Do water-resistive barriers get a sunburn?

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ABSTRACT
Water-resistive barriers and air barriers provide essential functions for wall assemblies, and in order to provide adequate performance and protection they must maintain their performance characteristics over the entire design life of the structure. While designers usually rely on manufacturers' data sheets to select suitable products, product specifications often avoid any reference to durability and long-term performance properties of polymeric membranes. Manufacturers' data sheets often allow exposure of such membranes to UV for several months during the construction phase; no information is provided on how the UV light affects the performance characteristics of the membranes.

The paper describes essential functions of water-resistive barriers and durability concerns associated with polyolefin-based WRBs. Common test methods that characterize the performance and durability of these membranes are provided, and degradation mechanisms are briefly described. UV index relation with field and laboratory exposure of building materials is described, and laboratory investigations on UV exposure conducted on different commercially available water-resistive barriers are presented. Results regarding the loss of physical properties of water-resistive membranes due to temporary exposure to UV light over time are provided. Furthermore, product specifications are suggested that are needed to confine the aging properties of polymeric water-resistive barriers and to design wall assemblies that perform adequately throughout the entire lifetime of the structure.

1. Introduction

A water-resistive barrier (WRB) can perform several different functions in a building enclosure. Its primary function is to serve as a secondary line of defense and shed water that penetrates the cladding. It may also serve as an air barrier, as long as the membrane meets the performance requirements of an air barrier material and is installed as part of a complete air barrier system, including suitable sealing of overlaps, penetrations and transitions to other materials and components.

In order to provide adequate performance and protection these membranes must maintain their performance characteristics over the entire design life of the structure. While designers usually rely on manufacturers' data sheets to select suitable products, product specifications often avoid any reference to durability and long-term performance properties of polymeric membranes. Manufacturers' data sheets frequently allow exposure of such membranes to UV light for several months during the construction phase until application of exterior cladding; however, generally no information is provided on how the UV light affects the performance characteristics of the membranes.

Not only should a water-resistive barrier or air barrier be evaluated regarding its effect on the performance of a wall assembly [1], but the designer should also be provided with information on how the performance characteristics of such a barrier membrane are affected by UV exposure in field conditions during the installation phase.

This paper describes common test methods that characterize the performance of water-resistive and air barrier membranes. A brief summary of degradation mechanisms of polymeric membranes is provided. UV index relation between field and laboratory exposure of building materials is described, and laboratory investigations on UV exposure conducted on different commercially available water-resistive barriers are presented. Results regarding the loss of physical properties of water-resistive membranes due to temporary exposure to UV light over time are provided. Furthermore, product specifications are suggested that are needed to confine the aging properties of polymeric water-resistive barriers and to design wall assemblies that perform adequately throughout the entire lifetime of the structure.

2. Common test methods for water-resistive barriers

ICC acceptance criteria AC38 [2] summarizes the most common test methods for water-resistive barriers. These tests include
   - dry tensile strength tests conducted in accordance with ASTM D828 [3] or D882 [4]
   - dry breaking force tests conducted in accordance with ASTM D5034 [5]
   - Water-resistance tests conducted in accordance with ASTM D779 [6]
   - for Grade D barriers, where testing in accordance with ASTM D779 is not applicable, tests shall be conducted in accordance with AATCC Test Method 127 [7], except that the specimens shall be held at a hydrostatic head of 55 cm for a period of five hours, or alternatively as per section 4.2.2 of AC38
   - water-vapor transmission tests conducted in accordance with ASTM E96 [8], Desiccant Method
   - tests demonstrating that the material does not crack when bent over a 1/16-inch-diameter mandrel at a temperature of 32°F
   - For self-adhering polymeric-based barriers, testing conducted in accordance with Sections 5.3, 5.4, 5.5, 5.6, 5.8 and 5.9 of AAMA 711 [9] for each substrate for which recognition is sought

- When the product is to be evaluated as an air barrier material, reports of air permeance testing in accordance with ASTM E2178 [10] shall be submitted, with a requirement for air permeance less than or equal to 0.02 L/(s·m2) @ 75 Pa
- ultraviolet light exposure tests where samples are exposed to light from ultraviolet sun lamps for 210 hours (10 hours per day for 21 days). Ultraviolet light exposure shall be directed on the sample surfaces that will be exposed to sunlight in normal application. Lamps and enclosure shall be adjusted so the specimen temperature is between 135°F and 140°F (57°C and 60°C). Sunlamp bulbs shall be General Electric Type H275 RUV (275 W) or equivalent bulbs, providing UV characteristics of 5.0 W/m2/nm irradiance at a wavelength of 315 to 400 nm at 1 meter.
- accelerated aging tests where specimens are cut from the ultraviolet-light-exposed samples. The samples are subjected to a series of drying and soaking

The use of polyolefins for barrier membranes in construction differs from many other applications since these membranes are intended to fulfill their function over long time periods. Where some articles made of polyolefins are required to last only for a short time (e.g. milk bottles), others are intended to last a number of years (e.g. kitchen articles). Water-resistive barriers and air barriers are generally expected to fulfill their function for the lifetime of the structure – typically in the range of 50 years or longer.

Durability concerns therefore need to be sufficiently evaluated and understood. Frequently the short-term properties of the involved materials are being considered without evaluating their durability and degradation factors. Important to the durability of water-resistive barriers is their raw material formulation, the imposed in-service conditions during their functional lifetime, as well as the environmental conditions to which they will be exposed between manufacturing and the actual service life. The last point is of particular importance since manufacturers' data sheets typically provide an exposure limit to UV light without providing any information on how this exposure will affect the long-term performance or durability of the product. Figure 1 shows an example of degradation of a 6 mil polyethylene membrane caused by exposure to UV light.

Figure 1: Degradation of polyethylene barrier membrane due to UV exposure

Hence, it is critically important that design guidelines are provided, and that the designer has the necessary understanding of the materials and environmental conditions to choose an appropriate product and specify its maximum exposure to UV light during the construction phase.

3. Degradation mechanisms of polymeric membranes

Aging and degradation of polymers essentially takes place at the molecular level. Polymers are materials composed of large molecules of very high molecular weight. The cohesive forces of a polymer, which greatly affect the physical and chemical degradation mechanisms that can take place, are determined by the chemical composition of the polymer.
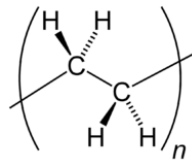
Figure 2 shows the molecular structure of polyethylene.

Figure 2: Molecular structure of polyethylene

The characteristics of the polymer depend on intermolecular forces and are greatly influenced by the chain structure (i.e. chain length, linearity, branching, cross-linking, etc.), morphology (i.e. crystallinity), molecular weight distribution, irregularities (i.e. impurities), additives (i.e. color pigments, antioxidants, UV stabilizers, flame retardants, antistatic agents, etc.), as well as by the manufacturing process itself, during which the polymer is exposed to thermal and shear stresses that will initiate degradation mechanisms. Process conditions will also determine the effectiveness of mixing additives and stabilizers into the polymer, which can influence the morphology of the end product as well as the degree of stabilization against environmental factors like heat, UV, oxygen, etc.

Essential aging and degradation mechanisms of polymers have been described in depth by Kay et al. [11]. One of the most relevant degradation mechanisms of polyolefins is oxidation, which can occur in form of thermo-oxidation, photo-oxidation, and chemical oxidation. The long-term durability and performance of polyolefin membranes can be improved through adequate stabilization with antioxidants and UV stabilizers.

In the presence of sensitizing agents, polyolefins can become sensitive to environmental stress cracking (ESC). The occurrence of ESC of stressed samples is linked to the presence of surface-active wetting agents such as alcohols and surfactants. The surface-active wetting agents don't chemically attack the polymer, nor do they produce any effect other than microscopically brittle-appearing fractures. The fractures initiate at microscopic imperfections in the material, and propagate through the crystalline regions of the polymer structure. In the absence of such surface-active wetting agents, these fractures would not occur in any reasonable time period under the same stress conditions.

In this paper, the effect of UV exposure on water-resistive barriers through accelerated weathering is investigated.

4. UV index relation with field and laboratory exposure of building materials

Since most polymers are sensitive to ultraviolet (UV) radiation, accelerated UV aging is commonly used to evaluate the degradation of polymers. During laboratory weathering, small specimens are exposed to UV light, heat, condensation and rain cycles. Solar exposure is commonly simulated using UV fluorescents or Xenon-Arc lamps, representing respectively the UV spectrum (for fluorescent lamps) and the complete sunlight spectrum from UV to infrared light (for Xenon-Arc lamps).

The most common correlation between laboratory exposure and outdoor service conditions is done through estimation of the dosage of radiant energy in the UV wavelength, taking into consideration that the UV irradiance varies with climate and latitude. Obtaining data of irradiance of a specific location is done through cumulated irradiance measurements from weather stations, frequently provided as UV index. The relation between the radiant energy of artificial weathering and the well-documented UV index as described by Beaumier [12] has been used in this paper, which is summarized below.

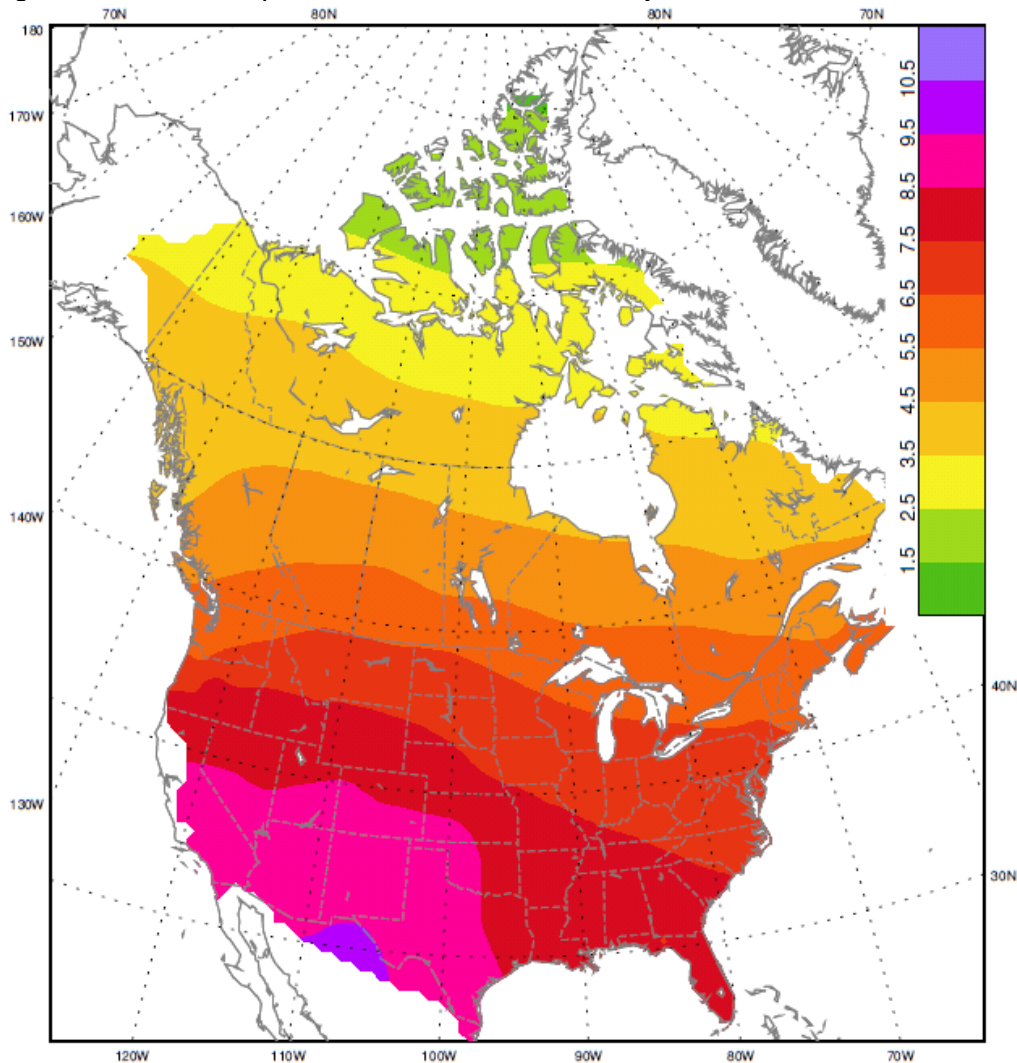Figure 3 shows a map of the mean UV index in July for North America.

Figure 3: Noon (11.00 am - 12.59 pm) mean UV Index in July, 1980 - 1990 (Source: WOUDC)

For most flexible building materials, like roof and wall membranes, polypropylene, polyethylene, polyesters, polyamides, bitumen and styrenic materials are commonly employed. When exposed outside, polymers will be challenged particularly by UV radiation, humidity, freeze and thaw cycles and cold or hot temperatures. Ultraviolet radiation will act differently on polymers by type because the ultraviolet sensitivity of a polymer will be specific to its chemical bonds and structure [13]. For instance, polyethylene will progressively absorb UV light below 220 nm, and polyethylene terephthalate (PET) will absorb UV light below 320 nm. Energy from the absorbed UV radiation will affect chemical bonding and result in chemical degradation.

Sunlight is composed of a range of irradiance energy, varying with wavelength, named spectrum. Standard sunlight spectra are documented in ASTM G173 [14], ASTM G177 [15] and ASTM G197 [16]. These spectra are specific to conditions, i.e. latitude, orientation, year time, day time.

4.1 Parameters affecting UV weathering of polymers

Different characteristics of the atmosphere will change the relationship between the total UV radiation and the UV index. These characteristics include water droplets and other particles, ozone in the stratosphere and the angle between the surface of interest and the sun.

Albedo

Albedo is a measurement of the amount of radiation that is reflected from a surface. An albedo of zero indicates that all of the incoming radiation is absorbed and appears black, and a surface with an albedo of one is a white surface that reflects all incoming radiation [17]. The UV radiation reflected off of the surface of the earth contributes to diffuse UV radiation, especially over reflective surfaces, such as snow [18].

Humidity, clouds and aerosols

In the atmosphere, water molecules absorb approximately 70% of solar radiation, mostly in the infrared part of the spectrum. Water is almost transparent to radiation in the visible range, but there is more absorption in the red portion of the spectrum compared to blue, which results in water appearing blue. Water molecules can vibrate (including stretching and bending of molecular bonds) in various ways, and can also dissociate at certain energy wavelengths. This results in water absorbing radiation at many wavelengths, and translating the energy into vibrations. Gaseous water absorbs radiation in the UV range at a wavelength of 266 nm [19].

Clouds and particles in the atmosphere (aerosols) have complicated effects on the UV spectrum that reaches the earth's surface. The UV radiation that is transmitted through clouds can shift from the 290 - 320 nm range to the 320 - 400 nm range. Stratus clouds (uniform, flat, layered, low altitude clouds) can reduce radiation in the band between 290 - 320 nm by 75% compared to the same conditions under a clear sky. Conversely, when partly cloudy, cumulus clouds (low, billowing clouds) can briefly increase radiation in the bandwidth between 290 - 320 nm because the edges of the clouds reflect and scatter UV radiation [20].

Aerosol particles are site and time specific, and can be sulfates, carbon black, organic carbon, dust or salt. They can range in size from 10^{-4} to 10 μm. These particles can absorb and/or reflect (scatter) solar radiation, as well as influence condensation in clouds, and create ice nuclei, which also affect solar radiation [21]. Radiation scattering by particles is inversely proportional to the wavelength; therefore, the scatter for UV radiation is five to ten times greater than for visible radiation [18].

Ozone
Ozone (O_3) in the stratosphere shields the surface of the earth from UV radiation. As ozone depletion occurs, more UV radiation reaches the surface of the earth [22]. Ozone absorbs the most radiation at a wavelength of 250 nm, and this absorption is reduced by 100 times at a wavelength of 320 nm. Radiations with wavelengths from 320 to 400 nm are not absorbed by atmospheric ozone. When ozone in the atmosphere is reduced, the spectrum shifts to shorter wavelengths and the intensity of wavelengths between 290 and 320 nm is increased [20].

Surface angle and orientation of exposed surface
Time of year, latitude and the angle of the surface control how much solar radiation reaches the surface of interest. Changing the angle of the sun compared to the surface of the earth changes the amount of air (and also, therefore, the volume of aerosols that may be encountered) that the solar radiation must pass through to reach the surface of the earth [20].
The axis of the earth is tilted 23.45°, so that the northern hemisphere is closer to the sun in June, and the southern hemisphere is closer to the sun in December. The solar zenith angle depends on the latitude, date, and time.

4.2 Relation between UV index and irradiance of Xenon-Arc lamps
Beaumier [12] established a relation between the UV index and the irradiance of accelerated aging using Xenon-Arc lamp, according to ASTM G155, cycle 3 [23]. The controlled irradiance of laboratory UV aging was related to UV index by estimating the irradiance over a bandwidth of 295 to 325 nm, which wavelengths are typically damaging the polymers that are used in water-resistive and air barrier applications. The following table summarizes the results and the associated acceleration factors between laboratory artificial weathering and natural exposure conditions in different climates.

Table 1: Result summary and acceleration factors from ASTM G155, cycle 3 to natural exposure conditions

Calculated Value	Everglades, FL, USA, 25.4°N, 80.7° W., 2003	Toronto, ON, Canada, 43.8°, 79.5° W., 2011
Year Average UV Index	8.5	4.4
Acceleration – Vertical Wall Facing South	12.0	15.4
Exposure time equivalency (days)		
…of 500 hours ASTM G155 cycle 3	85 – 250 days	177 – 321 days
… of 1000 hours ASTM G155 cycle 3	171 – 500 days	354 – 642 days

5. Laboratory investigations on UV exposure of water-resistive barriers and air barriers

Laboratory investigations were done on a number of different products that are commercially available in North America.

The selected membrane products were categorized as follows:

Self-adhering water-resistive barriers and air barriers:
Product A: 2 layers polypropylene spunbond substrate with film in middle
Product B: 2 layers polypropylene spunbond substrate with film in middle

Product C: 2 layers polypropylene spunbond substrate with film in middle
Product D: 2 layers polypropylene spunbond substrate with film in middle
Product E: 2 layer polypropylene spunbond substrate with coating on outside

Mechanically fastened water-resistive barriers for open-joint cladding systems:
Product F: spunbond polyester substrate with acrylic coating
Product G: spunbond polyester substrate with acrylic coating

Mechanically fastened water-resistive barriers and air barriers
Product H: spunbond polyester substrate with acrylic coating
Product I: 2 layers polypropylene spunbond substrate with film in middle
Product J: high density polyethylene spunbond nonwoven
Product K: high density polyethylene spunbond nonwoven
Product L: polypropylene spunbond nonwoven with microporous coating
Product M: polypropylene spunbond nonwoven with microporous coating

All products were submitted to breaking force and elongation tests as per ASTM D5035-11 [24] as well as a water resistance hydrostatic pressure test as per AATCC127-2008, option 2 [7].

These test criteria were chosen since breaking force and elongation, which are very simple to measure, give a very good indication whether the specimen overall has been affected by accelerated weathering or not, i.e. if the breaking force and elongation are nearly the same before and after aging other properties will likely not have changed significantly either, whereas if breaking force and elongation have changed noticeably before and after aging it is likely that other properties have changed as well. Water penetration resistance is obviously one of the most important performance criteria of a water resistive barrier and was therefore selected to be tested as well.

The three performance criteria breaking force, elongation and water penetration resistance were measured three times, i.e. on unconditioned samples, on samples exposed to accelerated weathering for 500 hours and on samples exposed to accelerated weathering for 1000 hours. Three specimens each per product were used for the water resistance tests, and 5 specimens each per product were used for the breaking force and elongation tests.

Accelerated weathering was performed as per ASTM G155-05a, Cycle 3 [25]: Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials. The apparatus used was a water-cooled xenon arc lamp. Samples were exposed to cycles of 90 minutes of light (70% RH, temperature of black panel 77ºC) and 30 minutes of light with water on the surface of the specimens. The illumination was 0.35 W/m^2/nm measured at 340 nm. Borosilicate inside and outside filters were used.

6. Results

The results of the laboratory investigation are shown in the figures below, with products of each particular category grouped in one chart showing their respective reduction/increase of the tested performance criterion.

Self-adhering water-resistive barriers and air barriers
Figure 4 shows the change in breaking force for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
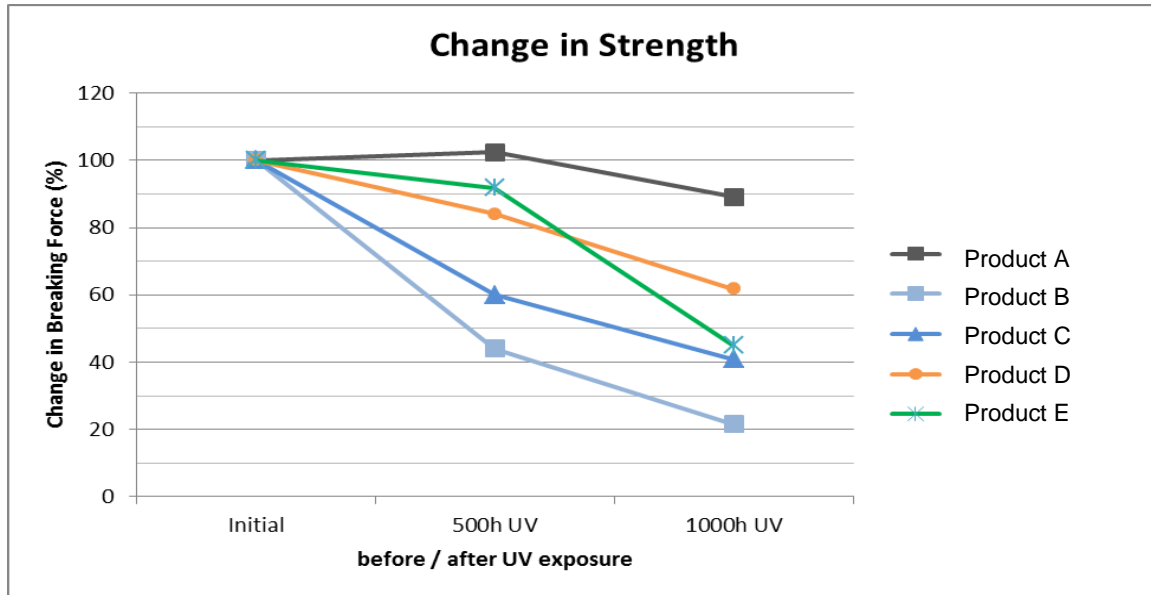

Figure 4: Change in breaking force between product samples before and after accelerated weathering

It is evident that the breaking force for Product A increases slightly above its initial value after 500h of accelerated weathering which is a typical indication of the onset of aging through crosslinking of the molecules. It maintains around 90% of its original breaking force after 1000h of accelerated weathering. The breaking forces of products B, C and D, which are comparable in their layer configuration (2 layers of spunbonded polyolefin with a film as middle layer) are dropping rapidly to after 500h of accelerated weathering, and continue to drop to values between 20 and 60% of their original values respectively after 1000h of accelerated weathering. Product E, which has a coating on the outside of a double layer of spunbonded polypropylene drops at a slightly lesser rate to around 92% of its original strength after 500h and then drops at a much faster rate to 45% of its original strength after 1000h of accelerated weathering.

Figure 5 shows the change in elongation for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
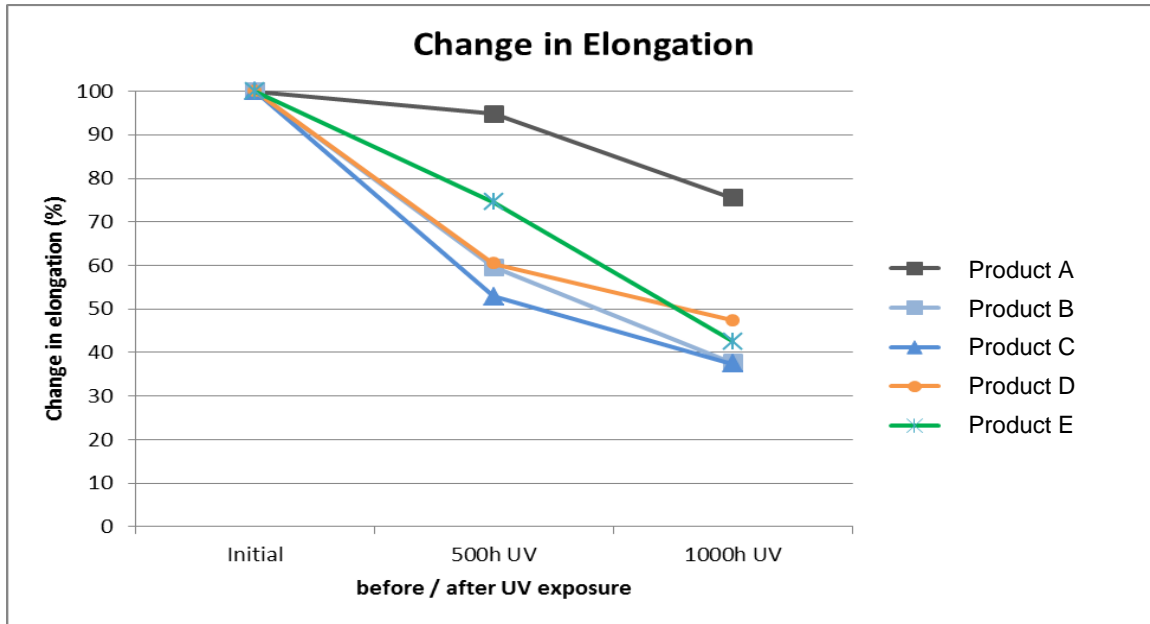
*Figure 5: Change in elongation between product samples before and after accelerated weathering*

The elongation of Product A drops to 95% after 500h and 75% after 1000h. Products B, C, D and E drop at a faster rate and all drop below 50% of their original breaking force after 1000h of accelerated weathering.

Figure 6 shows the change in water resistance for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
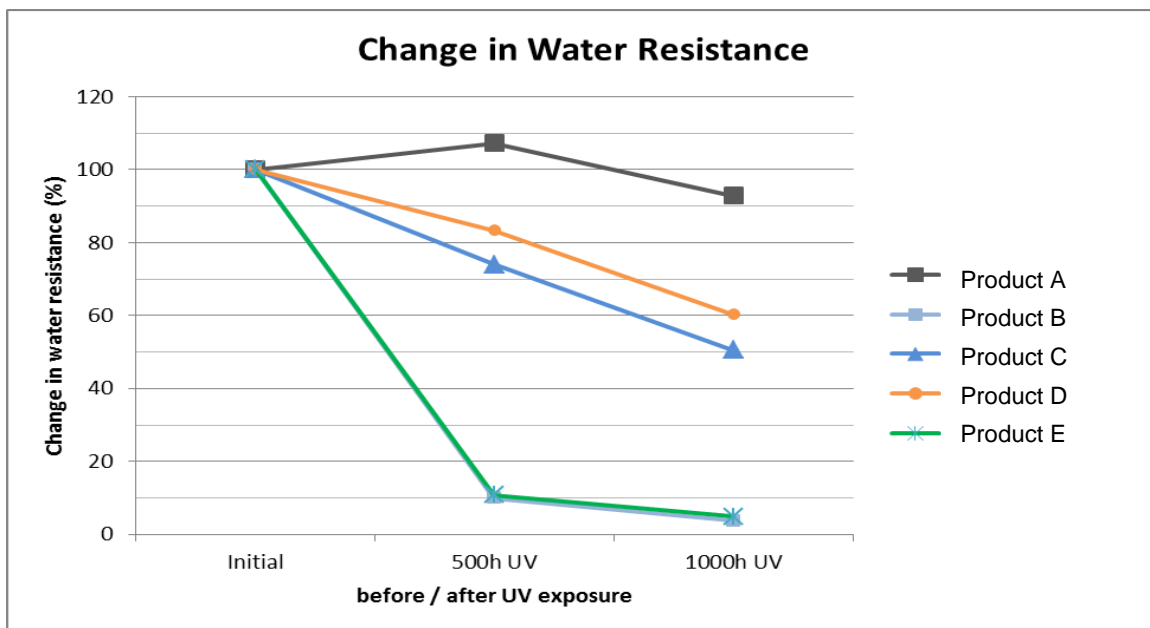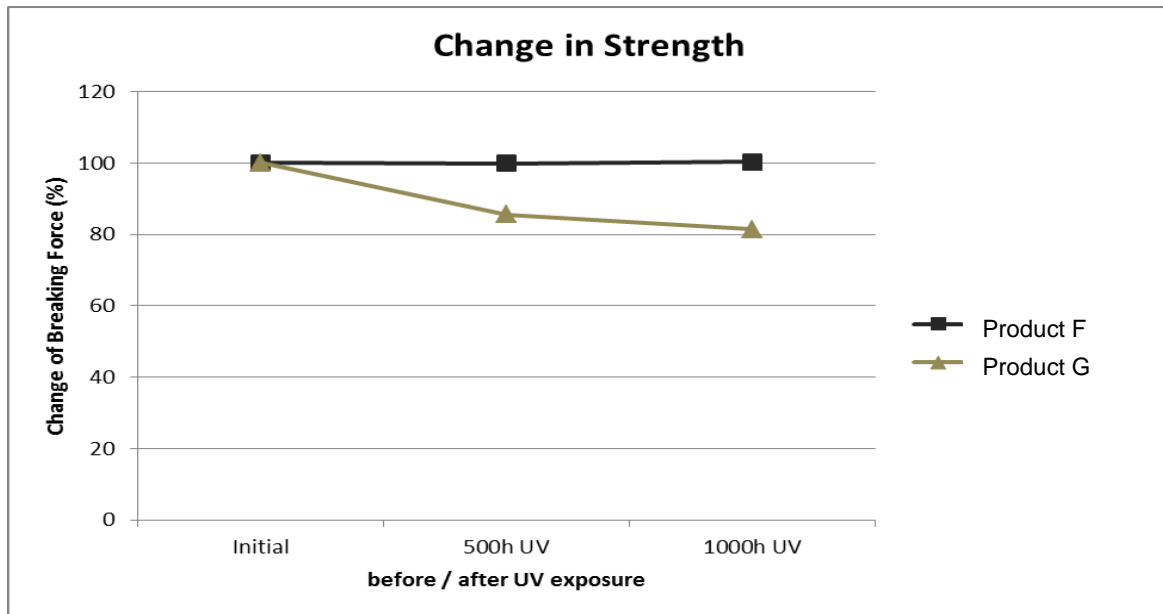

Figure 6: Change in water resistance between product samples before and after accelerated weathering

The water resistance of Product A slightly increases after 500h of accelerated weathering and drops to 93% after 1000h. For Products C and D the water resistance drops at a steady rate and

ends up at 50 and 60% of the original value respectively. For Products B and E the water resistance drops at a very fast rate during the first 500h of accelerated weathering to around 10% of the original value, and drops to 5% after 1000h of exposure.

Mechanically fastened water-resistive barriers for open-joint cladding systems:
Figure 7 shows the change in breaking force for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.

Figure 7: Change in breaking force between product samples before and after accelerated weathering

The breaking force of Product F remains unaffected after 500 and 1000h of accelerated weathering. Product G shows a loss of breaking force to 85% after 500h and to 82% after 1000 h.

Figure 8 shows the change in elongation for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
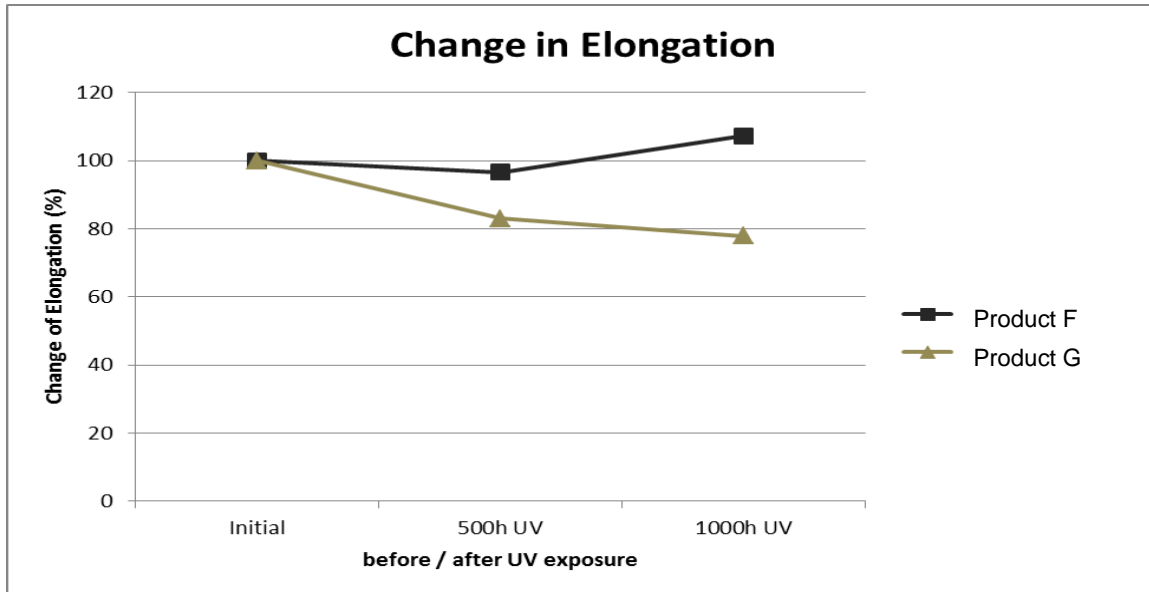
Figure 8: Change in elongation between product samples before and after accelerated weathering

The elongation of Product F increases by around 10% after 1000h, whereas the elongation of Product G drops to 78% of its original value after 1000h of accelerated weathering.

Figure 9 shows the change in water resistance for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
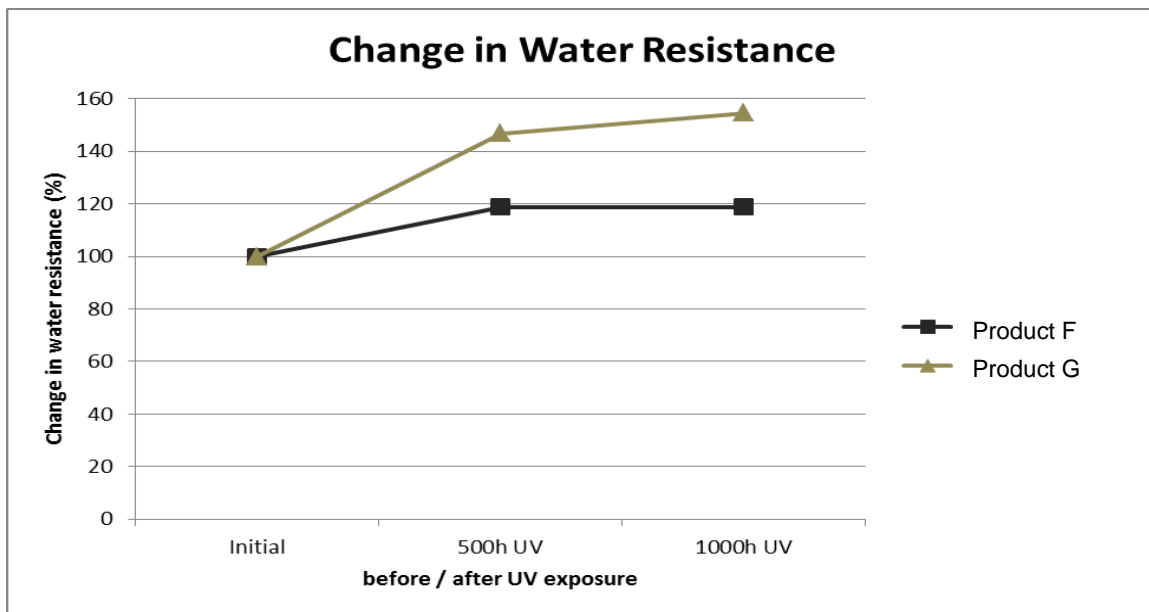

Figure 9: Change in water resistance between product samples before and after accelerated weathering

The water resistance of Product F increases to 120% of its original value after 1000h, and the value for Product G increases to 155% of its original water resistance after the same time of exposure.

Mechanically fastened water-resistive barriers and air barriers
Figure 10 shows the change in breaking force for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
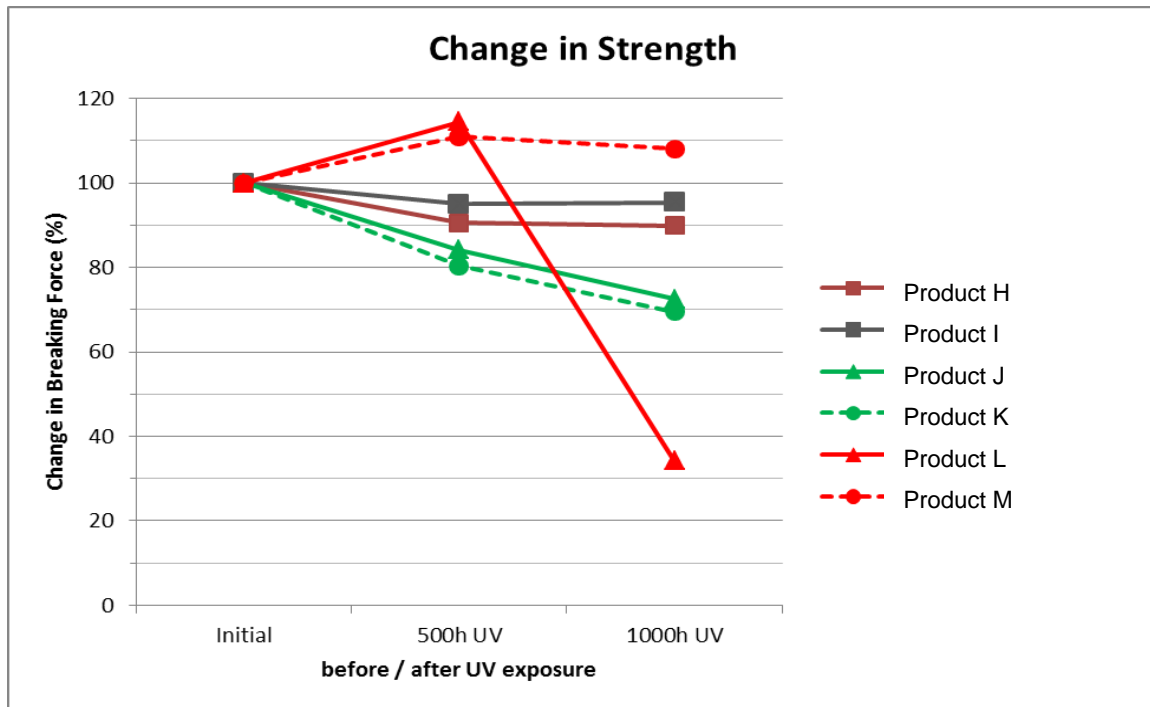

Figure 10: Change in breaking force between product samples before and after accelerated weathering

Product H and I remain within 90% of their original breaking force after 1000h of accelerated weathering. Products J and K drop to 73 and 70% respectively after 1000 h. Product L shows an increase of breaking force after 500h of exposure and a sharp drop to 35% of its original value after 1000h of accelerated weathering. Product M shows an increase of breaking force to 108% of its original value after 1000h of accelerated weathering.

Figure 11 shows the change in elongation for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
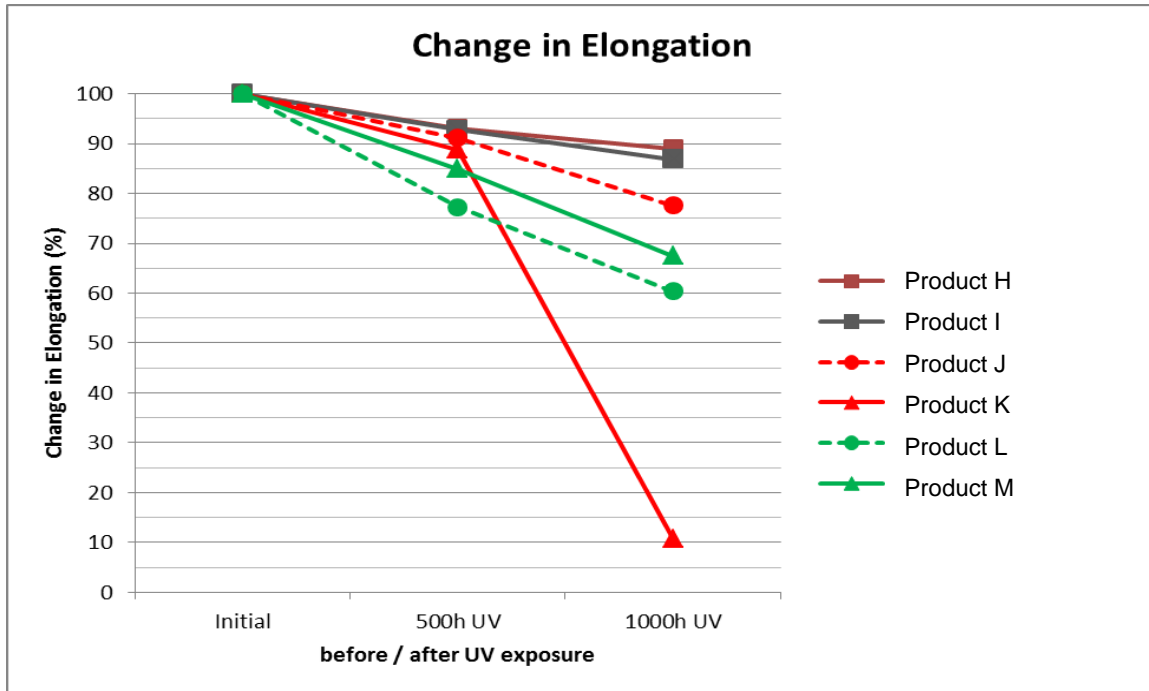
Figure 11: Change in elongation between product samples before and after accelerated weathering

The elongation of Product H and I shows a slight decrease to 89 and 87% respectively after 1000h of accelerated weathering. Products J and K show a slight drop of elongation after 500h of exposure and then the rate of loss increases, with Product J retaining 78% of its original value and Product K dropping down to 11% of its original value after 1000h of accelerated weathering. Products L and M drop to 60 and 68% respectively of their original value of elongation after 1000h of accelerated weathering.

Figure 12 shows the change in water resistance for unconditioned product samples versus product samples that have been exposed to accelerated weathering for 500h and 1000h.
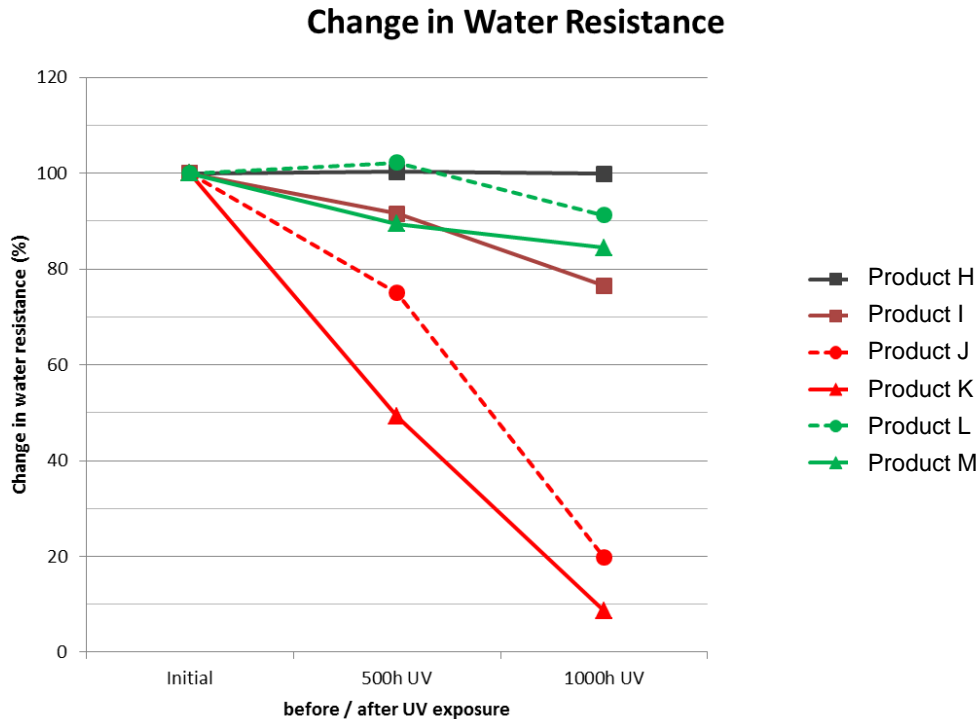
Change in Water Resistance

Figure 12: Change in water resistance between product samples before and after accelerated weathering

The water resistance of Product H remains unaffected by accelerated weathering for 1000h. The water resistance of Product I drops to 78% of its original value after 1000h of exposure. Products J and K loose water penetration resistance at a high rate and drop down to 20 and 9% respectively after 1000h of exposure. The water resistance of Products L and M drops to 90 and 85% respectively after 1000h of accelerated aging.

7. Product specifications to confine aging properties of water-resistive barriers

Based on the observations presented in this paper, the authors suggest that specifications of polymeric membranes as water-resistive barriers or air barriers should contain information regarding the physical properties of the products after the UV exposure that the manufacturers claim as acceptable in their product literature. If the maximum UV exposure time that a manufacturer allows for their product is not chosen as to ensure that the product remains entirely unaffected, the specification should explicitly indicate how much loss of the published physical properties is to be expected after the allowed solar exposure.

8. Conclusions

While manufacturers of polymeric water-resistive membranes that were evaluated in this study publish allowed UV exposure times anywhere between 6 weeks to 12 months, it is evident by the results shown in this paper that such products are not unaffected by UV light. The maximum exposure time that is provided by manufacturers is important to architects and designers in order to specify how quickly the exterior cladding is to be installed in order to protect the water-resistive barrier from excessive UV exposure. However, the maximum exposure times that are provided by

some manufacturers are not backed by any testing to show that the product performance remains unaffected. This paper has shown that some of the tested products commercially available in North America loose up to 80% of their initial breaking force, up to 90% of their initial elongation and up to 95% of their initial water resistance when exposed to accelerated weathering for 1000h. The type of accelerated weathering chosen for these exposure tests was equivalent to 171 to 500 days of field exposure in the Everglades, FL, or 354 to 642 days of field exposure in Toronto, ON. The results from exposure testing show that at maximum exposure times published by manufacturers the designer needs to be aware that the physical properties published on technical data sheets is valid pre exposure, and that properties may be significantly reduced after exposure to UV. It also shows that the negative impact on physical properties of water-resistive barriers is lower if the membranes are exposed to UV for shorter times. Hence it would be recommendable for architects to specify coverage of water-resistive barriers with exterior cladding as soon as possible after the installation of the polymeric membrane product.

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