ASPHALT ROOFING SHINGLES

CARL G. CASH
Simpson Gumpertz & Heger Inc.
San Francisco, Calif.

This paper reviews the history of the asphalt roofing shingle industry, discusses the current major problems of glass fiber felt shingle splitting, and recommends marketing and technical challenges for future work.

KEYWORDS

Asphalt roofing, glass fiber felt shingles, organic-based shingles, self-sealing strip shingles and tee-lock design.

INTRODUCTION

This paper presents a short, selective review of the history of the asphalt shingle industry, including some of the major problems discovered, some of the difficulties overcome, and some of the current challenges to the industry. I[1] have arbitrarily selected the years prior to 1970 as "the past," and the years after 1970 as "the present." I then make technical and marketing recommendations for the future of this segment of the roofing industry.

THE PAST

Asphalt roofing shingles have been protecting our homes and other buildings since the end of the nineteenth century.

The first asphalt shingles were individual shingles that closely mimicked slate shingles and wood shakes. These rectangular shapes are still associated with roofing and siding. Figure 1[2] shows a wide-spaced American lay-up often used for its efficiency (192 ft^2 of material to cover one square—100 ft^2—of deck). Figure 2[3] shows one of the fanciful shapes developed.

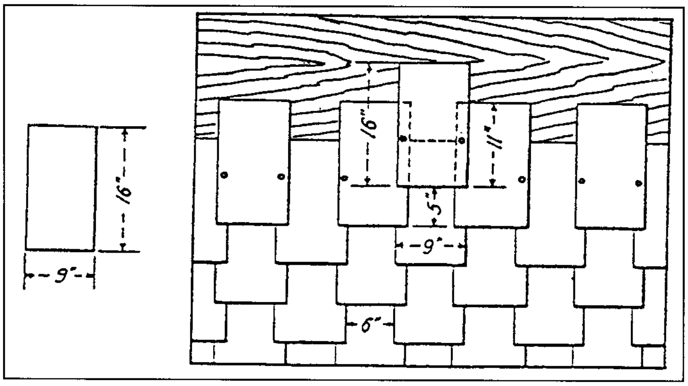


Figure 1.

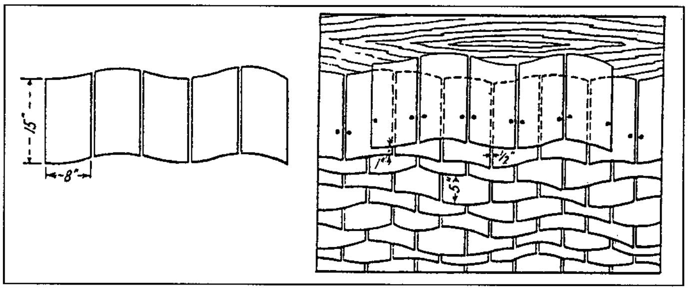


Figure 2.

Figures 3, 4, and 5[4] show some of the other shapes developed for individual shingles. All of these have a lock-down feature to hold down the bottom of the shingle.

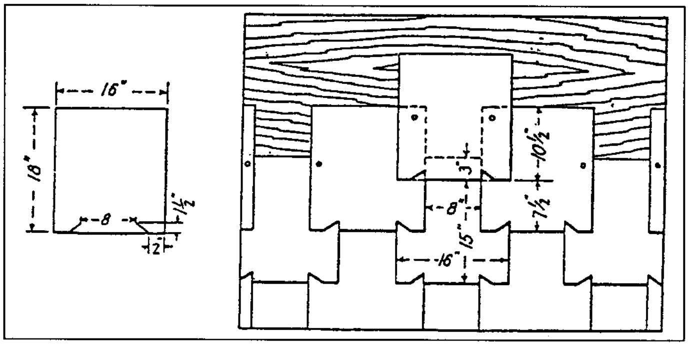


Figure 3.

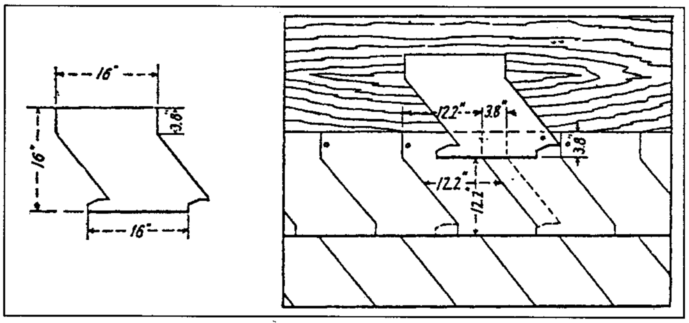


Figure 4.

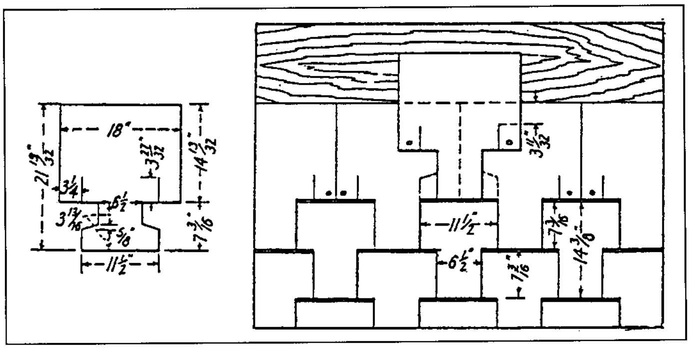


Figure 5.

Some variation of the "tee-lock" design is still being manufactured, while most of the other individual shingle designs, such as the hexagonal shapes in Figure 6,[5] are no longer produced.

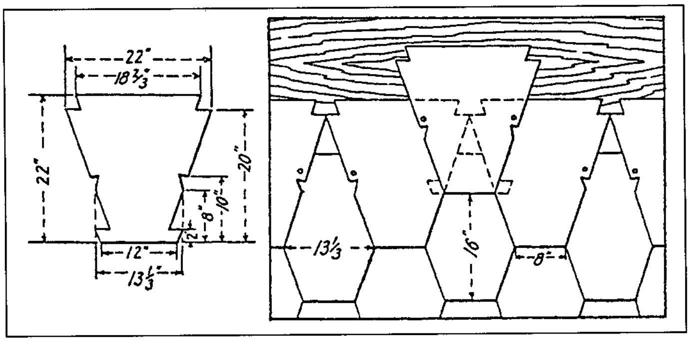
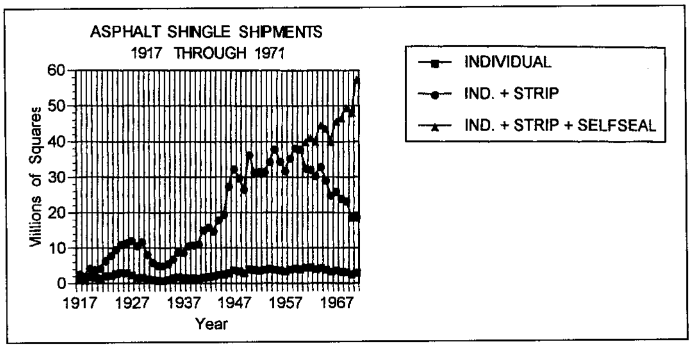


Figure 6.

Aside from the tee-lock shingles, used principally for reroofing, individual shingles are also produced for finishing the hips and ridges of roofs covered with other shingle styles. Approximately one to two million sales of squares (enough material to cover 100 ft^2 of deck) of individual shingles are shipped each year.

Graph 1[6] shows the individual shingle shipments from 1917 through 1971. Shortly after World War I, strip shingles (individual shingles joined together to make strips) started to dominate the market. After an 11 million sales of square peak in the 1920s, the market dipped in response to the Great Depression, then the total sales of squares shipped grew almost linearly to the end of the period.



Graph 1. *Asphalt shingle shipments, 1917 - 1971.*

Figure 7[7] shows a 10 x 36 inch, four-tab version of the strip shingle. This evolved into the 12 x 36 inch, three-tab strip shingle which is the most common strip shingle design. Figures 8 and 9[8] show some seldom seen, but creative strip shingle designs.

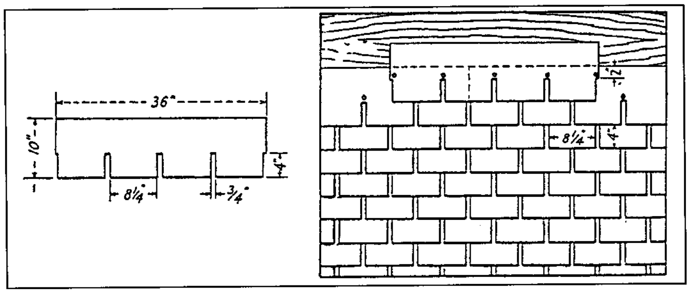


Figure 7.

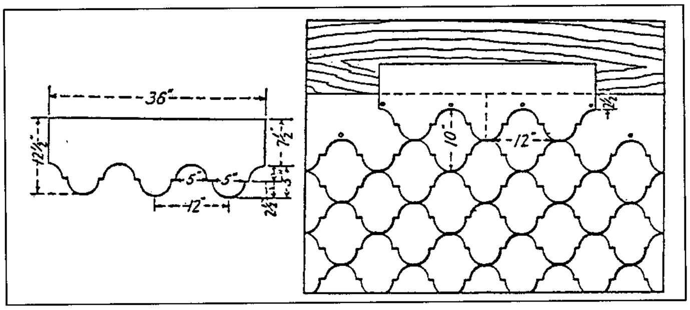


Figure 8.

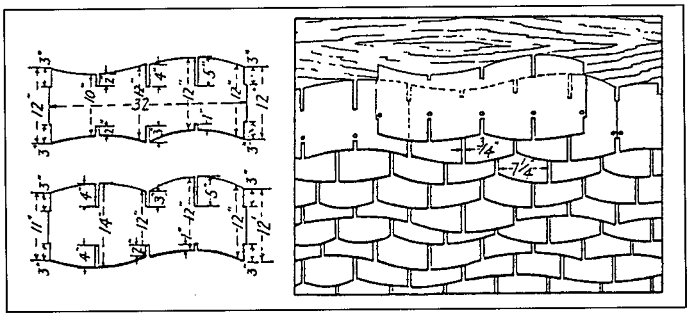
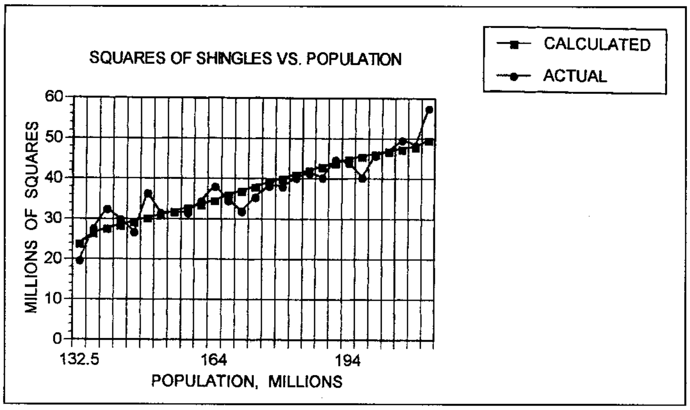


Figure 9.

In the late 1950s, self-sealing strip shingles were introduced. The volume of the plain strip shingles shipped dropped, as the market was taken over by the shingles with the self-sealing feature. As an interesting note, the total sales of squares of shingles shipped during each year is directly proportional to the population of the United States (Graph 2[9]). The linear regression coefficient for these data is a quite remarkable 0.93 (1.0 shows a perfect correlation). The "calculated" line in Graph 2 is the trend line.



***Graph 2.** Asphalt shingle shipments vs. population, 1937 - 1971.*

During these years of discovery and growth, there were many significant advances in product development and improvements in manufacturing methods. Indeed, the manufacturing at many plants became so efficient that the direct labor involved in production cost less than the kraft paper used to wrap the shingles. All of the major manufacturers developed research, manufacturing trouble shooting, and product development laboratories that trained personnel in the mysteries of asphalt and all the other components of the building products they manufactured, in addition to the research that was their primary function. These subjects are still not covered in any school's curriculum.

Do not presume that this growth was easy. It was not. At the time when people hoped to get 10,000 miles from a set of car tires, shingles were expected to last eight to 15 years. The granule surfacing fell off some of the shingles due sometimes to poor embedment and sometimes due to granule translucency. Holes were etched into some shingles just below the tab cutouts; this cutout "burn out" was due to insufficient asphalt coating on the part of the shingle under the cutouts.

Some shingles clawed (twisted into the shape of grasping talons) due to insufficient saturant in the organic felt and insufficient back coating to seal water out of the felt. Some shingles showed objectionable blotches or color patterning after they were installed due to asphalt staining or differences in the color caused by the reflection off the flat granules with different orientations.

Some of the relatively poor shingle performance was, and is, due to improper installation by unskilled installers such as college students and others that have little or no training in roofing, and who regard "flashing" as some kind of sexual aberration. Increases in the installation of shingles with staples rather than nails reduces the wind resistance of the roofing. The practice of "racking" or installing the shingles up the roof with alternating six-inch offsets, rather than the better practice of installing the shingles diagonally up the roof, can result in color blocking on the roof, and often results in missing the nails at the shingle corners covered by the racking lay-up.

In the early days of shingles with the self-sealing feature, some of the shingles never sealed because the sealant used was too hard, some of the shingles self-sealed themselves together in the bundle, making large flexible bricks, and some of the black sealants shattered all over the nice white shingles, leaving stains that were impossible to remove.

Many of these problems were solved by the dedicated work of individuals in the research laboratories and manufacturing plants. Some problems, such as the fungus or black staining that appears on shingles, have not yet been completely solved commercially. Zinc metal granules mixed with the normal ceramic-coated granule surfacing has been known for more than twenty years to prevent this problem, but "fungus resistant" shingles have only recently been aggressively marketed.

THE PRESENT

Currently, the National Roofing Contractors Association (NRCA) lists the following shingle styles: the individual shingle (mostly tee-lock designs—Figure 10), the strip shingles (with or without cutouts—Figure 11), and the laminated shingle (where an extra shingle thickness is laminated to a strip shingle—Figure 12).

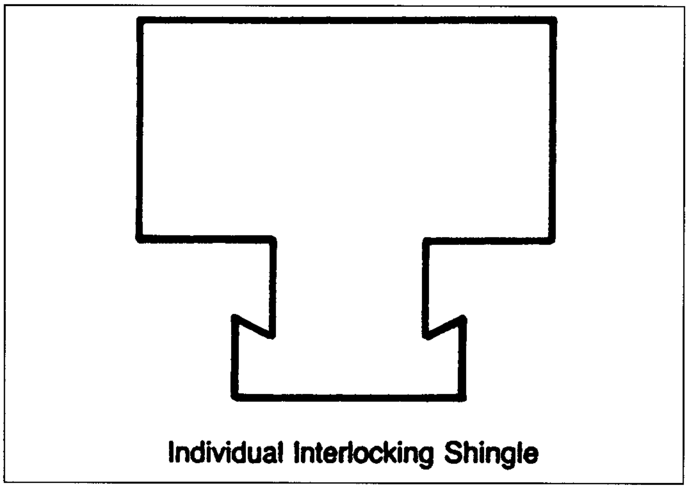


Figure 10.

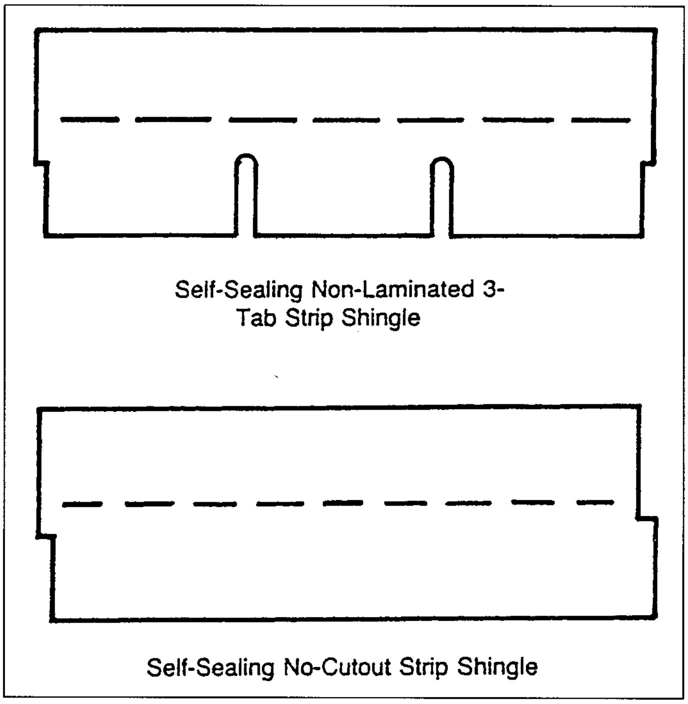


Figure 11.

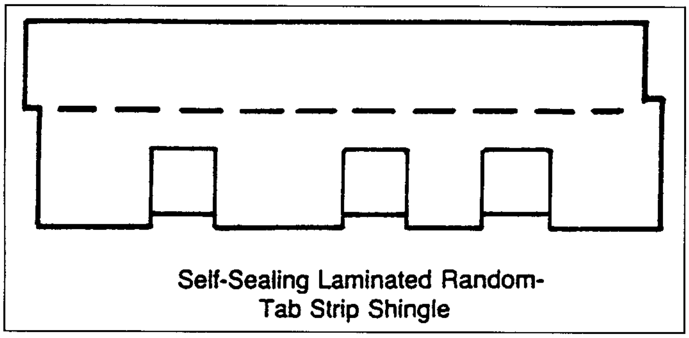
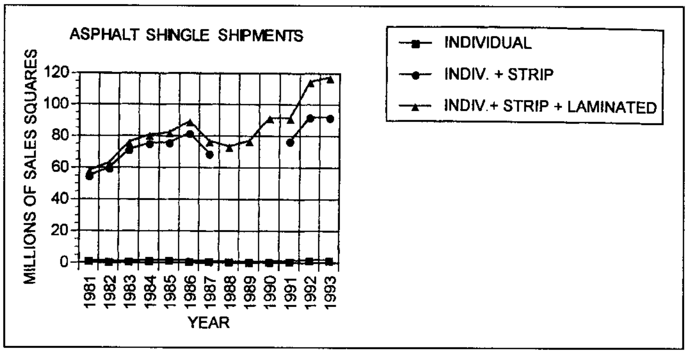


Figure 12.

Graph 3[10] shows the shipments of individual, individual plus strip, and individual plus strip plus laminated shingles. The individual shingles are a minor part of the market. The strip shingles have the majority of the market share (data for strip shingles was combined with laminated shingles during 1988, 1989 and 1990). Laminated shingles are a small, but growing part of the market.



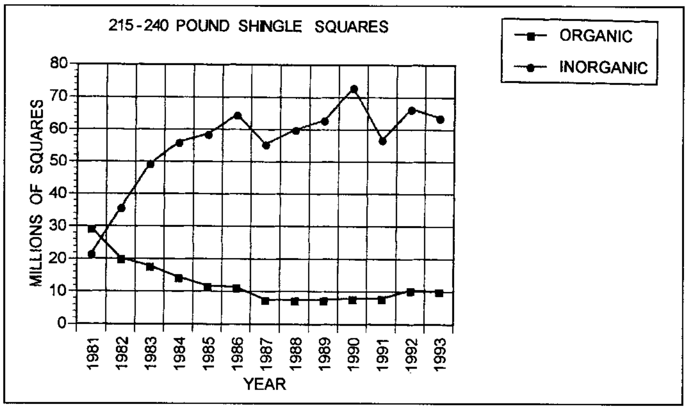
***Graph 3.** Asphalt shingle production, 1981 -1993.*

Before the introduction of the self-sealing feature, the shingles survived because the mass and stiffness of the organic felt-based shingle offered some protection against wind loss. Each organic felt-based shingle had the ability to adjust to movements of the deck and the shingle itself, much as the scales of a fish adjust to the fish's motion.

With the introduction of the self-sealing feature, the wind resistance of the shingles was greatly improved. Now, when the roof is blown off a building, I expect the roof structure to be displaced, with the shingles still in place. At the same time, the very securely sealed shingles must have enough strength to overcome the stresses induced into the now monolithic sheet with multiple stress concentration areas. Almost all of today's shingles are self-sealing.

The introduction of the self-sealing feature also permitted the use of glass fiber felts in shingles. The lack of natural fiber rags (rayon and other manmade fibers introduced during World War II can melt, and some ignite, in the asphalt saturator) was one of the principal reasons for the development of glass fiber felt shingles. Glass fiber-based asphalt shingles require the self-sealing feature in order to have some semblance of wind resistance. Graph 4[11] shows that of all 215- to 240-pound shingles, shipments of glass fiber felt-based shingles exceeded the organic-based shingles since 1982. In the 1990s, more than five times more of the less expensive glass fiber-based shingles were shipped than the organic-based shingles. At least part of the growth of the glass fiber-based shingle market is due to the increased use of shingles on condominiums and commercial structures that require a Class A fire rating. The glass fiber felt glass shingles' Class A fire rating results because the glass shingles, unlike their organic felt counterparts, contain saturant.

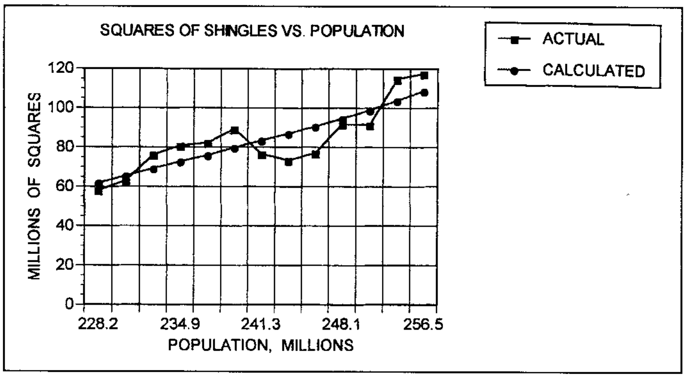
For the reader who is not familiar with the standard fire resistance tests, assemblies are listed as Class A (the most fire resistant—glass fiber-based shingles, aggregate surfaced built-up roofing, etc.), Class B (intermediate resistance), and Class C (lowest fire resistance—organic-based shingles). The ratings are based on the result of three arbitrary tests: burning brand, intermittent flame exposure and spread of flame. For details, consult the American Society for Testing and Materials (ASTM), Underwriters Laboratories (UL), or Factory Mutual (FM) publications.



***Graph 4.** 215 to 240 pound asphalt shingle production, 1981 - 1993.*

Graph 5[12] shows that population is still a major determinant of the sales of squares shipped. The slope of the trend line in Graph 2 is approximately ⅓ of a square per person per year. The slope of the trend line in Graph 5 is 1.7 squares per person per year.

These data sets are not directly comparable because the shipments in Graph 5 include Canadian shipments, not included in Graph 2 data. There is probably a real increase in the per capita shipment of shingles in recent years caused by bigger homes, and by the increased use of shingles on schools and other buildings that previously used low-sloped roofing.



***Graph 5.** Asphalt shingle production vs. population, 1981 - 1993.*

Table 1[13] lists the fourteen organizations, their addresses and telephone numbers, that currently manufacture shin-

Name and Address	Glass Fiber Shingle Plants	Organic Felt Shingle Plants
ATLAS ROOFING CORPORATION 802 Highway 19 North Suite 190 Meridian, MS 39307 601-484-8900	Hampton, GA Meridian, MS Franklin, OH Ardmore, OK Quakertown, PA Daingerfield, TX	Meridian, MS Franklin, OH Ardmore, OK Quakertown, PA
BIRD INCORPORATED 1077 Pleasant Street Norwood, MA 02062 617-551-0656	Norwood, MA	
BPCO 9510 St. Patrick La Salle, PQ H8R 1R9 Canada 514-364-0161		Edmonton, Alberta La Salle, Quebec
THE CELOTEX CORPORATION 4010 Boy Scout Boulevard Tampa, FL 33607-5750 813-873-1700	Brimingham, AL Camden, AR Fremont, CA Los Angeles, CA Goldsboro, NC Perth Amboy, NJ Cincinnati, OH Memphis, TN Houston, TX	Memphis, TN Perth Amboy, NJ
CERTAINTEED 570 E. Swedesford Road, Box 860 Valley Forge, PA 19482 610-341-7000	Shakopee, MN Oxford, NC Avery, OH	Shakopee, MN Avery, OH
ELK CORPORATION 14643 Dallas Parkway, Suite 1000 Dallas, TX 75240-8871 214-851-0400	Tuscaloosa, AL Shafter, CA Ennis, TX	
GAF MATERIALS CORPORATION 1361 Alps Road Wayne, NJ 07470 201-628-3000	Mobile, AL Fontana, CA Tampa, FL Savannah, GA Mt. Vernon, IN Millis, MA Baltimore, MD Minneapolis, MN Erie, PA Dallas, TX	
GLOBE BUILDING MATERIALS 2230 Indianapolis Boulevard Whiting, IN 46394 219-473-4500	Whiting, IN St. Paul, MN Chester, WV Lloydminster, Alberta Brantford, Ontario	
IKO CHICAGO, INC 6600 South Central Avenue Bedford Park, IL 60638 708-496-2800	Wilmington, DE Chicago, IL Franklin, OH Toronto, Ontario	Wilmington, DE Chicago, IL Calgary, Alberta Winnipeg, Manitoba Hawkesbury, Ontario Toronto, Ontario
MALARKEY ROOFING COMPANY 3131 North Columbia Boulevard Portland, OR 97217 503-283-1191	Portland, OR	Portland, OR
OWENS-CORNING FIBERGLAS Fiberglas Tower Toledo, OH 43659 419-248-8000	Compton, CA Denver, CO Jacksonville, FL Atlanta, GA Savannah, GA Waukegan, IL Brookville, IN Jessup, MD Minneapolis, MN Kearny, NJ Medina, OH Portland, OR Jackson, TN Memphis, TN Houston, TX Irving, TX	
PABCO ROOFING 1718 Thorne Road Tacoma, WA 98421 206-272-0374	Richmond, CA Tacoma, WA	
TAMKO ROOFING PRODUCTS, INC. 220 West Fourth Street Joplin, MO 64802 417-624-6644	Tuscaloosa, AL Phillipsburg, KS Fredrick, MD Joplin, MO	Fredrick, MD Joplin, MO
INTEC/PERMAGLAS Post Office Box 2845 Port Arthur, TX 77643 404-724-7024	Houston, TX	

Table 1. *Asphalt shingle manufacturers.*

gles in the United States and Canada. It also subdivides the 71 plants into the 60 plants that manufacture glass fiber-based shingles and the 24 locations that manufacture organic-based shingles.

Producers currently offer shingles with warranties that extend out a minimum of 20 years, despite the fact that few of these formulations have been in service for anywhere near the warranty term.

Prices for commodity shingles are similar to the prices charged in the 1970s. This has placed severe pressure on the manufacturers for "cost improvements," and may be responsible for the decimation of the industries' research facilities, and the consolidation and adjustments within the industry today.

It is sad, but true that for many of the ultimate customers who buy shingles, the choice is limited to the commodity shingles carried by the price-aggressive distributors. The homeowners buy based on the warranty term (which is highly questionable), price (which destructive competition has depressed), and availability (depending on the lowest cost paid by the distributor). If the homeowner elects to have a contractor install the shingles, I have been told by professional roofing contractors, it is not unusual that a contractor with marginal skills who is financed by the distributor will provide the lowest price, have the least amount of quality shingle choices to choose from, and have less than the skill required to install the shingles properly.

The principal materials problem today is the cracking or splitting of the glass fiber-based shingles. This cracking is more evident in colder climates, but it is not unknown in even the southern United States. It is known that cracking is associated with shingles which have poor tear resistance, and that many of the glass shingles manufactured do not comply with the minimal tear strength requirements of ASTM Standard D 3462. Weakness, such as poor tear strength, does not cause failure, it enables the failure to occur. Thus, some shingles with a low tear strength may not be firmly sealed to each other, or exposed to cold weather cycles.

All of the split shingles are firmly adhered to each other with the self-sealing adhesive. The self-seal feature makes the entire roof act as a unit, leading to unacceptable stress concentrations during cold weather cycles, rather than allowing the shingles to adjust positions, like scales protecting a fish.

The Asphalt Roofing Manufacturers Association (ARMA) is working on alternate test methods to try to predict which shingles will split, rather than rely on tear resistance. ARMA suggests that the initial tensile strength and the slope of the cycles to failure curve predicts performance. Data presented to date have yet to demonstrate this; far more data are needed. Currently, the tear test is still the best method to separate the shingles that will crack in service from shingles that will perform as advertised.

Some industry producers claim the tear test itself is invalid because it lacks precision, and the results obtained depend upon which of the two available pendulums for the test apparatus are used. Complaints are also raised because the tear resistance varies with the age of the product, and the degree of exposure.

The tear resistance of 17 new glass fiber-based shingles from various sources were tested. Strip shingles, laminated shingles, and two shingles made with modified asphalt were tested. The average tear resistance of 10 of the 17 shingles was less than the 1,700 gram minimum required by ASTM D 3462. The average estimated standard deviation for these data is 16 percent of the mean tear resistance; the estimated standard deviation of the mean (10 specimens were tested for each sample) is five percent of the mean tear resistance. Similar tests on organic felt-based shingles showed an estimated standard deviation, and an estimated standard deviation of the mean as five percent and two percent, respectively. Thus, the test itself is quite reproducible, and any excessive data variation is more than likely due to variation in the product.

Seven glass fiber-based shingles and one organic-based shingle from sample storage were tested with both the 3,200 gram and the 6,400 gram pendulums. These data (Table 2) show that there is no significant difference in the results obtained with either pendulum, nor is there a difference in the reproducibility of the test method.

A significant decline in the tear resistance of the shingles upon dry aging was observed. Table 3 shows the tear resistance of eight shingles tested shortly after they were received in the laboratory, the months of dry storage in the sample room, the tear resistance after dry aging, and the percent of the original tear resistance loss. The reason for this loss is unclear, but all the shingle tear resistances (except the organic felt based shingle) were reduced to less than 1,700 grams.

The tear resistance of many shingles from dry storage and shingles that had been exposed to the weather were tested. Significant losses in tear strength with increasing shingle age and increasing exposure severity was found.

In the northern hemisphere, glass fiber-based shingles facing south or west (Table 4) are more likely to have a lower tear strength and are more likely to split than shingles facing north or east. Note the very low tear strength values consistent with prolonged exposure.

Table 5 shows the analyses of some typical glass fiber shingles and an organic felt-based shingle. About the only factor that seems to relate to the tear resistance is the mass of the glass felt. Some contributory factors may be the percent of filler. Note that the actual percent filler found in the top coating is higher than the average percent of filler; it is sometimes higher than the 70 percent allowable in ASTM D 3462.

In 1993, a number of sample shingles were tested as part of an ASTM round robin test series. In addition to the round robin data, the shingles were analyzed and tear resistance tests run on all of the shingles with glass fiber felts. The linear regression equation and the actual paired data are shown in Graph 6. This suggests that a glass felt mass of more than 2 pounds per 100 square feet is required to develop an initial tear resistance greater than 1,700 grams.

Sample	Mean-3200g Pendulum	Mean-6400g Pendulum	Std. Dev. 3200g	Std. Dev. 6400g
A	1414	1402	283	295
B	1325	1414	250	189
C	1558	1523	238	245
D	970	986	169	151
E	1315	1401	149	113
F	1216	1408	250	165
G	1392	1728	276	343
H	2138	2221	248	253

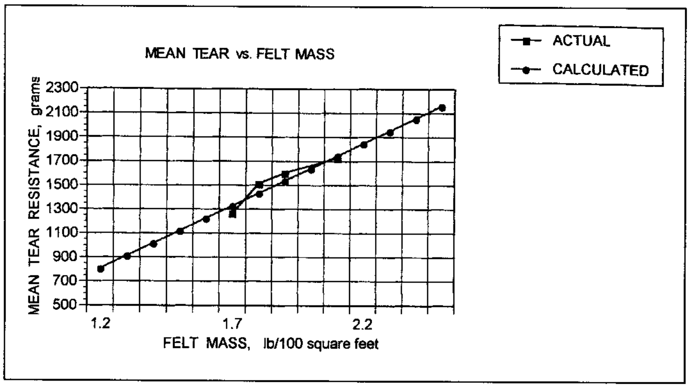
Table 2. Pendulum comparisons of tear strength, grams.

Sample	As Received Tear, grams	Dry Aging Months	Aged Tear, grams	Percent Tear Loss
A	2093	31	1414	32.4
B	1464	31	1325	9.5
C	1603	17	1558	2.8
D	1136	31	970	14.6
E	1581	34	1315	16.8
F	1485	31	1216	18.1
G	2131	34	1392	34.7
H	2339	17	2138	8.6

Table 3. Tear strength as received vs. dry aged shingles.

Exposure: Building Number	North	East	South	West
608	605	570	518	
622	756	509	470	
624	502	576	448	547
640	474	493	576	464
644	640	618	470	474
Grand Average:	596	553	497	495

Table 4. Asphalt glass fiber shingles, tear resistance, grams.

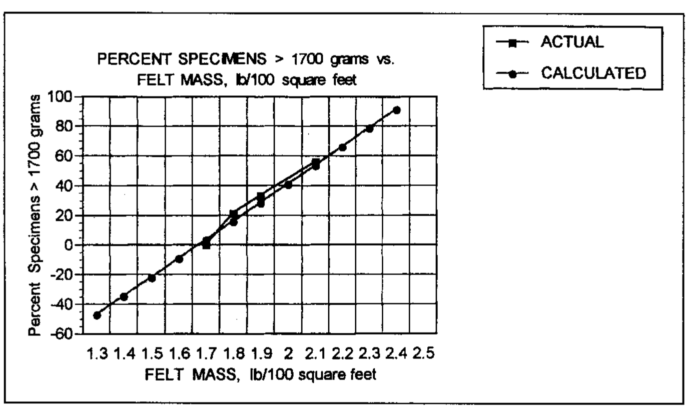


Graph 6. Mean tear resistance vs. glass felt mass.

Graph 7, where the percent of the specimens with a tear resistance greater than 1700 grams is plotted against the mass of the glass fiber felt, shows that a felt mass of greater than 2.4 pounds per 100 square feet is required to assure that all of the specimens have an initial tear resistance greater than 1700 grams.

Sample Designation: felt type:	A glass	B glass	C glass	D glass	E glass	F glass	G glass	H organic	ASTM D 225 organic	ASTM D 3462 glass
Analysis, lb/100 ft²										
Top surfacing	37.87	32.83	31.16	29.97	34.82	41.11	32.79	29.42	ˆ 18.5	ˆ 25
Top asphalt coating	9.65	6.32	5.65	11.03	12.45	13.25	8.48	7.34		
Top coating filler	16.01	14.69	14.75	14.73	16.54	16.94	20.17	14.19	II ˆ23	
Felt	1.90	1.68	1.85	1.94	1.84	1.94	2.33	11.40	ˆ 11	ˆ 1.35
Felt saturant	–	–	–	–	–	–	–	19.61		
% saturation	–	–	–	–	–	–	–	171	ˆ 165	
Felt asphalt coating	4.61	6.34	13.28	12.56	5.94	10.02	13.20	–		
Felt filler	5.54	5.63	13.03	22.42	26.26	15.09	14.54	–		
Back asphalt coating	1.45	1.53	0.31	0.64	2.54	3.71	1.50	16.99		
Back coating filler	2.65	7.21	5.32	1.16	0.0	4.30	3.59	6.22	II ˆ 3	
Back surfacing	0.98	3.14	2.55	1.65	0.83	1.71	4.25	8.42		
Total mass	89.58	79.37	77.90	96.09	101.22	108.08	99.85	117.13	ˆ 95	ˆ 70
Total coating asphalt	18,.85	14.19	19.24	24.23	20.93	26.98	23.18	13.56		ˆ 15
Mean % filler	61.37	66.07	65.83	61.26	67.16	57.38	62.30	60.08	\ 60	\ 70
Top coating % filler	62.40	69.93	72.59	57.18	57.05	56.12	70.40	65.91		
Felt coating % filler	54.58	47.03	49.54	64.09	81.55	60.09	52.42	–		
Back coating % filler	64.65	82.46	90.71	64.38	0.0	53.68	70.53	26.80		
Mean tear resistance, g	2093	1466	1558	1136	1580	1485	2130	2138		ˆ 1700
Fastener pull through, lb	49	53	–	22	43	36	51	–		ˆ 23

Table 5. *Asphalt shingle analyses.*



Graph 7. *Percent of specimens with a tear resistance of > 1700 grams vs. glass mass.*

CONCLUSIONS

The asphalt shingle industry has a long and illustrious history, overcoming a host of technical and manufacturing problems, to become one of the most efficient industries in the United States and Canada. But pricing pressures and low profits have driven corporate and industry restructuring, have decimated the research and product development departments, have hampered technological growth and education, and have "cost improved" many of the products until they no longer work.

The current shingle "splitting" problem of glass fiber felt based asphalt shingles is caused by a combination of poor and decaying tear resistance combined with very firm attachment by the self-sealing adhesive. Simple cold weather shrinkage provides the force needed to tear the shingles weakened by age, weathering, and perhaps "product cost improvements."

It is uncertain whether the aging of the shingles, the degree of weather exposure, or "product cost improvements" have the greater influence on the loss of tear resistance. Circumstantial evidence suggests that all are operational. I have no idea why the mechanism that causes the initial tear resistance of the shingles to decline so dramatically in protected storage. This should be a fruitful area for future research, if the funds for research are restored.

To decrease the incidence of shingle splitting, either reduce the strength of the self-sealing adhesive or increase the strength of the felt reinforcing. Going too far in decreasing the effectiveness of the adhesive is unacceptable, because it could lead to a dramatic increase in wind damage. Decreasing the sealant effectiveness so that it responds to all environmental conditions is probably beyond the current technology. Increasing the strength of the felt by increasing the mass of the felt is, perhaps, part of the answer.

In any event, the Elmendorf tear resistance test demonstrates that it is a sensitive, reproducible test that reveals changes in the shingles' tear resistance and toughness.

Prudence and the remarkable loss of tear strength of shingles in dry storage suggests the tear resistance requirements for ASTM D 3462 should be upgraded.

I do not presume that a higher tear resistance alone is the sole method of achieving shingles that do not self-destruct in service, but it is one of the major improvements that can be made at relatively low cost until all of the other parameters can be discovered.

Other areas of exploration might include reducing the filler content, changing fillers, using modified asphalts, and finding new felts for shingle construction. The one shingle made with SBS (styrene-butadiene-styrene) modified asphalt is very impressive in granule adhesion, flexibility, and tear resistance.

RECOMMENDATIONS

The following recommendations are based on my view of the asphalt shingle industry and research to date:

- Increase the investment in research and development to improve the current shingle products, to cure the glass fiber felt shingle splitting, and to develop the relationship between performance in the weather and performance in laboratory tests.

- Upgrade the requirements of ASTM D 3462 by increasing the minimum felt mass to 2.5 pounds per 100 square feet, and the minimum average shingle tear resistance to 2,000 grams.

- Do not provide any warranties on commodity shingles, or shingles that do not comply with the upgraded ASTM D 3462.

- Investigate the mechanism that causes the decline in the tear resistance with aging and weathering, and determine if it is consistent for all glass fiber-based products.

- Consider limiting the sales of glass fiber felt-based shingles to southern climates, if ways of strengthening the shingles and controlling excessive adhesion by the self-sealing feature are not achieved.

ACKNOWLEDGMENTS

Data used in this report was obtained from the Asphalt Roofing Manufacturers Association (ARMA), studies funded by CertainTeed Products Company, and the principals and associates of Simpson Gumpertz & Heger Inc.

The author was assisted in this study by the laboratory work of Arthur Davies, David Niles and Robert Sovie.

REFERENCES

1. Principal and vice president of Simpson, Gumpertz & Heger Inc., consulting engineers and building pathologists, Arlington, Mass., and San Francisco, Calif.
2. U.S. Patent 1145440 from Abraham, "Asphalt and Allied Substances."
3. U.S. Patent 1596680 from Abraham, op. cit.
4. U.S. Patents 1592015, 1657082 and 1441420, respectively from Abraham, op. cit.
5. U.S. Patent 1469041 from Abraham, op. cit.
6. Statistical Abstracts of the United States.
7. U.S. Patent 1150298 from Abraham, op. cit.
8. U.S. Design Patent 67565 and U.S. Patent 1688917 respectively, Abraham, op. cit.
9. Statistical Abstracts of the United States.
10. Asphalt Roofing Manufacturers Association (ARMA) data.
11. Asphalt Roofing Manufacturers Association (ARMA) data.
12. Asphalt Roofing Manufacturers Association (ARMA) data and Statistical Abstracts of the United States data.
13. Asphalt Roofing Manufacturers Association (ARMA) data.