Dens-Deck® Roof Board

PRODUCT Review, Testing, and Application Recommendations

By
Colin Murphy, RRC,
and
Robert Mills

Introduction

Dens-Deck® is a nonstructural, glass mat-faced, noncombustible roof board with a patented, water-resistant, treated gypsum core, manufactured by G-P Gypsum Corporation ("G-P") for use in commercial roof assemblies. Introduced in 1987 in 1/2-inch and 5/8-inch thickness, the 4-ft by 8-ft Dens-Deck® roof boards also became available in 1994 in a 1/4-inch thickness. Virtually all types of roof systems use the product as either a thermal fire barrier, recover board, or as a bonding surface.

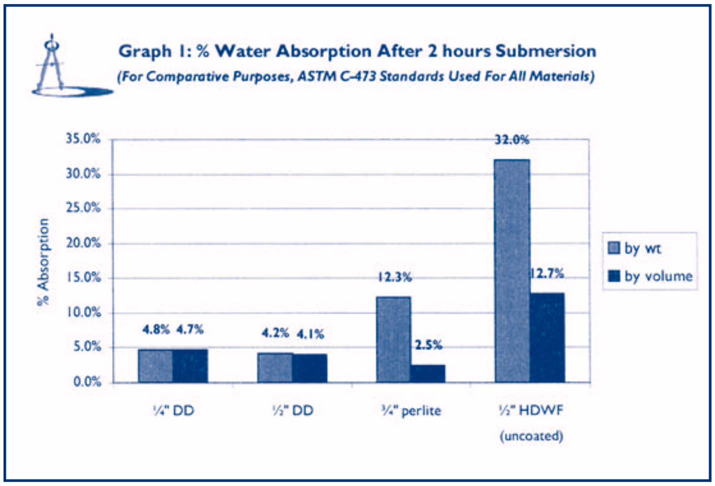
To date, G-P has published nieither general guidelines for Dens-Deck® installation, nor any recommendations for installation other than the system performance data provided in third-party testing reports and limited "Tech Notes"[1] Installers, some system manufacturers, and specifiers have extended the use of Dens-Deck® beyond the boundaries of its inherent performance capabilities.

In response to the expanding applications of the product, and some concerns regarding specific application performance, G-P commissioned Exterior Research and Design, LLC ("ERD") of Seattle, Washington. This was to carry out specific testing to better understand the boundaries of performance and to develop technical recommendations for the use of Dens-Deck® roofing products. The commission included a limited comparative review of other cover board materials, namely, perlite and uncoated, high-density, wood fiberboard ("HDWF").

General Product Review

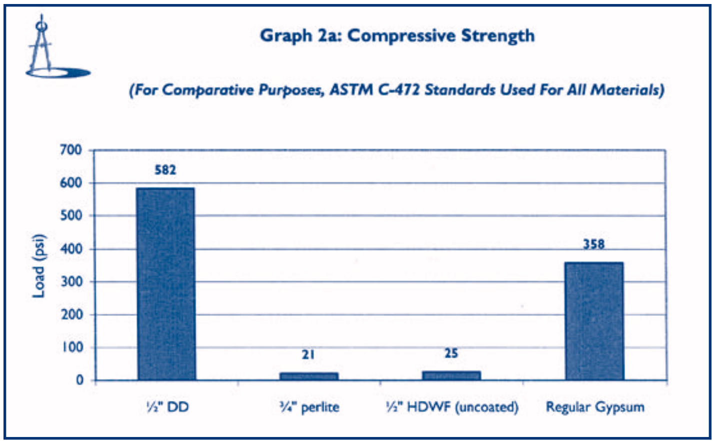
The attributes of Dens-Deck®, including density, moisture resistance, bond strength, flute spanability, and fire resistance, have led to its wide acceptance within the industry.

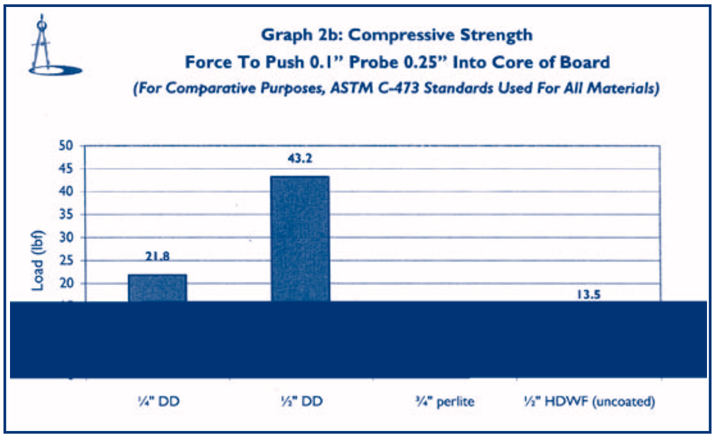
ERD physical property testing confirms the treated gypsum core resists moisture wicking, retards surface moisture absorption, and (like other gypsum products), promotes fire resistance. *Graph 1* provides comparative testing results for water absorption after two-hour submersion. It should be noted that the 2-hour submersion does not result in, and this data does not relate to, a condition of saturation, which can happen under wet conditions to any material and will adversely affect performance.

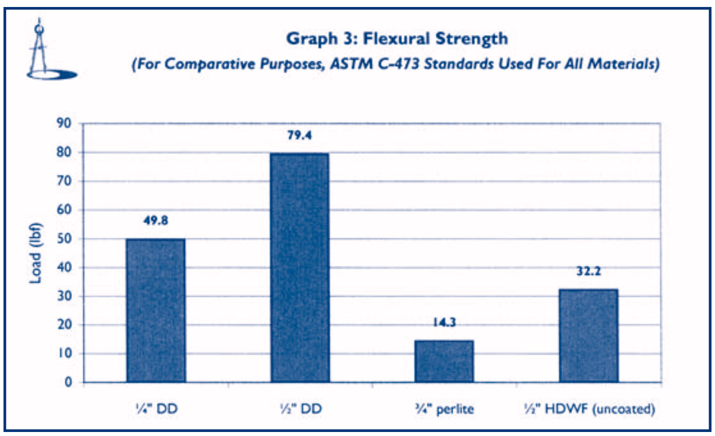


The embedded glass mats promote dimensional stability (the coefficient of expansion is 8.5 x 10-6 in/in °F); resistance to delamination, deterioration, warping, and puncturing; strength (i.e., flute spanability); and fire resistance (ASTM E-84 rating of zero flame spread and zero smoke developed).

Graphs 2a, 2b and *3* provide comparative results of ERD testing for "compressive" and "flexural" strength.







As a gypsum product, Dens-Deck® has unique fire-resistant properties due to the large proportion (~21%) of chemically-combined moisture contained in the gypsum crystal. In its various thicknesses, Dens-Deck® provides excellent thermal and fire resistance ratings. UL Class A listings include: UL 1256 (thermal barrier), UL 263, and UL 790 Class A, B, C (fire barrier).

Dens-Deck®, through its physical properties, is a versatile roof board that can be used as a thermal barrier (underlayment), fire barrier (overlayment), air barrier component, solvent barrier, recover board, and a roof membrane substrate providing good uplift resistance with a variety of bonding materials.

ERD Testing - Introduction

The ERD testing and analysis included field review of particular projects where applications issues, particularly moisture-related, were observed with Dens-Deck®. Projects were located in Washington, New York, Florida, Oregon, California, Virginia, and Louisiana.

Observations confirmed the use of the Dens-Deck® products extended well beyond proven performance—in particular, the application of the product in high moisture and humidity conditions, high humidity interior conditions without an adequate vapor retarder, and over damp and wet existing roof assemblies. In addition to moisture issues, observations of direct torch bonding and cold adhesive applications highlighted additional issues not identified in G-P literature and application data.

A particular focus of the ERD testing was the effect of calcination–the release, with sufficient heating, of chemically-combined water crystals (i.e., the water portion of the gypsum crystal changes from a solid to a gas). The amount of vapor release is dependent on the temperature and the duration of the heat application.

> "As gypsum is heated to temperatures in excess of 80°C (~175°F) it begins to undergo a thermal degradation process known as calcination in which the chemically-combined water dissociates from the crystal lattice. …Through continued heating, the remaining water is released as the resulting hemihydrate undergoes dehydration to form anhydrous calcium sulphate."[2]
>
> "The process of dehydration of the plasterboard is modeled as the movement of a thin layer of material (called the dehydration front) across the plasterboard in the direction orthogonal to its surfaces. The evaporation of water takes place only within the dehydration front. Behind the dehydration front, all water has been evaporated while the non-dehydrated part of the plasterboard is assumed to be chemically and structurally intact."[3]

While the calcination process begins at ~175°F, the water dissociation from the crystal lattice is slow. The process accelerates at 350°F, producing a more rapid release of water that can have an impact on roofing application. Thermal gain can result from the application of hot asphalt or the direct application of a torch to the Dens-Deck® surface.

Energy must be absorbed to allow the calcination to continue. The absorption of energy works to slow the heat transfer process, which is accompanied by a concurrent moisture transfer, due to pressure gradients, from beyond the hydration front. Unless the source of heat is continued, the released water will reduce the temperature at the hydration front, slowing or stopping the calcination process.

Built-up roofing, however, is a multiple layer process. If the lowered temperature is sufficiently elevated by a new application of asphalt, the calcination process will begin again, trapping rising moisture under the initial application and resulting in froth-

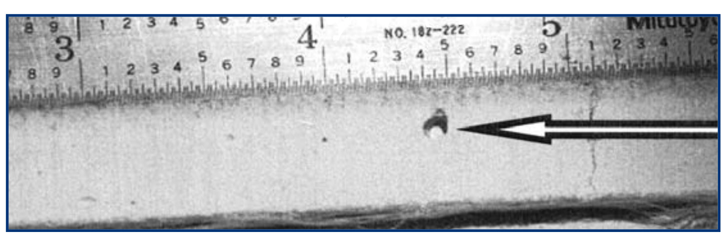


Photo 1—Darker area demarks progress of dehydration front as torch is applied.

ing and blistering. Therefore, the entire process must be closely reviewed to evaluate application procedures and boundaries.

Photo 1 provides a cross-sectional perspective of the downward movement of the dehydration front after a torch was applied to 1/2″ Dens-Deck®.

The material behind the dehydration front appears darker due to the voids (see *Photo 2*) remaining after the evaporating water has dissociated from the crystal lattice.

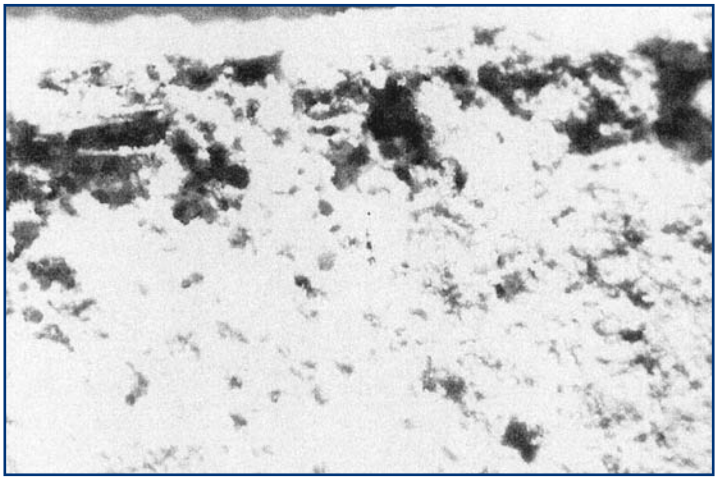


Photo 2—Microscopic cross-section of torched 1/2″ Dens-Deck.® (Note calcination voids remaining above the dehydration front).

During the manufacturing of gypsum board, the gypsum crystal is partially calcined, heating the gypsum to sufficient temperature to remove 75% of the chemically-combined water. The gypsum subsequently hydrates from water introduced in production, returning the crystal to its original state. In a similar way, chemically-combined water exiting the board as vapor (steam) during the heating process in hot roof installations is returned in the subsequent hydration process, taking moisture from the low portion of the board and the surrounding environment.

Standards and references used for the ERD testing included:

- "Peel Adhesion Testing," ASTM D-903-98.
- "Simulated Wind Uplift Testing," Factory Mutual 4470, Appendix C and K.
- Water Absorption, ASTM D-1037 and ASTM C-473.
- "Water Vapor Transmission," ASTM E-96-95.
- "Combined Water of Gypsum," "Combined Water of Gypsum Testing," (proprietary to G-P Gypsum Corp).

The following standard definitions are used for the ERD testing and resulting analysis:

- **Bleed-through:** The condition of exposed gypsum overtop the fiberglass facer in Dens-Deck® that is a result of the gypsum slurry passing through the fiberglass facer during the manufacturing process. Bleed-through is a result of additional weight applied through pressure bars at the edges and the slurry application point in the center of the board.
- **Blistering:** The result of air or vapor entrapment between or within impermeable or "low-perm" materials (e.g., between two membrane layers or within liquid asphalt).
- **Calcination:** The process by which heated gypsum releases water in a solid state that is chemically combined within the gypsum core. The temperature at which this reaction begins is 175°F.
- **Combined Water:** The water chemically held, as water of crystallization, by the calcium sulfate dihydrate or hemihydrate crystal. The amount of combined water in a gypsum sample is expressed as a percentage of its original weight (approximately 21% by weight in pure gypsum).
- **Free Water:** All water contained by a material that is not chemically combined.
- **Frothing:** The bubbling reaction of moisture vapor passing through a liquid adhesive material.
- **Gypsum:** Mineral composed of hydrous calcium sulfate, $CaSO_4 \bullet 2H_2O$ or calcium sulfate dihydrate. Gypsum has the same composition as Anhydrite, but contains combined water in its structure.
- **Perm:** A unit of measurement of water vapor permeance.
- **Permeance:** The ratio of the rate of water vapor transmission ("WVT") through a material or assembly between two parallel surfaces to the vapor pressure differential between the surfaces.
- **Perm Rating:** A rating given to vapor retarders to quantify their ability to resist water vapor transmission. A rating of 1 perm indicates the passage of 1 grain of water vapor (e.g., 1 pound of water vapor = 7,000 grains) through 1 square foot of material in 1 hour for each inch of mercury pressure differential that exists between the two sides of the material.
- **Water Vapor Transmission (WVT):** The rate of water vapor flow (under steady, specified conditions) through a unit area of material between its two parallel surfaces and normal to these surfaces.

RCI
RCI, Inc.
800-828-1902
www.rci-online.org

In addition, the following definitions relate to the conditioning and preparation of the test specimens during ERD testing:

- **Ambient Conditioning** is defined by a minimum of 2 hours conditioning at 75°F and 50% relative humidity ("RH").
- **Humidity Conditioning** is defined by 24 hours conditioning at 75°F and 95% RH and immediate specimen preparation thereafter.
- **Surface Moisture Conditioning** is defined by 24 hours conditioning with 2 fl. oz. of water of 48 in^2 (0.33 ft^2) of top surface area, and immediate specimen preparation thereafter.
- **Soak Conditioning** is defined by water immersion for 24 hours and standing on edge for 1 hour prior to specimen preparation. It should be noted that this "soak conditioning" does not result in saturation of the test specimen.
- **Sealed Edges** describes the dipping of specimen edges in hot asphalt, thereby eliminating this avenue of moisture migration and thus replicating conditions experienced in applications of full board, where the amount of surface area coverage precludes moisture egress from panel edges.

ERD Testing – Samples and Specimens

Samples of 1/4″ Dens-Deck® were delivered to the laboratory from the G-P Gypsum production facility located in Acme, Texas. G-P personnel inspected the product and confirmed the samples were representative of typical Dens-Deck® production.

The Dens-Deck® sample boards included 6-inch wide strips of visible gypsum material (bleed-through) above the fiberglass facer along the panel length running along each edge and through the center. G-P laboratory and production personnel advised this bleed-through is a normal condition associated with the manufacturing process and relates to maintaining edge integrity and the introduction of the gypsum slurry at the center of the board.

Asphalt used in specimen preparation was ASTM D-312[4] Type III or IV, as noted. For asphalt applications, Type III was heated to 400-425°F, and Type IV was heated to 475-500°F. Temperatures noted are at the point of application to the surface of the boards. No polymer-modified asphalts (which generally are applied at higher temperatures and coverage rates than D-312 roofing asphalt), were tested. Unless otherwise noted, the following specifications relate to roof covering materials used in specimen preparation:

- Base sheet materials were ASTM D-4601[5], Type II asphalt coated, fiberglass reinforced sheets. Vented base sheet materials were perforated ASTM D-4897[6], Type II asphalt coated, fiberglass reinforced sheets. Both sheet types are moderately permeable. D-4601 base-sheets vary in permeability depending on the asphalt application process. The degree of permeability will vary from product to product.
- Ply sheet materials were ASTM D-2178[7], Type IV asphalt saturated, fiberglass-reinforced sheets. These sheets are highly permeable.
- Membranes applied to hot asphalt were ASTM D-6163[8], fiberglass reinforced styrene-butadiene-styrene (SBS) modified bitumen sheets. These sheets have a low perm rating.
- Torch-applied membranes included D-6163 fiberglass reinforced or ASTM D-6164[9] polyester reinforced SBS modified bitumen sheets and ASTM D-6222[10] polyester reinforced atactic-polypropylene (APP) modified bitumen sheets. These sheets have a low perm rating.

Peel adhesion test specimens were prepared following the procedures outlined in ASTM D-903[11] using 6″ x 8″ substrate specimens of 1/4″ Dens-Deck®, 3/4″ perlite, and 1/2″ uncoated high density wood fiberboard and 6″ x 12″ membrane specimens. Substrate specimens were prepared to examine each of the conditioning exposures defined above–*Ambient, Humidity, Surface Moisture*, and *Soak*.

Membrane applications included: (1) Type III asphalt at 25 lbs/square; (2) Type III asphalt at 35 lbs/square; (3) Type IV asphalt at 25 lbs/square; (4) Type IV asphalt at 35 lbs/ square; and (5) torch applications. Membrane application rates divisible by five were examined for repeatability considerations. The rate of 25 lbs/square relates to the high-end (more heat = worst case) of BUR and modified bitumen recommended rates. The rate of 35 lbs/square was utilized to examine the effects of an increase (decrease in mopping temperature) from the high-end rate on a comparative basis.

Specimens for testing **water absorption** were prepared following the procedures outlined for the respective products' ASTM specifications under the conditioning exposures defined above— *Ambient, Humidity, Surface Moisture,* and *Soak*.

Specimens for testing combined water in gypsum were prepared following the procedures outlined in G-P Gypsum Corporation's proprietary test standard to examine the effects of hot asphalt application on the amount of chemically-combined water in the gypsum core. Specimen preparation included a control sample stored at ambient conditions for not less than 24 hours and an asphalt-application sample, using 475-500°F asphalt at 25 lbs/square.

Vapor transmission test specimens were prepared following the procedures outlined in ASTM E-96 (desiccant method) to examine the effects of asphalt application and vapor barrier application over 1/4″ Dens-Deck®. Variables include asphalt application temperature and use of fiberglass ply sheets forming a two-ply vapor retarder.

The following definitions apply for specimen construction and testing for **simulated wind uplift resistance:**

- **Full asphalt mopping** relates to complete substrate coverage at a rate of 25 lbs/square.
- **Strip asphalt mopping** relates to partial substrate coverage with approximately 3″-wide strips spaced 3″ o.c. at an application rate of 12 lbs/square.
- **Spot asphalt mopping** relates to partial substrate coverage with approximately 36″ diameter spots spaced 24″ o.c. at an application rate of 12 lbs/square.
- **Perforated venting base sheets** include holes through which asphalt flows when a subsequent ply is applied overtop, creating a spot bond to the underlying substrate.

Seven 5 ft. x 9 ft. wind uplift resistance specimens were constructed and tested following FM 4470 test procedures. All panels were built over standard 22 ga., type B, Grade C steel roof deck and included 1.5″-thick, loose-laid, polyisocyanurate below the Dens-Deck®. Specimen configurations included:

Panel 1

Cover board— 1/4″ Dens-Deck® attached using 18 Olympic #12 diameter fasteners and metal load distribution plates per 4′ x 8′ board.

Roof Cover— Torch-applied, SBS-modified, smooth-surface base followed by torch-applied, SBS-modified, granule-surfaced cap.

Panel 2

Cover board— 1/4″ Dens-Deck® attached using 16 Olympic #12 diameter fasteners and plates per 4′ x 8′ board.

Roof Cover— ASTM D-4601, Type II base applied in full mopping of Type IV asphalt –ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt–granule-surfaced, SBS modified bitumen cap in hot asphalt.

Panel 3

Cover board— 1/4″ Dens-Deck® attached using 16 Olympic #12 diameter fasteners and plates per 4′ x 8′ board.

Roof Cover— ASTM D-4601, Type II base applied in a strip mopping of Type IV asphalt—ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt–granule-surfaced, SBS modified bitumen cap in hot asphalt.

Panel 4

Cover board— 1/4″ Dens-Deck® attached using 16 Olympic #12 diameter fasteners and plates per 4′ x 8′ board.

Roof Cover— ASTM D-4897, Type II venting base applied in a spot mopping of Type IV asphalt—ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt.

Panels 5 and 6

Coverboard— 1/4″ Dens-Deck® attached using 16 and 18 Olympic #12 diameter fasteners and plates per 4′ x 8′ board.

Roof Cover— ASTM D-4897, Type II perforated venting base loose laid—ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt.

Panel 7

Cover board— 1/4″ Dens-Deck® attached using 18 Olympic #12 diameter fasteners and plates per 4′ x 8′ board.

Roof Cover— Siplast strip-torch sheet, torch-applied, followed by torch-applied SBS mod. bitumen roof cover.

In addition, one 12 ft x 24 ft wind uplift resistance specimen was constructed per FM 4470 test procedures:

Deck— 22 ga., type B, Grade C steel deck attached 6″ o.c. to steel supports spaced 5′ o.c.

Insulation— 1.5″ thick polyisocyanurate insulation, loose laid.

Cover board— 1/4″ thick Dens-Deck®, mechanically attached using Olympic #15 diameter fasteners and plates at a density of 1 per 1.3 ft^2 (24 fasteners per 4′ x 8′ board).

Base Sheet— CertainTeed GlasBase Base Sheet applied in a spot mopping of Type III asphalt.

Top Sheet— CertainTeed Flintlastic GTS, torch-applied.

Observations and Test Results—Frothing

After preliminary testing confirmed lateral movement and escape of moisture through edges (see *Photo 3*), specimen edges were sealed with asphalt prior to conditioning and membrane application. This was done to eliminate this avenue for moisture vapor egress and to replicate conditions experienced in applications over a full board size, where the amount of surface area coverage precludes moisture egress from panel edges. Moreover, field application confirmed asphalt flow into joints, partially sealing edges of full boards.

Photo 3—Blisters at edge of test specimen.

Laboratory and field observations of hot asphalt applications indicate that frothing can occur as soon as 10 seconds and as late as 60 seconds after asphalt application.

Use of primer has a marginal effect on the degree of frothing for hot asphalt applications. The variation in time is a result of various factors, including asphalt temperature, bleed-through, and temperature absorption and asphalt penetration through the fiberglass mat.

Asphalt coverage rate (25 lbs vs. 35 lbs per square) has a negligible effect on the degree of frothing for the two asphalt types examined.

Asphalt temperature has a significant effect on the degree of frothing. A marked increase in frothing is noted when applying Type IV asphalt at 475-500°F as opposed to applying Type III at 400-425°F. In addition, the presence of bleed-through (exposed gypsum) on 1/4″ Dens-Deck® has a significant effect on the degree of frothing. More frothing is noted at board edges and at the center length–wise running strip where gypsum bleed-through is present from the manufacturing process.

The degree of frothing over Dens-Deck® test specimens was not affected by the *Humidity* conditioning or the *Surface Moisture* conditioning. The free water resulting from these exposure conditions did not appear to absorb into the board and, therefore, This photo currently unavailable

Photo 4—Increased frothing after Dens-Deck® receives soak conditioning.

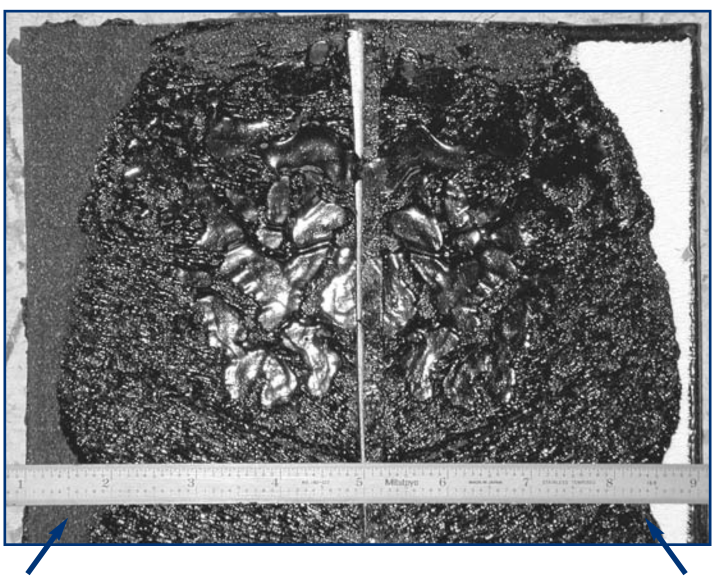
quickly flashed off upon application of hot asphalt. However, the degree of frothing over Dens-Deck® significantly increases (see *Photo 4*) in a *Soak* condition for both asphalt temperatures.

In comparison, while asphalt application to Ambient conditioned perlite and uncoated high-density wood fiberboard produced no frothing, application *Ambient, Humidity, Surface Moisture* and *Soak*. conditioned samples of perlite and high-density wood fiberboard produced a noticeable increase in frothing. Similar to Dens-Deck®, frothing over these conditioned cover board materials was more pronounced with the application of higher temperature asphalt.

Observations and Test Results - Blistering

Blisters that form beneath low-perm base sheets or membranes tend to form within the asphalt layer. The asphalt remains adhered to both the substrate and to the base sheet. See *Photo 5*.

Conventional torch applications, where heat is applied to both the underside of the membrane roll and the surface of the Dens-Deck®, result in a faster release of combined water when



Sheet underside peeled back from... ...the Dens-Deck® top side.

Photo 5—View of blisters within asphalt resulting from frothing. (Note that asphalt remains adhered to both surfaces.)

compared to asphalt applications. This is because the temperature created by the torch is much higher, and the rate of heat flux into the board is faster.

While the membrane roll weight tends to "push" moisture vapor out from beneath the membrane, blistering is noted, particularly at stress plates. This is attributable to the stress plate acting as an area of discontinuity in the substrate, thereby allowing released moisture vapor to breach the "sealed" surface, resulting in pressure below the membrane, pushing it off the Dens-Deck® substrate. If load distribution plates are placed in close proximity, the raised areas can merge, resulting in significantly large areas of non-adhesion (see *Photo 6*). The lack of adhesion may result in membrane stress and the potential for cracks and tears during thermal changes or substrate movement.

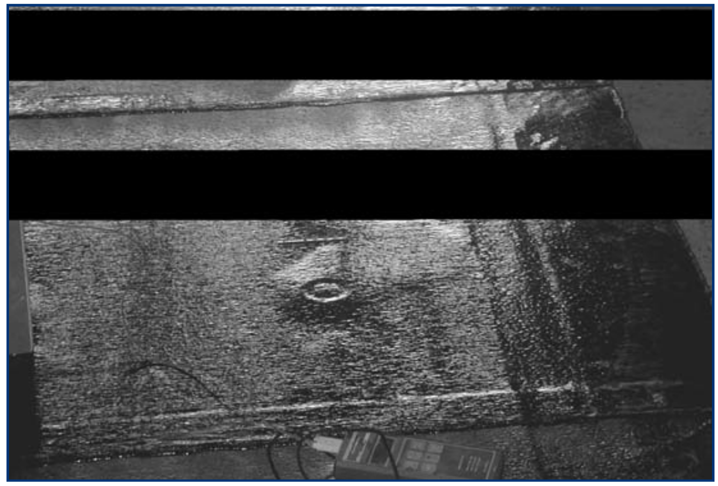


Photo 6—Blistering at stress plates, conventional torch application.

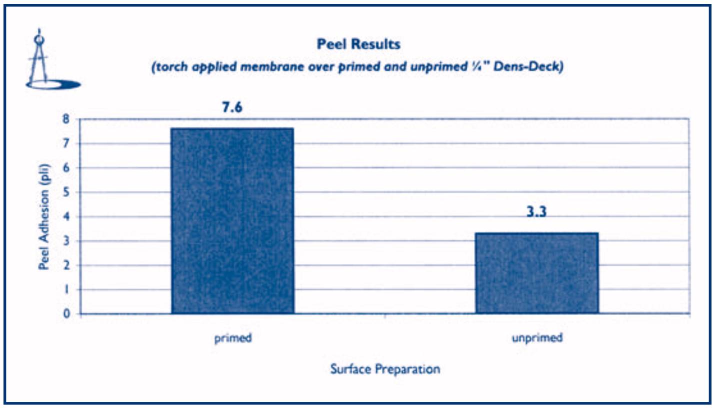
In addition, direct, prolonged exposure of Dens-Deck® to the torch flame damages the facer, resulting in a diminished bond. Initial "browning" is the discoloration of the mat binder and has little impact on the torch bonding. However, more prolonged torch applications result in melting of the fiberglass fibers, creating bond breakers between the membrane and the Dens-Deck®.

Observations and Test Results – Peel Adhesion

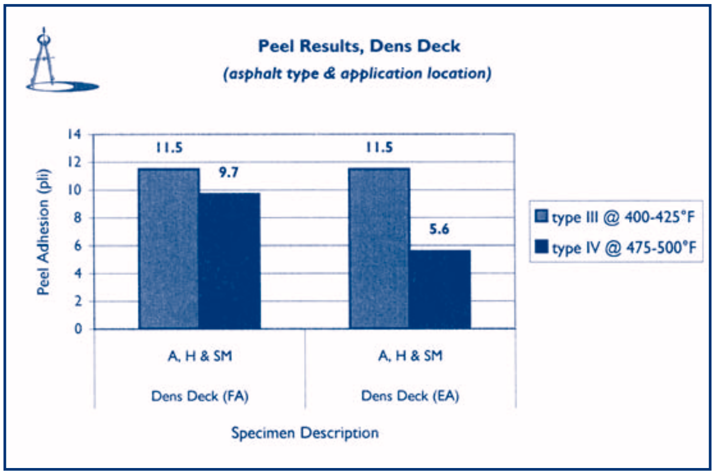
While initial observations and testing indicated that use of primer had a limited effect for asphalt applications, torch applications benefit from the use of primer. While primed torch applications resulted in an average peel value comparable to asphalt applications (7.6 pli), lack of primer reduced the peel adhesion value by 57% (to 3.3 pli). The lower values are attributable to damage to the fiberglass facer, thereby changing the mode of peel failure from membrane removal to facer removal. See *Graph 4*.

Testing reveals a minor decrease in peel adhesion performance from asphalt applied at 400-425°F to asphalt applied at 475-500°F. The reduction is more pronounced at "edge areas" ("EA") when compared to "field areas" ("FA") of the board. (See *Graph 5*.) Field areas do not include the section of bleed-through at the center strip.

These conditions are attributable to the increased frothing and blistering that occurs when a higher temperature adhesive is placed over the Dens-Deck®, coupled with the exposed gypsum bleed-through present at edge areas.



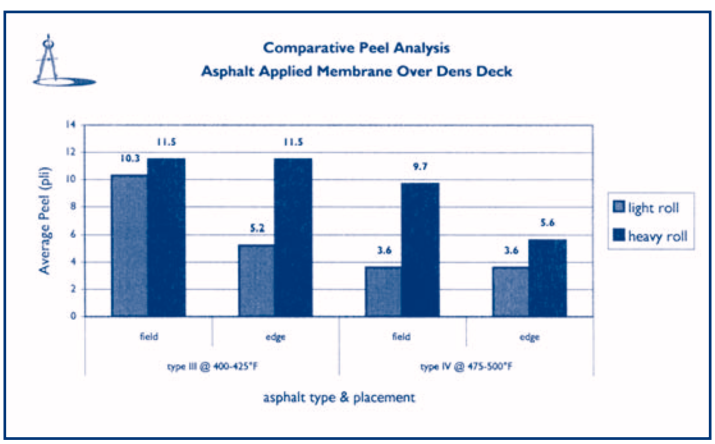
Graph 4—Decrease in peel adhesion performance with increased temperature.



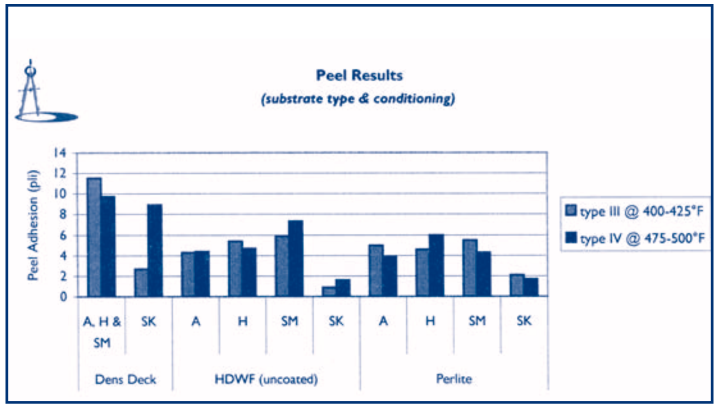
Graph 5—Decrease in peel adhesion performance with increased temperature.

The degree of blistering that results from frothing is a function of the weight of the membrane roll being applied into the asphalt application. A "heavier" roll applies more pressure to the liquid asphalt, thereby "pushing" the released moisture vapor in the direction of the roll. The end of a roll is lighter, thereby applying less pressure to the substrate during application. (See *Graph 6*.)

The application of primer encapsulates fibers and fills voids in the mat surface, resulting in a comparatively smooth surface. The melted asphalt flux bonds to this smooth surface with no "bleed" through the fibrous roof surface.



Graph 6—Peel adhesion was decreased with "lighter" rolls.



Graph 7—Dens-Deck peel adhesion performance exceeded results for perlite and HDWF (uncoated).

In all cases, the Dens-Deck® peel adhesion results exceeded those generated for perlite and uncoated high-density wood fiberboard. Dens-Deck® specimen performance exceeds perlite and HWDF by as little as 25% (for *Soak* with perlite) to as much as 167% (for *Ambient* with HDWF). (See *Graph 7*.)

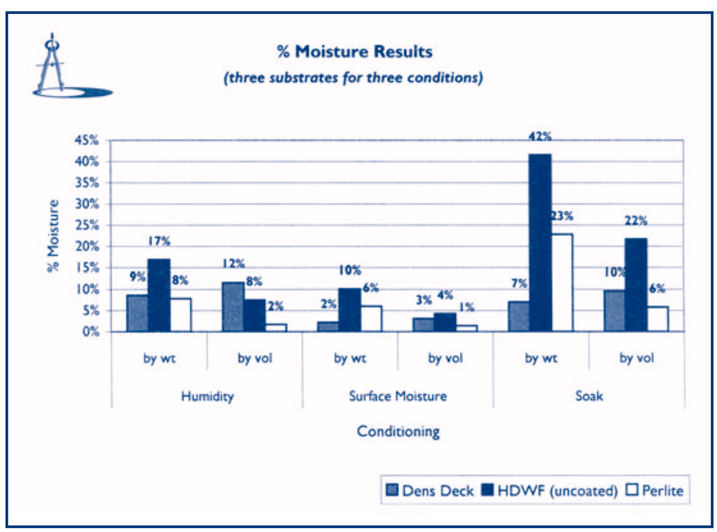
For all Dens-Deck® test specimens (with the exception of the *Soak* condition with bonding in Type III asphalt specimens,) the mode of failure is adhesive between the membrane and the asphalt (e.g., asphalt remains adhered to the substrate). In the *Soak* condition with bonding in Type III asphalt specimen, asphalt peeled from the Dens-Deck® facer.

Observations and Test Results—Water Absorption

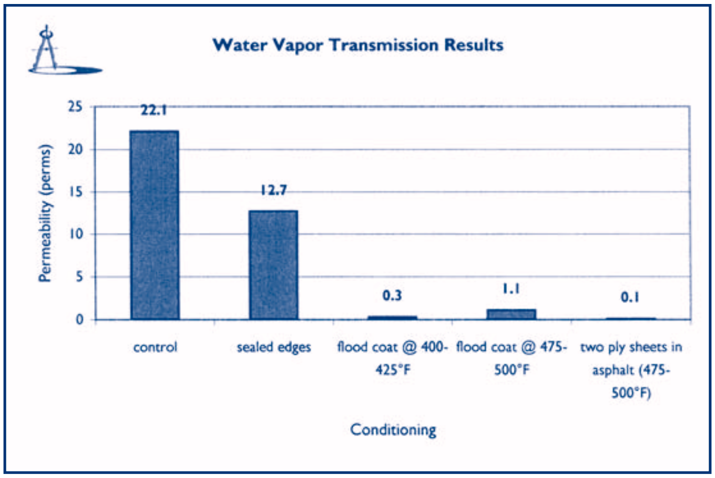
Water absorption results indicate higher absorption rate by weight for perlite and high density wood fiberboard products after all conditioning procedures with the exception of perlite in a *Humid* condition. (See *Graph 8*.)

Observations and Test Results—Combined Water/Calcination

The control specimen yielded 19.043% in chemically combined water, while the specimen tested after the application of asphalt yielded 18.632%. This equates to a 2.2% loss in com-



Graph 8—% moisture data.



Graph 9—Water vapor transmission.

bined water resulting from the application of Type IV asphalt at 475°-500°F to the Dens-Deck® top surface. Minimal water loss will not affect the fire resistive or mechanical properties inherent to Dens-Deck®. It should be noted that the test procedure examines ground gypsum material (in powdered form). Therefore, the 2.2% loss does not relate to any particular "location" within a particular board thickness, and the loss may be less based on limited exposure at the dehydration front.

Observations and Test Results—Water Vapor Transmission

A vapor retarder should have a perm rating of 0.5 perms or less to be considered an effective retarder of water vapor in most low slope roof assembly constructions.[12]

Testing (see *Graph 9*) of 1/4″ Dens-Deck® confirms:

- Moisture vapor transmits through the exposed gypsum core at board edges (control vs. sealed edges).
- The application of a flood coat of asphalt at 400-425°F produces an effective vapor retarder.
- The application of a flood coat of asphalt at 475-500°F produces pinholes in the application (resulting from frothing), creating an avenue for water vapor transmission and increased permeability (a 280% increase when compared to the lesser temperature applications).
- The application of two fiberglass ply sheets with the asphalt eliminates these pinholes, creating a homogeneous, effective vapor retarder.

Observations and Test Results – Wind Uplift Resistance

While frothing and resultant minor blistering were noted during construction of the fully-adhered 5 ft x 9 ft specimens (#1-torch and #2-asphalt), wind uplift resistance was not adversely affected. Panels performed to pressures in excess of those required for an FM Class 1-90 windstorm classification. (See *Table 1*.)

The 12 ft. x 24 ft. test panel, consisting of mechanically attached 1/4″ Dens-Deck® and a spot-mopped roof assembly, performed to a passing pressure of 135 psf, which is the pressure associated with an FM Class 1-135 windstorm classification. Similar to the 5′ x 9′ panels, the mode of failure was Dens-Deck® rupture at the fastener locations.

Additional Testing – Peel Adhesion

Subsequent comparative peel adhesion testing was conducted with samples of 1/4″ and 1/2″ Dens-Deck® that had been *Humidity* conditioned for 7 days at 75°F and 95% RH, with immediate specimen preparation thereafter—including *edge sealing*. Type III asphalt was applied at 425°F and Type IV asphalt was applied at 500°F.

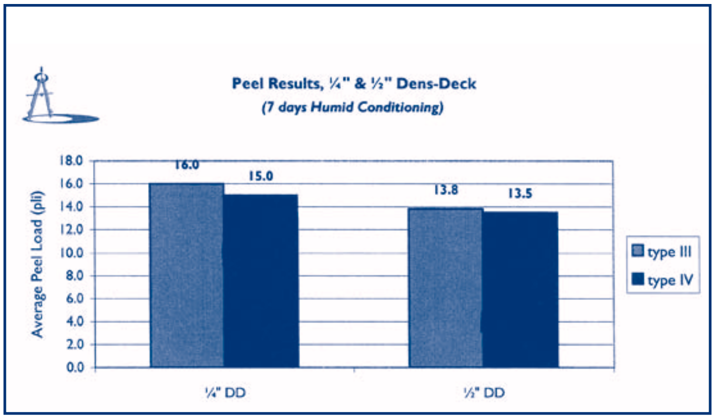
The 7-day period of *Humidity* conditioning did not result in decreased peel adhesion performance (see *Graph 10*) compared to the results (see *Graph 8*) of the previous 24-hour *Humidity* conditioning for the 1/4″ Dens-Deck®.

Testing also confirms the application of the hotter Type IV asphalt results in decreased peel adhesion performance. More-

Table 1: Simulated Wind Uplift, Summary of Results.
1/4" Dens-Deck Attached with Olympic Standard #12 Fasteners

Attachment (per 4x8 board)	Base Sheet	Roof Cover	Passing Pressure (psf)	Windstorm Classification
24	ASTM D-4601, Type II base applied in a *spot mopping* of Type IV asphalt.	ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt	135	Class I-135
16	ASTM D-4897, Type II venting base applied in a *spot mopping* of Type IV asphalt	ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt	135	Class I-90
16	ASTM D-4601, Type II base applied in *full mopping* of type IV asphalt	ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt	135	Class I-90
18	Torch-applied, SBS modified, smooth surface base membrane	Torch-applied, SBS modified, granule-surfaced cap	120	Class I-90
18	ASTM D-4897, Type II *perforated* venting base loose laid	ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS- modified bitumen cap in hot asphalt	120	Class I-90
18	Siplast strip-torch sheet, torch-applied	Torch-applied SBS modified bitumen roof cover	120	Class I-90
16	ASTM D-4601, Type II base applied in a *strip mopping* of Type IV asphalt	ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt	105	Class I-90
16	ASTM D-4897, Type II *perforated* venting base loose laid	ASTM D-2178 Type IV ply sheet in full mopping of Type IV asphalt—granule-surfaced, SBS modified bitumen cap in hot asphalt	75	Class I-75

Table 1—Simulated wind uplift, classification per FM 4470 protocol, summary of results.



Graph 10—Peel resistance, 1/4″ vs. 1/2″ Dens-Deck® with Type III and Type IV asphalt.

over, peel adhesion for 1/2″ Dens-Deck® is decreased, in comparison to the results for 1/4″ Dens-Deck®, for both Type III and Type IV asphalt.

Additional Testing – Blistering

Concurrent comparative testing for blistering was conducted with full 4 ft. x 8 ft. boards of 1/4″ and 1/2″ Den-Deck® that had been *Humidity* conditioned for seven days at 75°F and 95% RH. A three-ply BUR assembly consisting of ply IV ply sheet and Type IV asphalt was applied to both boards.

No blister formation was observed on the 1/4″ Dens-Deck® specimen. In contrast, the same BUR assembly for the 1/2″ Dens-Deck® was heavily blistered at the facer to ply sheet interface. In addition, some interply blistering was observed only at the edge of the sheet. See *Photos* 7 and 8.

Additional Testing – Thermal Penetration

Subsequent testing was conducted to obtain temperature data at various levels inside the core of sample 1/2″ Dens-Deck® during the application of hot-mopped Type IV asphalt and torch-applied roofing systems.

- Temperature readings from type "K" thermocouples were recorded by a Remote Measurement Systems ADC-1 recorder at the rate of one scan every two seconds.
- Five thermocouples were located within 1″ of the geometric center and placed at various levels (top surface, 1/4 depth, 1/2 depth, 3/4 depth, and bottom surface).

The results (see *Graphs 11* and *12*) for thermal penetration testing found:

- Temperatures sufficient (i.e. >175°F) to promote the commencement of the calcination process are limited to the topmost layer of the Den-Deck® board.
- Torch applications over gypsum boards will result in a faster release of combined water than asphalt applications, as the temperature is significantly higher at the surface and the rate of heat flux into the board is faster.

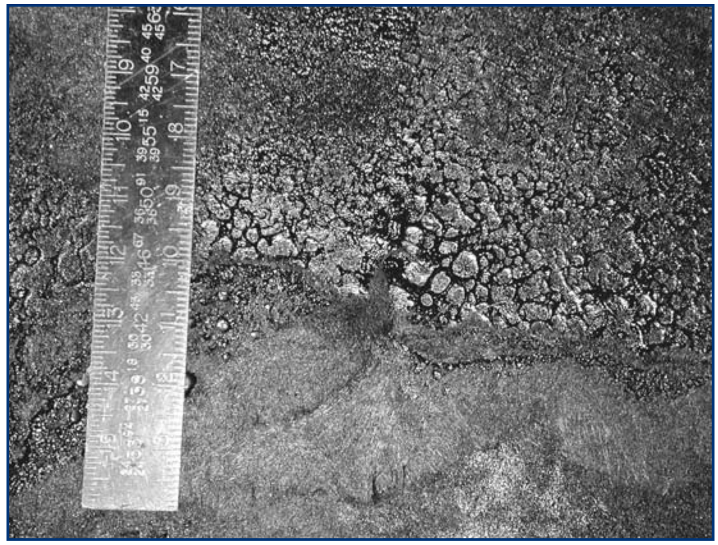
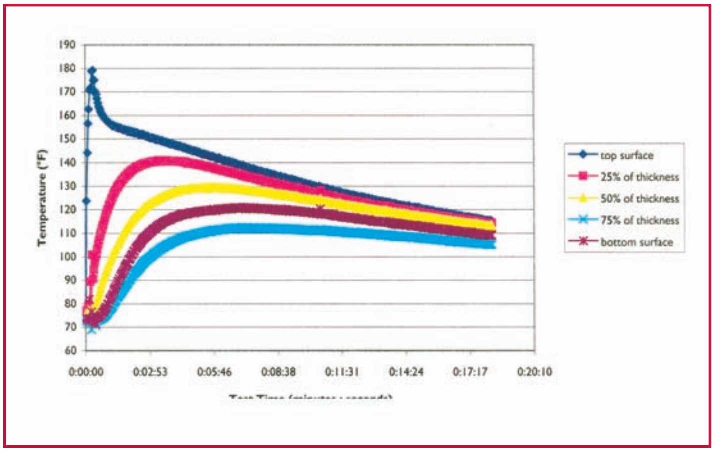


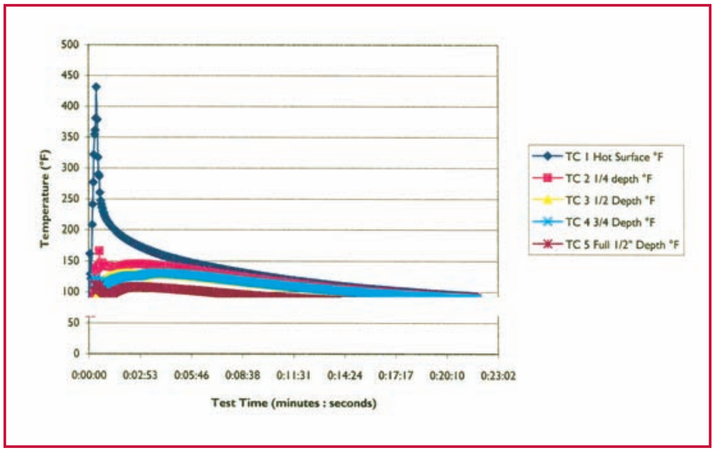
Photo 7—Observed blistering at facer-to-ply sheet interface.

Photo 8—Observed blistering at ply-to-ply interface.

RCI, Inc.
800-828-1902
www.rci-online.org



Graph 11—Thermal penetration—Hot-mopped Type IV asphalt to 1/2" Dens-Deck.



Graph 12—Thermal penetration—Torch-applied to 1/2" Dens-Deck.

Additional Testing – Cold Adhesive Applications

Additional testing and field observations confirm the application of cold adhesives (solvent or non-solvent) over Dens-Deck® results in no frothing or blistering.

Peel adhesion performance of solvent-based, cold adhesives (aliphatic or aromatic) over Dens-Deck® is low after 28 days due to the lack of complete curing within that time frame.

Non-solvent based adhesive (urethane) provides a higher peel adhesion performance with a greater degree of curing within the 28-day period. Hot asphalt applications result in a comparatively higher peel adhesion performance.

Application of cold adhesive systems with high aromatic solvent content over sealed assemblies such as vapor retarders, existing built-up roofing assemblies, or insulation bonded on hot asphalt, can result in trapped solvents that must pass through the roof assembly before full cure can take place. Depending on the composition of the sheet (and total roof assembly), the trapped solvent can have a negative impact on the assembly. Softened sheets, granule loss, and free solvent under the assemblies have all been observed.

Wind uplift resistance of roof assemblies using solvent-based cold adhesives over mechanically-fastened Dens-Deck® perform to a lesser level after 28 days than those using non-solvent based adhesive. This is attributable to increased loading at metal stress plate edges as the membrane loses adhesion to the metal, whether primed or not. Loss of adhesion at the metal stress plate is a result of accumulated trapped solvents at these locations.

Wind uplift resistance of roof assemblies using non-solvent based, cold adhesive (urethane) over mechanically fastened Dens-Deck® perform to a lesser level than those using hot asphalt when tested after 28 days. This is attributable to the greater rigidity and more even load distribution inherent to an asphalt-applied system when compared to a urethane, adhesive-applied system. Uplift testing after 45 and 60 day cure time is in process.

Conclusions

Dens-Deck® releases a minor quantity of combined water from the gypsum core in the form of water vapor (steam) when exposed to temperatures of 350°F or greater. The process, known as calcination, is an inherent reaction that contributes to the external fire resistance performance of roof systems installed over Dens-Deck®. The release of water works to repel the penetrating heat, reducing absorption into the board, decreasing surface temperature, and limiting the period of calcination.

Calcination, resulting from the application of hot asphalt to Dens-Deck®, causes frothing of the asphalt as water vapor is released from the gypsum by the heat transfer from the asphalt. The energy (heat) is partially consumed during calcination.

More frothing occurs at the edges and center of Dens Deck®—where gypsum slurry bleed-through is present—as asphalt is in direct contact with gypsum. The unprotected gypsum is heated more quickly and begins the calcination process before the period of heat transfer through the fiberglass mat typical for the balance of the board area. A larger volume (thicker) of gypsum bleed-through releases more combined water, producing increased frothing.

Frothing of hot asphalt over Dens-Deck® results from the release and upward migration of combined water from the gypsum. Dens-Deck® has a low water absorption rate when compared to other cover board materials. Therefore, the degree of frothing over Dens-Deck® is not significantly affected when exposed to high *Humidity* or *Surface Moisture* conditions.

Frothing of hot asphalt over perlite or HWDF does not occur in an "as received" condition. However, perlite and HWDF have a high water absorption rate when compared to Dens-Deck®. Therefore, frothing does occur, and the potential for blistering does exist when the products are exposed to high *Humidity* or *Surface Moisture* conditions.

Frothing of hot asphalt, as a result of calcination, can result in blistering between the Dens-Deck® and the overlying membrane. The potential for and extent of blistering in hot asphalt applications are dependent on:

- **Mopping techniques—** a greater potential for blistering exists when small voids ("holidays") in the asphalt application are present;
- **Material types—** a greater potential for blistering exists when the first sheet applied has a low perm rating;
- **Application methods—** while some potential exists for blistering in a full mopping application, no potential exists for strip or spot mop applications, or applications

of a perforated venting base sheet, as water vapor travels laterally between strips or spots; and
- **Roll weight—** a greater potential for blistering exists when there is insufficient weight in the roll to "push" the water vapor from the adhered layer (e.g., at the end of a roll).

The release of combined water (calcination) that occurs during the installation of a torch-applied membrane also can result in blistering between the Dens-Deck® and the overlying membrane. The potential for and extent of blistering in torch-applied applications are dependent on:
- **Substrate continuity—** a greater potential for blistering exists when torching over mechanically-fastened Dens-Deck® than fully-adhered Dens-Deck®. Rising water vapor accumulates at substrate discontinuities and becomes trapped;
- **Torching techniques—** a greater potential for blistering exists when the torch flame is placed directly over the Dens-Deck® surface (see *Photo 9*); and
- **Roll weight—** a greater potential for blistering exists when there is insufficient weight in the roll to "push" the water vapor from the adhered layer (e.g., the end of a roll).

Photo 9—There is a greater potential for blistering when the torch is applied directly to the Dens-Deck® surface.

Blistering decreases the peel adhesion performance of bituminous membrane applications over Dens-Deck®. However, with proper installation, the peel adhesion performance of these systems over Dens-Deck® exceeds that of perlite and wood fiberboard, regardless of exposure conditions (*Humidity* or *Surface Moisture*).

Perlite and uncoated HDWF fail cohesively when an overlying bituminous membrane is subjected to peel load. The peel load required to incur this cohesive failure is less than that required to peel the membrane from the asphalt, as displayed by applications over Dens-Deck®.

Use of primer over Dens-Deck® prior to the installation of a torch-applied roof cover increases peel adhesion performance by protecting the fiberglass facer from the open flame.

Dens-Deck® absorbs less free water than perlite or high-density wood fiberboard when exposed to high *humidity* and *surface moisture* conditions. Free water evaporation also causes frothing and blistering during roof installation.

The amount of combined water released from the gypsum core of Dens-Deck® through calcination is not sufficient to adversely affect the fire resistant properties or other mechanical properties of Dens-Deck®.

Dens-Deck® forms a good substrate for an asphaltic vapor retarder provided the installation includes use of a porous fiberglass or organic ply sheet. While pinholes form when a flood coat of asphalt is applied to Dens-Deck®, thereby increasing the system permeability, a proper application of one base sheet or two fiberglass or organic ply sheets in the asphalt eliminates the pin holes, forming a continuous, effective vapor retarder.

Frothing and the resulting blistering that may occur as a result of calcination during the installation of a full-mopping, bituminous, roof system do not adversely affect the system's wind uplift resistance. However, unbonded areas may result in membrane stress with resulting cracks and fissures and wind uplift resistance may be compromised should blisters grow over time.

Strip and spot mop applications, strip-torch applications, and applications over a perforated venting base sheet allow for lateral movement of water vapor (regardless of its origin). Moreover, these asphalt-applied systems utilize less asphalt than full moppings. The systems have demonstrated Class 90 and better uplift ratings (similar to ratings for fully adhered installations) and perform well when installed over Dens-Deck®.

The use of Dens-Deck® over wet existing roof assemblies will result in the deterioration of the board and will, over time, diminish the bond with the membrane layers above. The use of Dens-Deck® without an underlying vapor retarder where there is upward moisture migration from the building interior will result in saturation and bond failure.

Dens-Deck® should be installed in dry conditions. Current industry standards published by the NRCA, ARMA, and other industry trade organizations for storage, protection, and application should be followed. Storage tarps should be breathable to reduce condensation.

Recommendations – Torch-applied Applications Directly to Dens-Deck

- Prime the surface with an ASTM D-41[13] asphaltic primer. G-P should consider a pre-primed product to eliminate the problem of prolonged, unprotected exposure on the roof, awaiting the drying of the primer.
- Ensure proper torching of the membrane, resulting in continuous softening of the bitumen. Heat should be applied evenly across the roll.
  - Limit the heat applied to the Dens-Deck® substrate. Maintain a majority of the torch heat directly on the roll. Proper torching will differ from standard torching methods used for APP, SBS and TPO modified bitumen membranes but is necessary to avoid calcination, blistering, and damage to the fiberglass facer.
  - The modified torch technique should address the additional heat that is typically applied at membrane laps to ensure a good lap bond, thus eliminating the potential for "mole-runs."
- Utilize stress plates having a flat upper surface and a lower surface that does not damage the Dens-Deck® facer.
- Ensure sufficient pressure is applied to the membrane roll to press the membrane to the surface.
- Consider the use of strip and spot torch-applied base membranes (allowing the lateral movement of moisture)

available from some manufacturers. Strip-torch applications are documented to 90 psf simulated wind uplift resistance. (Factory Mutual Research testing would be required to incorporate these systems into the existing approvals.) Further uplift testing is necessary on the 12 ft. x 24 ft. device to quantify elevated performance and optimum fastening patterns.

- Consider the use of "self-adhered" membranes over primed Dens-Deck®, whereby the base membrane is rolled out, and adhesion thereof is achieved upon application of heat to its top surface, or by solar radiation alone. The level of adhesion, and therefore wind uplift performance, will vary among membrane products. Additional testing is needed to quantify performance of the current offering of membranes.
- Consider the use of base sheets that are factory-laminated to Dens-Deck® prior to application of the waterproofing layer.

Recommendations – Mopping Applications

- For full mopping applications, only use asphalt heated to a maximum application temperature of 425°F. This temperature limitation eliminates the use of ASTM D-312 Type IV asphalt in fully-mopped applications. (As discussed below, Type IV asphalt can be used in strip or spot mop applications.)
- For full mopping applications, limit the initial sheet to a permeable sheet (e.g., a permeable ASTM D-4601, Type 1 or II base sheet or ASTM D-2178, Type IV or VI ply sheet).
  - No membranes or fully-coated felts should be used as the first sheet in full mopping applications. If use of asphalt heated to a higher temperature (e.g., Type IV asphalt) is required to meet slope or membrane application requirements, a perforated venting base sheet application, a strip mop base sheet application, or a spot mop base sheet application should be specified.
  - Back-nailing may be required in some applications, depending on slope and type of asphalt. The level of adhesion, and therefore wind uplift performance, will vary among membrane products. Additional testing is needed to quantify performance of specific systems.
- Ensure sufficient pressure is applied to the roll. At the end of a roll, utilize a stiff broom to "press" the membrane into place immediately after the application.

Summary Overview

Dens-Deck® should be installed in dry conditions and over substrates recommended in standard roofing practices for recover applications. While Dens-Deck® is moisture resistant, this property only allows the component to become wet (e.g. at points of leakage through the membrane) for limited periods while still remaining in stable service after the appropriate repairs. Installation of this product in a wet environment will

RCI, Inc.
800-828-1902
www.rci-online.org

lead to saturation and loss of the mechanical bond at the facer and the overlying roof assembly.

Current industry standards for storage, protection, and application of cover boards, as published by the NRCA and ARMA, should be followed. Storage tarps should be breathable to reduce condensation. Wet substrates and ponded water should be removed prior to any recover application. Vapor rise from the building interior should be managed with a vapor retarder.

Calcination is a process that can lead to frothing, which may result in blistering. The calcination process will only impact the assembly at high application temperatures such as those associated with the use of Type IV asphalt. For all roofing systems, asphalt application at high temperatures will accelerate frothing and the potential for blister formation, and the presence of moisture will increase the frequency and occurrence of blisters.

Dens-Deck® is a proven product with 13 years of field applications. However, some of these applications have extended the boundaries of Dens-Deck® use, and others have identified product limitations reducing optimum performance. Manufacturers should consider incorporating data from this testing into their cover board recommendations.

The information produced in this technical analysis of Dens-Deck® roof board applications should be recognized by G-P Gypsum Corporation and incorporated into its "Tech Notes" library in a manner that provides clear and concise guidance to the specifier and the installer.

The authors gratefully acknowledge the assistance of ERD Laboratory Staff, Charles Phillips, Andrew Linnemann, Noel Putaansuu, and Lonnie Haughton for their efforts in the production of this article and the data contained therein.

REFERENCES

1. "Tech Notes" are published jointly by G-P Gypsum and membrane manufacturers. Tech Notes can be found on the Internet at the following URL: http://www.gp.com/gypsum/solution/densdecktech.html.
2. Mehaffey, J.R., Cuerrier, P., and Carisse, G., "A Model for Predicting Heat Transfer Through Gypsum-board/Wood-stud Walls Exposed to Fire," *Fire and Materials,* Vol. 18, 1994, pp 297-304.
3. Axenenko, Olga, "Structural Failure of Plasterboard Assemblies in Fires," *Australian Mathematical Society Gazette.*
4. "ASTM D-312-95a, Standard Specification for Asphalt Used in Roofing," ASTM, February 1996.
5. "ASTM D-4601-97a, Standards Specification for Asphalt-coated Glass Fiber Base Sheets Used in Roofing," ASTM, January 1998.
6. "ASTM D-4897-97a, Standard Specification for Asphalt-Coated Glass-Fiber Venting Base Sheet Used in Roofing," ASTM, January 1998.
7. "ASTM D-2178-97a, Standard Specification for Asphalt Glass Felt Used in Roofing and Waterproofing," ASTM, January 1998.
8. "ASTM D-6163-98a, Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bitumen Sheet Materials Using Glass Reinforcements," ASTM, October 1998.
9. "ASTM D-6164-98, Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bitumen Sheet Materials Using Polyester Reinforcements," ASTM, September 1998.
10. "ASTM D-6222-98a, Standard Specification for Atactic Polypropylene (APP) Modified Bitumen Sheet Materials Using Polyester Reinforcements," ASTM, April 1998.
11. "ASTM D-903-98, Standard Test Methods for Peel or Stripping Strengths of Adhesive Bonds," ASTM, October 1997.
12. *NRCA Roofing & Waterproofing Manual*, National Roofing Contractors Association, 1996.

ABOUT THE AUTHORS

COLIN MURPHY, RRO, RRC

Colin Murphy, RRO, RRC, founded Trinity Group Fastening Systems in 1981. In 1986, he established Trinity Engineering, focusing primarily on forensic analysis of roof systems, materials analysis, laboratory testing, and long-term analysis of in-place roof systems. The firm, formally known as Exterior Research & Design, LLC, Trinity Engineering, is based in Seattle, WA. Colin joined RCI in 1986 and became an RRC in 1993. He is currently the Director of Region VII. In 1996, he was honored with the Richard Horowitz Award for Excellence in technical writing for *Interface*. In 1998, RCI granted Colin the Herbert Busching Jr. Award for significant contributions to the general betterment of the roof consulting industry. Murphy and Ian Lurie authored the *Roof Construction Guide for General Contractors*, marketed by RCI.

ROBERT MILLS

Robert Mills joined Exterior Research & Design, LLC, Trinity Engineering, in 1993 after obtaining a B.S. in Aerospace Engineering from Arizona State University. He has since become a senior engineer with the firm, focusing his knowledge of aerodynamics, material properties, and testing and engineering principles in the field of exterior design and analysis. Robert has provided his knowledge of roofing design and testing to RCI as an instructor in its Advanced Roof Consulting courses.