PLASTIC BASED MATERIAL (PBM) FLOORING—NORTH AMERICAN RESEARCH AND COMPETITIVE OPPORTUNITIES FOR CERAMIC TILE

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ABSTRACT

For more than half a decade, plastic based material (PBM) flooring has experienced rapid market growth around the world. PBM flooring includes luxury vinyl tiles, luxury vinyl planks, wood, stone, and clay polymer composites, rigid core boards, and several other types of resilient floor coverings.

It is widely understood that claims such as waterproof, dent-proof, scratch-proof, etc. have commonly been made by PBM flooring manufacturers, which has led consumers to believe that such products can be used in many applications that are excluded from product warranties.

An in-depth research project is ongoing at the Tile Council of North America's (TCNA) laboratory, in conjunction with the Bishop Materials Laboratory at Clemson University, and other departments, to examine the performance of PBM products in general. Through testing to existing standards, empirical data was collected to characterize PBM flooring wet performance and scratch resistance, and to identify potential risks to consumers.

This paper provides an overview of the initial results from this ongoing PBM research project.

1. INTRODUCTION

Over the last half decade, the market share of plastic based material (PBM) flooring has been rapidly growing in the United States. From 2013 to 2017, the PBM share of the flooring market increased in square feet from 16.9% to 21.1% [1]. As the sector has grown, luxury vinyl products in particular have been regularly advertised as scratch resistant and suitable for wet applications, but commonly contain warranty statements excluding damage from such applications. In the absence of supporting technical data, standards, and clear marketplace communication, this research was undertaken to better understand the performance of these products.

PBM flooring is comprised of products recognized in the marketplace as Resilient Floor Coverings, including but not limited to, Luxury Vinyl Tiles (LVT), Luxury Vinyl Planks (LVP), Cushion Vinyl Tiles (CVT), Vinyl Composition Tiles (VCT), Wood Polymer Composites (WPC), Stone Polymer Composites (SPC), Clay Polymer Composites (CPC), and Rigid Core Boards (RCB). ASTM International standard F141-12 [2] defines resilient floor covering as:

> "An organic floor surfacing material made in sheet or tile or formed in place as a seamless material of which the wearing surface is non-textile. The resilient floor covering classification by common usage includes, but is not limited to asphalt, cork, linoleum, rubber, vinyl, vinyl composition, and polymeric poured seamless floors. Resilient in this sense is used as a commonly accepted term but does not necessarily define a physical property."

There is in fact a wide assortment of resilient floor coverings with integrated polymeric compounds, which for the purposes of discussion and research in North America, is broadly referred to herein as "PBM."

From even a cursory review of the flooring sector, one can quickly observe that many PBM flooring materials emulate the appearance of ceramic tile and advertise use in applications where ceramic tile is commonly used. This includes areas regularly subjected to moisture. It also includes areas where increased surface durability, especially scratch resistance, is desirable.

Tile Council of North America's (TCNA) Product Performance Testing Laboratory, under the direction of the Bishop Materials Laboratory at Clemson University along with the Department of Biological Sciences at Clemson University, conducted a series of tests on a sampling of 25 PBM flooring products to study scratch resistance and moisture performance under standard laboratory test conditions. Regarding moisture performance, tests for waterproofness, slip resistance, and microbial growth were conducted. This paper provides the initial results of these tests, and also provides generalized context relevant to real-world usage and common market expectations.

2. MOISTURE AND MICROBIAL PERFORMANCE—RATIONALE FOR RESEARCH

Until the last few years, PBM products were less likely to be used in wet areas due to the risk of the vinyl peeling, cupping, peaking, discoloring, or glue degrading [3,4,5]. However, it is not uncommon today for PBM products to be advertised for wet areas. From a recent market survey, flooring purchasers identified that flooring described as "waterproof" ranked 8.9 out of 10 in importance where 1 is not important and 10 is extremely important in deciding which floor covering to purchase [6]. While many PBM flooring manufacturers now advertise their products as waterproof, many warranty statements also exclude damage from moisture.

From an online search of product-specific warranties and installation guidelines for various PBM products, "waterproof" is often described as the product itself being unaffected by moisture, with damage to the flooring substrate due to moisture commonly excluded from warranty coverage.

Merriam Webster [7] defines waterproof as, "impervious to water - especially covered or treated with a material (such as a solution of rubber) to prevent permeation by water." The Oxford English Dictionary [8] definition of waterproof is also "impervious to water," while the Cambridge Dictionary [9] defines waterproof as "not allowing water to go through." Based on these definitions, it is clear that "waterproof" in the context of floorcoverings means that it is both unaffected by moisture and will not allow water to pass through it.

These definitions also dovetail with North American ceramic tile industry standards for achieving a waterproof installation [10] and common expectations that waterproof systems are engineered to protect the substrate from moisture in "waterproof" applications. Given the discrepancy between waterproof claims and product warranty exclusions, research was conducted on a sampling of PBM flooring products to determine whether or not the coverings would prevent water from passing through to the substrate in a fashion comparable to that of waterproof ceramic tiling systems.

Also, when considering wet applications, flooring slipperiness is especially important. However, PBM flooring manufacturers commonly only report slip resistance under dry conditions [11]. As PBM flooring products are increasingly advertised for use in wet applications, testing was conducted on a sampling of products to determine wet Dynamic Coefficient of Friction.

The potential presence of moisture also raises the possibility of microbial growth. Chemically, many PBM floor coverings are a combination of polyvinyl chloride, plasticizers, polyurethanes, and organic and inorganic fillers-binders [12]. Because these organic substances are sources of carbon, there is presumably the potential for microbial growth. Especially given that some common PBM flooring products on the market click together mechanically and are installed as floating floors [13], the edges and backs of products may be accessible to water and/or atmospheric moisture, thus creating conditions which are favorable for the growth of fungi. Testing was conducted to characterize the mold growth potential of multiple samples of PBM flooring.

3. WATERPROOF TESTING

For the waterproof testing conducted, a total of 25 PBM flooring products were purchased between October 2018 and March 2019 from various retail locations in South Carolina. These products met one or more of the following criteria: (1) easily obtainable, (2) popular among specialty flooring resellers, designers, and architects, or (3) representative of current or upcoming trends among floor coverings. For this research, of the twenty-five products purchased, all products advertised as "100% waterproof" and installed with interlocking joints were selected for research (10 in total). The ten test specimens included: one wood polymer composite (WPC) product, three stone polymer composite (SPC) products, and six rigid polymeric core board (RCB) products.

Regarding test methodology, two standards were used to evaluate waterproofness: EN 13553[14] (*European specification for resilient floor coverings – polyvinyl chloride floor coverings for use in special wet areas*) and ASTM D4068 [15] (*Standard specification for chlorinated polyethylene sheeting for concealed water-containment membrane*).

In accordance with EN 13553, the floor covering specimens were installed on a rigid, non-porous substrate. The substrate was a 19 mm thick, transparent acrylic sheet, so that any water movement through or beneath the floor covering could be observed from below. Each floor covering specimen was installed on the substrate per manufacturer specifications, resting directly on the substrate without the use of adhesives or fasteners as specified for free-floating flooring. The floor covering specimens were comprised of individual units assembled to cover an area of at least 500 × 800 mm. A 500 mm long × 300 mm wide × 300 mm high transparent, watertight, and bottomless acrylic box-frame was constructed per EN 13553. The box-frame was secured atop the floor covering using silicone sealant and cured for at least 12 hours to seal the interface between the box-frame and the floor covering. The floor covering within the box-frame (the test area) was installed such that at least two seams of the product were parallel, and at least one seam was perpendicular to the long dimension of the box-frame. A drawing of how the products were aligned and a picture of an assembled specimen are provided in Figure 1.

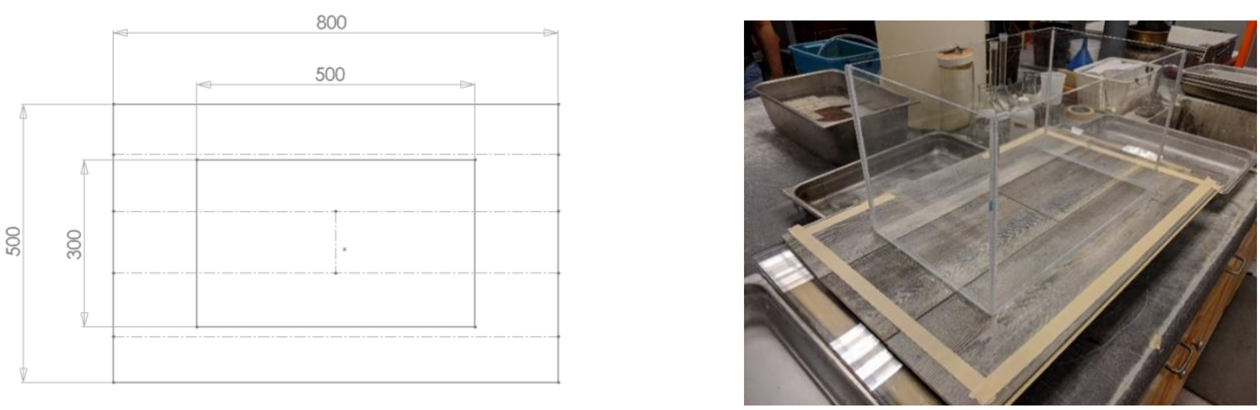

Figure 1: *Orientation of box-frame in relation to floor covering seams (seams represented by dotted lines) and box-frame installed atop floor covering test specimen*

After curing the sealant, the box-frame was filled with approximately 30 L of water to a level 200 mm above the surface of the test assembly. Test specimens were monitored for water leakage through the floor covering. Per EN 13553, any water leakage constituted failure. For the purpose of this research, testing was allowed to continue for at least 1 hour after the first observation of leakage so that the volume of water leaking per unit time could be determined for each specimen.

Testing was also conducted per ASTM D4068. Hydrostatic pressure was applied to test specimens using a PVC pipe with an inner diameter of 51 mm and a water column of 610 mm. Each specimen was 76 × 76 mm and consisted of two interlocking pieces of floor covering, assembled together per manufacturer specifications, with a seam in the center. Each floor covering specimen was secured to the apparatus using a silicone sealant with the wear surface facing the water. The silicone sealant was allowed to cure for at least 12 hours to seal the interface between the specimen and the apparatus. A photograph of an installed test assembly is provided in Figure 2.

Figure 2: *Constructed test assembly, per ASTM D4068*

Following preparation of the test assembly, hydrostatic pressure was applied to the floor covering specimen's wear surface, per ASTM D4068. Although any water leakage constituted failure of the subject material, in this research, testing continued for 10 minutes after the first signs of water leakage so that the volume of water leakage per unit time could be determined.

When tested per EN 13553, all 10 PBM floor covering samples leaked immediately upon initiation of the test. The measured rates of leakage ranged from 0.49 to 7.54 liters per hour. For each assembly, water leakage was observed in three locations: (1) through the seam to underneath the floor covering; (2) into the seam and exiting at the edges of the assembly; and (3) into the seams and exiting atop the assembly, outside of the sealed containment box.

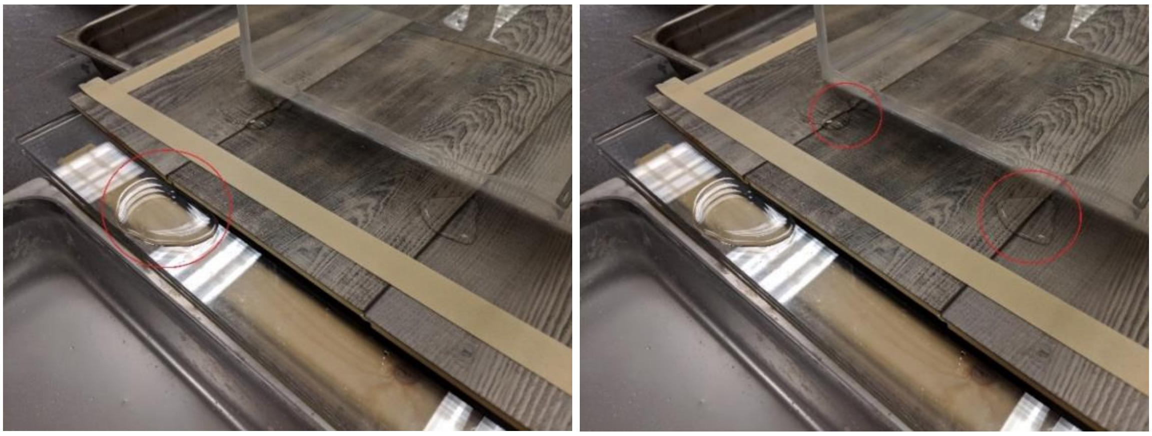

Figure 3: *Water penetration into the seams and exiting at the edge of the assembly (left), and water penetration into the seams and exiting atop the assembly outside the sealed containment box (right)*

When tested per ASTM D4068, all 10 PBM floor covering samples also leaked immediately upon initiation of the test. Measured leakage rates ranged from 0.38 to 2.43 liters per hour. All samples leaked through the center seam with water exiting from the edges. Additionally, some specimens leaked through the center seam to the back of the floor covering.

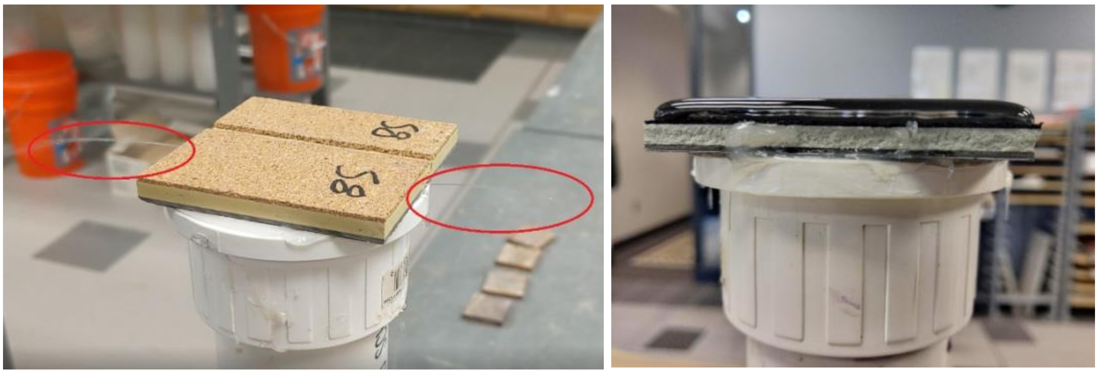

Figure 4: *Water penetrating the seam and exiting from the edges (left), and water penetrating the seam and leaking onto the back of the sample (right)*

4. EVALUATION OF DYNAMIC COEFFICIENT OF FRICTION

Twenty-two PBM flooring options that the manufacturers advertise or claim to be waterproof or water resistant, or depict being used in areas where flooring gets wet were tested for their wet dynamic coefficient of friction (DCOF). Wet DCOF of a material is defined as the ratio of the force necessary to keep a surface already in motion sliding over another divided by the weight (or normal force) of the sliding object under wet conditions [16,17]. It is a useful comparative indicator of a product's slip resistance in wet applications.

ANSI A326.3, American National Standard Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Materials, was used to measure the wet DCOF of each PBM sample. The ANSI A326.3 test method was developed through a broad consensus of stakeholders across the U.S. flooring industry and is widely used in the North American ceramic tile, polished concrete, and stone industries. Per ANSI A326.3, testing was conducted using a BOT 3000E tribometer, a styrene-butadiene rubber (SBR) sensor, and 0.05% sodium lauryl sulfate (SLS) solution. For each product, three specimens were tested four times each using a calibrated BOT 3000E. The four tests were performed in a different direction on each specimen's surface so that directionality was taken into account.

Figure 5: *ANSI A326.3 equipment used and testing (left to right): BOT 3000E/sensor reconditioning wheel/SBR sensor, BOT prior to making a measurement, BOT after making a measurement*

In relation to the wet DCOF threshold of 0.42 specified by ANSI A326.3 for surfaces installed in level, interior spaces expected to be walked upon when wet, only 18.2% of the products measured above the threshold. 81.8% of the products measured either below the threshold in all test directions (72.7%) or below the threshold when tested on their long axis (9.1%). According to ANSI A326.3, any product measuring below 0.42 would not be suitable for use in wet applications.

5. DETERMINATION OF SUSCEPTIBILILTY TO MICROBIAL GROWTH

With many PBM products being advertised for applications in areas subjected to moisture, twenty-five samples were subjected to microbial testing.

ASTM G21-96(2015) [19] was used to evaluate the capacity of fungi to grow on the flooring materials. *Aspergillus niger* (ATCC no. 9642), *Gliocladium virens* (ATCC no. 9645), *Chaetomium globosum* (ATCC no. 6205), *Aureobasidium pullulans* (ATCC no. 15233) and *Penicillium pinophilum* (ATCC no. 11797) were used for the inocula. Minimal salts media was prepared and poured into 150mm x 25mm sterile petri plates. The salts agar has no nutrients to support mold growth.

The samples were cut into a rectangular shape 50 mm x 50 mm in size, sterilized with 70% ethyl alcohol and dried for 24 hours. All five mold fungi were separately inoculated onto potato dextrose agar plates and incubated at 29 ± 1°C and relative humidity ≥85% until the entire surfaces of the petri plates were covered with fungal hyphae. A spore suspension of each fungal inoculum was prepared by washing the culture surface of each fungus with 10 mL of sterile water. The resulting suspension was then transferred to respective sterile tubes containing sterile water. Tubes were shaken vigorously to separate the spores and break the spore clumps. A precipitate was obtained when the spore suspension was filtered and centrifuged. A final spore suspension was obtained by re-suspending the precipitate in sterile water. The concentration of the suspension was determined and adjusted to about 1×10^7 spores per ml using a counting chamber. Equal volumes of the resultant spore suspensions were mixed together to obtain the final mixed spore suspension. This suspension was then transferred to a 50 mL spray bottle and used as the source of fungal inoculum for testing.

Each sample, after inoculation, was placed in the center of a Petri dish containing nutrients salts agar prepared as instructed in the test method, and then incubated for 28 days at 29 ± 1°C and relative humidity ≥85%. Growth observations were carried out every week.

The tests showed that all 25 PBM flooring samples were susceptible to mold growth. Growth levels varied, with the sides found to be the most susceptible. Growth was also observed on the bottom of more than half of the samples tested. As a control, porcelain tile, wall tile and glass tile were also evaluated and exhibited no mold growth.

This testing was repeated twice for a total of three test runs over four and a half months to allow an assessment of repeatability. In all tests, the results repeated exactly (i.e., no variation in the extent of mold growth per specimen as evaluated according to the test method).

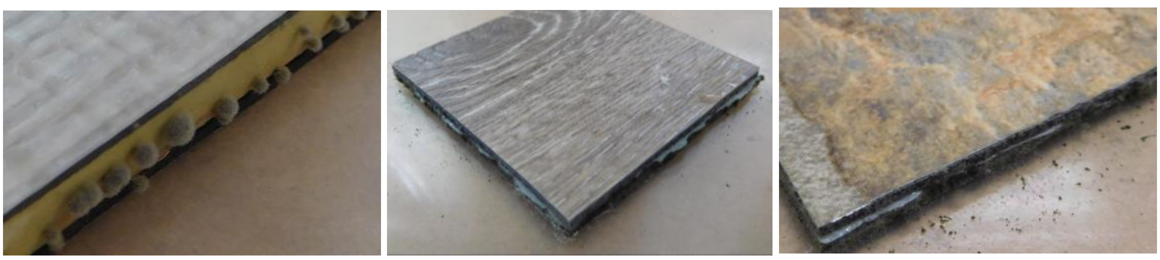

Figure 6: *Examples of PBM test specimens which supported mold growth*

6. DURABILITY—RATIONALE FOR RESEARCHING SCRATCH RESISTANCE

In a recent survey of flooring purchasers, flooring described as "scratch and puncture resistant" ranked 8.9 out of 10 in importance, where 1 is not at all important and 10 is extremely important when deciding which floor covering to purchase [6]. Perhaps reflecting this, many PBM flooring products are advertised as scratch-resistant or otherwise represented as having a highly durable and/or scratch-resistant surface. Such claims include references to topical coatings with ceramic beads, alumina oxide, or similarly hard materials.

Given the importance of scratch resistance to consumers, it's a reasonable expectation that test data from standardized test methods would be available to support manufacturer claims. However, in an evaluation of 23 widely available products, no data or test methods supporting such claims were found. Further, while 19 products out of the 23 studied specifically claimed scratch resistance, 74% excluded damage from scratches entirely in their warranties and the remaining 26% excluded loss of gloss or similar (as would be caused by scratches).

By comparison the ceramic tile industry has employed a variety of standard surface abrasion test methodologies, such as ISO 10545-6 [20] *Determination of Resistance to Deep Abrasion for Unglazed Tiles* and ISO 10545-7 [21] *Determination of Resistance to Surface Abrasion for Glazed Tiles*. Additionally, Mohs scratch hardness is widely reported with ASTM C1895 [22] *Standard Test Method for Determination of the Mohs Scratch Hardness of Ceramic Tile* the standard for making Mohs measurements.

Given the importance of scratch resistance to consumers, and the easy comparability of Mohs hardness data, an evaluation of PBM flooring products for Mohs hardness was warranted.

7. EVALUATION OF SCRATCHING SUSCEPTIBILITY

To evaluate PBM flooring susceptibility to scratching, 23 PBM flooring samples were evaluated according to ASTM C1895. All of the samples tested were advertised as either scratch resistant (79%) or otherwise having a durable surface (21%). As previously noted, 74% of the products claiming scratch resistance excluded damage from scratches in their warranties and an additional 26% excluded loss of gloss or similar. No supporting scratch resistance data were provided by any of the manufacturers of the products sampled.

Per ASTM C1895, a sled is used to hold hardness picks (one at a time) at a 70 ± 5° angle in contact with the test specimen. Each hardness pick has an assigned Mohs hardness (see Figure 7) [23]. An auxiliary weight is added atop the sled, such that 3.2 ± 0.2 kg (7 ± 0.5 lb.) is applied to the point where the hardness pick is in contact with the test surface, and testing is initiated by placing the assembly into motion at a uniform pace along the surface of the specimen.

Mineral	Mohs Hardness	Can be scratched by
Talc	1	Fingernail
Selenite	2	Fingernail
Calcite	3	Copper coin
Fluorite	4	Iron nail
Apatite	5	Knife
Microcline	6	Steel nail or file
Quartz	7	Masonry drill bit
Topaz	8	Grinding wheel
Corundum	9	Diamond
Diamond	10	Another diamond

Figure 7: *List of minerals and associated hardness*

Following each test, specimens were inspected through a jeweler's loupe for scratches. If there was a scratch present, the hardness pick used was reported. If no scratch was present, the test was repeated using the next highest hardness pick.

All 23 PBM products tested scratched at a Mohs hardness of three and did not scratch at a Mohs hardness of 2. A hardness of three is equivalent to calcite or a copper penny [23]. With pet nails typically having a Mohs hardness of 2.5, and the sand in dirt typically having a hardness of 6 or greater, this testing showed all products susceptible to scratching from household dirt and possibly pet nails.

8. DISCUSSION AND CONCLUSIONS

Test results indicated that using PBM products in wet applications potentially introduces a host of concerns, including 1) water leaking through seams in flooring claimed to be 100% waterproof, 2) slippery conditions, and 3) mold growth.

Regarding water leaking through the seams, the average bathroom size in the United States, based on a variety of sources, is 3.7 m^2 [24]. This means, extrapolating from the results recorded for testing conducted per EN 13553, a typical bathroom could leak water up to rates ranging from 12 L/hr. to 186 L/hr. For perspective, an average sink faucet flows at approximately 500 L/hr., and an average washing machine uses approximately 170 L per load. Given the rate of leakage through the seams extrapolated from results of the tests conducted, it's reasonable to question the suitability of such flooring in wet areas and the "waterproof" claims made by the product manufacturers.

Not only can water penetrating into the subfloor potentially cause degradation of the structural integrity of wood-framed assemblies, moisture trapped between floor coverings and subflooring can create conditions favorable for mold growth [25,26]. While visible mold growth is easily remediated through cleaning, non-visible mold growth is a hidden cause for issues including structural damage, material degradation and sickness [27]. Mold spores can contaminate indoor air by simple day-to-day activities such as walking on the flooring [28]. As reported herein, testing conducted to evaluate microbial growth on PBM flooring samples demonstrated all 25 samples supported mold growth.

Regarding slipperiness, of the twenty-two products tested, all of which advertised wet area applications, none provided an assessment of their traction under wet conditions. Eighteen products (81.8%) tested below 0.42 wet DCOF in one or more directions, meaning those products did not meet the ANSI A326.3 criteria for interior, level floors expected to be walked upon when wet. Six products exhibited directionality when wet (including two additional to the 18 already mentioned), indicating that a change in direction of ambulation when wet could cause a change in traction to occur. If unexpected, such a change could result in a dangerous loss of traction. In total 91% of the products should be considered for a dry use-only warning.

Regarding surface durability as it relates to scratch resistance, evaluation per the widely understood Mohs scratch hardness test demonstrated that all twenty-three products tested are easily scratched, despite manufacturer claims of scratch resistance or durability. Specifically, all products scratched at a Mohs hardness of 3, well below the hardness of sand that can be brought in through routine foot traffic.

In conclusion, it is widely known that PBM flooring products compete with and claim to emulate the benefits of ceramic tile, particularly regarding surface durability and suitability for wet applications. To test these attributes, TCNA, under the direction of the Bishop Materials Laboratory at Clemson University, and the Department of Biological Sciences at Clemson University conducted a series of tests. The results can be broadly summarized as follows:

- All PBM products tested leaked water through the seams at substantial rates
- All PBM products tested were confirmed to be nutrient sources for mold growth under moist conditions
- More than 90% of the PBM products tested were either slippery when wet (based on wet DCOF below 0.42) or exhibited wet directionality
- All PBM products tested could be scratched by materials of Mohs hardness 3 or greater.

Of the 25 products sampled, the products tested were drawn from major brands with significant market penetration.

At a minimum, the test results and the disparity between advertised properties versus warranty exclusions raise concerns regarding the use of the tested PBM products in either wet conditions or applications with normal foot traffic bringing in outdoor soil.

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