Mineral Wool and Polyisocyanurate Insulation:

A Comparative Study of Water Absorption, Drying and Rewetting

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ABSTRACT – Wetting behaviors of common insulation products were assessed by standard two-hour water immersion. Mineral wool slabs absorbed 8 to 38 times more water than foil-faced polyisocyanurate (PIR) and 4 to 19 times more water than coated glass-faced PIR. Drying within vented benchtop assemblies required 2 to 6 days longer for mineral wool as compared to PIR. Rewetting of mineral wool specimens increased water absorption by 130% to 190% and extended dry times by an additional four days. In comparison, sorption behaviors of PIR remained unchanged. Repeated wetting of mineral wool revealed dynamic holding capacities that varied on the basis of pore structure and slab macrostructure.

INTRODUCTION

New practices in wall design favor exterior insulation outboard of the water-resistive barrier. The exterior insulation layer is now located within a highly variable environment prone to episodic wetting. Under these conditions, effective performance of common insulation materials may not align with design intent as assumed sorption characteristics for mineral fiber and cellular products reflect vastly different properties and test methodologies. These discrepancies, together with varied and unknown exposure scenarios, lead to high uncertainty regarding actual performance in response to liquid water.

Sorption properties of insulation materials are largely influenced by pore structure, the void spaces between solid portions of the material matrix. Materials having voids that are accessible to adjacent pores and their external environments are referred to as 'open pore' (e.g. mineral fibers). Such materials are intrinsically vulnerable to water absorption as air within open voids may be readily displaced by water. Conversely, 'closed pore' structures have void spaces that are compartmentalized or closed to adjacent pores and their external environments (e.g. closed cell foam). This compartmentalization vastly reduces the potential for water absorption.

Void accessibility alone oversimplifies the nature of fluid flows through porous media. Other attributes involving pore size, pore size distribution, and pore continuity also play crucial roles [1, 2]. For fibrous materials, specific properties of density, fiber orientation, binders, and hydrophobic additives have further influence on wetting and drying behaviors [2-4].

Key Terms

Wetting – displacement of a solid-air interface with a solid-liquid interface.

Drying – loss of water due to drainage, evaporation, or desorption.

Sorption – a general term in physical chemistry used to describe the combined processes of absorption and adsorption.

Absorption – uptake of matter in bulk by other matter, for example, the penetration of substances into the bulk of another solid or liquid

Adsorption – surface retention or adhesion of an extremely thin layer of molecules to the surfaces of solids or liquids with which they are in contact

Holding Capacity – the ability of a pore structure to physically hold water against the force of gravity.

Because pore structure is so integral to water absorption, it is not surprising to find its influence in standard sorption testing. For example, methods for closed pore foam employ full water immersion with test durations varying on the basis of material type and intended application: ASTM D2842 (96 hours); ASTM C272 (24 hours); or ASTM C209 (2 hours) [5, 6, 7]. In contrast, sorption potentials for mineral wool are evaluated in accordance with ASTM C1104, which utilizes water vapor (95 ± 3% RH), not liquid water as the wetting medium [8]. Such diverging methodologies are predicated on the need to demonstrate low water absorption or the perception of quality performance in response to liquid water. Sorption potentials for mineral wool are therefore underestimated as shown by prior studies involving partial or full immersion [4, 9-12]. The consequences are similarly misjudged as even partial wetting negates thermal performance to near negligible levels [12-15].

In light of non-uniform testing methodologies, a direct comparison of sorption attributes for fibrous and cellular insulation is not possible. Therefore, professionals lack even a conceptual understanding of potential risks for current design practices. In this study, wetting and drying characteristics of mineral wool and polyisocyanurate (PIR) are compared with particular emphasis on rewetting and dynamic pore structures in response to liquid water.

METHODS

Insulation Products

The selected insulation materials represent products intended for exterior facades and rainscreen applications. Test specimens consisted of new, 2-inch thick, 1 ft x 1 ft panels free of visible defects or inconsistencies. Polyisocyanurate panels were bi-faced with either a tri-laminate foil or coated glass. Reported densities for mineral wool panels were 4.5 lbs/ft^3 (72 kg/m^3) and 4.3 lbs/ft^3 (>69 kg/m^3) for MW-1 and MW-2, respectively.

Sorption Testing

Sorption testing was performed in general accordance with ASTM C209 [7]. These methods include two-hour full immersion under one inch of standing water. Post-immersion draining was in keeping with the standard's test protocols; however, panels were oriented vertically as opposed to the specified 45° position. This modification reflects the typical orientation of insulation panels as installed in real building enclosures. The orientation of mineral wool was deemed particularly relevant in assessing the influence of slab macrostructure. Therefore, fiber layer orientation was kept constant throughout these studies.

Water absorption was expressed as an increase in weight percent derived from a mean of three replicates.

$$\text{Percent Water Absorption} = [(\text{Wet weight} - \text{Dry weight}) / \text{Dry weight}] \times 100$$

In accordance with ASTM C209 [7], specimens were allowed to drain for 10 minutes prior to initial weighing. The use of 'sorption' and 'water absorption' as referenced herein therefore depicts holding capacity, not total absorption.

Drying

Vented benchtop assemblies provided an estimate of drying characteristics within a mock wall assembly. Components included cladding, vented air space, wetted insulation specimen, and substrate (Fig. 1). Plastic angles served as closure backing at the top and sides to prevent excess convection. Assemblies remained open at the base and held off from the benchtop surface to allow venting and unobstructed drainage.

Water content was determined by weighing insulation slabs at 24-hour periods. Specimens were reported as effectively dry when two of the three replicates achieved a minimum of moisture content of 0.5% (weight basis).

Ambient temperature and relatively humidity were maintained at 68 °F (± 2 °F) and 30% (± 5%), respectively.

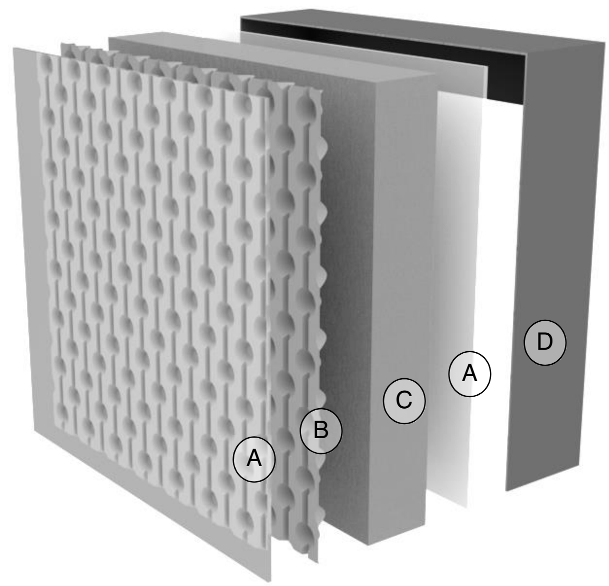


Fig. 1. Illustration of vented benchtop assembly. A. Acrylic Sheet; B. Plastic Drainage Mat (3/8"); C. Insulation (2"); and D. Closures.

Rewetting

The effects of rewetting were assessed in two phases. The first phase compared water absorption by mineral wool and PIR; whereas the second phase focused solely on the two mineral wool products. Polyisocyanurate was excluded from Phase II studies based on Phase I findings showing no change in water absorption.

Phase II rewetting entailed three independent studies, each involving three replicates and seven cycles. Wetting was performed by two-hour full immersion as previously described. After each wetting cycle, slabs were weighed and then oven-dried at 125 °F to 150 °F. This drying regimen reflects the upper temperature range for typical rainscreens and enclosure systems.

FINDINGS

Water Absorption and Drying

Percent water absorption and corresponding drying rates are summarized in Figs. 2 and 3. As expected, sorption behaviors differed on the basis of facer type and pore structure. For example, fibrous mineral wool absorbed 8 to 38 times more water than foil-faced PIR and 4 to 19 times more water than coated glass-faced PIR. Although coated glass-faced specimens absorbed twice as much water as foil-faced panels, this difference reflected dissimilarities in facer porosity, not increased absorption by the respective foam cores. Drying times for the two PIR products remained virtually identical. High drying potentials for PIR were attributed to low water absorption coupled with the ability to release water vapor at facer-substrate interfaces, regardless of facer type.

Contrasting outcomes for the two mineral wool products were unexpected. Product declarations report similar densities, binder type, and binder fractions. Although the products do differ on the basis of slag to igneous rock ratios; this factor alone is unlikely to impart the observed differences in water absorption. Other factors are therefore implicated such as variations in binder distribution, binder curing, hydrophobic additives, fiber orientation, and layer crimping. It should also be noted that while slabs of MW-2 absorbed nearly 400% more water, the range of sorption values varied significantly between individual panels of a given product. Initial pilot studies showed that product-specific variability was particularly evident for MW-1, which also revealed high variation in fiber layer integrity, color, and physical properties. Corresponding water absorption varied by an order of magnitude.

Drying times ranged from 1 to 7 days as a function of insulation type. Both PIR products were effectively dry at 24 hour whereas mineral wool slabs required an additional two to six days to achieve the same endpoint of 0.5%. Regardless of the employed methods, these findings defy common claims regarding wetting and drying behaviors of mineral wool. For example, it is assumed that water freely drains within the void structure. And it is further assumed that retained water dries quickly due to mineral wool's inherently high vapor permeance. Based on these findings, neither is true. Water that is absorbed by mineral

Fig. 2. Polyisocyanurate (PIR)

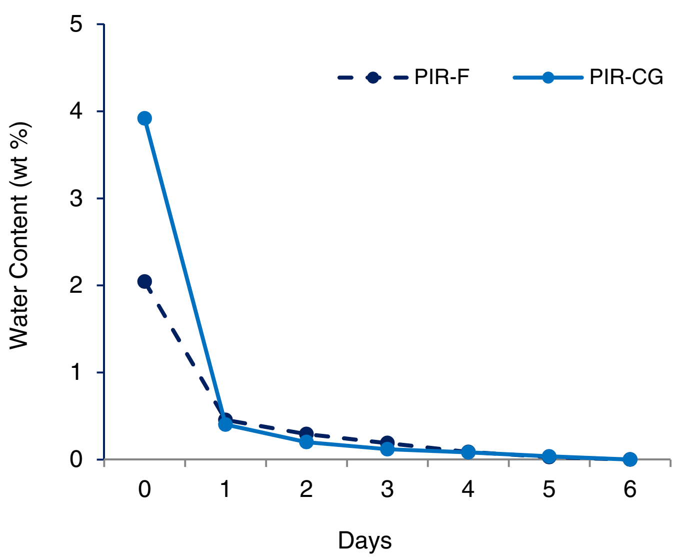
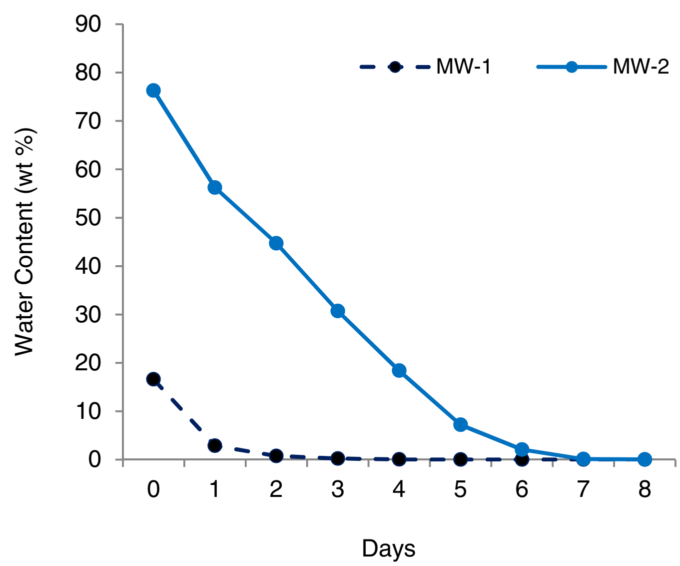


Fig. 3. Mineral Wool

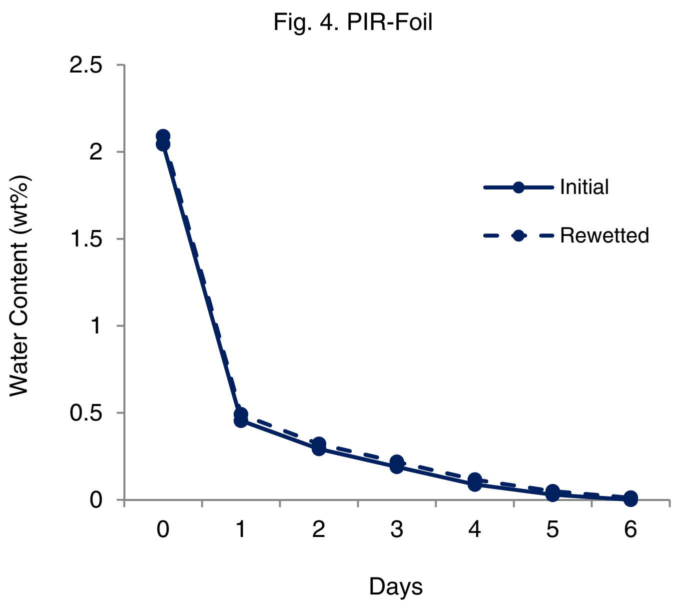


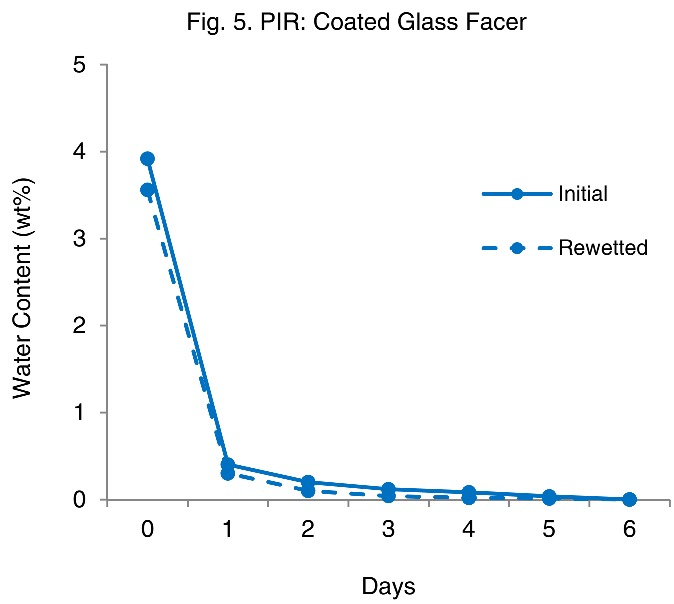
Figs 2-3. Water absorption and corresponding drying of PIR (Fig 2) and mineral wool (Fig 3).

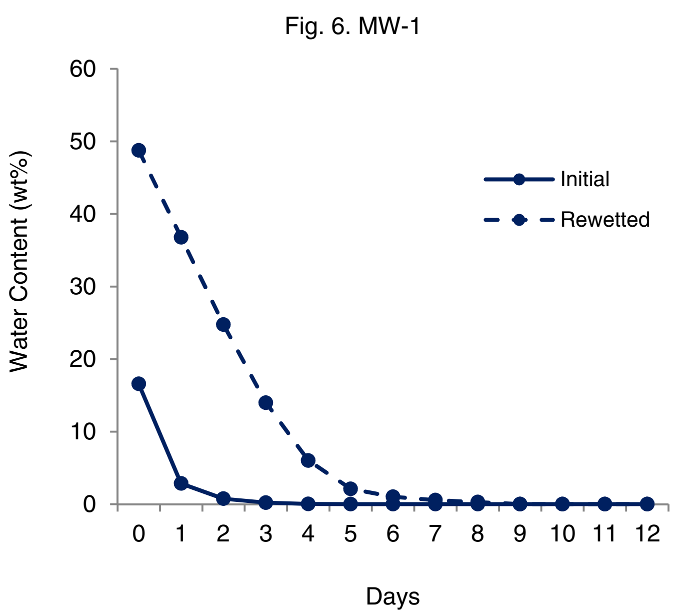
wool will drain only when subject to the combined forces of gravity and sufficient displacement by water released from the above voids. In these studies, drainage was largely achieved during the standard 10-minute drain period, which immediately followed the two-hour immersion. In other words, the bulk of drainage occurred prior to initial weighing. The remaining water therefore represents the specimen's holding capacity, not total water absorption. After initial draining, water retained by the pore structure is not subject to appreciable drainage. Instead, water is suspended by capillary forces and the fibrous lattice itself where its fate is determined by evaporation and vapor diffusion. In the absence of external forces or changing environmental conditions, void structure becomes the primary determinant of holding capacity and drying times.

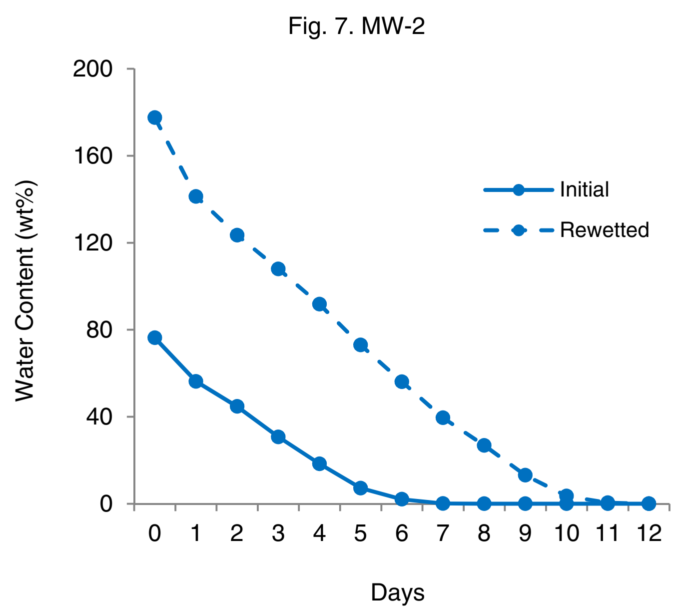
The Effects of Initial Rewetting

The effects of a single rewetting event are demonstrated by Figs 4-7. Rewetting of PIR specimens showed no appreciable influence on water absorption (Figs. 4-5). These findings were anticipated as the solid framework of polyisocyanurate is rigid, compartmentalized, and insoluble in water. Because the void structures are unaltered, sorption behaviors and dry times remained constant. The striking differences in holding capacities for PIR and mineral wool are further compared in Fig. 8.









Figs 4-7. Effects of rewetting on water absorption and drying of PIR (Figs. 5-6) and mineral wool (Figs. 6-7).

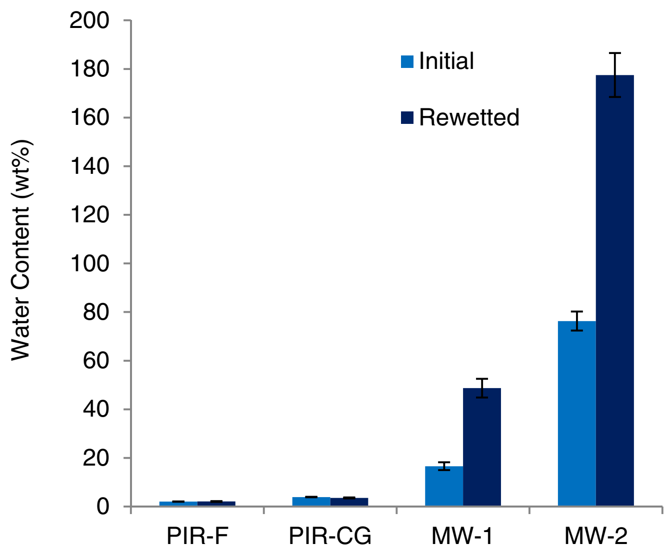


Fig. 8. Comparison of holding capacities (i.e. post-drain water absorption). Values represent a mean of three replicates with standard deviation plotted as error bars.

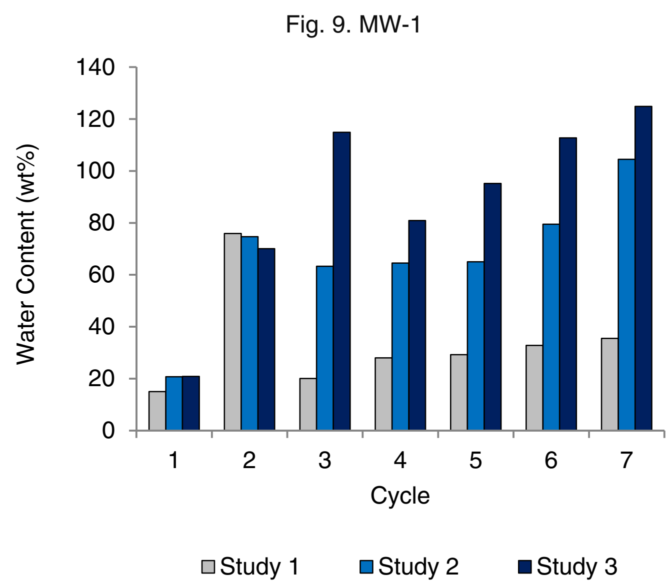
Rewetting of mineral wool specimens increased water absorption by 132% (MW-2) to 195% (MW-1). Corresponding drying times within vented benchtop assemblies required an additional four days (Figs 6-7). Interestingly, MW-1 absorbed less water during the initial wetting but showed the greatest increase when rewetted. This finding is noteworthy as results from standard sorption testing do not account for prior exposures to water. These results demonstrate that even a single exposure to liquid water may yield very different outcomes.

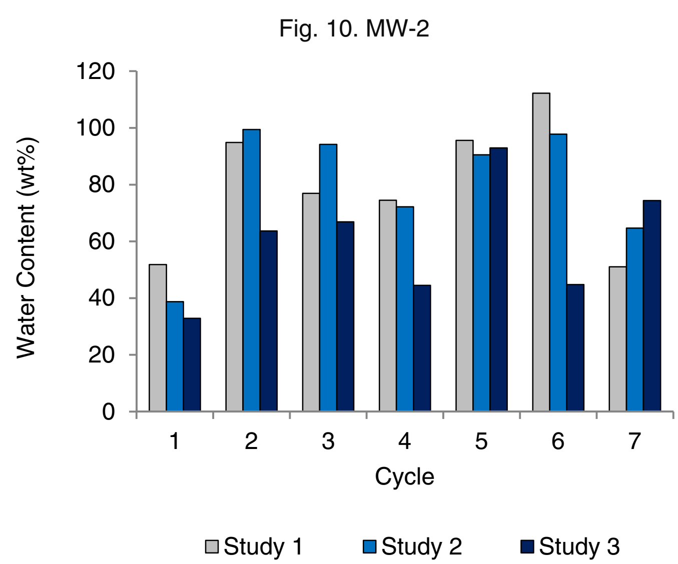
Prior research has shown that dry mineral fibers previously subjected to weathering or wetting exhibit increased moisture sorption. The presumed causes are linked to separation of fibers from binder resins or actual loss of binders and hydrophobic additives [14, 16, 17].

It is certainly plausible that loss of binder resins and hydrophobic additives may influence the absorption characteristics reported herein. However, a more plausible scenario involves changes in void geometries resulting from bulk water transport during wetting and draining. This is likely coupled with the separation of fibers from binder resins [14]. These changes are expected to occur throughout the three-dimensional matrix where some void volumes increase while others decrease. Fiber layers will also separate as individual fibers detach from the binder resin. Physical plasticity of the void structure is therefore implicated whereas potential migration of hydrophobic additives and resins may assume a synergistic but secondary role.

The Effects of Repeated Rewetting

To further assess the effects of repeated wetting, mineral wool specimens were rewetted over the course of seven cycles. These results support my initial findings of fluctuating holding capacities in response to repeated wetting (Figs. 9-10). For both products and all studies, water absorption increased after the initial wetting. However, subsequent rewetting did not necessarily result in greater water absorption. If the observed variability was due to loss of binder or hydrophobic additives, then water absorption would likely increase successively over the course of all cycles. Such a pattern was not observed.

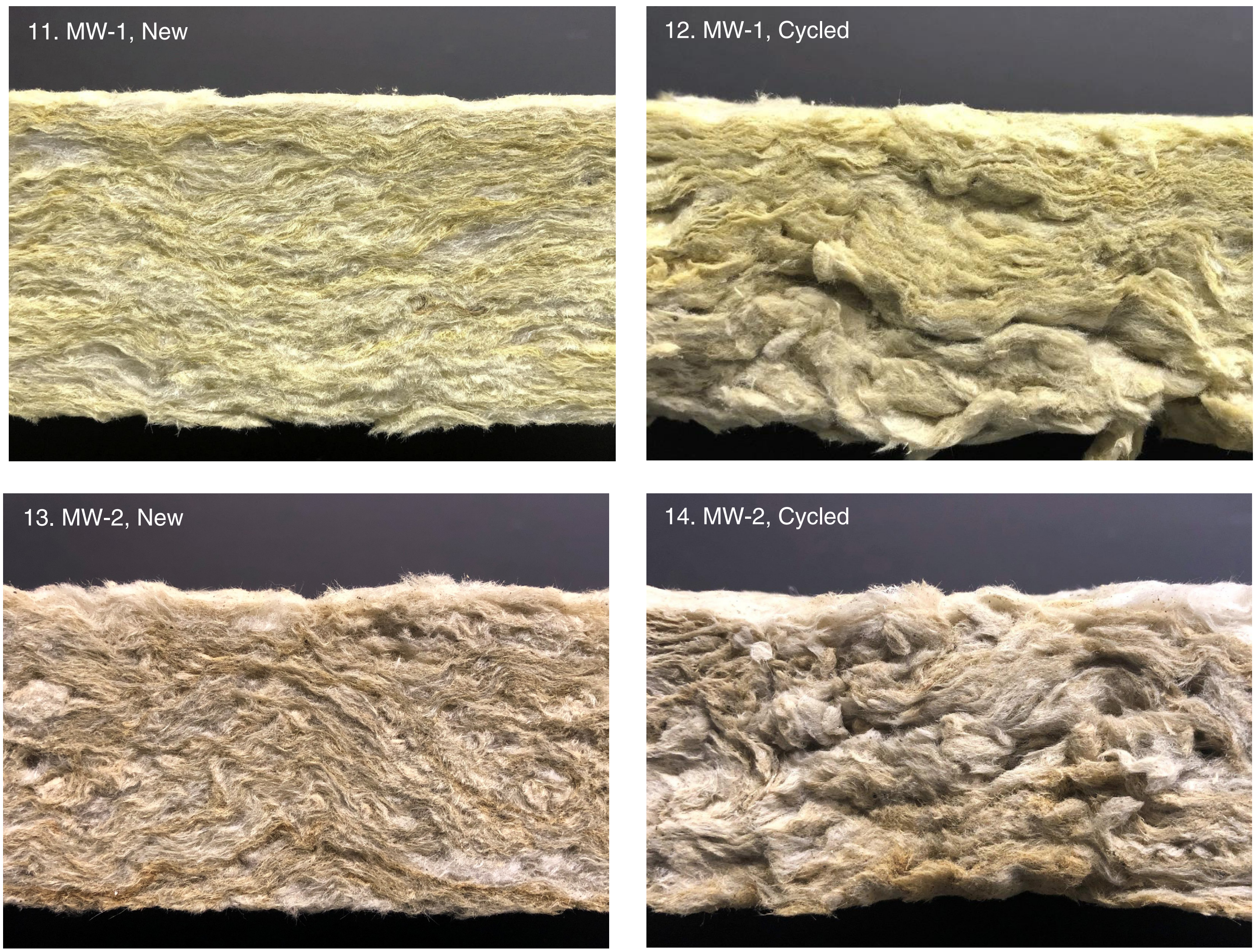




Figs. 9-10. The effects rewetting on water absorption by MW-1 and MW-2.

Changes in sorption capacities, and specifically the lack of clear association with repeated wetting, lend support to the influence of pore structure. As indicated by Phase I outcomes, bulk water flow induced by immersion and draining cause fibers to shift with corresponding changes in void volumes. These fiber shifts are likely due to degraded fiber-resin bonds. During repeated cycles, fiber layers begin to separate as slabs become visibly tattered and weathered (Figs 11-14). Each cycle offers a slightly different pore structure that absorbs and drains differently from the preceding event. These dynamic effects represent offsetting factors where a given slab may absorb more water only to release a proportionate amount during post-immersion draining. Although possible resin loss and migration of hydrophobic additives remain important considerations, they are expected to play secondary roles.

The methods employed by this study were intended to represent a stringent wetting scenario combined with a realistic drying scenario. With respect to mineral wool, wetting by 2-hour immersion may seem extreme; however, water absorption was still nowhere near saturation. For example, typical moisture absorption values of 50-100% are significantly lower than total saturation, which may readily exceed 800%. Moreover, by incorporating the post-immersion drain, the results actually underestimate total sorption potentials. Significantly greater retention is expected for mineral wool slabs held horizontally or where assembly components impede vertical drainage (e.g. horizontal girts). Regardless of the specific methodologies employed, they remained consistent for all products. The results therefore offer a valid risk analysis for products prone to episodic wetting by bulk water.



Figs 11-14. Changes in slab macrosturcture in response to rewetting. Cycled specimens exhibit separation of fiber layers and notable voids. Cycled slabs also show evidence of reduced tensile and compreshive strength.

CONCLUSIONS

This study compared the behaviors of mineral wool and polyisocyanurate (PIR) in response to partial wetting with liquid water. The following conclusions may be drawn from these findings:

1) Water absorption is inherently linked to pore structure. Open and fibrous matrixes such as mineral wool will absorb and retain significantly more water than closed cell PIR. This relationship holds true regardless of wetting processes typically encountered in building enclosures.

2) The reported sorption values for mineral wool are orders of magnitude greater than those derived from standard methods where high humidity, not liquid water, is used as the wetting medium (i.e. ASTM C1104). A further two-fold increase in absorption is observed when mineral wool is rewetted.

3) These results are aligned with prior accounts showing similar sorption attributes for mineral wool with corresponding effects to thermal performance. Notable reductions in claimed R-values are therefore expected as even partial wetting negates thermal performance to near negligible levels.

4) Drying times are a function of holding capacity, which is particularly relevant for mineral wool prone to partial saturation. When slabs are rewetted, holding capacity and drying times increase, indicating a high potential for moisture accumulation under recurring exposures to water.

5) Claims regarding water repellency and matrix drainage must be balanced against the fundamental realities of pore structure. While mineral wool products do possess a certain degree of water repellency, this resistance is readily breached by factors such as low external pressures, changes in surface energies, and water immersion. Claims regarding matrix drainage imply partial saturation where water transport is determined by gravity and facilitated by displacement from water in upstream voids. Appreciable release of bulk water does not occur after this initial drain period as evidenced here by high holding capacities. The lower portion of such wetted slabs will remain partially saturated for several days.

6) The hydraulic conductivity (fluid flow) within mineral fiber insulation fluctuates during the course of repeated wetting and drying. This variability is likely due to fiber-binder separation and corresponding changes in void geometries. Changes in macrostructure are ultimately expressed as separated fiber layers, reduced slab densities, and reductions in tensile and compressive strength. Water migration through the pore structure therefore alters the solid portion of the collective matrix, which, In turn, alters the dynamics of water absorption, water retention, and drying.

7) Mineral wool products vary considerably in their wetting and drying behaviors. Even greater differences are observed for slabs of a given product where absorption may vary by an order of magnitude. Absorption and holding capacities may therefore lack meaningful comparison without standardized methods for wetting, draining, and slab conditioning. Moreover, observations of notable product-specific variability highlight manufacturing flaws that are not readily recognized during routine installation.

FUNDING

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