ROOFING UNDERLAYMENT MATERIALS AND MANUFACTURING

By Steve Ratcliff and Shaik Mohseen

Roof consultants should know their materials inside and out. To fully understand underlayment, one must have a basic understanding of raw materials and manufacturing. Subtle variations at the molecular level have large effects on the properties of materials; furthermore, variations on the macroscopic scale also affect performance. Ideally, the manufacturer of the roofing underlayment is knowledgeable of engineered polymers, and its technical staff can work with polymer producers to optimize the formulas for polymers that are blended for use in the production of the underlayment.

There are many similarities among traditional, specialty, and synthetic underlayment products. Here we compare analogous manufacturing processes for traditional asphalt-coated felts and premium modified-bitumen membranes, as well as synthetics.

An underlayment company should be intimately involved with the manufacturing processes. Manufacturing facilities that are dedicated to the production of roofing underlayment can be continually improved as more is learned from the end-users.

Figure 1 – Asphalt unloading.

ASPHALT-SATURATED ORGANIC FELT

The manufacture of asphalt-saturated felt begins with the delivery of dry organic felt to the factory. This material is made out of cellulose fibers obtained from post-consumer and post-industrial waste such as newspapers, cardboard, and wood. The cellulose fibers are reduced to a water-based pulp, formed into sheets, dried, cut into strips, and wound onto rolls. Being made from 100% post-consumer recycled material, dry organic felt mat is an eco-friendly or "green" material.

The dry felt is delivered to the plant by truck and stored on-site. Meanwhile, hot asphalt is delivered by tanker truck (*Figure 1*) and pumped into one of several asphalt storage tanks. The asphalt is kept hot by electric and natural gas-fired heaters located at the asphalt storage tanks. The liquid asphalt circulates in a loop through the saturator and back to the asphalt tanks. The asphalt temperature is carefully controlled at all times.

Rolls of dry felt are loaded onto the unwind stand (*Figure 2*) and unrolled through the dry looper section (*Figure 3*). The dry looper consists of a series of rollers, pulled along by a chain, which is used to form loops, maintain tension on the paper, and allow product accumulation.

From the dry looper, the dry felt enters the saturator (*Figure 4*). The saturator consists of a series of rollers, commonly referred to as "gates." The bottom rollers of these gates are submerged in hot asphalt, maintained usually at a temperature of 350°F (177°C). The gates can be raised or

Figure 2 – Unwind stand.

Figure 3 – Dry looper.

lowered to change the level of saturation of the asphalt into the felt paper.

The saturation level is expressed as a percentage, ranging between no absorption (0%) and fully saturated (100%). It describes the extent to which the felt, upon being immersed in hot asphalt, absorbs and adsorbs the asphalt and retains it under the processing conditions. The type of asphalt used is called "saturant asphalt." The saturation level has a direct correlation to the finished product weight; the greater the saturation, the higher the weight.

Saturation level depends on various factors, such as:

- Type of dry felt, whether soft or hard
- Temperature of the asphalt
- "Dwell time," or the period of time that dry felt resides in the saturator
- Speed of the production line

After the felt is saturated, it passes over a series of three to five scraper blades to remove excess asphalt. The second blade

Figure 4 – Saturator.

Figure 6 – Winder.

Figure 5 – Finish looper.

can be adjusted in or out to increase or decrease the amount of asphalt removed from the surface of the paper. The saturator is totally enclosed; asphalt vapors from the process are routed to the scrubber/cooler (for cooling) and to the fiber-bed filter mist eliminator for control of emissions.

The asphalt-saturated felt enters the cooling section (also known as "the black rack" or the "striking section"), where it is drawn over several rollers and allowed to cool in ambient conditions. The cooling section is also enclosed, and the vapors are routed to the scrubber/cooler and then to the mist eliminator for emissions control. From the cooling section, the saturated felt rolls onto the finish looper, which is another series of rollers that forms the saturated felt into hanging loops (*Figure 5*). The asphalt-saturated felt is pulled into the winder, where the rolls are formed and cut into varying lengths (*Figure 6*).

At this stage, "ply marks" or "laying lines" can be printed on the surface of the felts. They are typically marked at 2, 8½, 11¼, 17, 19, 24¾, 27½, and 34 in.

The roll is pushed along a conveyor, where it is wrapped with a paper label and stacked vertically on pallets. When a pallet is full, it is automatically banded and stored in the warehouse, ready for shipment.

MODIFIED-BITUMEN ROOFING

Modified bituminous self-adhering underlayments are made of bitumen compounds such as asphalt that have been modified with polymers to be more rubber-like and easier to handle. A tough fiberglass mat gives strength against rips and tears and makes it easy to handle the modified-bitumen material. The fiberglass mats used in roofing are made of chopped strands of fiberglass.

The manufacture of polymer-modified bituminous specialty underlayment products consists of several distinct steps:

- Mixing and filler addition
- Saturating and coating the reinforcement
- Surfacing
- Cooling
- Cutting and winding (into roll form)

Mixing and Filler Addition

Asphalt is blended with polymeric additives such as atactic polypropylene (APP), styrene butadiene styrene (SBS), polyethylene (PE), and other chemicals in mixing tanks or vessels (*Figure 7*). Typical mixing tanks have a capacity of 25,000 lbs., which is approximately 3,000 gallons (*Figure 8*). Asphalt is heated to approximately 400°F (204°C), and the various polymers are added into the tank. The exact quantities depend on the specific product formulation.

Mix tanks are equipped with agitators or blades that keep the asphalt and polymers in circulation at high speeds. The blending process takes from two hours up to six hours, depending upon the quantity and type of polymers, as well as the equipment specifications. During this process, the polymers break down and bond with asphalt, resulting in a homogeneous asphalt-polymer network or matrix. Other ingredients such as oil and tackifying resins are added as needed. Filler materials such as limestone or talc are added into the mix

Figure 7 – Polymer additives.

tank and allowed to blend, usually for one hour or so. In some cases, the polymer-modified asphalt blend is transferred to a holding tank before being transferred to the production line.

Saturating and Coating the Reinforcement

From the mix tank or holding tank, the modified-asphalt blend is transferred to the coater in the production line. From the unwind stand located at one end of the production line, the reinforcement (also known as carrier or mat)—such as dry felt, glass mat, or polyester—is unwound from master rolls.

The coater section typically consists of a rectangular tank and a series of rollers. When the reinforcement enters the coater, it is saturated with the modified-asphalt blend. Simultaneously, the modified-asphalt coating is applied to the upper and lower surfaces of the saturated reinforcement.

The level of saturation again is greatly dependent upon several factors. In this case, the factors include the following:

- Dwell time of the reinforcement in the coater
- Run speed
- Type of modified-bitumen compound
- Viscosity of the modified-bitumen compound
- Temperature of the modified-asphalt blend
- Type of reinforcement

Figure 8 – Mix tanks.

Also present at the coater section are metering rollers, which are employed to achieve the desired product thickness by controlling the amount of modified-asphalt blend applied on either side of the reinforcement.

Surfacing

Once the saturated and coated reinforcement exits the coater section, the necessary surfacing material is applied. Surfacing materials are added for various reasons. For example, sand, talc, or liquid parting agent (LPA) is applied to the upper surface of the product to keep the material from sticking within itself when wound into roll form. Silicone-coated release film is applied to the self-adhesive compound on the bottom side to prevent roll sticking and to maintain the adhesive characteristics of the finished product (*Figure 9*).

Alternatively, polymeric film or fabric materials are applied to the topside, depending on the product configuration and end use. In the case of mineral-surfaced membranes or underlayments, mineral or ceramic granules are applied to the topside of the finished product. However, nongranulated sheets bypass this step.

Depending upon the type of surfacing, various auxiliary equipment and devices are utilized in the production line. For example, during the production of a fabric-surfaced underlayment, a fabric applicator is employed.

Cooling

The sheet is then fed through water-cooled drums to allow it to cool rapidly (*Figure 10*). In some cases, the sheet travels through a chilled water bath. Alternatively, water spray may be used to cool the sheet. Some manufacturing lines are equipped with dryers to air-dry the sheets. After cooling, the sheet enters the accumulator section, which consists of a series of rollers that allow the material to form into loops.

Figure 9 – Release film application.

Cutting and Winding

From the finished product looper at the accumulator section, the sheet travels to the winder, where it is cut to the required lengths and wound into roll form (*Figure 11*). The finished rolls are labeled or taped for product identification, and paper tubes or cores are inserted into the inner diameter of the rolls to provide stability during storage and shipment. The rolls are stacked on pallets, secured using stretch film or shrink bags, and stored in the warehouse prior to shipment to customer locations.

THE MANUFACTURE OF SYNTHETICS

Producing synthetic underlayment from polypropylene (PP) pellets is a marvel of modern manufacturing. The process can be subdivided into several distinct stages as follows:

- Spinning the fibers or filaments
- Weaving the PP filaments into scrim
- Extrusion-coating on scrim
- Extruding PP nonwoven fabric
- Bonding various layers together to form the synthetic felt
- Printing, cutting, and packing into individual rolls

Let's take a closer look at the manufacturing equipment used at each stage, from the point where the plastic pellets are extruded to the point where the components are finally assembled together into synthetic underlayments and packaged for the roofing marketplace.

Figure 10 – Cooling section.

Figure 11 – Winder.

Figure 12 – Mixer.

Figure 13 – Extruder hopper.

An appreciation of the manufacturing processes will make it easier to understand the slight differences between product offerings, including the features and benefits of different products from the same manufacturer. For polymer-based fabrics, it is a maxim that the "figure of merit" is tear resistance divided by weight. The use of woven polymers in synthetic underlayments greatly increases their tear resistance and imparts other properties, as well. It has been found that a woven scrim with widely spaced fibers combined with flat, nonwoven (extruded) polymer sheets provides high tear resistance.

Producing Filaments

The textile industry has been making fabrics from polymers for more than 50 years; as a result, the processes and equipment are highly evolved. A fiber of continuous length is typically referred to as a "filament." With modern equipment, it is possible to convert a thousand pounds of polymers into filaments without a single break occurring. In the textile industry, molten polypropylene passes through an adapter into a die that has a pattern of holes in it. The liquid polymer being forced through these holes solidifies in a short distance—typically about 100 centimeters or 40 inches (one meter)—and it can be further stretched or treated before winding onto spindles.

In the manufacture of synthetic underlayment, the threads used to manufacture scrim are made by slitting an extruded polypropylene sheet into many strips, which are further processed into threads or filaments.

The primary raw material employed in the manufacture of PP filaments or fibers is PP granules, which can also be referred to as "pellets." Depending on the color requirement of the final product, color pigment is incorporated into the master batch. Furthermore, depending on the end use and expected outdoor exposure of the finished product, ultraviolet stabilizers (UV additives) are included in the master batch. The various ingredients are blended at precise formulations at the mixer (*Figure 12*) and then conveyed through a suction pipe to the hopper, which then follows to the extruder hopper.

The extruder hopper allows the raw materials to enter the feed section of the extruder (*Figure 13*) in a continuous fashion, by gravity. The feed section is connected with the pipes to the water supply system for flow and return of chilled water. The cooling system eliminates slippage of the raw materials as they are pumped in the direction of a series of drums towards the die.

Raw materials are continuously fed at a rate proportional to the speed of the extruder screw. The temperatures at each of the heating zones are maintained to assure proper mixing, melting, and conveying of material. The extruder screw plasticizes the granules into melt form and conveys it forward. At the exit end of the extruder screw, a screen pack consisting of varying mesh sizes screens out the unmelted particles. The polymer melt must be filtered to ensure there are no bubbles or contaminants. Ideally, the polymer melt will have a consistent chemical composition and, hence, also predictable physical properties. The lengths of molecules within the polymer melt will not vary greatly such that the viscosity, melt flow characteristics, and melting temperatures do not vary over the length of the filaments (or "strips," "threads," or "tapes").

The polymer emerging from the slot die is chilled to a solid form at a water tank, and the chilled film passes through two pairs

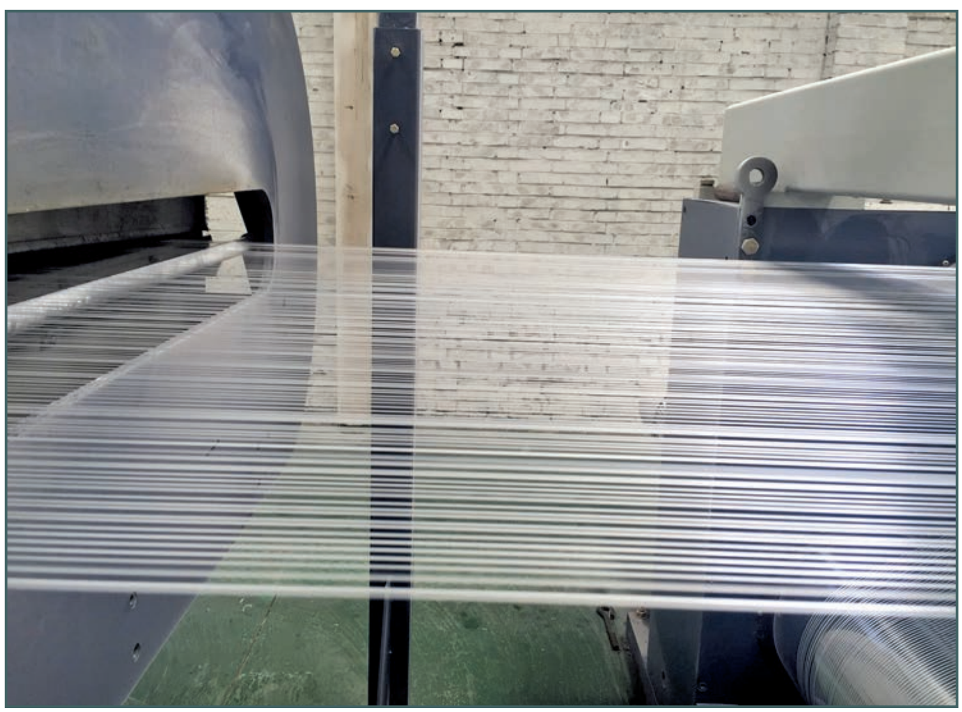

Figure 14 – Film slit into filaments.

Figure 15 – Winding filaments into spools.

Figure 16 – Quality control equipment.

of scrapers on the way to the squeeze-off rollers, where the remaining drops of water are removed.

Then the film enters a slitter where a spreader roller straightens any wrinkles in the film, and slitting blades cut the film into fibers or filament (*Figure 14*). The width of individual fibers is adjusted by using spacers of suitable size in between the slitting blades.

A system of godets is used to draw the filaments. (In the textile industry, a "godet" is a roller for guiding synthetic filaments during drawing. It is derived from a French word for a "cup" or a Dutch word for a "cylindrical piece of wood.") Filaments from a first godet station pass through a hot air oven and enter a second godet station, which is maintained at ambient temperature. The speed of this second godet is four to five times higher than the speed of the first godet. (The speed corresponds to draw ratio, which is chosen according to the properties of the raw material and the expected quality of the fibers.) The filaments then enter a third godet station, which is maintained cold using a chilled water circulating system, thereby freezing the molecules and aligning them in an oriented state.

Such oriented filaments possess high tensile strength and other desirable physical characteristics. Ultimately, these threads are gathered into spindles and wound onto spools (*Figure 15*). The spools will in turn feed the weaving machines. Various properties of the filaments can be inspected to maintain quality control before the spools are sent to the next processing step (*Figure 16*).

Weaving the Scrim

Just as spinning polymers into filaments involves highly evolved equipment, so, too, does the weaving of the filaments into scrim. The weaving pattern resembles one that might be used to weave a stocking hat or a sweater arm. Such weaving processes are demonstrated on YouTube videos, which can be found by searching for "circular loom." The main difference is the high-speed operation of a large circular loom.

Dozens of spools of filament are fed into an automated circular weaving loom, including both the "woof" and "weft" filaments (*Figure 17*). The filaments are woven into scrims at the circular loom (*Figure 18*). Miles of woven fabric are produced by each loom; and typically, many looms run in parallel at the same factory.

The closeness of weave is represented by mesh in terms of X by Y, where "X" represents the warp mesh, and "Y" represents the weft mesh. (The "mesh" is also known as the "count" or "weave.") The warp weave is in the machine direction; the weft weave is in the cross-machine direction. The number of tapes in one inch in warp direction is known as warp mesh (X). These tapes are passed through a series of inline process equipment for reed weaving on the circular loom. Technically speaking, the equipment includes eyelets, a roller, intake combs, a water-tank-chilled roller, eyelet bows, compensators, heddle belts, and reed rings of suitable dent. (See any good textile-industry glossary for

Figure 17 – Thread to weaving.

Figure 18 – Circular loom.

Figure 19 – Winding scrim into rolls.

definitions of these terms.) In this manner, the loom is threaded to define the weave in warp direction. The weft filaments are woven through the weave filaments in the circular loom. Finally, the woven scrim is wound into rolls of suitable width and length (*Figure 19*).

Extrusion Coating on Woven Scrim

Extrusion coating is the process of coating a polymeric resin on a woven scrim substrate by extruding a thin film of molten resin and pressing it onto or into the woven scrim substrate or both, with or without the use of adhesives. This process of extrusion coating on woven scrim is conducted on an extrusion-coating machine. The basic raw material for coating the woven fabric is polyolefin. Other raw materials used are the color master batch, UV master batch, and so on.

The blended raw materials are fed to the extruder hopper. The woven scrim in suitable roll form is loaded onto an unwind stand and guided through the rollers to the die. The molten material from the die is extruded onto the woven scrim surface in film form. The molten film laminated to the woven scrim is passed under heavy pressure through rubber rolls and a chilled roll, and eventually, it is wound into roll form at the winder. Thus, one side of the coating process is completed. The one-side coated roll is once again loaded onto the unwind stand, and the other side is coated in the same manner. The excess material (overhang) is trimmed off the edges, and the final product is wound in roll form at the winder.

Figure 21 – Nonwoven fabric roll ready for lamination.

Extruded Nonwoven Fabrics

Meanwhile, in another part of the factory, the sheets of nonwoven polypropylene are also extruded. Blown extrusion is commonly used in the manufacture of trash bags and shopping bags; in the case of blown extrusion, a tube of melted polymer is expanded with air pressure. However, the nonwoven sheets used for synthetic

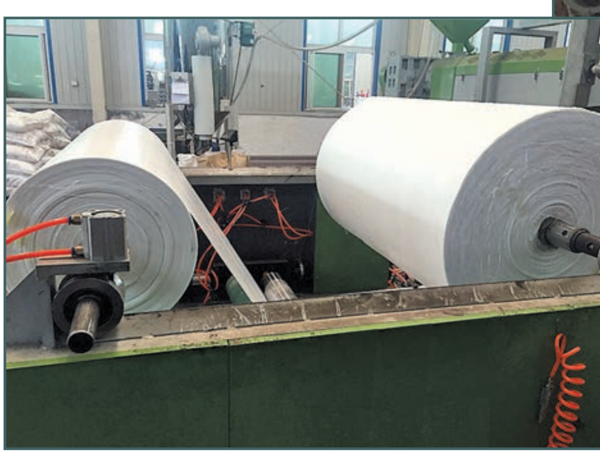

Figure 20 – Woven scrim ready for lamination.

felts are too thick to be blown. Instead, the polymer melt is forced through a die that has a thin rectangular hole for an exit.

The dies must guide the polymer melt from the circular outlet of the extruder screw to a thin, flat planar flow. This flow must be uniform across the entire cross-sectional area of the die. The sheets may then be passed between additional rolls for cooling and to establish the desired sheet thickness and surface texture. At this stage, the surface of the extruded sheets could be enhanced in such a way to allow for improved walkability of the finished product. It is a simple matter to transfer an emboss pattern from a preformed mechanical roll to the sheet shortly after it comes out of the die and before it has fully cooled.

Colored dyes are best added at this stage. While it is possible to print on polypropylene sheets after they have been extruded, polypropylene cannot be dyed after it has been extruded in the sense of dyeing in an aqueous bath as is done with other textiles. Of course, that is because the very properties that make polypropylene a good (water-resistant) roofing underlayment also make it impossible to dye. Nonetheless, vivid colors can be obtained by adding the dyes to the melt before the sheets are extruded.

Bonding the Layers Together

A synthetic underlayment really has a multilayer configuration. As mentioned earlier, the use of woven polymers in synthetic underlayments greatly increases their tear resistance and imparts other properties, as well. Once the woven and nonwoven components are ready, they need to be bonded together. Typically, synthetic underlayments are composed of two layers, with the nonwoven fabric as the top layer and the woven scrim as the bottom layer.

From the unwind stand at the coating machine, the master roll of woven scrim is unwound and guided through a series of drums (*Figure 20*). From another unwind stand, the nonwoven fabric is unwound and guided through a series of guide rollers (*Figure 21*). The woven scrim and the nonwoven fabric are sandwiched together at the pressure roller. It is important to set the suitable temperature, pressure, and tension in order to eliminate the possibility of film burn-through or deformation in the mesh surface. However, the process parameters must be adjusted so as to achieve the target bonding strength. In addition, coatings can be added on either surface of the material (*Figure 22*). The resulting laminate then follows a series of chilled rollers to the winder, where any excess overhang is trimmed

Figure 22 – Application of surface coating.

off from the sides, and the material is slit to the desired lengths and wound into roll form (*Figure 23*).

The underlayment material is then stored in the form of master rolls. The master roll is a space-saving method for storing synthetic underlayment, but not a very efficient way to bring it to market.

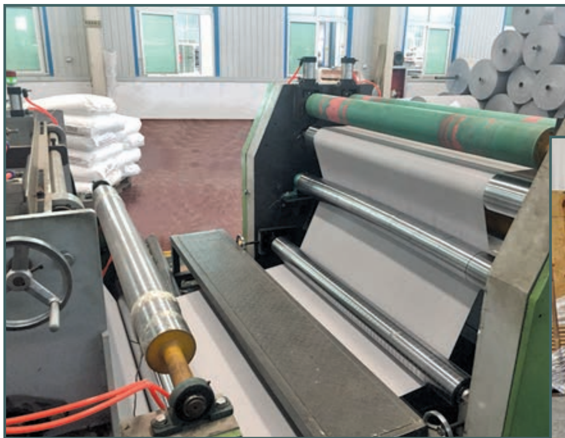

Figure 23 – Ready for winding at winder.

Figure 24 – Printer.

Figure 25 – Winding into small rolls.

Printing and Packaging in Roll Form

Printing is typically done at this final stage. The material is printed with the necessary artwork at the printing press (*Figure 24*). Standard products include markings to show where to apply fasteners and also product name and other useful information. The logo of the end-user could also be printed on the synthetic underlayment at this stage.

The final step of the manufacturing process involves packaging the synthetic felts into lightweight rolls that can be easily handled by the roofing contractor. Synthetic roofing underlayments are thinner and lighter than conventional asphalt-saturated roofing felts. Consequently, it is possible to package them in rolls that can cover a total area of ten squares rather than one or two squares, and yet the roll will still be light enough to be handled by one person. Making the rolls wider also results in labor savings, since the roofer can cover twice the area with the same sheet length if the sheet is twice as wide.

At the rewinder, the master rolls are unwound and cut to desired lengths and then wound into roll form onto plastic or paper cores (*Figure 25*).

SUMMARY AND CONCLUSION

All of these manufacturing processes involve rollers for moving sheets of material through various processes. Thicknesses, temperatures, and material properties must be tightly controlled.

For conventional felts, the original shape of the sheet is obtained by heating and compressing the nonwoven organic felt material. This material is then saturated with asphalt to impart water resistance.

For specialty underlayment, the mat is, in many cases, a woven or nonwoven polymer that is sandwiched between layers of modified-bitumen material.

Now it is easy to understand how the final product features are obtained by starting with various sheets or scrims and processing them further with asphalt or polymer coatings. It is also easy to understand how these features relate to the practical considerations of the roofing contractor.

A thorough knowledge of the underlayment manufacturing process is useful for understanding specific product features of various types of underlayment; how they can be modified to match the underlayment to the application; and how the performance, ease of handling, walkability, and other features can be improved.

For specific examples of the properties of underlayment products with reference to the above manufacturing processes, read the complete white paper, entitled "Rethinking Roofing Underlayments," available from Tarco at www.tarcoroofing.com.

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