RESEARCH AND PERFORMANCE EXPERIENCE OF ASPHALT SHINGLES

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Good performance is achievable through technology. Technology, on the other hand, is the product of research and performance experience. This paper recalls technical highlights of the 100-year history of asphalt shingles performance in the United States. It features examples of the 40-year cooperative research program between the National Bureau of Standards (NBS), now the National Institute of Standards and Technology (NIST), and the Asphalt Roofing Industry Bureau (ARIB), now the Asphalt Roofing Manufacturers Association (ARMA). This program has had a major influence on development of asphalt shingles in the United States through the 1970s. The research covered the components of shingles, including asphalts, base felts and surfacing granules.

The paper describes investigations into performance deficiencies and how the findings are incorporated into improved standards to enhance shingle durability and serviceability. The development of test methods for measuring uplift and impact resistance involving natural exposures and experimental wind and hail test devices exemplify the relevance of research to on-the-roof performance. The application of x-ray projection microscopy to view the interior of shingles provides a novel approach to identify latent defects produce by weathering.

The paper concludes that research and performance experience are essential contributors to address test method and product standards to assure acceptable performance.

KEYWORDS

American Society of Testing and Materials (ASTM), Asphalt Roofing Industry Bureau (ARIB), Asphalt Roofing Manufacturers Association (ARMA), asphalt shingles, consensus standards, criteria, deficiencies, National Bureau of Standards (NBS), National Institute of Standards and Technology (NIST), performance, requirements, research, technology, test methods.

INTRODUCTION

Research provides the technical basis for producing high quality standards. The 100-year history of asphalt shingles illustrates the importance of reliable technology in standard development and acceptable performance in service.

This paper highlights the 40-year history of the National Bureau of Standards (NBS)* and the Asphalt Roofing Industry Bureau (ARIB)** cooperative research program. It illustrates the role research plays in producing technology that impacts on the successful performance of asphalt shingle roofing.

ASPHALT SHINGLES

American Society of Testing and Materials (ASTM) defines asphalt shingles as small units of prepared roofing designed for installing with similar units in overlapping rows on inclines normally exceeding 25 percent.[1]

The National Roofing Contractors Association's (NRCA) 1991 Annual Market Survey[2] revealed that contracts for the application of asphalt shingles amounted to $2.73 billion or 64 percent of the $4.26 billion residential roofing market. Fibrous glass-based shingles accounted for 87 percent of the $2.73 billion portion.

Snoke,[3] a NBS researcher, reported that asphalt prepared roofing, the predecessor of asphalt shingles, was first marketed in the United States in 1893. The material consisted of an asphalt impregnated and coated organic felt. Four years later, in 1897, mineral surfacing was applied to the surface for additional weather protection. The first asphalt shingles, surfaced with slate granules, appeared in 1901 and came into general use about 1911. By 1939, 32 manufacturers produced over 11 million squares of shingles.

COMPOSITION

Asphalt Roofing Manufacturers Association (ARMA)[4] describes asphalt shingles as a composite of three essential components; felt, asphalt and surfacing granules. The performance of the shingles depends on the quality, quantity and compatibility of these components.

Organic Felts

Until the late 1920s, shingle reinforcing felts were made of cotton rags of varying quality. However, the increased cost of cotton rags in the 1920s precipitated more extensive use of substitute materials to produce felts. The question arose as to what effect this change might have on the performance of shingles? In 1926, the Asphalt Shingle and Research Institute*** established a research associate program at NBS to investigate the function of felt in asphalt shingle performance.

In 1929, NBS researchers[5] described the production and composition of 22 experimental felts containing various fibers and reported on the weathering qualities of shingles made from these felts. Strieter,[6] drawing on this early work, concluded that no significant difference in the weathering qualities of felts could be attributed to the kind of fibers used.

The asphalt shingle industry faced another crisis in 1941. World War II caused a rapid increase in the production of asphalt roofing for military construction. This, along with a

**Now the National Institute of Standards and Technology.*
***Now the Asphalt Roofing Manufacturers Association.*
****Predecessor of the Asphalt Roofing Industry Bureau.*

growing shortage of imported rags, generated a quest for substitutes. The industry, somewhat reluctantly, offered products made from defibrated wood produced by the recently introduced Asplund process.[7] However, the industry was concerned about the long-term effects wood fibers might have on the durability of shingles.

Consequently, in 1942, ARIB inaugurated a comprehensive outdoor exposure program at NBS to evaluate hard- and soft-wood fibers in combinations of up to 60 percent of dry felt weight. Members of ARIB's research committee and the NBS staff inspected the Washington D.C. exposures in 1948, 1954, 1958 and 1965. Greenfeld,[8] in describing the program, concluded that durable shingles could be made from organic felts irrespective of the type of the defibrated wood fibers used in concentrations up to 60 percent.

Fibrous Glass Felts

In the early 1950s, fibrous glass mats, impregnated with an asphalt, were employed as alternatives for the inorganic felts. Based on a NBS study, Cullen[9] reported acceptable performance of these products in built-up roofs.

In the early 1960s, one manufacturer introduced experimental, fiber glass base shingles. The product consisted of a two layer arrangement of thin fibrous glass mats impregnated and coated with a filled asphalt. Mineral granules provided the finish surfacing. These products met with only limited success. Nevertheless, they provided the basis for fibrous glass shingles of the future.

Research and development of glass reinforcement felts has been mostly proprietary. Richards[10] provides an excellent summary of the history and development of fibrous glass felt for use in roofing materials.

The weight and thickness of the glass felts are less than that of organic felt. Glass felts are considerably less susceptible to moisture absorption than organic felts. They also posses better fire resistant characteristics. On the negative side, Carlson[11] reported on complaints about the questionable performance of fibrous glass shingles by fracture, breakage and cracking.

Asphalt

Asphalt, a residual material produced in the oil-refining process, is another important shingle component. It is an extremely complex chemical compound. Each asphalt has unique physical and chemical characteristics that affects its behavior as a component of shingles. Simply stated, shingle quality depends largely on the quality of asphalts used in production.

In shingle production, organic felts are first impregnated with a soft flowable asphalt, called a saturant. The felts are then coated with harder, mineral filled, coating grade asphalt. Coating grade asphalts are used exclusively in manufacturing glass-based shingles for both impregnation and coating.

Asphalt is of extreme importance to weather resistance of shingles. Therefore, the effects of weathering on composition and durability of coating grade asphalt was the primary thrust of the research program. Some examples are of interest:

In the 1920s, Snoke and Strieter[12] developed an accelerated weathering test method to simulate effects of outdoor weathering on roofing asphalts. ASTM adopted these test procedures as their standard tests methods in 1933. The succeeding pioneering work for determining asphalt durability involving test method development, which employed various ultraviolet radiation sources, moisture and temperature effects, were defined to evaluate shingle performance. Further, test methods for sample preparation, exposure conditions, evaluation methods and interpretation of results were developed. This work provided the information on which numerous voluntary standards are established.

Coating-grade asphalt quality depends not only on its source but also on the quantity and characteristics of the mineral additives use as stabilizers. Consequently, another ARIB investigation studied the role of mineral stabilizers on the durability of asphalts. Greenfeld,[13] ARIB's research associate at NBS, concluded that shingle durability could be improved appreciably by the judicious incorporation of selected mineral additives. Particle size distribution of stabilizers and thorough mixing with asphalt also had a significant influence on durability.

For instance, in 1962 Greenfeld reported that concentrations of up to 60 percent of certain (not all) stabilizers resulted in a considerable increase in asphalt durability. Mica, crushed oyster shell, and blue-black slate appeared to be the most effective in increasing asphalt durability. Dolomite and fly ash were of less influence, and silica and clay, the least. The results indicated that minerals with plate-like particle shapes were the more effective in increasing durability.

SHINGLE PERFORMANCE

Clawing

In 1957, the shingle industry experienced an industry-wide performance problem of near epidemic proportions with the 210-pound, organic base shingles. Shingle tabs curled downward on weathering to the extent that roofs became unserviceable after two to four years exposure. The problem is known as clawing. For example, the cost associated with replacing shingles due to clawing at military installations resulted in the U.S. Defense Department requesting NBS assistance.

NBS conducted an extensive field and laboratory investigation to determine causes for clawing. ARIB's research committee members provided assistance to NBS in the investigation. Marshall and Ruegg,[14] provided details of the investigation and the economic benefits of the program to the nation.

NBS concluded that undersaturation of organic felts and insufficient back coating caused the clawing problem. Investigators identified the mechanism of failure as expansion and shrinkage of the shingles caused by alternate wetting and drying of the organic felt. The porous back coating accelerated this process by allowing moisture to penetrate to the felt.

NBS recommended increased felt saturation and heavier back coating to provide sufficient protection from moisture infiltration to eliminate clawing. NBS, along with ARIB, ASTM and Underwriters Laboratories (UL), cooperated toward the immediate revision of ASTM and UL shingle consensus standards. NBS's labors came to fruition with updated ASTM and UL standards by 1962.[15] In essence, a nominal 235-pound organic shingle replaced the 210-pound shingle by 1962.

X-Ray Point Projection Microscopy

The ability to see within asphalt products has been hampered by the opacity of these materials. Greenfeld applied point projection microscopy using soft x-rays, recently developed by NBS, to view the interior of asphalt products. The technique permits observance of variations within an asphalt roofing material as they occur upon undergoing natural or simulated weathering exposure.

In 1962, Greenfeld[16] provided a series of x-ray photographs illustrating interior views of several asphalt and coal-tar composites. He exemplified the technique using x-rays taken of the interior of an unexposed, 210-pound asphalt shingle and a weathered, 210-pound shingle that experienced clawing.

Figure 1 shows the value of this non-destructive technique to observe latent failures, even in newly manufactured shingles, such as adhesion of granules, saturation of felt and asphalt coating thicknesses.

Figure 2 corroborates the conclusions of clawed shingle investigation by illustrating an x-ray of the interior of a clawed shingle. It reveals the porosity of the shingle's back coating to allow moisture to penetrate to the felt causing deterioration of the under-saturated felt base.

Uplift Resistance

Self-Sealing asphalt shingles were introduced in the 1950s.

Manufacturers applied heat-sensitive adhesives to the back of shingle tabs to increase uplift resistance, a deficiency common to free-tab asphalt shingles.

The U.S. Defense Department asked NBS to undertake an investigation to determine the effectiveness of sealed tabs to provide additional protection from wind damage. In 1955, Cullen and Snoke[17] described a three phase program consisting of laboratory research, field observations and wind-resistance testing. Ten manufacturers provided samples of self-sealing shingles for the program. Characterization of the products included measuring the area and thickness of the self-sealing adhesives.

Researchers constructed an apparatus to measure adhesive bond-strength of sealants after conditioning at three service temperatures and after a water-soak. Table 1 gives the results of the bond-strength tests along with pertinent information on the sealing techniques. The measurements varied widely in area and thickness. Bond-strength values ranged from no adhesion to over 20 lbf after conditioning. The results indicated:

- Shingle tabs sealed after exposure to 140°F for 16 hours.
- Bond strengths increased with increased area and thickness of adhesive.
- Water soaking had no appreciable effect on bond strength once sealant had been activated.

NBS personnel made inspections of 40 self-sealing projects located in nine states. The areas represented warm, moderate and cold climates. Observations indicated that self-sealing shingles performed adequately on slopes of 2 to 6 in./ft. in all climates.

The third phase involved measuring uplift resistance of heat-activated, self-sealing systems using a storm test machine. The apparatus delivered a horizontal stream of air at controlled velocities up to a maximum of 60 mph.

Shingles applied to 4 ft. x 3 ft. test panels, on a 2 in./ft. slope, were conditioned for five hours at temperatures of 120°F, 140°F, and 160°F. Testing consisted of exposure to air velocities of 40, 50 and 60 mph each for two hours. Lifting of one or more tabs constituted failure. Table 2 provides the results of the uplift resistance tests using pass-fail criteria.

Cullen[18] reported these conclusions:

- The development of self-sealing shingles represented a major improvement in asphalt shingles by the industry.
- Test methods and criteria for the performance of self-sealing systems should be established. The criterion specified that shingles, conditioned for 16 hours at 140°F be required to withstand air velocities of 60 mph for 2 hours without uplift.

The project was completed in 1959. Following the program, UL established a standard test method and performance criteria for wind resistance of self-sealing shingles for labeling purposes.[19] ASTM published a tentative test method for wind-resistant asphalt shingles in 1972 based on the NBS research.[20]

Hail Resistance

In the 1960s, ARIB and NBS initiated a joint study on hail effects on asphalt roofing materials. Testing comprised shooting hailstones (ice spheres), up to 2 inches in diameter, from a compressed air, hail gun. Hailstones impacted shingles at controlled, free-fall terminal velocities of 60 to 75 mph. Indentations, granule loss and shingle fractures were observed after impact. In 1969, Greenfeld[21] described the program and offered these conclusion:

- Asphalt shingles have considerable hail resistance. However, as the size of the hail increases, a level of impact energy is reached at which damage occurs. This level lies in the range of 1½ to 2-in. diameter hailstones for asphalt shingles.
- Solidly supported areas of shingles tend to be the most resistant areas. For example, shingles with a 15 pound underlayment were less resistant than those with no underlayment.
- Weathering (aging) lowers the hail resistance of asphalt shingles.
- Shingles applied on 1 in. x 6 in. tongue and groove decks were more resistant than those on plywood decks. Those applied on ⅜ and ½-in. plywood decks performed equally well.
- Heavier shingles tend to be more resistant to hail damage.

Staples vs. Nails

In the early 1950s, hammer-applied staples were introduced as alternative fastening devices to replace roofing nails. The United States Federal Housing Authority (FHA) requested that NBS evaluate the performance of asphalt shingles applied with hammer-applied, ¾-in. staples.**** The investigation included observations of shingle roofs in nine states comparing stapling versus nailing. Holding power

*****Staples currently used are somewhat larger and pneumatically applied.*

retention, staple position, uplift experience, appearance and fastener corrosion were compared.

A test procedure, employing a tab peel back method, was designed to measure the fastener pull through resistance of asphalt shingles fastened to plywood substrates. Measurements compared performance using nails with that using ¾-in. staples. Tear resistance was determined with staples placed parallel, perpendicular and at a 45° angle to the base of the shingle. Table 3 gives the tear test results.

In 1955, Cullen and Snoke[22] reported on the project and offered the following conclusions:

- Field observations revealed that corrosion resistance, appearance and holding power retention of stapled shingles compared favorably with nailed shingles.
- Staples were more prone to be improperly placed than nails.
- The average tearing resistance of two staples ranged from 21 to 23 pounds regardless of parallel, horizontal or angle positioning.
- The average pull through resistance of two staples (22 pounds force) was approximately equal to one nail (21 pounds force).
- The pull through resistance of two nails was 37 pounds force.
- Winds of high intensity will damage stapled shingles more readily than nailed shingles if the same number of fasteners are used and tabs are not sealed.
- Six staples per shingle will give about the same resistance to tearing as four nails.

ASTM STANDARDS

Research conducted by the National Bureau of Standards (NBS), now NIST and the Asphalt Roofing Industry Bureau (ARIB), now ARMA provided major input to the development of several consensus shingle standards. The standards cover both product and test methods. Two ASTM standards define requirements for glass and organic base materials as follows:

- D225-89 Standard Specification for Asphalt Shingles (Organic Felt) Surfaced with Mineral Granules. Originally published in 1925.
- D3462-87 Standard Specification for Asphalt Shingles made from Glass Felt and Surfaced with Mineral Granules. Originally published in 1983.

One specification merely defines requirements for wind resistance, fire resistance, and loss and behavior on heating for Class A shingles:

- D3018-90 Standard Specification for Class A Asphalt Shingles Surfaced with Mineral Granules. Originally published in 1972.

The results of NIST and ARMA research efforts continue to be reflected in many test method standards. The following exemplify standard ASTM test procedures referenced in asphalt shingle product specifications:

- D228-90 Standard Test Methods for Asphalt Roll Roofing, Cap Sheets and Shingles. Originally published in 1925.
- D529-90 Test Method for Accelerated Weathering Test Conditions and Procedures for Bituminous Materials (Carbon-Arc Method). Originally published in 1939.
- D1669-89 Standard Practice for Preparation of Test Panels for Accelerated and Outdoor Weathering of Bituminous Materials. Originally published in 1959.
- D1670-90 Standard Test Method for Failure End Point in Accelerated and Outdoor Weathering of Bituminous Materials. Originally published in 1959.
- D1922-90 Standard Test Method for Propagation Tear Resistance of Plastic Films and thin sheetings by the Pendulum Method. Originally published in 1963.
- D3161-81 Standard Test Method of Wind Resistance for Asphalt Shingles. Originally published in 1972.

COMMENTARY

This paper highlights the 100-year history of research and standards development for asphalt shingles. It emphasizes the critical role that research played to create today's technology. It recalls examples taken from the 40-year NBS and ARIB programs that continue to have a major impact on the performance of asphalt shingles and the standards that define them.

ARMA continues to sponsor and conduct research to improve the performance of asphalt roofing products and upgrade current standards. For example, ARMA supports a comprehensive program at a major university to better understand wind forces and their effects on shingle roofing.[23] ARMA continues to sponsor in-house research to investigate such matters of concern as bond strength of seal-tab sealants, effectiveness of fasteners for shingles and overall performance. ARMA sponsors a program to produce performance requirements for asphalt shingles which, hopefully, in time will result in ASTM standards that reflect performance in service.

The National Roofing Contractors Association (NRCA) joined ARMA in conducting a program investigating shingle underlayments and their effect on shingle performance. This program will get underway in the spring of 1993.

Western States Roofing Contractors Association has undertaken a field and laboratory investigation of cracking problems with fibrous glass shingles that resulted in premature failures. The initial report[24] disclosed the failure of many marketed asphalt shingles to meet the minimum requirements of ASTM standards. It encourages the manufacturing segment to upgrade their material and production standards of fiberglass shingles to meet the requirements of ASTM current standards. It also recommends manufacturers label their products accordingly.

This study has prompted ARMA to implement a research program to develop data and information on performance-oriented tests and criteria to incorporate into ASTM standards.

The research programs described here provide ample evidence of how technology is used for producing high quality, serviceable products, as well as the technology to produce good quality standards and acceptable performance. It is now time for the roofing industry to apply judiciously this technology in the design, manufacturing and application processes commensurate with current technology. In summary, asphalt shingle performance excellence is achievable through technology.

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			Bond Strength, lbf, Conditioned @					
			120°F@ hrs.		140°F@ hrs.		160°F@ hrs.	
Sample #	Area in.^{2}	Thick. in.	5	16	5	16	5	16
1	1.5	.025	—	—	3.4	3.4	5.3	5.9
2	2.5	.015	7.2	8.8	13.9	14.8	19.3	11.4
3	2.5	.015	—	2.2	3.3	6.5	7.7	4.0
4	1.5	.008	—	—	—	2.8	2.9	3.8
5	3.0	.010	—	—	—	10.1	15.6	16.3
8	3.3	.040	10.3	10.3	11.2	13.4	13.6	15.0
9	3.5	.020	4.7	6.0	10.3	11.4	14.7	15.3
11	1.8	.025	3.7	4.9	12.0	+20.0	+20.0	+20.0
12	0.5	.012	—	—	1.3	3.1	6.4	6.2

Table 1 *Bond strength, self-sealing asphalt (organic) shingles (1959).*

Conditioned @→ / Sample #	16 hrs. @ 120°F Failed @	16 hrs. @ 140°F Failed @	16 hrs. @ 160°F Failed @
1	40 mph	60 mph	*Passed*
2	40 mph	*Passed*	—
3	50 mph	60 mph	*Passed*
4	50 mph	*Passed*	—
5	50 mph	*Passed*	—
8	*Passed*	—	—
9	*Passed*	—	—
10	40 mph	*Passed*	—
11	60 mph	*Passed*	—
12	30 mph	40 mph	*Passed*

Table 2 *Uplift resistance, self-sealing asphalt shingles (1959).*

Sample #	Staples Tear Resistance, lbf			Nails Tear Resistance, lbf	
	Position =	Position ⫫	Position /	One	Two
1	22.5	23.0	21.5	21.0	35.5
2	23.5	23.5	22.0	17.5	35.5
3	16.0	18.0	21.0	17.0	33.5
4	20.5	20.0	22.5	17.5	38.5
5	22.5	22.0	21.5	22.5	38.0
6	27.0	20.0	20.0	19.0	40.5
7	27.0	22.5	23.5	22.5	31.5
8	24.0	20.0	20.0	23.5	37.5
9	22.0	22.0	23.0	24.0	38.0
10	26.5	21.0	22.5	20.0	36
Avg.	21.2	21.0	21.8	20.5	36.5

Table 3 *Asphalt (organic) shingle tab pull resistance, hammer-applied staples vs. roofing nails (1956).*

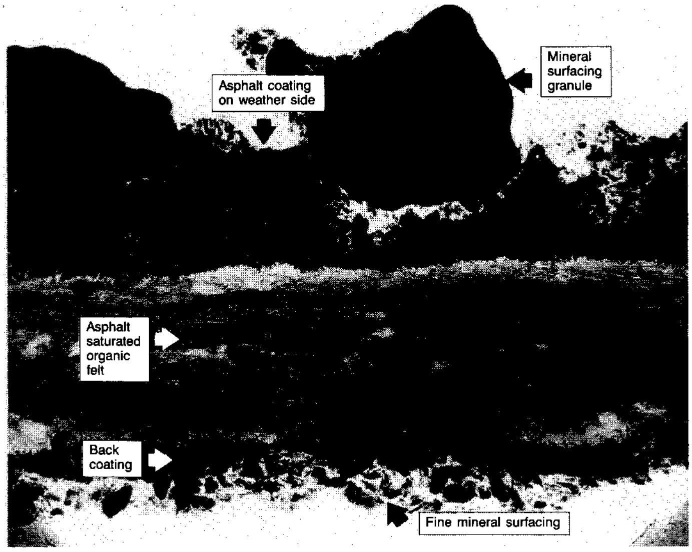

Figure 1 *This is an x-ray taken of the interior of an unexposed 210-pound asphalt shingle. The photo demonstrates the value of this non-destructive technique to observe latent failures in newly manufactured shingles, such as adhesion of granules, saturation of felt and asphalt coating thicknesses.*

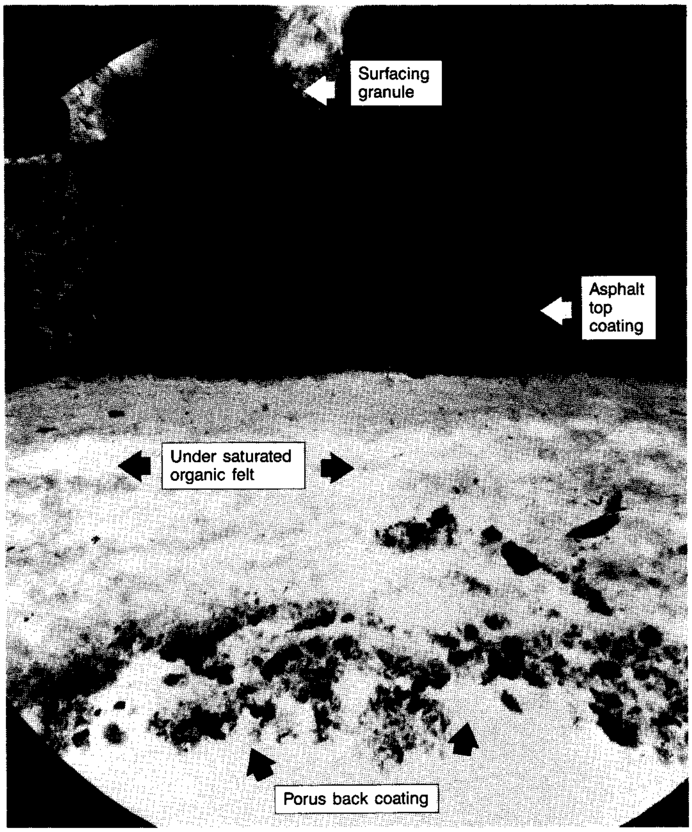

Figure 2 *In the case of a "clawed" shingle, the x-ray clearly shows moisture deterioration of the saturated felt base and the porosity of the shingle's back coating, which allows moisture to penetrate the felt.*