Freeze-Thaw Cycling of Coated Magnesium Oxide: A New Approach for Evaluating Water Resistance

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ABSTRACT – There is a fundamental void in our understanding of how Air and Water Barriers (AWB) perform in response to freeze-thaw cycling. Water resistance is merely implied based on physical changes imparted by the cycle regimen. This blind spot is particularly relevant considering emerging strategies placing AWBs outboard of exterior insulation. In this study, I describe a new approach for evaluating water resistance under freeze-thaw cycling and intermittent hydrostatic pressure. Predictive value for AWB evaluation is vastly improved beyond considerations for test rigor, resolution, and duration.

INTRODUCTION

Exterior insulation presents new considerations for the placement and continuity of Air and Water Barriers (AWBs). The prevailing approach places AWBs inboard of the insulation where it is better protected from weathering and seasonal perturbations such as ultraviolet light, temperature extremes and freeze-thaw cycling. This strategy was born largely out of convenience and familiarity rather than actual performance benefits. Consequences inherent to this approach such as fastener penetrations and interstitial moisture are often dismissed in favor of a more familiar installation practice.

Alternative approaches place the AWB outboard of the insulation layer, or the insulation itself serves as the air and water barrier. The benefit here is accessibility for AWB treatment and improved continuity. More importantly, the barrier is reunited with the rainscreen cavity where arguably it does the greatest good. Notable shortfalls include substrate suitability and added considerations for flashings and rough openings. Perceptions that inboard substrates are ostensibly unprotected present further dilemma.

Structural Insulated Sheathing (SIS) offers variation to the typical outboard strategy. Here, the sheathing is brought forward of the insulation to serve as a cladding fastener base. Repositioning the barrier to its conventional substrate offers a more uniform and compatible surface that ultimately accommodates a wider array of AWBs.

A leading criticism of both outboard strategies stems from their perceived vulnerability to prolonged weathering and freeze-thaw cycling. On one hand, the outboard AWB is no different from its historical placement on assemblies designed without exterior insulation. Still, precedence is lacking as many AWB types, including thin-mil acrylic coatings, have seen limited use as true exterior barriers.

Regardless of preferred placement, it is important to recognize that conventional evaluation methods do not consider the effects of freeze-thaw cycling in terms of water resistance. In other words, water resistance is merely inferred based on observable changes in cycled barriers. This disconnect is especially concerning for fluid-applied systems, many of which are prone to water absorption and potential freeze-thaw failures. These considerations, combined with the lack of historical precedence, question whether AWB coatings can aptly serve on the exterior side of modern walls.

In this study, I examine water resistance of coated magnesium oxide under freeze-thaw cycling and intermittent hydrostatic pressure. This novel approach employs test specimens that are re-tested at each step of a multi-step cycling regimen. The effects of freeze-thaw are therefore assessed explicitly and repeatedly to offer a much-improved indicator of AWB durability.

METHODS

The AWB System

This study evaluated critical components of the ArmorWall Plus SIS panel (DuPont Performance Building Solutions). The proprietary system consists of fluid-based polyurethane insulation that is pressure-fused to the back side of half-inch thick magnesium oxide (MgO). The AWB is factory-applied and is characterized here as a modified acrylic coating. In this investigation, only the AWB and MgO sheathing were assessed. Omitting the insulation has no effect on barrier continuity and was done here merely to facilitate monitoring during each fill step.

Prepared MgO panels (24” w x 28” h) were coated with the DuPont™ ArmorSeal Plus AWB applied with foam rollers in two coats. The initial coat was allowed to fully dry before applying the second coat. Specimens were then maintained at 70°F ±5°F for seven days prior to apparatus assembling. Dry coat thickness was 7-8 mils as confirmed by microscopic analysis of sectioned panels.

Test Apparatus

Water resistance was evaluated using the face column technique, a method originally developed for the assessment of integrated WRB panels [1] and AWB interfaces [2]. The apparatus represents a column of water established vertically against exterior planes of test specimens (Figs. 1 and 2). Unlike conventional hydrostatic columns, this approach achieves a broad range of hydrostatic pressures expressed simultaneously as a function of fill height. The maximum height used in this investigation was 21.6 inches, which aligns with prevailing criteria for hydrostatic pressure testing.

Columns were assembled using 0.22-inch thick acrylic sheets (18” w x 24” h) sealed to panel specimens at the base and sides with a fast-cure adhesive sealant. The acrylic sheets were held off from panel specimens with self-adhered spacers (0.22 inch). As a manner of routine, the 21.6-inch columns are configured with two reinforcing angles to mitigate shear stress at column seals.

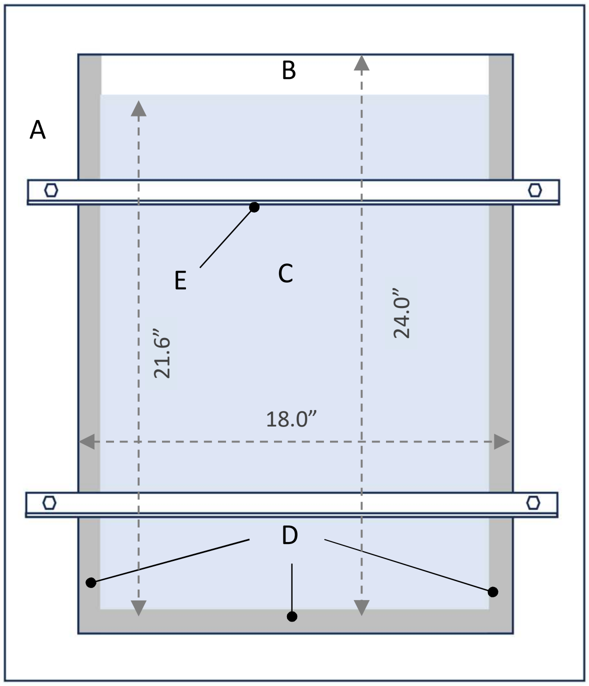


Fig.1. Schematic of face column test apparatus. A. panel specimen; B. acrylic sheet; C. water column; D. adhesive sealant; E. aluminum reinforcing angle

Fig.2. Established face columns at 21.6-inch fill height.

Cycling Regimen

Duplicate face columns (Fig. 2) served as fixed, reusable test specimens for the pre-designated 12-cycle regimen. Each cycle consisted of a freezing step, a fill step, and intermittent drying (Table 1). It should be noted that drying steps did not necessarily achieve complete drying. Residual water droplets and small pools were frequently present at the end of each drying step.

Each fill step entailed a fill height of 21.6 inches using pre-mixed solution of distilled water and dilute dye. The dye solution enabled visual tracing of potential water migration into the panel as determined by panel sectioning upon completion of all 12 cycles.

Table 1. Freeze-thaw cycling regimen.

Cycle	Freeze -15°F	Dry 70°F±5°F	Fill 70°F±5°F	Dry 70°F±5°F
1	30 days	24 hours	30 days	24 hours
2-12*	7 days	24 hours	7 days	24 hours

*Studies were deliberately terminated following the 12th cycle.

Water heights were monitored daily during each fill step and columns replenished as necessary to offset evaporative water loss.

Cycles were initiated at the freeze step where unfilled columns were maintained at -15°F for the designated step duration. Cycle 1 employed freeze and fill periods of 30-days whereas all subsequent cycles utilized 7-day step durations.

Evaluation

Columns were monitored daily for the duration of each fill step by visually assessing the back side of panels. Following completion of all 12 cycles, face columns were sectioned horizontally at two-inch intervals for full panel height. Sections were then examined at 10x-30x magnification for trace presence of the blue dye.

Failure was defined as any breach in the coating layer resulting in water entry through the MgO panel or into the panel itself as determined by microscopic analyses of panel sections (Figs. 3, 4).

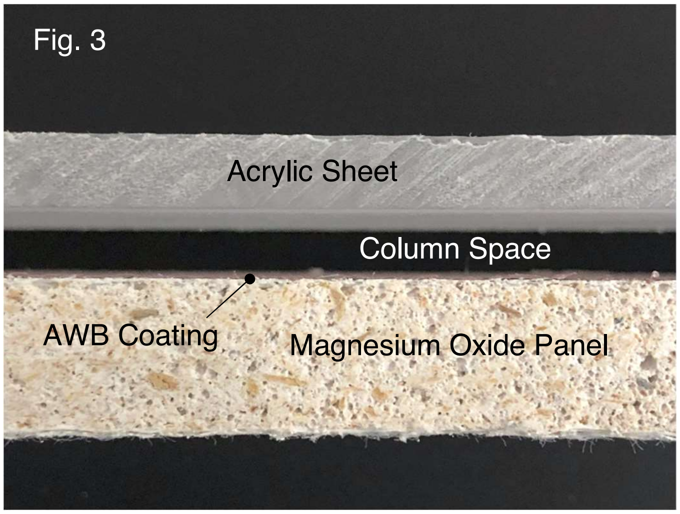
RESULTS & DISCUSSION

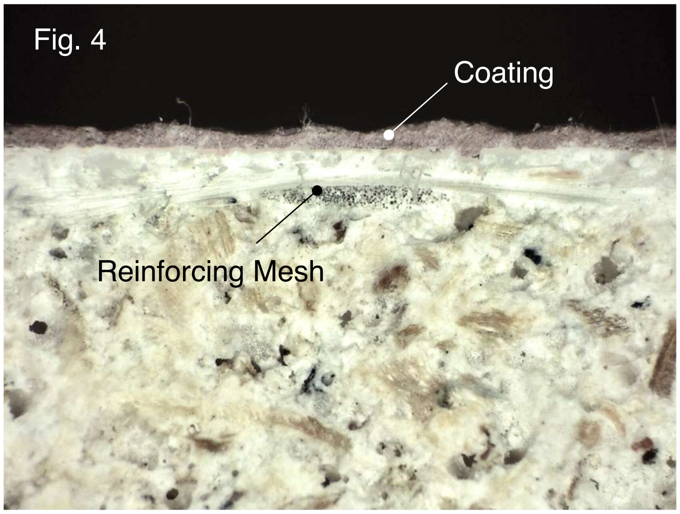
Test columns demonstrated watertight performance throughout the 12-cycle evaluation. In neither instance was water expressed through the test panel or into the MgO substrate. Furthermore, analyses of sectioned panels showed no evidence of water migration beyond the AWB coating (Figs 3, 4). These outcomes demonstrate unequivocally the coating's efficacy under freeze-thaw cycling and intermittent hydrostatic pressure.

Context and Implications

Context is necessary to better appreciate the significance of these outcomes. Current evaluation methods for AWB coatings do not assess water resistance in response to freeze-thaw cycling. Instead, barrier efficacy is simply implied based on physical changes imparted by the cycle regimen. For example, protocols outlined by ASTM E2570 assess water resistance in response to ultraviolet light and wet/dry cycling [3]. Criteria for water resistance employ the same 21.6-inch rigor used in this study. While the standard also considers freeze-thaw cycling, the effects are evaluated subjectively based on the barrier's changed physical appearances. A similar approach is taken by AC212 where the effects of freeze-thaw cycling are evaluated based on potential physical effects such as cracking, checking, crazing, or erosion. Again, water resistance of the post-cycled barrier is not assessed. Both approaches reflect standard methodologies outlined by ASTM E2485 [5].

That freeze-thaw cycling is conspicuously absent from post-weathering evaluations begs the question, can typical AWB coatings endure such conditions?





Figs. 3, 4. Panel sections of face column apparatus. A. Perspective view of acrylic sheet and coated magnesium oxide panel. B. Magnified panel illustrating intact coating and absence of indicator dye.

Test Considerations

There is high sensitivity associated with the face column method. Potential failures are overt and easily discernable even without the aid of panel sectioning and microscopic analyses. Sectioning merely offers improved resolution – to address the concern that water entry into the substrate is every bit as important as water that migrates through it. Sectioning also offers insights when evaluating discrete migration pathways, the effects of plasticizer release, or unique properties such as self-healing.

When considering MgO substrates, most AWB coatings perform poorly. Two modes of failure are common, and both occur with or without freeze-thaw cycling. The first is characterized as highly discrete and independent of the column's pressure field. Such failures are usually caused by incomplete coverage of surface pores. To achieve full coverage, the coating must span the pore or it must line the pore's inner surfaces. Application methods and coating properties are therefore critical.

The second mechanism of failure is conveyed over a much broader area and is almost exclusively a function of hydrostatic pressure. These failures are caused by high water absorption, delamination, and poor overall resistance to the expressed hydrostatic rigor. The role of water absorption is particularly relevant and deserves further study. My ongoing work with the ArmorSeal Plus AWB has shown very low water absorption, an attribute that sets it apart from many other thin-mil acrylic coatings. Indeed, its resilience to freeze-thaw cycling is likely attributed to this very property.

It is important to emphasize that the 12-cycle regimen used here was largely arbitrary. I sought only to combine initial long-term steps with several shorter-term steps in sequence. By incorporating intermittent drying, cycles emulated what naturally occurs in service. Likewise, step durations may reflect any preferred period. The initial 30-day period used here reflects a preferred benchmark for resilience and extreme performance. Moreover, the employed step durations should not imply performance limits for the ArmorSeal Plus AWB. Prior evaluations using the same hydrostatic rigor have shown robust resistance for periods well-exceeding one year.

Implications for Product Evaluation

Product evaluation is intended to predict real-world service under real-world conditions. But all too often testing methods fail to accurately predict actual product performance. They therefore lack predictive value, and they most certainly lack adequate margins of safety.

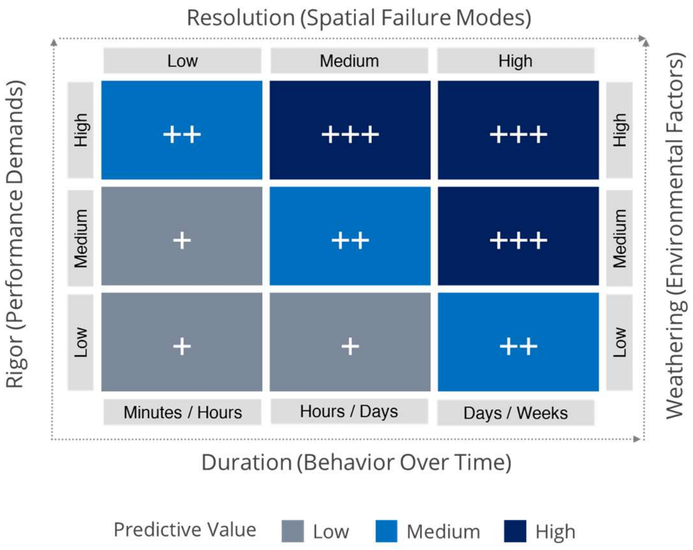


Fig. 5. The Predictive Value Matrix.

The Predictive Value Matrix juxtaposes current evaluation practices with those for improved durability [2]. I have used this matrix extensively in advocating for greater rigor, improved resolution, and longer test durations. This concept is further modified here to reflect the importance of weathering as an integral part of enhanced evaluation (Fig. 5). Likewise, I have extended application of the face column method as a useful platform in these pursuits.

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