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PREDICTION OF WATER TRANSPORT IN CONCRETE WITH AID OF EXPERIMENT INVESTIGATIONS AND DEVELOPED MOISTURE MEASUREMENT METHOD

Parnthep Julnipitawong[1*] and Lutz Franke[2]

[1]*CONTEC, Sirindhorn International Institute of Technology*
[2]*Institute of Materials, Physics and Chemistry of Building, Hamburg University of Technology*

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**Corresponding Author,*
Email address: parnthep@siit.tu.ac.th

ABSTRACT :

The developed moisture transport model is introduced in forms of water vapor transport described by Fick's diffusion and liquid water transport described by Darcy's law. The transport models are evaluated by comparing with the experiment results of concrete samples subjected to specific studied boundary conditions and measured by microwave based and traditional methods.

KEYWORDS : Water transport, Microwave

1.Introduction

The use of concrete is widespread in constructionindustry according to inexpensive material and various forms of casting ability. However, concrete material can be degraded by environmental attacks. Most deterioration processes involve moisture transport[1], [2], [3] and the successful repair strategies are only possible if the moisture content of building material is known [4]. Regarding to studies of moisture transport in concrete they are focused on both moisture measurement techniques and mathematical modeling. According to the modern technology of computerit is possible to apply moisture transport model to simulate behavior of moisture movement in building materials

In this research the developed moisture transport model will be introduced. The liquid water transport model described by Darcy's law and water vapor transport model described by Fick's law are the two main components of moisture transport model of concrete. To be capable of evaluating the simulated results the experiment investigations concerning to measure moisture content and moisture distribution inside concrete specimens subjected to specified boundary conditions by developed and gravimetric measurement techniques are conducted.

2. Moisture transport in concrete

2.1 Water vapor transport model

The water vapor transport in pore system of porous building materials can be described by the sum of water vapor diffusion of gas phase,$\dot{m}_{d,diff}$, and the convection of gas flow, $\dot{m}_{d,conv}$ in consequence of partial water vapor partial pressure. From [5] the gradients of water vapor concentration and total pressure induce the diffusion transport. Due to constant air pressure the diffusion process caused by total pressure can be neglected. In addition, the diffusion caused by temperature gradient can also be neglected since this study deals only with isothermal transport. Therefore,

$$\dot{m}_{d,diff} = -D_d \cdot \nabla C_d = -D_d \cdot \nabla\left(\frac{p_d}{R_d \cdot T} \cdot \theta_d\right) \approx \frac{-D_d}{R_d \cdot T} \cdot \nabla(p_d \theta_d) \quad (1)$$

where $\dot{m}_{d,diff}$ is water vapor diffusion of gas phase in kg/m^{2}s, $\dot{m}_{d,conv}$ is convection of gas flow in kg/m^{2}s, R_d is gas constant, T is temperature in K, p_d is water vapor partial pressure in Pa, θ_d is water vapor in kg/m^3. In case of convection of gas flow, the driving potential is pressure gradient ∇p_g in gas phase consisting of dry air and water vapor. K_g is the permeability coefficient of materials for water vapor. If there is a constant atmospheric pressure p_a in the pore system, this pressure is generally much larger than the water vapor partial pressure p_d, i.e.,∇p_g approaches to zero. Consequently, the term $\dot{m}_{d,conv}$ in Equation (2) is near zero and neglected.

$$\dot{m}_{d,conv} = -\theta_d \cdot \rho_d \cdot K_g \cdot \nabla p_g \quad (2)$$

The total water vapor transport can be derived as:

$$\dot{m}_d = -\frac{D_d}{R_d \cdot T}\nabla(p_d\theta_d) - \underbrace{\theta_d p_d K_g \nabla p_g}_{\approx 0} = -\frac{D_d}{R_d \cdot T}\nabla(p_d\theta_d) \quad (3)$$

where $p_d = \varphi \cdot p_{d,sat}(T)$, $p_{d,satt}(T)$ is saturation water pressure under temperature φ is relative humidity, D_d is $\frac{D_L(T,p_g)}{\mu}$, D_L is diffusion coefficient of water vapor in m^2/s and equal to $2.3 \times 10^{-5} \frac{p_o}{p_L}\left(\frac{T}{273}\right)^{1.81}$, p_L is ambient atmospheric pressure in Pa, p_o is standard pressure in Pa ≈ 100KPa, and μ is water vapor diffusion resistance factor.

2.2 Water transport

The water transport can be described by the sumof diffusive and convective terms of water transport. As shown below the first term is the diffusion of liquid water in pore system. On theoretical basis, the diffusion of liquid water transport is considered in water vapor diffusion transport term since there is no measurement method which can isolate both transport processes from each other. Thus,

$$\dot{m}_w = \underbrace{-D_w \nabla w}_{diffusive} \underbrace{- \theta_w \rho \frac{K_w}{\eta_w} \nabla p_k}_{convective} = \underbrace{-D_w \rho_w \nabla \theta_w}_{\approx 0 \text{ and considered in } \dot{m}_d} - \theta_w \rho \frac{K_w}{\eta_w} \nabla p_k \quad (4)$$

where K_w is permeability in m^{2}depending on water content (θ_w), η_w is viscosity of waterPa·s, ρ is density of water kg/m^{3}and p_k is capillary pressure in Pa.

3. Simulation program

In this study the transport simulation program, ASTRa, which allows calculating couple heat, moisture and ion transport in pore system of building materials developed under Institute of Materials, Physics and Chemistry of Buildings, Hamburg University of Technology is used. The previously described transport models are applied in ASTRa computer program.

4. Experiment programs

This section is aimed to explain the details of developed moisture measurement method and case study used to compare with simulated results.

4.1 Moisture measurement method

Based on similar concept used in microwave moisture measurement method the frequency of 3 to 10 MHz generated by network analyzer was used. This technique measured loss of transmission (or attenuation) signal between 2 electrodes which were attached to concrete samples by conductive epoxy. After the network analyzer was enabled, the loss of signal will be measured and stored in floppy disk format. By analyzing results in computer, the relationship between moisture content and loss of signal (or attenuation, unit in dB) can be observed at frequency of 6.023 MHz. With knowing calibration curves, the unknown moisture content in concrete samples can be estimated by measuring attenuation of transmission signal. The detail of set-up equipmentcan be shown in Figure 2.

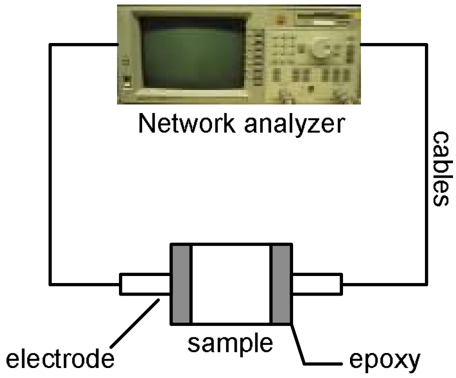

Figure 1 Moisture measurement test configuration

Considering Figure 2 the relationship between water content and loss of signal can be described. In Figure 2, if the sample has relative dielectric constant ε', the absolute dielectric constant is ε_0, the conductivity of sample equals to σ, the area of electrode is A, the distance between electrode is d and frequency is ω, and the electrical engineering admittance (inverse of impedance) can be formulated, y:

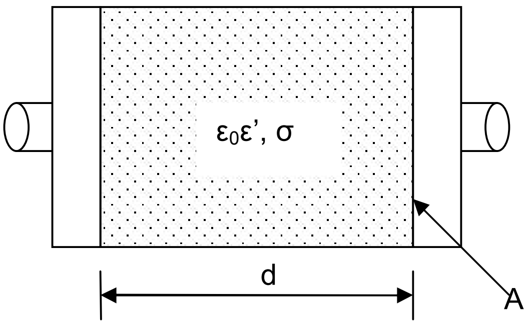

Figure 2 Basic diagram used to explain relationship between moisture content and loss of signal

$$y = j\varpi\varepsilon_0\varepsilon' C' + G \rightarrow y = j\varpi\varepsilon_0\varepsilon'\frac{A}{d} + \sigma\frac{A}{d} \qquad (5)$$

where $\varepsilon_0\varepsilon'C'$ equals to susceptance and G is conductance. Regrouping above equation it becomes

$$y = j\varpi\varepsilon_0(\varepsilon' - j\frac{\sigma}{\varpi\varepsilon_0})\frac{A}{d} \qquad (6)$$

where ε* is complex dielectric constant and equals to $\varepsilon' - j\frac{\sigma}{\varpi\varepsilon_0}$. ε* can be written in simple form ε*= ε'-jε''. From the Equation (6), it can be noticed that ω is known (applied frequency), A, d and ε_0 are constant values. Hence, y depends only on ε* which is equivalent to corresponding measurement value; loss of signal or electrical current and is influenced by water content of a sample.

The corresponding calibration results are shown in Figure 3. The calibration tests were done on small concrete cubes (4x4x4cm) with different moisture content. The x-axis represents the attenuation in decibel and y-axis represents the moisture content in %vol. of concrete cubes with w/c 0.45. By performing regression analysis, the calibration equations can be derived as shown in Equation (7). Therefore, on this basis, the water content of samples can be approximated.

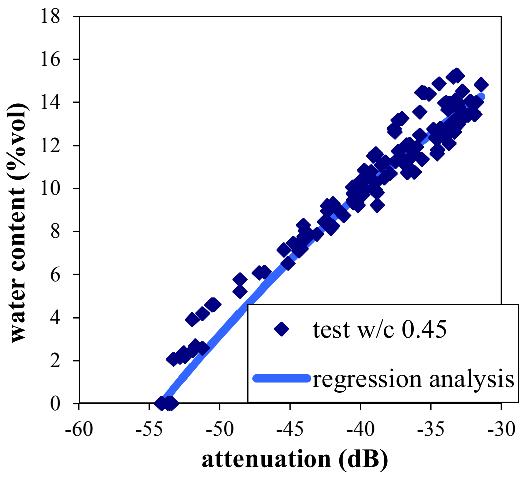

Figure 3 Calibration curve of w/c 0.45 concrete

$$w = 213.18 + (-0.065 \cdot |At|^{2.02}) \qquad (7)$$

where w is calculated water content in kg/m^3, the parameter *At* is measured signal loss (attenuation) in dB. From Figure 4, increased moisture content of the sample yields adecrease in signal loss in accordance with Equation (7).

4.2 Case study: water absorption and constant drying

The case study was designed in order to investigate moisture content of 4x4x15cm concrete samples by gravimetric method and attenuation method subjected to specific boundary conditions. In this case study concrete samples (4x4x15cm) with water cement ratio 0.45 were dried at 105ºC to obtain dry weight of samples. After drying, the electrodes were attached on 2 sides of samples by using conductive epoxy at five different positions to observe moisture profile inside the samples as shown in Figure 4. Those samples were subsequently coated with epoxy on 4 surfaces to simulate 1-dimensional moisture transport.

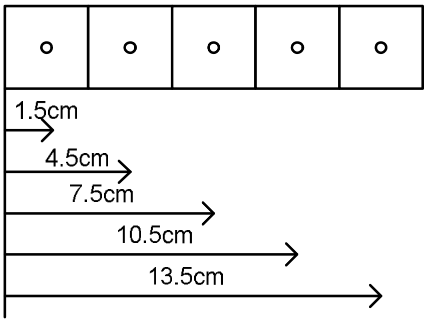

Figure 4 Side view of tested concrete sample

After that those samples were subjected to uptake water at one surface until 28 days. After 28 days, samples were dried at 50% R.H., 23°C in controlled climate room up to 56 days. For both cases of absorption and drying the moisture content was measured periodically up to 28 days. In addition the samples were cut at 28 days and 56 days at five different positions. Each proportion was dried at 105°C to obtain moisture content of samples.

The corresponding mix proportion of concrete with water cement ratio 0.45 is shown in Table 1

Table 1 Mix proportion of w/c 0.45 concrete per m^3

Compositions	Description	Volume(litre)
cement	CEM I 42.5 R	113
additive	P40 MC-Bauchemie	1.78
	FK 99 MC-Bauchemie	3.10
gravel		359
sand		359
water		154
air		10

5. Results and discussions

The concrete prism samples 4x4x15 cm. were subjected to water reservoir at bottom surface whereas the top surfaces were in contact with laboratory condition. The other 4 sides were coated with epoxy. The ambient conditionswere controlled and constant at 23°C and 50% relative humidity. At the beginning of the experiment, the initial water content of samples was approximately 5 kg/m^3. After 28 days, the test samples were dried at 50% relative humidity and 23°C.

Figure 5compares the experiment and simulated result of 4 sides coated samples of w/c 0.45 concretes. All experiment results obtained by gravimetric and attenuation showed similar tendency. During period of 28 days the water content of samples increased according to gradually uptaking water through bottom surface. When the samples were removed from water reservoir, the drying period began after 28 days. The experiment results showed a sharp drop of the curve as results of simultaneous drying at suction surface. The simulated results were represented by ASTRa as shown in the figure. It seemed that ASTRasimulated results reasonably conformed to experiment results.

The measured and calculated moisture distributions by attenuation and ASTRa of the w/c 0.45 concrete samples are shown in Figure 6 from 1 day to 56 days. At the beginning of water absorption, there were moisture fronts gradually penetrating through the samples from 1 to 28 days. At 28 and 56 days the samples were split to investigate moisture distribution inside the sample as denoted as triangle notation in Figure 6. These results were correlated to measured results conducted by attenuation method. Regarding to simulated results, the ASTRa program provided the same aspect.

After 28 day the samples were exposed to relative humidity of 50% in controlled climate room. The measured water contents by attenuation in Figure 6 from 28 to 56 days gradually decreased. Comparing between measured and calculated results, the reduction of water content due to drying calculated by ASTRa were lower than measured value.

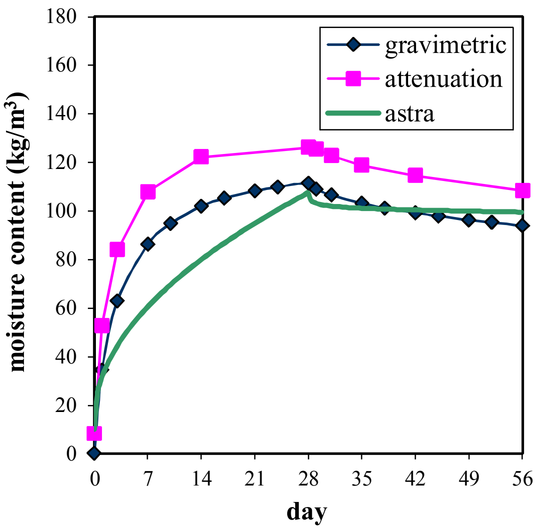

Figure 5 Water content investigation of 4 sides coated w/c 0.45 concrete subjected to water absorption and drying

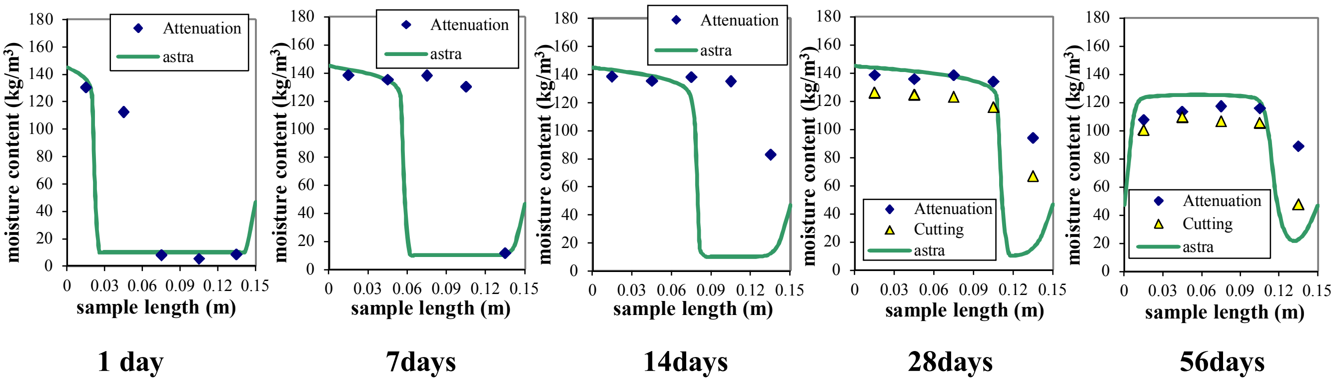

Figure 6 Water content distribution in 4 sides coated w/c 0.45 concrete samples

6. Conclusions

There are two main components contained in this transport model; i.e, water vapor transport model described by Fick's diffusion, liquid water transport model described by Darcy's law.To evaluate the transport models the moisture content of concrete has to be determined experimentally as measured by attenuation and gravimetric method. In overall the proposed models give acceptable simulated results compared with those measured value. In addition the developed moisture measurement technique also gives satisfied approximate moisture content of concrete sample.

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