MOISTURE TRANSPORT IN BUILDING MATERIALS WITH IMPERFECT HYDRAULIC CONTACT INTERFACES

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ABSTRACT

Based on the experimental results and predictions of a numerical model, the effects of uncertainty in estimation of imperfection of the interface on moisture transport were studied in the present study. It was found that, even though the imperfection of the interface varied with moisture content during the wetting process, the prediction using a constant resistance of the interface was close to that using an actual value. Through comparing the predictions using accurately determined resistance of the interface to that using resistance with error up to 70%, it was concluded that, in order to achieve acceptable predictions, it is necessary to control the uncertainty in resistance of the imperfect hydraulic contact interface within 20% of the actual value.

KEYWORDS

Moisture transport, Building materials, Imperfect hydraulic contact, and Mismatching resistance.

INTRODUCTION

Moisture engineering is important for overall building envelopes design. Because of the presence of moisture, the estimated cost on increased energy consumption in North America alone is approximate $1 billion dollars (Karagiozis et al. 2001). Therefore, accurately predicting moisture behavior in building envelopes is becoming an important task.

Moisture accumulation in building envelopes normally involves the process of the moisture transport across interfaces. According to the hydraulic performance of the interface, there are two interfaces: perfect hydraulic contact interface and imperfect hydraulic contact interface. When an interface between building materials has no effect on moisture transport, it is perfect hydraulic contact interface. Otherwise, it is imperfect hydraulic contact interface. Some typical interfaces between building materials such as bounded contact interface might not be perfect hydraulic contact, as demonstrated by many studies (e.g., Pel 1995; and Freitas et al. 1995). Previous studies, however, have not investigated the sensitivities of the moisture transport with respect to the imperfection of the interface. This paper presents a test and a series of simulations to analyze the sensitivities of the moisture transport with respect to the imperfection of the interface.

NUMERICAL MODEL

The numerical model MTIMB developed by Qiu et al (2002) is used to investigate the impacts of imperfection of the interface on moisture transport. This model assumes that the interface between building materials is imperfect hydraulic contact. The model uses following governing equation to predict moisture transport in a material:

$$q_l = -D_w \left(\nabla w + \frac{\rho_w \vec{g}}{\partial P_c / \partial w} \right) - \delta_p \nabla P_v \tag{1}$$

Where D_w is the moisture diffusivity ($m^2 \cdot s^{-1}$), w is the moisture content ($kg \cdot m^{-3}$), ρ_w is the density of liquid water ($kg \cdot m^{-3}$), g is the acceleration of gravity ($m \cdot s^{-2}$), P_c is the capillary pressure (Pa), P_v is the partial water vapor pressure (Pa), and δ_p is the water vapor permeability ($kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$). The governing equation of moisture transport across imperfect hydraulic contact interface is:

$$q_{imp} = -\left(\frac{P_{c2} - P_{c1}}{R_l} + \delta_{P1} \frac{\partial P_v}{\partial x} \right) \tag{2}$$

Where P_{c1} is the capillary pressure at contact surface of the first layer (Pa), P_{c2} is the capillary pressure at contact surface of the second layer (Pa), q_{imp} is the rate of moisture flow across the imperfect hydraulic contact interface ($kg \cdot m^{-2} \cdot s$), R_l is the mismatching resistance ($m \cdot s^{-1}$), and δ_{P1} is the water vapor permeability of the first layer ($kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$). Therefore, the imperfection of the interface is represented with the mismatching resistance.

For two building materials with an imperfect hydraulic contact interface in case of 1–D free wetting process, the initial and boundary conditions are:

$$At \ t = 0, \qquad w = w_0 \tag{3}$$

$$At \ x = 0, \qquad w = w_{cap1} \tag{4}$$

$$At \ x = h \qquad q = \beta \cdot (P_{va} - P_{vl}) \tag{5}$$

Where w_0 is the initial moisture content of the both layers (kg/m^3), w_{cap1} is the capillary moisture content of the first layer, h is the height (m) of the whole material, β is the mass transfer coefficient (s^{-1}), P_{vl} is the partial water vapor pressure at the open surface of the second layer (Pa), and P_{va} is the partial water vapor pressure of the ambient air (Pa). The first layer refers to the material moisture transported from, while the second layer refers to the material moisture transported to.

EXPERIMENTS AND SIMUALTION ANALYSIS

In the present study, a free wetting test on a bounded material was carried out. The bounded material is made by aerated concrete (AC) and Portland cement lime mortar S type (PCLMS). The thickness, width and height of both AC and PCLMS are 20 mm, 50mm and 15 mm, respectively. The vertical surfaces of the specimen were sealed with epoxy to ensure 1 – D moisture transport. The moisture content profile of the specimen during a free wetting test was measured with the gamma–ray attenuation method. The results are shown as marked points in Figure 1. The vertical line on the moisture content profile represents the position of the interface. During the free wetting test, the open surfaces of the AC and PCLMS were in contact with liquid water and the ambient air, respectively. The temperature of liquid water was 22.5 ± 0.1°C. The air temperature, relative humidity and velocity were 22 ± 1°C, 49.5 ± 2% and 0.1 ± 0.05m/s, respectively.

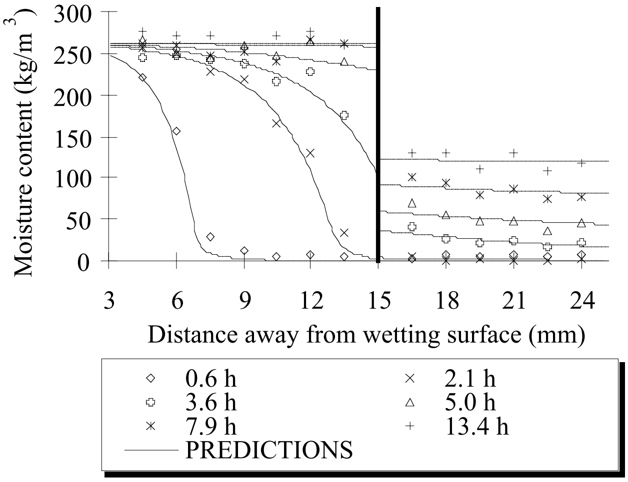

Figure 1: Moisture content profile of the specimen during the free wetting test

As shown in Figure 1, when the first layer reached capillary saturation, the contact surface of the second layer had not reached capillary saturation, indicating that there was a jump of capillary pressure across the interface. Therefore, the bounded contact interface between AC and PCLMS was imperfect hydraulic contact.

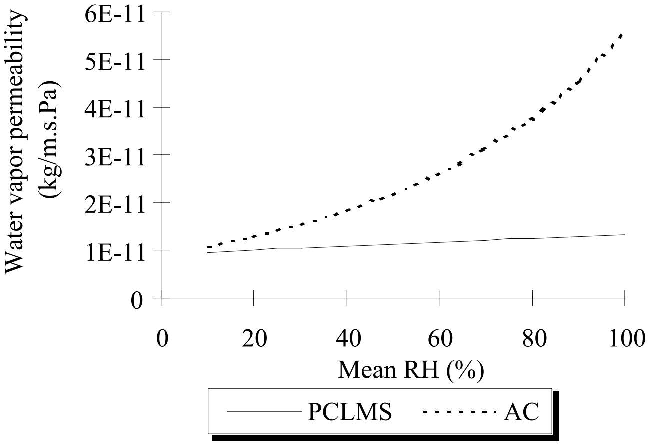

Figure 2: Water vapor permeability of AC and PCLMS

This test was then simulated with the numerical model MTIMB. The properties of the AC and PCLMS, water vapor permeability, sorption/suction isotherm and moisture diffusivity, were experimentally determined and shown in Figure 2, 3 and 4, respectively. The mass transfer coefficient was determined with Lewis relation at condition of air velocity 0.1m/s, and the air permeability was 2e–10 $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ (Lackey, et al. 1995). The partial water pressure of the air was determined with 22°C and 49.5%RH. The capillary moisture content of AC and PCLMS referenced to the moisture content at 50%RH were 263 kg/m^3 and 155 kg/m^3, respectively. According to the least error between predicted and experimental determined moisture content of the second layer, the mismatching resistance was determined and listed in TABLE 1. The predictions are shown as lines in Figure 1.

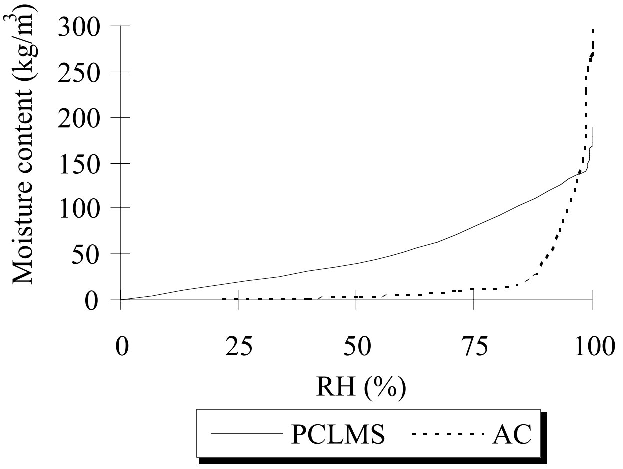

Figure 3: Moisture retention curves of AC and PCLMS

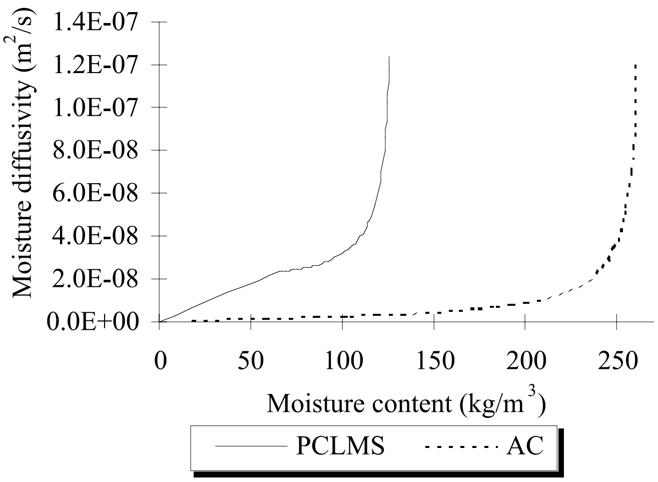

Figure 4: Moisture diffusivity coefficients of AC and PCLMS.

TABLE 1
Mismatching resistance of the interface

Time (hour)	< 3.55	3.6 – 5.0	5.0 – 7.9	7.9 – 13.4
Mismatching resistance (m/s)	1.3e +12	1.1e+12	1.0e+12	9.8e+11

Figure 1 shows that there is a good agreement between predictions of the model and experimental results, indicating that the parameters used were well measured or estimated. Therefore, the mismatching resistance listed in TABLE 1 is well determined and the prediction shown in Figure 1 is accurate. As shown in TABLE 1 and Figure 1, the variation of the mismatching resistance is relatively small after the first layer reached the capillary saturation. Therefore, the variation of mismatching resistance depends on the size of the materials. However, due to the same impact of mismatching, the mismatching resistance of the same type of interfaces should have the same range of variation, even though the variation might not be exactly the same. Therefore, it is desirable to know whether the variation of mismatching resistance has significant effect on predictions. Otherwise, those materials with the same type of interface can be estimated with a constant. In addition, because of various practical uncertainties in estimating mismatching resistance of the interface, it is also necessary to know how accurate mismatching resistance needs to be known to obtain an acceptable prediction. Since the mismatching resistance mainly affects the moisture accumulation in the second layer, according to prediction shown in Figure 1, the moisture accumulation in the second layer during the test is plotted and called as "Acc-R". Hence, it is an accurate prediction and can be used as benchmark for other predictions. TABLE 2 lists the predictions performed. Figure 5 compares predictions using the constant mismatching resistance to that using the accurate one. Figure 6 compares predictions using the accurate mismatching resistance to those using various inaccurate mismatching resistances.

TABLE 2
Simulations performed for parametric analysis

Code	Variation of the mismatching resistance listed in TABLE 1.
Acc-R	The accurate mismatching resistance is used and the results agree with experimental results well
Const-R	The mismatching resistance is taken as a constant, 1.3e+12m/s
Aver-R	The mismatching resistance of the interface is taken as average, 1.1e+12m/s
0.3R	The mismatching resistance of the interface was decreased by 70% of the accurate one
0.5R	The mismatching resistance of the interface was decreased by 50% of the accurate one
0.8R	The mismatching resistance of the interface was decreased by 20% of the accurate one
1.2R	The mismatching resistance of the interface was increased by 20% of the accurate one
1.5R	The mismatching resistance of the interface was increased by 50% of the accurate one
1.7R	The mismatching resistance of the interface was increased by 70% of the accurate one

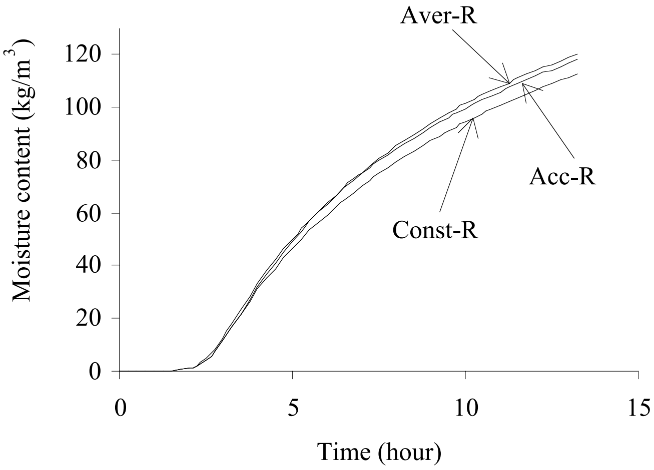

Figure 5: Comparisons of effects of constant mismatching resistance with actual one

As shown in Figure 5, even though a random constant mismatching resistance within the range of variation may result in significant error, the one based on the average mismatching resistance is close to the accurate curve. Therefore, it is acceptable to use a selected constant instead of a varied mismatching resistance to estimate moisture accumulation in building materials. Hence, the moisture transport across the same type of interface could be calculated with a constant mismatching resistance.

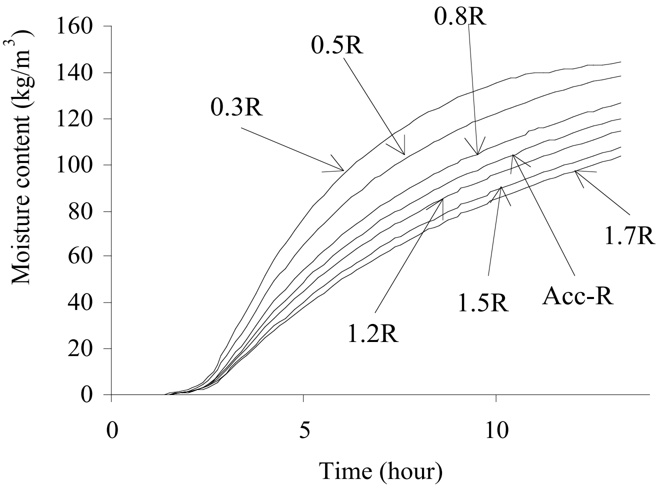

Figure 6: Comparisons of effects of uncertainty in mismatching resistance.

As shown in Figure 6, the mismatching resistance has significant effect on moisture accumulation in the second layer. As shown in Figure 6, the 20% error in mismatching resistance results in slight deviation. However, over 50% error in estimation, especially underestimation, of mismatching resistance may result in very erroneous results. Therefore, to obtain acceptable prediction results, it is desirable to control the uncertainty in mismatching resistance within 20% of the actual value.

CONCLUSIONS

By comparing experimental results to predictions of a numerical model, it was concluded that moisture transport across the same type of interface could be estimated with a constant mismatching resistance. Furthermore, it was found that uncertainty in estimation of mismatching resistance had significant effect on accuracy of the predictions. In order to obtain an acceptable prediction on moisture accumulation in building materials with imperfect hydraulic contact interfaces, the uncertainty in mismatching resistance should not exceed 20% of the actual value.

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