ASPHALT SHINGLES–A CENTURY OF SUCCESS AND IMPROVEMENT

MICHAEL J. NOONE
CertainTeed Corporation
Valley Forge, Pa.

W. KENT BLANCHARD
Tamko Asphalt Products, Inc.
Joplin, Mo.

The popularity of asphalt shingles is discussed in terms of the value that they provide as steep-roof coverings. This value is derived from their demonstrated performance of over a century of experience as the dominant roofing material in the United States. The role of each of the critical components is discussed and is related to the materials science principles involved in the construction of the shingle. Understanding the shingle as a composite material provides an understanding of the performance requirements of shingles and can explain performance deficiencies. The improvement in components and in performance that have accompanied the evolution of the asphalt shingle are related to its value to the building owner.

KEYWORDS

Asphalt shingles, composition, performance, properties, steep roofing.

INTRODUCTION

This paper will address issues related to the performance, appearance and value of asphalt shingles. Asphalt shingles have been the most popular form of residential roof coverings in the United States in the last 100 years. Despite many competing roofing systems, this popularity has been maintained in recent years to the extent that the annual installed area of asphalt shingles regularly exceeds 100 million roofing squares. The total area of roofs covered by asphalt shingles in the United States today is estimated in the billions of squares.

Why is it that asphalt shingle roofing materials dominate the market? The answer is partly related to the history of petroleum in the United States where asphalt has been readily available as a relatively low cost petroleum by-product. The major reasons for the success of asphalt shingles relate, however, to the value that they provide as an effective water-shedding system for steep-sloped surfaces, and the varied appearance that they achieve at a relatively low installed cost.

The most dramatic changes in the development of the asphalt shingle have occurred over the last 25 years or so. These include the use of fiber glass as a major reinforcing membrane, and the introduction of architectural or designer-type shingles based on multi-layered laminations and overlays with a dramatic blend of colors and patterns (see Figure 1). Improvements in the processing of asphalts and the introduction of polymer-modified adhesives and sealants, together with improvements in the consistency and performance of reinforcing membranes—both fiber glass mats and the traditional organic felts—have led to even greater value in the form of enhanced roofing performance.

Over the same period, there have been significant improvements in manufacturing efficiencies and in the more efficient use of raw materials. This improvement is clearly evident in the marketplace in which commodity shingles can be purchased today for about the same price, or even less than, they could 20 years ago. All of this has happened despite considerable increases in the costs of labor, raw materials and energy over that same time frame. As a result, asphalt shingles have not only retained their dominant position in the United States residential roofing market, but have considerably increased in value for both the homeowner and the construction trade.

The popularity of asphalt shingles comes from this value that they have provided by performing reliably for many years, and this history of performance must always be taken into account when discussing possible performance improvements. This paper will address the principles involved in the manufacture of shingles and the influence of composition on performance. The relationship of these factors to the existing ASTM shingle standards will be discussed. The paper will also show that an understanding of the relationships between raw-material properties, composite materials science and shingle performance characteristics will provide the foundation for advancing the use and success of asphalt shingles as the dominant steep roofing material for the next hundred years.

THE ASPHALT SHINGLE AS A COMPOSITE MATERIAL

Asphalt shingles are constructed from as many as 10 different materials, each of which is designed to perform a specific function in the final product. The words "composition shingle" are often used to describe these products; but, these simple words do not come close to describing the complexity of the composite material construction involved in the "common" asphalt shingle that is sold for only pennies per pound and provides many years of reliable service.

To succeed in producing a construction that will perform satisfactorily during application and in service, the designer and manufacturer of asphalt shingles must understand the materials science principles involved in the construction of composite materials. As part of this understanding, it is important to recognize that the matrix or "body" of the shingle is the asphalt itself. Asphalt is a very complex and crude "resin" with physical properties that change dramatically with temperature and time. A materials science approach must be employed in the choice, design and amount of reinforcements, stabilizers, processing methods, etc., if the resulting product is to have the performance characteristics necessary to survive the rigors of the thermal and mechanical stresses that are experienced by asphalt shingles during their service life on the roof. The nature of the four major constituents and the role that each plays in the performance of the shingle "composite" will be discussed in the following sections. Understanding these factors will provide improved understanding of the reasons for successful performance, as well as for failures that may occur if the design principles are violated in the manufacture of the shingle.

ASPHALT–THE MATRIX OR "BODY" OF THE ASPHALT SHINGLE

In the 100-year history of asphalt roofing, the asphalt material itself has been obtained as a by-product of the refining of crude oils whose origins have included a variety of petroleum operations worldwide. All crude oils do not produce asphalts acceptable for quality roofing. The majority of the world's crude oils can, however, be processed to provide high quality materials from which roofing shingles can be produced. Obviously, because of the wide range of crude oil sources and variations in refinery operations, all asphalts are not identical. Specific materials must be processed carefully, both at the refinery and in the preparation for use in the roofing plants, to provide such characteristics as pliability and durability that are critical to shingle performance.

In general, the asphalt can be considered to provide the "body" or, technically, the matrix of the composite shingle. It is the basic waterproofing element and forms an integral film throughout the shingle. While asphalt chemistry is complex and not fully understood, the past 100 years' experience and extensive studies in recent years allow the asphalt technologists and roofing manufacturers to recognize those characteristics that are critical to performance on the roof. The asphalt must retain its integrity during handling and installation, which demands that it be sufficiently pliable (e.g., when forming hips or ridges), and yet be stiff enough to resist scuffing forces caused by kneeling and foot traffic. Roofing technologists have developed criteria for these rheological properties of asphalt over the years, and in the simplest form, these criteria are described in terms of softening point and penetration. These simple measurements relate to other physical properties, such as the flexibility or toughness of the asphalt, but are by no means the only measurements that are used in evaluating the quality of asphalt.

Because asphalt shingles are intended to serve as water-shedding systems for many years, the most critical element in the selection or processing of an asphalt is its durability. Durability can be defined as resistance to weathering, and may be assessed in equipment designed for accelerated weathering or aging studies. The most obvious change that takes place in asphalt over time is a hardening or stiffening that results from complex chemical changes involving thermal oxidation. The most desirable asphalts for roofing shingles are those that harden or stiffen as little as possible over as long a period of time as possible. Stiffening of asphalt is inevitable, but by careful processing and control of the starting material, the rate of change of properties can be minimized.

One of the most important criteria of assuring the performance of asphalt shingles is, therefore, the use of a "durable," i.e., pliable, slow-hardening asphalt. The asphalt component of the shingle structure is the only part whose properties change dramatically over time. It is therefore critical to examine the nature, amount and distribution of asphalt in the shingle composite whenever performance problems develop as a function of age. The asphalt experiences dramatic changes in properties as a function of time and temperature, and these changes must be considered when exploring the long-term performance characteristics of shingles.

The asphalt matrix alone does not define performance, because other parts of the composite—particularly the reinforcement web, and the type, amount and particle size distribution of the mineral stabilizer—can have dramatic effects on the performance of the shingle.

REINFORCEMENTS–THE "BACKBONE" OF THE ASPHALT SHINGLE

If asphalt is the "body" of the asphalt shingle, then the reinforcement web is the "backbone." While the characteristics of the asphalt dominate the flexibility of the shingle, it is the backbone layer in the laminar composite that dominates most other physical properties of the shingle. The reinforcement is the carrier on which the shingle is built as it moves as a continuous web through the manufacturing process.

In its simplest form, the process involves passing the web through a coater, where layers of hot stabilized asphalt are applied to the top and back surfaces, colored granules are then dropped on the front surface and other mineral materials are applied to the back. The web then passes through a press section to set the granules in place; the composite laminate sheet is then cooled, cut into shingle shapes and packaged for shipment. The process generally involves application of sealants and release tapes, etc., (see Figures 2 and 3), and is more complex for overlay or laminated shingles.

As the foundation on which the shingle is built, the reinforcement web must have sufficient integrity, tensile strength, tear strength, etc., to allow it to be processed without damage or breaking; however, the physical requirements for performance of the shingle may be significantly greater than those necessary for the mat to survive the production process. Also, the reinforcement for organic shingles is significantly different from that used to make fiber glass shingles, which results in significantly different shingle properties. Because of these differences, the detailed nature of the two basic reinforcements and their influence on shingle properties must be discussed separately.

ORGANIC REINFORCEMENT WEBS

Organic shingles are built on a backbone of asphalt-saturated organic felt. When the felt enters the coating process, it typically weighs 24 lbs. per 100 sq. ft. for standard shingles and about 30 lbs. per 100 sq. ft. for heavyweight shingles. The organic felt itself is a heavyweight paper formed from virgin wood pulp mixed with recycled cellulose fibers from corrugated boxes and paper. This is saturated with soft asphalt (softening point about 130°F) to at least 165 percent of its weight before it is presented to the coater. The process of applying the stabilized (filled) asphalt coating to the top and back of the web is very similar with both organic and fiber glass reinforcements; the rest of the shingle forming process is identical. There is generally greater emphasis placed on the addition of backcoating at the coater for organic shingles, and typically the filler content is lower than for fiber glass shingles.

The major differences in performance between organic and fiber glass shingles are directly related to the nature of the reinforcement. The thick, organic saturated felt backbone causes organic shingles to have high tear resistance and high fastener pull-through resistance, and to be generally much more rigid, and thus more resistant to blow-off in strong winds. The soft asphalt in the felt (the marrow?) causes the shingles to retain good mechanical properties and general toughness at low temperatures, while the thick felt preserves stiffness even at high temperatures. The continued popularity and successful performance of organic shingles in northern climates is testimony to the importance of these tough physical properties in cold weather and under thermal cycling conditions.

Cellulose reinforcement fibers are, on the other hand, the reason why organic shingles have diminished in popularity in the South where hot humid conditions prevail. Cellulosic materials, if not protected, are sensitive to attack by moisture and may change dimensions as a result of swelling of the individual fibers. This is why total saturation of the felt by the soft asphalt is essential to the performance of organic shingles. If efficient saturation is not achieved, then exposure to moisture can, over time, cause dimensional changes that manifest themselves as curling, clawing or fishmouthing distortions on the roof. The use of a heavy layer of coating asphalt on both sides of the reinforcement is the traditional way to protect the felt from moisture attack. It also gives rise to the concept of the "balanced" shingle. Heavy backcoating also improves the shingles' resistance to cold weather curling by providing balanced forces from the thermal contraction of asphalt on both sides of the web, thus helping to keep the shingle flat.

Improvements in the production of organic felt and in its conversion into roofing shingles have been significant in recent years, despite the fact that it is a 100-year-old technology. The use of heavier backcoatings, consistently high felt saturation levels and greater consistency of the felts themselves has dramatically improved the performance of the current generation of shingles reinforced with saturated felt. In fact, the toughness of the resulting shingle, as measured by tear resistance, fastener pull-through resistance, etc., is even greater than shingles of similar weight made in prior years.

Because the coating asphalt is essentially the same for both organic and fiber glass shingles, and all asphalts become progressively harder and more brittle with age, it is interesting to compare the differences in resistance to cracking between the two types of reinforcement as shingles age. In old organic shingles, cracking of the hardened surface coating generally takes the form of hairline crazing patterns that, in the extreme, may penetrate down to the reinforcing web. These cracks are unable to penetrate the thick heavy felt and its soft saturant asphalt; therefore, they are stopped and do not threaten the integrity of the shingle. The reinforcement mat in fiber glass shingles presents negligible resistance to cracks that form in the old hardened asphalt coating, and the mechanism of cracking and the consequences of cracking are often different.

FIBER GLASS REINFORCEMENT WEBS

The fiber glass mats that form the backbone of fiber glass shingles are non-woven webs produced in a wet-process similar to papermaking, from dispersions of surface-treated glass fibers (typically 1 inch long and 14 to 16 microns in diameter) that are bound together by resin and cured in an oven. The binder is generally a modified urea formaldehyde resin that is about 20 percent of the mat weight and is designed to produce mats with high tear resistance, tensile strength and flexibility. Shingle reinforcing mats range in weight from about 1.3 lbs. to more than 2 lbs. per 100 sq. ft.

Because of the high strength and stiffness of the glass fibers, and their strong binder systems, these mats can have tensile strength that rivals the saturated organic felts—despite being 10 times lighter in weight. With appropriate surface treatments and binder modifiers, the mats can develop good flexibility and tearing resistance. The mats are a simple composite in themselves; fiber diameter, length, dispersion, surface coatings, and binder type and curing, all play a part in determining the mat properties. The heaviest mats are generally the strongest, toughest mats.

The major advantage of fiber glass mats over saturated cellulose felts is their much greater resistance to moisture and fire. As a result, fiber glass shingles are dimensionally stable under conditions of high humidity and have become the shingle of choice in the majority of the United States, representing virtually 100 percent of the market in the South. Also, the noncombustibility of fiber glass and the absence of the volatile saturant, asphalt, allows fiber glass mat-reinforced shingles to attain the Class A fire-resistance rating.

When the glass mat is presented to the coater in the shingle production process, the filled asphalt coating penetrates the porous mat and encapsulates the glass fibers. While a thick backcoating is not necessary to protect the fibers from moisture (unlike organic), it is nevertheless important to apply sufficient backcoating to balance the shingle against thermal contraction forces at low temperatures; otherwise, cold-weather curling will result.

The mechanical properties of the fiber glass mats directly impact the mechanical properties of the shingle, such as its tensile strength, fastener pull-through resistance, etc. The position of the mat within the thickness of the shingle can have an effect on the apparent flexibility of the shingle, even though the flexibility is governed by the pliability of the asphalt. For example, if the mat is in the middle of the shingle, it acts as a hinge and the shingle can readily flex (subject to the pliability of the stabilized asphalt) with little strain on the mat. If, however, the mat is right on the back surface (little or no backcoating) and the shingle is flexed with the granule side on the inside of the bend (as it would be when an unsealed shingle is subject to the uplift force of the wind), then the shingle appears more stiff because the reinforcement mat is on the back (i.e., the surface being subjected to the maximum strain). If the mat is weak and unable to resist this strain (i.e., because of insufficient weight), it may readily break under the strain, and blow-off could result.

Another consequence of positioning the mat on the back of the shingle is that all of the filled coating would be on the front of the shingle. The result, as the asphalt coating ages and becomes harder and more brittle, is that if hairline or craze cracks should begin to form, they will encounter no reinforcement until they have penetrated almost entirely through the thickness of the shingle. Even in a well-balanced shingle with the mat well within the thickness of the shingle, as cracks form, they will encounter little resistance from the lightweight, low-density reinforcement. This is the major difference in resistance to catastrophic cracking between fiber glass and organic shingles. It indicates that the shingle manufacturer must make greater efforts to avoid the initiation of cracks in fiber glass shingles, because the consequences of their propagation are much more severe than in organic shingles that have a heavy, tough backbone that acts as an effective "crack stopper."

Clearly, while the fiber glass-mat reinforcement represents only a small fraction of the shingle weight (often less than 1 percent), its properties dominate the long-term performance of the shingle. Apparently, small differences in weight (e.g., between 1.6 lbs. and 2.0 lbs. per 100 sq. ft.) can have dramatic effects on mat properties, which, in turn, can result in very significant differences in shingle properties. This would be true even if all other aspects of the shingle composite were equal. These other factors, including the nature and properties of the asphalt and the nature and amount of stabilizer, etc., cause changes in the demands placed on the reinforcement as the shingle is stressed. As the stabilized asphalt ages and becomes more stiff, the mechanical forces that are generated in the shingle by temperature changes, wind forces or deck movements, etc., put a much greater strain on the reinforcement than those same forces can apply when the asphalt is fresh and pliable. The demands placed on the reinforcement can dramatically change with time even though, as discussed above, the asphalt matrix is the only component of the composite whose properties are changing.

As the backbone of the structure, any deficiencies in mat strength and toughness can result in deficiencies in shingle performance. Lightweight mats with low tear resistance can result in damage, such as tearing during handling and application of the shingles, blow-off of unsealed shingles (or even of sheets of sealed shingles if the fastener pull-through resistance is low), and ultimately, in cracking. Therefore, designers of shingles recognizing the importance of the "backbone" of their product place greater emphasis on all aspects of the performance characteristics of the mat (its weight, binder cure and moisture sensitivity, etc.), to ensure the successful performance of the shingle.

Major improvements have been made in the production of fiber glass reinforcing mats over the last 25 years or so, as they have become the dominant reinforcement in the roofing industry. The trend to lighter mats appears, for the most part, to have been reversed. It is possible that in the future, the technology of reinforcement construction could advance to the point where acceptable shingle performance could be attained with lighter mats and, indeed, lighter product weight. With the present, state-of-the-art shingle formulation and manufacture, it appears that mats of about 1.8 lbs. to 2.0 lbs. per 100 sq. ft. (or greater) are required to ensure successful performance.

MINERAL STABILIZERS–THE "FILLER" IN THE ASPHALT SHINGLE

Mineral stabilizers, commonly called fillers, are essential ingredients in the production of durable asphalt shingles and are critical to the successful performance of the shingles. The filler has several roles in the composite material design, and to perform these functions, it must be finely ground to a carefully controlled distribution of particle sizes. The ideal size distribution has been extensively studied in recent years in an effort to maximize shingle performance, while minimizing the costs of production.

The most commonly used fillers in the industry today are ground limestones—particularly dolomitic limestones. Other materials that have been used include ground rocks, fly ash, slate dust and even fine sands. The choice is generally dictated by local availability to the plant site. The principles of their function and the importance of particle size distribution are similar for all filler materials.

The primary function of the filler is to stabilize the asphalt by providing particulate reinforcement at appropriate loadings to stiffen the asphalt against scuffing and flow during application, and at roof service temperatures. The stabilizer also increases the durability of the coating asphalt when mixed at appropriate loadings to reduce the potential shrinkage of the asphalt as it ages. The expansion coefficient of mineral stabilizers is much less than that of asphalt so that the presence of filler, at appropriate loading, increases the ability of the asphalt to resist cracking when subjected to thermal cycling. The presence of filler also adds significantly to the weight of the final product; indeed, high density (high specific gravity) fillers are desirable, so that at a given weight percent loading they will have a minimum volume percent loading, which has a significant effect on the flexibility of the shingle. Appropriate loadings of filler are also essential in achieving the fire-resistance ratings of asphalt shingles.

Please note, the phrase "appropriate loadings" is key to any discussion on fillers. There is an appropriate level of loading that enhances the performance of the asphalt shingle. Above the appropriate loading, the consequences of excessive filler can be disastrous in reducing the durability, increasing the stiffness and greatly reducing the pliability of the shingle. The appropriate level depends on the specific filler, its size distribution, shape, specific gravity, etc., and on the rheological properties of the asphalt being used. With pliable asphalts and well-controlled fillers mixed homogeneously in the production process, filler loadings of approximately 60 percent may be appropriate.

However, with harder asphalts and less controlled fillers, appropriate loadings may be less than this level.

Above a critical level, the asphalt/filler mixture and, of course, the shingle, will be susceptible to cracking in handling during application and could fail by splitting in service. When designing a shingle, it is essential to determine the optimum loading of filler consistent with the particular asphalt and reinforcement being used. The design must, of course, be supplemented by extensive product testing both in the fresh "as produced" condition and after "aging" by artificial accelerated methods, to assure acceptable long-term field performance.

Improvements in understanding the optimum particle size distribution of filler materials has been advanced by university studies sponsored by the Asphalt Roofing Manufacturers Association (ARMA). This improved understanding has allowed the process of grinding fillers to be better controlled to optimize the loading in the shingle. Major manufacturers have also improved filler mixing systems to assure uniformity of loading and have improved process control and measuring methods. At least one manufacturer has even employed sophisticated nuclear magnetic resonance techniques to accurately measure the filler loading and to aid in the control of the mixing process.

SEALANT–A KEY PERFORMANCE ELEMENT IN THE ASPHALT SHINGLE

The nature, amount and geometry of the self-sealing materials used on asphalt shingles are designed to provide for sealing of the shingles under the action of the heat from the sun when the shingles are applied to the roof. Major advances in recent years, particularly with the advent of fiber glass shingles, have resulted in improved sealant formulations designed to seal faster and at lower temperatures than the traditional sealants used on organic shingles, and which generally provide higher bond strength.

These improvements are necessary because, as discussed earlier, the fiber glass shingle has much less rigidity than the organic shingle, and is also generally lighter in weight. As a result, the fiber glass shingle is inherently more vulnerable to blow-off and requires more aggressive sealants if it is to perform satisfactorily. One consequence of using a strong sealant to rigidly hold down a lightweight, fiber glass shingle against blow-off is that (if the shingle has not been correctly designed) the mechanical properties of the composite structure may be insufficient to prevent mechanical failure (cracking and splitting) for reasons already discussed. Also, the shingle must be designed to have adequate fastener pull-through resistance, or it is possible that whole sheets of shingles, strongly sealed together, may be blown off of the roof under the influence of wind uplift forces.

The sealant material represents only a small fraction of the weight of an asphalt shingle—typically about 1 lb. per square—yet, this small amount of material is absolutely critical to both the blow-off and cracking resistance of the shingles. A sealant material must be designed to remain pliable at low temperatures when fresh, as well as after aging. Of course, these are the same desirable features for the asphalt from which the shingle is made. The requirements are even more critical in the sealant, because this small amount of material must be designed to allow the shingle to seal quickly and firmly at low temperatures, yet be pliable enough in service to provide stress relief to the shingle when it is subjected to thermal or mechanical stresses in service. A hard, brittle sealant may not only be too strong and too rigid to allow any movement of the shingle, but may become so brittle that it could fracture when stressed at low temperatures, allowing blow-off to occur, even though a high strength bond had previously been formed at higher temperatures.

The science of sealant formulation has advanced significantly in the past 10 years or so and will continue to do so as the industry gains a better understanding of the role of the sealant in the total performance of the roof. The test method developed by ARMA for measuring the bond strength of sealants (and currently being considered as an ASTM test method) will facilitate testing of different sealant materials sealed at different temperatures for various periods of time. The results of such testing will guide the development of improved sealants.

Strong, aggressive sealants are not a substitute for good shingle design. They can be a critical component in the successful performance of an asphalt shingle roof when used with shingles that have been designed to address all of the other factors involved (i.e., asphalt, mat, filler, etc.) in determining performance. Asphalt shingles, when well-sealed, have demonstrated remarkable resistance to blow-off forces. The factors that relate to this critical area of performance, as well as the recent work being sponsored by ARMA, will be discussed separately in a later section of this paper.

OTHER COMPONENTS IN THE ASPHALT SHINGLE

The following components of the asphalt shingle composite provide important functions but do not directly influence the physical properties that relate to performance.

Mineral Granules–The Surface of Asphalt Shingles

The mineral granules used on the surface of asphalt shingles are the only part of the complex composite that is visible to the observer of the finished roof. They are, therefore, critical to the design of the product and the appearance of the roof. Many variations of blends and arrangements of granules have been developed over the years to enhance the appearance of asphalt shingles.

The only technical function of the granules is to protect the underlying asphalt from the degrading ultraviolet radiation from sunlight. The presence of the granules obviously contributes to the weight of the shingle. The granules are carefully screened to provide a size distribution that will pack together and cover the entire surface of the shingle, and effectively block the sunlight from reaching the asphalt.

Most appearance problems observed on asphalt roofing relate to the way that the granules are blended and applied to the moving web in the roofing plant. The pressing operation can be influenced by the speed of production, the temperature of the asphalt, the filler loading and the amount of granules applied to the moving web.

Press variation or "shading" is a particularly frustrating problem to address, because the effect is only visible at particular viewing angles, or at particular times of the day and conditions of lighting. This is because the apparent changes in appearance are due to differences in reflection from the surfaces of the granules, which tend to line up differently under different conditions of pressing. Control of the pressing operation is continuing to receive attention from manufacturers, resulting in major improvements in process control in recent years. However, the traditional method of measuring granule adhesion or embedment, using the scrubbing action of a wire brush under controlled conditions is not as sensitive to the subtleties of press variation.

Most manufacturers use slag materials or uncolored crushed rocks for headlap areas of the shingles, which are generally covered up when the shingles are applied to the roof. Some years ago, there were incidences of "burn-through" of the cutout areas of shingles produced using slag and rock materials that were not sufficiently opaque. These granules allowed ultraviolet light, shining in the cut-out areas, to affect the asphalt beneath them. This caused deterioration of the asphalt and loosening of the granules. When the granules were eventually washed off the affected area, rapid deterioration or burn-through occurred.

Observations of this burn-through process on older roofs have caused many contractors to be wary of the use of shingles with cut-outs. Knowledge of these past problems has reinforced concerns among manufacturers today to enforce the criteria for opacity in slags and rocks used in the headlap area of shingles. In fact, most manufacturers have the same criteria for qualifications of headlap granules as they do for colored granules. As a result, the durability of the shingle in the cut-out region (exposed headlap area) should be identical to that of the major exposed area of the shingle.

Backsurfacing Materials

The technical function of the mineral materials applied to the back surface of the shingles is to prevent the shingles from sticking together in the bundles during storage, and to keep the shingles separated so that asphalt from the back of one shingle does not transfer to, and stain, the granule surface of the shingle beneath it. The backsurfacing material is also important in preventing sticking of the shingle to the roofing machine during production.

Traditionally, finely ground talc was the standard backsurfacing material used to prevent sticking and staining of shingle materials. In recent years, other materials, particularly sand, have been employed because of the superior ability of the sand to keep the shingle separated and prevent sticking and staining. Other materials commonly used include ground limestones, slags and mica. Some manufacturers have used granular rock and slags similar to those used in the headlap area of the shingle. These coarse materials have a significant effect on the weight and thickness of the shingle design. The nature of the backsurfacer has little effect on most physical properties of the shingle, though the coarse materials can have an effect on flexibility in handling.

No matter which backsurfacer is used, the extent of sticking and staining in shingles is determined by the time, temperature and pressure under which they are stored. The softness and staining characteristics of the asphalt, of course, do have an influence on the staining potential of the shingles. When shingles are stacked two or three pallets high for extended periods of time in the heat of the summer, it is obviously difficult to avoid some sticking and staining in bundles at the bottom of the pile. Staining observed during application of shingles is almost always related to the storage history of the product. Fortunately, this backcoating transfer staining will readily weather off the surface of granules under the influence of sunlight and rain.

Release Tape

The narrow strip of release tape applied to the back of self-sealing shingles deserves comment in any discussion of shingle performance issues. The release tape provides an absolutely critical technical function in protecting the sealant during packaging and storage, and in preventing adjacent shingles from sticking together in the bundle. This is the only function of the release tape, and once the shingles are removed from the bundle, it plays no role in the application or subsequent performance of the shingles.

The technical function of the release tape has become even more critical in recent years with the advent of the more aggressive "tacky" sealants. Shingles with these advanced sealants almost exclusively use a polyester tape pre-coated with a silicone-based release agent formulated to resist sticking to the sealant in even the most extreme conditions of storage.

There is ongoing confusion in the minds of many consumers about how to treat the release tape during application. Many make the mistake of insisting that the tape be removed! The answer to this confusion is obviously that more education of the consumer about the function of the tape is needed. Some manufacturers have gone so far as to print, "Do Not Remove This Tape," on the release tape, a step that has been favorably received by contractors.

UNDERSTANDING CRACKING OF FIBER GLASS SHINGLES

The above discussion on the nature of the asphalt shingle as a composite material allows its physical properties and performance characteristics to be analyzed using principles of materials science (or materials engineering). It is clear that, as with many other composite materials, all of the constituents have a role to play in the successful performance of the product. In considering cracking of fiber glass shingles, four components—the asphalt, the stabilizer, the reinforcement mat and the sealant—are involved.

To resist cracking, a shingle must have sufficient mechanical integrity or "toughness" to resist the stresses that are applied to it on the roof as a result of changes in temperature, movement of the underlying structure or movement (flutter) induced by wind. It is clear that these kinds of stresses are present on the roof and are generally similar from year to year (with the exception of severe strains in extreme storms, such as hurricanes).

So why do some shingles that have performed acceptably for several years fail by cracking or splitting? The answer is that the asphalt has become hardened and is no longer capable of resisting the roof stresses without cracking. Because all asphalts harden with age, why don't all shingles crack? The answer to this is that those shingles that do not crack are properly formulated with durable asphalts, appropriate loadings of mineral stabilizer, pliable sealants and built on sufficiently strong fiber glass mats that can carry the loads imposed on the roofing as the shingles age. These factors will now be discussed separately.

As emphasized earlier, the only component of the shingle whose properties change dramatically with age is the asphalt matrix. Some asphalts age-harden faster than others, and the rate of aging is definitely a factor in shingle cracking. For example, field studies have shown that even on roofs with badly cracked shingles, the worst damage is on south-facing decks. The north-facing slope of the same building with the same shingles often shows less damage and sometimes no damage at all. Obviously, the shingles on the south-facing slope have been exposed to more direct sunlight and have, on average, spent more time at higher temperatures than shingles on the north-facing slope. Thus, the shingles on the south-facing slope become more stiff and more brittle (i.e., have "aged" more) than those on the north-facing slope and, as a result, will be more likely to fail when subjected to stress—even if the same stress is experienced by the entire roof.

The asphalt cannot alone be blamed for the cracking failure of shingles. The aging of asphalt is a well-known phenomenon in the asphalt roofing and paving industries. Thin-film, dark-oven aging tests have been used for many years to study the behavior of different asphalts, by using heat to accelerate the natural aging process. Many millions of squares of shingles have obviously been made with asphalts that age-harden and yet perform very well. Better quality asphalts have hardened and embrittled at a slower rate and given better long-term performance even when exposed to higher service temperatures associated with south-facing roofs, poorly ventilated attics or insulated roof decks, etc. Asphalts that stiffen at a faster rate may require greater reinforcement to give satisfactory performance, and they may require more moderate filler loadings. There have clearly been factors other than asphalt involved in the cracking phenomenon.

As discussed in the "Mineral Stabilizers" section, fillers are essential to the successful performance of asphalt shingles, provided they are present in an appropriate amount. The addition of filler stiffens the asphalt against scuffing, etc.; adding more filler increases the stiffness (and brittleness) until, in the extreme, the mixture could behave like a low-strength Portland cement. Obviously, even the most pliable and age-resistant asphalt can be reduced to a hard, friable material if excessive amounts of filler are added. The reverse is also true; i.e., asphalt that is by nature harder and less pliable may provide acceptable performance in shingles if used at more moderate filler loadings. The rheology of the specific asphalt/filler combination must be studied and understood—especially as a function of aging (accelerated by dark-oven exposure)—as part of any effort to understand or predict the performance of shingles and their susceptibility to cracking.

Another common observation on cracked roofs is that shingles, or individual shingle tabs, that are unsealed (for whatever reason) are rarely cracked. It is obviously wrong to place blame entirely on the sealant for the cracking. The sealant simply provides the restraint at the lower edge of the tab, which is firmly restrained at the upper edge by the fasteners. If this restraint is not present at all, then lighter weight fiber glass shingles will be extremely susceptible to blow-off. Clearly, a restraint is essential, but the nature of the restraint—e.g., the strength and stiffness of the asphalt sealant—does influence the nature of the stress imposed on the shingle tab. Softer, more pliable asphalt sealants (like the shingle asphalt itself) are more desirable for long-term shingle performance.

A high-strength "aggressive" sealant that firmly bonds the shingle tab in place and allows no movement (stress relief) to the tab—especially at low temperatures—is generally much stronger than the tab itself. As a result, when an aged shingle is subjected to thermally or mechanically induced stresses, it will crack if its strength is less than that of the sealant bond. A pliable sealant that resists stiffening with age, or at low temperatures, provides a degree of stress relief against these forces, however, no practical amount of stress relief will prevent cracking in weak, lightweight shingles made with hard asphalt, a high filler loading and inadequate reinforcement.

What about the role of the reinforcement mat? As the backbone of the shingle, the mat is the primary load-carrying member when the shingle is stressed. Greater reinforcement is provided by mats with greater strength and toughness as measured by tensile strength, tear strength, flexibility, etc. Generally, the greater the weight of the mat, the greater its reinforcing potential in the shingle. The tensile strength, tear strength and fastener pull-through resistance of the shingle are all dominated by the tensile and tear characteristics of the mat. A greater mat weight will produce a shingle with greater resistance to cracking—all other things being equal—than a lighter weight mat.

With a pliable asphalt at moderate filler loading, it is possible to get acceptable shingle performance with lighter weight mats than are required for that same performance in a harder, more heavily filled asphalt. A measure of the toughness of a shingle is its tear strength as measured by the Elmendorf technique. The only physical performance requirement for fiber glass shingles in ASTM D 3462, "Specification for Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules," is the minimum tear strength of 1,700 grams measured on fresh shingles at room temperature. There are those who would argue that this *alone* is not a sufficient measure of shingle quality, and the authors agree.

As discussed previously, other factors, especially the pliability of the asphalt as a function of age, are important in determining cracking resistance. The tear resistance of fresh shingles is, nevertheless, a good indicator of the performance potential of the shingles. The authors are not aware of any significant performance problems—either from blow-off or from cracking—with shingles whose tear strength exceeds the D 3462 minimum.

Obviously, all of the components involved in shingle construction have a role in shingle performance, which is not surprising since that is the very nature of composite materials. Some minimum performance characteristics are required of each component and best-case/worst-case scenarios can be developed. The best case is a shingle made from a pliable, durable asphalt with the optimum loading of mineral stabilizer, reinforced by a strong heavyweight reinforcement mat, and sealed on the roof with a pliable, durable sealant. The worst case is a shingle made from hard asphalt (or one with rapid age-hardening characteristics) with high stabilizer loadings, weak lightweight reinforcement mat and sealed with a hard strong sealant. Frequently the cause of poor performance in shingles is shown to be a combination of factors relating to two or more of the components. Sometimes the cause is shown to be from a single factor, such as a high loading of stabilizer or a lightweight weak mat.

Since, by definition, cracking implies that the shingles are brittle (or are at temperatures where they become brittle; i.e., below the ductile/brittle transition temperature), it is critical that tests for cracking resistance should be performed at low temperatures and, ideally, on shingles that have aged naturally or have been artificially aged. The easiest tests to perform on brittle materials involve the bending of simple beams. Testing the bending flexibility of strips cut from old (or cold) shingle tabs are not only simple to perform, but are excellent indicators of resistance to cracking. A simple flex test is included in ASTM D 228, "Test Methods for Asphalt Roll Roofing, Cap Sheets and Shingles," which has been used on roll roofing for many years. This test is currently not part of any shingle standard, but is being recommended for inclusion in ASTM D 3462.

Major improvements are currently being made to ASTM standards for fiber glass shingles as a result of the concerns discussed previously, and as a result of the investigations and research performed by ARMA, the Western States Roofing Contractors Association (WSRCA), and others on the performance failures in roofing. The objective is to develop performance-related tests that will supplement the current tear test requirement with other criteria, such as fastener pull-through resistance, flexibility, tab uplift resistance and dark-oven accelerated aging. When these are in place, they will more specifically define shingle performance than current prescriptive standards. Once performance standards are developed, contractors and consumers will have the option to insist upon independent certification of compliance of the shingles to these standards. This would be similar to the present approach for fire and wind resistance.

IMPROVEMENTS IN WIND PERFORMANCE OF ASPHALT SHINGLES

Because asphalt shingles are an excellent material for helping to protect structures with steep-slope roofs from the elements, they are used on a variety of buildings in every part of the United States. Resistance to wind blow-off is one of the most important performance requirements of these shingles, and the generally good performance in this regard is one of the reasons for the success of asphalt shingles. The performance requirement is heightened in areas of the country where winds are more forceful, such as the high plains area of the western part of the United States, and coastal areas where wind forces can actually destroy entire buildings. The wind performance of asphalt shingles is especially important to building code groups located in these coastal and other high-wind areas. Building codes in these regions are usually designed to include the damaging nature of the wind and attempt to ensure that the basic parts of the shelter (the roof and the walls) will withstand high winds when they occur.

Shingle manufacturers have long been concerned with meeting customer requirements for products resistant to the damaging effects of wind. Early work in this regard involved the development of interlocking types of shingle designed so that the individual shingles are firmly locked together during application. This type of shingle is still widely used in the western and northern interior portions of the United States, and its resistance to higher than normal winds is well-known, especially for shingles with organic felt reinforcement.

Attempts to improve the wind resistance of three-tab shingles have been ongoing for many years. The self-sealing strip was designed to adhere the individual tabs and prevent them from lifting up and damaging the shingle during wind storms. This self-sealing aspect greatly improved the wind resistance of the shingle and was particularly important in the acceptance of fiber glass shingles. Recent work on self-sealing strips designed to address the performance problems of lightweight fiber glass shingles has included the use of additives in the sealant asphalt. These so-called modified sealants have provided for a faster tack and, in some cases, superior holding power. This advance in technology has not been without its drawbacks, because the increased holding power of the sealant may be a related factor in the cracking of fiber glass shingles.

Because the roofing industry has been sensitive to wind performance for quite some time, it has addressed the issue with ASTM standard D 3161—the standard test method for evaluating wind resistance of asphalt shingles—originally published in 1972. ASTM D 3161 is actually a version of a wind test that was developed at the National Bureau of Standards (NBS) in the late 1950s and implemented as an industry-accepted test method by Underwriters Laboratories (UL) in 1960. The test procedure examines shingles that blow off, or tabs that lift or crack, when test panels are subjected to the constant wind speed of 60 mph for a period of two hours. The shingle test panels themselves are constructed by applying the shingles in strict accordance with the manufacturer's instructions. The panels are then conditioned in a hot room at 135°F for 16 hours to allow for the self-sealing strip on the shingles to be activated.

Both the UL and the ASTM tests for wind resistance test the shingles at a constant wind speed of 60 mph. In the "real world," however, wind speeds do not remain constant, and the geometry of individual roofs create different effects based on the design of the structure itself. The effect of winds gusts, the relationship of uplift pressures to direct velocity and the nature of vortices created by roofing geometry are presently being addressed by work funded by ARMA. This further work on wind is designed to understand in detail the intricate nature of the effects that actually occur when wind impinges on a steep-sloped roof and is being done at Colorado State University. The ARMA project has three phases designed to answer these questions. Phases one and two have been completed, while phase three is in progress.

In phase one of the study, wind-tunnel testing of scale models of roofs was used to develop ideas on how the approach wind velocity was related to the velocities that actually occurred near the roof surface. This wind-tunnel testing also allowed the researchers to check where turbulence and peak wind gusts might be a significant factor in shingle performance. Mean roof velocity contour maps were developed to assist in determining particular areas of the roof to study. Shingle tab pressure differential with respect to wind velocity and wind approach angles was also studied. This helped to answer the questions of the mechanism of wind blow-off and to establish the effect of wind speed versus the uplift forces that develop as a result of the wind passing over the shingle. This phase one study helped in quantifying the effects of wind velocity and calculating the required tab uplift resistance.

In phase two of the Colorado State University work, additional wind testing was performed to check the results of the phase one work and to measure the effects of vertical protrusions, such as chimneys, skylights and dormers, on a roof. These vertical projections created vortex gusts that resulted in higher uplift pressures, and the effects of these gusts on shingle tab uplift were determined.

Phase three of this work will encompass the building of a full-scale test house on a turntable located near Fort Collins, Colo. This area of Colorado has regular wind speeds measured at 80 to 100 mph. The test house will be fully instrumented to take both velocity and uplift measurements. The turntable will allow the researchers to position the house at various angles to the prevailing wind, check the wind tunnel work (done in phase one and two), as well as take actual measurements of the effects of wind on a full-scale structure. The results may allow for the development of a design guide based on the uplift forces experienced by roofs as a function of wind speed, building and exposure conditions.

This scientific approach from the theoretical, to laboratory modeling, to full-scale confirmation is typical of the manufacturers' approach to problems that customers feel are important and require proper answers. It is a part of the continuing commitment to design products that meet the customer expectations for shingle performance.

The observed modes of failure of shingles under the action of wind include lifting (or bending over) of individual shingles or tabs of shingles, cracking of tabs after repeated flexing, tearing off of parts of shingles or entire tabs and blow-off of the entire shingle or of several shingles. Resistance to these kinds of damage is provided by three primary factors: 1) using the correct number, type and position of fasteners during application; 2) activation of the sealant by sufficient exposure to heat to develop the sealant bond strength; and 3) the physical properties of the shingle, especially its tear resistance, fastener pull-through resistance and pliability or stiffness.

The primary factor determining the success of shingle sealant activation is the heat of the sun, and a sufficient time and temperature is required to develop an adequate bond strength. The use of modified sealants reduces the time and the temperature required, but the most common incidences of shingle blow-off are observed with shingles that have not yet had sufficient time or heat to develop the desired bond, or where the bond has been unable to form because of dust, granules or improperly applied fasteners interfering with the action of the sealant.

While observations made following hurricanes give useful information on the failure modes of building materials, it is important to note that despite the successful performance of asphalt shingles in high wind conditions, building owners should not expect them to withstand the destructive forces associated with catastrophic wind events, such as experienced in hurricanes when the entire structure is destroyed. Fastener pull-through is the typical failure mode in shingles blown off in high winds—particularly those that have not yet sealed, or of sealed shingles that blow-off in sheets. In a study of the performance of roofing shingles during Hurricane Hugo, NRCA and researchers working in conjunction with Texas Tech University's Institute for Disaster Research reported that, with few exceptions, where shingles were blown off, the roofing nails remained in the deck. Similar observations have been made in southern Florida in the aftermath of Hurricane Andrew. A revision of the ASTM D 3462 fiber glass shingle standard to include a requirement for a minimum fastener pull-through resistance is currently being considered as part of the upgrading of the standard to recognize this important characteristic in relation to resistance to blow-off.

Obviously, resistance to damage from repeated lifting and flexing of shingles under the action of wind relate to the stiffness or pliability of the shingle, and improvements to ASTM D 3462 to include a pliability requirement are being proposed. The biggest improvements in resistance to blow-off will clearly come from improved attention to the manufacturers' instructions for correct application of the shingles and from improvements in sealants that activate faster and at lower temperatures.

Correct application of the shingles to the roof is a critical factor in providing proper wind resistance. Using the proper type and number, and the proper placement of fasteners, is critically important in keeping the shingles on the roof during a windstorm. Historically, the best type of fastener is a hot galvanized 11 or 12 gauge roofing nail with a minimum ⅜ inch head and a length that will penetrate the deck to a depth of ¾ inches or through it if the deck is thinner. This type of nail is easily driven into the wood decking and provides excellent resistance to wind forces.

Over the past few years, the use of staples to apply asphalt roofing has become popular because of speed of application and lower application cost. This compromise has resulted in more wind blow-offs—not necessarily because of less wind resistance of the staple itself, but because properly driving a staple into a shingle is more difficult than properly driving a roofing nail. This lead ARMA to establish a new position with regard to fastening shingles. ARMA states that "properly-driven and applied roofing nails are the preferred fastening system for all asphalt shingles."

WEIGHT/QUALITY PERCEPTIONS IN ASPHALT SHINGLES

Among many professional roofers, builders and architects, product weight has long been perceived as one of the most reliable measures of asphalt shingle quality. The conventional wisdom has been that the greater the product weight (lbs. per square), the better its quality. Unfortunately, data from shingle testing and observations from field performance have frequently shown that weight alone is not a sufficient indicator of shingle quality nor a good predictor of field performance.

The total weight is only one element of the performance equation. The weight and quality of the individual components of the composite structure—the reinforcement, the asphalt and the filler—are much better indicators of shingle performance. For example, the granules contribute more to shingle weight than any other component, yet their primary function is to protect the asphalt from the aging effects of ultraviolet light. The opacity of the granules is the critical performance factor, not their weight. There is a minimum weight of granules (of a given size) required to provide adequate coverage to protect the asphalt, but beyond this, the total granule weight has little effect on shingle performance. Coarse granular materials used as backsurfacing increase the total weight of the product by 50 to 75 lbs. per square with negligible, if any, effect on shingle performance.

By contrast, an increase in the weight of fiber glass mat reinforcement of as little as 0.2 lbs. per 100 sq. ft. has a dramatic effect on shingle performance because of its critical role as the backbone of the shingle. In fact, the reinforcement web, especially the mat in fiber glass shingles, is the only component whose weight directly relates to shingle performance.

There is also a minimum weight of asphalt required to provide the waterproofing integrity of the shingles; however, the quality of the asphalt, as measured by its resistance to embrittlement with age, is much more important than the total weight of asphalt. A heavyweight shingle made with a poor quality asphalt that ages rapidly does not perform as well as a standard weight shingle made with a high quality asphalt. Heavy (thick) unreinforced asphalt layers—even those with optimum stabilizer loading—are more susceptible to crazing than thinner layers with adequate reinforcement. The stabilizer (filler) used in the asphalt is a major contributor to shingle weight but, again, and perhaps more obviously than for the other components, adding more filler to increase product weight is not likely to improve shingle performance!

The quality of the individual raw materials and their optimum arrangement in the composite structure is a much better indicator of quality and performance of asphalt shingles than the total weight of the product.

CONCLUSIONS

Asphalt shingles provide excellent performance, together with a variety of appearances that are used to complement homes and commercial buildings. They also represent the best value in the steep-slope roofing marketplace for performing the vital function of protecting property. To make an asphalt shingle, one must understand the materials science involved in combining the critical components of the "composition shingle," so that the shingle will survive the thermal and mechanical stresses that ravage roofing materials. The shingle development process must include testing at low temperatures and after heat aging to assure satisfactory long-term performance.

The asphalt (body) must have appropriate composition and processing to be tough as well as pliable, especially as a function of age. The reinforcement (backbone) provides the web upon which shingles are built and must provide the foundation of the mechanical properties that determine shingle performance. The mineral stabilizer (filler) is key to stabilizing the asphalt, providing scuffing and weathering resistance, and must be used at "appropriate loadings" to be successful. The shingle sealant must be pliable enough to allow for movement to occur on the roof, yet aggressive enough to seal in a reasonable time and restrain the shingles in strong winds.

The mineral granules provide a variety of colors and appearances, as well as protection from the ultraviolet radiation from the sun. The backing material and release tape prevent the shingles from sticking together in the bundle, until they can be applied on the roof. All of these elements, as well as the other critical components of the shingle, must be properly designed and assembled to produce a shingle that will perform properly. The success of asphalt shingles over the past 100 years is testimony to the ability of the industry to understand and manufacture this complex composite.

The evolution of the asphalt shingle has involved improvements in components, in performance and in appearance. These improvements have allowed asphalt shingles to successfully satisfy the customers' requirements by providing the best value (i.e., performance/cost) of any steep-slope roofing material. In the "real world," owners have demanded roof coverings that provide the lowest cost protection for their buildings. The economics of this reality has had an effect throughout the supply channel from the contractor, through the distributor, to the manufacturer. In some cases, driven by these economic forces, the improper combination of the critical components has caused performance problems with asphalt shingles.

To be sure that asphalt shingles will perform, the purchaser must be convinced that the manufacturer understands the materials science involved, that the products meet the applicable performance standards and the purchaser must be to make the commitment to use quality shingles.

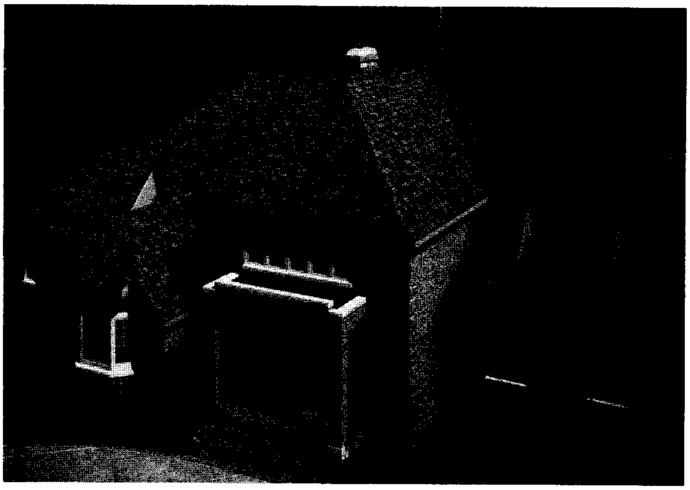

***Figure 1** Asphalt shingles come in a variety of styles from the standard three-tab shingle to the designer-type shingle based on multi-layered laminations. Dramatic color blends combined with various design patterns create the dimensional look found in natural slate and wood shakes.*

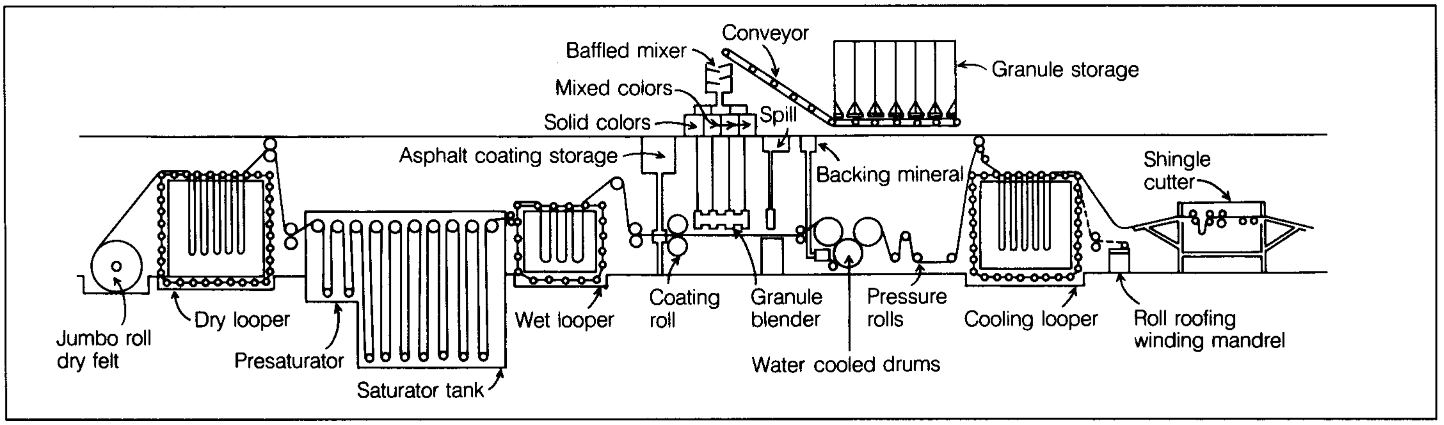

Figure 2 Representative flow diagram of roofing machine.

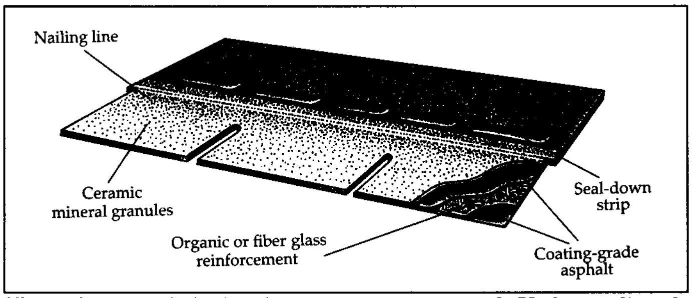

Figure 3 An asphalt shingle is a composite material. Understanding the materials science involved in blending these components is key to their performance.