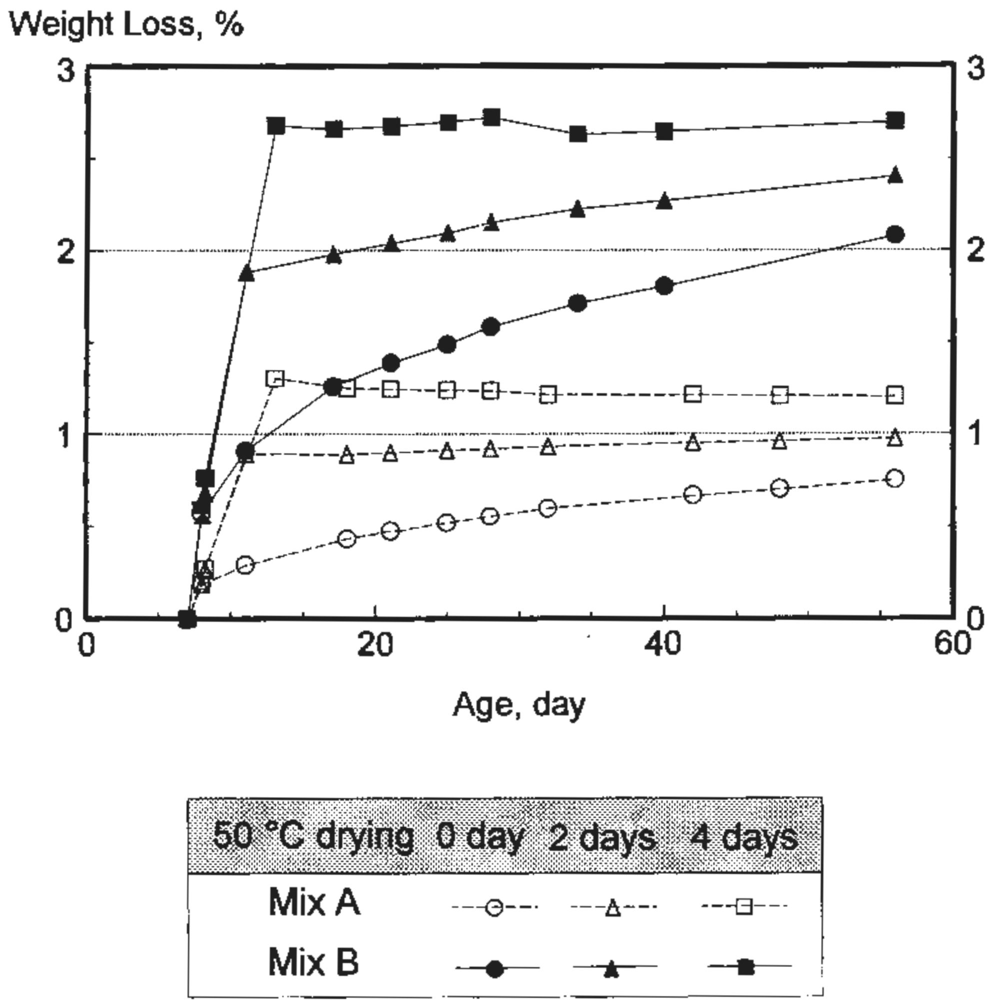

Fig. 3—Weight loss of concrete discs under different preconditioning.

Air Permeability

The experimental results of air permeability are listed in Table 2.

Table 2—Air Permeability of the Concrete Discs, ×10 $^{-18}$ m^2

Mix	50 °C drying	Age	Permeability	Mean value	St. deviation
A	0	28 days	4.61 4.02 4.31	4.31	0.21
	2 days	28 days	12.5 9.42 10.2	10.7	1.13
	4 days	28 days	11.9 12.8 13.3	12.7	0.50
B	0	28 days	272 315 392	326	43.0
	2 days	28 days	295 441 353	363	52.0
	4 days	28 days	222 492 368	361	95.6

As expected, the air permeability of concrete with a low water-cement ratio is much lower than that of concrete with a high water-cement ratio. The drying intensity greatly increased the air permeability of concrete with a low water-cement ratio, but had no remarkable effect on that of concrete with a high water-cement ratio.

Moisture Distribution Profiles

The results of relative humidity and capillary saturation degree are plotted in Fig. 4 and 5, where each value was an average over three parallel tests.

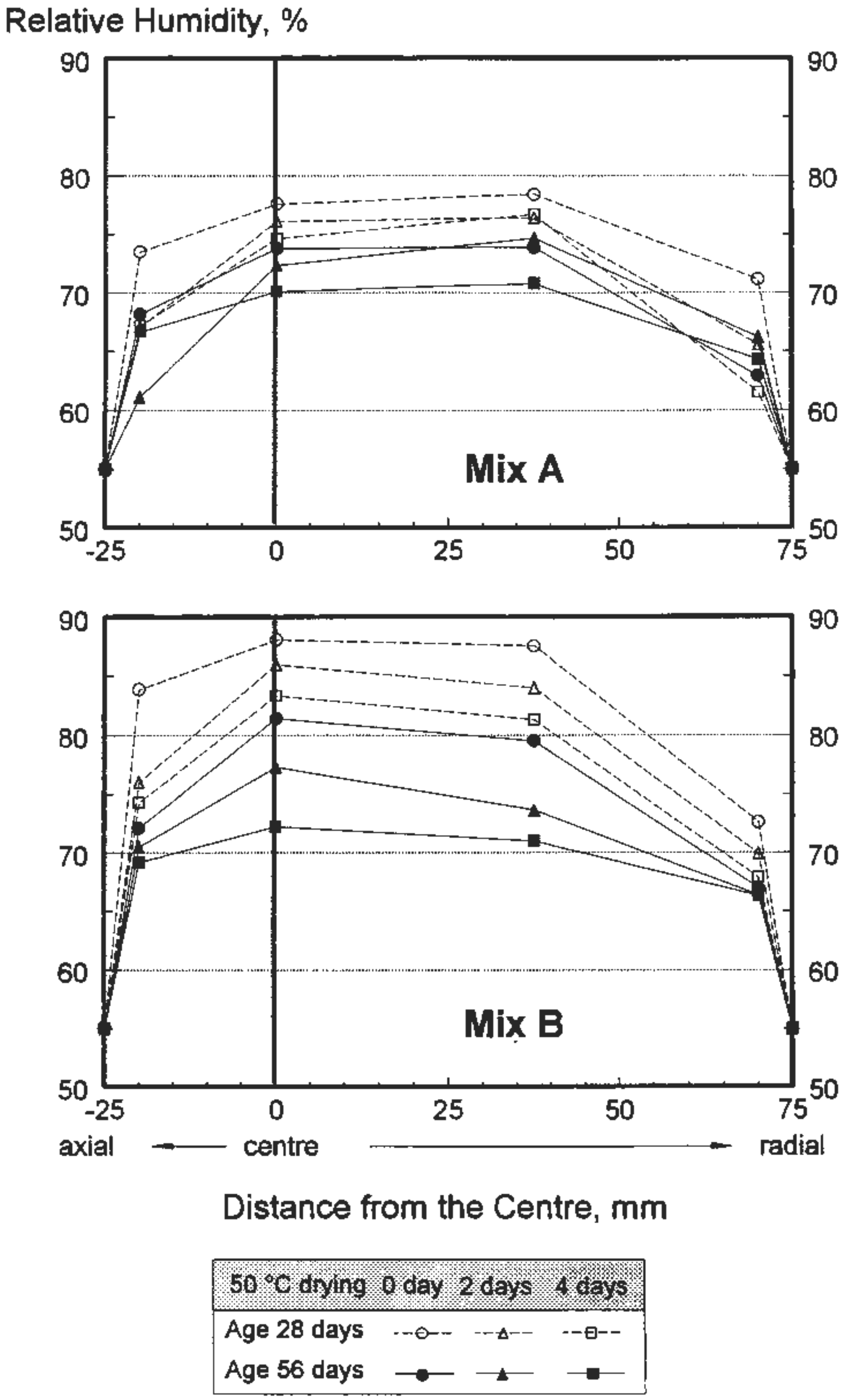

Fig. 4—Humidity profiles in concrete discs.

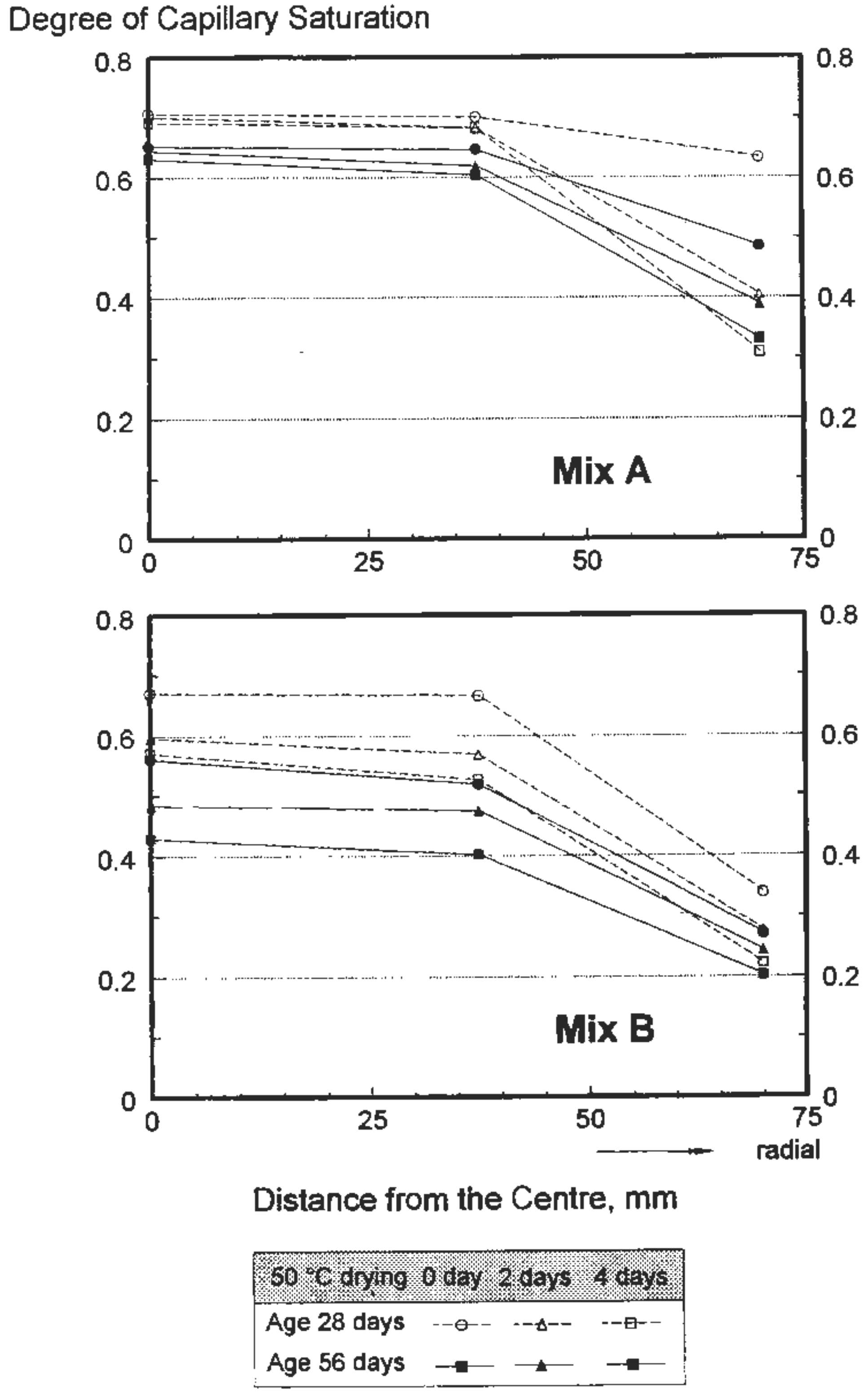

Fig. 5—Profiles of capillary saturation degree in concrete discs.

The moisture distributions in Fig. 4 show that, even after 56 days of drying, the core of the specimens in all cases, is far from in equilibrium with the surrounding air, although the total moisture content (the area below the profile of relative humidity, or see Fig. 3) decreased, and even became constant (see Fig. 3) with the drying intensity. It can be seen from Fig. 5 that the surfaces are dry but the moisture contents in the core are two to three times as high as at the surfaces. This means that the air permeability was measured with large moisture gradients below the test surface and at the edges of the specimens. As will be discussed below, these large moisture gradients might introduce cracks into the specimens.

The contradiction between constant total moisture content in Fig. 3 and larger moisture gradient in Fig. 5 indicates that constant total moisture content does not necessarily represent homogeneous moisture distribution. It is difficult to get the information about the uniformity of moisture conditions from the measurement of weight loss.

Since the drying of the specimens at 50 °C for two or four days does not minimise, or even increase the moisture gradients in the specimens, as shown in Fig. 5, the preconditioning by drying at an elevated temperature at an early age, therefore, does not improve the uniformity of moisture conditions for measuring air permeability, or in contrast, it might make the conditions worse.

Relations between Relative Humidity and Capillary Saturation Degree

If there are no new cracks introduced into the pore system of the specimens, the moisture content in the specimens at different drying stages should follow the desorption isotherms which have been well investigated /3/. According to Hedenblad and Nilsson /4/, the degree of capillary saturation S_{cap} can be also expressed as:

$$S_{cap} = \frac{W_e/C}{W/C - 0.19\alpha} \tag{2}$$

where W_e/C: evaporable water content, kg/kg cement;
W/C: water-cement ratio;
α: degree of hydration.

With the help of the desorption isotherms according to Nilsson /3/, we can calculate the relationship between relative humidity and capillary saturation degree, assuming $\alpha = 0.5 \sim 0.7$ for the concrete with a water-cement ratio of 0.4, and $\alpha = 0.6 \sim 0.8$ for that with a water-cement ratio of 0.7, respectively. The calculated curves and the measured results are shown in Fig. 6.

It can be seen from Fig. 6 that the results measured from the central parts of the specimens correspond very well to the curves calculated with the higher degree of hydration, but those measured from the parts near the surfaces drop down to, or even under, the curves calculated with the lower degree of hydration. The deviations increase with the drying intensity, and are quite proportional to the moisture gradients, as compared with Fig. 5. This implies that the hydration of the surface parts of the specimens has been greatly retarded due to surface drying, and probably some new cracks, which supply more space for water to fill in, have been introduced due to the large moisture gradients. In other words, at a certain moisture content these new cracks increase the capacity of capillary suction, or decrease the degree of capillary saturation. It is evident that drying at an elevated temperature degrades the homogeneity of the specimens.

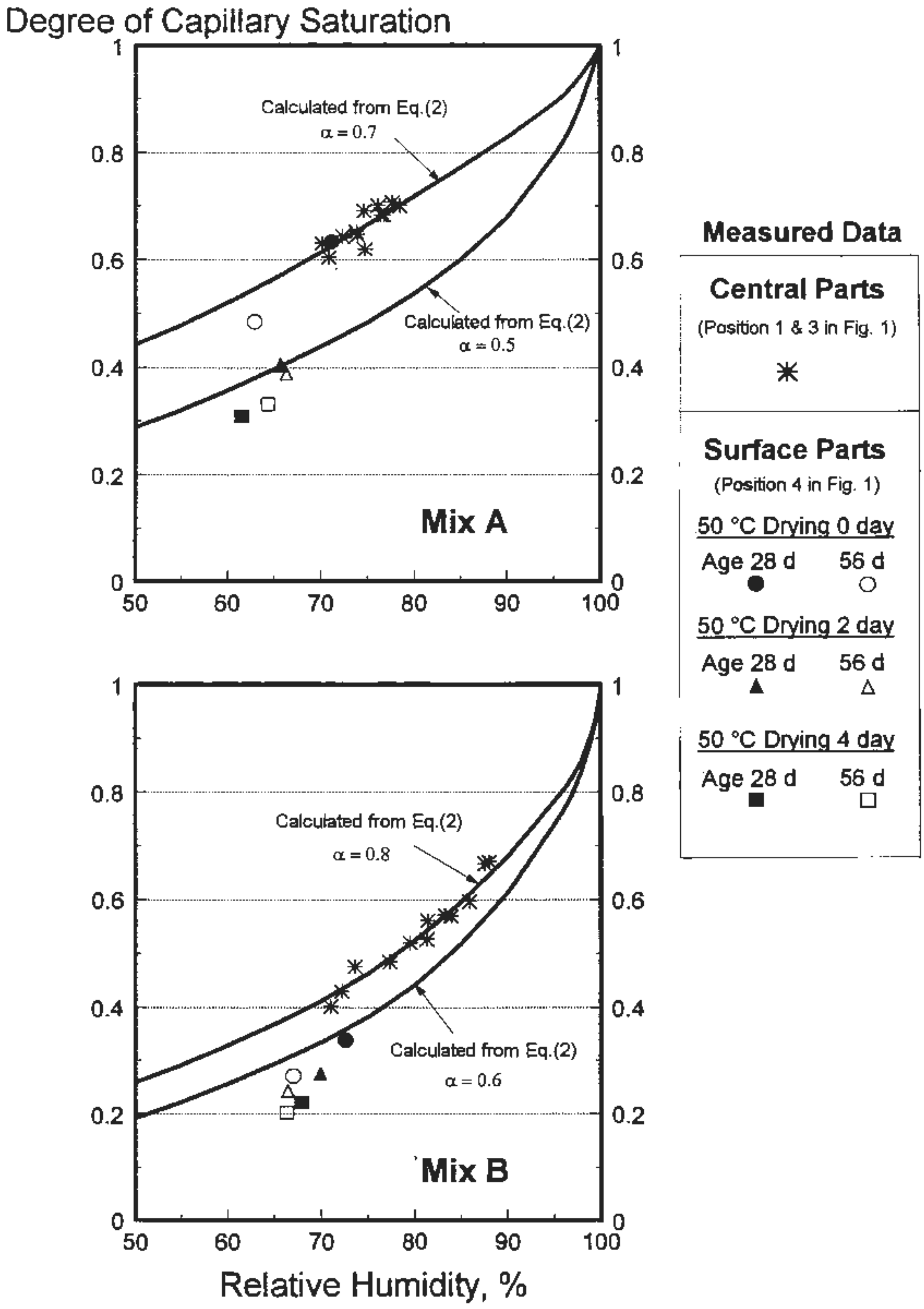

Fig. 6—Relationships between relative humidity and capillary saturation degree.

4. CONCLUSIONS

In all cases in this study, the specimens for air permeability test are far away from reaching a uniform moisture condition.

Although drying at 50 °C for two or four days can greatly reduce the total moisture content, the core of the specimens is still wet, and the moisture gradient eventually increases with the drying intensity.

Constant total moisture content does not necessarily represent homogeneous moisture distribution. It is difficult to get the information about the uniformity of moisture conditions from the measurement of weight loss.

The preconditioning by drying at an elevated temperature at an early age, as mentioned in this paper, does not improve the uniformity of moisture conditions for the measurement of air permeability, or in contrast, it might make the conditions worse.

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