WEATHER RESISTIVE BARRIERS: LABORATORY TESTING OF MOISTURE FLOW[1]

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ABSTRACT

A prime function of a weather resistive barrier (WRB) is to shed the water, which may penetrate the cladding. Furthermore, the WRB functions to reduce airflow and control transport of water vapour through a wall. This means that the moisture balance of the material adjacent to WRB will be strongly affected by the water vapour flow caused by thermal drive that in turn may vary depending on the outdoor temperature or solar radiation. In other words, WRB products must be evaluated with a view to the way in which they will contribute to the performance of a wall system. This paper provides a first step in this direction.

The purpose of the reported research was not to determine how the different WRB products may perform under exposure to various climatic and service conditions but to evaluate the effectiveness of the existing test methods used in characterizing their moisture performance. To provide a benchmark for assessment of different laboratory tests, moisture transmission of four WRB products was determined under different boundary conditions. The test materials were placed between water and various types of hygroscopic sinks, which included vacuum-cast gypsum, oriented strand board (OSB), thick adsorbing paper (blotting paper) and a desiccant (calcium chloride anhydrous). The WRB materials were either placed directly in contact with the hygroscopic sink or were separated from it by an air gap.

The results indicated that the test methods described in existing material standards did not yield precise information. Neither was the information provided by these test methods suitable for input to heat, air and moisture computational models (HAM). Therefore, new methods were developed and proposed with a view to providing a better basis for evaluating performance of the WRB in wall assemblies.

Keywords: water resistive barrier, weather resistive barrier, sheathing membrane, wrap, home-wrap, drainage plane, moisture protection, weather protection, air leakage control, air retarder.

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1. INTRODUCTION

Weather resistive barriers, alternatively called water resistive barriers (WRB[3]) perform many different functions in a building envelope. WRB serves as a second line of defence in water penetration control that enables designers to prepare for the issues, which cannot be predicted. While building professionals could design a perfect structure, experience shows that because of defects created during construction process or those occurring during the service life, sooner or later water may enter the envelope. So, to ensure the second line of defence, walls are constructed to permit draining (typically on the surface of the WRB) and the drying of any excess moisture. The WRB must therefore be breathable, allowing for an outward diffusion of water vapour, while being capable of reducing vapour flow inwards when the reverse thermal gradient causes its diffusion into the wall cavity. Thus, depending on the climate and the service conditions, different types of the WRB may be incorporated in wall assemblies to optimise their performance and ensure their durability.

WRB products play an important function by controlling the flow of air through the assemblies. Energy efficiency and the resulting economic benefits related to restricting airflow are well known. It was observed that the addition of WRB reduced infiltration by about 12% on homes that had infiltration rates well below 1.1 air change per hour (Plastics, 2000)

The first stage of this research project included a review of factors that will affect the performance of the WRB in wall systems. Three issues are reported in this paper:

1. A review of test methods used in evaluation of the WRB products
2. A development of testing methods for characterisation of WRB products
3. Evaluating changes when soap or wood extracts are dissolved in the interstitial water

The later stages of this research will address moisture performance of the WRB in wall assemblies and the development of an integrated testing and HAM computation methodology to optimise the selection of the WRB products for specific climate and service conditions.

2. METHODS FOR TESTING MOISTURE FLOW THROUGH WRB

The current test methods utilised in characterizing the WRB products have been adopted from various test standards developed by respective paper, textile, and polymer industries. In spite of the same purpose, the diversity of test methods remains (see Table 1).

Table 1. Methods listed in various standards for testing moisture performance of the WRB.

Test number	Title and standard reference
1	'Boat test' (Method 181) in the US Federal Specification UU-P-31b
2	'Dry indicator test' (ASTM D779-94)
3	'Ponding test'-Canadian Construction Materials Center (CCMC)
4, 5	'Hydrostatic pressure test'-American Association of Textile Chemists and Colourists (AATCC-127)

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[3] The following classification of WRB products is used in this paper:
Class C - Asphalt -impregnated cellulose fibres, Class M - Micro-porous film; Class P - Polymeric fibres,
Class PP - Perforated polymeric film; Class LA - Liquid-applied (trowel) film.

There are three distinct types of tests used in water transfer testing:

(i) tests performed without the use of hydrostatic pressure,
(ii) tests that utilise low hydrostatic pressure, e.g., 25-mm water head
(iii) Tests to characterise the onset of liquid flow through the membrane.

The first group of tests assesses the time it takes for the ‘dry indicator’ to change colour under a simultaneous transmission of liquid and vapour while WRB is in contact with water. A typical test involves fabrication of a small boat from the material being tested, sprinkling on a surface of the boat some powder (dry indicator) that changes colour when wet, and floating this “boat” on water.

The traditional ‘boat test’ appears to have poorly controlled boundary conditions. The moisture needed to change the color of the powder may come either as water or vapour transmission through the material or from the ambient air. Additional factors that affect the time to change the colour include: non-uniform distribution of the dry indicator, crumpling and creasing of the membrane during fabrication of the boat, the possibility of air entrapment on the underside of the boat, and the operator’s judgement in establishing the time the colour change of the indicator. Despite a number of improvements such as placing a watch glass over the dry indicator, or use of a shaker for uniform distribution of the dry indicator, these test methods are suitable for quality assurance but not suitable for performance evaluation and will not be analyzed in this paper.

The second group of tests uses hydrostatic pressure to determine the material’s resistance to water penetration under a 25-mm water head (250 Pa). For acceptance one requires no more than 3 water drops to pass through the WRB within the 2-hour test. This test method is worth further analysis despite the uncertainty introduced by the visual method of detection of water droplets appearing on the underside of the specimen, and poorly specified conditions of air temperature and humidity at the lower boundary of the test specimen.

The third group of tests employs much higher water heads, ranging from 0.55m to 2.8 m. In the method 4 (Table 1), the water is supplied automatically to the top of WRB at a constant rate of 600 mm per minute. The method 5 (Table 1) uses electronically controlled pump to apply pressure corresponding to 600 mm per minute to the underside of the specimen. These tests are used to measure the pressure needed to break the water menisci and create an instantaneous liquid flow. Again, these tests methods are suitable for QA but not for our purposes.

The above review shows that the existing test methods assume water flow to be dominant factor in moisture transmission and disregard the possible effects of water vapour flow. To analyze validity of these assumptions one must step backward and examine how changes in boundary conditions can affect moisture transmission through the WRB. To this end, the WRB products were placed between water and various types of hygroscopic sinks. Vacuum-cast gypsum, oriented strand board (OSB), thick adsorbing paper and a desiccant were used as hygroscopic sinks. The WRB materials were either placed directly in contact with the hygroscopic sink or were separated from it by an air gap.

3. EFFECT OF THE SUBSTRATE (MOISTURE SINK) ON MOISTURE TRANSMISSION THROUGH THE WRB

Figures 1 and 2 show the rate of moisture transmitted through the class C and class P membranes and Figure 3 through the class P membranes (see footnote 3). It is evident that the rate of transmission is dependent on the type of moisture sink used. The rate of transmission is highest, and almost constant from the beginning to the end of the test, when the desiccant was used alone. The rate of transmission with moisture sinks other than the desiccant falls off after some period of time.

The rate of moisture transmission tested with the hygroscopic sinks other than the desiccant shows a variation which may be explained by the superposition of a few effects. In addition to the possible change in the transmission properties of the WRB product associated with the changes in its moisture content, there is a change in the moisture content of the hygroscopic sink. Evidently, the magnitude of this change depends on the nature of the hygroscopic sink material. In turn, the change in moisture content of the hygroscopic sink affects the partial pressure of vapour at the material surface, which in turn modifies the driving force for the vapour flow through the WRB.

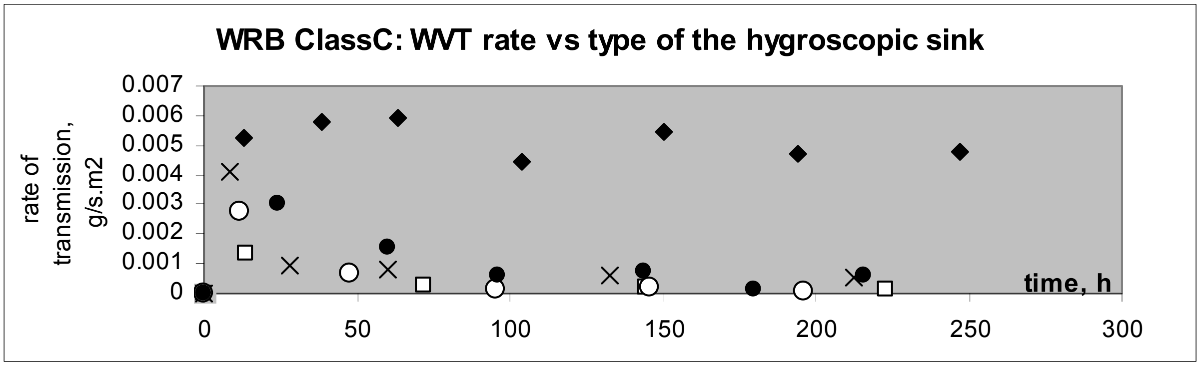

Figure 1. Transmission rates of WRB class P product with various hygroscopic sinks. Test employed the following hygroscopic sinks ♦ - desiccant, • - gypsum, **o** - blotter, - empty container (no hygroscopic sink), × - OSB

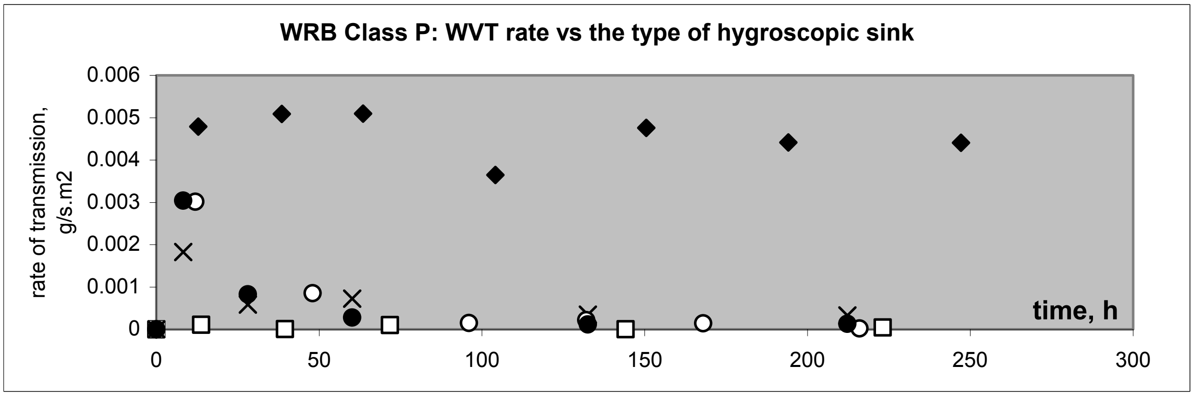

Figure 2. Transmission rates of WRB class P product with various hygroscopic sinks. Test employed the following hygroscopic sinks ♦ - desiccant, • - gypsum, **o** - blotter, - empty container (no hygroscopic sink), × - OSB

Figures 1and 2 make it clear that moisture transmission through the WRB covered with water on one side may vary depending on the conditions at the on the other side. Bomberg et al (2002) who studied this issue in a detail reached the conclusion that all moisture transmission test conducted with the water on the top side and a hygroscopic sink or an empty container on the bottom side are not consistent, even if the depth of the container was reduced to a few millimetres. Conversely, by maintaining a constant RH of air (e.g., by using desiccant) can provide a steady level of moisture transport through the WRB.

In effect, to achieve a repeatable and a reproducible laboratory test, in which the WRB was exposed to a layer of water on the upper surface. The lower boundary conditions had to be defined by one of the two following two conditions: (1) Near-zero relative humidity maintained by a frequently changed desiccant (i.e., an inverted cup test as described in ASTM E96), or (2) water in contact with the material on both sides of the WRB (measurement of water filtration when a continuous water field stretches from the upper to the lower boundary of the WRB).

4. NEW LABORATORY TEST METHODS

The ASTM E96 inverted cup method with a standardised depth of water is a method that intuitively appears to be correct. The boundary conditions on both sides of the material are well defined. They correspond to the worst set of conditions, namely water with hydrostatic pressure of 250 Pa and driving force for water vapour diffusion is at the maximum (the difference between nominal 100 % RH and 0% RH). We denote this test method as a *modified inverted cup (MIC)* and recommend using this test method for material characterisation in standards.

4.1 Modified inverted cup for measuring water vapour transmission

Figure 3 shows that the results obtained from the modified inverted cup test are not significantly affected by the change in the thickness of the water layer placed on the top of the WRB membrane.

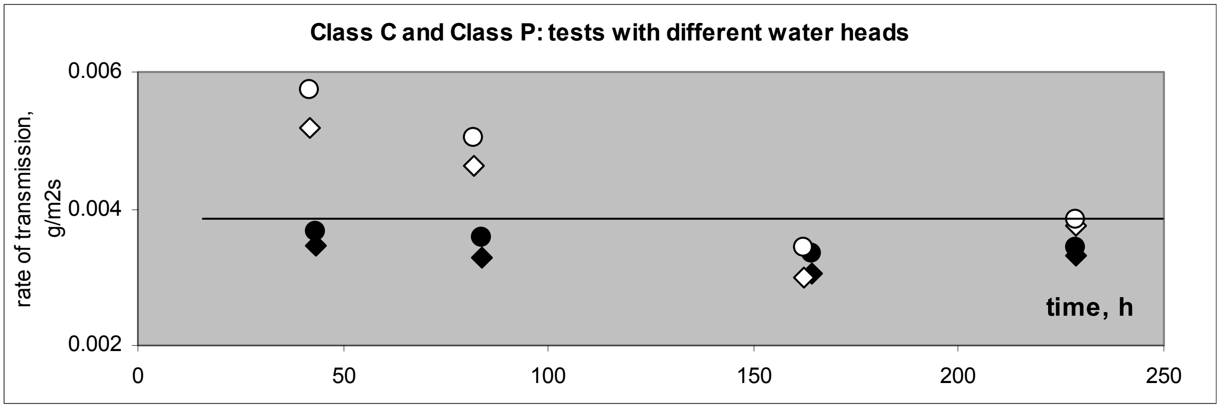

Figure 3. Rate of moisture transmission measured on class C and P products at 25-mm and 100 mm water head. Test employed the following membranes ♦ - Class C - 250 Pa pressure, ◇ - Class P - 250 Pa pressure, ● - Class C - 1000 Pa pressure, ○ - Class P - 1000 Pa pressure.

Figure 3 shows that (since for both of the tested WRB the breakthrough hydrostatic pressure was significantly higher than 100 mm), despite of the increased height of the water head from 25 mm to 100 mm, there is no observed difference in transmission rate. In other words for these two types of WRB products (four materials tested) the water vapour flow clearly dominates over the liquid flow.

4.2. Moisture characteristics needed for the input to HAM models

Grunewald and Bomberg (2002) postulated that two moisture transport characteristics must always be determined; namely, the dry cup water vapour transmission test (WVT, ASTM E 96) and the saturated liquid conductivity coefficient. (Alternatively, the liquid conductivity can be determined indirectly, namely calculated form the measurement of water absorption coefficient). These recommendations also apply to the WRB products.

To determine the saturated liquid conductivity coefficient one must ensure continuity of the liquid phase flow. To this end one must eliminate the air entrapped in the WRB pores by use of vacuum saturation or application of water pressure higher than the so-called bubbling point of the membrane (i.e., pressure at which an air bubble can pass through the membrane that is saturated with water). To illustrate the extent to which measurement of the liquid filtration may be influenced by the entrapped air we performed two series of tests: (A) untreated specimens were exposed to water on both sides and 150-Pa pressure difference was applied across them, (B) prior to the test being conducted, the specimen was sealed in the specimen holder, immersed in a water tank to which vacuum was applied to de-air the specimen. The actual test was conducted at a 250 Pa pressure difference.

Figure 4 shows the results of test series A performed on four WRB products.

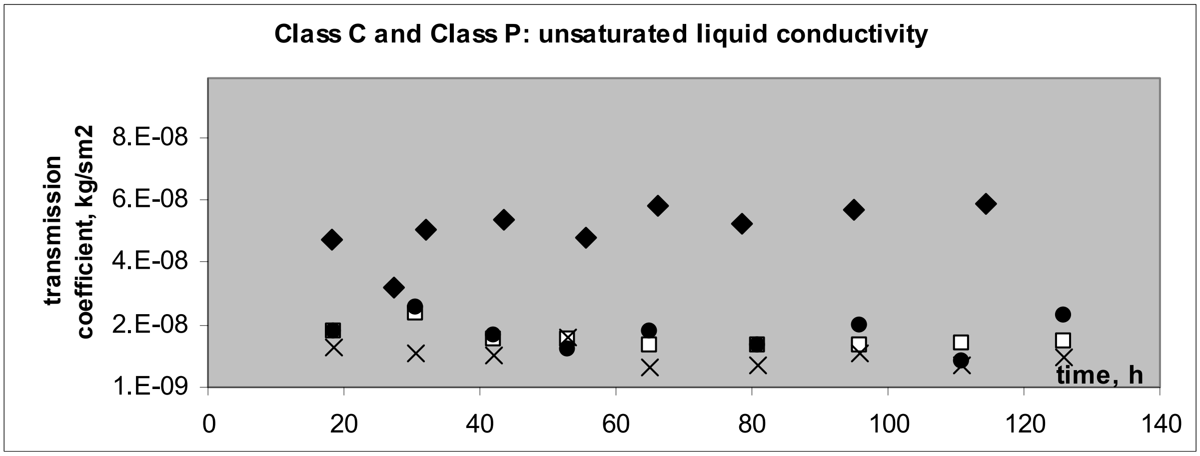

Figure 4. Unsaturated liquid conductivity coefficient measured on class C and class P materials. Symbols denote ♦ product class C, □ product class C, ● product class P and ✖ product class P.

Results shown in Figure 4 are consistent, and yet these results may vary about two orders of magnitude when compared with those obtained under conditions of the series B. The measurement of unsaturated liquid conductivity requires addressing additional experimental considerations. Until such time this test methods is not discussed.

For time being, we use another experimental technique where a one-dimensional, cumulative flux of water entering upwards into the specimen immersed about 2 mm is presented as a linear function of the square root of time. The slope of this function represents so called water absorption coefficient (Figure 5).

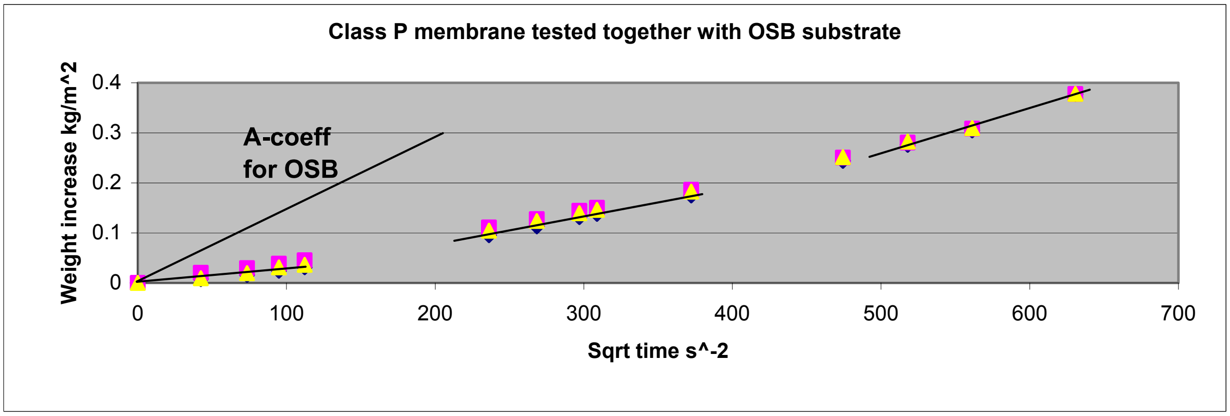

Figure 5. Water absorption coefficient measured on a class P membrane and OSB-substrate composite.

From theoretical analysis one may infer the water absorption coefficient of a composite may vary. At the initial stage of water absorption, this coefficient is governed by the properties of the material surface. When water penetrate deeper into the composite the properties of the substrate will play more important role and after a sufficiently long period the water absorption coefficient of this composite will depend mainly on that of the substrate. To gain insight into the retardation of water flow provided by the WRB one must focus on the initial stage of the absorption process. We shall use the first hour results as a valid measure of the retardation offered by the WRB.

5. APPLICATION OF NEW TEST METHODS

We now will examine changes in liquid and vapour transfer through the WRB when either soap (Figure 6) or wood extracts are dissolved in the interstitial water.

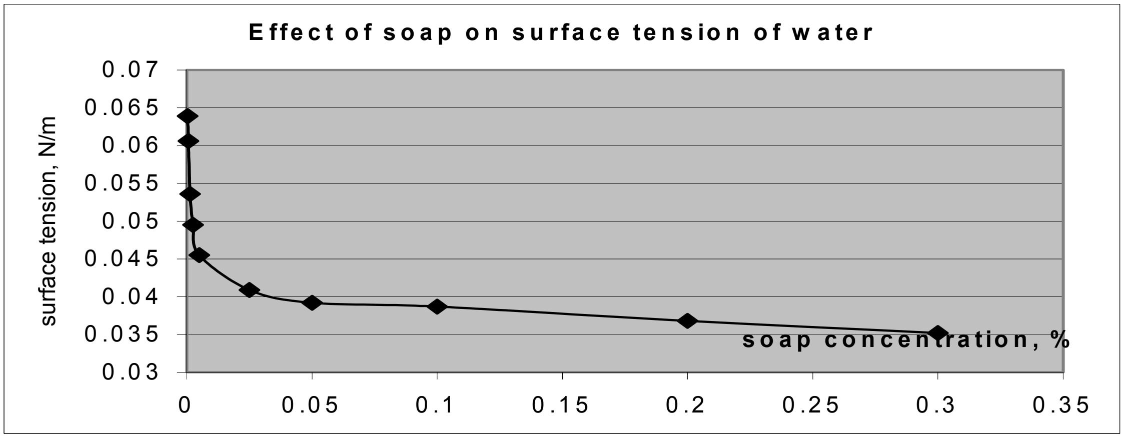

Figure 6. Changes in surface tension as a function of the liquid soap concentration

5.1. Effect of soap and wood extracts on surface tension of water.

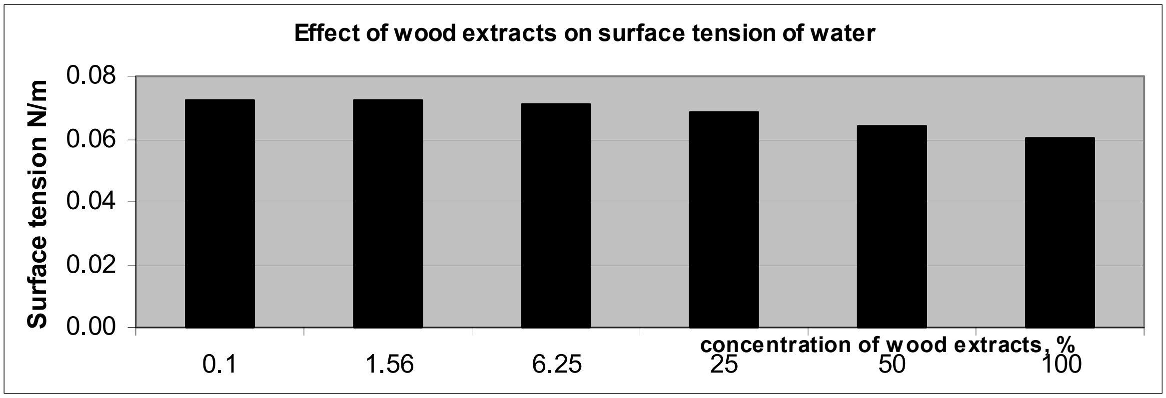

Figure 7. Surface tension of water vs. concentration of the wood extracts.

Figure 6 shows that even small quantities of soap in water (concentration as low as 0.01%) can have a significant effect on the surface tension of the water. Conversely, Figure 7 shows that the differences between surface tension of water and that of wood extracts[4] obtained from oriented strand board (OSB) are small.

To complement measurements of surface tension, the kinematic viscosity of the tap water, the soap solution, and the wood extracts was also measured[5]. The magnitude of relative changes of the kinematic viscosity is similar to that of the surface tension. The kinematic viscosity values were: $\nu = 0.68$ mm^2/s for tap water, $\nu = 0.77$ mm^2/s for the wood extract, $\nu = 1.15$ mm^2/s for 1% solution of the liquid soap

5.2. Moisture transmission measured with MIC using tap water and wood extracts

Table 4 shows moisture transmission measured with MIC the tap water, and the wood extracts.

Table 4. Effect of wood extracts on transmission coefficient, kg/m^2 s Pa, obtained from MIC test method.

Product code	Transport coefficient, kg/m^2 s Pa-	
	Tap water	wood extract
Class C	1.29E-09	1.10E-09
Class C	1.65E-09	1.24E-09
Class C	0.79E-09	0.88E-09
Class C	1.00E-09	1.07 E-09
Class C	0.96E-09	0.83E-09
Class P	1.23E-09	1.02 E-09
Class P	1.23E-09	1.02E-09

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[4] The OSB extract was prepared by dissolving soluble substances from OSB in warm water.

[5] These measurements were performed at 40 °C

Class P	1.01E-09	0.93E-09
Class PP spec 1	1.37E-09	--
Class PP spec2 & 3	3.25E-08*	--
Class PP spec1-3	3.2E-08*	--
Class PP spec 1	6.24E-10	--
Class PP spec2 & 3	3.6E-08*	--

Note that (*) denotes the case when direct penetration (visible water flow) of the water was observed. This was observed only on class PP specimens.

Table 4 shows that for class P and C specimens the differences in MIC conducted with the tap water and the wood extracts are small.

5.3. Characterization of moisture transmission with the means of an A-coefficient

Table 5. Water absorption coefficient measured on the WRB products combined with a drywall substrate

Specimen	A-coefficient	Standard deviation
Class C	1.0E-03	1.56E-05
Class C	1.4E-03	2.86E-05
Class P	3.8E-04	7.2E-06
Class P	2.6E-04	2.6E-05
Class PP	2.3E-04	4.6E-05
Class PP	2.7E-04	3.5E-05

Note the drywall substrate has A_w =2.0E-03 kg/m^{2}s$^{0.5}$

Table 5 shows measurements on samples of two products from each class C, P, and PP. The information presented in Table 5 needs an additional comment. While water absorption coefficient for a class PP membranes determined with this technique is much lower than that of class C products, it has been previously noted that at least two out of the three class PP products showed penetration of water. Conversely, class C and class P products did not show any visible water penetration.

5.4. Effect of chemical interaction during weathering with wood extracts

Despite expectations to the contrary, this study demonstrated that wood extracts do not significantly affect the rate of water transmission. It was conceivable that some factors contributing to the observed field effects, (e.g., presence of dust particles coming from the air or leached from adjacent materials) were not represented in the laboratory testing. One of such factors could be presence of electro-osmotic potential created by electrically charged particles interacting with the wood extract solutions. To verify this assumption the same membranes as those listed in Table 5 were subjected to the following weathering sequence.

- A mixture of bentonite and OSB extract solution made at Concordia University (ratio: 25g/L) was prepared and poured on every previously tested WRB membrane. The amount of 0.1 L mixture was spread on the specimen over a 0.5 m^2 area. The mixture was allowed to dry at a 25 ± 2°C room temperature.

- After the drying of the bentonite/wood extract solution was completed the same quantity of wood extract (this time without bentonite) was poured on the test specimen, allowed to dry, and repeated three more times.

- The total extract applied in five applications is equivalent to 1L/m^2 but only 5 g of bentonite was applied in the first wetting cycle.

Two series of interactively aged specimens were prepared for testing. Series A involved 5-cycle exposure of the WRB and series B involved two identical cycles (i.e., the WRB being exposed to 10 cycles with the 1st and the 6th cycle involving addition of bentonite to the wood extract solution). Results obtained with water absorption coefficient are listed in Table 6.

Table 6. One hour water absorption coefficient, kg/$m^2s^{0.5}$, measured on WRB products combined with the drywall substrate

Specimen	Initial	After 5 cycles	After 10 cycles
Class C	1.05E-03	1.28E-03	1.76E-03
Class C	1.39E-03	1.83E-03	2.28E-03
Class P	3.81E-04	2.00E-03	2.50E-03
Class P	2.58E-04	1.35E-03	1.38E-03
Class PP	2.29E-04	3.60E-03	5.79E-03
Class PP	2.73E-04	7.77E-03	8.75E-03

The effect of interactive aging is clearly visible for both polymeric materials. While class C showed initially one magnitude higher water flow rate, the effect of chemical interaction for these materials is much smaller than for class P and class PP materials. In effect, after the interactive aging class C and P materials indicate flow rate of the same magnitude while class PP products show the highest rate of water flow. One should also note that A-coefficient for class P and C membranes is below that of the substrate (A_w =2E-03 kg/$m^2s^{0.5}$). But the class PP membranes exceed this value. This indicates that water has accumulated between the membrane and the substrate, despite of the fact that this test does not use hydrostatic pressure. In instances when the absorptive capacity of the drywall was not sufficient to pick the water that penetrated through several WRB membranes during the test, the water, which accumulated at the specimen/drywall interface, was wiped.

Specimens subjected to interactive aging were also tested with the MIC test method and the results are shown in Table 7.

Table 7. MIC permeance coefficient, kg/(m^2sPa), measured on fresh and aged WRB products.

Specimen	Initial	After 5 cycles
Class C	9.98E-10	1.02E-09

Class C	9.62E-10	1.03E-09
Class P	1.37E-09	1.12E-09
Class P	1.01E-09	0.88E-09
Class PP	6.93E-10	6.94E-09
Class PP, spec 2	As above	1.02E-07
Class PP, spec 3	As above	4.8E-08
Class PP	2.28E-06	4.18E-06

Table 7 shows different results for Class P and Class C products. For these WRB products MIC method is not sensitive to interactive aging. On the other hand, variability in results obtained on class PP products appears to override possible effects of the interactive aging.

6. ANALYSIS OF THE RESULTS AND DISCUSSION

Existing tests involved either a total moisture transport (with undefined ratio between liquid and vapour contribution such as boat or dry indicator tests) or water penetration (with undefined boundary conditions at the lower surface of the tested membrane). The results obtained when the moisture transmission test was performed with various hygroscopic sinks highlighted that conditions at the lower surface of WRB may affect vapour diffusion from the WRB and thereby also the apparent rate of "water" transfer. To ensure that the test is repeatable and reproducible, one must maintain steady and well defined conditions on both boundaries of the test specimen. Placing 25-mm thick water layer on the upper boundary and the desiccant at the lower boundary of the tested specimen was an acceptable solution. Changing the desiccant frequently enough allowed to maintain the relative humidity near zero, and provided a constant driving force for vapour diffusion. This ensured a precision of the test method.

The relative humidity at the lower surface of the WRB was not constant when hygroscopic sinks such as gypsum, absorbing paper, an infrequently changed desiccant or OSB were used. It could be inferred that even a small increase of moisture content in these materials significantly increases RH at their surface. Increased RH at the surface of the hygroscopic sink, in turn, reduces the driving force for diffusion of water vapour. In effect, these observations highlight that existing water transmission tests with unspecified boundary conditions are inappropriate. *Additional errors are introduced by specifying the test period to be two hours while the transient flow conditions were observed to last for duration of few days.*

Traditional test methods attempted to quantify the onset of water penetration through the WRB products. Specifying conditions for vapour flow was, therefore, not considered as significant as specifying the water head acting on the membrane. In reality, the opposite is true in most of the cases. It is the water vapour flow that dominates over the liquid flow in the fine pores of the WRB membrane.

To understand moisture flow through the WRB membranes one must understand the nature of class C and P products where pore size is determined by the diameter of the fibre and degree of compaction during the manufacturing process. The WRB has a fine porous structure created by the fibrous matrix. A hydrophobic nature of Class P products and impartment of Class C products with asphalt provides a negative wetting angle, which acts as the filter separating water molecules contained in the liquid from those already evaporated and contained in the vapour phase. Unless there is a continuous field of water *with air purged from the WRB pores* the water meniscus created at the membrane surface exposed to air or even in the situation of partly air filled porous material the water vapour transmission typically dominates over the liquid flow.

This may not be the case with some PP products where size of perforation of the continuous film determines the critical dimension of porosity. Since the traditionally applied test methods were not able to catch these differences, we had to develop different testing methodology that also involves a hydrostatic pressure of 250 Pa.

Finally, one needs to compare the transport coefficients generated with different test methods. Table 8 shows such a comparison for a class P product for which the water vapour permeance values measured with dry and wet cups are practically identical

Table 8. Comparison of flow rates for a Class P product.

Description of transport Conditions	Transport coefficient, kg/m^2 s Pa.	Moisture density , kg/m^3	Driving force, Pa	Moisture flow rate kg/m^2s
WV permeance (100-0%RH)	0.70E-09	0.023	3,000	2.1E-06
Modified Inverted Cup	1.28E-09	0.023	3,000	4E-06
Moisture transmission test OSB	1.8E-09	unknown	unknown	
Moisture transmission plywood	1.9E-09	unknown	unknown	
Moisture transm. OSB + staple	1.3E-08	unknown	unknown	

The water vapour test involved measuring transmission between two environments, one with near100 %RH and the other near 0 %RH. The transport coefficient determined with the MIC test method is somewhat higher than that represented by the water vapour diffusion. This difference may be caused by two factors (1) typical WVT includes errors caused by the resistance of the still air layer (see Bomberg et al 2003) and (2) water in contact with the WRB is being under 250 Pa pressure. In effect, the MIC test represents the worst case conditions.

Except for double cup method, all moisture transfer tests listed in Table 8 involved a 25-mm thick layer of water placed on the top of WRB. Total moisture transfer (water plus vapour) from this water layer to substrates such as OSB or plywood was somewhat higher than MIC but was within the same order of the magnitude.

The results in Table 8 show the arbitrary character of “moisture transmission” tests that include a combination of both liquid and vapour phase transport. Since neither the composition nor the density of the mixture of liquid and vapour were known, this information cannot be used for any simulations with computer models. Considering the temperature 25 ^{o}C, the corresponding partial pressure of water vapour above the water meniscus in the WRB pores is 3.17kPa. The partial pressure of water vapour at the surface of the desiccant is near zero. A 3 kPa difference is used to calculate rate of vapour flow in the test. These results, once more clearly contradict the popular assumption that water penetration is a dominant mechanism of moisture transfer though WRB products.

Having evaluated tools for measuring moisture transmission through WRB products one can continue to examine the potential for changes in the moisture transport through the WRB products when different salts, soap or wood extracts are dissolved in the interstitial water.

Table 4 shows that water vapour permeance coefficient measured with MIC set-up –on tap water and wood extracts are similar. In contrast to this laboratory observation there were some field cases where water was assumed to have penetrated trough a weathered membrane (note that the field observations often does not distinguish between water bypassing the membrane or passing through it). Assuming that the electro-osmotic potential created by the electrically charged particles interacting with the solution of wood extracts could affect the rate of flow, some aged membranes were evaluated with MIC and water absorption test methods.

Table 6 shows that the effect of interactive aging is small for class C membranes and somewhat more significant for class P products. While class C shows initially one magnitude higher water flow rate, after aging four class C and P products indicated flow rate in the same order of magnitude. On the other hand, aged class PP products show the highest rate of water flow and even exceed the value of absorption by the substrate alone indicating that water accumulates between the membrane and the substrate. This accumulation took place in the water absorption test with hydrostatic pressure as little as 10 to 20 Pa and water flowing upward.

On the other hand, Table 7 showed that using the MIC method no significant differences were measured between the fresh and the aged membranes. The comparison between results shown in Tables 6 and 7 leads to the conclusion that when evaluating performance of the WRB as it may change with the service conditions one needs to employ both test methods.

8. CONCLUDING REMARKS

This paper is the first in a series aimed at development of an evaluation methodology relevant to the field performance of WRB products. In it, we have focused on examining the existing laboratory test methods. Thus, the results presented here are not to characterize various products, but to illustrate the scope of the use and the discriminating power of the analyzed test methods. Similarly the method used in simulating interactive aging is only to pose a question. Whether or not it relates to the field performance is unknown. To avoid traceability of tested materials, the products are only presented as class C, P and PP. Each value presented in this report is an average of a minimum three tested specimens.

Even though the moisture transfer through the WRB products is of primary importance, it was found that the existing laboratory test methods involve a number of shortcomings:

- Currently specified test methods include both liquid and vapour phase transport in an arbitrary and undefined ratio.
- Since the relative contribution from liquid and vapour transport is not known, information generated from these tests cannot be used for computer simulations.
- The initial stage of transient flow conditions typically lasts for a few days while these tests are usually limited to the period of a few hours (i.e., they do not represent steady state conditions.)

Given the shortcomings of these tests, we have proposed alternative test methods that can be used for two purposes:

- For material characterization – a modified inverted cup for water vapour permeance (MIC-WVP); were a 25mm thick water layer is placed on the top of the specimen and a frequently changed desiccant is positioned below the tested specimen
- For input to HAM models (1) the dry cup WVT (0 to 50% RH)
  (2) the saturated liquid conductivity coefficient, or
  (3) water absorption coefficient (the last two methods require more development)

These tools were used to examine the potential for changes in moisture transport through WRB products when different salts, soap or wood extracts are dissolved in the interstitial water. While Table 4 showed that water vapour permeance coefficient measured with MIC set-up –on tap water and wood extracts was similar, Table 6 involving effect of interactive aging with wood extract and bentonite mixture showed significant changes in the rate of flow that took place in polymeric materials. These changes eliminate the difference in performance of WRB products of class C and class P. On the other hand, aged class PP products show the highest rate of water flow, which exceed the value of substrate alone indicating that water accumulated at the membrane and substrate interface

The analysis of interactive aging indicates that one must utilize both methods to be able to evaluate performance of WRB under service conditions. Since the modified inverted cup was found to easily discriminate between products that did not have sufficient water resistance it was considered suitable as a means of characterization of WRB product performance for the purpose of standardization. In effect, the methodology developed in this project will permit discriminating between different levels of WRB performance, which was not possible with the test methods currently employed.

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