RESEARCH HIGHLIGHT

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Summary of Research on Water Resistive Barriers

INTRODUCTION

Recent failures of face-sealed facades with tight exteriors, such as Portland cement plaster (stucco) in the lower mainland of British Columbia and exterior insulation finish systems (EIFS) in Wilmington, North Carolina, have reminded the building community about the importance of details in controlling rain penetration.

Sheathing membranes have a critical role in managing moisture that penetrates the primary cladding. These membranes are also counted on to assist in controlling vapour movement and air infiltration and exfiltration.

As a class of materials, they have been given several descriptive names. *Water* (or *Weather*) *Resistive Barrier* (WRB) is used in this *Research Highlight* for all types of sheet membranes, including bonded coatings that serve that function.

Canada Mortgage and Housing Corporation (CMHC) sponsors many activities and programs to provide better information to the building community. As part of these initiatives, CMHC formed an external consortium at Concordia University, in Montréal to study the moisture performance of WRB materials. This consortium received support from DuPont (U.S.), Fortifiber Corporation (U.S.), Hal Industries Inc., Surrey, B.C., the Homeowner Protection Office of B.C. and Concordia University. This *Research Highlight* summarizes the major findings from the research program.

RESEARCH PROGRAM

The four main objectives to the research were:

1 To develop a material classification system.

2 To review laboratory test methods for characterizing the properties of WRB products.

3 To examine various effects on WRB performance, including:

- the effect of various substrates on moisture transfer through selected WRB products
- the effect of various boundary conditions, such as water head,
- the effect of outdoor weathering on WRB properties
- the influence of various extractives and surfactants.
- the effect of fastener penetration on moisture transmission into substrates.

4 To develop a performance-oriented test methodology to more realistically characterize WRB for product standards.

There are many specialized membrane products with properties tailored for various applications. Those intended for WRB applications vary in manufacture and basic materials. The following is a classification of WRB products the consortium researchers found convenient.

Class C Asphalt-impregnated cellulose fibre WRB. These include felts and compressed building papers. The asphalt or other component imparts water resistance to the hydrophilic cellulose fibres.

Class P Polymeric fibrous WRB. These include sheet materials manufactured from spun-bonded polyolefin fibres that are hydrophobic and form a mat that repels water.

Class PP Perforated polymeric film. These sheet materials are monolithic poly films that are mechanically perforated to permit vapour to pass and to provide some resistance to water penetration.

Class M Micro-porous film WRB. These sheet materials are monolithic poly films that have particles incorporated into the material. When the film is stretched, some of the particles fall away, leaving a film with micro-pores.

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Class LA Liquid-applied (by spray or trowel) WRB. These films are formed by applying one or two coats of a liquid base-coat material to wood-based or gypsum-based sheathing. When cured, the films provide a water resistive coating on the sheathing and at joints.

Although much of the research was conducted on Class C and Class P materials and reported upon in this Highlight, all classes, except the micro-porous films, were included in the investigations. There are many types of products within each classification but this research included only some representative materials.

METHODOLOGY—CURRENT TEST METHODS

The paper, textile and polymer industries have developed test methods to evaluate membrane products for WRB applications. Their primary purpose is quality control.

These include the "boat test," the "dry indicator test," the "ponding test" and the "hydrostatic pressure test." Each tests checks certain abilities of WRB to repel or prevent moisture from passing through the membrane.

The boat test makes a small boat of the material, placing a powder that changes colour when it becomes wet inside the boat, and floating the boat. The time taken for the colour to change is a measure of the material's resistance to passing moisture.

The dry indicator test is a modification of the boat test. The experimental set-up consists of an aluminium float or a hollow cylinder with an attached wire frame clamp for mounting of the specimen and a watch glass. The test specimen's lower surface is exposed to water and the time required for moisture to pass through the specimen, as indicated by the colour change of the moisture indicator, on the specimen's upper surface, is measured.

For the ponding test, a 25 mm (1 in.) head of water is placed on the membrane. Researchers measure how long it takes for three drops of water to pass through.

For the hydrostatic pressure test, researchers apply high water heads against the membrane to determine the pressure needed to overcome the surface tension of water in the pores to allow flow to take place through them.

None of the tests provides direct information about how these materials perform in wall assemblies. Water flow has been the dominant consideration and vapour flow a secondary consideration. Some materials appear to perform better in one type of test than another. As a result of these comparisons, the consortium felt that more fundamental measurements were necessary to better understand how WRB materials function to protect walls.

METHODOLOGY—EXISTING AND NEW TEST METHODS

One method of obtaining fundamental properties of membranes is the "dry cup" and "wet cup" test in *ASTM E96*. The dry cup test exposes the membrane to a differential relative humidity (RH) of 50 per cent and measures the weight gain in a desiccant used to establish the low RH (near zero per cent). This provides a measure of the water vapour flow through the material. For the wet cup test, water is placed inside the cup instead of desiccant and an RH of 50 per cent is maintained on the outer face of the specimen. The researchers monitor the weight loss of moisture from the assembly.

For the "inverted cup test," a standardized depth of water is placed on top of the membrane in a test cup and the change in weight is measured as moisture escapes by diffusion through the membrane. Usually, the RH applied on the "dry" side is 50 per cent. This test appears to be intuitively correct for assessing vapour flow.

Requiring that the top surface be exposed to water, say to a depth of 25 mm (1 in.), with the bottom surface exposed to a known dry environment, such as that provided by a conditioned space or by a desiccant, provides very well defined boundary conditions. Under these conditions, the highest possible driving force is created for diffusion of water vapour through the material. The MIC does not need special chambers or equipment. Exploratory testing showed that the effect of moderately higher water heads did not significantly affect the results. When a desiccant is used, this test is known as the "modified inverted cup test (MIC)."

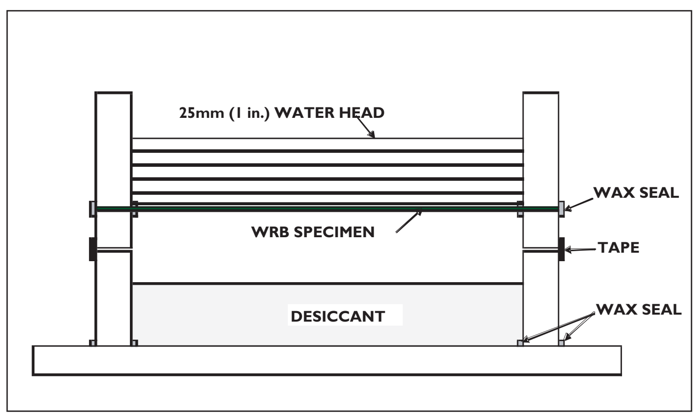

Figure 1 Modified inverted cup test

When a moisture sink of a building material is used instead of a desiccant, the test becomes an assessment of an assembly or a composite. For example, when the membrane is placed directly over OSB, plywood, gypsum or other sheathing material, the ability of moisture to move through both the membrane and the substrate is a measure of the resistance of the assembly, not just the membrane.

This reflects actual use of membranes. While the test cannot be used for obtaining fundamental properties directly, it is a very useful way to examine order-of-magnitude effects involving penetrations and some other physical parameters. This test method is designated a "moisture flux test (MF)."

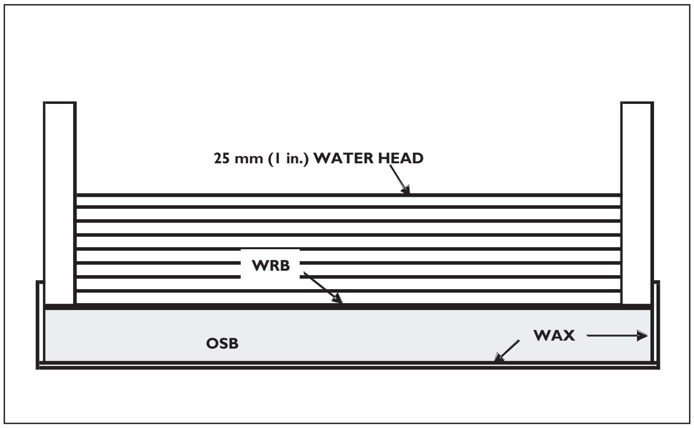

Figure 2 Moisture flux test

The third test assesses moisture flow through a membrane when both sides are exposed to water. This represents the situation when water may penetrate to wet the outer surface of a WRB and moisture from within the wall has wet the inner face at the same time.

Air entrapment in the WRB pores normally prevents water from passing through most membranes under most conditions. Water evaporates from the meniscuses and diffuses through pores as a vapour. Even when the WRB pores are only partially filled with air, water vapour diffusion was still found to dominate the transport of moisture.

Water filtration takes place only when most of the menisci are broken and there is a continuous field of water across the WRB product. A very considerable pressure applied to one side of a WRB membrane, say between 5.5 kPa and 28 kPa, is needed to break the water meniscuses in small pores of most WRB products. This high differential pressure does not occur in practice. However, a low hydrostatic differential pressure of 250 Pa (25 mm (1 in.) head of water) might be considered possible for use in a standard test to evaluate "liquid penetration resistance (LPR)" when both faces of the membrane are in contact with water. Two variables measured in this test are the time for onset of liquid flow, and the water conductivity coefficient under steady state conditions. Through-flow only occurs through the larger pores that might limit application of the membrane for this application.

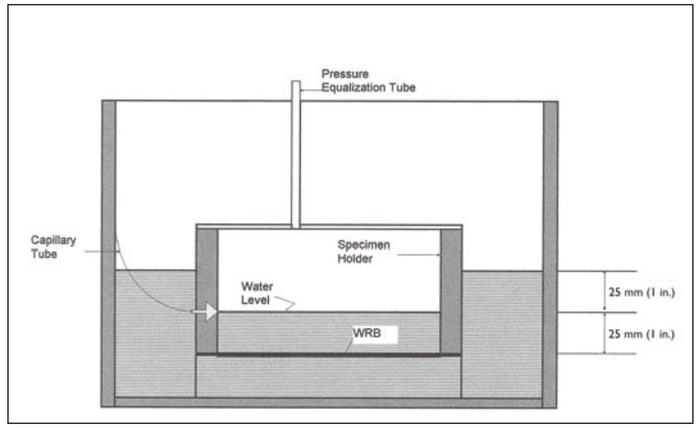

Figure 3 Liquid penetration test

RESULTS

In parametric testing, it was confirmed that the small water head employed for the MIC test had little influence on the amount of moisture transported through the membrane.

Based on tests of all Class C and P WRB products, it was found that with a water head of 25 mm (1 in.) using the MIC test, vapour flow dominated moisture transmission through the membranes for one time wetting. The explanation for the dominance of vapour flow for Class C and P WRB products tested is that the fine porous structure created by the fibrous matrix that is provided with a negative wetting angle acted as the filter, separating water molecules contained in the liquid from those contained in the vapour phase on the opposite side of the WRB. The vapour diffused freely through the fibrous network. *(Note that in this discussion we do not include materials that are mechanically perforated, where changes in physical and chemical conditions on the material surfaces during the service life may be completely different from those occurring in fibrous materials).*

In the case of liquid applied membranes (LA) these form films that do not have the same pore connectivity as C and P materials but have very low absorptivity and high resistance to liquid flow. LA membranes cannot be tested except as composites with other materials to which they are bonded.

When the MF test was employed using various materials for the moisture sink against which the WRB material was placed, the rate of moisture transport varied depending on the properties of the moisture sink used. Only the MIC test showed a constant rate of moisture transfer over time. When the desiccant was not changed frequently enough to maintain a near zero RH level during the test, the driving force for vapour transmission was reduced.

EFFECT OF SURFACTANTS

It has been shown that chemicals can be leached out of adjacent materials such as OSB or stucco. Also, in maintenance of certain siding systems, pressure-spray washing of the exposed surfaces can penetrate them and wet the WRB behind. The question was whether surfactants could affect the performance of WRB materials.

A very significant effect of surfactants (such as soap) on surface tension and kinematics was found. On the other hand, the soluble parts of wood extracts from some OSB materials were found to have a relatively small effect on the properties of pore water. However, this research also showed that moisture transfer through Class C and Class P membranes using tap water or a one per cent soap solution did not show a significant difference in moisture flow through them. This implies that the reduction in surface tension was still insufficient to break the meniscuses bridging the pores in these membranes.

EFFECT OF PENETRATIONS

When nails and staples penetrate a WRB membrane, the moisture flux increases by at least one order of magnitude when expressed as flow per unit of area (m^2) of the specimen size used. Figure 4 shows the results for two types of two WRB classes.

The moisture flux through the WRB with penetrations into a plywood substrate (using the MF method) was much higher than that obtained for an undisturbed WRB. However, the moisture flux for an undisturbed product without the presence of the plywood substrate using the MIC method was much higher than when the plywood was present. In other words, when there is air on both sides of the membrane and the vapour pressure drive is high, more moisture can be driven through it compared with the liquid flow around the fastener shank into the substrate (without it being clamped by the head of the fastener). The comparisons (with and without fasteners, and with and without substrates) simply reflect the reality that the rate of moisture flow through an assembly is controlled by the more resistive elements in it.

Research is needed on assemblies to assess the effect of moisture entry at fasteners, particularly given the stresses experienced by membranes attached under field conditions. Local water penetration and subsequent dissipation at fasteners are highly complex problems to assess.

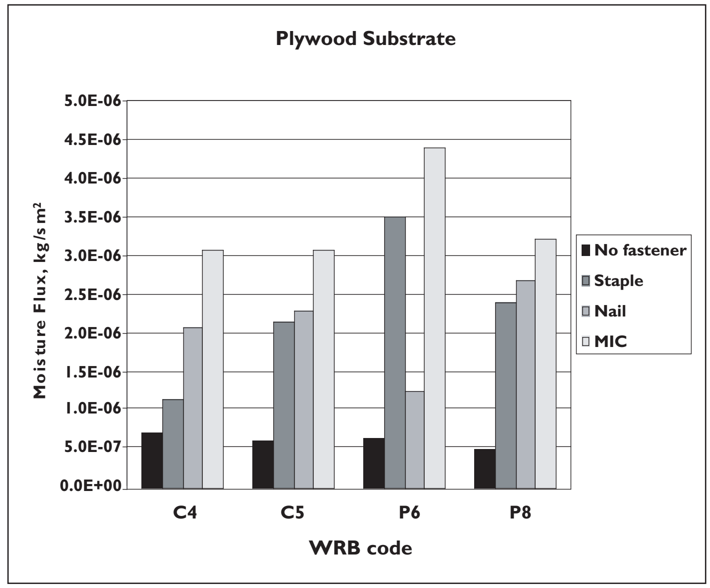

Figure 4 Moisture flux measured for two Class C and two Class P products attached with nails or staples to a plywood substrate compared with the moisture flux measured using the MIC method on the membranes without the influence of the plywood substrate

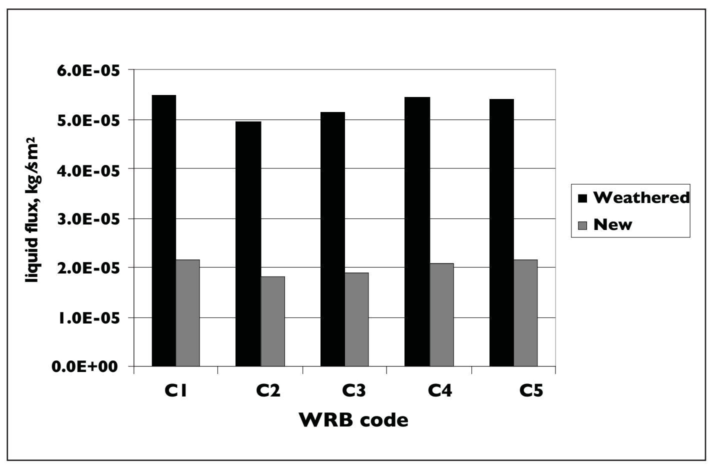

Figure 5 Liquid flux measured for several new and weathered Class C products

EFFECT OF WEATHERING

Two series of materials were aged for four months, one series starting at the end of July, 2002 and the other at the end of November, 2002. These served as a benchmark for comparisons. A small, non-significant reduction in measured moisture transmission was observed using the MIC test.

Table 1 Comparison of flow rates for one Class C product		
Line number	**Description of transport conditions**	**Moisture flux, kg/m^{2}s**
1	Liquid flux (LPR)	5.0 E–05
2	Modified Inverted Cup (MIC)	4.0 E–06
3	Double Cup (0 to 100 % RH) (ASTM E96)	2.1 E–06
4	Moisture flux with OSB sink+staple (MF)	3.3 E–06
5	Moisture flux with OSB sink (MF)	4.5 E–07
6	Moisture flux with plywood sink (MF)	4.8 E–07

Some Class C and Class P membranes were also tested for airflow resistance before and after four-month exposure on an outdoor weathering rack. The results obtained showed that this degree of weathering did not significantly affect the air permeance. Figure 5, however, shows a significant difference between these two cases, using a liquid penetration test.

This finding shows that both the MIC and LPR test methods are needed to evaluate the performance of WRB under different conditions that are more closely aligned to field conditions.

Finally, as an example of the order-of-magnitude results obtain for one sheathing paper membrane (Class C) for different tests, the mean results obtained for 3-5 replicates of the same membrane are shown in the following table.

With the exception of the double cup method, all tests listed in Table 1 involved a 25 mm (1 in.) water head introduced on the top surface of the WRB. Total moisture transfer from the water to the substrates, such as OSB or plywood, was measured with the MF method. While this method is arbitrary, as it includes combined liquid and vapour phase transport through both the WRB and the substrate, it was the only method that allowed the effects of mechanical penetrations to be assessed.

The MIC test represented the worst condition for water vapour-dominant moisture transport. Water transfer obtained by the MIC test of 5.0 E-06 kg/(m^{2}s) represents the most permeable product amongst all tests performed on Class C and P products. This value is still one order of magnitude smaller than the moisture flux resulting from water filtration.

IMPLICATIONS

This research has shown that the performance of class C and P membranes used for WRB applications is quite different from many other porous materials used in construction.

In practice, WRB materials are intended to block rainwater from passing through them to the inner wall. To this end, two physical phenomena explain how they achieve that aim—they have sufficiently small pore sizes and a negative wetting angle. In these tests, the pore size was not much affected by aging, by weathering or even by mechanical stretching of the WRB products. The air or vapour permeability was not much affected by weathering conditions expected during construction. The use of soap or wood extracts solutions also did not affect the air or vapour permeability (at least for a one-time wetting) because moisture transport through the WRB was dominated by the vapour transfer phase.

Despite this, under some combinations of weathering in the presence of wood extracts and other solutes significant increases in water transmission resulted—one could observe water droplets passing through some membranes in a time span measured in minutes instead of days. Use of the liquid penetration tests (water contact on both sides of the WRB) was found to discriminate between materials with local deficiencies and those materials where the negative wetting angle was neutralized by weathering. Some WRB products, which performed sufficiently well when assessed using existing test methods in product standards (for example, some types of PP products), experienced onset of liquid flow within a few minutes.

The lesson for designers is a simple one. To reduce the risk of water penetration the designer must eliminate the possibility for water contact on both sides of the WRB for prolonged periods. This is achieved by specifying assemblies that incorporate an air cavity on one side of the WRB. This measure is recommended for climatic conditions where the probability of water penetration is high. Under moderate climatic conditions a small air gap of a magnitude 1 to 3 mm may be sufficient, if it can be maintained. Such an air gap may be sufficient to allow free water drainage and, in combination with other measures, it may provide a substantial reduction in moisture loads acting on WRB materials. This issue is of significant practical interest and should be subject to more detailed research.

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