REINFORCING MATERIALS FOR POLYMER MODIFIED BITUMEN ROOFING SHEETS

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A variety of combinations of woven and non-woven reinforcing mats are used in polymer modified bitumen roofing sheets to provide stability to the finished roofing membrane under thermal load, and to act as a carrier for the polymer modified bitumen through the manufacturing process. This paper provides information about the various functions and properties of reinforcing mats commonly used in polymer modified bitumen roofing sheets manufactured in the United States.

Although polymer modified bitumens may be used for waterproofing without reinforcements by direct application to various types of substrates, the most common usage of polymer modified bitumen in the United States is in the form of polymer modified bitumen waterproofing/roofing sheets which are manufactured with reinforcing mats and sold as premanufactured finished waterproofing or roofing sheets in rolls.

Reinforcing materials used in the manufacture of polymer modified bitumen roofing sheets provide desirable physical and handling properties to the finished product. Some types of reinforcing mats provide elongation properties to the finished sheet, others provide tensile properties for the finished sheets.

The two most common polymer modifiers used to modify waterproofing bitumen for polymer modified bitumen sheets are atactic polypropylene—APP, and styrene butadiene styrene (sequenced butadiene styrene)—SBS. APP essentially "plasticizes" asphalt, while SBS (when properly blended and mixed with select grade asphalt) changes the molecular structure of the asphalt hydrocarbon chain introducing the butadiene link between the carbon and hydrogen atoms to make a "rubberized" asphalt.

No matter which polymer modified bitumen is used, specific types of reinforcing mats are used in the manufacture of the finished sheet. Logic would dictate that APP modified bitumen sheets should have reinforcements with sufficient tensile properties to keep the plasticized asphalt (with relatively low elongation properties) from separating (fracturing or "splitting") under thermal load, and that sheets manufactured with SBS (rubberized) modified bitumen (with relatively high elongation properties) may incorporate extensible reinforcements to provide satisfactory "load-strain" properties associated with elongatable materials.

The philosophy of which type reinforcing material is used with the various types of polymer modified asphalts varies from manufacturer to manufacturer, and in some cases defies logic. The variations and combinations of reinforcements used in the many finished polymer modified bitumen roofing sheets available to the U.S. market make development of "standards" most difficult, which, in part, accounts for the fact that no ASTM specifications have been developed to date for polymer modified bitumen roofing sheets in the United States.

KEYWORDS

Glass fiber scrim, laminated mats, non-woven glass fiber, non-woven polyester, reinforcing mats, woven glass fiber, woven polyester.

REINFORCING MATERIAL TYPES

Glass fibers and various types of polyester fibers are the most common elements of reinforcing mats used in the manufacture of polymer modified bitumen sheets. Both glass fiber and polyester fiber mats may be either "woven" or "non-woven." Non-woven glass fiber mats are dependent on "binders" for their physical properties, while non-woven polyester fiber mats are usually thermally bonded. Heat-resistant polyester formulations are generally used in the production of polymer modified bitumen sheets. Polyester fibers are always more heat-susceptible than glass fibers, however, there is a great difference in the heat-resisting properties of various types of polyester fibers.

Glass fiber mats are the most heat resistant and dimensionally stable of available reinforcing materials. The weathering properties of glass fiber mats are superior to the weathering properties of polyester fiber mats since glass fibers are not subject to degradation from ultraviolet (UV) exposure as are polyester fibers.

NON-WOVEN GLASS FIBER MATS

Non-woven glass fiber mats may be produced from several varieties of glass fibers. The fibers may be single filament or "yarn" composed of a number of glass filaments. Mats may be produced by attenuation of glass fibers, "pulling" glass fibers from bushings or from chopped yarn segments. The most common non-woven mats used in polymer modified asphalt membranes are produced in a "wet-process" by "chopping" glass fiber yarns, dispersing the chopped yarns in a "binder" solution and drawing the glass fibers onto a blanket to form a mass of glass fibers covered with thermoset binders. The glass fibers and residual binders are laid between forming chains, run through an oven to "set" the binders and pulled into large rolls for subsequent processing.

The type of binder used to bond the glass fibers together in the mats, fiber quantity and size, and fiber distribution determines the physical characteristics of the finished mat. Binders may be more or less resistant to moisture, more or less flexible or pliable, and provide greater or lesser tensile strength to the finished mat.

Non-woven glass fiber mats have relatively good tensile strength, but have little or no elongation properties. They may have more or less "loft" (mat thickness) depending on

the total quantity of fibers and how much the finished mat is "compressed" during manufacture.

Non-woven glass fiber mats may be used in finished polymer modified bitumen roofing/waterproofing sheets to provide good tensile properties, better heat resistance, better weathering properties or better fire resistance properties. A non-woven glass fiber mat near the top surface of the polymer modified asphalt membrane will provide uniform weathering of the membrane surface without separation (alligatoring) of the non-reinforced bitumen on the surface of the sheet common to "mid-reinforced" polymer modified asphalt sheets. Some "fire resistant" sheets depend on non-woven glass fiber mats to obtain suitable UL/FM classifications for external fire resistance.

Non-woven glass fiber mats are produced in different "weights" expressed as "X" pounds of glass fibers per 100 square feet of finished mat. Very lightweight glass fiber mats (less than .5 lbs/100 sq. ft.) are called "tissues" which may be laminated (bonded) to other types of reinforcements to form laminated mat reinforcements.

Non-woven glass fiber mats may be used in combination with woven polyester or glass fiber mats to enhance certain properties of the finished roofing/waterproofing membrane. Non-woven glass fiber mats usually possess sufficient tensile properties to enhance process properties of the finished sheet. Non-woven glass fiber mats are not subject to "stretching" while being "pulled" through the manufacturing line (but lightweight mats may "tear-out" in a manufacturing line), and provide a stable carrier for the polymer modified bitumen during the manufacturing process.

Inclusion of relatively "heavy" (1.5 lbs/100 sq. ft. or greater) non-woven glass fiber mats will generally produce a finished product which is "stiffer" than finished products using only a woven glass or polyester fiber reinforcement, or non-woven polyester mats. Non-woven glass fiber mats have a "memory" (a propensity to try to return to a flat plane, exerting significant force/strain on waterproofing bitumen in the finished sheet) not common to woven mats or non-woven polyester mats which are much more "compliant" or "conformable" than heavy non-woven glass fiber mats.

Non-woven glass fiber mats are not subject to deformation or melting under temperatures developed by propane torches used in the application heat-welding process. Placement of the non-woven glass fiber mats in the plane of the finished product is critical, since non-woven glass fiber mats placed too close to (or on) the top surface of the finished sheet may delaminate (separate from the waterproofing bitumen in the finished sheet) from the sheet under normal application temperatures. There must be sufficient polymer modified asphalt above the glass fiber mat (top side of the finished sheet) to allow bonding of the lap areas and assure a positive bitumen-to-bitumen seal between the top and bottom surfaces of adjacent polymer modified bitumen sheets.

"WOVEN" GLASS FIBER MATS

"Woven" glass fiber mats may be truly "woven" (intertwined fibers) with glass fiber yarn, or may be "scrim" (yarns laid perpendicular without "weaving" held in mat form by a thermoset binder). Woven or scrim mats are differentiated by the number of parallel yarns per inch; i.e., a 6 x 6 woven mat or scrim would contain six fibers per inch in both the machine and cross machine direction.

Both woven and scrim glass fiber mats usually have very good tensile properties, with tensile properties varying with the number of yarns per inch and the size of the yarn. Woven glass fiber mats generally have good flexibility without the "memory" (the propensity to exhibit "stiffness" and return to flat, planar reinforcement) of non-woven glass fiber mats. Glass fiber scrims may not have the soft flexibility and "conformability" of woven mats depending on the type of binder used to bond the scrim fibers together.

Glass fiber yarns used for both woven and scrim mats may have different tensile properties depending on the number and size of glass fiber filaments contained in the yarns that are formed into scrim or woven into mats. Tensile properties of the finished mat are directly proportional to the strength of the individual yarns and the number of yarns-per-inch used to produce the mats.

Woven or scrim glass fiber mats have heat resistance similar to non-woven glass fiber mats and will not deform or melt under normal application temperatures produced by a propane torch.

Scrim mats may be bonded to other types of reinforcing mats with binders or adhesives to form laminated reinforcements. Laminated mats are usually selected by manufacturers to provide some unique property to the finished sheet; i.e., a glass fiber "tissue" for surface weathering laminated to a polyester or glass fiber scrim for tensile properties. Woven mats are generally not used in laminated mat reinforcements.

Woven or scrim mats are not usually used to enhance weathering properties of the finished membrane. Finished membranes containing woven glass fiber mats usually are conformable during application, but woven and scrim mats have very limited elongation properties. Both types of mats produce a finished product with good tensile properties, no matter which of the polymer modified bitumens are used in the finished sheets.

WOVEN POLYESTER MATS

Woven polyester mats are usually truly "woven." The woven mats have good tensile properties and resist stretching through the manufacturing process.

Woven polyester mats do not have the inherent heat resistance of woven or scrim glass fiber mats, and may melt or deform under temperatures normally associated with application with a propane torch (and in some instances, hot asphalt).

Woven polyester fiber mats may be combined with other types of reinforcing mats in the finished polymer modified asphalt membrane. Woven polyester fiber mats are sometimes laminated to non-woven glass fiber tissue to form a laminated reinforcing mat with acceptable weathering and tensile properties.

NON-WOVEN POLYESTER FIBER MATS

Non-woven polyester fiber mats are probably the most common type of reinforcements used in the manufacture of polymer modified asphalt membranes. They are manufactured by extruding polyester filaments in different

weights usually expressed in "X" grams per square meter of mat. Non-woven polyester mats are usually thermally bonded, unlike non-woven glass fiber mats which depend on thermoset binders to hold the glass fibers in the form of the mat. Non-woven polyester mats may be less commonly bonded with thermoset binders. Heat-resistant polyester fibers are spun or extruded in conjunction with polyester fibers of a lower softening point. The mat containing the two different fibers is carried through an oven sufficiently hot to melt the lower-softening point fibers (but not the higher-softening point fibers) causing the lower-melting fibers to bond together around the more heat-resistant fibers holding all fibers in the mat form.

Some non-woven polyester mats are "needle-punched" to maximize shear resistance in the cross-section (loft) of the mat. The semi-formed mat is "punched" by needles resembling miniature crochet hooks which catch the bottom fibers on the upward cycle pulling some of the horizontally dispersed fibers vertically through the cross section of the mat.

Non-woven polyester fiber mats usually provide good extensibility qualities, with limited tensile strength. The concept of "load/strain" properties[1] has been used to evaluate the physical properties of polymer modified bitumen sheets reinforced with non-woven polyester fiber mats, since this type of sheet will stretch significantly before the reinforcing mat fails. Although the non-woven polyester mats exhibit significant elongation properties, permanent deformation of the mat occurs long before the mat breaks during load/strain testing. The elastic limits of non-woven polyester mats used in polymer modified bitumen roofing sheets are generally between 5 percent and 10 percent.

Non-woven polyester fiber mats do not weather well, and degrade relatively quickly on exposure to UV rays. Long-term *in situ* performance of the non-woven polyester fiber mats is dependent on a layer of polymer modified bitumen or other surfacing material to protect the mat from exposure.

Non-woven polyester fiber mats, even though "heat-resistant," may deform or melt under temperatures associated with application by propane torch. Placement of the non-woven polyester fiber mats in the finished sheet must be such that the top surface of the mat is protected from sun exposure, and a sufficient quantity of bituminous material exists between the bottom surface of the membrane and the non-woven polyester mat to prevent distortion of the mat during the membrane application by torch.

The trend in the United States has been to manufacture and use high-modulus non-woven polyester mats in polymer modified bitumen sheets to facilitate processing. Recent testing indicates that high-modulus non-woven polyester reinforcements have a tendency to "shrink" (mainly in the machine direction of the sheet) following application of the membrane, causing movement and potential separation of the surface sheet at endlaps when roof surface temperatures approximate 176°F (80°C) (or a temperature approximately 9°-18°F (5-10°C) higher than the glass transition point for most polyester fibers). At this temperature, the cohesive strength of the lap bond is weaker than the shrinkage "strength" of the high-modulus polyester mats, and the sheets are "pulled" across the end lap area. Some "shrinkage" may also occur across the sheet width, but the relatively narrow width of the sheet and the longitudinal orientation of the fibers in the reinforcing mat typically do not result in significant cross-machine displacement of the finished sheet. Consideration must be given to increasing the recommended lap area in the finished membrane when high-modulus non-woven polyester reinforcing mats are used in any given product to allow sufficient bonded surface area at endlaps to minimize the effects of mat shrinkage in the machine direction.

Heavy (in excess of 200 g/M^2) non-woven polyester mats are difficult to saturate (impregnate), requiring special precautions in the manufacturing process to insure complete impregnation of the reinforcing mats. The more dimensionally stable the mat during the polymer modified bitumen sheet manufacturing process, the more difficult impregnation of the mat becomes because of the close proximity of fibers to each other in the finished mat.

There are an infinite number of variables in non-woven polyester mats:

- infinite combinations of molecular structures in the polyester fibers;
- varying "spinning" and/or extrusion techniques;
- varying "needle punching" techniques;
- various mat weights and fiber orientation; and
- filament size and bonding techniques.

These variables make processing of non-woven mats in the manufacture of polymer modified asphalt sheets less than predictable. Mats most suitable for a given manufacturing process are not necessarily most suitable for long-term polymer modified bitumen sheet performance.

LAMINATED REINFORCEMENTS

Laminated reinforcements are typically formed by "laminating" two mats of similar or dissimilar configuration together with a thermoset binding agent. The most common laminates consist of a non-woven mat and a woven mat or scrim. Laminated reinforcements may take on many varied properties depending on the type of materials laminated together to form the finished reinforcing mat.

Extraordinary tensile properties may be achieved in laminated reinforcements by combining a non-woven glass fiber mat with a woven (or scrim) glass or polyester fiber mat. Tensile properties may be altered by the overall weight of the non-woven glass fiber mat or by the number and type/weight of yarns per inch in the woven mat or scrim.

Non-woven polyester mats are not commonly used in laminated configurations because there would be nothing gained by laminating an extensible non-woven mat to a non-extensible mat, except perhaps increased fire resistance or weathering properties. Although the use of glass fiber mats laminated to non-woven polyester mats is not common, improvements in fire-resistance, weathering properties and dimensional stability have been noted in finished products incorporating the combination of non-woven glass fiber mats and non-woven polyester mat materials.

REINFORCEMENT CONFIGURATIONS IN FINISHED SHEETS

Single Mat Reinforcement

The most common (single or one-layer) reinforcing mat

used in finished polymer modified bitumen roofing/waterproofing sheets in the United States is non-woven polyester. Non-woven polyester mats are commonly used in both APP and SBS modified bitumen roofing/waterproofing sheets. The weight of the non-woven polyester mats used in various products varies from approximately 100 grams/m^2 to 250 grams/m^2. Obviously, the weight of the reinforcing mat dramatically affects the performance, application characteristics and physical properties (abuse/puncture resistance, tensile strength, etc.) of the finished membranes.

Some polymer modified bitumen roofing/waterproofing sheets have been manufactured using a single non-woven glass fiber mat (either chopped or continuous fiber), but that configuration of finished membrane has not generally been particularly successful in field performance in "single layer" applications. There are successful exceptions which appear to be dependent on the quality of the polymer modified asphalt compound and the configuration of the multiple-layer roofing membrane assembly.

Woven glass fiber mats are used in some product lines as the single reinforcing layer in the finished sheet. This configuration sheet is generally used in conjunction with multiple layers (base plies or built-up roofing membranes) to provide a multi-layer finished roofing membrane.

Dual-Mat Reinforcement

Some manufacturers produce finished products which are manufactured using two distinct layers of reinforcing material. This dual-reinforced configuration of finished membrane may have enhanced fire resistance properties, improved surface weathering characteristics and better abuse resistance than single-mat reinforced membranes.

The use of multiple reinforcing mats in a finished polymer modified bitumen sheet requires special manufacturing equipment and operator skill in maintaining alignment of the multiple plies through the manufacturing process. Any pre-saturation of the reinforcing mats must be accomplished using polymer modified bitumen with a softening point similar to the waterproofing bitumen used in the finished sheet to prevent delamination of the reinforcing mats during field application.

TOTAL ROOF MEMBRANE REINFORCEMENT

Virtually all manufacturers'/brokers' specifications for complete polymer modified bitumen roofing membranes include multiple plies of polymer modified bitumen sheets, glass fiber reinforced base sheets and/or a built-up roofing membrane under the polymer modified bitumen surfacing sheet.

The best logic for combining polymer modified bitumens with the various available reinforcing materials would be: to combine reinforcements and polymer modified bitumen with good elongation properties (SBS modified asphalt with non-woven polyester reinforcing mats); and to combine high tensile strength reinforcements with polymer modified bitumen having little or no elongation properties (woven/non-woven glass fiber mats with APP modified bitumen). In fact, following field investigations, these combinations appear to be the better performers in the polymer modified bitumen roof membrane category. But the other inescapable fact is that polymer modified bitumen membranes not in consort with this logic have performed reasonably well for their expected service life (which is generally less than that of the membranes following the logical methods).

The "single-ply game" in the polymer modified bitumen membrane business is over. It is no longer acceptable practice to "torch" one ply of polymer modified bitumen membrane directly to the surface of roof insulation. Most of the ill-conceived application practices have been too costly (in terms of claims for non-performance) for purveyors of polymer modified bitumen membranes to continue.

The combination built-up roofing membrane/polymer modified bitumen roofing membrane has become most popular with sellers and applicators. When two or three ply built-up roofing membranes are used in conjunction with APP modified asphalt membranes, the complete finished roofing membrane generally possesses sufficient tensile properties to exceed the National Bureau of Standards' (now referred to as National Institute of Standards and Technology) recommendation of a minimum of 200 lbs/inch.

Questions most often arise about the combination of glass fiber base sheet/SBS modified bitumen membrane and/or a built-up roofing membrane base covered with an SBS modified bitumen surfacing sheet. The SBS modified bitumen sheets usually contain non-woven polyester reinforcements giving the polymer modified bitumen sheet good elongation properties while the glass fiber base sheet/built-up roofing membrane has reasonably good tensile properties with virtually no elongation characteristics. The general response has been that the glass fiber base sheet/built- up roofing membrane provides a solid base for the high-elongation SBS modified bitumen sheet. Should there be any movement sufficient to rupture the glass fiber base sheet/built-up roofing membrane, the SBS modified bitumen membrane will elongate sufficiently to accommodate the movement without rupture, leaving the complete roofing membrane watertight. Whether or not this argument is valid remains to be seen, but the combination glass fiber base sheet/built-up roofing membrane and heavy non-woven polyester reinforced SBS modified bitumen sheets have had an enviable performance record over the past several years.

The other predominant concept in SBS modified bitumen roofing membranes has been the use of woven and/or non-woven glass fiber mats in conjunction with SBS modified bitumen. The woven and non-woven glass fiber mats restrict the inherent elongation properties of SBS modified bitumen, although lateral movement is tolerated by the non-woven reinforcements. Even though the concept appears flawed by common sense and logic, these types of roofing membranes have also enjoyed an enviable performance record.

CONCLUSION

Reinforcements used in polymer modified bitumen roofing and in waterproofing sheets perform several varied functions during both the manufacture and the service life of the finished membrane.

Reinforcing mats used in the manufacture of polymer

Reinforcement Type	Elongation (Load/Strain)	Tensile Strength	Weathering Properties	Heat Resistance	Abuse Resistance	Memory
Non-Woven Glass Fiber	Poor	Good/Exc.	Good	Good	Fair/Good	Strong
Woven Glass Fiber	Poor	Good/Exc.	Good	Good	Good/Exc.	N/A
Glass Fiber Scrim	Poor	Good/Exc.	Good	Good	Good	Moderate
Woven Polyester	Poor	Good	Poor	Poor	Good/Exc.	N/A
Non-Woven Polyester	Good/Exc.	Poor	Poor	Poor	Good/Exc.	Weak
Laminated Mats	Fair	Good/Exc.	Good	Good	Good/Exc.	Moderate-Strong

modified asphalt membranes must be an acceptable "carrier" for the waterproofing bitumen through the manufacturing process without stretching or deforming under temperatures and stresses imposed by the manufacturing equipment.

In the finished product, reinforcements play a key role in external fire resistance, weathering characteristics, tensile properties, abuse resistance, dimensional stability and application handling characteristics.

The variables in reinforcement properties and in polymer modification techniques contribute to a finished product with an infinite number of potential physical properties. Some combinations have performed well contrary to logic and common sense.

In general, it appears prudent to evaluate APP modified asphalt membranes based on tensile properties, since the APP plasticized asphalt has very little inherent elongation capability. SBS modified bitumen membranes are generally better evaluated using load/strain properties, given the inherent elongation properties of properly processed SBS modified bitumen and the widespread use of non-woven polyester mat reinforcements in the SBS modified bitumen roof membranes. Exceptions have already been noted.

Recent evaluations of field performance of polymer modified asphalt roofing membranes conducted jointly by the Midwest Roofing Contractors Association (MRCA) and National Roofing Contractors Association (NRCA) provided some valuable insight as to the weathering properties of both APP and SBS modified asphalt roofing membranes in diverse geographical locations. In general, APP modified asphalt roofing membranes with non-woven polyester mats that were placed near the center of the membrane plane exhibited a tendency to "surface craze." This is not common to APP modified asphalt membranes incorporating laminated or non-woven glass fiber mats placed near the top surface of the roofing membrane. The mid-reinforced non-woven polyester mats were more susceptible to deformation or "finger wrinkling" caused by excessive heat (and resultant shrinkage of the non-woven polyester mat) during the application process. The weathering characteristics of SBS modified asphalt membranes reinforced with both non-woven polyester mats and woven or non-woven glass fiber mats appeared to be more dependent on retention of surface granules than on the performance of the reinforcing materials.

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