UNDERLAYMENTS FOR STEEP-SLOPE ROOF CONSTRUCTION

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Underlayments for steep-slope roofing provide many functions. Most products currently used possess both positive and negative attributes. Identification of the functions that underlayments must perform should promote understanding, solve some current problems, and lead to the development of improved underlayment products and thus better performing steep-slope roof systems.

Experience has indicated that the current generation of asphalt-saturated organic felts are not performing as well as they have in the past. Wrinkling of these underlayments is especially disconcerting when lightweight fiberglass shingles are used, as these very readily telegraph substrate irregularities (e.g., joints between tongue and groove decking, plywood clips, wood panel joints, etc.).

An in-situ research project was recently conducted jointly by ARMA and NRCA in order to evaluate the performance of seven of the most commonly used types of underlayment when exposed to varying climatic conditions. Both high efficiency of asphalt impregnation and quantity of asphalt impregnation were identified as being very important to an organic felt's wrinkle resistance.

This paper describes materials available today, discusses industry problems and issues, reviews research including the ARMA/NRCA-sponsored study of asphalt-saturated felt underlayment composition and field performance.

Guidelines are provided to minimize wrinkling when the current generation of asphalt-saturated felt materials are used. Compliance with ASTM D 226 is strongly recommended. Additionally, design recommendations are offered for underlayments to be used in conjunction with the more common steep-sloped roofing systems.

KEYWORDS

Asphalt-saturated organic felt, ice-dam protection membrane, performance, saturation, self-adhering, sheathing paper, steep-slope, synthetic, underlayment, watershedding and wrinkling.

INTRODUCTION

Roofing underlayments are generally used in all steep-sloped roof assemblies, regardless of the type of primary roof covering (e.g., asphalt shingles, wood shakes or shingles, architectural metal roof systems, slate or tile, or other steep slope watershedding systems). Underlayments have become so "taken for granted" that often little thought is given as to why they are used, or what purposes they must serve in any specific roof system. When the National Association of Homebuilders (NAHB) challenged underlayment use a few years ago,[1] some in the roofing industry didn't even know how to react to their challenge, other than to sputter "but we need them!"

The NAHB challenge forced the industry to address current problems with underlayment such as wrinkling and buckling, as well as more precisely define the functions that underlayments serve. Primary functions are:

- To block wind and wind-blown rain and snow from entering the building if it passes by the joints of the primary roof covering.
- To "dry-in" a building (i.e., provide weather-proofing until the primary roof covering is installed).
- To provide secondary defense, should the primary roof covering be displaced or damaged.
- To weatherproof the roof assembly in the event that the watershedding ability of the primary roofing is temporarily impaired, such as by an inundating rain, or when a blockage of the drainage is caused by leaves, debris build-up or formation of ice dams.
- To enhance fire performance of the roof assembly by providing both a flame deflector and heat barrier for combustible decking.
- To improve the watershedding capabilities of valleys. A valley has lower slope than either of its intersecting planes and the resulting slope may be too low to reliably shed water runoff throughout its length.
- To serve as a mortar bed for "mortar-set" tile roofs.
- To act as a slip sheet for the primary roof covering during thermal movement.
- To separate the primary roofing from the substrate, to avoid chemical incompatibility or galvanic action.
- To help close-in or seal the system where penetrated by fasteners.
- To bridge gaps and roughness of the substrate, helping to cushion and smooth the substrate surface for the primary roofing.
- To block the flow of liquid bitumen from both hot- and cold-applied sealing operations.
- To restrain solder drips from metal-roof seaming operations.
- To act as an air retarder, reducing air flow, a source of heat loss and moisture accumulation from within the structure.

An underlayment should *not:*

- disrupt the roof s *drainage;*
- degrade the *aesthetics* and *performance* of the primary roofing;

- be a *fire hazard;*
- be *slippery;*
- *trap water vapor* (unless the underlayment is intentionally designed to be a vapor retarder);
- *degrade* prematurely in service or when stored;
- *disintegrate or melt* while in service;
- be so difficult to work with that it significantly *impairs* the application of the roof; and
- be *perforated.*

The underlayment for asphalt-prepared roofing, wood shakes and shingles, slate, tiles and architectural metal roof systems has traditionally been asphalt-saturated organic felt. Since production of organic felt is somewhat tied to the production of organic-felt-based shingles, the reduction of organic shingle volume has diminished the availability of saturated felt for underlayment. In addition, raw materials that serve as the feed stock for organic felt production have changed. Rags and other components that enhanced bitumen absorption are rarely used today. Current blends of waste-paper and mechanically pulped wood are dense and, depending upon saturating conditions, can be harder to saturate. The mills that produce organic felt are fewer in number, due to age, difficulties in meeting effluent regulations, and the increased cost of energy to dry the wet-produced sheet.

Glass-mat shingles now dominate the asphalt shingle market. Glass fiber-based underlayments have been tried, but can be more difficult to work with than saturated organic felt and have not been widely accepted by the industry. While the absorptive nature of cellulose soaks up excess saturant during production, glass fibers become sticky as the coating asphalt remains on the surface. Anti-stick treatments such as fine sand and talc are used in greater quantities to keep the glass fiber felt from blocking or sticking together when unrolling. However, roof mechanics prefer to avoid heavily sanded sheets as they tend to be abrasive, slippery and messy.

Alternatives to asphalt-saturated organic felt underlayments are available and are in use in many parts of the world. One of the options is a modified bitumen membrane with a self-adhering bottom surface, which in many locations has replaced the traditional organic felt, asphalt-sealed ice-dam protection membranes. These modified bitumen membranes are also used as valley liners and secondary flashing at penetrations where additional water-resistance is critical beneath the primary roof covering.

Synthetic fiber mats and polymer films are used extensively in Europe as underlayments. While synthetic materials tend to be more expensive than saturated organic felts, they can have handling and performance advantages.

In spite of the availability of alternate materials, asphalt saturated organic felt continues to dominate the U.S. underlayment market. While meeting most of the requirements described above, marginal performance and sometimes poor quality are of concern. One of the performance issues today is wrinkling, which telegraphs through the superimposed, light-weight asphalt shingles—and, when severe, even laminated shingles as well. This is aesthetically objectionable as well as can be an impairment to roof performance.

Underlayment Background Information

There is a great deal of confusion regarding product names, grades and standards for organic felt, which is the most common underlayment material. For example, what is the difference between "fifteen-pound" felt and "No. 15 felt?" What does a forty-pound felt weigh? Is it a coated product or not? The following brief treatise may help remove some of the confusion.

Dry felt, the first step in organic roofing felt production, consists of a blend of mechanically ground wood fiber and recycled waste paper. After dispersing these raw materials in water and beating to a pulp consistency, the dispersion is formed into "felt," a rather course grade of paper. Common industry designations for this dry felt are: #27, #36 and #50. This corresponds to the weight in pounds of a felt ream which is 480 sq. ft. This is convenient, because in the imperial system, weight equals thickness. (A #27 felt has a thickness of about 27 mils [0.69 mm].)

This dry felt is then impregnated with a relatively soft asphalt, referred to as "saturant," which is similar to an ASTM D 312, Type II, roofing asphalt. While the term "saturation" is used, not all the voids are actually filled with bitumen. Organic felt is very much like blotter paper, and can absorb more than its own weight in saturant. For example, if a 5 lb./100 sq. ft. (0.24 kg/m^2) dry felt absorbed 7.5 lbs. (3.4 kg) of asphalt, it would be said that it was saturated to 150 percent (of its dry felt weight). Even saturated that much, the felt can still absorb some water (whether exposed to liquid water or water vapor).

A measure of the absorbency of dry felt is the *kerosine number* (ASTM D 727). The dry felt is dipped into kerosine, and the density of the absorbed kerosine is converted to a theoretical measure of how much asphalt the felt could absorb. One hundred (100) percent saturation efficiency would, theoretically, mean that all the voids in the felt are filled. Saturation efficiency of modern day organic roofing felts is approximately 60 to 70 percent.

Saturated felts are typically sold by the square, with an actual area of 108 square feet (10 m^2). When applied to a roof substrate, the additional material provides for side and end laps, while still covering 100 square feet (9.3 m^2) of roof area.

Common nomenclature of ASTM D 226 products has been "fifteen-pound, twenty-pound and thirty-pound" felt, although it should be clear to the reader that current products meeting the standard are well below this "weight" nomenclature. The term "number" is preferred by felt manufacturers to "pounds," and as such their products are catalogued as "Number-15" and "Number-30" felt.

In January 1988, ASTM published a new standard for Asphalt-Saturated Organic Felt Shingle Underlayment, ASTM D 4869. The standard provides for two new products, a Type I "Shingle Underlayment" and a Type II "Heavy-Duty Shingle Underlayment." It should be clear that neither of these materials defined by the ASTM specifications resembles the 15-lb. or 30-lb. felt materials available in past years.

Today a great deal of saturated organic roofing felt is not manufactured to comply with *any* specific standard. Although some manufacturer's non-specification felts have tested to be heavier than the ASTM labeled materials, weights as low as 7.2 lbs./100 ft.^{2} (.35 kg/m^2) have been documented.[2]

In addition to the above saturated felts, coated sheets are also available. The coating is a blend of harder asphalt (similar to an ASTM D 312, Type III, roofing asphalt) and mineral filler, applied to both the back- and top-surface of saturated felt. To prevent sticking in the roll, coated sheets are "dusted" with a parting agent or anti-stick material.

Materials Available Today—Pros and Cons

No. 15 and No. 30 Asphalt Saturated Organic Felts—Currently the Most Commonly Used Underlayments in the United States

Asphalt-saturated felts have been used as underlayment in steep-slope roof systems throughout the different climatic regions of the U.S. for more than a century. Originally, the organic felts used as steep roofing underlayment were composed of cotton and other organic fibers saturated with asphalt. Since the late 1940s, the majority of asphalt-saturated felts have been composed of cellulose fibers that are saturated with asphalt.

Although underlayment may be composed of various types of materials, in the U.S. the vast majority of steep-slope roof systems use asphalt-saturated underlayment felt as underlayment material. The two ASTM specifications for asphalt-saturated organic felts currently used as underlayment are:

- ASTM D 226 *Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing.* This standard was originally published in 1925. This material standard has Types I and II (usually referred to as "No.15" and "No. 30"). This is the traditional organic felt material that is used in built-up roofing, and is currently gaining in use as a steep-slope roofing underlayment. (See Table 1.)
- ASTM D 4869 *Specification for Asphalt-Saturated Organic Felt Shingle Underlayment Used in Roofing.* This newer specification, published originally in 1988, also has two Types of material and specifically relates to underlayment used with asphalt shingles. This standard does not have the same physical properties as D 226, with D 226 having higher requirements for the mass of the felt and saturant. This standard requires that the material pass a water shower exposure test indicating resistance to liquid water transmission. (See Table 2.)

Asphalt-saturated felts have been and are still commonplace in steep-slope roofing systems because they are low-cost, readily available materials with which most people are familiar. Since these products have been around for so long, and people have become accustomed to their ease of installation and workability, they remain relatively steadfast in the marketplace.

However, as time has passed, the materials used in steep-slope roofing systems have evolved. In many markets, organic asphalt shingles have been displaced by fiberglass asphalt shingles. Generally, these fiberglass asphalt shingles are lighter in weight than their predecessors. If an irregularity develops in the substrate, it can easily telegraph through today's lighter weight materials. Also, the manufacturers of asphalt-saturated felts, in order to stay competitive, have had to make the product more economical to keep costs in check, resulting in a material that is less substantial than its predecessors.[3] Concern has been raised regarding the performance of the asphalt-saturated felts, especially since problems continue to be reported. Additionally, those materials that have been identified by some as relatively good performers (e.g., ASTM D 226 asphalt-saturated felts) are not readily available in many markets.

Other Organic Felt Products

Besides the No. 15 and No. 30 asphalt-saturated felts that are commonly used as underlayments, there are other asphalt-saturated felts that some roofing professionals feel are under-utilized opportunities. These other asphalt-saturated felts include two categories of material, the first is simply a heavier type of asphalt-saturated organic felt.

Heavier Asphalt-Saturated Felts—This category of felt weighs more than the No. 30 because a more substantial, heavier dry felt is used. This heavier dry felt has the capacity to absorb more asphalt, thus yielding a heavier product. Some roofing professionals use this heavier asphalt-saturated material in select steep-slope roof systems because of the felt's better weatherproofing characteristics, as well as

Dry Felt gauge	Dry Felt lbs/100 ft² [kg/m²]	Dry Felt ASTM D 226 min lbs/100 ft² [kg/m²]	Saturant % of dry felt wt, min	Saturant ASTM D 226 min lbs/100 ft² [kg/m²]	Product Weight Nominal lbs/108 ft² [kg/m²]	ASTM D 226 min weight lbs/100 ft² [kg/m²]
27 (Type I)	5.6 [.27]	5.2 [.25]	120	6.2 [.3]	15 [.72]	11.5 [.55]
36 (Type III)	7.5 [.36]	6.8 [.33]	120	8.2 [.39]	20 [.96]	15 [.72]
50 (Type II)	10.4 [.5]	10.0 [.48]	150	15 [.72]	30 [1.44]	26 [1.25]

Table 1. *Typical saturated products described in ASTM D 226.*

Dry Felt gauge	Dry Felt lbs/100 ft²	Dry Felt ASTM D 4869 min lbs/100 ft² [kg/m²]	Saturant % of dry felt wt, min	Saturant ASTM D 4869 min lbs/100 ft² [kg/m²]	Product Weight Nominal lbs/108 ft²	ASTM D 4869 min weight lbs/100 ft² [kg/m²]
Type I	—	4.0 [.19]	100	4.0 [.19]	—	8.0 [.38]
Type II	—	9.0 [.43]	120	10.8 [.52]	—	20 [.96]

Table 2. *ASTM D 4869 "Shingle Underlayment."*

for the extended longevity that the product has provided in various steep-slope roof systems.

Most often this heavier asphalt-saturated felt is used as underlayment under the more substantial asphalt prepared roof coverings, such as heavy organic interlocking shingles, the heavier laminated shingles (both organic and fiberglass) and concrete tile. This heavier weight felt is not used under lightweight organic or fiberglass shingles due to its stiff, non-conforming nature.

The heavy organic asphalt-saturated felts can be somewhat board-like and stiff to apply, especially during cooler weather. Therefore, it is advisable when considering specifying the heavy products to utilize them only in combination with a primary roof covering that is adequately weighty. To clarify, the heavyweight felts' non-conforming nature is such that a lightweight roof covering can be held up off the substrate by irregularities in the smoothness of the felt. Therefore, the overlying roof covering must be of adequate weight and rigidity so that irregularities are not telegraphed from the felt through the primary roof covering. The actual weight and name of heavyweight types of asphalt-saturated felt vary depending upon the manufacturer. In some portions of the U.S., this heavier organic felt is referred to as a No. 40 or 45; these are not to be confused with the saturated and coated No. 40 and heavier felts.

Coated Felts—The second category of heavier felts are the several types of heavy-weight coated felts. In addition to being asphalt saturated, these felts are asphalt coated. (See Table 3 for typical products.)

Specifiers should be very familiar with coated felts, in order to be able to specify the correct felt for a specific steep-slope roofing project. Some coated felts are surfaced with talc, as a release agent, to keep the material from sticking together while in the roll. Talc makes coated felts very slippery under foot traffic, and their slick nature makes some coated felts unsuitable for use as underlayment on steep-slope roofs. Depending upon manufacturer and area of the country, some of the felts surfaced with talc are sold as No. 40, 42 and 43. These coated felts surfaced with talc are typically used as base sheets for low-slope built-up and some modified bitumen roof membranes. Some coated felts are surfaced heavily with sand, which makes them unsuitable for use on steep-slopes as well.

However, there are coated asphalt felts that make excellent underlayments for various types of steep-slope roof systems. It is the lightly surfaced, heavyweight coated felts that are currently under-utilized by the design community. These heavyweight coated asphalt felts shed water very well, and their substantial composition makes them good long-term performers under various types of long-term, steep-slope roof coverings. This correctly coated felt can be a superior underlayment for use with clay and concrete tile, various types of metal roofing, slate and even some synthetic roof coverings.

As with the heavyweight saturated felt, the coated felts can be stiff and board-like to apply. Although, their thick composition makes them good cushions for steep-slope roof coverings that are to be installed over wood plank roof decks which are not always smooth. Similar to the heavyweight saturated felts, most coated felts should be used with primary roof coverings that will not be affected by irregularities that might be telegraphed through lightweight roof coverings.

Polymer Modified Bitumen Materials

There are numerous polymer modified bitumen sheet materials that are applicable for use as underlayment in steep-slope roof assemblies. The polymer modified asphalt materials that are intentionally manufactured for use as underlayment are limited mainly to the self-adhering membranes that are commonly used as ice dam protection membrane in steep-slope roofs. However, there are other polymer modified bitumen sheet materials that are well suited for use as underlayments. Among these are various atactic polypropylene (APP) and styrene butadiene styrene (SBS) modified sheets. One such category of SBS polymer modified asphalt sheets that can make good underlayments are those sheets that are currently manufactured as SBS modified heavyweight base sheets.

SBS Base Sheets for Use as Underlayment—SBS modified bitumen base sheets are typically manufactured for use in low-slope roof membrane systems. However, many of the heavyweight SBS base sheets can be excellent underlayment, as they shed water, lay smooth, are easy to roll out and apply (even in cold weather), and are manufactured from relatively high quality ingredients (such as carefully selected asphalt flux).

However, specifiers must be familiar with the types of polymer modified bitumen materials, so that they can correctly specify a particular steep-slope roof assembly. There

ASTM Designation	Dry Felt lbs/100 ft² [kg/m²] min	Saturant % of dry felt wt, min	Mass of coating & surfacing lbs/100 ft² [kg/m²] min	Net mass lbs/100 ft² [kg/m²] min	Common Nomenclature
D 2626	5.2 [.25]	140	18.0 [.86]	37 [1.78]	40/43/45 base
D 224 Type I	5.2 [.25]	140	18.0 [.86]	39.8 [1.91]	No. 45 roll roofing
D 224 Type II	10.0 [.48]	160	18.0 [.86]	54.6 [2.62]	No. 65 roll roofing
D 224 Type III	9.0 [.43]	150	18.0 [.86]	51.1 [2.45]	No. 55 roll roofing
D 224 Type IV	5.2 [.25]	120	18.0 [.86]	39.8 [1.91]	—
D 249 Type I	10.0 [.48]	150	Granules	83.0 [3.98]	"ninety-pound"
D 249 Type II	9.0 [.43]	150	Granules	80.3 [3.85]	—

Table 3. *Some typical coated organic felt products.*

are several noteworthy items of caution that must be considered before specifying these materials. The first item to consider relates to the roof's fire rating. In order for a roof assembly to obtain a particular fire rating, it must be tested—tested as a particular assembly. Most types of asphalt shingles are fire tested with a No. 15 or No. 30 asphalt- saturated organic felt as the underlayment. This means that in order for the assembly to maintain the fire rating achieved during testing, the specification for an actual roof must contain the same type of components. In other words, an asphalt shingle roof covering that is specified with a heavyweight SBS modified asphalt base sheet may be an excellent long-term weathering performer as a combined roof covering, but the materials together may not have achieved any fire rating whatsoever, because the manufacturers may not have tested the primary covering with an SBS base sheet.

Another caution to be aware of when considering SBS polymer modified bitumen base sheets for use as underlayments, is that many of the lightweight (e.g., No. 28, and others commonly referred to as 30 or 32 lb.) base sheets are so porous that they do not shed water well. In fact, with some of the more porous sheets, water will percolate through them rapidly. It is these lightweight SBS base sheets that should not be considered for use as underlayment in most steep-slope roof construction. The lightweight sheets may make for a good separation material to separate the deck from the primary roof covering, but if the material will not shed water, then it is not providing one of the principle functions of underlayment. A requirement that they pass the shower test prescribed in ASTM D 4869 would help to screen out unacceptable products.

Self-adhering Polymer Modified Sheets—There are numerous advantages when using self-adhering polymer modified sheets in steep-slope roof assembly construction. Among these reasons are:

- The material is a true membrane and thus it sheds water very well.
- Self-adhering material makes for excellent ice dam protection membrane for use along downslope perimeters.
- Self-adhering materials serve well as valley liners because they conform so well to the substrate.
- Its conformability and membrane characteristics also make it very suitable for use as secondary flashing around chimneys and other penetrations through steep-slope roofs.

However, self-adhering sheets have some disadvantages as well. Among the disadvantages are:

- It can be quite difficult to work with due to its sticky nature (e.g., once the release paper is pulled off, and the sheet contacts the substrate, it is stuck in-place, allowing for minimal tolerance when adjustments in sheet alignment are necessary, unless the sheet is cut and re-started). Also, during warm weather application difficulties can be compounded with some of the products, as the release paper is sometimes difficult to pull free without tearing, etc.
- Some self-adhering products are slippery. However, self-adhering products that comply with ASTM 1970, *Standard Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection* are required to meet criteria for slip resistance.
- Most self-adhering sheets do not stick well to asphalt-saturated felt or other asphaltic materials, this impairs or hinders their use in numerous steep-slope roof configurations.
- Once self-adhering sheet material is applied to a wood roof deck, the membrane can not be easily separated from the deck for future reroofing. In situations where the self-adhering sheet material needs to be removed, this may necessitate tear-off and removal of the deck.

The perm rating of polymer modified self-adhering sheets is typically very low (i.e., less than 0.1 perm) compared to other materials that are commonly used as steep-slope roof underlayment. This low perm rating makes most self-adhering membranes effective vapor retarders. A low perm rating is an excellent characteristic when an effective vapor retarder is needed. However, project designs that are not well thought-out and employ a self-adhering membrane over the entire roof area, simply for added leak protection, can be problematic. If this vapor retarder is inadvertently specified in the incorrect location within the configuration of the roof assembly, condensation problems, and even decayed decking and framing can result. The problem is often compounded by inadequate ventilation.

Synthetic Underlayment Materials

Numerous types of synthetic roll good materials are available as underlayments in steep-slope roof assemblies. Among these are woven and non-woven mats, films of polyethylene, polypropylene and polyvinyl chloride. In virtually all cases, they are not asphalt treated, although both saturants and emulsions are technically possible.

Non-woven mats are generally moisture permeable and are similar to house-wraps. When used on top of the roof deck, just below the primary roofing, it is desirable that the film be vapor-permeable, as a cold-side vapor retarder might cause moisture accumulation and possible deck decay. Some of these mats absorb liquid water and will not serve the primary functions of steep-roof underlayments. A requirement that they pass the shower test prescribed in ASTM D 4869 would help to screen out unacceptable products.

In general, non-wovens are fairly stiff and will easily bridge small deck irregularities. Products are offered as textiles with weights in ounces per square yard. A typical 2½ oz. per square yard converted to a roofing square basis would weigh less than 2 lbs./100 sq. ft. (.1 kg/m^2), compared to the organic felts discussed previously at 8 to 30 lbs./100 sq. ft. (.38 to 1.44 kg/m^2). This light weight permits many more squares per roll, which can be an economy for the wholesaler, shipper and installer.

Plastic films will tend to be vapor impermeable unless factory perforated. Many such films, as plasticized PVC and 4 mil (.1 mm) (or thinner) polyethylene may not lay flat when unrolled and may lift in the slightest breeze during application. Plastic films can be very slick, which can be a problem compounded by slope, and thus difficult to work with.

Laminates of woven scrim and plastic film are also available. The woven scrim greatly enhances tear resistance and layability of the film. Most vapor retarders used in pre-engineered metal buildings take advantage of these properties in providing a vapor retarder, batt insulation support and reflective ceiling for the building.

INDUSTRY PROBLEMS AND ISSUES

Current industry problems with underlayments can be classified into these categories: aesthetic, performance, application and other.

- **Aesthetic:** Underlayments by definition will not be visible in the finished roof. However, wrinkles or buckles that telegraph through the finished roofing may not be acceptable. The underlayment should be sufficiently wrinkle-resistant.
- **Performance:**
  - While *wrinkling* is mentioned as an aesthetic problem, distortion of underlayment can cause asphalt shingles to deform. Shingles over buckled underlayment—buckle along with the underlayment. These deformed shingles may eventually fatigue along lines of stress, and can crack—curtailing the shingle's performance. Shingle tabs lift over irregularities in the substrate, making them more vulnerable to wind damage. Wrinkling can also interfere with free drainage of water which can then migrate into the roof system.
  - *Melting* of the adhesive portion of the underlayment has been observed, especially when dark-colored metal panels or valley metal or dark-colored asphalt shingles are used. Melted asphalt can run out onto the roof's surface causing unsightly stains, but worse; sections of metal panels or valley metal can adhere to the melted material and eventually tear it with continued thermal movement.
  - *Embrittlement or disintegration* from loss of plasticizer, natural aging or moisture attack will eventually require replacement of the underlayment. In cases of long-lasting roof coverings (e.g., slate and clay tile), the underlayment may have to be replaced while the primary roofing has decades of service remaining.
  - *Water penetration:* An underlayment's inability to shed water thus allowing water to penetrate through to the substrate causes water damage to the deck, framing and interior, in addition to contributing to premature failure of the roof assembly. Some underlayments are unable to provide secondary protection due to the porous nature of the base felt and/or due to pin-holes in the sheet.
  - *Moisture (vapor) entrapment:* Some underlayment materials (e.g., self-adhering modified bitumen membranes) when installed continuously over the deck will act as a vapor retarder, preventing the movement of moisture laden air through the roof system. Without appropriate ventilation of the space below the roof deck, moisture may condense on the underside of the vapor retarder causing deterioration of the underlying roof deck.
  - *Nail tear-through:* After the underlayment is rolled out into place, it is typically secured with staples or nails. The underlayment should have sufficient tear resistance to withstand the forces (concentrated around fastener punctures) from foot traffic until the overlaying primary roof covering is installed. Additionally, for new construction and reroofing, the underlayment should have sufficient tear strength to withstand the commonly encountered wind uplift forces until the primary roof covering is installed. Tear strength should also be sufficient so that the underlayment may remain in-place if the primary roof covering is dislodged during a moderate storm. Underlayments have been observed flapping in the wind after breaking or pulling free from around the fasteners, as well as tearing under foot during roof construction (which can be immediately very dangerous).
  - *Conformability:* Some materials will break or crack when being installed at detail locations, where the material must bend to conform to transitions (e.g., at penetrations, at roof-to-wall junctures, etc.). Some materials will not conform easily to transitions, as they are too stiff or contain reinforcement that has memory.
- **Application:** Underlayments must be easy to handle. Rolls need to be tightly wound and be stout enough to be jostled without damage. When unrolled, edges must not scallop nor the roll arc. The material should unroll without cracking, even the last few wraps nearest to the core, at application temperatures. If a release paper is part of an underlayment, it should detach without tearing or shredding, or in any way damage the underlayment. The surface of the underlayment should not shed release particles that are slippery or that interfere with the work. Because of the steep slopes involved, underlayment should not be slippery when dry or damp.
- **Other Concerns:**
  - Roofing systems are rated as a part of a complete assembly. Fire tests, such as conducted following ASTM E 108, require the underlayment to be installed just as it would be installed on the actual rated roof.
  - If the code requires underlayment meeting ASTM D 226, Type I, to be installed, then substitution of another underlayment would not be acceptable. In order for a substitute to be fire rated, it must be approved/tested, listed (and sometimes labeled) for use with the primary roof covering and the balance of the roof assembly.

SYNOPSIS OF PREVIOUS AND CURRENT UNDERLAYMENT RESEARCH

Briefing on Previous Research of Asphalt-Saturated Organic Felts

In general, there have not been many articles or research reports written on the subject of underlayment felts as they relate to steep roofing applications. However, there is a wealth of research reports on organic felts used in roofing. In the 1950s and 1960s several government agencies, academic institutions and private individuals conducted various research programs where organic felts were the subject of the research. These reports were prompted by the increase of premature built-up roof failures being experienced within a few years after installation. The researchers at that time focused attention on the felts used as the reinforcing plies—namely organic, asbestos, and to a limited extent glass fiber plysheets—for built-up roofing.

The correlation between this historic research and the organic felts used today for steep roofing underlayment is that the same general type of products that were used in the past for built-up roofing are still in use today as underlayments (as well as built-up roofing ply felts). The means by which underlayment is manufactured is essentially unchanged since the 1940s.

A literature survey encompassed 31 references dating from 1929 to present. Asphalt-saturated organic felt was the predominate review subject since it is the major product used for shingle underlayment materials. The majority of authors described research results and often related them to performance experience. Most papers discuss cause and effects of changes in the felt's moisture content on the product's performance in various roofing applications. Moisture change in organic felts causes dimensional changes. Of importance is that the researchers of the 1950s and 1960s noted the impact that percent saturation and *moisture absorption* had on the organic felts.

The literature survey revealed that felt composition has changed constantly throughout its history. The researchers described changes in the various types of wood, rag and paper fibers used to produce the base felts. They related how the base felt is saturated with asphalt to produce the finished asphalt-saturated organic felt product, the major component of asphalt shingles, built-up roofing organic ply felts, and shingle underlayments. The fibers of the base felt are hygroscopic causing the felt to expand and shrink as the fibers absorb and lose moisture under changing moisture conditions. The literature relates how asphalt saturants protect the base felt's fibers, thus decreasing their ability to take on moisture. Some authors of the historic research concluded that the better the saturation, the less movement is likely to occur under changing ambient moisture conditions.

In brief, the consensus among the authors of the historic research clearly demonstrates that moisture changes in organic felts result in dimensional changes of the material, often resulting in unsatisfactory performance. Therefore, it would seem that these changes are functions of the ability of the base felt to hold asphalt (kerosine value and therefore saturation efficiency) and the amount of asphalt saturant in the base felt (percent saturation). The literature concludes that deficiencies in saturation efficiency and percent saturation are key to unsatisfactory performance under changing moisture conditions. Some authors suggested a minimum percent saturation level of 140 percent and a minimum saturation efficiency level of 70 percent. Today, according to ASTM D 226, for Type I (i.e., No. 15) felt, the mass of the saturant only has to weigh 1.2 times the mass of the dry felt (i.e., 120 percent), with a saturation efficiency of 70 percent,[4] a 14 percent reduction in saturant mass compared to a material with a minimum percent saturation of 140 percent (which is where the value was set at in ASTM D 226 until the 1980s when it was lowered to its current level). Additionally, according to the current ASTM D 4869, Type I, felt's requirements, the mass of the saturant only has to weigh 1.0 times the mass of the dry felt (i.e., 100 percent),[4] a 29 percent reduction in saturant mass compared to a material with a minimum percent saturation of 140 percent.

As early as 1959, K.G. Martin recommended to the industry that performance tests be used in standards for felt products. He even offered a *Laboratory Shrinkage Test for Saturated Felts.*[5]

Sidney Greenfeld concluded in his research, "A Study of the Variables Involved in the Saturating of Roofing Felts," *NBS 19,* June 1969, that "even the most highly saturated felts in this study absorbed moisture to some extent. It is, therefore, necessary to front- and back-coat roofing products to isolate and protect the felts from moist environments."[6] For the lighter weight felt, Greenfeld emphasized that the "vulnerability to moisture absorption is very significant" and because saturated felts do not receive the higher levels of saturant by design, this susceptibility to "moisture absorption, if accomplished non-uniformly throughout a roll of felt, can also lead to temporary or permanent distortions of the felt."[6]

Synopsis of ARMA/NRCA Research Report on the Performance of Asphalt-Saturated Underlayment Felts

The ARMA/NRCA Study on the performance of asphalt-saturated underlayment felts was conducted because the wrinkling and buckling performance of asphalt-saturated felts used as underlayment has been a concern of contractors and builders in the past several years. This multi-faceted field and laboratory research project evaluated seven different types of asphalt-saturated underlayment felts that are typically used with steep-slope watershedding roof coverings, such as asphalt shingles.

The report (in process) documents the materials included in the evaluation, the field exposure conditions, the materials response to the exposure, and the laboratory evaluations. Conclusions are drawn as to the factors that contribute to the wrinkling or buckling, and recommendations are presented as to how to improve the material's performance.

The seven types of underlayment felts evaluated were:

Sample Identification Number	Category
A30	Non-Classified, Type II*
B15	ASTM D 226, Type I
C15	Non-Classified, Glass-Reinforced*
D15	ASTM D 4869, Type I
E30	ASTM D 4869, Type II
F15	Non-Classified, Type I*
G30	ASTM D 226, Type II

The underlayment felts were exposed to the effects of outdoor conditions on actual full-scale roofing projects in five different climatic areas of the United States. The climatic areas selected were based upon their diverse temperatures and humidities. The areas included: Boulder, Colo. (cool temperatures and dry); Neenah, Wis. (cold temperatures and damp); Phoenix, Ariz. (hot temperatures and dry); Seattle, Wash. (moderate temperatures and damp); and Tampa, Fla. (hot temperatures and high humidities).

The field research was conducted to investigate each product's performance during exposure to weathering conditions. After installation, the felts were left exposed from two to 28 days at the various sites. During exposure,

* *Non-classified products are those materials that are manufactured in the same manner as the ASTM labeled products except that the material may not have the same physical properties that the ASTM standard requires.*

data were recorded on the product's susceptibility to wrinkling and buckling. The product's watershedding capabilities were also examined. Laboratory analysis was conducted to characterize the seven types of underlayment felts.

The field exposures resulted in varying degrees of wrinkling of most products under differential exposures (i.e., various weather conditions and orientations).

Roof exposures played a major part of the investigation. The test sites, in Arizona, Colorado, Florida, Washington and Wisconsin, are areas of widely different climates. The underlayment materials were applied by professional roofing contractors and observed by members of the project team. Parameters such as temperature, humidity, solar radiation and moisture condition of deck and underlayment materials were monitored during application and test exposure period.

The amount of wrinkling and buckling, predominate defects associated with the performance of shingle underlayments, were observed and rated according to the extent of wrinkling and buckling that occurred. Ratings were recorded and underlayment conditions photographed.

Most of the products exposed wrinkled to some degree at all the sites. While wrinkling may not be a serious problem in all cases, the fact that the felts responded to the moisture to the extent they did is cause for concern. This is especially of concern if you consider the lighter weight asphalt shingle materials that are being used today. (Refer to Photos 1 through 9.)

The results showed significant differences in the response of test underlayment exposure to moisture and temperature conditions present at any one site or among the five sites.

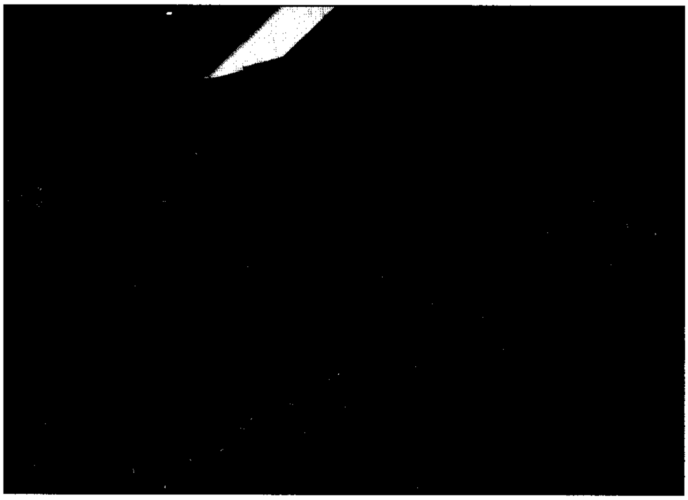

Photo 1. *Wisconsin: Product A30 on the morning of the day after installation.*

Photo 2. *Wisconsin: Product B15 on the morning of the third day, east exposure, after snow.*

Photo 3. *Colorado: Product C15 on the morning of the fifth day, west exposure, after dew overnight.*

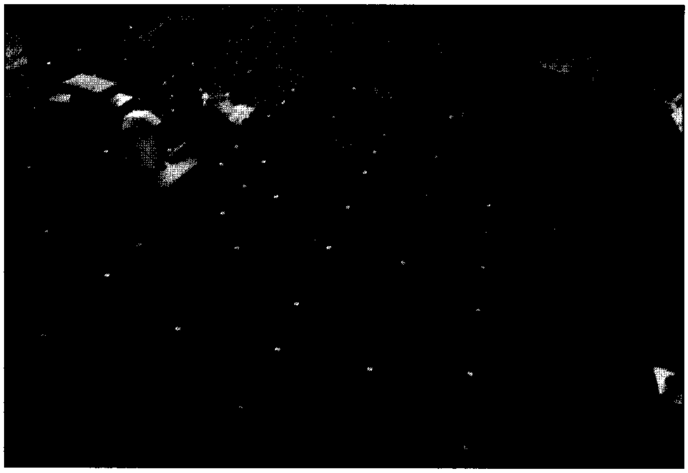

Photo 4. *Colorado: Product D15 on the day of installation.*

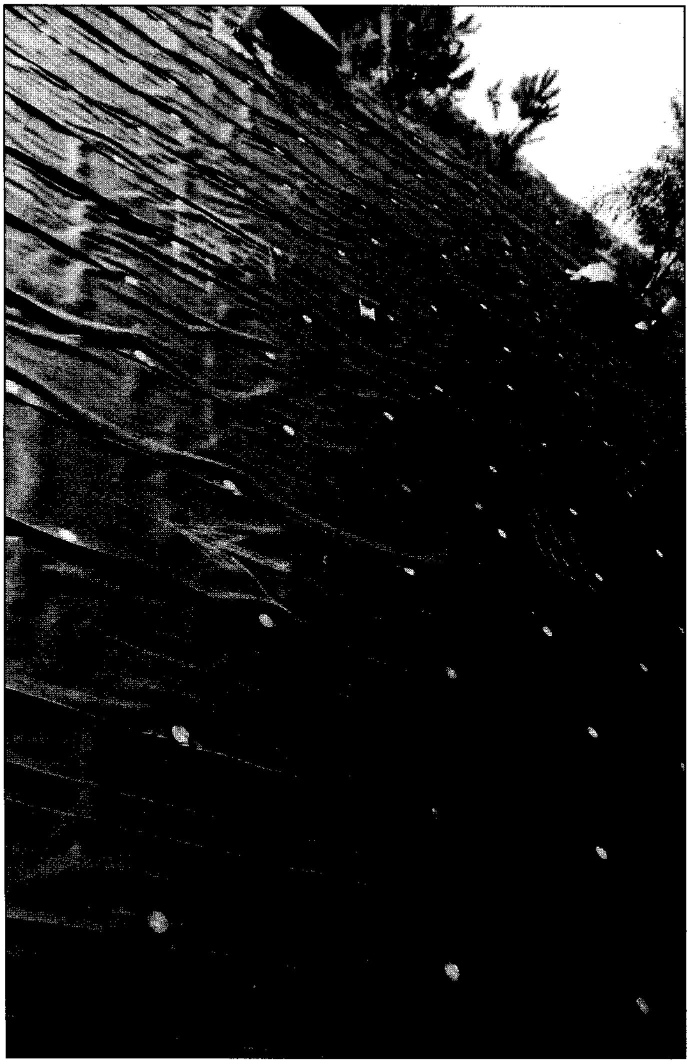

***Photo 5.** Florida: Product F15, third day after installation, 9:30 a.m., west exposure.*

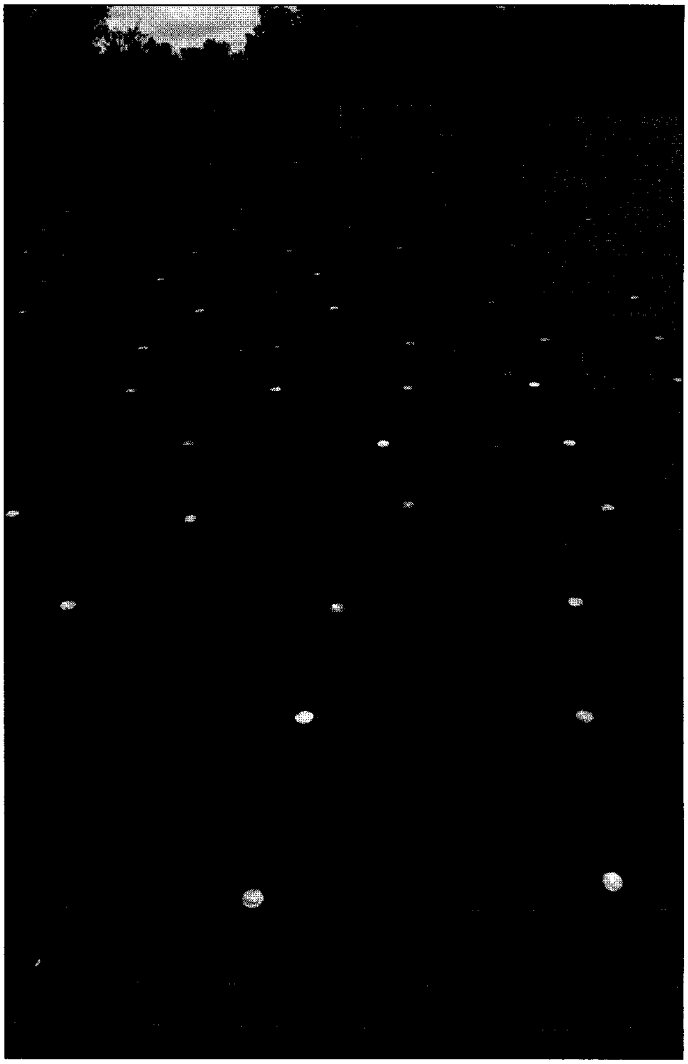

***Photo 6.** Florida: Product F15, third day after installation, 2 p.m., west exposure.*

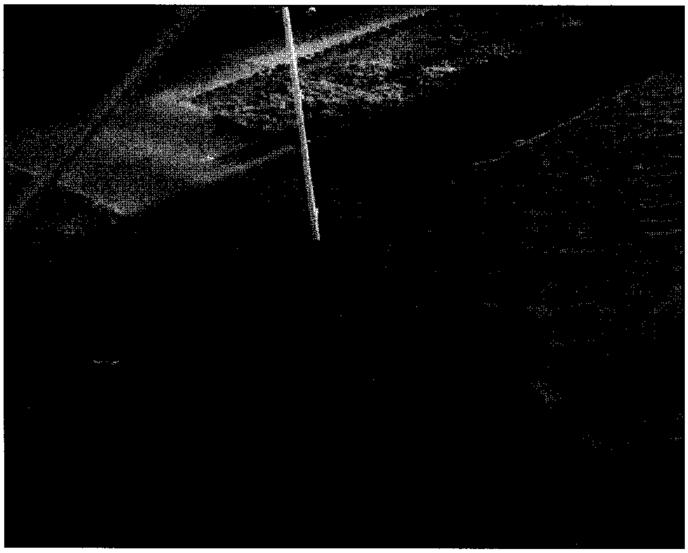

***Photo 7.** Arizona: Product G30 on the morning after the day of installation, north exposure.*

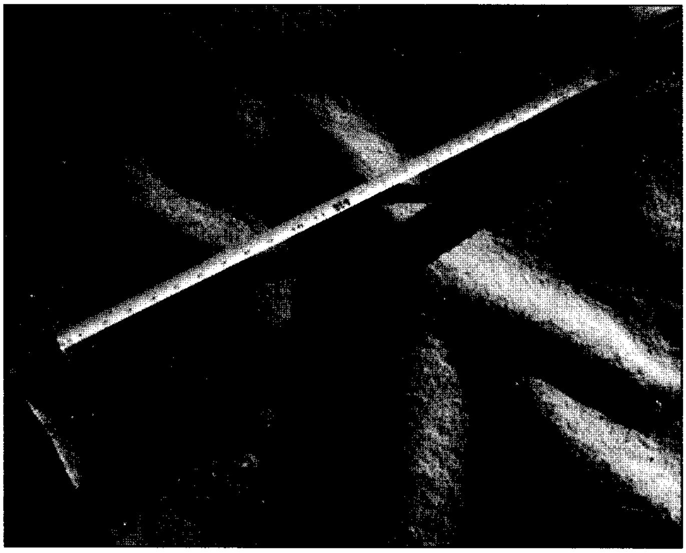

***Photo 8.** Washington: Product G30 on the morning of the second day, north exposure.*

Photo 9. Arizona: Product E30 on the morning of the fourth day after installation, north exposure.

APPLICATION NOTES

Items to note regarding the use of underlayment felts on actual projects include the aesthetically objectionable and performance impairing result that can occur when the underlayment wrinkles. By delaying application of the shingles over the underlayment felt, dimensional changes in the underlayment felt can occur which can then telegraph through the shingles making them appear buckled. It is not always possible to install shingles over the entire roof area by the end of the day's work, thus necessitating that some of the underlayment felt be exposed for a period of time under normal working situations. A possible solution to this is to tear-off underlayment felt that has been exposed and has experienced dimensional changes and replace it with new felt. However, this is wasteful, adds cost, will not help situations where underlayment felts wrinkle even after the installation of the shingles, nor will it solve the problems of felts that wrinkle soon after being rolled out onto the roof deck. Experience has proven that just because the underlayment felt is covered with the primary roof covering, it is not immune to wrinkling. Exterior moisture-laden air can migrate past air-permeable roof coverings to effect the underlayment, and moisture can be induced from within the building.

CONCLUSIONS

Based upon the previous research and field experience, the authors of this paper offer the following conclusions:

- Asphalt-saturated underlayment felts have changed extensively throughout their history.
- Asphalt-saturated underlayment felts available today are susceptible to wrinkling and buckling. They wrinkle under a variety of weather conditions and varying exposures.
- Seasonal differences (between winter and summer) affect underlayment workability, handleability and performance.
- The physical characteristics set forth in the two current ASTM standards (D 226 and D 4869) are not sufficient to ensure reliable consistent field performance. The current ASTM standards lack any performance tests, with the exception of the shower test in D 4869, that relate to product performance.
- With some underlayments products, it appears that the quality and quantity of the materials used in manufacture (in relation to the base felt and saturant) have been lowered to a point where these suspect products can no longer be relied upon to consistently perform as desired in the field.
- Coated felts are under-utilized today in steep-slope roofing systems. Coated felts are potential performers with some steep-slope systems (e.g., tile, slate, heavy weight asphalt shingles, etc.), where as the wrinkling and buckling problems associated with some of today's saturated felts are making these saturated felts problematic.
- Self-adhering modified bitumen membranes serve well as ice-dam protection membranes and at flashing conditions. However, caution should be exercised if they are used as a primary underlayment throughout the building's roof area(s). A vapor retarder in some roof configurations can also be detrimental to roof assembly performance and longevity.
- Some SBS modified bitumen base sheets can serve as underlayments, but their performance has not been widely reported on, nor have they been widely tested as part of fire-rated steep-slope roofs.
- Synthetic materials hold potential as long as they meet the outlined "functions" of an underlayment.
- Care and consideration should be given to all decisions made about the use of, and type of, underlayment for steep-slope roof assemblies. Underlayment should be given the same type of design consideration as the primary roof covering.

RECOMMENDATIONS

Possible Answers to Current Problems

- Upgrade current ASTM standards for asphalt-saturated felt underlayments:
  - — Increase saturation efficiency of asphalt felts to above 70 percent.
  - — Upgrade to better dry felt (i.e., consider adding fibers to improve felts' absorptive quality, strength and texture.)
  - — Establish new performance criteria to be added to ASTM specifications for underlayments by developing and/or standardizing performance tests for dimensional stability, tear strength, water absorption and possibly a different water permeability test. Include these performance test requirements in all organic felt standards.
- Develop laboratory tests which more closely predict field performance.
- When asphalt-saturated organic felt underlayments are to be used on projects, utilize products that comply with the criteria set forth in ASTM D 226.
- Use asphalt-coated felts where better suited for specific projects.
- Use synthetic materials where suited for specific projects.

Design Recommendations for Underlayments To Be Used with Various Steep-Slope Watershedding Roof Coverings

The following are suggested minimums for the current generation of organic felt underlayments to be used with various steep-slope watershedding roof systems:

- Underlayment for Asphalt Shingle Roofing
  — For typical asphalt strip shingles that are engineered and manufactured for application with 2 inch (51 mm) headlaps (which is common for standard- and metric-sized strip shingles), one layer of No. 15 or No. 30 (depending upon type of shingle specified) asphalt-saturated organic felt, complying with or exceeding ASTM D 226 is recommended. For heavier weight shingles and laminates with expected long-term service life, No. 30 is recommended.
- Underlayment for Slate Roofing
  — For standard sized slates that will be applied at typical 3 inch (76 mm) headlaps (which is common for slopes between 8:12 (66 percent) and 20:12 (166 percent), two layers (installed shingle fashion) of No. 30 complying with or exceeding ASTM D 226 asphalt-saturated organic felt, or one layer of No. 43 complying with or exceeding ASTM D 224 or D 2626 asphalt-saturated, coated organic felt is recommended. Designers must be cognizant of the parting agent or top side surfacing of these heavier weight sheets to be sure a manufacturer's specific product is applicable for steep slope use.
- Tile (Clay and Concrete) Roofing
  — For nail-on tile roof designs that utilize tiles that are manufactured for application at the typical 3 inch (76 mm) course-to-course overlap (which is common for most types of flat and profiled tile), two layers (installed shingle fashion) of No. 30 complying with or exceeding ASTM D 226 asphalt-saturated organic felt, or one layer of No. 43 complying or exceeding ASTM D 224 or D 2626 asphalt-saturated, coated organic felt is recommended. Designers must be cognizant of the parting agent or top side surfacing of these heavier weight sheets to be sure a manufacturer's specific product is applicable for steep slope use.
- Wood Roofing
  — Wood Shakes: For 7½ and 10 inch (191 and 254 mm) exposures of No. 1 Heavy 18 and 24 inch (457 and 610 mm) wood shakes (which are the common exposures with these most common lengths of shakes), one layer of 36-inch (914 mm) wide No. 30 asphalt-saturated organic felt, complying with or exceeding ASTM D 226 (Type II), is recommended for use as a downslope underlayment. One layer of 18-inch (457 mm) wide No. 30 asphalt-saturated organic "shake felt," complying with or exceeding the criteria in ASTM D 226 (Type II) is recommended for use as interlayment between individual courses of shakes.

  — Wood Shingles: For 5½-inch (140 mm) exposure of No. 1, 18 inch (457 mm) wood shingles (which is the common exposure used with this most common length of shingle), one layer of No. 30 asphalt-saturated organic felt, complying with or exceeding ASTM D 226 (Type II), is recommended for use as a downslope underlayment; no interlayment felt is suggested for use with wood shingles.
- Synthetic or Other Steep-Slope Roofing Products
  — For many of the other steep-slope roofing materials that are sometimes referred to as "synthetic" products, the underlayment often suggested is the same as is used with the natural (e.g., slate, wood shake, etc.) or composite (e.g., cement tile, etc.) product that the synthetic material has been manufactured to simulate. However, due to the proprietary nature of most of the products currently categorized as "synthetic" steep-slope materials, designers and contractors are urged to consult the specific product manufacturer's instructions, and then use good conservative steep-slope roofing sense to upgrade the underlayment where needed according to slope, product headlap and weather-proofing characteristics of the synthetic product.

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