MOISTURE ACCUMULATION IN IMPERFECT HYDRAULIC CONTACT BUILDING MATERIALS

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ABSTRACT

This paper presents the results of a series of specially designed experiments to study moisture transport across bonded or natural contact interfaces between building materials. The results showed that the bonded or natural contact interfaces between aerated concrete and mortar are imperfect hydraulic contact. In addition, all the tested cases were simulated using a numerical model. The results showed that there was good agreement between experimental results and predictions made by the model. Based on predictions of the model and experimental results, the present study found that imperfection of an interface between different types of building materials significantly depends on the direction of the moisture transport. Moreover, the bonded interface between AC and PCLMS showed similar characteristics as the natural contact interface between AC and PCLMS: indicating that the bonding has no critical effect on moisture transport, and the bonded interface can be approximately treated as the natural contact interface.

KEYWORDS

Moisture transport, interface, building materials, imperfect hydraulic contact.

INTRODUCTION

Moisture has been identified as a major factor affecting durability of building materials. Moreover, moisture accumulation in building envelopes results in poor performance of HVAC and indoor air quality. Since moisture transport in the building envelope normally involves interface phenomena, it is important to gain better understanding of the impacts of an interface between building materials on moisture transport. When two materials have good physical contact without penetrating pore structure of each other, the interface between these two materials is called as natural contact interface. Bonded interface refers to the interface between bonded materials. The special features of bonded interface are that two materials are attached together through interactions between them and difficult to separate. Many studies (e.g., Pel, 1995, and Qiu, et al 2002) demonstrated that natural contact or bonded interfaces between building materials resist moisture transport, i.e., imperfect hydraulic contact. Although there were a lot of achievements in previous studies, the characteristics of imperfect hydraulic contact interfaces are still not clear. In addition, the impacts of the bonding on the moisture transport have not been studied. This paper presents the results of a series of experiments to study characteristics of bonded or natural contact interfaces between building materials. Moreover, using a numerical model, the impacts of the bonding on the moisture transport are also investigated.

EXPERIMENTAL RESEARCH

Test Materials

In the present study, the PCLMS (**P**ortland **C**ement-Lime **M**ortar **S** type) and AC (**A**erated **C**oncrete) was utilized to study the impacts of natural contact or bonded interfaces between building materials on the moisture transport. The properties of AC and PCLMS were experimentally determined. The moisture retention curves of AC and PCLMS were measured using pressure plate and relative humidity chambers, and shown in Figure 1. Figure 2 shows the moisture diffusivity coefficients of AC and PCLMS, which were measured using gamma ray attenuation method. The water vapor permeability of AC and PCLMS were measured with wet and dry cups methods, and shown in Figure 3.The specimens used in the free wetting tests are shown in TABLE 1. The width and thickness of all specimens were 50mm and 20mm, respectively. All vertical sides of specimens were sealed with epoxy to ensure 1 – D moisture transport.

TABLE 1
Specimens used for free wetting tests

Specimens	First layer (height)	Contact	Second layer (height)
A	AC (15mm)	Bonded together	PCLMS (15mm)
B	AC (15mm)	Natural contact	PCLMS (15mm)

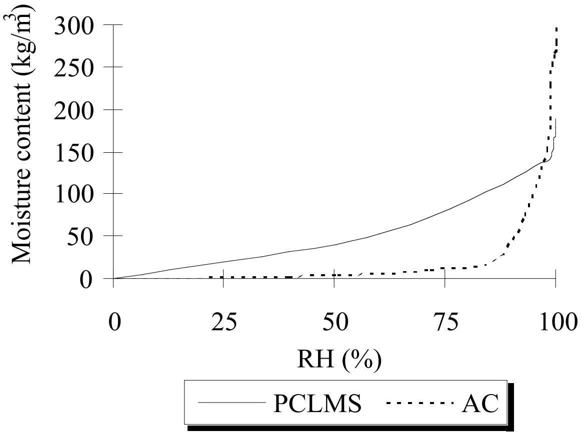

Figure 1: Moisture retention curves of AC and PCLMS.

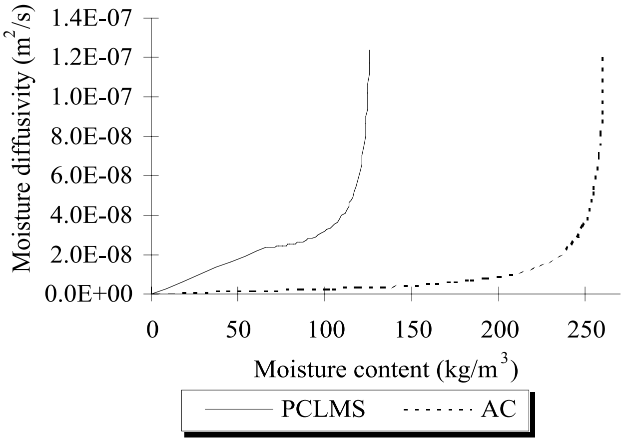

Figure 2: Moisture diffusivity of AC and PCLMS.

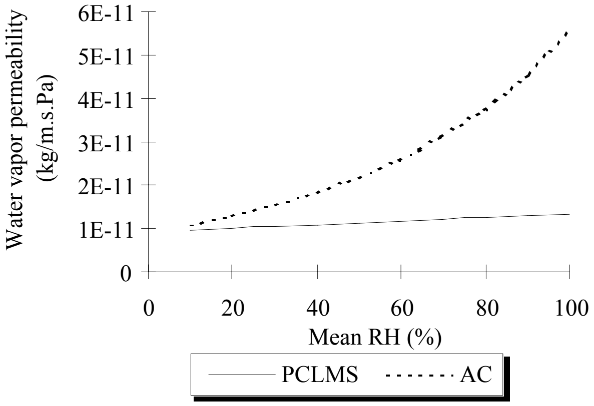

Figure 3: Water vapor permeability of AC and PCLMS.

Test Conditions

The tests performed are listed in the TABLE 2. Before the tests, all specimens were dried in a 50% RH chamber to ensure the same initial conditions. The temperature of the liquid water and ambient air were 22.5±0.1°C and 22±1°C, respectively. Air velocity and relative humidity were 0.1±0.05m/s and 49.5± 2%, respectively.

TABLE 2
Free wetting tests performed

Test No.	1	2	3	4
Specimens	***A***	***A***	***B***	***B***
Wetting surface	AC	PCLMS	AC	PCLMS

Experimental Results

The moisture content profiles of the specimens during the tests are shown as marked points in Figures 4 – 7.

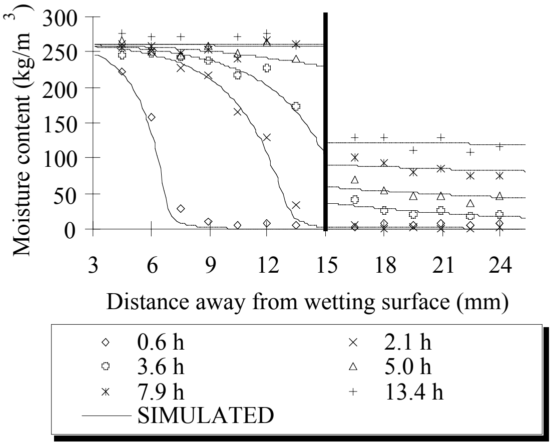

Figure 4: Measured and predicted moisture content profiles of ***A*** during test 1.

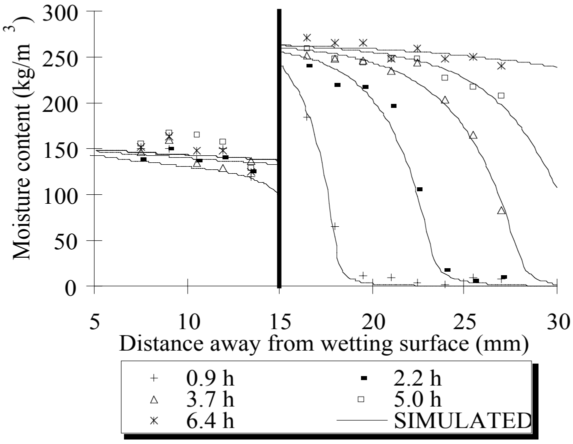

Figure 5: Measured and predicted moisture content profiles of ***A*** during test 2.

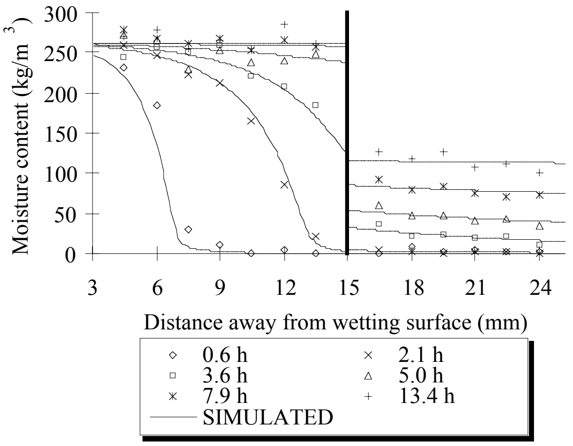

Figure 6: Measured and predicted moisture content profiles of ***B*** during test 3.

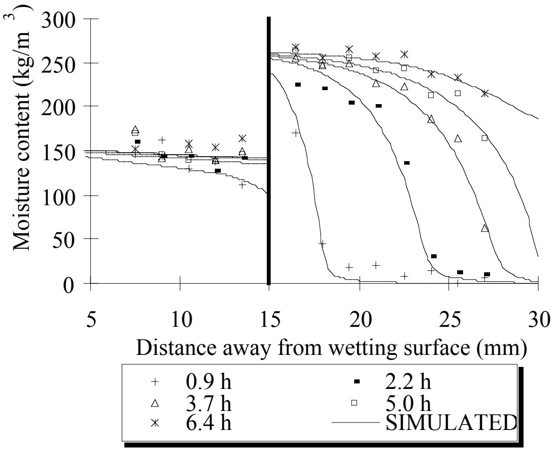

Figure 7: Measured and predicted moisture content profiles of ***B*** during test 4.

The vertical lines on moisture content profiles represent the positions of the interfaces. As shown in Figures 4 and 5, irrespective of the direction of moisture transport, the moisture content of the second layer had not reached capillary saturation after the first layer near the contact surface reached capillary saturation. This indicates that there was a jump of capillary pressure across the bonded interface between AC and PCLMS during wetting process. The similar phenomenon could also be found in Figures 6 and 7: indicating that there was also a jump of capillary pressure across the natural contact interface between AC and PCLMS. Therefore, bonded or natural contact interfaces between AC and PCLMS were imperfect hydraulic contact.

MODELING ANALYSIS

In order to obtain detail information such as imperfection of an interface between building materials from experimental results, all the tested cases were simulated using a numerical model developed by Qiu et al (2002). The governing equation of moisture transport in the material is:

$$\frac{\partial w}{\partial t} = div\left(D_w \nabla w + \frac{D_w}{\partial P_c / \partial w} \rho_w \vec{g} \right) + div(\delta_v \nabla P_v) \tag{1}$$

Where, D_w is the moisture diffusivity coefficient ($m^2 \cdot s^{-1}$), w is the moisture content ($kg \cdot m^{-3}$), P_c is the capillary pressure (Pa), ρ_w is the density of liquid water ($kg \cdot m^{-3}$), g is the acceleration of gravity ($m \cdot s^{-2}$), δ_v is the water vapor permeability ($kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$), and P_v is the partial water vapor pressure (Pa). This model considers the increased length of the path for moisture transport due to mismatching as the source of imperfection of the interface, and assumes that moisture flow across interface is resisted by the mismatching resistance resulting from this increased length of path for moisture transport and is forced by the unbalanced capillary pressure of two contact surfaces. In addition, this model assumes that an interface with good physical contact has no effect on water vapor transport. Therefore, for the tests performed, the initial and boundary conditions become:

For both layers:

$$At\ t = 0, \qquad w = w_0 \tag{2}$$

For the first layer:

$$At\ x = 0, \qquad w = w_{cap} \tag{3}$$

$$At\ x = h_1, \qquad q_1 = \frac{P_{c2} - P_{c1}}{R_l} + \delta_{P1} \frac{\partial P_v}{\partial x} \tag{4}$$

For the second layer:

$$At\ x = 0, \qquad q_2 = -\ q_1 \tag{5}$$

$$At\ x = h_2 \qquad q_3 = -\beta \cdot (P_{vl} - P_{va}) \tag{6}$$

Where, w_0 is the initial moisture content. w_{cap} is the capillary moisture content ($kg \cdot m^{-3}$), h is the height (m) of the material, β is the mass transfer coefficient (s^{-1}), P_{vl} is the partial water vapor pressure at open surface of the second layer (Pa), and P_{va} is the water vapor pressure of the ambient air (Pa). According to the least square error between the experimental results and simulations of the model, the mismatching resistances were determined and listed in TABLE 3. The mass transfer coefficient was estimated using the Lewis relation (Lackey, et al 1995). Capillary moisture content of AC and PCLMS referenced to moisture content corresponding to 50% RH are $263 kg/m^3$ and $155 kg/m^3$, respectively.

TABLE 3
Mismatching resistance of A and B (m/s)

Time (hour)	< 3.55	3.6 – 5.0	5.0 – 7.9	7.9 – 13.4
Specimen A in test 1	1.3E +12	1.1E+12	1.0E+12	9.8E+11
Specimen B in test 3	1.7E +12	1.4E+12	1.2E+12	1.1E+11
Time (hour)	< 0.9	0.9 – 2.2	2.2 – 3.7	3.7 – 5.0
Specimen A in test 2	2.8E +9	2.4E+9	2.3E+9	2.2E+9
Specimen B in test 4	3.6E +9	3.0E+9	2.9E+9	3.0E+9

The predictions are shown as lines in Figures 4 – 7. As shown in Figures 4 and 5, the predictions made by the model agree well with experimental results. Similarly, the good agreement between predictions of the model and experimental results could also be found in Figures 6 and 7. Therefore, the parameters used in predictions were well determined. As shown in TABLE 3, the mismatching resistance was different for the directions of moisture transport. This may result from different properties of AC and PCLMS. Compared to AC, which has high porosity (75%volume) and is dominated with pores with diameter over 500μm, PCLMS has much lower porosity (25.4% volume) and is dominated with pores with diameter between 500μm and 1000μm (Qiu et al 2002). Therefore, the impacts of mismatching are different for PCLMS and AC. As a consequence, the increased length of the path for moisture transport is different for the different directions of moisture transport and thereby, the mismatching resistance significantly depends on the direction of moisture transport. Moreover, TABEL 3 also shows that, the mismatching resistance of natural contact interface between AC and PCLMS was in the same range and followed the same trend as bonded interface between AC and PCLMS. This suggested that bonding has no critical impact on moisture transport and the bonded interface could approximately to be treated as the natural contact interface.

CONCLUSIONS

The experimental results showed that a bonded or natural contact interface between AC and PCLMS is imperfect hydraulic contact. Furthermore, the present study found that the imperfection of an interface between different types of building materials significantly depends on the direction of the moisture transport. In addition, based on similarity of performance between natural contact and bonded interfaces, it was concluded that bonding has no critical impact on moisture transport, and the bonded interface can be approximately treated as the natural contact interface.

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