FACTORS AFFECTING THE DURABILITY AND WIND RESISTANCE OF ASPHALT SHINGLES

by

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INTRODUCTION

Scope of Study

Asphalt shingles structurally are among the weakest of roofing materials. This inherent weakness must be compensated for by flexibility and toughness so if the shingle is bent it will not immediately break and/or tear.

The customary design of asphalt shingles in a tab-type manner leaves the lower part of the shingle exposed to resist the stresses of nature as a cantilever. This presents many problems, which it is evident from available loss experience data (Table 1), have not been solved satisfactorily to date.

The use of asphalt shingles is becoming more and more prevalent on farm buildings in Iowa, although they are not the predominant type of roofing material. Unless improvements are made in the quality of the asphalt shingles as well as in the application of them, the problem of wind damage will increase in seriousness as time goes on.

It is believed that specifications pertaining to wind-resisting qualities must be established and followed closely by manufacturers and applicators in order to lessen this waste to farmers and other users.

It is due to the increasing trend of the tremendous wind losses to farm building roofing materials that this basic research to determine the weaknesses of asphalt shingles in resisting wind was undertaken.

History of the Project

This study of factors affecting the durability and wind resistance of asphalt shingles has been carried out under an Iowa Agricultural Experiment Station project entitled "An Investigation of Farm Building Losses due to Wind and Fire". The project has been sponsored jointly by the Iowa Mutual Tornado Insurance Association and the Farmers Mutual Reinsurance Company since 1930, when the two companies requested such a study with the view of determining what types of wind and fire losses are most prevalent in Iowa and what can be done to minimize them through improved design of farm buildings, education of farm builders, more frequent inspections, and a more thorough continued maintenance program for the existing farm buildings.

The present study pertaining to roofing materials and particularly to asphalt shingles was undertaken because of the findings (Table 1) of previous statistical studies. Loss experiences of the Iowa Mutual Tornado Insurance Association were studied and field observations made. Also structural analyses and laboratory tests of many kinds have been carried out under this project with the view of improving the basic design of buildings so as to better withstand wind pressures.

Objectives of Study

The effective life of a farm building roof depends upon four main factors:

1. Basic quality of material
2. Manner of application
3. Exposure of roof
4. Probability of wind and hail damage

It was with these factors in mind that this investigation was undertaken. No one of the above may be said to be independent of the others, instead they are all dependent one on another and very much interrelated. Primarily this study was undertaken to determine to what extent the various ingredients of asphalt shingles (felts, bitumens, and minerals) contribute to the wind resisting qualities of the material. It was realized, however, in designing the experimental tests that various conditions of application (nail pattern, number of nails, and distance of nails from outer edge of shingle) could be studied simultaneously with the various types of shingles that were to be tested, without lessening the value of the data pertaining to composition of the shingles.

Therefore this study was initiated with the following specific objectives:

1. To determine to what extent the various ingredients of tab-type asphalt shingles contribute to the wind-resisting qualities of the material
2. To predict the behavior of asphalt shingles in winds when composed differently from those tested
3. To determine the advantage if any of six nails per strip shingle over four
4. To determine the effect of nailing distance from the lower edge on the bending resistance of asphalt shingles
5. To determine the effect of temperature on the wind-resisting characteristics of tab-type asphalt shingles
6. To determine the comparative wind-resisting ability of the three common types of tab-type asphalt shingles, namely, square-tab, thick-butt; square-tab, uniform thickness; and hex-tab shingles
7. To set up specifications for tab-type asphalt shingles pertaining to composition and application, that will assure the maximum amount of wind resistance

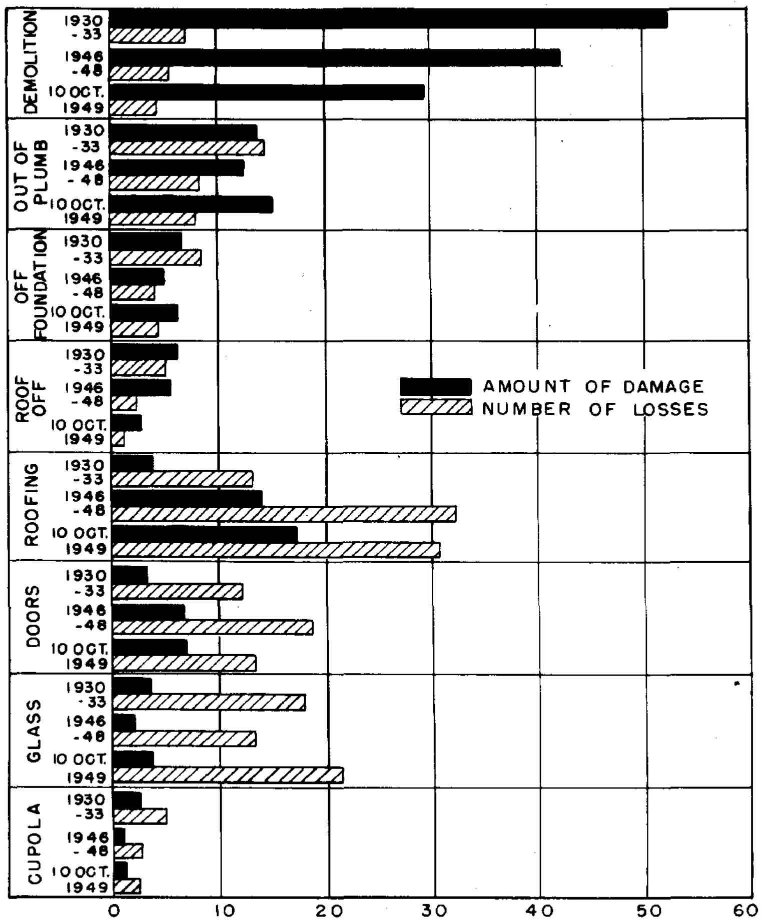
JUSTIFICATION

Wind Damage to Iowa Farm Building Roofing Materials

Wind damage to farm building roofing materials has steadily increased in the last twenty years in Iowa. As determined from Iowa Agricultural Experiment Station investigations and published in a technical paper by Esmay and Giese (4), damage to farm building roofing in the four years from 1930-33 amounted to only 3.8 per cent of all wind damage; whereas for the period 1946-48 it had increased to 14.1 per cent and accounted for approximately one out of every three losses. Fig. 1 shows graphically the percentage of wind damage to roofing materials on farm buildings as compared to other types of damage for the two periods mentioned above as well as for the single windstorm on October 10, 1949. Demolition or total loss of farm buildings by wind has continued to be the dominant type of loss in dollar damage and by per cent; however, on a percentage basis it has shown some decrease since the early 1930-33 period. This percentage reduction of demolition is not necessarily a dollar reduction, but is brought about on a percentage basis mainly by the large increase in roofing damage.

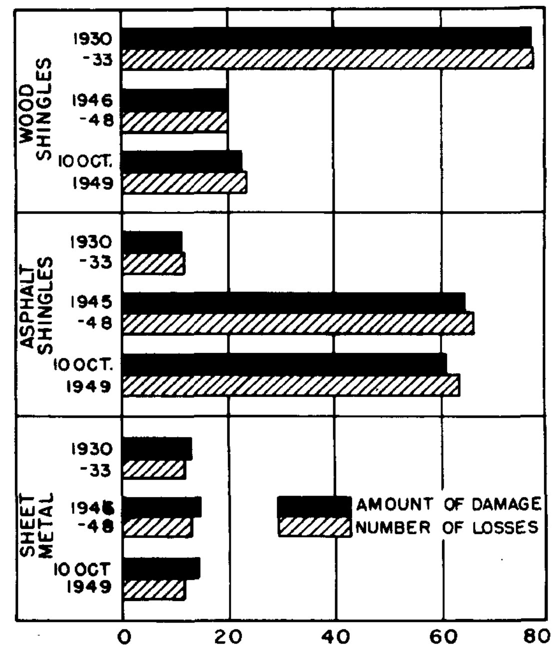
If the exact cause of failure were known in all cases of wind damage including the buildings which are demolished, "demolition" as a cause should not exist, because it is a result of some failure,not a cause. In such a case the damage which is here listed as demolition would be distributed among the other causes in some manner which could likely leave roofing damage as the dominant type.

In order to present somewhat more clearly the fact that increased roofing losses have accounted for the major change in wind damage trends since 1930, Fig. 2 was included. In this graph all types of wind damage to farm buildings were grouped into two categories. Demolition, out of plumb, off foundation, roof off, end or side out, and miscellaneous structural damage were designated as major structural failures. The remaining types of damage, including damage to roofing, doors, windows, etc. make up the second group called minor-type damages. These latter types of damage are not necessarily minor in total magnitude but are failures of a type which do not tend to cause the building to collapse. It may be noted on this graphical presentation that again wind damage in the major structural category, on a percentage basis, shows some decrease. This decrease is associated with a similar increase in the damage to the minor damage category of failures. In the minor damage category the roofing damage portion has been isolated by a differential shading of the



PERCENT OF TOTAL
IOWA FARM BUILDING DAMAGE BY ALL CAUSES EXCEPT HAIL

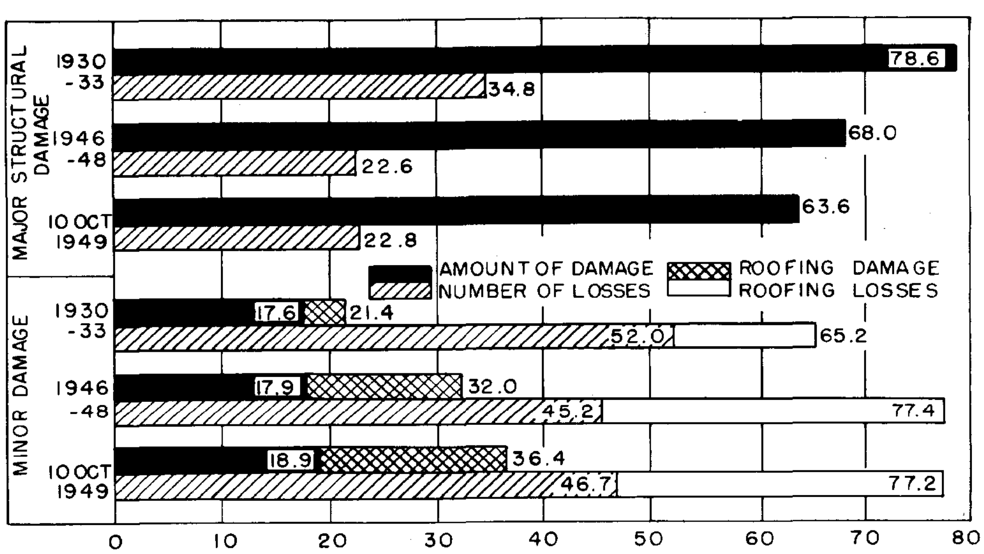
FIG. 1



PERCENT OF TOTAL ROOFING DAMAGE

WIND DAMAGE TO IOWA FARM BUILDING ROOFING

FIG. 3



PERCENT OF ALL DAMAGE EXCLUSIVE OF HAIL

MAJOR STRUCTURAL AND MINOR WIND DAMAGE TO IOWA FARM BUILDINGS

FIG. 2

bars of the graph. It is here very significant to note that minor damage exclusive of damage to roofing has continued almost on a level of approximately 18 per cent throughout the 20-year period and that damage to roofing has been responsible for practically all of the increase of the minor type classification. The percentage of number of minor type losses excluding roofing shows some decrease indicating that the roofing losses more than accounted for the increase in number.

When the increase in wind damage to farm building roofing materials was analyzed in more detail an interesting reversal of trend between damage to wood shingles and asphalt shingles was brought to light as indicated by Fig. 3. This graph shows that damage to wood shingles has reduced from about 80 per cent of all damage to roofing in 1930-33 to 20 per cent for October, 1949. In contrast to this percentage-wise reduction of damage to wood shingles, damage to asphalt shingles has increased proportionately. The damage to asphalt shingles has increased from 11.1 per cent of the total roofing damage in 1930-33 to 64.5 per cent in 1946-48, or nearly six times within twenty years.

Wind damage to roofing materials in Iowa as recorded from the loss experience of the Iowa Mutual Tornado Insurance Association is as shown in Table 1.

Table 1

Wind Damage to Iowa Farm Building Roofing (Hail Excluded)

		1930	1931	1932	1933	1946	1947	1948	Oct 10 1949
Wood shingles	D	5675	8624	783	7442	6212	15554	9794	50839
	N	324	592	66	849	333	671	330	2456
Asphalt shingles	D	223	709	88	2246	33026	55276	13487	137883
	N	19	42	5	207	1517	2288	614	6712
Sheet metal	D	771	1345	344	1243	5012	12267	5206	31647
	N	41	84	23	134	241	477	155	1257
Other types	D					538	242	1225	5088
	N					19	13	23	147
Total	D	6669	10678	1215	10931	44788	83339	29712	225457
	N	384	718	94	1190	2110	3449	1122	10572

D - damage in dollars
N - number of losses

The increasing trend of damage to asphalt shingles on Iowa farm buildings by wind was illustrated graphically by Fig. 4. The dollar damage to asphalt shingle roofing was very insignificant in the early 1930's due mainly to the fact that there was little of this type of roofing in use at that time, particularly on farm buildings. During 1946 and through the subsequent years shown the dollar damage came up to very large amounts. The number of losses occuring is also shown by year on this graph as represented by the shaded bars. The scale for number of losses is on the right

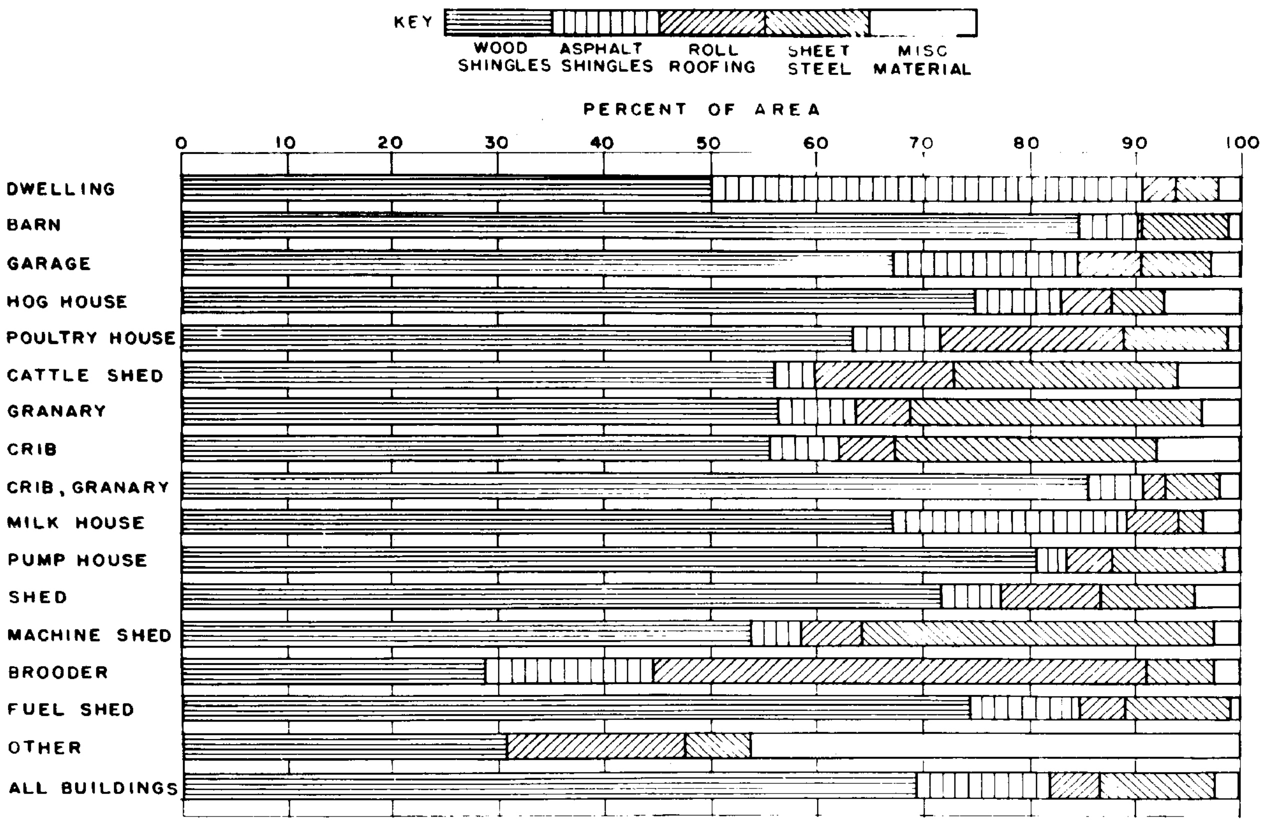


Fig 5. DISTRIBUTION OF ROOFING MATERIALS BY AREA ON IOWA FARM BUILDINGS

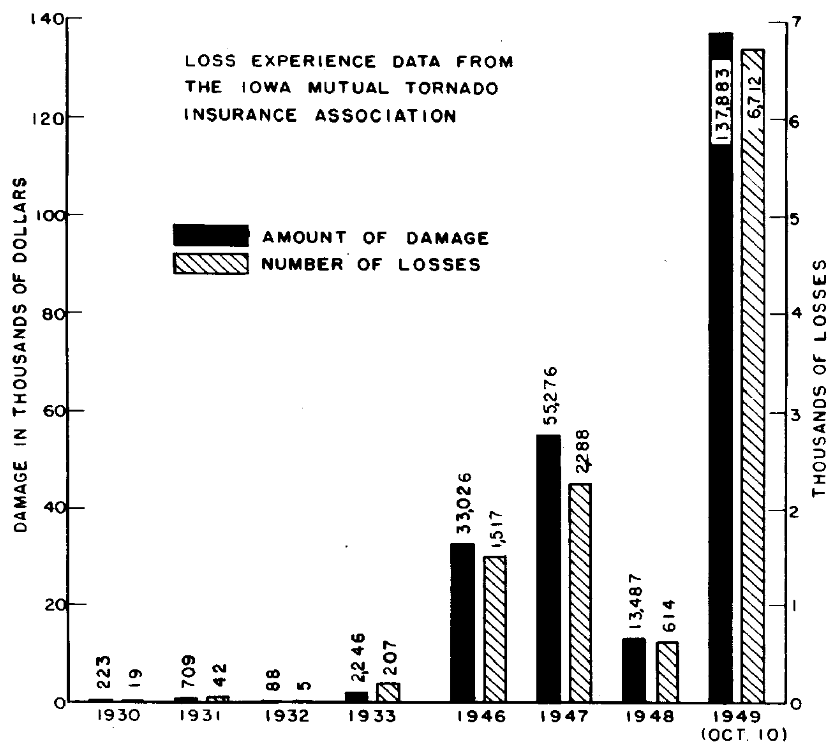


Fig. 4. WIND DAMAGE TO ASPHALT SHINGLES ON IOWA FARM BUILDINGS BY YEAR

side of the graph while that for dollar damage is on the left.

The damage to asphalt shingles by the windstorm on October 10, 1949 shows an increase of more than two and a half times over any of the previous total years shown. It might be argued that this was an extremely severe storm with only a fifty or a one hundred year expectancy; but in 1950, the very next year and within six months of the October storm, there was another general cyclonic type windstorm in the Midwest, which created even more damage to farm buildings, including roofing damage, than the previous one in 1949. In Iowa alone one insurance association, the Iowa Mutual Tornado Insurance Association, paid out approximately one and one-half million dollars for wind damage resulting from the October, 1949 storm and over twice that amount for a similar but more devastating storm in May, 1950. This Association's coverage was predominantly over farm buildings. A detailed breakdown on damage by cause was not available for this latter storm.

<u>Distribution of farm building roofing materials in Iowa</u>

It might be rationalized by some that this increase in damage to asphalt shingles on a percentage basis is only normal with the corresponding increase in the utilization of this type of roofing material on farm buildings during the post-war period. It is very true that the utilization of asphalt shingles on farm buildings has increased considerably since 1930 and is now the prevailing type of replacement roofing material. However, a survey made by Cleveland (2) in 1949 for the Iowa Agricultural Experiment Station found that at that time only one-eighth of the area of all farm building roofing in Iowa was asphalt shingles. Fig. 5 shows graphically the distribution of roofing materials on farm buildings in Iowa by per cent of area for each of the common types of farm buildings. Table 2 shows the exact percentage figures for the same roofing distribution.

The bottom bar on Fig. 5 represents the overall percentage distribution of roofing materials on all farm buildings in Iowa. From it, it is noticed that wood shingles are still the dominant type, accounting for 69.2 per cent of all the roofing area. Asphalt shingles accounted for 12.3 per cent, roll roofing 4.8 per cent, sheet steel 10.9 per cent and the balance of 2.8 per cent was accounted for by miscellaneous types such as wood slats, aluminum and asbestos.

It is noticed from Fig. 5 that the distribution of roofing materials on the farm dwellings and barns was quite different. The dwelling had only a 50 per cent coverage of wood shingles with slightly over 40 per cent by area of asphalt shingles; whereas, the barn had nearly 85 per cent coverage of wood shingles with only 5 or 6 per cent by area of asphalt shingles. These figures indicate that the dwelling has accounted for a good deal of all the asphalt shingles

Table 2

Distribution of Roofing Materials by Area
on Iowa Farm Buildings - 1949

Roofing		1 Dwelling %	cum.	2 Barn %	cum.	3 Garage %	cum.	4 Hog house %	cum.
Wood	1	50.0		84.7		67.2		74.9	
Asphalt shingles	2	40.6	90.6	5.5	90.2	17.2	84.4	7.9	82.8
Roll	3	3.3	93.9	0.4	90.6	6.0	90.4	4.9	87.7
Steel	4	3.9	97.8	8.1	98.7	6.8	97.2	5.1	92.8
Asbestos	5	2.2	100.0	--	98.7	1.2	98.4	--	--
Alum.	6	--		1.3	100.0	1.3	99.7	0.7	93.5
Tile	7	--		--	--	--		--	--
Slats	8	--		--	--	0.3	100.0	6.5	100.0

Roofing		5 Poultry house %	cum.	6 Cattle shed %	cum.	7 Granary %	cum.	8 Crib %	cum.
Wood	1	63.3		56.0		56.4		55.7	
Asphalt	2	8.4	71.7	3.9	59.9	7.3	63.7	6.4	62.1
Roll	3	17.0	88.7	13.0	72.9	5.1	68.8	5.2	67.3
Steel	4	10.1	98.8	21.1	94.0	27.5	96.3	24.8	92.1
Asbestos	5	0.2	99.0	--	--	--	--	--	--
Alum.	6	0.6	99.6	--	--	2.5	98.8	1.4	93.5
Tile	7	--	--	--	--	--	--	--	--
Slats		0.4	100.0	6.0	100.0	1.2	100.0	6.5	100.0

Roofing		9 Crib & Granary %	cum.	11 Milk house %	cum.	12 Pump house %	cum.	14 Shed %	cum.
Wood	1	85.5		67.1		80.6		71.6	
Asphalt	2	5.3	90.8	22.0	89.1	2.9	83.5	5.8	77.4
Roll	3	2.1	92.9	4.9	94.0	4.3	87.8	9.1	86.5
Steel	4	5.2	98.1	2.4	96.4	10.8	98.6	9.2	95.7
Asbestos	5	1.2	99.3	1.2	97.6	--	--	--	--
Alum.	6	0.7	100.0	1.2	98.8	--	--	0.8	96.5
Tile	7	--		--		--	--	--	--
Slats	8	--		1.2	100.0	1.4	100.0	3.5	100.0

(Continued on next page)

Table 2 (Cont'd)

Roofing		15 Machine house %	cum.	16 Brooder house %	cum.	17 Fuel house %	cum.	33 Other %	cum.	34 All bldgs
Wood	1	53.6		28.7		74.5		30.8		69.2
Asphalt	2	5.0	58.6	16.0	44.7	10.4	84.9	--	30.8	12.3
Roll	3	2.8	61.4	46.3	91.0	4.1	89.0	16.9	47.7	4.8
Steel	4	36.2	97.6	6.6	97.6	10.1	99.1	6.2	53.9	10.9
Asbestos	5	--	--	--	--	--	--	--	--	0.4
Alum.	6	0.7	98.3	1.1	98.7	0.9	100.0	41.5	95.4	1.0
Tile	7	--	--	--	--	--	--	--	--	
Slats	8	1.7	100.0	1.3	100.0	--	--	416	100.0	1.4

Data taken from Cleveland's survey

utilized on the farm buildings. No other farm building shows a comparable percentage of asphalt shingle coverage. The garage and brooder house both show a per cent some higher than average but they are both comparatively small buildings. The dwelling roof is replaced sooner than any of the other farm building roofs. Consequently, since World War II a great deal of asphalt shingle roofing has been utilized for this purpose; because of its fire resistance, attractiveness, ease of application, availability and low first cost.

Probability of damage

The previously presented data indicates that the probability of wind damage to asphalt shingles is much higher than for wood shingles. Fig. 5 showed 69.2 per cent of the roofing area to be wood shingles as compared to 12.3 per cent asphalt shingles, or stating it in another way, the ratio of wood shingles to asphalt was 5.62 to 1. The damage to roofing materials as set forth in Table 1 and Fig. 3 on a percentage basis for 1946-48 was 20 per cent accountable for by wood shingles and 64.5 per cent by asphalt shingles. The damage to wood shingles as compared to asphalt was then in a ratio of .310 to 1. It is noted then by proportion that 5.62 is to .310 as 18.1 is to 1. This indicates that on a weighted basis, area for area, the probability of wind damage to asphalt shingle roofing on Iowa farm buildings is about 18 times greater than for damage to wood shingle roofing. This probability does not bring into account the fact that the existing wood shingle roofs during the period of 1946-48 were considerably older than the asphalt shingle roofs and that reporting errors favored the asphalt shingles.

This emphasizes that if all farm building roofing were of asphalt shingles of the present condition and wind-resisting capability the problem of wind damage to roofing would be one of major proportions.

Field Observations of Wind Damaged Asphalt Shingles

On May 5, 1950 the author had occasion to get out with a camera during the severe windstorm of that date and catch some action shots of asphalt shingles blowing up. Detail studies were not made of each roof observed as to age and type of shingle; however, it is believed the pictures will serve to bring out a few points. Figures 6 and 7 are pictures of comparatively new houses, post-war houses at least, showing shingles blowing up in a pretty uniform pattern. Near the ridge appears to be critical areas on both houses, as well as adjacent to each of the dormers. The air is no doubt at its highest velocity as it goes over the ridge and when swirling around the dormers, thereby creating the most suction or negative pressure on the roofing material at those points.

Fig. 8 shows the asphalt shingles blowing up in general

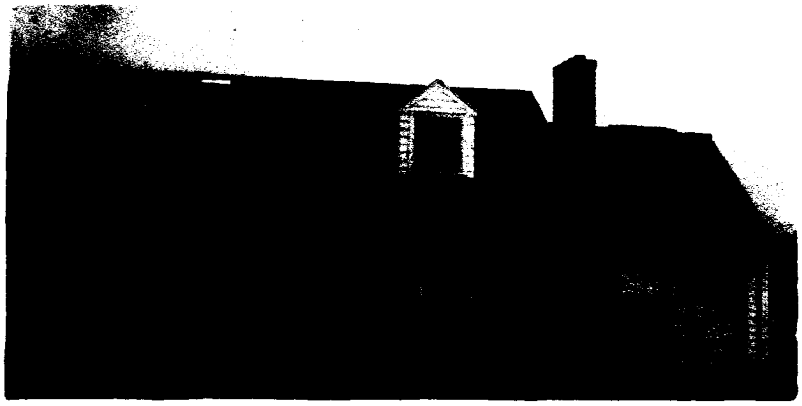


Fig. 6. New Asphalt Shingles Blowing up on Ridge and around Dormers

Fig. 7. New Asphalt Shingles Blowing up in a Uniform Pattern Similar to the One Above

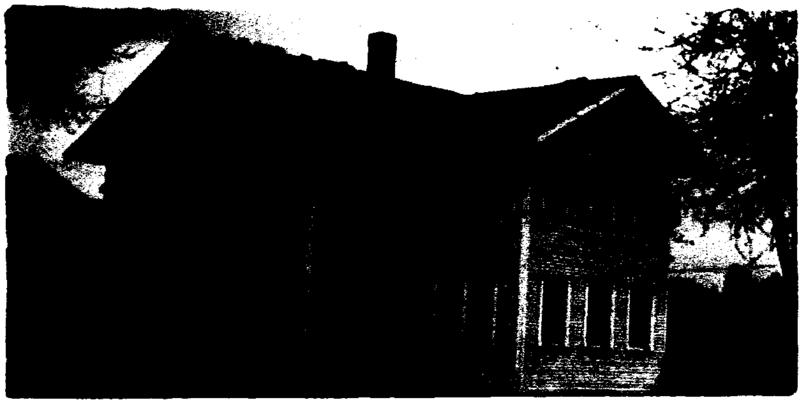


Fig. 8. Thick-butt Shingles which were Nailed too High Blowing up

all over the dwelling roof. The author talked to the owner of this house and the owner stated that he had applied the shingles himself, and went on to say without further quizzing that he couldn't figure out why they should blow up, because he had been particularly cautious in applying them. He said that he put the nails good and high so they wouldn't be exposed to the weather. It can be observed from the picture that long portions of the shingles are sticking up in the air bearing out the statement of the owner pertaining to the high nailing. Improper nailing, allowing the shingles to be bent up easily, no doubt accounted for the severe blowing up.

Fig. 9 shows a hex-tab asphalt shingle roof being blown up quite severely, also on May 5, 1950. Nearly all of the shingles on the high velocity end of the roof appeared to have insufficient bending resistance to withstand the stresses on that date. The most severe blowing up was along the gable end where the wind got under the shingles to some extent. Fig. 10 is closeup of the same roof showing how after bending so long, the shingles break off on a line generally along the top line of the cut-outs. The nailing on this roof appears to be adequate according to recommended specifications.

Fig. 11 shows the square-tab asphalt shingles on a new machine shed being blown up on May 5, 1950. Although these shingles were only observed from the ground and the owner

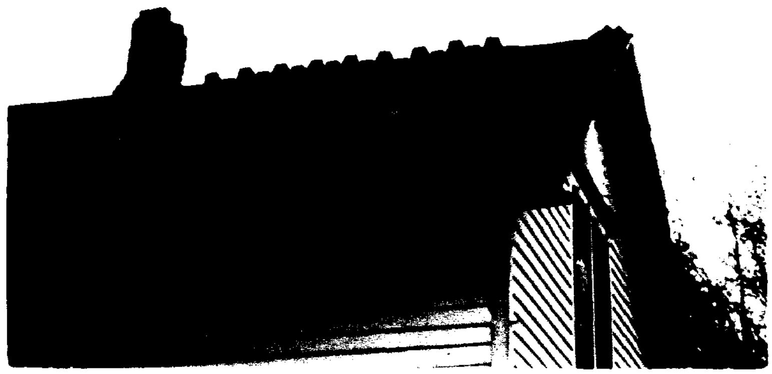


Fig. 9. Hex-tab Asphalt Shingles Blowing up over a Large Area of the Roof

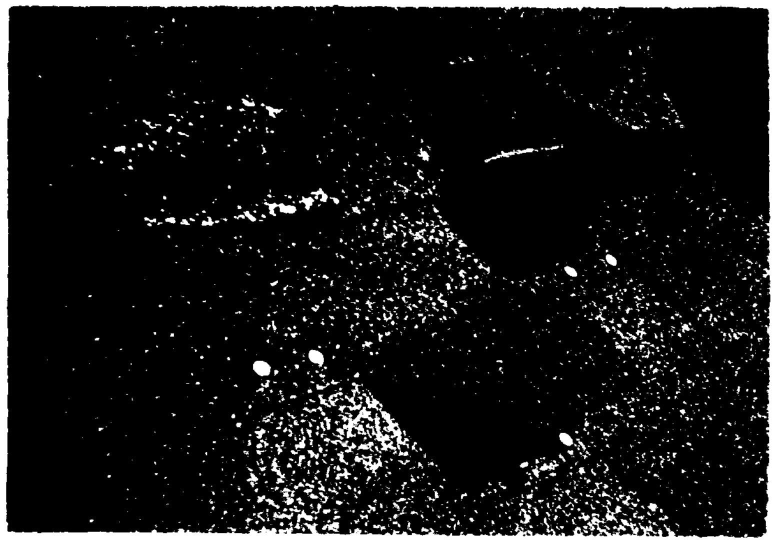


Fig. 10. A Close-up of the Above Roof Showing how after Continued Flapping the Shingles Broke Off

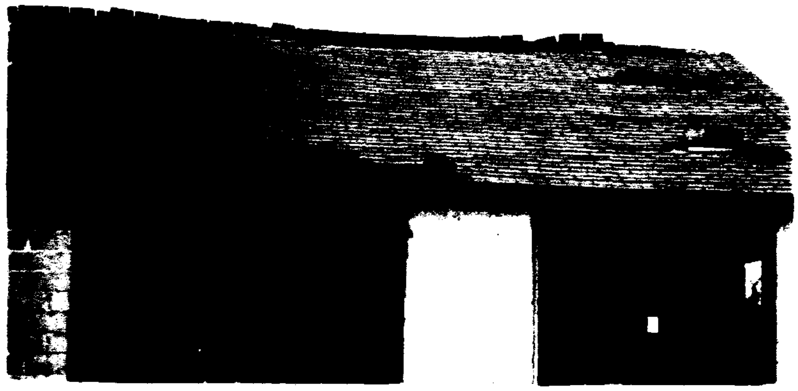


Fig. 11. New Asphalt Shingles on a Machine Shed Blowing up Around the Edges and in Spots

Fig. 12. Ten-year-old Asphalt Shingle Roof Showing how Shingles Have Been Flapped and Broken Off

Fig. 13. Three Types of Roofing Materials Showing Through on One Roof

was not available, it appears that they were also nailed too high. Again the ridge line pattern is in evidence.

Fig. 12 shows the result of wind damage sustained by ten-year-old asphalt shingles; however, it was apparent that some damage had been sustained at this point of the roof some years before and not repaired. It was no doubt due to the lack of two or three tabs that the wind was able to get under some of the remaining tabs and break them off by flapping.

Fig. 13 shows a dwelling roof that has suffered greatly from wind damage evidently numerous times. Three roofing materials are in evidence. The old wood shingle roof was applied first and then other roofing materials applied subsequently right over the wood shingles. A roll roofing was applied first over the wood shingles and later asphalt shingles over that and none of them was able to sustain normal wind stresses.

Fig. 14 shows damage to a thick-butt type asphalt shingle with an embossed top surface. Even though the shingles were applied with six nails, and not too differently from the recommended specifications that come with such shingles, the nails were very nearly on the line of transition from the thick to the thin portion of the shingle. In such a case where the bending was allowed to take place near this transition line the stresses were concentrated in this weak line

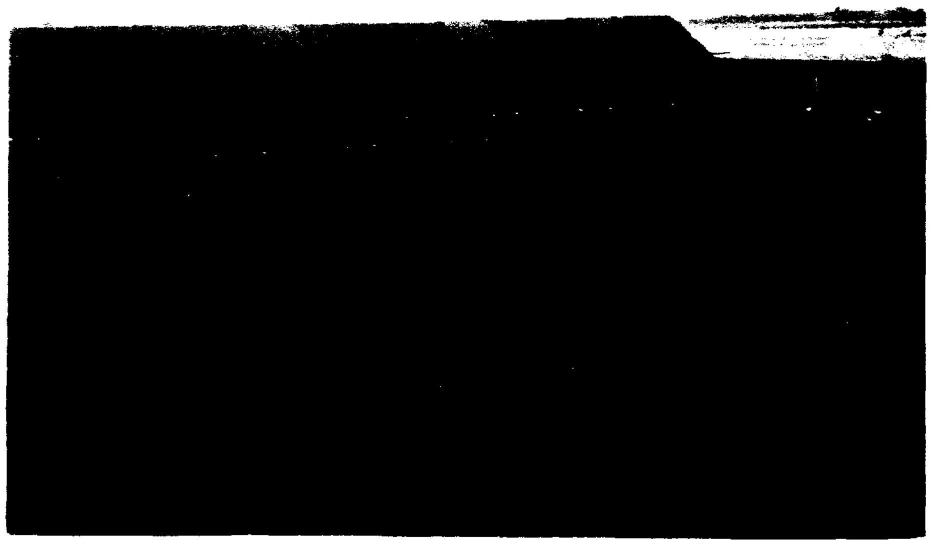


Fig. 14. Nails nearly on Transition Line but not much Higher than Standard Specifications Call for

Fig. 15. Shingles have been Applied on an Inadequate Deck

Fig. 16. Two-tab Hex Shingles Applied over an Inadequate Deck and Nailed too High

Fig. 17. Hex-tab Shingles Nailed well but still Damaged by Wind

and the resistance to bending was very low.

Fig. 15 shows wind damage to square-tab asphalt shingles that were applied over a very inadequate deck. Old curled, cracked wood shingles such as these cannot possibly offer much withdrawal resistance to the nails driven into them. Only four nails per strip were used and no doubt a few of the nails that didn't happen to hit anything solid gave way allowing the shingles to be damaged.

Fig. 16 shows a two-tab hex-type asphalt shingle roof damaged by wind. Only a scattered few nails are in evidence and most of them placed very high on the shingle. The major point in this case is, however, that regardless of how many nails might be driven into that base of old cracked wood shingles very little withdrawal resistance could be gained with them.

Fig. 17 shows where an individual tab of a hex-tab shingle roof has been torn off. It is noticed that the shingles were applied over wood shingles; however, there was no evidence of nailing being inadequate in this case. The wood shingle deck may have had something to do with the damage, however, inasmuch as the shingles were not able to conform well to such a deck.

These pictures present some of the more common types of damage sustained by asphalt shingles.

REVIEW OF LITERATURE

Early History of Asphalt Shingles

According to Abraham (1, p. 50):

> Arvid Foxe of Sweden is given credit for having produced the first composition roofings between the years 1780 and 1790 in the following crude manner: the roof boards were first covered with plain paper impregnated with a mixture of copper and iron sulfates, which after being nailed in place, was coated with heated wood tar to make it waterproof and then surfaced with various colored mineral earths.

In the year 1791 a newspaper in Leipsic, Germany, credited Michael Kag of Muhldorf, Bavaria, with having produced an improved form of prepared roofing by saturating raw paper with varnish, and coating the surfaces with a mineral powder. Similarly, the Magdeburg Zeitung on November 16, 1822, contained a notice stating that paper impregnated with tar was being used to displace straw and wooden shingles for roofing purposes, and that the former may be made fire-resistant by treating the tar with unslaked lime and surfacing with sand.

Also from Abraham's book on <u>Asphalts and Allied Substances</u> (1, p. 52) comes the information that the first composition roofing in the United States was reported by Rev. Samuel M. Warren to have been used during 1844-45 on roofs in Newark, New Jersey. The roofing consisted of square sheets of ship's sheathing paper treated with a mixture of pine tar and pine pitch, and surfaced with sand. In 1847 coal tar was used by Cyrus M. Warren as a substitute for the pine tar, to soften the pine pitch, and employed as a saturant for the paper. Fine gravel was next used to substitute for sand. The square sheets were dipped into the melted mixture by hand, sheet by sheet, and then the excess was pressed out. The next step consisted in running the paper or felt in rolls through continuously operating saturators designed to saturate with tar. Finally, in Buffalo, New York, coal tar was distilled down to a roofing pitch, which was used to replace the more expensive mixture of pine pitch and coal tar.

A publication by the Asphalt Roofing Industry Bureau entitled "Manufacture, Selection and Application of Asphalt Roofing Products" (10, p. 5) states that:

> For 5,000 years asphalt has been used by men as a preservative, waterproofing and adhesive agent. It was used by the Babylonians to waterproof baths and as a pavement. The Egyptians used it to preserve their mummies. Throughout the Middle Ages, asphalt was in common use in Europe. One of the largest natural deposits was discovered by Columbus on the Island of Trinidad in the British West Indies during his third voyage in the Year 1498.

It is quite natural that the early attempts to make composition roofs were as described, with various types of papers and waterproofing agents, it being realized that some sort of sheet material was needed and a means of waterproofing it after application. Many changes have taken place in the past until today we have the three common types of composition roofs; namely, asphalt shingles, roll roofing and the tar and gravel built-up roof.

Terminology of Bituminous Substances

It goes without saying that the words "bitumen", "asphalt", "resin", "tar", "pitch", and "wax" have been used quite loosely through the centuries since their origin. At first very little was known regarding the properties of the various substances so the interchangeable use of the words resulted.

Abraham (1, p. 56) defines "bitumen" as a generic term applied to natural substances of various color, hardness and volatility; composed principally of hydrocarbons, substantially free from oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being fusible and largely soluble in carbon disulfide, yielding water-insoluble sulfonation products. This definition includes petroleums, native asphalts, native mineral waxes and asphaltites (gilsonite, glance pitch and grahamite).

"Petroleum" is defined (1, p. 60) as a species of bitumens, of variable color, liquid consistency, having a characteristic odor; comparatively volatile; composed principally of hydrocarbons, substantially free from oxygenated bodies, soluble in carbon disulfide, yielding water-insoluble sulfonation products.

"Mineral wax" is defined (1, p. 60) as a term applied to a species of bitumen, also to certain pyrogenous substances; of variable color, viscous to solid consistency; having a characteristic lustre and unctuous feel; comparatively nonvolatile; composed principally of saturated hydrocarbons, substantially free from oxygenated bodies; containing considerable crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being easily fusible and soluble in carbon disulfide, yielding water-insoluble sulfonation products.

"Asphalt" is defined (1, p. 61) as a term applied to a species of bitumen, also to certain pyrogenous substances of dark color, variable hardness, comparatively nonvolatile; composed principally of hydrocarbons, substantially free from oxygenated bodies; containing relatively little or no crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being fusible, and largely soluble in carbon disulfide, yielding water-insoluble sulfonation products. This definition is applied to native asphalts and pyrogenous asphalts. Native asphalts include asphalts occurring naturally in a pure or fairly pure state, also asphalts associated naturally with a substantial proportion of mineral matter (rock asphalts). The associated mineral matter may be sand, sandstone, limestone, clay, shale, etc. Pyrogenous asphalts include residues obtained from the distillation, blowing, etc. of petroleums (e.g., residual oil, blown asphalts produced by blowing air through heated residual oils, residual asphalts produced by a steam distillation of semi-asphaltic and asphaltic petroleums, sludge asphalt, etc.).

"Pitch" (1, p. 63) is a term defined to include residues obtained from the distillation of organic materials; of dark color viscous to solid consistency; comparatively nonvolatile, fusible; composed principally of hydrocarbons.

The Composition of Asphalt Shingles

Raw materials

There are three basic materials from which asphalt shingles are manufactured; felt, asphalt, and mineral. The quality and quantity of these three materials of course, vary in the many different makes of asphalt shingles now on the market.

Felt. As defined by the Asphalt Roofing Industry Bureau in their manual on the Manufacture, Selection and Application of Asphalt Roofing Products (10, p.5),

> Dry felt is made from various combinations of rag, wood and other cellulose fibers blended in such proportions that the resulting characteristics of strength, absorptive capacity and flexibility will be as required to make an acceptable roofing product.

Besides certain specifications as to weight, tensile strength and flexibility, the felt must be capable of absorbing from 1-1/2 to 2 times its weight in asphalt saturants. The main item going into the manufacture of dry felts is waste paper. The waste paper is repulped and then felted according to the desired specifications for the dry roofing felt.

Asphalt. Asphalt is used in asphalt shingles as a protective agent as it is in many other products. The asphalt used today is obtained mostly from the petroleum industry. It is a product of the fractional distillation of crude oil that occurs toward the end of the distilling process, and is known to the trade as "Asphalt Flux". The flux then is subsequently refined for use in roofing materials. In describing saturants and coatings, the Asphalt Roofing Industry Bureau (10, p. 5) states the following:

> The preservative and waterproofing characteristics of asphalt reside very largely in certain oil constituents. Therefore, in the manufacture of roofing it is desirable to construct the body of the sheet of highly absorbent felt impregnated or saturated to the greatest possible extent with a type of oil-rich asphalt known as "saturant", and then to seal the saturant in with an application of a harder, more viscous 'coating

> asphalt' which itself can be protected, if desired, by a covering of opaque mineral granules.
>
> The asphalt used for saturants and coatings is prepared by processing the flux in such a way as to modify the temperature at which it will soften. The softening point of saturants varies from 100° to 160° F, whereas that of the coating runs as high as 260° F.

Mineral. Minerals in two classifications are found in asphalt shingles. A finely ground mineral is used as a so-called stabilizer in the coating asphalt. The following are among the materials which have been used as stabilizers: silica, slate dust, high calcium limestone, dolomite, and trap rock. Besides this fine material a coarser mineral is used for surfacing of the coating. The minerals most frequently used for this purpose are: natural slate, quartz, trap rock and slag. Some surfacings are manufactured from clay which is subjected to a ceramic treatment, thus producing synthetic granules. Some talc or mica is also used for surfacing the underside of the roofing to prevent sticking together in shipment.

General Features of Asphalt Shingle Manufacture

Shingles may be manufactured with the cut edges of the central layer of felt left exposed or with "sealed edges"; or the lower edge may be cut in a finely serrated form to give illusion of greater thickness; or the lower edge may be cut in a ragged form and charred to accentuate the thickness;

or the coating may be depressed along the edges to give an illusion of thickness (1, p. 768).

Following 1930 the asphalt roofing industry began looking for a thickening substitute for the expensive heavy felt and asphalts. They came up with a thick, filled type, protective coating which was applied in a thickened layer over the butt portion of the shingle. In this way the thickness and weight of the shingle was brought up to that of the previous 70 lb. felt shingle by only using a 50 lb. felt.

Thick-butt shingles according to Abraham (1, p. 768) are manufactured in a number of ways such as, using a tapered felt; applying asphalt coating in a tapered manner; applying a tapered coating of asphalt-cork mastic; applying a thick, grooved rear coating; applying one, two or three uniformly thick surface coatings with mineral surfacings to the lower portion of the shingle; by forming various types of laminated shingles with one or more layers of felt; encasing the entire shingle in a layer of felt with a thick mastic in the center; encasing the entire shingle in a layer of metal with a thick tapered mastic layer in the center of the shingle (either on the upper or the lower surface); indentations in the felt and coatings in various ways; cementing together two layers of saturated and coated felt at the portion of the shingle to be exposed; folding the postion of the shingle to be exposed and cementing same together.

Sheet metal and wire mesh reinforcing cores have been tried for strengthening the shingles, but according to Abraham (1, p. 770) have not made much commercial headway. Also asphalt shingles reinforced on the underside with wooden laths have been suggested.

Asphalt Shingle Research

Very little fundamental research pertaining to the wind-resisting characteristics of tab-type asphalt shingles had been accomplished prior to this study. Various methods of manufacturing and applying asphalt shingles have been underwritten by companies without first having complete information on the effect such would have on the actual behavior of the material in the field.

The Asphalt Roofing Industry Bureau has maintained a research department for years and has done much to increase the resistance of asphalt shingles against all elements of nature except wind and hail. It is somewhat futile to develop a shingle, however, that will last twenty years in the sun and heat if it is going to be blown off before it is seven or eight years old. The Bureau works together through a research committee, which as quoted from a publication of theirs (10, p. 10) functions as follows:

> This committee, in addition to meeting for discussing problems of mutual scientific interest to its members, also administers the work of the National Bureau of Standards Fellowship, which has been supported by the Industry since 1926. The Bureau's Research

> Fellow is engaged with such problems as the determination of the value of mineral stabilizers in coating asphalts; the effect of the use of various kinds of fibers on the formation and other characteristics of roofing felt; the characteristics of the various constituents of asphalt to determine which ones contribute most to satisfactory weathering, and to what extent; developing procedures for making accelerated weathering tests of roofing samples by means of special laboratory equipment, and the like.

In all cases, insofar as the author has been able to ascertain, the reference to weathering, as such, has been weathering other than by wind.

James L. Strahan, the technical director, Asphalt Roofing Industry Bureau, wrote in 1948 (9, p. 117) that:

> Attention has recently been focused on certain types of failures which seem to be more prevalent in wind areas. Insurance companies have noticed an increasing number of wind damage claims and naturally want to reduce or eliminate the trouble. In this their interests are exactly parallel to those of the roofing industry which is now concentrating its engineering resources to meet this situation.

Being aware of such damage, Strahan also states in the article that the research committee had been assigned the primary task of preparing standard application specifications which would include, not only the details of applying the many different types of products, but also the important characteristics of good roof decks, both old and new, together with good methods of flashing. He stated also that:

> This assignment is approaching completion, and in the near future each company in the industry will be having an opportunity to revise its instruction sheets to make them consistent with the committee recommendations. Having been closely associated with this project almost from its inception, my guess is that such revisions will not be drastic, for the reason that technical differences for the most part are minor and relatively unimportant.

A preview of the specification was given also; however, the resulting effect of such leaflets in the packages of shingles has not been to lower the wind damage to such material. Previously presented loss experience data (Table 1) show an increasing trend of such damage.

Some of the first fundamental research, having to do with the durability of composition roofing was carried on by Henry Giese and others and published in 1932 (6). The work was begun in 1913 by J. B. Davidson and consisted of outside exposure tests of roll roofings as well as composition analyses of the materials to determine correlations of makeup and durability. In such tests, however, the wind did not appear to be a particularly destructive weathering agency.

The National Bureau of Standards reported in a publication (8, p. 669) entitled "Accelerated Weathering Tests of Mineral-Surfaced Asphalt Shingles" in 1937 that:

> Except that the samples containing fine mineral filler in the asphalt coatings appear to be the most resistant to weathering, analyses of the samples under test, including fiber analyses of the felts and petrographic examination of the mineral

> fillers and fine surfacing materials, show no differences in composition sufficiently great to warrant the prediction of decided differences in their behavior to weathering.

Here again if wind damage were considered in the weathering tests some factors, for example the filler in the coating, might be decidedly detrimental to bending resistance and overshadow any benefit that such might offer against other types of weathering.

Wind-Resisting Characteristics of Asphalt Shingles

Cleveland (2) in 1948 made extensive field observations to determine what constitutes a good asphalt shingle roof and what constitutes a poor one. A poor roof was considered as one giving twenty years service only with considerable repair and maintenance or one not lasting twenty years without complete replacement. A good roof in turn was considered as one serving for twenty years or more with no maintenance or repair requirements. Some preliminary laboratory physical and composition tests were also made by Cleveland. Three pertinent conclusions that Cleveland (2, p. 134) made from his field studies were:

> Good asphalt shingles were found to be 10 percent thicker than damaged asphalt shingles which makes the good shingle more rigid and longer lived due to the availability of more bitumen.
>
> Good asphalt shingles had 0.63 inch less exposure than the damaged asphalt shingles.

> Damaged asphalt shingles had 0.79 inch more distance from the edge of exposure to the point of nailing than did the good shingles.

It is quite evident that the wind resistance of asphalt shingles is a function of both the shingle composition and its application. To what extent the many variables of composition, nailing patterns and number of nails has on the wind-resisting capabilities of asphalt shingles has not been determined previously through any type of a controlled experiment offering sound unbiased results.

COMPOSITION ANALYSIS OF ASPHALT SHINGLES

Hypotheses and Assumptions

It is the author's hypothesis that the composition of asphalt shingles determines to a large extent the wind-resisting ability of the material. It, however, is realized that application of the material also plays a part in its durability and wind-resisting ability, and that part of the problem enters into the study and is discussed later in this manuscript. Basically, asphalt shingles are made up of three ingredients; felt, bitumen and mineral. The extent these ingredients, all other things being equal, contribute to the wind-resisting characteristics of tab-type asphalt shingles will be determined through the correlation of composition findings of the samples tested with the results of physical bending tests.

It is generally assumed by most people that the weight of felt plays the largest part in determining the wind-resisting ability of asphalt shingles; however, to what extent has never been determined through controlled tests.

Also the matter of filler in the bitumen coating, used as an extender, has been thought by many to be a weakening factor as pertains to the shingle's lasting bending resistance and its resistance to cracking and tearing after repeated bending in a windstorm. Through the composition analysis and controlled physical tests this too will be tested by correlation as to its significance.

Method of Procedure

General

The author's hypothesis pertaining to the significance of the composition of asphalt shingles in resisting wind was tested by analyzing various makes, grades and weights of new asphalt shingles, available on the retail markets in Central Iowa, and testing them also for physical performance. It was felt by the author that composition analyses and physical tests of available new shingles would furnish more significant quantitative information than the analysis of wind-damaged asphalt shingles of which the original composition was not known. Some analyses of such damaged shingles were made in this study; however, only from an interest standpoint and for any implications that might be drawn from the few shingles analyzed.

Chemical analysis. The chemical analysis of asphalt shingles involves the breakdown of the shingle ingredients into three basic materials; felt, bitumen and mineral matter. A more detailed analysis consists of determining the makeup of the felt, the amounts of the various types of bitumens, and the various types of minerals. The laboratory analysis of this study was in detail up to but not including the fiber contents of the felts, the compound structure of the bitumens, and the basic minerals in the granules and filler material. An analysis of this scope was not considered justified for this study nor to have a significant effect on each hypothesis being tested.

The analysis made did include the determination of the felt saturant bitumen and coating bitumen separately; as well as the difference between granule mineral on the top surface, back coating mineral and the filler mineral in the coating bitumen. The coating bitumen is of a more viscous nature with a comparatively higher melting point than that used for saturating the felt. The protective coating may be a pure bitumen or as in many shingles is a mixture of bitumen and various amounts of fine mineral filler. The total mineral matter is made up of the above mentioned filler, designated as that which passes through a No. 100 mesh screen; the top surface granules being generally of natural slate or crushed materials treated with pigments or ceramic materials; and some type of back dusting, consisting generally of mica dust or fine sand.

Types of asphalt shingles tested

One bundle of 27 different shingles amounting to one-third of a square for the 5-inch exposure square-tab shingles and one-half of a square for hex-tab and 4-inch exposure shingles, was procured from retail stores. The 27 shingles were made by 14 different manufacturers as listed below:

Barrett Roofing Company
Bird and Son, Inc.
Celotex Corporation
Certain-teed Products Corporation
Flintkote Company
The Lloyd A. Fry Roofing Company
Globe Roofing Products Co., Inc.
Gold Seal Asphalt Roofing Company
Johns-Manville Sales Corporation
Logan-Long Company
The Lehon Company
Philip Carey Manufacturing Company
Ruberoid Company
United States Gypsum Company

Seven of the 27 shingles tested were of the hex-tab design; of which one was a three-tab rounded-tab type, one a two-tab type, and the remainder three-tab types. Six shingles were square-tab uniform thickness design. One shingle was a taper-type 10" shingle. The balance of 13 were square-tab, thick-butt shingles all of the 12" design; except two, which were 10", for a 4-inch exposure, one of which was a four-tab design.

Technique of analysis

In general the laboratory method used for analyzing asphalt shingle was patterned after procedures outlined in Federal Specifications SS-R-521 (11), entitled "Roofing and Shingles; Mineral-Surfaced, Asphalt-Prepared", except that it was altered for the purpose of adapting it to the equipment available for this study and in some cases to increase the accuracy of the analysis. The common method of quantitative chemical analysis has been the extraction of the bitumens from the remainder of the shingle constituents by using a bitumen solvent. The amount of total soluble bitumen is then determined by calculating the difference in weight of the original shingle sample and the final oven-dried desaturated sample. Carbon disulfide (CS_2), which was used in this analysis, has proved in the past by others to be the best solvent for this purpose even though it presents problems in its use.

Equipment used. Glass extraction equipment, as shown in Figures 18, 19 and 20, was used for this study inasmuch as a metal New York Testing Laboratory type extractor, specifically made for extracting bitumens, was not available from manufacturers. A diagrammatic drawing of the assembled equipment is shown in Fig. 21. Two large (3" diameter barrel) sized Soxhlet extractors made of pyrex glass, suitable for the extraction of 2"-by-3" samples, were obtained

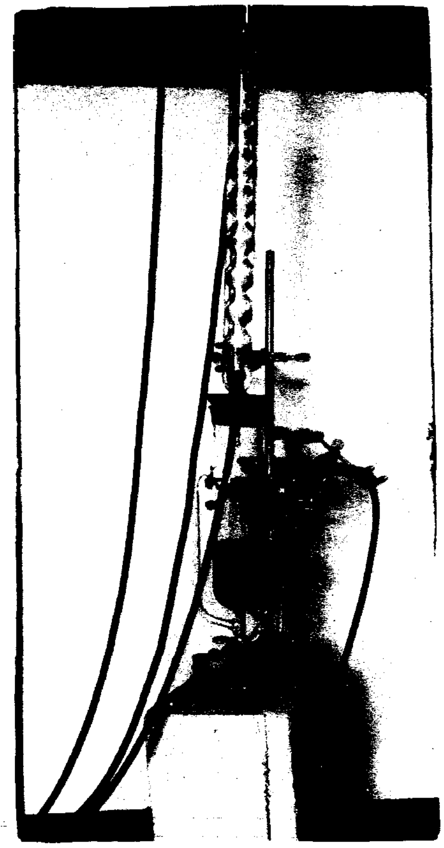


Fig. 18. Apparatus for Extracting Bitumen from Asphalt Shingle Samples

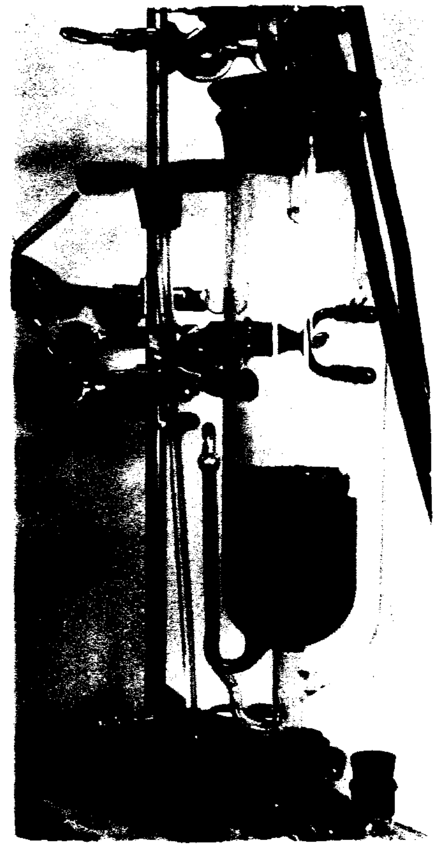


Fig. 19. Close-up of the Soxhlet Extraction Tube

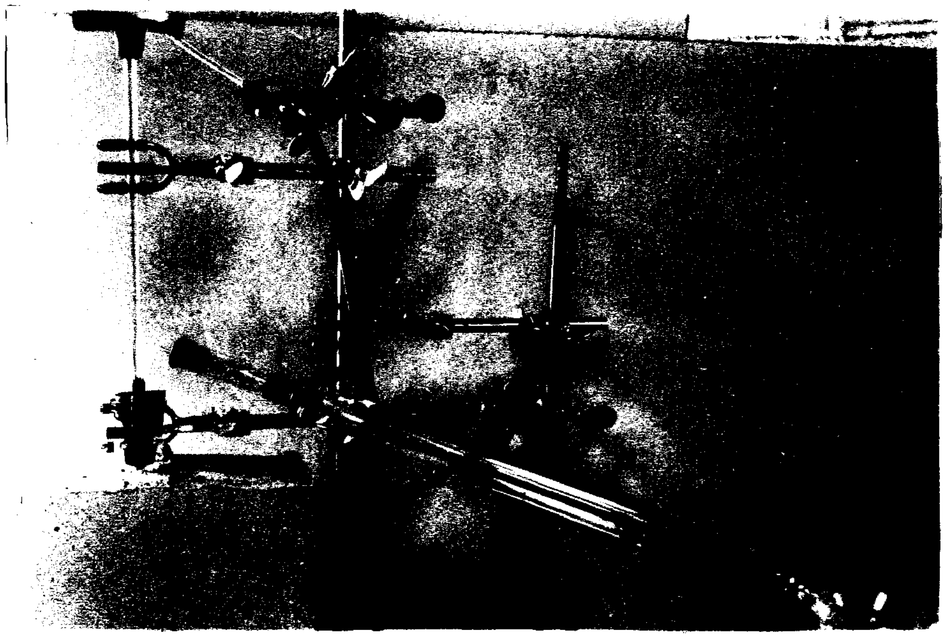


Fig. 20. Apparatus for Distilling off Carbon Disulfide

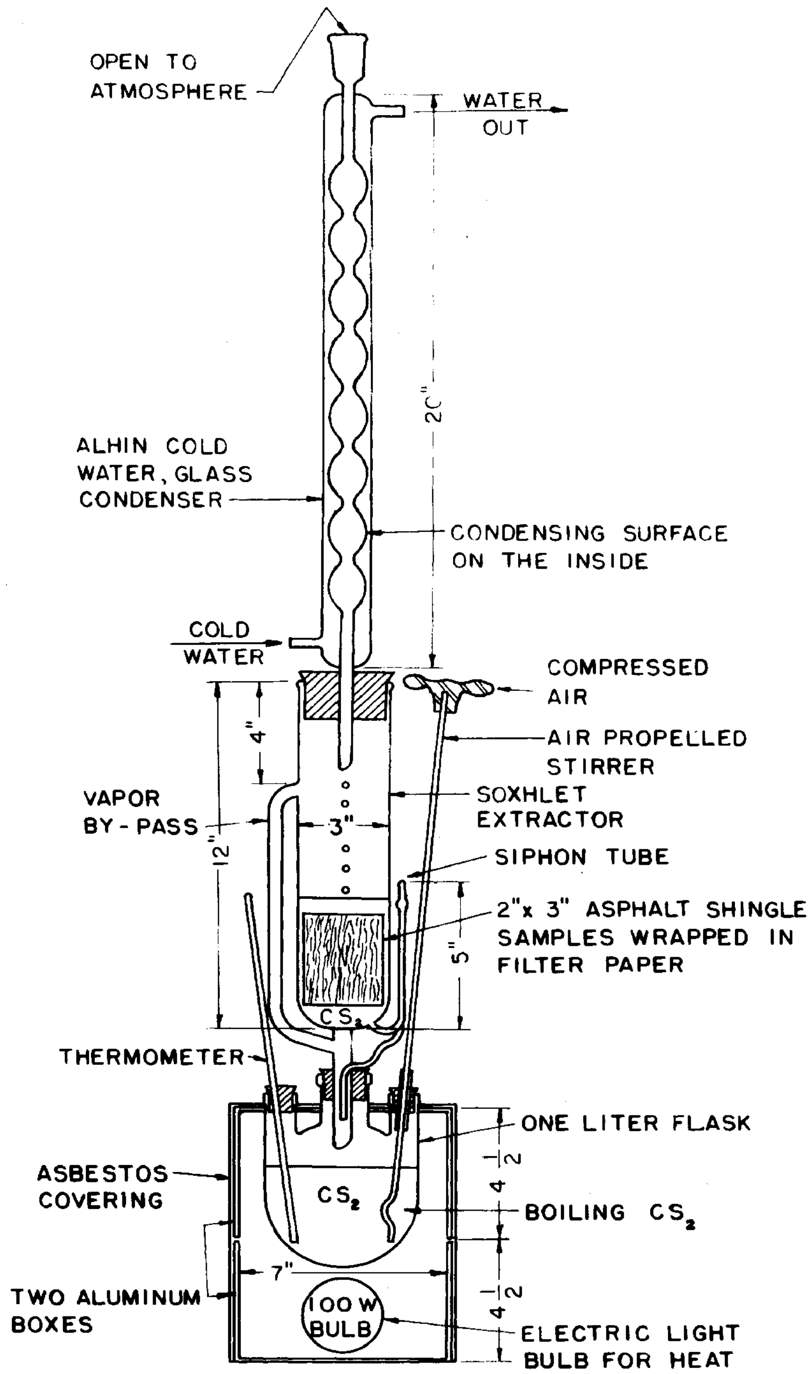


Fig. 21. ASPHALT SHINGLE EXTRACTING APPARATUS.

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and with the illustrated pyrex glass evaporating flasks and condensers worked very satisfactorily. Fig. 19 shows a close-up view of center part of the assembled apparatus, bringing out in more detail how the Soxhlet extractor was mounted on the ringstand with the other equipment and how the samples were placed in it for extracting. As shown in this view the solvent has not risen quite to the top of the samples. When it completely submerges the samples and raises to the top of the siphon tube on the right side of the barrel the extractor automatically drains and the process is repeated. The air-driven stirrer may also be seen in operation in Fig. 19, to the right of the extractor barrel and siphon tube.

Fig. 20 shows the apparatus assembled as a distiller. In this way the excess CS_2 in the evaporating flask with the dissolved bitumen may be retrieved. A straight tube cold water condenser is used in this case instead of the Alhin type as shown in Fig. 20. The Alhin type was needed for extraction purposes to offer a maximum amount of condensing surface with the least restriction possible. To allow for uneven boiling the condenser must be assembled with an unrestricted opening to the atmosphere.

The method of heating the solvent for evaporating may be seen in detail in Fig. 20. The container was made of two aluminum boxes, one placed upside down on the other. The top box was adapted to receive the three necks of the evaporating flask and the bottom one to receive the socket for the light bulb through one end. To serve as an insulator and a protection against fire spreading, the boxes were covered with asbestos as illustrated and as can be seen from the outside in Fig. 18. The thermometer was used for indicating the temperature of the boiling liquid during the initial stages of experimentation with the apparatus. The stirring device was found to be necessary to assure uniform boiling of the liquid and to eliminate "bumping".

Problems encountered. Numerous problems in the operation of the extraction equipment were confronted and eventually solved satisfactorily. Carbon disulfide boils at 115.6° F and is highly flammable, making it impossible to use an open flame for vaporizing purposes. Inasmuch as very little heat is required to vaporize the liquid carbon disulfide, a one-liter evaporating flask was used with a one hundred watt electric light bulb for the heat source. The size of light bulb required had to be determined as well as the type of enclosure for the flask.

Considerable trouble was encountered with the boiling characteristics of the carbon disulfide, especially after it had accumulated a considerable amount of bitumen in solution. The addition of bitumen in the carbon disulfide tends to make the liquid more viscous resulting in considerable "bumping" as the boiling process continues. The "bumping" or rushing of vapor and droplets of liquid up through the vapor by-pass tube to the top of the Soxhlet extractor made it impossible to ever get all the bitumen entirely dissolved out of the shingle samples. Various types of boiling chips and glass beads were ineffectively used to remedy the uneven boiling. Ultimately a stirrer was tried and proved satisfactory.

The amount of solvent had to be determined so that there would still be sufficient in the flask for evaporation purposes when the extractor barrel was full and not be too much when it drained back into the flask. Six hundred cubic centimeters of solvent were found to be sufficient.

Some trouble was encountered with the use of rubber stoppers. The carbon disulfide caused the rubber to expand; however, never to the extent of bursting a flask. The rubber would, however, contract back to its original size and shape when left overnight away from the carbon disulfide fumes, with no apparent deterioration resulting. It is recommended that ground glass fittings be used if such equipment were to be procured for a similar study. Such equipment was not available in this case. The cost of equipment with ground glass fittings, to replace the rubber stoppers, is more expensive but much more convenient.

Normally about twenty hours were required to extract all the bitumen from a set of samples. The same carbon disulfide was generally used for three extractions with only adding some extra solvent at the beginning of each operation to replace what was lost through evaporation and removal with the extracted samples. After three extractions the apparatus was converted over to a straight distilling process in order to retrieve the surplus carbon disulfide. Fig. 20 shows the apparatus set up for this purpose. It was not found practical to remove all the excess solvent, because it would then be very difficult to remove the remaining bitumen from the flask without introducing as much or more solvent than was distilled off.

Sampling. The individual samples of asphalt shingle were limited to 2x3 inches by the size of the Soxhlet extractor barrel. With samples of this size about a dozen to a dozen and a half, depending on their thickness, could be placed in the extractor at one time and processed together. Fig. 26 shows a group of samples wrapped in filter paper and ready to be placed into the extractor. In this case the group shown was placed in at one time.

Normally the contents of one extraction process were all samples of the same bundle of shingles. Representative samples were taken from each bundle in sufficient number so that duplicate data were obtained in all cases. The 2x3-inch samples were obtained from the strip shingles by pressing a die, as shown in Fig. 24, through them. By using a die designed accurately to the dimensions desired, uniform samples were obtained.

For purposes of composition analysis, two strip shingles

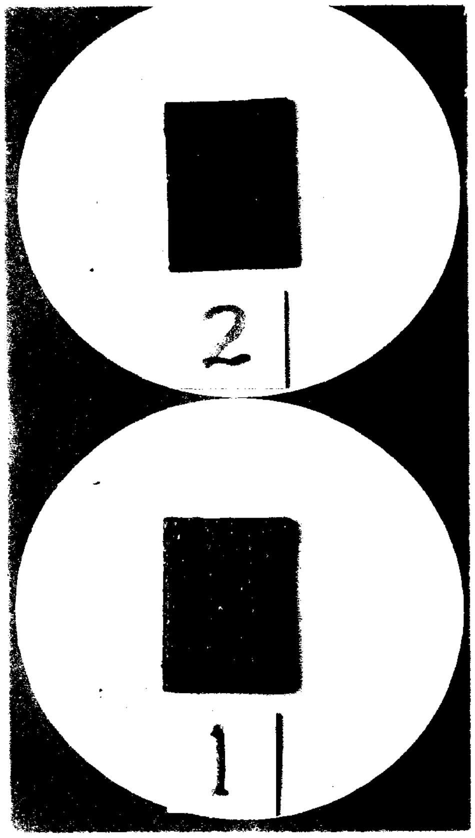

Fig. 22. Thick-butt and Thin-top Portions of Asphalt Shingles

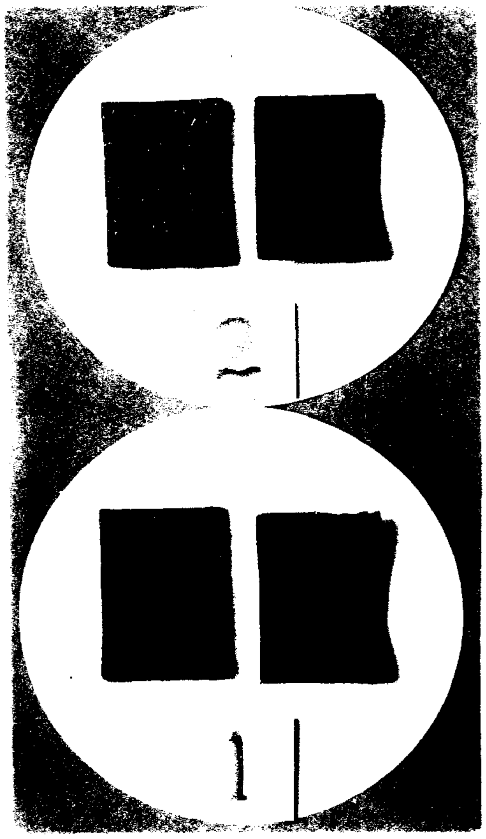

Fig. 23. Top Portion and Back Portion of Asphalt Shingles

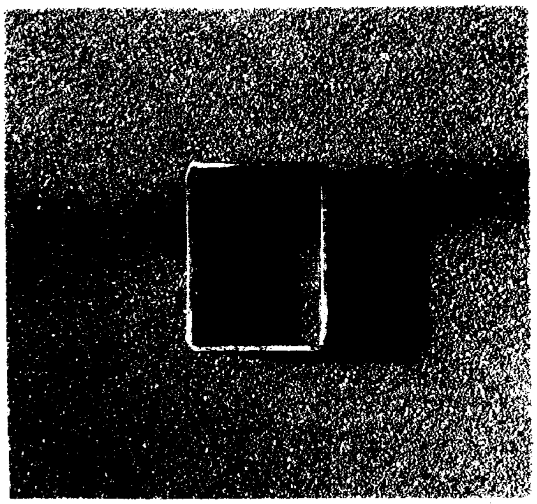

Fig. 24. Die for Cutting Out 2"x3" Samples of Asphalt Shingles

were taken at random from each bundle of new shingles. Six samples were then cut from the butts of each strip shingle, two from each tab, and three from the top portion of each of the shingles. The samples were taken from the top portion in order to analyze the makeup of that part of the shingle, particularly for those known to be thick-butt or tapered type shingles. Fig. 22 shows two typical samples from a thick-butt type shingle. In this illustration Sample No. 1 was taken from the butt portion and No. 2 from the thin top portion of the shingle.

In order to obtain samples as uniform as possible and representative of the entire bundle of shingles as to weight and makeup, the two shingles used for sampling purposes were first weighed and the weight of an equivalent 2x3-inch sample calculated. All 18 samples cut from these two shingles were then weighed and only the ones agreeing within 2 per cent with the calculated figure were used for analyzing purposes. This procedure eliminated any discrepancies that might show up in any one sample due to variance in manufacture or in obtaining the sample.

Record sheet. The record sheet used for the asphalt shingle composition analysis is shown in Fig. 29. One of these sheets was used for each different type of shingle analyzed. It is noted that columns are present for two duplicate samples in all cases. Samples in the No. 1

column were taken from one of the two shingles drawn at random from the bundle and the ones in the No. 2 column from the other shingle. Reading No. 1 of the record sheet, weight of large sample, pertains to the entire strip shingle as mentioned previously. In the cases of thick-butt type shingles or ones varying in cross section in some manner, two record sheets had to be used, one for the butt portion and one for the top portion.

After weighing all samples cut from the two strip shingles, the two samples of each the butt and thin-top agreeing closest with the calculated weight of a 2x3-inch sample were recorded on the data sheet on line No. 2 as original shingle samples. To distinguish the felt bitumen from the coating bitumen two samples of felt only were obtained, as shown in Fig. 25, and their weight recorded on line No. 11 of the record sheet. To obtain such samples of felt only, the samples were first warmed in an oven and then the top portion and the bottom portion torn away on the bias being careful to eliminate all ingredients except the felt and its saturant.

In order to distinguish the back coating from the top coating, two samples of each the butt and top portion of the shingles were separated on the bias as shown in Fig. 23. Sample No. 1 of this figure shows the thin-top portion of a thick-butt shingle, having been separated on the bias,

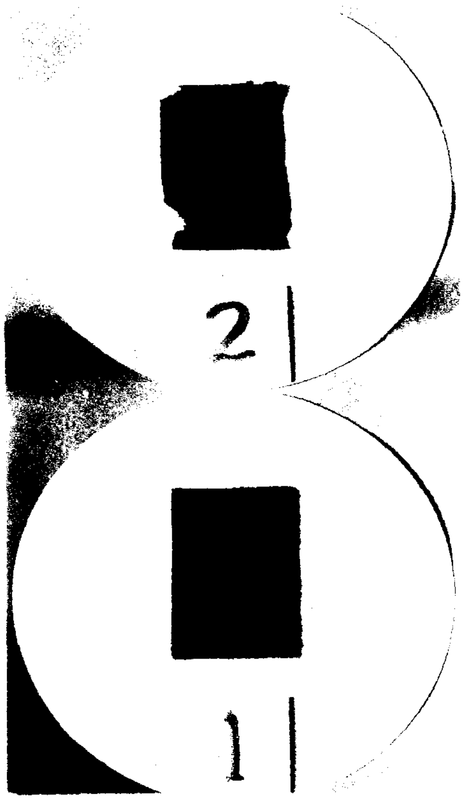

Fig. 25. Core Samples of Saturated Felts

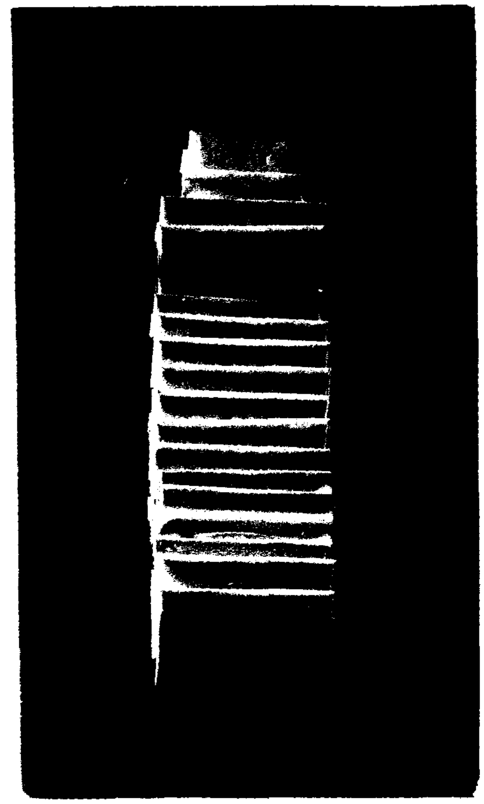

Fig. 26. Wrapped Samples Ready to go into the Extractor

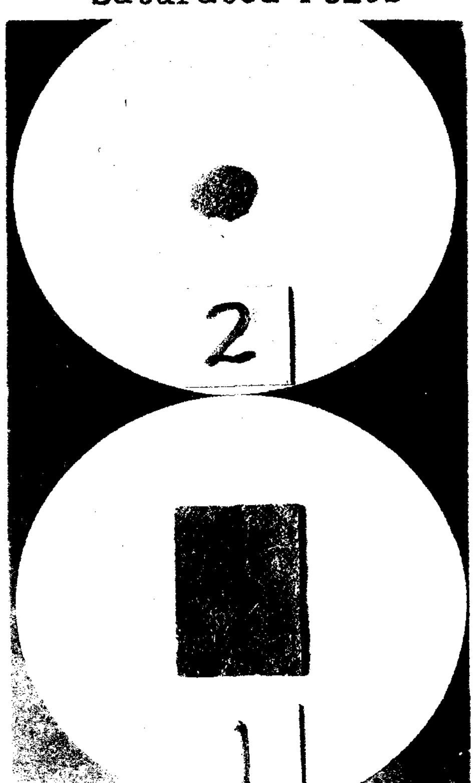

Fig. 27. Desaturated Felt and Back Dusting Mineral

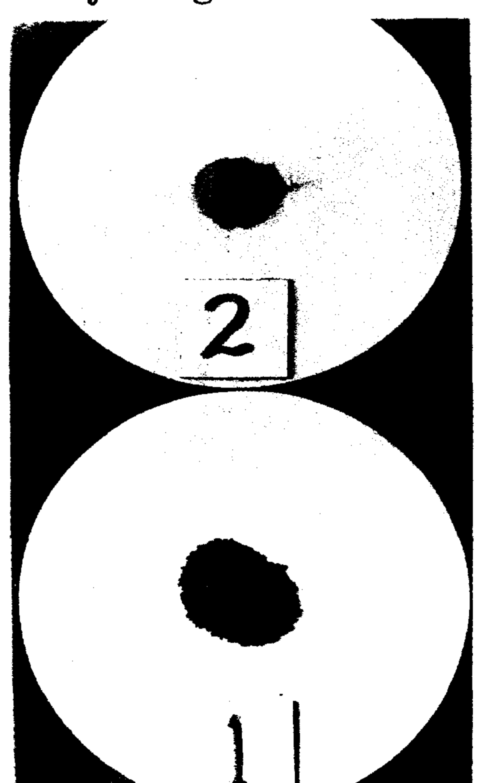

Fig. 28. Top Surface Granules and Mineral Filler

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Date ____________

Shingle No.		2"x3" samples #1	2"x3" samples #2	108 sq ft #1	108 sq ft #2
1.	Weight of large sample	____	____	____	____
*2.	Original shingle sample	____	____	____	____
3.	Sample less bitumen plus paper	____	____	____	____
4.	Desaturated felt (bone dry)	____	____	____	____
5.	Filter paper	____	____		
6.	Sample less bitumen	____	____		
7.	Soluble bitumen (saturant & coat)	____	____	____	____
8.	All mineral in sample	____	____	____	____
9.	Mineral retained on #100 screen	____	____	____	____
10.	Mineral passing #100 mesh screen	____	____	____	____
*11.	Central core of felt	____	____		
12.	Desaturated felt core(bone dry)	____	____		
13.	Soluble bitumen in felt core	____	____		
14.	Parts saturant in felt	____	____		
15.	Saturant in total felt	____	____	____	____
16.	Total bitumen in coating	____	____	____	____
*17.	Top portion peeled into felt	____	____		
18.	Top portion less bitumen plus paper	____	____		
19.	Desaturated felt in top peelings	____	____		
20.	Filter paper	____	____		
21.	Top portion less bitumen	____	____		
22.	Total mineral in top peelings	____	____	____	____
23.	Mineral retained on #100 screen	____	____	____	____
24.	Mineral passing #100 mesh screen	____	____	____	____
25.	Total bitumen in top peelings	____	____		
26.	Felt saturant in top peelings	____	____		
27.	Coating bitumen in top peelings	____	____		
28.	Min. passing #100 in % of coat. bit.	____	____		
29.	Back coating bitumen	____	____	____	____
30.	Back coating filler	____	____	____	____
31.	Back dusting mineral	____	____	____	____
*32.	Back portion peeled into felt	____	____		
33.	Desaturated felt	____	____		
34.	Filter paper	____	____		
35.	Back portion less bitumen	____	____		
36.	Total bitumen	____	____		
37.	Felt saturant	____	____		
38.	Coating bitumen	____	____		

Fig. 29. Record Sheet for Asphalt Shingle Analysis

with the top surface portion on the left and the back or underside of the shingle on the right. Sample No. 2 of the same figure shows the thick-butt portion of the shingle similarly displayed. The weights of the top surface portion of these samples were entered on Line No. 17 of the record sheets and the back surface sample weights on Line No. 32.

With the weights of the eight original 2x3-inch samples recorded for the uniform thickness shingle and 16 samples for the thick-butt types, the extraction of bitumen from them was accomplished. They were wrapped in filter paper to retain all ingredients except the bitumen.

After the samples have been freed of all soluble bitumen and dried in an oven to assure complete dryness, they were weighed individually to the closest milligram as set forth in the record sheet shown in Fig. 29. The weights and calculations represented by each line of the record sheet must be accomplished to obtain a complete quantitative analysis of the shingles. The samples were weighed first prior to unwrapping so as not to lose any of the ingredients.

The four ingredients left after the bitumen has been extracted out are shown in Figures 27 and 28. Sample No. 1 of Fig. 27 shows the dry desaturated core felt from which the parts saturant was determined on Lines 11-16 of the record sheet. Sample No. 2 of the same figure shows the back dusting material which was generally a mica dust or fine sand.

The amount of this material was determined from the back portion samples. In Fig. 28, Sample No. 1 shows a quantity of surfacing granules, and Sample No. 2 some filler consisting of a very fine mineral. These samples of mineral were obtained from the sample of the top portion of the shingle and separated by using a No. 100 mesh screen. In some cases some roofing sand was found which was separated from the mineral filler and granules by use of a somewhat coarser screen than the No. 100, generally a No. 65.

After analyzing the composition of the 2x3-inch samples the weights of all ingredients were projected to a 108 square feet basis. This process multiplies any possible error, however, seemed desirable in order to put the information on a common basis with other researchers and manufacturers.

Findings of Composition Analysis

Thick-butt asphalt shingles

Fifteen different shingles with varying cross section were originally analyzed. The numerical findings are listed in Table 3 and presented graphically in Fig. 30. The values shown are averages of the duplicate analyses made. Shingle No. 6 was analyzed for composition only and not subjected to the physical tests because of an inadequate number of sample shingles. Any further mention of this shingle in the results and discussion has been omitted.

Table 3

Composition of Thick-butt Asphalt Shingles - Embossed

No. of shingle hex-tab	Total shingle: Wt/108 sq ft lbs	Total shingle: Thickness ins	Felt: Wt/108 sq ft lbs	Felt: Thickness ins	Felt: Portion of total %	Felt: Saturation %	Bitumen: Top wt/108 sq ft lbs	Bitumen: Bot. wt/108 sq ft lbs	Bitumen: Sat. wt/108 sq ft lbs	Bitumen: Total asphalt %	Mineral: Filler wt/108 sq ft lbs	Mineral: Gran. wt/108 sq ft lbs	Mineral: Filler as part of coat %	Mineral: Total mineral %	Back dusting min. lbs
1 Butt	130.0	.179	11.4	.059	8.8	197	27.0	---	22.4	38.0	13.4	56.3	34.9	53.3	1.0
1 Top	62.0	.115	11.2	.059	18.1	197	5.3	---	22.0	43.9	3.0	20.1	34.9	38.2	1.0
3 Butt	106.8	.176	12.2	.069	11.5	191	19.4	3.7	23.4	43.6	6.7	37.0	23.2	44.9	7.5
3 Top	85.0	.135	11.6	.069	13.7	191	11.5	3.7	22.2	42.9	4.5	25.7	22.8	43.4	7.5
4 Butt	123.8	.188	12.3	.071	10.0	181	29.2	1.3	22.1	42.9	15.3	40.6	33.8	47.1	1.5
4 Top	84.9	.144	12.6	.071	14.8	181	12.1	1.3	22.9	42.1	6.2	27.8	31.0	43.1	1.5
6 Butt	115.8	----	11.2	.067	9.7	195	22.1	1.0	21.9	38.7	9.8	48.8	29.7	51.7	0.8
6 Top	66.5	----	10.8	.067	16.3	195	6.9	1.3	21.0	44.7	2.9	20.8	27.1	39.2	0.8
10 Butt	111.3	.153	11.2	.055	10.0	179	18.5	1.5	20.1	36.3	15.9	43.0	44.4	53.7	0.5
10 Top	76.4	.112	10.8	.055	15.0	179	8.4	1.1	19.3	39.4	6.7	28.5	44.0	33.0	0.5
13 Butt	116.0	.186	11.3	.061	9.7	177	30.1	2.2	20.1	45.9	20.5	30.2	39.4	44.4	0.8
13 Top	72.3	.114	11.4	.061	15.8	177	8.3	1.4	20.4	41.8	6.0	23.2	38.6	42.5	0.8
14 Butt	105.5	.176	11.4	.059	10.8	153	15.5	13.4	17.5	44.8	16.4	29.7	36.9	44.4	7.8
14 Top	83.3	.146	11.8	.059	14.2	153	14.9	0.7	18.0	40.2	9.0	29.0	36.9	45.6	0.8
16 Butt	125.9	.197	13.7	.071	10.9	177	19.4	14.9	24.2	46.6	21.4	29.0	38.5	42.7	5.6
16 Top	104.6	.168	14.2	.071	13.6	177	17.7	1.1	25.2	38.5	11.8	31.9	38.5	44.5	0.6
17 Butt	113.8	.166	11.5	.060	10.1	204	12.2	13.9	23.4	43.3	23.0	30.3	47.6	46.6	1.2
17 Top	94.9	.137	11.4	.060	12.0	204	12.2	1.8	23.1	39.7	12.6	31.6	47.5	48.4	1.2
19 Butt	111.6	.174	11.6	.059	10.4	175	23.2	1.1	20.4	39.7	17.0	37.0	40.6	49.9	0.8
19 Top	82.2	.144	11.7	.059	14.2	175	8.9	1.0	20.6	37.2	7.2	31.3	42.2	48.6	1.3
21 Butt	127.5	.180	11.8	.063	9.2	188	24.9	8.3	22.2	43.7	23.5	36.0	41.5	47.0	1.5
21 Top	94.5	.151	11.1	.063	11.7	188	10.1	8.1	20.9	42.2	12.6	30.1	40.7	45.9	1.5
26 Butt	118.2	.170	11.9	.062	10.1	167	20.6	0.7	19.8	33.7	8.8	56.1	28.6	55.8	0.9
26 Top	76.9	.126	11.6	.062	15.1	167	14.0	1.1	19.4	44.9	6.5	24.0	22.0	40.6	0.6

(Continued on next page)

Table 3 (Cont'd)

Smooth

No. of shingle hex-tab	Total shingle: Wt/108 sq ft lbs	Total shingle: Thickness ins	Felt: Wt/108 sq ft lbs	Felt: Thickness ins	Felt: Portion of total %	Felt: Saturation %	Bitumen: Top wt/108 sq ft lbs	Bitumen: Bot. wt/108 sq ft lbs	Bitumen: Sat. wt/108 sq ft lbs	Bitumen: Total asphalt %	Mineral: Filler wt/108 sq ft lbs	Mineral: Gran. wt/108 sq ft lbs	Mineral: Filler as part of coat %	Mineral: Total mineral %	Mineral: Back dusting min. lbs
9N Butt	115.9	.160	12.5	.061	10.8	185	21.2	1.3	22.9	39.3	19.1	37.4	46.0	50.1	0.7
9N Top	67.7	.116	12.1	.061	17.9	185	5.0	1.3	22.4	43.4	4.4	19.6	44.7	38.6	0.7
11N Butt	118.6	.159	11.5	.056	9.7	164	19.3	0.7	18.7	32.9	14.1	52.2	41.8	57.4	1.1
11N Top	62.0	.116	11.3	.056	18.2	164	6.7	1.0	18.4	42.8	5.7	18.1	43.7	39.0	1.1
24N Butt	123.8	.175	11.3	.066	9.1	203	22.3	---	23.0	37.0	8.9	56.8	29.0	53.9	0.9
24N Top	73.9	.130	11.1	.066	15.0	203	7.8	---	22.5	42.8	3.0	26.0	31.9	42.4	0.9

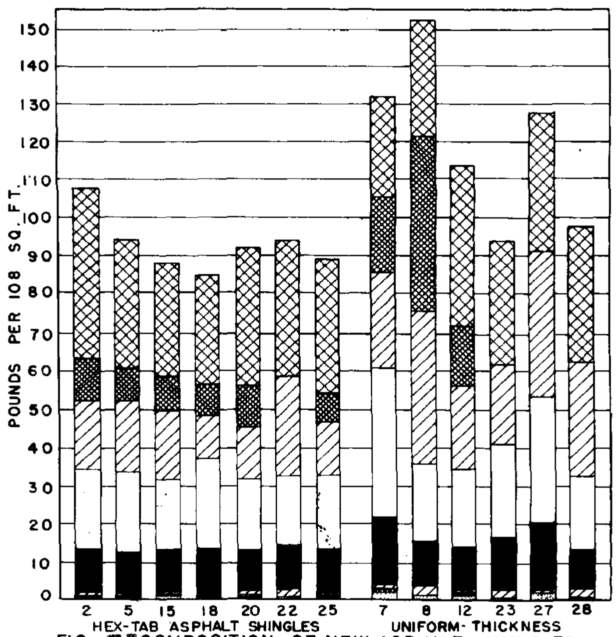


FIG. 31 COMPOSITION OF NEW ASPHALT SHINGLES.

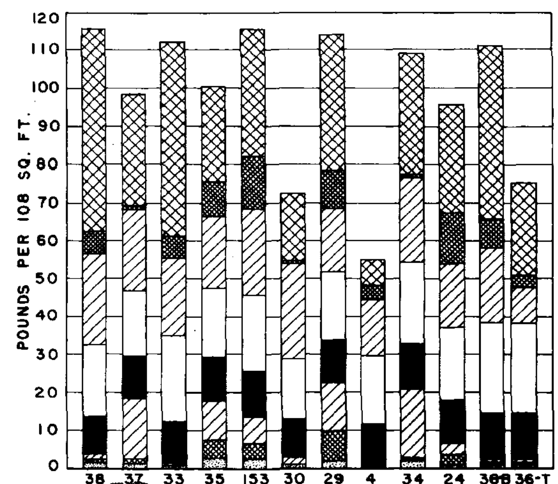


FIG. 32 COMPOSITION OF SOME WIND DAMAGED ASPHALT SHINGLES.

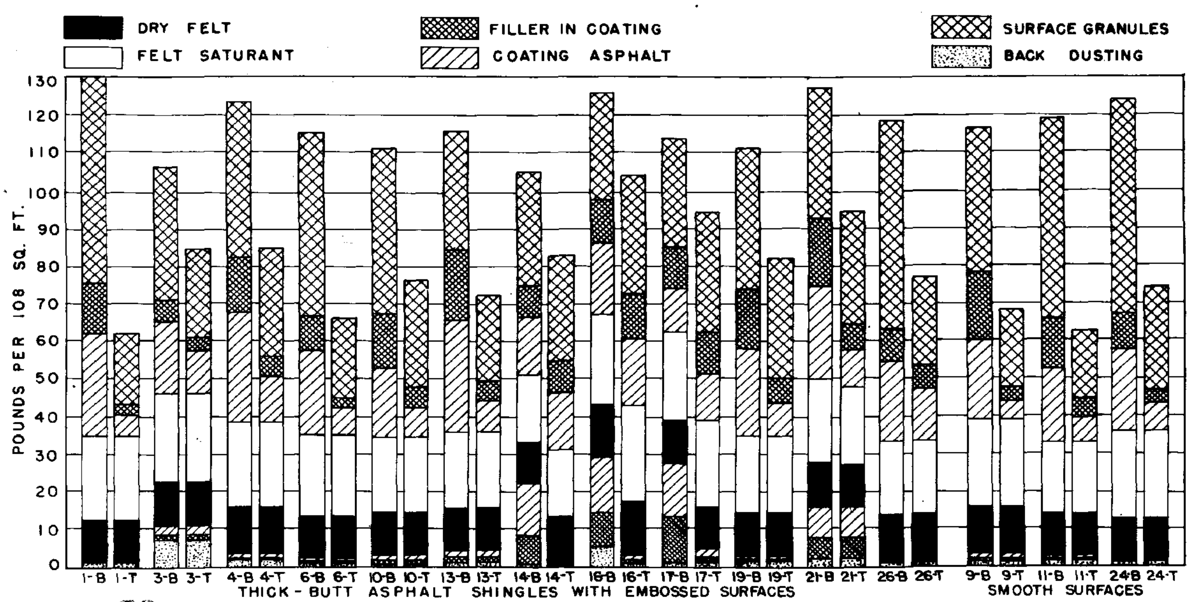


FIG. 30 COMPOSITION OF NEW THICK-BUTT ASPHALT SHINGLES.

Of the 14 shingles in this group of varying cross sections, one, No. 21, was a tapered-type 10" shingle and the rest were thick-butt types. Of the thick-butt shingles, one, No. 4, was a four-tab shingle designed for a 4-inch exposure. One other thick-butt shingle was a 10" shingle designed for a 4-inch exposure also. The remainder of the thick-butts were of the standard 12" design with three tabs and 5-inch cut-outs. Three of the 14 thick-butt shingles had smooth surfaces while the rest were embossed.

Considerable variance in the composition of these thick-butt shingles was found even though the author had been led to believe by some manufacturers of asphalt shingles that there was very little. Fig. 30 shows at a glance the variance of the total weights of the shingles as well as the weights of the individual ingredients. The bars of this graph are graduated in pounds per 108 square feet the same as the figures given in Table 3. Two bars are shown for each thick-butt shingle, one for the top or thin portion and the other for the thick-butt portion. The bars are divided and shaded differently to designate the various ingredients in the sequence that they would be found in the actual shingle, with the exception of the bitumen coating and the mineral filler and the felt and saturant which in actuality are found together but divided on this graph. In the order shown on the graph the top two shaded portions represent the total mineral of the top portion and the next lower two areas represent the total bitumen in the top coating and felt.

Considerable variance is noted in the back coating, that is, the total amount of material below the felt represented by the black portion of the bar graph. Shingles No. 1, 24 and 26 showed evidence of no protective back coating other than the back dusting amounting to less than a pound of material per 108 square feet. Shingle No. 3 had an exceptionally heavy coating of dusting but very little back coating otherwise. Shingle No. 21 had a heavy back coating on both the thick-butt and thin-top with about an average amount of dusting material, while shingles No. 14, 16 and 17 had a very thick back coating on the thick-butt portion of the shingle only. The varying back coating of the latter three shingles made the only significant difference between the thick-butt portion and thin-top portion of these shingles; while in all other shingles the back coatings were uniform throughout and the differences between top and butt sections were brought about by cutting down the amount of surfacing mineral and the amount of top coating. In all cases except the tapered shingle, No. 21, the felt weight and amount of felt saturant were materially the same in both top and butt portions of the shingles.

The very important point to be noted in the composition analysis of the thick-butt type shingles is the great reduction, in many cases, of the materials in the top part as compared to the butt portion. The thin-top of shingle No. 1, for example, has less than half the total amount of material as the thick-butt portion. The butt portion of this shingle is fairly heavy; however, it is noted that over 50 per cent of the total materials in the shingle are minerals.

The amount of filler mineral in the bitumen coatings is also noticed to be quite different among the thick-butt shingles, as represented by the darker cross-hatched areas of the bars. The amounts vary from slightly over 22 per cent of the total amount of coating, bitumen and filler, for Shingle No. 3 to slightly over 47 per cent for Shingle No. 17.

The parts saturant in the felts of the various thick-butt shingles varied from a minimum of 153 parts per 100 for Shingle No. 17.

Hex-tab asphalt shingles

The composition of the seven hex-tab type asphalt shingles analyzed is shown in Table 4 and graphically on Fig. 31. The seven shingles included one with a rounded-type tab and one with two tabs. They are, respectively, Shingle No. 20 and 22. Shingle No. 2 5 was of the three-tab design; however, it was four inches longer than the standard 36" shingles and designed for 4-inch exposure instead of the more common 5-inch exposure. The remainder of the shingles were of the more common three-tab 36" hex-tab type.

Table 4

Composition of Hex-tab Asphalt Shingles

No. of shingle hex-tab	Total shingle: Wt/108 sq ft lbs	Total shingle: Thickness ins	Felt: Wt/108 sq ft lbs	Felt: Thickness ins	Felt: Portion of total %	Felt: Saturation %	Bitumen: Top wt/108 sq ft lbs	Bitumen: Bot. wt/108 sq ft lbs	Bitumen: Sat. wt/108 sq ft lbs	Bitumen: Total asphalt %	Mineral: Filler wt/108 sq ft lbs	Mineral: Gran. wt/108 sq ft lbs	Mineral: Filler as part of coat %	Mineral: Total mineral %	Mineral: Back dusting min. lbs
2N	107.1	.161	11.7	.063	10.9	175	18.6	1.1	20.4	39.0	11.0	43.6	31.1	49.8	0.5
5N	94.2	.146	10.7	.057	11.4	187	18.8	1.0	21.2	44.5	8.7	32.1	30.6	43.9	0.2
15N	88.0	.136	11.4	.060	12.9	162	18.0	0.9	18.5	42.4	9.8	29.2	36.1	44.8	0.2
18N	85.0	.132	12.3	.067	14.5	189	11.7	0.5	23.3	41.3	8.2	28.5	41.2	44.2	0.3
22N	94.0	.147	11.3	.060	12.0	163	26.2	2.4	18.3	49.2	----	36.0	----	38.8	0.5
25N	88.9	.139	11.5	.059	13.0	173	13.7	0.8	19.5	38.5	8.1	35.2	36.3	48.9	0.5
20N	92.1	.141	10.8	.061	11.8	175	13.2	1.0	18.9	36.1	11.7	36.4	45.2	52.2	0.4

Very little back coating or dusting was noted on any of this group of shingles. The felt of Shingle No. 18 was found to be about a pound heavier per 108 square feet than the other hex-tab shingles, resulting in a higher amount of saturant bitumen than the others. Part of the high amount of saturant bitumen was due to the 189 parts saturation as compared to lower values for the others, down to 162 parts. This shingle was low in coating bitumen, however, with a comparatively high percentage of filler in the coating. Shingle No. 22 shows a noted difference from the others inasmuch as no coating filler is in evidence as compared to the amounts in the other coatings varying from 30 to 41 per cent.

As a group, the total weights of the hex-tab type shingles are somewhat less than other types of shingles on a 108 square foot basis, and particularly on a laid basis because of the 50 per cent reduction in the overall size of the tabs.

Uniform-thickness asphalt shingles

The small group of six uniform-thickness, square-tab type shingles shown in Table 5 has a wide variance in overall weights and also in their respective composition. Two of the shingles, No. 7 and 27, have a considerably heavier felt than average, being over 17 pounds per 108 square feet

Table 5

Composition of Uniform-thickness Asphalt Shingles

No. of shingle: uniform thickness	Total shingle: Wt/108 sq ft lbs	Total shingle: Thickness ins	Felt: Wt/108 sq ft lbs	Felt: Thickness ins	Felt: Portion of total %	Felt: Saturation %	Bitumen: Top wt/108 sq ft lbs	Bitumen: Bot. wt/108 sq ft lbs	Bitumen: Sat. wt/108 sq ft lbs	Bitumen: Total asphalt %	Mineral: Filler wt/108 sq ft lbs	Mineral: Gran. wt/108 sq ft lbs	Mineral: Filler as part of coat %	Mineral: Total mineral %	Back dusting min. lbs
7N	131.8	.192	17.6	.095	13.3	223	24.4	1.2	39.2	49.5	21.2	26.6	49.6	37.2	1.7
8N	151.8	.210	11.4	.062	7.5	180	39.8	2.8	20.6	42.4	45.9	30.1	53.6	50.0	1.0
12N	114.0	.166	10.8	.066	9.5	191	21.8	1.0	20.6	38.4	16.3	42.1	42.1	52.2	1.2
23N	94.2	.151	13.6	.072	14.5	183	20.6	2.2	24.8	50.0	----	32.7	----	35.5	0.4
27N	127.6	.208	17.2	.095	13.5	193	37.7	1.1	33.2	56.2	----	35.9	----	30.3	2.7
28N	98.0	.155	10.1	.058	10.3	192	29.6	2.7	19.5	53.6	----	34.9	----	36.0	0.5

in both cases. On the other hand, Shingle No. 28 has only slightly more than a 10-pound felt per 108 square feet. The parts saturant in the heavy felt of Shingle No. 7 is 223 parts per 100 of felt, which results in an exceptionally high total amount of felt saturant bitumen. This shingle also has a very high percentage of filler in the coating, being very close to 50 per cent, or in other words, the coating is made up of nearly equal parts of bitumen and mineral filler by weight.

The filler in most all of the shingles was of a very fine texture, being of calcium or clay origin; however, that of Shingle No. 8 was of an asbestos fibre material. The shingle was made up of an exceptionally heavy coating which was in turn made up of nearly equal parts of bitumen and asbestos fibre. The felt, felt saturant, and top granules were not in any heavier proportion than that of the average-weight shingles.

Shingle No. 12 is what might be called an average-weight shingle with a fairly high amount of mineral filler, making up about 42 per cent of the coating.

Shingles No. 23, 27 and 28 vary mainly from the others in that they have no coating filler. They vary among each other mainly in that they have different weights of felt. Shingle No. 28 is heavier than No. 23, however, with a lighter felt.

Damaged asphalt shingles

Cleveland (2), in his roofing study made in 1948 for the Iowa Agricultural Experiment Station, gathered many samples of wind-damaged asphalt shingles as well as pertinent information concerning the life history of the shingles. A composition analysis was run on 11 of these shingles picked at random from the supply gathered. Fig. 32 shows graphically the results of the analysis and Table 7 the specific numerical findings.

As mentioned previously, no conclusions can be drawn from this brief analysis; and furthermore, it is doubted that an extended analysis of such would produce really significant data because of the lack of correlation material such as initial composition, exact age, varying type of exposure, and similar methods of application.

Table 6 sets forth what pertinent information was available on these 11 damaged shingles.

Many of the damaged shingles had only small amounts of filler in evidence, and none an exceptionally high amount. An interesting point of this analysis is that five of the 11 shingles had very heavy back coatings, from which an implication might be drawn that such a coating does not add anything to the wind-resisting capabilities of the shingle. It is the author's untested hypothesis that a thick back coating in effect weakens the shingle in bending, because

Table 6

*Pertinent Data on the Eleven Damaged Shingles Analyzed

No. of shingle	Age	Type of building	Type of deck	Thickness of shingle ins.	Nail dist. from edge ins.	Type of shingle	Nails per sq.	Cause of failure	Comments
4	16	Dwelling	Wood shingles	0.120	5.5	Hex-tab	344	Broke off	
24	8	Dwelling	Wood shingles	0.125	6.0	Square-tab	320	Broke off	Some hail
29	1	Poultry house	Solid sheathing	0.170	5.5	Square-tab	480	No damage	
30	22	Dwelling	Solid sheathing	0.150	6.0	Hex-tab	252	Broke off	Worn out
33	4	Dwelling	Wood shingles	0.160	6.0	Square-tab	320	Broke off	
34	6	Dwelling	Wood shingles	0.180	6.5	Square-tab	300	Broke off	Some sealed
35	2	Barn	Wood shingles	0.170	7.5	Square-tab	440	Broke off	Poor nailing
36	4	Poultry house	Solid sheathing	0.160	6.5	Square-tab	320	Broke off	Poor sheathing
37	4	Dwelling	Wood shingles	0.165	6.0	Square-tab	320	Broke off	Some sealing
38	1	Barn	Solid sheathing	0.170	6.0	Square tab	320	Broke off	Some pulled past nail head
153	2	Dwelling	Asphalt shingles	0.150	6.0	Square-tab	320	Broke off	

*Data taken from survey of roofing damage made by Cleveland (2) in 1948

Table 7

Composition of Damaged Asphalt Shingles

No. of shingle old	Total shingle: Wt/108 sq ft lbs	Total shingle: Thickness ins	Felt: Wt/108 sq ft lbs	Felt: Thickness ins	Felt: Portion of total %	Felt: Saturation %	Bitumen: Top wt/108 sq ft lbs	Bitumen: Bot. wt/108 sq ft lbs	Bitumen: Sat. wt/108 sq ft lbs	Bitumen: Total asphalt %	Mineral: Filler wt/108 sq ft lbs	Mineral: Gran. wt/108 sq ft lbs	Mineral: Filler as part of coat %	Mineral: Total mineral %	Back dusting min. lbs
38	115.0	.170	10.3	.058	8.95	186	23.4	1.7	19.1	38.9	6.2	53.0	20.2	52.0	1.3
37	98.5	.165	11.1	.054	11.3	155	21.7	15.8	17.2	55.9	1.9	29.7	4.8	32.8	1.5
36 Butt	111.1	.160	11.8	.063	10.6	203	20.1	1.3	24.0	40.3	7.4	45.9	25.6	49.1	0.6
36 Top	75.2	.120	11.7	.065	15.6	203	9.3	1.3	23.8	45.7	3.6	24.2	25.6	38.8	0.6
33	111.9	.160	10.8	.058	9.7	210	20.5	0.3	22.7	38.3	6.1	51.9	22.7	52.1	0.7
35	100.3	.170	11.7	.064	11.7	157	19.1	10.1	18.4	46.8	13.4	26.3	31.6	41.4	2.8
153	115.4	.150	12.0	.062	10.4	171	22.8	6.9	20.4	43.2	17.3	33.2	36.9	46.4	2.4
30	72.2	.150	9.9	.052	13.8	155	25.6	2.2	15.4	61.3	0.8	16.6	2.7	25.0	0.7
29	114.0	.170	11.1	.061	9.7	165	16.8	12.5	18.3	41.7	17.4	37.9	37.2	48.5	2.1
4	54.9	.120	11.0	.059	20.0	165	14.8	0.3	18.1	57.7	4.1	8.2	21.3	22.2	0.1
34	109.0	.180	11.5	.064	10.5	188	22.5	18.2	21.6	58.1	1.4	32.4	3.0	31.2	2.1
24	95.8	.125	10.9	.056	11.3	178	16.8	3.2	19.3	41.1	16.3	28.8	45.0	47.6	1.1

the felt is removed partially from the tension side of the shingle and placed closer to the neutral axis. The felt is the only part of an asphalt shingle that will take any appreciable amount of tension, so should be placed in the most advantageous position for that capacity.

Only one thick-butt shingle, No. 36, was found out of the 11. Others of the 11 may have been such; however, only samples were available of the thick-butt portion of the shingle and no other evidence was at hand as to the type of shingle.

Shingles No. 30 and 4 had lost a good portion of their coating mineral during the years of exposure. Nearly all of it had cracked from No. 4. No. 30 was in all aspects a very light shingle, having a felt weighing only 9.9 pounds per 108 square feet with only 155 parts saturant in it.

None of the damaged shingles analyzed were exceptionally heavy, with only a few totaling more than 110 pounds per 108 square feet.

PHYSICAL TESTS OF ASPHALT SHINGLES

Object of Tests

A bending test was designed from which comparative wind-resisting capabilities of asphalt shingles could be measured. Once having a comparative wind resisting rating for a shingle, correlations were made with the composition and type of shingle as determined from the first phase of the experimental investigation of this study. The primary purpose was to determine to what extent the various components of a shingle played in determining its wind-resisting characteristics. Secondary purposes were to establish the extent various methods of application play in determining the wind resistance of any given shingle and to determine the effect of temperature on the wind resistance of asphalt shingles.

A test which could be correlated with actual wind velocities and actual conditions was not deemed feasible, because of the numerous variables encountered in practice, such as protection of roof by buildings and trees, orientation of roof, pitch of roof, consistency of applications, and variance of wind velocities over various portions of the roof in any one windstorm. On the other hand, a test designed to measure the actual wind-resisting ability of a shingle in a controlled manner was considered to be the most informative in this case. If the effects the various ingredients of a shingle and the various methods of application have upon its wind-resisting ability are known, a wind-resistant shingle can be designed and applied.

It is not believed by the author that tests in wind tunnels on asphalt shingles offer a good measure of the wind-resisting capacity of a shingle. Due to the constricted cross section of most wind tunnels the velocities and the effect of them on asphalt shingles cannot be correlated satisfactorily with field conditions. The author, as well as many other investigators, has observed in the field that wind damage to asphalt shingles generally comes from continuous blowing-up or bending, which results in the shingle cracking or tearing off or a combination of both taking place after a shingle's fatigue resistance has been exhausted. In contrast to the above described behavior under actual conditions, asphalt shingles in a wind tunnel do not flap. They merely bend up slowly as the wind velocity is increased in the tunnel.

It was felt by the author that a controlled test, which would eliminate the many variables, but still measure the initial resisting force of a shingle as well as its resistance with repeated bending under various methods of application and in different temperatures, would offer the best index of the wind-resisting characteristics of a shingle. It was also deemed desirable to have the test as near mechanical in its operation as possible so as to eliminate the human error.

Description of Equipment

The bending apparatus as designed and constructed, to fulfill the objectives as set forth in determining a wind resistance index for asphalt shingles, is shown by photograph in Figures 33-36 and in detail by the illustration of Fig. 37. The motor, gear reduction box and rotating arm were built in one assembly as a portable unit so it could be mounted on any table or work bench. Fig. 33 pictures this portion of the equipment quite clearly. The picture shows the equipment mounted with a spring balance in place ready to begin a bending test. Two "C" clamps are required to fasten this portion of the equipment down to the table. The rotating arm is geared down by pulley and gear box so it turns at the speed of 14 revolutions per minute.

Figures 35 and 36 show side views of the machine in action. In Fig. 35 the bending cycle is just beginning. The shingle is starting to bend upward. In Fig. 36 the shingle is shown bent to the maximum amount. It will be returned to the original position from that point. In all cases the shingles were applied in the regular manner to a

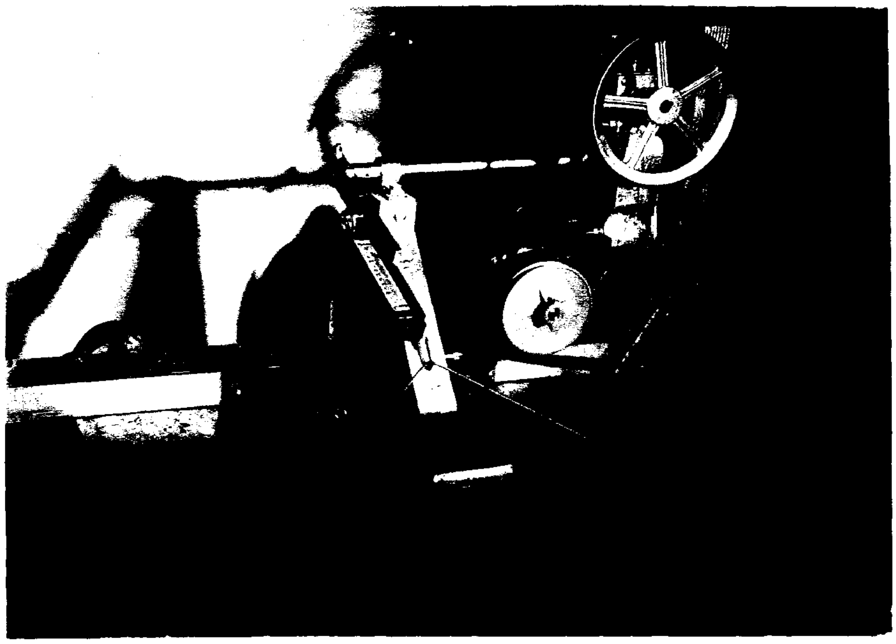


Fig. 33. Front View of Bending Apparatus

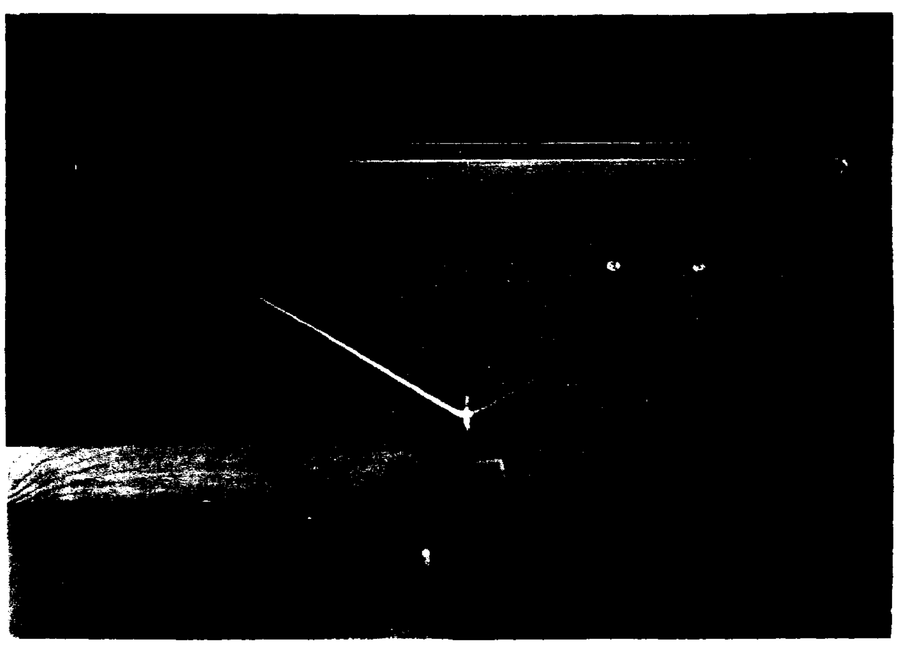


Fig. 34. Top View of Shingle in Position for Testing

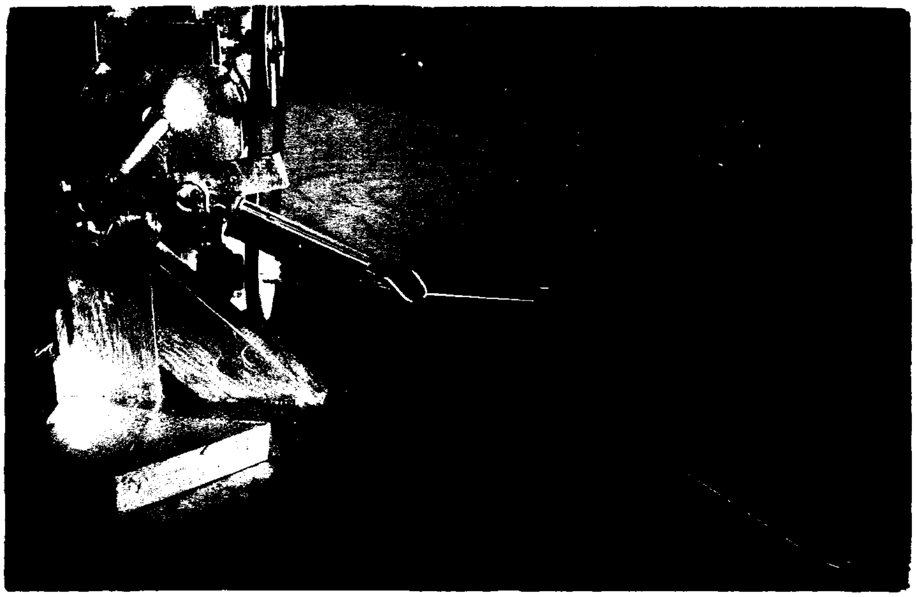


Fig. 35. View of Machine Beginning Bending Cycle

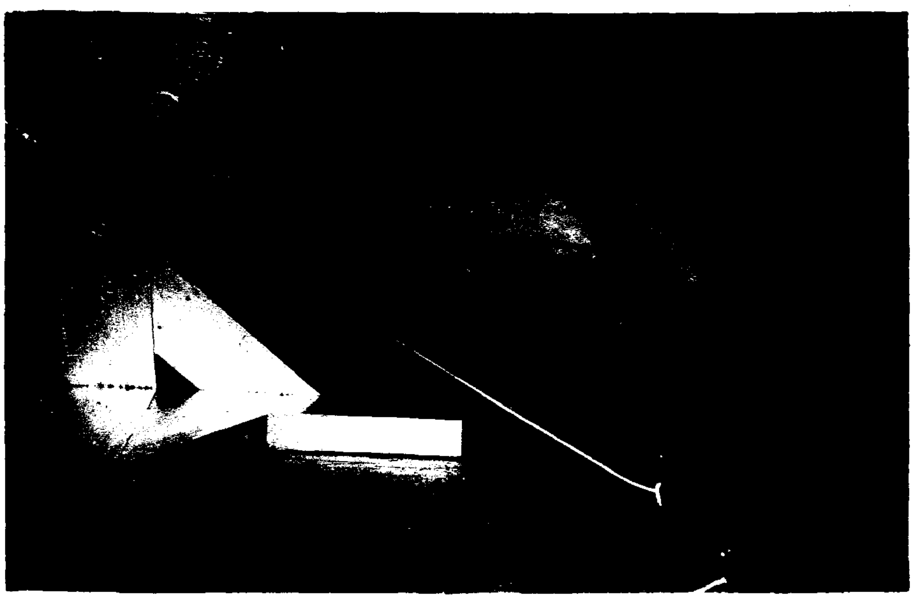


Fig. 36. View of Machine with Shingle in the Extreme Bending Position

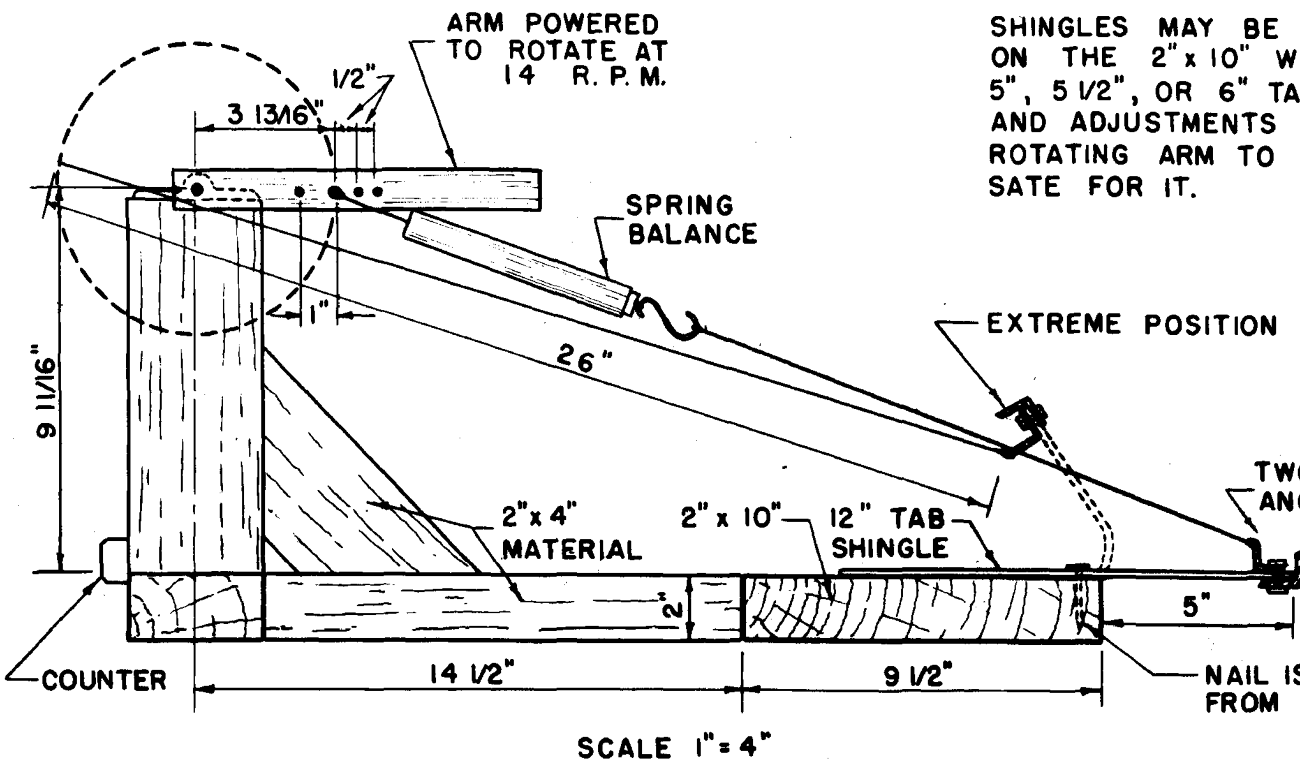
2x10-inch member. The 2x10 was also clamped with two "C" clamps which made it convenient for changing between tests.

The type of clamping device on the outer edge of the shingle may also be observed in Figures 35 and 36. Rather than being a channel as it might appear, it is two angles bolted together in the cut-outs of the shingles. The butt of the shingle is placed in between the two angles as shown in more detail in the illustration of Fig. 37. The detail drawing of this figure also gives the various dimensions of the bending machine.

A trip-type counting device was mounted on the back of the rotating arm upright so that the rotating arm would trip it on each revolution. This allowed for a count on the number of bends for each test shingle. The repetition bending was continued in each test until only a force of 10 pounds was required to bend the shingle. In some cases the test was continued to readings below this amount; however, all of them were brought down to at least 10 pounds.

The detailed side view of Fig. 37 also shows the adjustments allowable for various nailing distances. In all cases the shingles were nailed on the 2x10, five-eighths of an inch from the outer edge. The setting of the bolt in the rotating arm was adjusted in various holes depending on the exposure distance being used on the test shingles.

On all tests made, the forces required for the first five bends were recorded individually on the data sheets,



SHINGLES MAY BE APPLIED ON THE 2"x 10" WITH 4", 5", 5 1/2", OR 6" TAB EXPOSURE AND ADJUSTMENTS MADE ON ROTATING ARM TO COMPENSATE FOR IT.

FIG. 37. MACHINE FOR BENDING ASPHALT SHINGLES

and then the number of bends at each force divisible by five on down until the force of 10 pounds was reached. Also observation notes were made as to the type of failure.

Fig. 34 shows a top view of a shingle in the bending machine ready for the bending tests. The angle of this photograph from over the rotating arm is the same as many others taken for this study to show the nailing patterns and types of failure.

Method of Procedure

Experimental design

After considerable research into the design of experiments it was decided to set the tests of the 27 different types of shingles up as a factorial experiment. It was desired to determine an overall comparative index of bending resistance for the various types of shingles as well as to determine the effect of various methods of application. Cochran and Cox (3, p. 126) in their book entitled *Experimental Design* state in discussing factorial experiments as follows:

> In experiments designed to lead to recommendations that must apply over a wide range of conditions, subsidiary factors may be brought into an experiment so as to test the principal factors under a variety of conditions similar to those that will be encountered in the population to which recommendations are to apply.

A 6x3 factorial design was used for this series of tests; six different types of nailing patterns being used at three different levels of temperature. Eighteen tests of each type of shingle were made; that is, one test of each combination of a 6x3 factorial arrangement.

As mentioned previously, it was first desired to obtain a bending resistance index for each type of shingle tested. As stated by R. A. Fisher (5, p. 104) in his text on the Design of Experiments:

> ...this comparison will have the same precision as if the whole of the 96 trials had been devoted to testing the efficacy of one single component.

In the design of this study the experiment had 18 trials for each shingle type instead of the 96 spoken of in the example cited in the quotation above. Mr. Fisher (5, p. 104) goes on to say in speaking of experimental design, that:

> ...the first fact contributing to the efficiency of experiments designed on the factorial system, is that every trial supplies information upon each of the main questions which the experiment is designed to examine.

It might be argued that such a design loses precision because of the loss of replications as in this one where no absolute replications were made. In other words, no one shingle was tested under exactly the same conditions as to nailing and temperature as any other shingle of that type. In support of this Mr. Fisher (5, p. 114) states that:

> Although each test is only made in duplicate, yet all the primary questions, into which the difference among them may be resolved, are answered with the same precision as though the whole experiment had been devoted to each of these questions alone; the loss of absolute replication is made good by the hidden replication inherent in the factorial arrangement.

The efficiency of any experiment is of utmost importance in order to gain the most significant information with the least outlay of money and effort, and if no precision is lost in applying the treatments under various conditions, the scope of the experiment can be broadened materially. In summary, the factorial design of the physical tests allowed information to be gathered from a limited number of samples of each make and weight of available asphalt shingles, which not only pertained to the wind-resisting characteristics as related to shingle composition but also the effects of nailing at varying heights using various numbers of nails and tested at various temperature levels. Such a design also allows for the study of any interactions between the various combinations of conditions.

Tests made

In order to obtain significant information on the effects of number of nails, nailing distance, and temperature level on the wind-resisting characteristics of asphalt shingles, the 6x3 factorial arrangement was decided on.

This allowed for six different nailing patterns, as illustrated in Fig. 38, to be tested at three different temperature levels. For analysis purposes pertaining to the above mentioned three variables, each series of 18 tests run on each different type of shingle was considered as a replication. The 18 separate tests consisted of 18 separate treatments, as there was no absolute replication of treatments within one type of shingles.

Number of nails. Information on the important question of number of nails necessary in one strip shingle was desired. In order to obtain such information from this experiment some of the treatments were designed to use six nails in the application of each strip shingle and some only four. In the past the use of four nails has been more customary than six; however, more recently, since the manufacturers have become more conscious of wind damage, most specifications call for the use of six nails per strip shingle.

As may be noticed in Fig. 38 there were two treatments set up for a 5-5/8-inch nailing distance, one with six nails and one with four per strip shingle. Also with the 6-5/8-inch nailing distance treatments, one with six nails and one with four has been used. This duplication of treatments with different numbers of nails would have been accomplished for the 4-5/8-inch nailing distance also if it was possible to do so; however, with a shingle having a 5-inch cut-out it

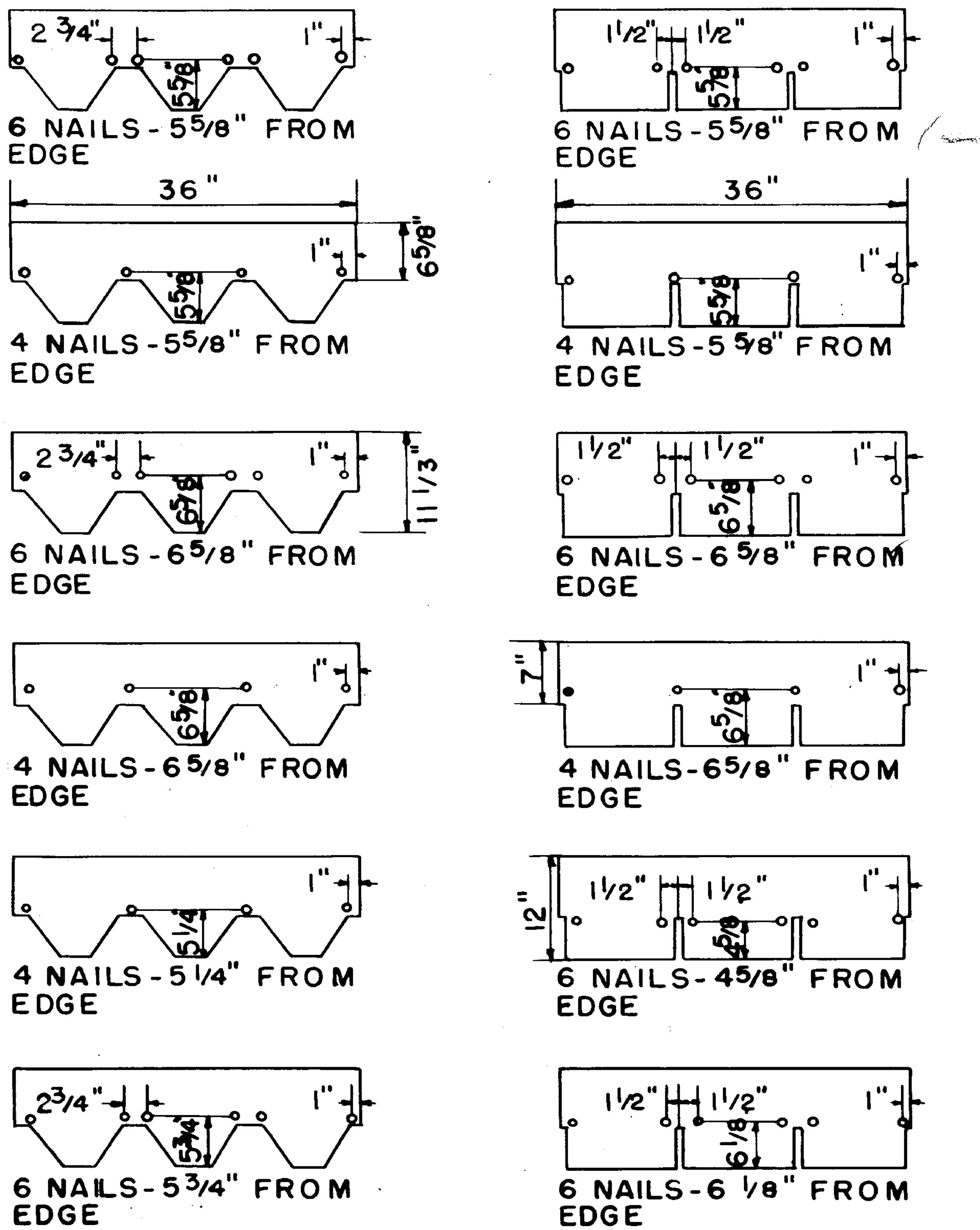


FIG. 38. THE SIX NAIL PATTERNS USED FOR ASPHALT SHINGLE BENDING TESTS

is impossible to use only one nail unless one is placed on one side of the cut-out and none on the other. This method was not felt practical nor to be one of common usage. The above treatments allowed for comparison of six nails with four under like conditions for two nailing distances.

Nailing distance. Three different nailing distances were at first contemplated for this investigation, one at 5-5/8 inches to represent the most common 5-inch exposure application, one at 4-5/8 inches to represent the more cautionary 4-inch exposure sometimes used, and one at 6-5/8 inches to represent the extremely high nailing application. However, after beginning the tests it was realized that, particularly with the thick-butt shingles, a nailing distance in between the 5-5/8 and 6-5/8 inch distances was very critical as well as the range where a good many of the nails are placed in practice. Fig. 38 shows the four different nailing distances used. This figure presents in detail the six nailing patterns used as applied to both the square-tab and the hex-tab shingle.

The fraction of 5/8 of an inch was used in all nailing treatments because most of the standard specifications put out by manufacturers with their products call for the nail to be placed 5/8 of an inch above the exposure line. No tab-type shingles are specified to be placed with a 6-inch exposure; however, in practice many shingles are applied with the common 5-inch exposure but with the nails up 6 inches or more from the bottom edge of the shingle. Cleveland (2) found in his observations of 87 damaged asphalt shingle roofs with 5-inch exposures that the average distance of the nails from the lower edge of the shingles was 6-1/3 inches. Inasmuch as many nails are actually placed up 6 inches and more from the bottom edge of the shingle, it was felt desirable to obtain test data in that range also. The 6-5/8-inch distance was chosen to keep a uniform distance from the 5-5/8-inch distance as the 4-5/8-inch is.

The 6-1/8-inch nailing distance was chosen for the fourth type of nailing distance treatment inasmuch as it is a halfway point between the 5-5/8-inch specified distance and the extreme distance of 6-5/8 inches. This nailing treatment was considered to be a critical one because in many of the thick-butt, thin-top type shingles the transition line of the thick to thin portion of the shingle was very close to this nailing distance.

Temperature levels. It was realized from the beginning that all tests would have to run at controlled temperatures in order to obtain comparable data. Inasmuch as no one temperature would be representative of field conditions when wind damage takes place, it was decided to run the tests at three temperatures, namely, 55°, 70°, and 85° F. This meant in other words that the six nailing treatments would be repeated at each temperature level and would in effect eliminate all absolute replications. It was felt that the three temperatures chosen would bring out the trend of the effect of temperature on the wind resistance of asphalt shingles in the range most windstorms occur. The use of different temperatures also allowed a study of the effect of different nailing patterns at different temperatures.

Testing techniques

The 486 separate bending tests of this investigation were made in a randomized manner. The shingles of the bundles minus the two shingles used for the composition analysis were assigned numbers in a randomized order. The bundles were then sorted and put in numerical order and separated into groups of six shingles. All shingles numbered one to six inclusive were tested at 55° F, 7 to 12 at 70° F, and 13 to 18 at 85° F.

The actual tests were then made by type of treatment. Each shingle of each type was treated with one nailing pattern in the order of the number of that type of shingle. For example, the 5-5/8-inch nailing with six nails was tested for each of the 27 shingles at one temperature level starting with shingle type No. 1 through No. 28. While the temperature control room was at that particular temperature level the other five nailing patterns were tested in turn for each of the shingles of each type.

Results of Factorial Experiment

Tabular results

The recorded data taken from the 486 separate bending tests on 27 different types of tab-type asphalt shingles are shown in Appendix 1. Data were taken on each shingle tested pertaining to its initial bending resistance in pounds and each successive bending force through bend No. 5. Beyond bend No. 5 only readings as to the number of bends at force readings in pounds divisible by 5 were taken. The readings recorded in the left part of the table therefore pertain to forces in pounds and the right half the number of bends at designated bending resistances.

The coding of the test number shown in the extreme left column of the tables is interpreted as follows: the first two numbers preceding the first dash represent the temperature at which the test was run, in degrees Fahrenheit; the number between the two dashes represents the number of nails used in the application of each strip shingle for test purposes; and the number following the second dash represents the distance in inches the nails were placed from the butt edge of the shingle for that particular test. For example, the test number 55-6-5-5/8 means the test was run at 55° F and the shingle was applied with six nails placed 5-5/8 inches from the butt edge of the shingle.

The table shows the tests for each type of shingle grouped by temperature level of the tests, with respective sub-totals. The grand total at the bottom representing the total of the first five forces for each of the 18 tests has been obtained by summing the data vertically as well as horizontally. Also given in the grand total line at the extreme right are the total number of bends for the 18 tests required to reduce the bending resistance of the shingles to 10 pounds.

Pictorial results

Figures 39 to 65 inclusive show each of the 27 types of shingles tested. The pictures were all taken at the 70° F temperature level after the bending test with six nails placed one-half inch above the recommended nailing distance for each particular shingle. For the standard 12-inch strip shingle this distance was 6-1/8 inches while for the shingles recommended for 4-inch exposure it was 5-1/8 inches and for the hex-tab shingles 5-3/4 inches. The number on each of photographed shingles designates its type number, as given in Tables 3, 4 and 5.

The nailing distance used for test shingles photographed was chosen because of the critical nature of placing the nails one-half of an inch above the recommended position with many of the thick-butt shingles. This is discussed in the latter part of the thesis in the analysis of the results.

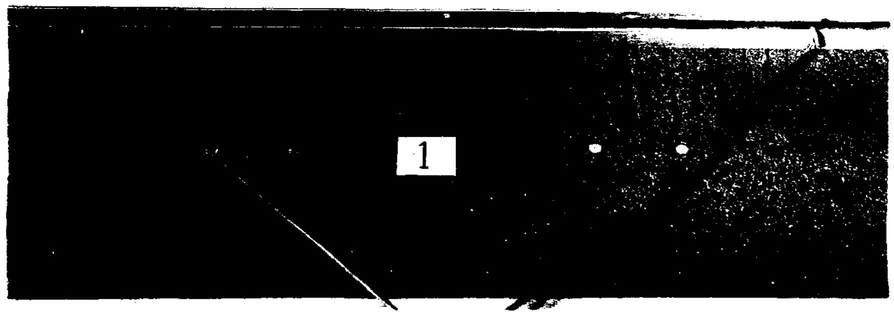


Fig. 39. A 12" Thick-butt Asphalt Shingle with Embossed Surface

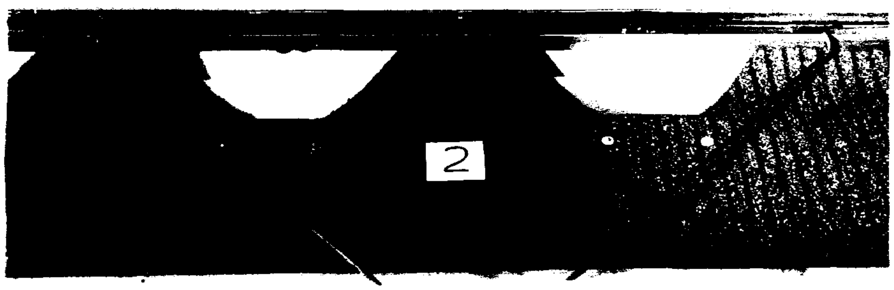


Fig. 40. A Three-tab Hex Shingle with Deep Vertical Embossing

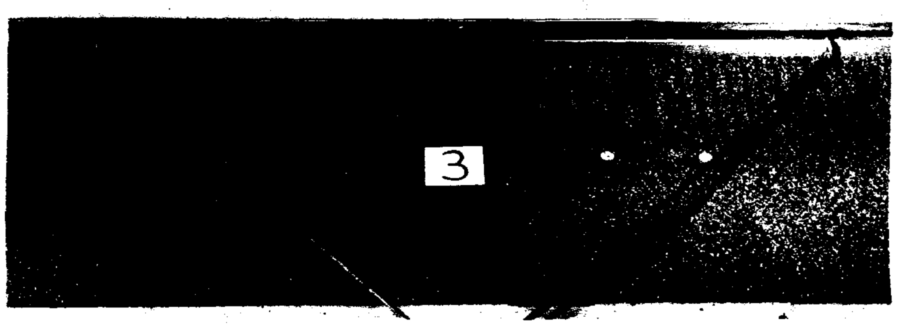


Fig. 41. A 12" Thick-butt Asphalt Shingle with Vertical Embossing

Fig. 42. A 12" Thick-butt, Four-tab Asphalt Shingle with Vertical Embossing and 4" Cut-Outs

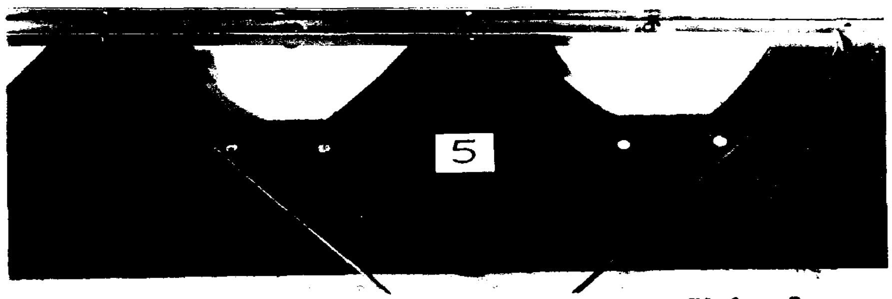


Fig. 43. A Three-tab Hex Asphalt Shingle with Embossing

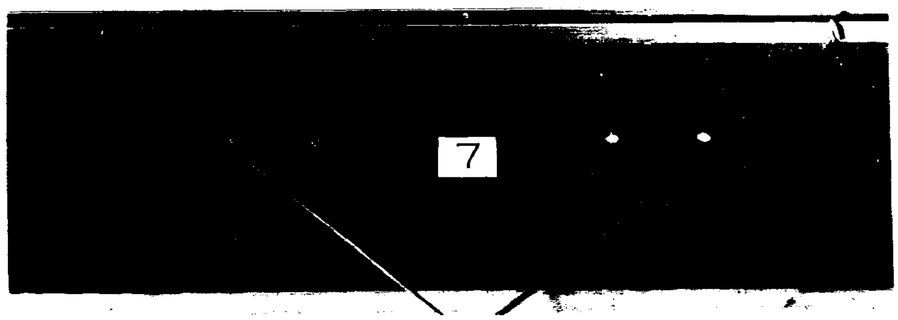


Fig. 44. A Heavy-Weight, Uniform-Thickness 12" Asphalt Shingle with a Smooth Surface

Fig. 45. A Heavy-Weight, Uniform-Thickness 12" Asphalt Shingle with a Smooth Surface

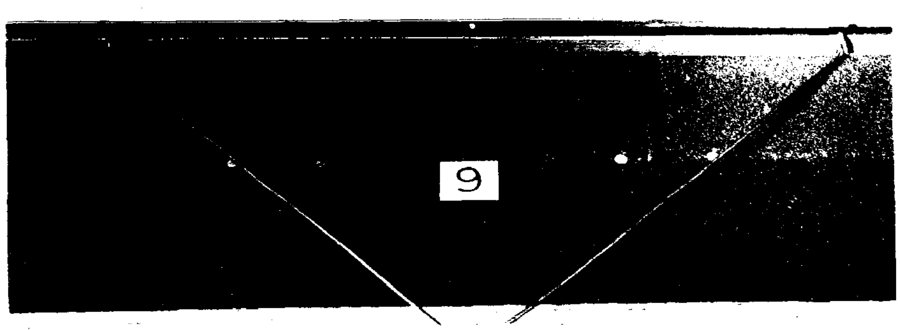


Fig. 46. A 12" Thick-butt Asphalt Shingle with a Smooth Surface

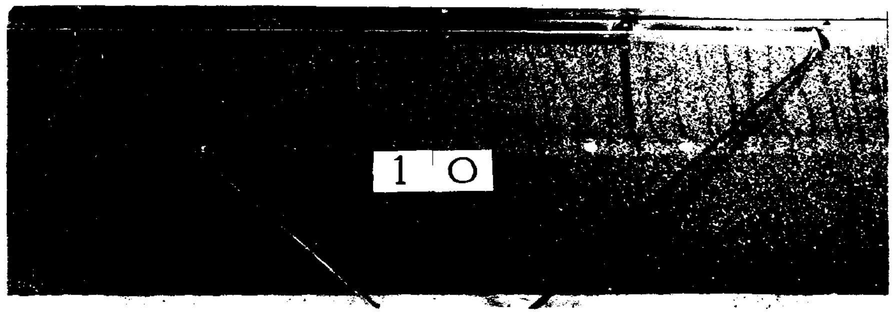


Fig. 47. A 12" Thick-butt Asphalt Shingle with Embossing; Shingle not Cut Out Properly

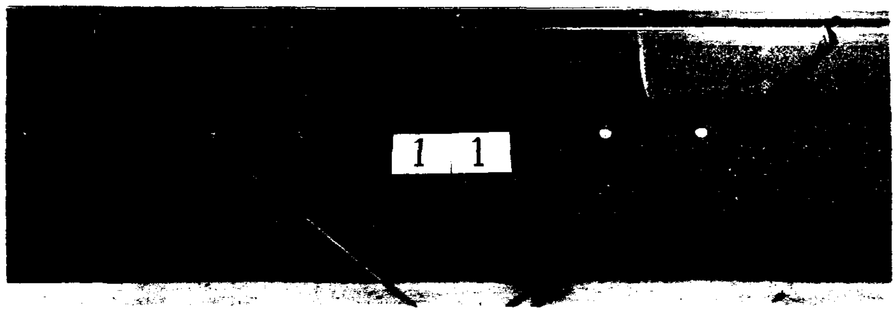


Fig. 48. A 12" Thick-butt Asphalt Shingle with Smooth Surface

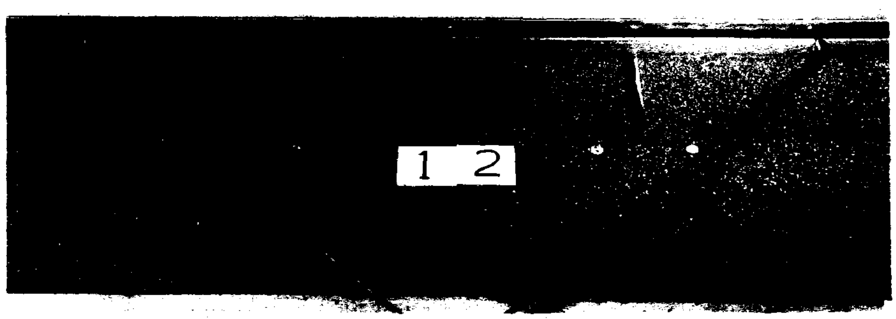


Fig. 49. A 12" Uniform-thickness Asphalt Shingle with Smooth Surface

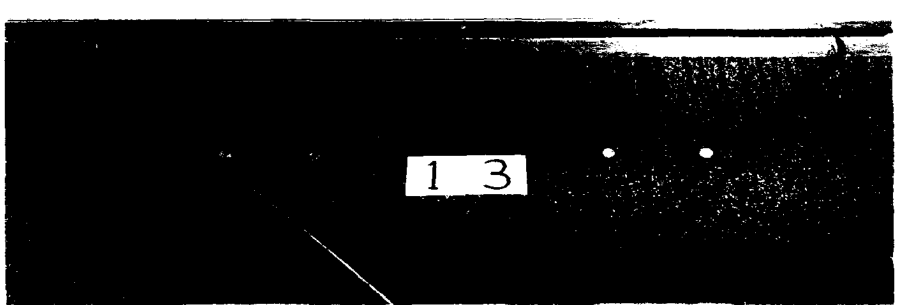


Fig. 50. A 12" Thick-butt Asphalt Shingle with Embossing

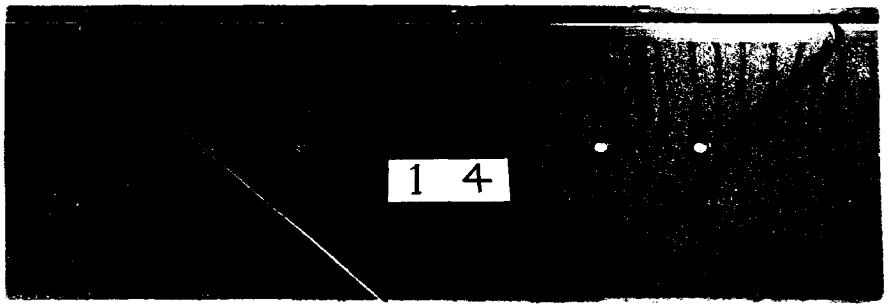


Fig. 51. A 12" Thick-butt Asphalt Shingle with Embossing

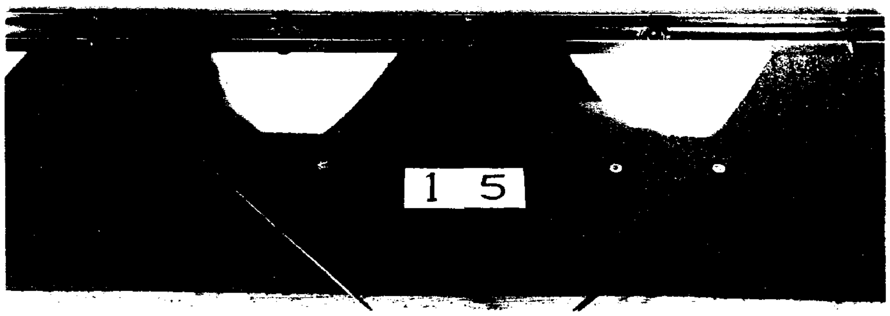


Fig. 52. A Three-tab Hex Asphalt Shingle with Embossing

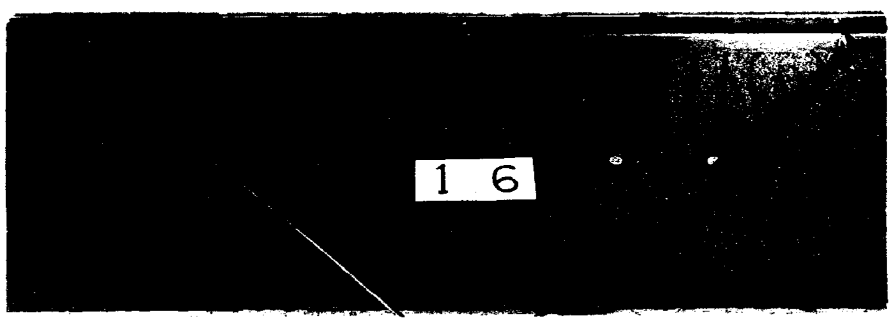


Fig. 53. A 12" Heavy-weight, Thick-butt Asphalt Shingle with Embossing

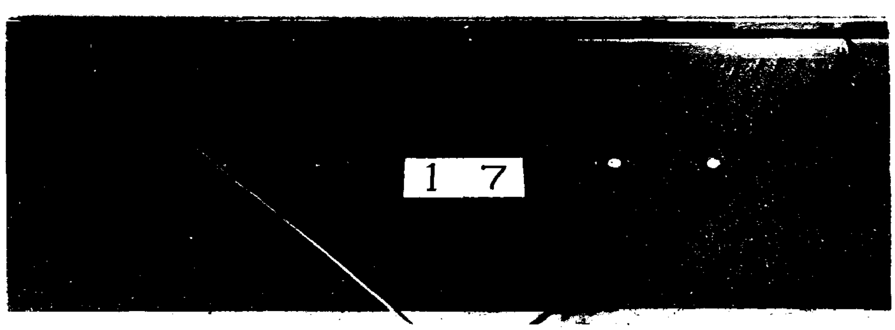


Fig. 54. A 12" Thick-butt Asphalt Shingle with Embossing

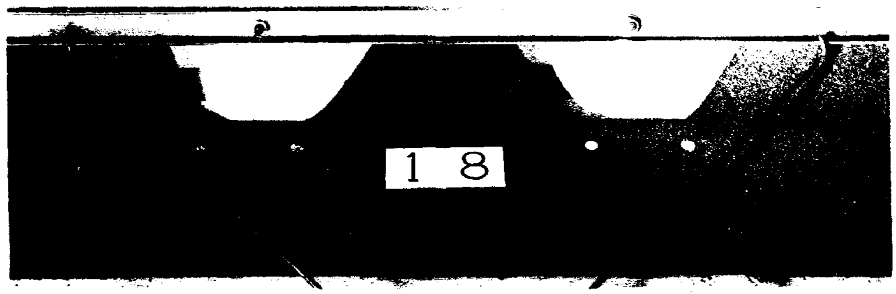


Fig. 55. A Three-tab Hex Asphalt Shingle with Smooth Surface

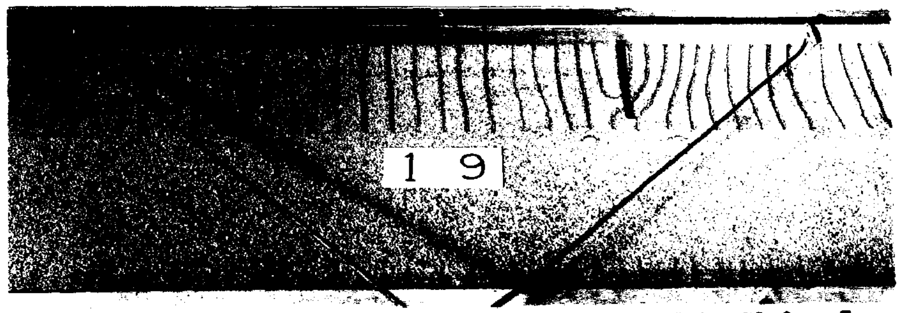


Fig. 56. A 12" Thick-butt Asphalt Shingle with Embossing Shingle Not Cut Out Properly

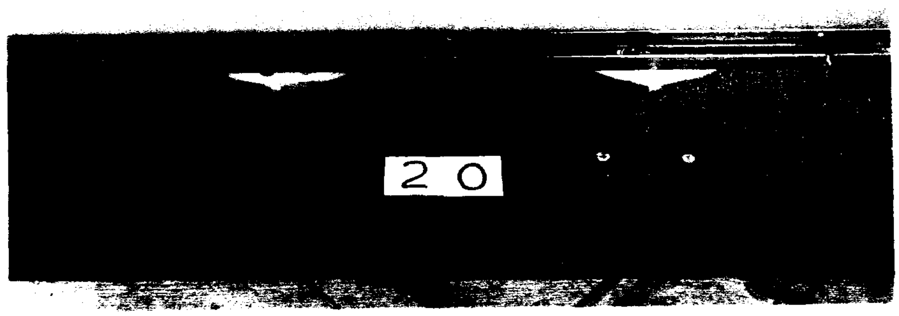


Fig. 57. A 10" Rounded-tab Type Asphalt Shingle with Embossing

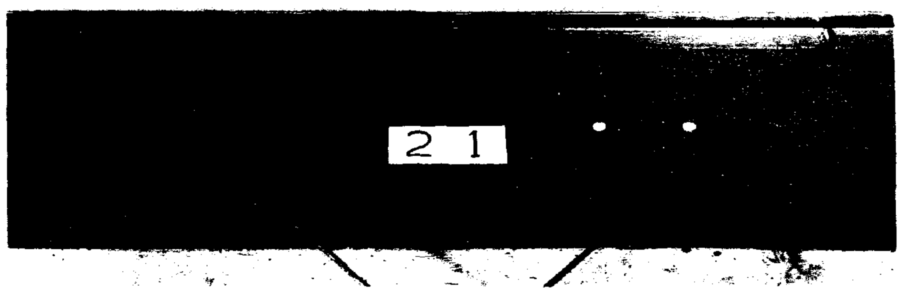


Fig. 58. A 10" Tapered-tab Type Asphalt Shingle with a Smooth Surface

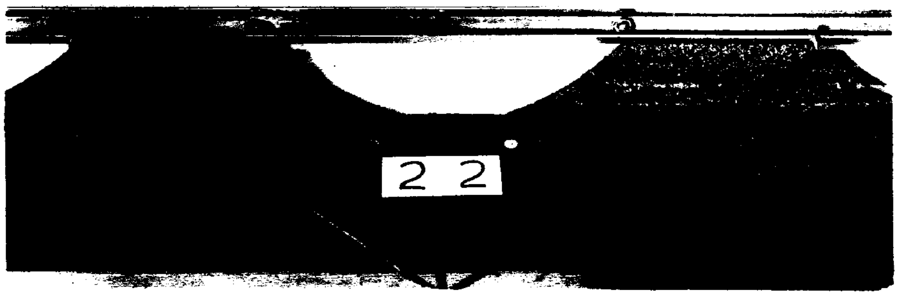


Fig. 59. A Two-tab Hex Asphalt Shingle with a Smooth Surface

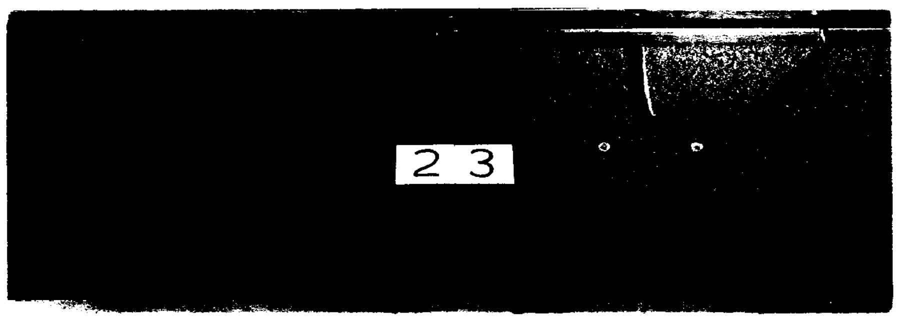


Fig. 60. A 12" Uniform-thickness Asphalt Shingle with Smooth Surfacing

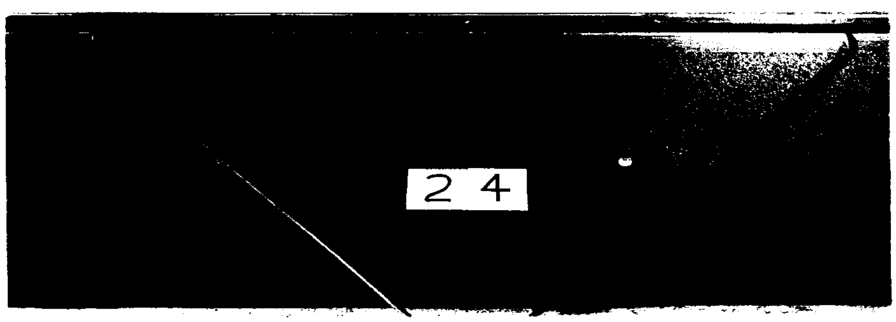


Fig. 61. A 12" Thick-butt Asphalt Shingle with Embossing

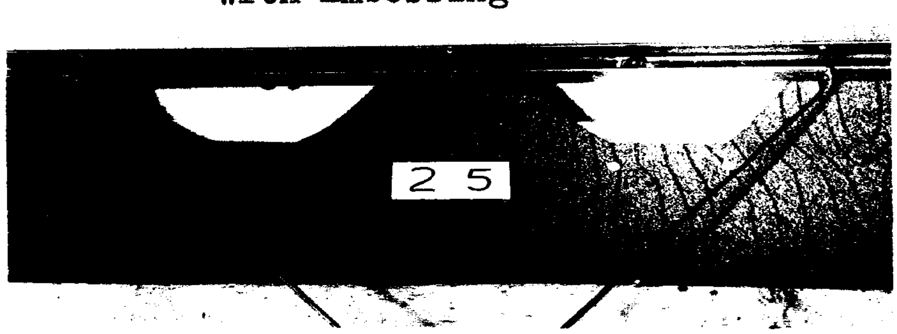


Fig. 62. A 10"x40" Three-tab Hex Asphalt Shingle with Embossing

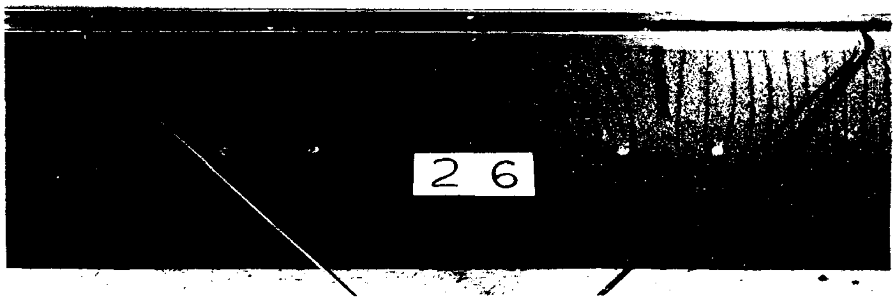


Fig. 63. A 10" Thick-butt Asphalt Shingle with Embossing

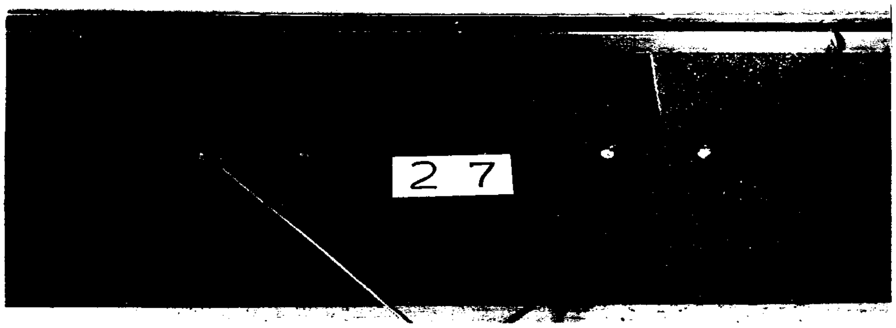


Fig. 64. A 12" Heavy-weight, Uniform-thickness Asphalt Shingle with Smooth Surface

Fig. 65. A 12" Uniform-thickness Asphalt Shingle with a Smooth Surface

ANALYSIS

Factorial Design

Analysis of variance

Two analyses of variance were run on data pertaining to each group of asphalt shingles tested in the factorial experiment; namely, thick-butt shingles, hex-tab shingles, and uniform-thickness shingles. One of the two analyses of variance was made on data pertaining to the sums of the first five forces required to bend each of the 18 shingles tested of each type of shingles. The other analysis of variance was made on data pertaining only to the initial forces required for bending the 18 shingles the first time. Tables 8, 9 and 10 present the preliminary analysis of variance for the thick-butt shingles, hex-tab shingles, and uniform-thickness shingles, respectively.

These analysis of variance tables show the degrees of freedom, sums of squares, and mean squares for each group studied as well as the "F" ratios. The "F" ratios were added to show the significance of the effects of the five types of nailing patterns as a group and the three temperature levels as well as their interactions.

Table 8

Preliminary Analysis of Variance of Thick-butt Shingle Factorial Test Data

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" ratio
		Part A Totals of First Five Forces		
Replications	12	12,528.67	1,044.06	5.43
Types of tests	5	101,254.87	20,250.97	105.33
Temp. levels	2	57,265.62	28,632.81	149.00
Types x Levels	10	10,097.36	1,009.74	5.24
Expt'l error	204	39,235.48	192.33	
Total	233	220,382.00		
		Part B Totals of Initial Forces		
Replications	12	1,123.60	93.63	12.38
Types of tests	5	4,616.60	923.32	122.00
Temp. levels	2	5,191.80	2,595.90	343.00
Types x Levels	10	402.14	40.21	5.32
Expt'l error	204	1,545.02	7.57	
Total	233	12,879.16		

Table 9

Preliminary Analysis of Variance of Hex-tab Shingle Factorial Test Data

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" ratio
		Part A Totals of First Five Forces		
Replications	6	6,159.30	1,026.55	29.80
Types of tests	5	1,899.75	379.95	11.03
Temp. levels	2	42,188.44	21,094.22	613.00
Types x Levels	10	643.08	64.308	1.87
Expt'l error	102	3,509.56	34.407	
Total	125	54,400.13		
		Part B Total of Initial Forces		
Replications	6	422.22	70.370	36.70
Types of tests	5	108.76	21.752	11.38
Temp. levels	2	2,336.90	1,168.450	610.00
Types x levels	10	30.91	3.091	1.61
Expt'l error	102	195.21	1.914	
Total	125	3,094.00		

Table 10

Preliminary Analysis of Variance of Uniform-thickness Shingle Factorial Rest Data

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" ratio
		Part A **Totals of First Five Forces**		
Replications	5	111,827.05	22,365.41	173.70
Types of tests	5	7,662.16	1,532.43	11.91
Temp. levels	2	92,931.35	46,465.68	360.50
Types x Levels	10	1,142.65	114.26	0.89
Expt'l error	85	10,944.45	128.76	
Total	107	224,507.66		
		Part B **Total of Initial Forces**		
Replications	5	8,643.50	1,728.70	170.30
Types of tests	5	373.50	74.70	7.36
Temp. levels	2	5,736.69	2,868.34	283.00
Types x Levels	10	53.64	5.36	0.53
Expt'l error	85	861.67	10.14	
Total	107	15,669.00		

Significance of group treatments

Thick-butt shingles. From the magnitude of the "F" ratios for each of the group treatments on thick-butt shingles it is noted that they are all significant above the 1 per cent level, as checked with Table 10.7 of Snedecor's (7, p. 223) text on Statistical Methods. This may be interpreted to mean, assuming randomized sampling and tests were made, that there is less than one chance in 100 of drawing a sample having a larger value of F from the distribution specified if a hypothesis of no effect is assumed.

Even though all the "F" ratios are significant to the 1 per cent level including the smallest one of 5.24, a great variance in the ratios is noted. The greatest effect is noticed to be that of temperature level on the initial forces. A comparison of this "F" ratio with the similar one for the sum of the first five forces indicates that the effect of temperature is less than half as great on the latter. It is also noticed that the "F" test representing effect of replications for the totals of five forces is less than half of that for initial forces. The effects of the various nailing patterns are very great for thick-butt shingles, however, being somewhat less for the totals of the first five forces. The interaction between types and levels show up with small "F" ratios as compared to the other ratios; however, they are above the 1 per cent significance level.

Hex-tab shingles. A somewhat different pattern of "F" ratios is noticed for the hex-tab shingle as compared to the thick-butt shingle. The effect of temperature is very great as compared to the other group treatments, and it is noticed to be very similar for both analyses. The effect of the various nailing patterns as a group is very small as compared to that of temperature; however, the significance as gauged by the "F" test is far above the 1 per cent level. A far greater spread of significance is noticed between the effect of temperature and nailing patterns for the hex-tab shingles as compared to the thick-butt shingles. The effect of temperature appears to be greater for the hex-tab shingles and the nailing patterns much less than that of the thick-butt shingle group. The most variance between the "F" ratios for the two sets of hex-tab shingle data was for the replications. This difference showed up somewhat similar to the thick-butt shingle group with the initial force results being the most significant.

Uniform-thickness shingles. The pattern of "F" ratios for the uniform-thickness shingle group is some different from either of the other groups of shingles. The effect of temperature appears to be the greatest for this group but not to the extent of that for hex-tab shingles. It is noted also that the effect of temperature on uniform-thickness shingles is less for the initial force than for the totals of the first five bending forces. This is a reverse trend as compared to the thick-butt shingle group.

The effect of nailing patterns as indicated by the "F" ratios is very small for uniform-thickness shingles as compared to the thick-butt shingles. This trend is very similar to that of the hex-tab shingle group. The nailing pattern effect is noticed to be less for the initial forces than for that of the first five force totals. This is also a reverse trend as that shown by the thick-butt shingles.

One of the big differences, of the uniform-thickness shingle "F" ratio patterns, from the other groups is the large variance in replications as indicated by the large replication "F" ratio. This was brought about by the very heavy-weight shingles tested in this group as well as some comparatively light-weight ones.

<u>Summary</u>. In general it may be said from this preliminary analysis of variance that the effect of temperature was the greatest for the hex-tab shingle group and somewhat the same for the other two groups. The effect of the nailing patterns as a group was far greater for the thick-butt shingles than for either of the other two groups. The interaction of types and levels was significant at the 1 per cent level for the thick-butt shingle group but not significant even at the 5 per cent level for either of the other two groups. No trend was evident amongst all three

groups of shingles between initial force bending resistance and the totals of the first five bending forces.

Significance of individual treatments, types, and levels

In order to determine the significance of the effects of specific nailing patterns as well as the various temperature levels on bending resistance, Tables 11, 12 and 13 were prepared and included in this analysis. The treatment totals as well as the totals for types and levels for the six sets of factorial data analyzed were included in these tables. Besides the totals and means of the 6x3 factorial arrangements, in these tables the standard errors of individuals, treatments, types, and levels have been calculated and included. From these standard errors and the 5 and 1 per cent level "t" values taken from table 3.8 of Snedecor (7, p. 65), the significant differences for treatments, types, and levels were figured and also included. These tables will serve as ready references for checking the significant difference between any two values of the factorial arrangements of data that might be in question.

Determination of significant difference. To determine the significant difference first the standard error of the difference must be calculated. The standard error of individuals is obtained by taking the square root of the mean square of the experimental error as determined by the analysis of variance. If the standard error of the difference between

Table 11

Results of an Analysis of Variance of the Factorial Data from Thirteen Types of Thick-butt Shingles

Temp. levels	Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-5/8	Six 6-1/8	Sum	Mean
	Types of tests							
	Part A Totals of First Five Forces							
55° F	1531	1280	965	787	1948	1296	7807	100.09
70° F	1200	1078	779	660	1394	1139	6250	80.13
85° F	914	901	602	511	1079	812	4819	61.78
Sum	3645	3259	2346	1958	4421	3247	18876	
Mean	93.46	83.56	60.30	50.21	113.36	83.26		80.67

Analysis

Error sum of squares = 192.33 Degrees of freedom = 204

	S.e.	M.s.e.	S.e. of diff.	M.s.e. of diff
Standard error of individuals	13.88	13.88	19.68	19.68
Standard error of treatments	50.1	3.85	71.00	5.45
Standard error of types	86.7	2.22	122.70	3.14
Standard error of levels	122.7	1.57	174.00	2.22

$t_{.05} = 1.972$, $t_{.01} = 2.601$

	5% level Sum	5% level Mean	1% level Sum	1% level Mean
Sig. dif. of treatments	140.0	10.75	184.5	14.18
Sig. dif. of types	242.0	6.20	31.90	8.18
Sig. dif. of levels	343.0	4.38	452.0	5.77

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Table 11 (Cont'd)

Temp. levels	Types of tests Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-5/8	Six 6-1/8	Sum	Mean
				Part B Totals of Initial Forces				
55° F	396	393	288	241	484	391	2193	28.12
70° F	297	290	223	198	350	315	1672	21.44
85° F	238	241	174	150	277	217	1297	16.63
Sum	931	924	685	589	1111	922	5162	
Mean	23.87	23.67	17.56	15.10	28.49	23.64		22.06

Analysis

Error sum of squares = 7.57 Degrees of freedom = 204

	S.e.	M.s.e.	S.e.of diff.	M.s.e. of diff
Standard error of individuals	2.75	2.75	3.89	3.89
Standard error of treatments	9.93	0.765	14.07	1.083
Standard error of types	17.22	0.442	24.40	.625
Standard error of levels	24.33	0.312	34.40	.422

$t_{.05} = 1.972$, $t_{.01} = 2.601$

	5% level Sum	5% level Mean	1% level Sum	1% level Mean
Sig. dif. of treatments	27.70	2.140	36.6	2.820
Sig. dif. of types	48.10	1.237	63.5	1.625
Sig. dif. of levels	68.00	0.832	89.5	1.098

Table 12

Results of an Analysis of Variance of the Factorial Data from Seven Types of Hex-tab Shingles

Temp. levels	Types of tests: Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-1/4	Six 5-3/4	Sum	Mean
	Part A **Totals of First Five Forces**							
55° F	696	710	686	622	655	726	4095	97.50
70° F	492	485	490	453	486	581	2987	71.12
85° F	363	368	372	347	380	393	2223	52.93
Sum	1551	1563	1548	1422	1521	1700	9305	
Mean	73.85	74.43	73.71	67.71	72.43	80.95		73.85

Analysis

Error sum of squares = 34.407 Degrees of freedom = 102

	S.e.	M.s.e.	S.e. of diff.	M.s.e. of diff
Standard error of individuals	5.88	5.88	8.36	8.36
Standard error of treatments	15.51	2.22	22.05	3.16
Standard error of types	26.95	1.285	38.30	1.82
Standard error of levels	38.10	0.907	54.20	1.29

$t_{.05} = 1.984$, $t_{.01} = 2.626$

	5% level Sum	5% level Mean	1% level Sum	1% level Mean
Sig. dif. of treatments	43.7	6.28	57.9	8.30
Sig. dif. of types	75.0	3.61	101.0	4.78
Sig. dif. of levels	107.5	2.56	142.2	3.39

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Table 12 (Cont'd)

Temp. levels	Types of tests: Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-1/4	Six 5-3/4	Sum	Mean
				Part B Totals of Initial Forces				
55°F	169	171	169	155	160	181	1005	23.93
70°F	119	121	122	115	120	143	740	17.62
85°F	92	94	96	88	96	99	565	13.45
Sum	380	386	387	358	3766	423	2310	
Mean	18.10	18.38	18.43	17.05	17.90	20.14		18.33

Analysis

Error sum of squares = 1.914   Degrees of freedom = 102

	S.e.	M.s.e.	S.e. of diff.	M.s.e. of diff
Standard error of individuals	1.388	1.388	1.968	1.968
Standard error of treatments	3.67	0.524	5.200	0.743
Standard error of types	6.35	0.302	8.99	0.428
Standard error of levels	8.98	0.2135	12.73	0.303

$t_{.05} = 1.984$, $t_{.01} = 2.626$

	5% level Sum	5% level Mean	1% level Sum	1% level Mean
Sig. dif. of treatments	10.33	1.473	13.66	1.94
Sig. dif. of types	17.87	0.850	23.60	1.12
Sig. dif. of levels	25.30	0.602	33.45	0.80

Table 12 (Cont'd)

Temp. levels	Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-5/8	Six 6-1/8	Sum	Mean
				Types of tests				
				Part B Totals of Initial Forces				
55° F	169	169	155	160	181	1005	23.93	

Table 13

Results of an Analysis of Variance of the Factorial Data from Six Types of Uniform-thickness Shingles

Temp. levels	Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-5/8	Six 6-1/8	Sum	Mean
	Types of tests							
	Part A Totals of First Five Forces							
55° F	972	989	926	831	1061	951	5730	159.17
70° F	699	693	663	621	785	737	4198	116.61
85° F	532	554	507	475	585	506	3159	87.75
Sum	2203	2236	2096	1927	2431	2194	13087	
Mean	122.39	124.22	116.44	107.06	135.06	121.89		121.18

Analysis

Error sum of squares = 128.76 Degrees freedom = 85

	S.e.	M.s.e.	S.e. of diff.	M.s.e. of diff
Standard error of individuals	11.37	11.37	16.1	16.1
Standard error of treatments	27.8	4.63	39.4	6.55
Standard error of types	48.2	2.68	68.2	3.79
Standard error of levels	68.2	1.89	96.4	2.68

$t_{.05} = 1.988$, $t_{.01} = 2.635$

	5% level Sum	5% level Mean	1% level Sum	1% level Mean
Sig. dif. of treatments	78.3	13.03	103.8	17.25
Sig. dif. of types	135.5	7.54	179.3	10.00
Sig. dif. of levels	191.8	5.33	254.0	7.06

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Table 13 (Cont'd)

Temp. levels	Types of tests: Six 5-5/8	Four 5-5/8	Six 6-5/8	Four 6-5/8	Six 4-5/8	Six 6-1/8	Sum	Mean
Part B — Totals of Initial Forces								
55° F	241	249	232	213	260	242	1437	39.92
70° F	174	178	166	159	195	186	1058	29.39
85° F	134	140	128	122	147	127	798	22.17
Sum	549	567	526	494	602	555	3298	
Mean	30.50	31.50	29.22	27.44	33.44	30.83		30.54

Analysis

Error sum of squares = 10.14 Degrees freedom = 85

	S.e.	M.s.e.	S.e. of diff.	M.s.e. of diff
Standard error of individuals	3.19	3.19	4.52	4.52
Standard error treatments	7.81	1.30	11.07	1.84
Standard error of types	13.53	0.75	19.15	1.06
Standard error of levels	19.10	0.53	27.00	0.75

$t_{.05} = 1.988$, $t_{.01} = 2.635$

	5% level Sum	5% level Mean	1% level Sum	1% level Mean
Sig. dif. of treatments	22.0	3.66	29.2	4.85
Sig. dif. of types	38.1	2.11	50.5	2.79
Sig. dif. of levels	53.7	1.49	71.2	1.975

individuals, treatments, types, or levels is desired; it may be obtained by multiplying the standard error of one individual by the square root of the number of individuals involved. Once having the standard error the significant difference may be obtained by multiplying the standard error by the "t" value at the level desired and for the degrees of freedom involved. The above is derived from the definition of "t" given by Snedecor (7, p. 45), as follows:

t = mean difference/standard error of the difference

Significance of Number of Nails

Thick-butt shingles

The advantage to be gained from six nails per strip shingle over four seems to be interrelated with a number of other factors. Table 14 presents numerically in pounds the difference in bending resistance between the use of six nails and four nails at the different temperature levels and at the 5-5/8 and 6-5/8 inch nailing distance. The significant differences at the 5 and 1 per cent levels, as taken from Table 11, are also given in this table for convenience of comparison.

From Part A of the table pertaining to thick-butt shingles it is noticed that only at the 55° F temperature level was there a significant difference between the use of six nails over four. In considering the total of the

Table 14

The Significance of Six Nails over Four on Bending Resistance of Asphalt Shingles in Pounds

	Temp level	Difference at 5-5/8"	Difference at 6-5/8"	Significance 5%	Significance 1%
		Part A Thick-butt shingles			
Total of 1st 5 forces	55° F	251**	178*	140.0	184.5
	70° F	122	119	140.0	184.5
	85° F	13	91	140.0	184.5
	Sum of dif.	386**	388**	242.0	319.0
	Mean of dif.	9.9**	10.09**	6.2	8.2
Total of initial forces	55° F	3	47**	27.7	36.6
	70° F	7	25	27.7	36.6
	85° F	- 3	24	27.7	36.6
	Sum of dif.	7	96**	48.1	63.5
	Mean of dif.	0.2	2.46**	1.237	1.625
		Part B Hex-tab shingles			
Total of 1st five forces	55° F	-14	64**	43.7	57.9
	70° F	7	37	43.7	57.9
	85° F	- 5	25	43.7	57.9
	Sum of dif.	-12	126**	75.0	101.0
	Mean of dif.	- 0.58	6.0**	3.61	4.78
Total of initial forces	55° F	- 2	14**	10.33	13.66
	70° F	- 2	7	10.33	13.66
	85° F	- 2	8	10.33	13.66
	Sum of dif.	- 6	29**	17.87	23.60
	Mean of dif.	0.28	1.38**	0.850	1.12

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Table 14
(Cont'd)

	Temp level	Difference at 5-5/8"	Difference at 6-5/8"	Significance 5%	1%
		Part C Uniform-thickness shingles			
Total of 1st 5 forces	55° F	-17	95*	78.3	103.8
	70° F	6	42	78.3	103.8
	85° F	-22	32	78.3	103.8
	Sum of dif.	-33	169*	135.5	179.3
	Mean of dif.	- 1.83	9.38*	7.54	10.0
Total of initial forces	55° F	- 8	19	22.0	29.2
	70° F	- 4	7	22.0	29.2
	85° F	- 6	6	22.0	29.2
	Sum of dif.	-18	32	38.1	50.5
	Mean dif.	- 1.0	1.78	2.11	2.79

*Significant at 5% level
**Significant at 1% level

first five forces at 55° F the advantage was significant at the 1 per cent level with 5-5/8-inch nailing distance and only at the 5 per cent level with 6-5/8-inch nailing distance. In summing the effect for all temperature levels, however, the advantage of six over four nails was significant at the 1 per cent level for both the 5-5/8 and 6-5/8 inch nailing distance. There was then a very significant advantage of six nails over four when compared through the first five bends; however, most of the advantage was found to be at the lower temperatures.

When only the initial forces were considered, an advantage of six nails over four for thick-butt shingles was only found at the extreme nailing distance of 6-5/8 inches.

The same trend of advantage of thick-butt strip shingle application with six nails instead of four is brought out by the data of Table 15 which is plotted in Figures 70 and 71. The data of this table includes the tapered-type shingle tested as a thick-butt, so has 14 instead of 13 shingle types included in the thick-butt group. The data are also weighted on the basis of the weights of the respective shingles on a 108 square foot basis. In this manner the curves of Figures 70 and 71 present weighted comparisons of the various types of shingles as well as the difference between the use of six nails as compared to four.

The shaded area of the curves representing the thick-butt shingle tests in these two figures show that the

Table 15

The Effect of Nailing Patterns on the Continued Bending Resistance of Asphalt Shingles in Pounds

Nailing pattern	Number of bends 1	2	3	4	5	Tot. of 1st 5 bending forces	Wt of shingles in lbs/108 ft^2
			Part A Thick-butt shingles (14 including 1 taper-butt)				
6 - 5-5/8							
Total	995	816	729	686	649	3875	1648.7
Av/test	23.7	19.8	17.4	16.3	15.6	92.3	117.8
Av/lb	.2015	.1680	.1475	.1383	.1325		
4 - 5-5/8							
Total	988	753	643	585	540	3509	1648.7
Av/test	23.6	17.9	15.3	13.9	12.9	83.3	117.8
Av/lb	.2005	.1520	.1300	.1180	.1095		
6 - 6-5/8							
Total	745	547	470	423	394	2579	1648.7
Av/test	17.8	13.0	11.2	10.1	9.4	61.3	117.8
Av/lb	.1510	.1105	.0950	.0855	.0798		
4 - 6-5/8							
Total	643	453	387	355	330	2168	1648.7
Av/test	15.3	10.8	9.2	8.4	7.9	51.7	117.8
Av/lb	.1298	.0916	.0780	.0713	.0670		
6 - 4-5/8							
Total	1194	991	904	850	811	4750	1648.7
Av/test	28.4	23.6	21.5	20.2	19.3	113.2	117.8
Av/lb	.2410	.2005	.1825	.1713	.1635		
6 - 6-1/8							
Total	1003	757	658	596	553	3567	1648.7
Av/test	23.9	18.0	15.6	14.2	13.2	84.9	117.8
Av/lb	.2030	.1530	.1323	.1205	.1120		

(Continued on next page)

Table 15
(Cont'd)

Nailing pattern	Number of bends 1	2	3	4	5	Tot. of 1st 5 bending forces	Wt of shingles in lbs/108 ft^2
Part B Hex-tab shingles (7 shingles)							
6 - 5-5/8							
Total	380	322	299	284	266	1551	649.3
Av/test	18.1	15.3	14.2	13.1	12.7	73.7	92.8
Av/lb	.1950	.1648	.1529	.1405	.1369		
4 - 5-5/8							
Total	386	327	300	282	268	1563	649.3
Av/test	18.4	15.6	14.3	13.4	12.8	75.7	92.8
Av/lb	.1980	.1680	.1540	.1442	.1380		
6 - 6-5/8							
Total	387	324	293	279	265	1548	649.3
Av/test	18.4	15.4	13.9	13.3	12.7	73.7	92.8
Av/lb	.1980	.1660	.1498	.1432	.1368		
4 - 6-5/8							
Total	358	298	272	253	241	1422	649.3
Av/test	17.0	14.2	13.0	12.0	11.5	67.7	92.8
Av/lb	.1832	.1530	.1400	.1292	.1238		
4 - 5-1/4							
Total	376	318	291	275	261	1521	
Av/test	17.9	15.1	14.3	13.1	12.4	72.3	
Av/lb	.1930	.1627	.1540	.1415	.1335		
6 - 5-3/4							
Total	423	353	324	307	293	1700	
Av/test	20.1	16.8	15.8	14.6	13.9	81.0	
Av/lb	.2170	.1810	.1700	.1570	.1498		

(Continued on next page)

Table 15 (Cont'd)

Nailing pattern	Number of bends 1	2	3	4	5	Tot. of 1st 5 bending forces	Wt. of shingles in lbs/108 ft²
			Part C Uniform-thickness shingles (6 shingles)				
6 - 5-5/8							
Total	549	459	420	396	379	2203	717.4
Av/test	30.5	25.5	23.3	22.0	21.0	122	119.7
Av/lb	.2545	.2122	.1945	.1835	.1753		
4 - 5-5/8							
Total	567	467	426	398	378	2236	717.4
Av/test	31.5	25.9	23.7	22.1	21.0	121	119.7
Av/lb	.2630	.2160	.1975	.1845	.1750		
6 - 6-5/8							
Total	546	436	400	376	358	2096	717.4
Av/test	30.3	24.2	22.2	20.9	19.9	116	119.7
Av/lb	.2530	.2020	.1850	.1743	.1660		
4 - 6-5/8							
Total	494	403	366	341	323	1927	717.4
Av/test	27.4	22.4	20.3	18.9	18.0	107	119.7
Av/lb	.2288	.1868	.1695	.1577	.1500		
6 - 4-5/8							
Total	602	507	464	438	420	2431	717.4
Av/test	33.3	28.2	25.8	24.3	23.3	135	119.7
Av/lb	.2780	.2350	.2150	.2030	.1945		
6 - 6-1/8							
Total	555	456	419	394	369	2194	717.4
Av/test	30.8	25.3	23.3	21.9	20.5	122	119.7
Av/lb	.2570	.2110	.1945	.1825	.1715		

continued advantage of six nails over four was gained with the 6-5/8-inch nailing distance; however, with the nails placed at 5-5/8 inches from the butt the advantage after five bends was 21 per cent even though there was no advantage initially. This 21 per cent advantage after five bends with the 5-5/8-inch nailing is greater than at the 6-5/8-inch nailing, and as mentioned before is highly significant. This indicates then that at the standard nailing distance of 5-5/8 inches there may be no or only little advantage of six nails over four to resist the initial bend, but the extra two nails are highly advantageous in preventing the bending resistance from reducing so rapidly with successive bends.

Figures 66-69 illustrate pictorially two different thick-butt shingles that have torn past the nails in bending tests when only four nails were used; however, with six there was no tearing around the nail heads and the line of bending was above the nails. The two shingles of Figures 66 and 67 are thick-butt shingles with embossed surfaces from Bundle No. 1. The two shingles of Figures 68 and 69 are similar thick-butt shingles only with smooth surfaces and from Bundle No. 9 of the 27 different shingles tested. All four of the bending tests were made at 55° F with the nails all placed at the standard distance of 5-5/8 inches from the butt of the shingles. From the original test data on

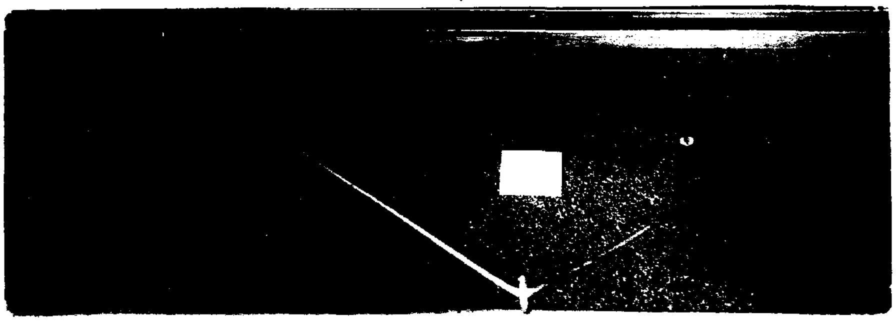

Fig. 66. Bending with Six Nails Placed 5-5/8 Inches High

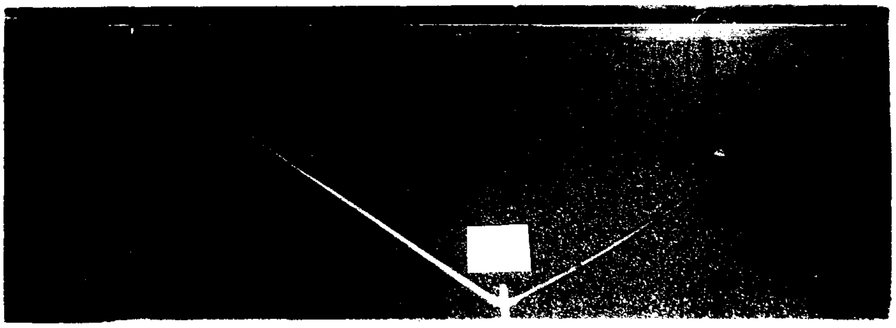

Fig. 67. Tearing Past Nails with Four at 5-5/8 Inches High

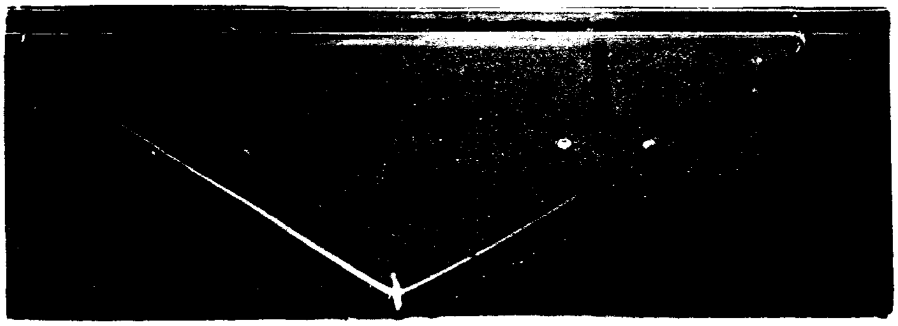

Fig. 68. Bending with Six Nails Placed 5-5/8 Inches High

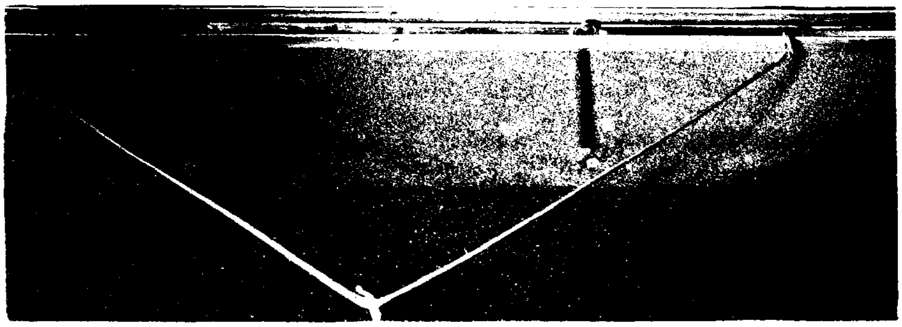

Fig. 69. Tearing Past Nails with Four at 5-5/8 Inches High

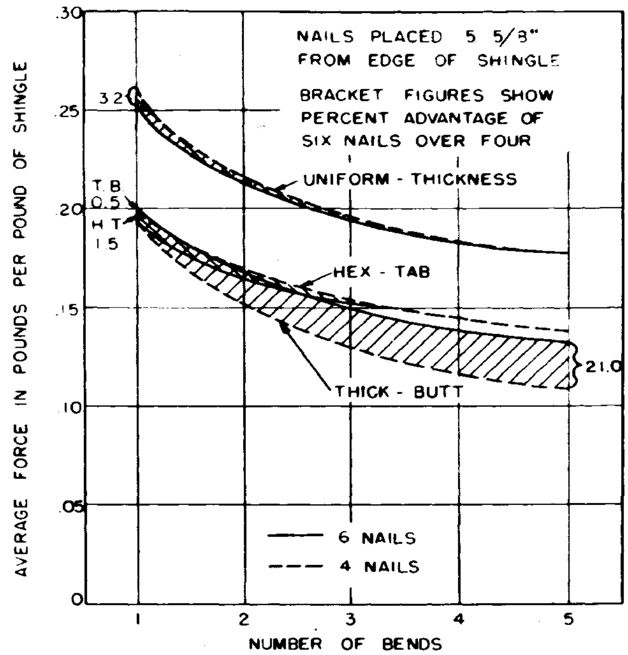

FIG. 70 THE EFFECT OF NUMBER OF NAILS ON BENDING RESISTANCE OF ASPHALT SHINGLES

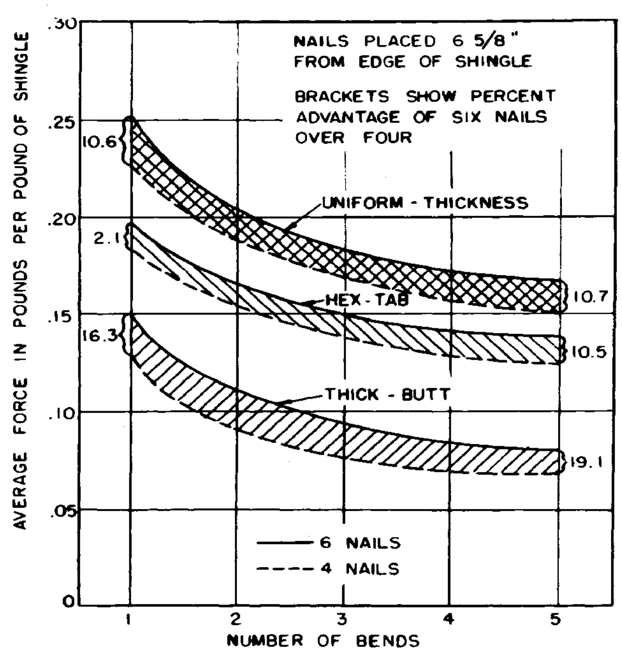

FIG. 71 THE EFFECT OF NUMBER OF NAILS ON BENDING RESISTANCE OF ASPHALT SHINGLES

the individual shingles it is noticed that both No. 1 shingles shown here had an initial bending resistance very nearly the same, being 37 pounds with six nails and 36 pounds with four; however, after five bends the resistances were 26 and 15 pounds, respectively, and 125 bends were needed to reduce the resistance of the shingle with six nails to 10 pounds where only 10 were needed with only four nails. The record of shingle No. 9 was very nearly the same with initial resistances of 32 and 33 pounds; however, after five bends they were 23 and 16 pounds, respectively, with 112 bends required to reduce the resistance of the shingle with six nails to 10 pounds and only 17 bends required for the one with four nails.

<u>Hex-tab shingles</u>

The only significant advantage of six nails over four in the application of hex-tab shingles, as shown by the test results of Table 14, was at the 6-5/8-inch nailing distance at the 55° F temperature level. The advantage at the higher temperature levels for this extreme nailing distance were high enough, however, so that when the sum difference was considered for this nailing it was highly significant. The pattern of differences for the bending forces through the fifth and the initial forces was somewhat the same for the hex-tab shingle.

The weighted bending resistances of hex-tab shingles as tested through five bends with six and four nails are shown in Part B of Table 15. These data are plotted in Figures 70 and 71 for a graphical presentation of the differences. As with the thick-butt shingles, the six-nail application showed a continued advantage through the first five bends at the extreme nailing distance of 6-5/8 inches. It is also noted that the weighted advantage of the hex-tab shingles over the thick-butt was quite significant with the extreme nailing distance. At the 5-5/8-inch nailing distance the weighted initial bending resistance was the same for the two groups; however, with continued bending the resistance of the thick-butt shingles fell off rapidly in comparison to the hex-tab shingles which showed no advantage of six nails over four. In fact, four nails showed up slightly better than the six initially; however, not a significant amount.

Uniform-thickness shingles

The trend of differences in bending resistance between six and four nails for uniform-thickness shingles was somewhat similar to that of the hex-tab shingles. As shown in Part C of Table 14, the only significant advantage of six nails over four was found at 55° F with the nails placed 6-5/8 inches from the butt, and then only significant at the 5 per cent level. The 5 per cent level significance did, however, carry down to the sum difference for that nailing distance.

As with the hex-tab shingles, only greater in the case of the uniform-thickness shingles, some reduction in bending resistance with the addition of the extra two nails was observed with the standard nailing distance of 5-5/8 inches. The slight reduction was somewhat consistent through the tests; however, the magnitude of the difference was not statistically significant at the 5 per cent level. This trend is also brought out with the data of Part C of Table 15 and shown graphically in Figures 70 and 71. The continued advantage of six nails over four with the extreme nailing distance of 6-5/8 inches is shown in Fig. 71 to be about 10 per cent through the fifth bend. The disadvantage of 3.2 per cent initially with the standard nailing distance is shown in Fig. 70.

<u>Summary</u>

From 8 to 16 per cent initial advantage and 10 to 20 per cent advantage after five bends was shown for all groups of shingles with the extreme nailing distance of 6-5/8 inches.

The only advantage of six nails over four for the standard nailing distance of 5-5/8 inches was found to be with the thick-butt shingle group and then only after five bends. The extra two nails in this case did account for a very appreciable increase in resistance to continued bending, being 21 per cent after five bends. The tests for hex-tab shingles as well as uniform-thickness shingles showed no advantage of six nails over four after five bends with the standard nailing distance, and showed up to a 3.2 per cent disadvantage for the initial bending.

From the test observations it was found that the big advantage of the extra two nails per strip shingle was in the prevention of the shingle tearing past the nail heads in bending. Where this condition of tearing past did not appear to be imminent the advantage of the extra nails was not apparent. The tendency to tear past the nail heads was quite evident in the thick-butt shingle group at the lower temperature levels as is shown in the original test data.

Significance of Nailing Distance

Thick-butt shingles

Table 16 shows the numerical differences of bending resistances in pounds at the various nailing distances tested for the three groups of shingles analyzed. The differences in bending resistance for one inch differences in nailing distance are all statistically significant at the 1 per cent level. The drop in resistance with the one inch more distant nailing is much greater than the increase over the standard when the nails are placed at the 4-5/8-inch distance. This is particularly true with the thick-butt

Table 16

The Significance of Nailing Distance on Bending Resistance of Asphalt Shingles in Pounds

	Temp level	Dif. between 4-5/8" and 5-5/8"	Dif. between 5-5/8" and 6-5/8"	Dif. between 5-5/8" and 6-1/8"	Significance	
					5%	1%
			Part A **Thick-butt shingles**			
Total of 1st five forces	55° F	417**	566**	235**	140.0	184.5
	70° F	194**	421**	61	140.0	184.5
	85° F	165*	312**	102	140.0	184.5
	Sum of dif.	776**	1299**	398**	242.0	319.0
	Mean dif.	19.90**	33.16**	10.20**	6.2	8.2
Total of initial forces	55° F	88**	108**	5	27.7	36.6
	70° F	53**	74**	-17	27.7	36.6
	85° F	39**	64**	21	27.7	36.6
	Sum of dif.	180**	246**	9	48.1	63.5
	Mean dif.	4.62**	6.31**	0.22	1.237	1.625

*Significant at 5% level
**Significant at 1% level

(Continued on next page)

Table 16 (Cont'd)

	Temp level	Dif. between 4-5/8" and 5-5/8"	Dif. between 5-5/8" and 6-5/8"	Dif. between 5-5/8" and 6-1/8"	Significance 5%	1%
			Part B Hex-tab shingles			
Total of 1st five forces	55° F	-41	10	-30	43.7	57.9
	70° F	- 6	2	-89**	43.7	57.9
	85° F	+17	-11	-30	43.7	57.9
	Sum of dif.	-30	3	-149**	75.0	101.0
	Mean dif.	- 1.42	0.14	- 7.10**	3.61	4.78
Total of initial forces	55° F	-9	0	-12*	10.33	13.66
	70° F	1	-3	-24**	10.33	13.66
	85° F	4	-4	- 7	10.33	13.66
	Sum of dif.	-4	-7	-43**	17.87	23.60
	Mean dif.	-0.20	-0.33	- 2.04**	0.850	1.12

*Significant at 5% level
**Significant at 1% level

(Continued on next page)

Table 16 (Cont'd)

	Temp level	Dif. between 4-5/8" and 5-5/8"	Dif. between 5-5/8" and 6-5/8"	Dif. between 5-5/8" and 6-1/8"	Significance 5%	Significance 1%
			Part C Uniform-thickness shingles			
Total of 1st five forces	55° F	89*	46	21	78.3	103.8
	70° F	86*	36	-38	78.3	103.8
	85° F	53	25	26	78.3	103.8
	Sum of dif.	228**	107	7	135.5	179.3
	Mean dif.	12.67**	5.95	0.50	7.54	10.0
Total of initial forces	55° F	19	9	-1	22.0	29.2
	70° F	21	8	-12	22.0	29.2
	85° F	13	6	7	22.0	29.2
	Sum of dif.	53**	23	6	38.1	50.5
	Mean dif.	2.94**	1.28	-0.33	2.11	2.79

*Significant at 5% level
**Significant at 1% level

shingle because in most cases when the nails are placed as high as 6-5/8 inches they are in the thin-top portion of the shingle.

The decrease in bending resistance when the nails were placed 6-1/8 inches from the butt, one-half of an inch higher than recommended, was also highly significant when considering the first five bending forces. This decrease was not, however, noticed in the initial bending resistances.

Fig. 72 illustrates these differences graphically. The curves of this figure are shown on a weighted basis similar to Figures 70 and 71, the data being taken from Table 15. The initial advantage of the 4-5/8-inch spacing over the standard 5-5/8-inch was about 20 per cent, while the disadvantage of placing the nail one inch farther out at 6-5/8 inches was 25 per cent. After five bends the advantage and disadvantage, respectively, were 23.4 and 40 per cent.

It is important to notice that, although initially there appeared to be no advantage of the 5-5/8-inch nail distance over the 6-1/8-inch nailing, the resistance dropped off rapidly and the curve representing that nailing distance on Fig. 72 immediately took the shape of the 6-5/8-inch curve. The more rapid drop-off of bending resistance with the one-half inch more distant nailing indicates that some of the nails in the thick-butt shingles were on or near the very weak transition line of the shingle where they change

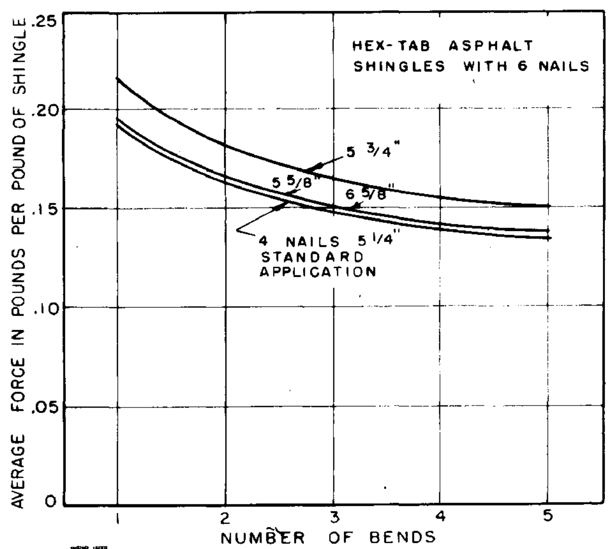

FIG. 73 EFFECT OF NAILING DISTANCE ON BENDING RESISTANCE OF HEX-TAB SHINGLES.

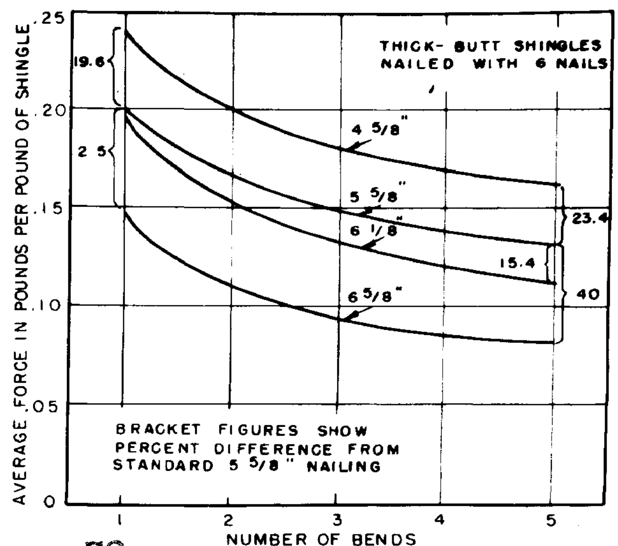

FIG. 72 EFFECT OF NAILING DISTANCE ON BENDING RESISTANCE OF THICK-BUTT SHINGLES.

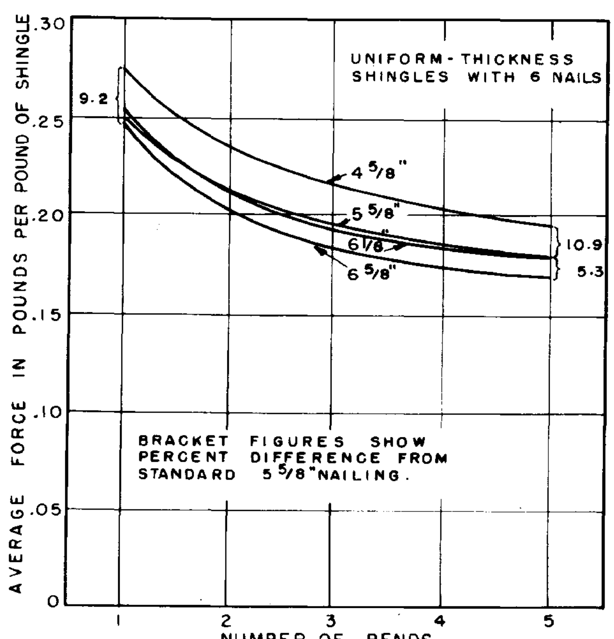

FIG. 74 EFFECT OF NAILING DISTANCE ON BENDING RESISTANCE OF UNIFORM THICKNESS SHINGLES.

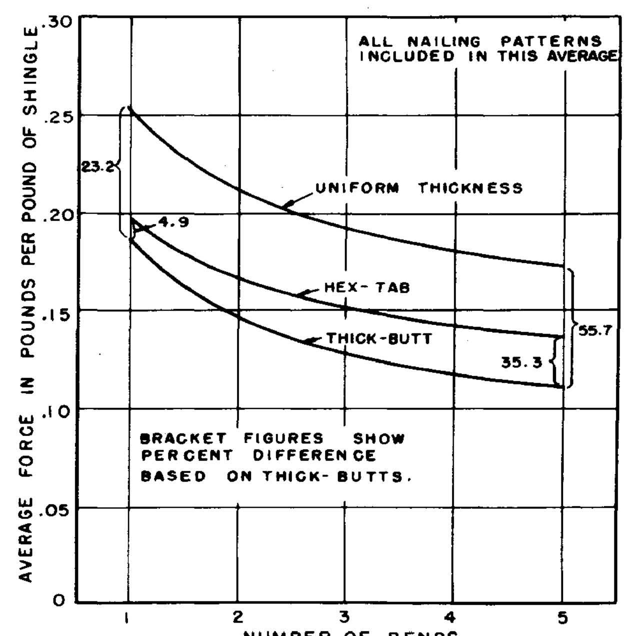

FIG. 75 A WEIGHTED COMPARISON OF BENDING RESISTANCE OF THREE CLASSES OF SHINGLES.

in thickness from the thick-butt to the thin-top. This location of the nails allows them to tear out quite rapidly so that the bending takes place on this transition line where the resistance is very low. The nearness of the nails to the transition line on many of the thick-butt shingles, with the nails placed 6-1/8 inches from the edge, can be observed in the photographs of the individual shingles in Figures 39 to 65. The resulting tearing past of many of these same shingles during the bending tests may also be observed.

Hex-tab shingles

The behavior of the hex-tab shingles in this series of tests was somewhat eratic. Due to the difference in design of the shingle and the necessity for different nailing and application, the test results are not readily comparable with those of the other types of shingles. The four tests described in the previous section on number of nails were identical in nailing pattern to the similar ones for the square-tab shingles; however, the 4-5/8-inch and the 6-1/8-inch tests on the square-tabs were somewhat changed for the hex-tabs. It being impossible to nail a hex-tab shingle, with the customary 5-inch cut-out, with a 4-5/8-inch nailing distance, the recommended nailing pattern was used. This called for four nails placed 5-1/4 inches from the edge instead of the six used in that test for the other shingles at 4-5/8 inches. The other test on the hex-tab shingles instead of having the nails at the 6-1/8-inch distance as used for the square-tabs was with six nails placed one-half inch higher than specified which was 5-3/4 inches. This latter described nailing pattern proved to be the best of the six different ones tried in this investigation. As shown in Part B of Table 16, there was no statistical difference between the other tests made either initially or after five bends.

Fig. 73 illustrates graphically the small differences observed for the different nailing distances used on the hex-tab shingles. It is noted that the curves for the 5-5/8-inch and the 6-5/8-inch nailing distances coincide. Some decrease is noted between these two nailing patterns and the recommended nailing pattern with 5-1/4-inch nailing distance. This was evidently because of the fewer nails used with the 5-1/4-inch tests as compared to the 5-5/8 and 6-5/8-inch tests. The significant increase of the 5-3/4-inch nailing distance tests over the others is not explainable. Further tests with more types of hex-tab shingles would be needed to determine this.

Uniform-thickness shingles

The effect on bending resistance of uniform-thickness shingles by the various nailing distances used was only significant between the 5-5/8-inch and 4-5/8-inch nailing distance. As shown by Part C of Table 16 the difference was significant at the 1 per cent level when the nails were placed one inch lower than the customary recommended application. In contrast to this significant increase there was no significant decrease even at the 5 per cent level when the nails were placed one inch higher than standard as in the 6-5/8-inch nailing tests.

As with the thick-butt and hex-tab shingles, Fig. 74 illustrates these differences graphically on a weighted basis. On this graph it is noted that the advantage of the 4-5/8-inch nailing was initially about 9 per cent and after five bends near 11 per cent. The decrease with the 6-5/8-inch nailing was not evident initially; however, after five bends it amounted to 5.3 per cent of the 5-5/8-inch bending resistance.

Summary

In summary, the greatest differences brought about by varying the nailing distance was with the thick-butt shingles. With the thick-butt shingles the placing of the nails one inch higher than the recommended 5-5/8 inches brought about a decrease in bending resistance of 40 per cent after five bends. With the nails only one-half inch higher than recommended a reduction in bending resistance of 15 per cent was observed after five bends, which was a greater difference than found between any of the nailing distances tested on the other types of shingles.

The great reduction of initial bending resistance of thick-butt shingles as well as the rapid dropping-off with successive bends was brought about by the fact that when the nails were placed as little as one-half inch higher than the specified 5-5/8-inch nailing distance they were near enough to the transition lines so the tearing past was more in evidence and the resulting bending line coincided with the transition line.

Significance of Temperature Level

Effect by type of shingle

In all cases the increase in bending resistance was greater with the 15° F drop in temperature from 70° F than the decrease with the 15° F raise in temperature to 85° F. Table 17 shows these respective differences along with the significant differences for the 5 per cent and 1 per cent levels as taken from Table 11. All of the differences for the 15° F intervals were highly significant. In comparing the differences as tested with the 5 per cent significant differences, it is noticed that with the thick-butt shingles the effect of temperature differences was greater initially than after five bends; however, with the other types of shingles there was little difference.

Table 17

The Significance of Temperature on Bending Resistance of Asphalt Shingles in Pounds

Type of shingle	Difference between 70° & 55°F	Difference between 70 & 80° F	Significance 5%	Significance 1%
Thick-butt				
Total of 5 forces	1557**	1431**	343.0	452.0
Initial forces	521**	375**	68.0	89.5
Hex-tab				
Total of 5 forces	1108**	764**	107.5	142.2
Initial forces	265**	175**	25.3	33.5
Uniform-thickness				
Total of 5 forces	1532**	1039**	191.8	254.0
Initial forces	379**	260**	53.7	71.2

Table 18 includes the continued weighted bending resistance of the various groups of shingles tested at the three temperature levels. This table divides the data into four parts by type of shingle and the total of all; while Figures 76-79 present graphically the same data by temperature level. In Fig. 76 the continued bending resistance at 55° F is shown for the three types of shingles as well as curves representing the average for all tests at 55° F and the average for all tests at all three temperature levels. The latter curve establishes a base line from which the curves of the three may be compared.

Table 18

The Effect of Temperature on the Continued Bending Resistance of Asphalt Shingles in Pounds

Temp level	Number of bends 1	2	3	4	5	Total of first 5 bending forces	Weight of shingles in lbs per 108 sq ft
Part A — Thick-butt shingles (14 including 1 taper-butt)							
55° F							
Total	2367	1794	1563	1430	1335	8489	1648.7
Av/test	28.2	21.4	18.6	17.0	15.9	101.0	117.8
Av/lb	.2390	.1820	.1580	.1445	.1350		
70° F							
Total	1802	1423	1255	1169	1097	6746	1648.7
Av/test	21.4	16.9	14.9	13.9	13.1	80.2	117.8
Av/lb	.1820	.1435	.1265	.1180	.1115		
85° F							
Total	1399	1100	973	896	845	5213	1648.7
Av/test	16.65	13.1	11.6	10.65	10.1	62.2	117.8
Av/lb	.1415	.1110	.0985	.0903	.0855		
Part B — Hex-tab shingles (7 shingles)							
55° F							
Total	1014	856	787	741	706	4104	649.3
Av/test	24.2	20.4	18.7	17.7	16.8	98.6	92.8
Av/lb	.2610	.2200	.2015	.1900	.1810		
70° F							
Total	740	622	572	540	513	2987	649.3
Av/test	17.6	14.8	13.6	12.9	12.2	71.1	92.8
Av/lb	.1895	.1595	.1465	.1385	.1315		
85° F							
Total	565	464	420	399	375	2223	649.3
Av/test	13.45	11.05	10.00	9.52	8.92	53.0	92.8
Av/lb	.1450	.1190	.1078	.1025	.0960		

(Continued on next page)

Table 18 (Cont'd)

Temp level	Number of bends 1	2	3	4	5	Total of first 5 bending forces	Weight of shingles in lbs/ 108 sq ft
			Part C Uniform-thickness shingles (6 shingles)				
55° F							
Total	1501	1195	1092	1029	977	5794	717.4
Av/test	41.7	33.2	30.4	28.6	27.1	160.8	119.7
Av/lb	.3480	.2770	.2540	.2390	.2260		
70° F							
Total	1102	873	799	752	716	4242	717.4
Av/test	30.6	24.3	22.2	20.9	19.9	117.6	119.7
Av/lb	.2550	.2030	.1853	.1742	.1660		
85° F							
Total	830	660	604	562	535	3191	717.4
Av/test	23.1	18.4	16.8	15.6	14.9	88.6	119.7
Av/lb	.1927	.1530	.1400	.1302	.1238		
			Part D All Shingles Tests (27 shingles)				
55° F							
Total	4882	3845	3442	3200	3018	18,387	3015.4
Av/test	29.8	23.5	21.0	19.5	18.4	113.3	111.8
Av/lb	.2665	.2100	.1880	.1748	.1645		
70° F							
Total	3644	2918	2626	2461	2326	13,975	3015.4
Av/test	22.2	17.8	16.0	15.0	14.2	86.2	111.8
Av/lb	.1985	.1595	.1430	.1340	.1265		
85° F							
Total	2794	2224	1997	1857	1755	10,627	3015.4
Av/test	17.08	13.57	12.18	11.33	10.70	65.6	111.8
Av/lb	.1525	.1212	.1090	.1014	.0957		
Gr. tot.	11320	8987	8065	7518	7099	42,989	3015.4
Av/test	23.3	18.5	16.6	15.5	14.6	88.4	111.8
Av/lb	.2080	.1653	.1485	.1385	.1305		

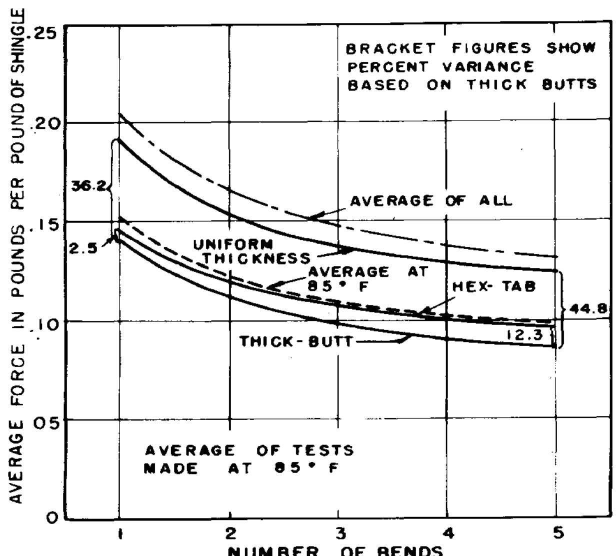

FIG. 78 BENDING RESISTANCE OF ASPHALT SHINGLES AT 85° F.

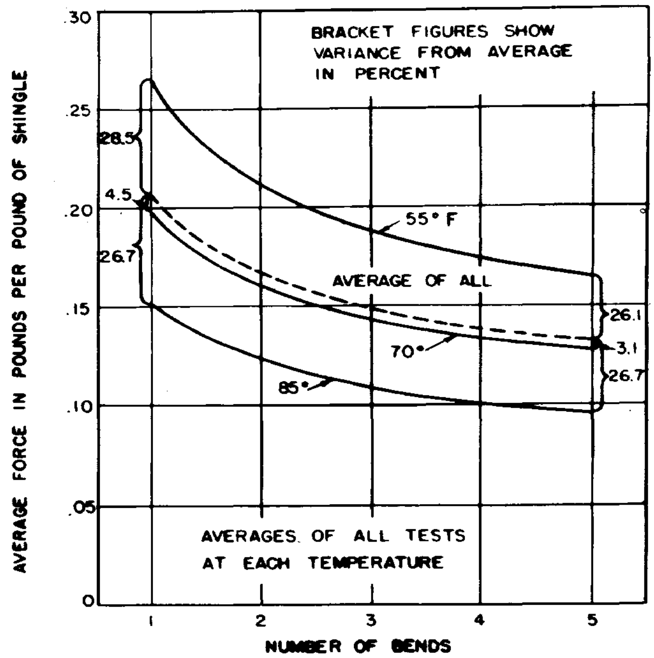

FIG. 79 BENDING RESISTANCE OF ASPHALT SHINGLES AT VARIOUS TEMPERATURES

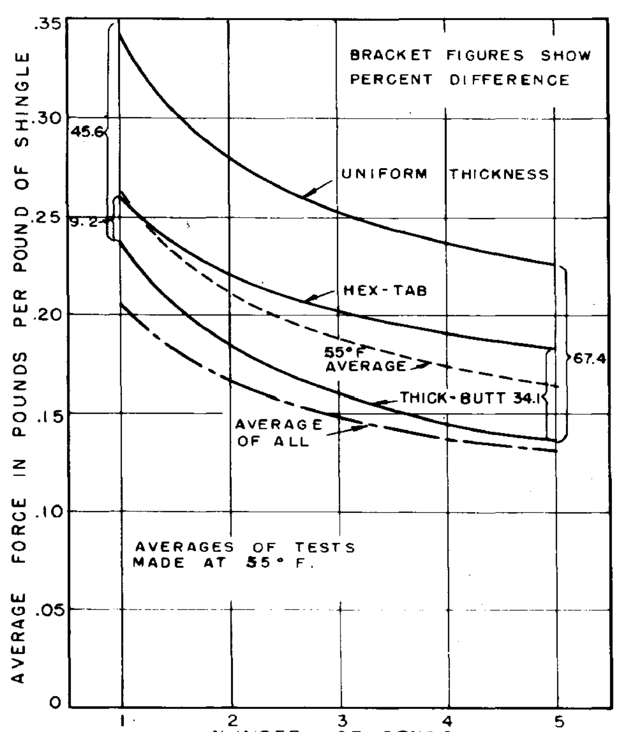

FIG. 76 BENDING RESISTANCE OF ASPHALT SHINGLES AT 55° F.

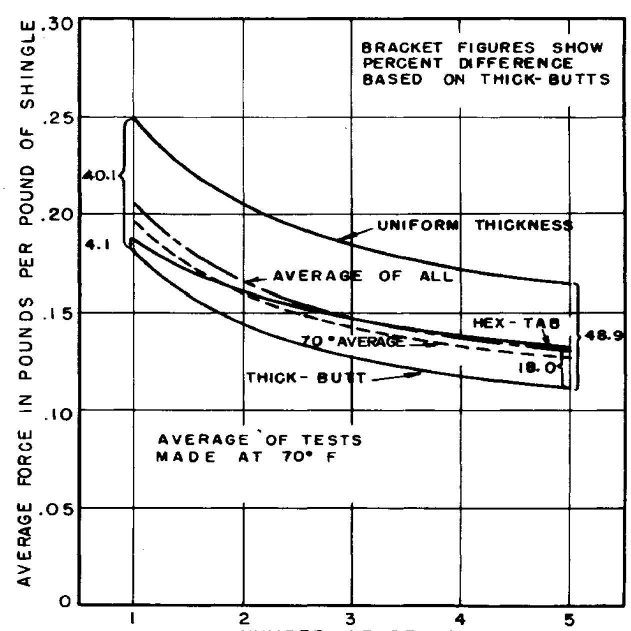

FIG. 77 BENDING RESISTANCE OF ASPHALT SHINGLES AT 70° F.

At the 55° F temperature level the uniform-thickness shingles were 45.6 per cent better in initial bending resistance and 67.4 per cent better after five bends. The hex-tab shingles also showed up some better on a weighted basis at this temperature. The initial advantage was 9.2 per cent and after five bends 34.1 per cent. There is a very noted difference in the shapes of the curves for the three types of shingles at the 55° F temperature. The curve representing the thick-butt shingle tests falls off much more rapidly than the other two after the first bend. This was because of many of the thick-butt shingles tearing past the nails in the bending tests at this temperature.

The spread of differences in weighted bending resistances for the three types of shingles was not so great for the other two temperature levels, as shown by Figures 77 and 78. In all cases, however, the uniform-thickness shingles were far above the others on a weighted bending resistance basis and the hex-tab shingles some above the thick-butt shingles. It also may be noticed from these curves that the shape of the ones representing the thick-butt shingles takes on more the shape of the others at the higher temperatures, particularly at the 85° F temperature level. In all cases the curves representing the total of all tests at the respective temperature levels are below the center of the spread of the three types of shingles tested because of the greater number of thick-butt shingles involved.

Overall effect of temperature

Part D of Table 18 shows numerically and Fig. 79 graphically the effect of temperature on bending resistance of asphalt shingles when all types were considered together. The curve representing the bending resistances at 70° F being below the overall average curve indicates a nonlinear relation between bending resistance and temperature. The increase is greater as the temperature goes down from 70° F than the decrease is when the temperature goes up from that level. This increase in bending resistance at lower temperatures is more pronounced initially than after five bends as brought out by the differences from the average shown in percentages. Some differences in the shapes of the curves are also noticed, the initial slope being much greater at the 55° F temperature level. This again indicates the more rapid falling-off of resistance at the lower temperatures as brought about by the higher per cent of nails tearing past in bending at those levels.

Comparison by Type of Shingle

The relative bending resistances of the three types of shingles tested has been brought out indirectly to some extent in the material presented previously. Table 19 presents a summary of the weighted bending resistances of the shingles by group for all the tests made in the factorial

Table 19

A Weighted Comparison of Continued Bending Resistance of Asphalt Shingles by Type in Pounds
(all shingles included)

Type of shingles	Number of bend 1	2	3	4	5	Total of first 5 bending forces	Wt of shingles in lbs/ 108 sq ft
Thick-butts							
Total	5568	4317	3791	3495	3277	20448	1648.7
Av/test	22.2	17.2	15.1	13.9	13.0	81.1	117.8
Av/lb	.1885	.1460	.1280	.1180	.1105		
Hex-tab							
Total	2310	1942	1779	1680	1594	9305	649.3
Av/test	18.35	15.4	14.1	13.3	12.7	74.0	92.8
Av/lb	.1977	.1660	.1520	.1438	.1362		
Uniform-thickness							
Total	3295	2728	2495	2343	2228	13087	717.4
Av/test	30.55	25.30	23.10	21.70	20.60	121.0	119.7
Av/lb	.2550	.2110	.1930	.1810	.1720		

experiment. The tests were purposely made to pretty well cover the expected range of application for asphalt shingles as far as number and position of nails were concerned as well as at various temperatures; therefore, a weighted comparison of the behavior of the shingle types under test should be quite meaningful. Fig. 75 shows graphically the continued resistances of the three types of shingles through the fifth bend. Preliminary studies showed very little relative change in behavior of the three groups after the fifth bend; therefore, such an illustration was not attempted.

As shown by the graph, initially the uniform-thickness shingles were 23.2 per cent or nearly one-fourth better than the thick-butt shingles in bending resistance under all testing conditions, and after five bends 55.7 per cent or over one-half again better. The hex-tab shingles did not show a great advantage over the thick-butts initially, being less than 5 per cent; however, after five bends they maintained a resistance to bending 35.3 per cent or nearly one-third better than the thick-butt shingle group.

CORRELATION OF BENDING BEHAVIOR WITH COMPOSITION OF ASPHALT SHINGLES

Total Weight of Asphalt Shingles

From the physical tests and field observations the heavier shingles had been observed to perform the best against bending stresses. For this reason the first correlations attempted were with total weights of the individual shingles tested. One correlation was made between weight of shingles on a 108 square foot basis and the initial bending resistances of the 27 shingles for the 18 tests made on each. A similar correlation was made with the totals of the first five resisting forces. Linear regressions were plotted for these two as shown by the solid lines of Figures 80 and 81. In plotting the points for the above overall regressions it was noted that the points for the three different types of shingles pretty well grouped themselves. Separate correlations were then calculated and the respective regression lines plotted on the same graphs.

The overall correlation coefficients were found to be highly significant for both the initial forces and the totals of the first five; however, the correlation was somewhat lower with the totals of the first five bends than with the initial bends only. This would indicate that something other than mere weight played a part in the continued bending resistance of asphalt shingles.

In studying the individual correlation coefficients the same trend was noted; however, being more pronounced with some groups than others. The correlation coefficient for the initial resistance of the thick-butt shingles was somewhat higher than the overall coefficient and for the total of the first five forces it was considerably smaller. The correlation coefficient in the latter case was only significant to the 5 per cent level. Less difference was seen between the coefficients of the hex-tab shingles and neither were significant even at the five per cent level. The coefficients for the uniform-thickness shingles were exceedingly high indicating that with the six shingles of that type tested the correlation with weight alone was very high. It could very well happen though that the two or three heavy-weight uniform-thickness shingles of the six could, besides being heavy, have high bending resistance characteristics because of composition or makeup in general.

These correlations with the weights of shingles were exceedingly high because the normal tendency when making a heavy-weight shingle is to improve it in respects other than mere weight; such as, using a heavier felt and more bitumen. The lower correlations with continued bending resistance indicated quite definitely that other factors

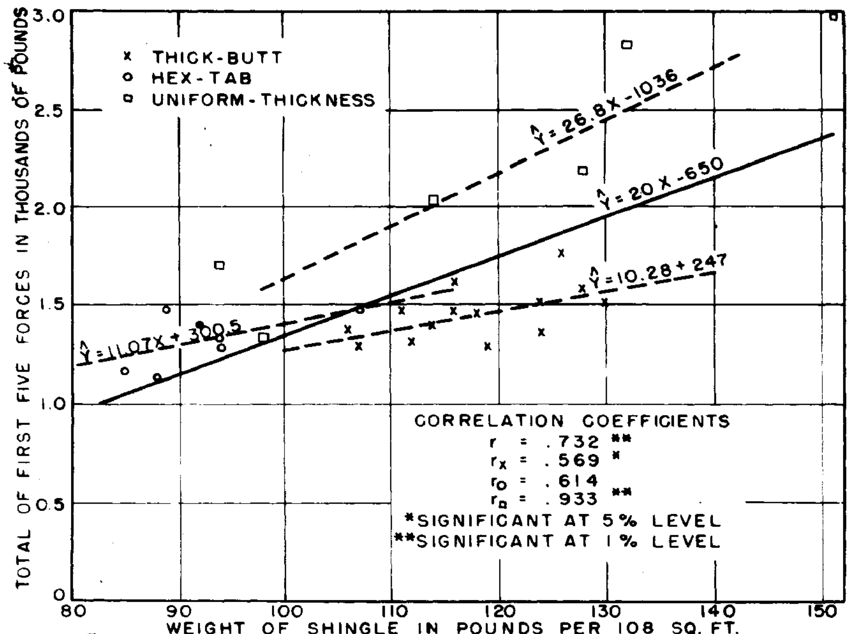

FIG. 81 CORRELATION OF TOTAL OF FIRST FIVE BENDING FORCES OF ASPHALT SHINGLES WITH TOTAL WEIGHT.

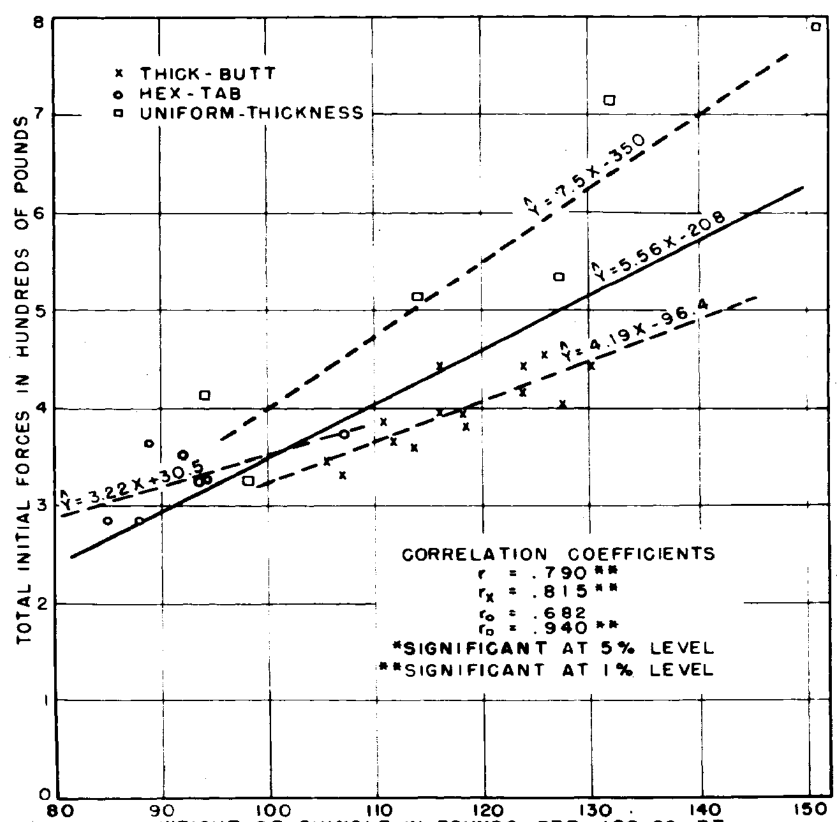

FIG 80 CORRELATION OF INITIAL BENDING FORCES OF ASPHALT SHINGLES WITH TOTAL WEIGHT.

enter into the picture other than weight in giving a shingle higher resistance against continued bending.

Calculations for the determination of the correlation and regression coefficients are found in the Appendix.

Continued Bending Resistance

In order to obtain an index for continued bending resistance of asphalt shingles as tested in this study, the per cent of the initial bending force remaining after five bends was taken. The resulting percentages are listed in Column Y of Table 20. For the thick-butt shingles these percentages were obtained from the 5-5/8-inch nailing with six nails only, in order to eliminate many of the other factors such as thin tops, tear throughs, etc. In checking the continued bending resistances for the uniform-thickness shingles, both hex-tab and square-butt, it was seen that they were quite uniform in performance under all tests so the overall per cent was taken.

Simple correlation coefficients were obtained between Y, the per cent of continuing resistance, and the dependent variables, X_1, X_2, X_3, and X_4, which were, respectively: per cent of filler in the coating, per cent of felt by weight in the shingle, per cent of total bitumen by weight in the shingle, and per cent of total mineral by weight in the shingle. The coefficients obtained were as follows:

Table 20

Correlation of Shingle Composition and Continued Bending Resistance

	Y 5th force as per cent of 1st	X_1 Per cent of filler	X_2 Per cent of felt	X_3 Per cent total asphalt	X_4 Per cent total mineral
1	70.6	34.9	8.8	38.0	53.3
2	67.3	31.1	10.9	39.0	49.88
3	67.8	23.2	11.5	43.6	44.9
4	60.8	33.8	10.0	42.9	47.1
5	66.3	30.6	11.4	44.5	43.9
7	67.2	49.6	13.3	49.5	37.2
8	62.1	53.6	7.5	42.4	50.0
9	71.6	46.0	10.8	39.3	50.1
10	68.3	44.4	10.0	36.3	53.7
11	64.0	41.8	9.7	32.9	57.4
12	67.4	42.1	9.5	38.4	52.2
13	67.0	39.4	9.7	45.9	44.4
14	70.1	36.9	10.8	44.8	44.4
15	69.3	36.1	12.9	42.4	44.8
16	69.0	38.5	10.9	46.6	42.7
17	64.5	47.6	10.1	43.3	46.6
18	72.5	41.2	14.5	41.3	44.2
19	66.0	40.6	10.4	39.7	49.9
20	68.3	45.2	11.8	36.1	52.2
21	66.0	41.5	9.2	43.7	47.0
22	69.8	0.0	12.0	49.2	38.8
23	71.9	0.0	14.5	50.0	35.5
24	65.0	29.0	9.1	37.0	53.9
25	70.4	36.3	13.0	38.5	48.9
26	68.5	28.6	10.1	33.7	55.8
27	71.6	0.0	13.5	56.2	30.3
28	71.4	0.0	10.3	53.6	36.0

$r_1 = -.4537$*

$r_2 = .6148$**

$r_3 = .3027$

$r_4 = -.4175$*

*Significant at the 5% level

**Significant at the 1% level

It is noted from the above coefficients that for the 27 shingles tested the continued bending resistance was mainly dependent upon the proportion of felt in the shingles. The felt dependent variable was highly significant while those for the portion of filler in the coating and portion of total mineral were nearly the same and significant at the 5% level. These two coefficients were similar because the simple correlation between the two was .6258. This is logical inasmuch as the figure for total mineral includes the filler and as the filler is increased the figure for the total mineral normally increases unless there is a similar decrease in the surface minerals used.

The multiple correlation coefficient between the per cent of continued bending resistance and the four dependent variables mentioned above was calculated to be as follows:

$R = .6213$**

**Significant at the 1% level

This multiple correlation being significant at the 1 per cent level indicates high success in estimating the continued bending resistance of asphalt shingles from these four dependent variables of shingle composition. However, since the R value is little larger than the r_2 value, little advantage would be gained from a multiple regression so far as estimating the continued bending resistance of asphalt shingles.

Linear regressions

Linear regressions were calculated for the three significant dependent variables of the group studied. The regression lines are plotted in Figures 82, 83, and 84. The regression line of Fig. 82 representing proportion of felt, is the most significant of the three. In observing the actual points which were also plotted on this graph, a few extreme deviations from the regression or running average are noted; however, in general the grouping of the points is very much in trend with the line shown. This estimate of the continued bending resistance of asphalt shingles indicates that as the per cent of felt increases 1 per cent, the bending resistance after the fifth bend in per cent of the initial bend increases 1.0516 per cent.

The grouping of points in the graph showing the regression line for portion of filler in the coating is not nearly as uniform as with portion of felt. Extreme deviations are noted in the behavior of the shingles within the

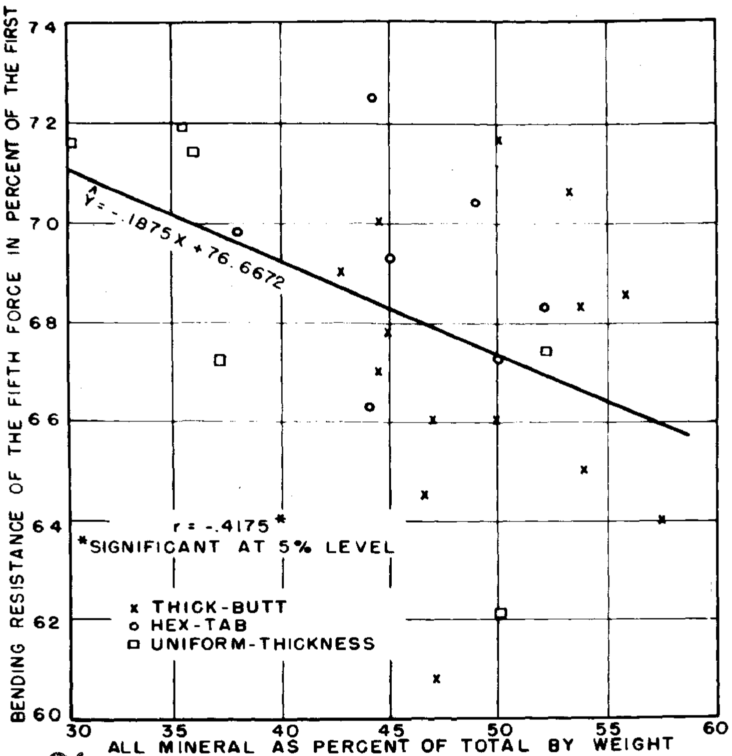

FIG. 84 EFFECT OF THE PORTION OF MINERAL ON THE CONTINUED BENDING RESISTANCE.

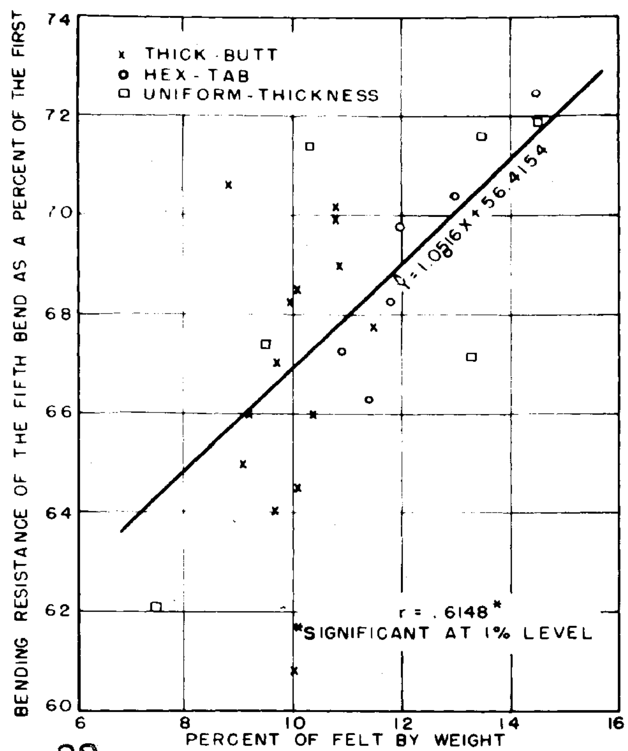

FIG. 82 EFFECT OF THE PORTION OF FELT IN AN ASPHALT SHINGLE ON ITS CONTINUED BENDING RESISTANCE.

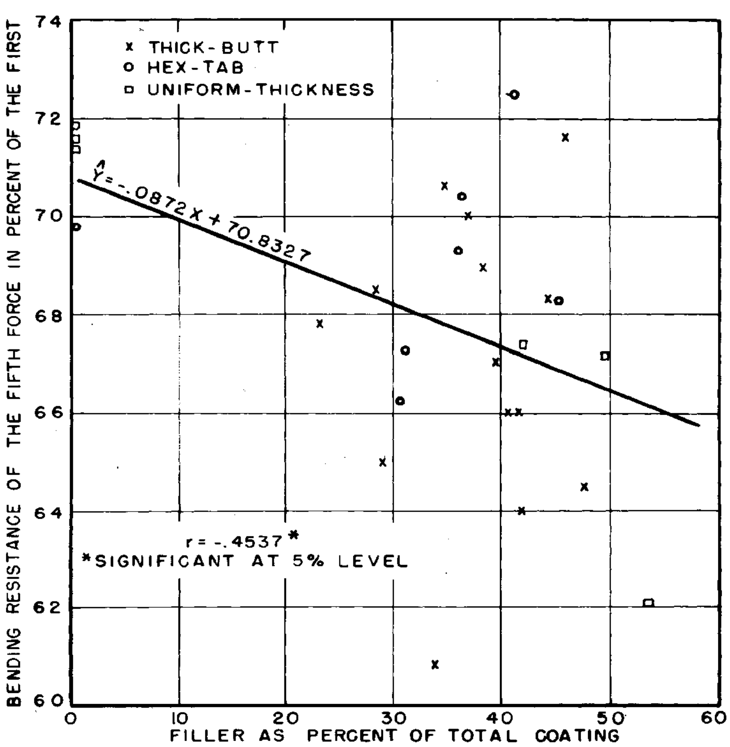

FIG. 83 EFFECT OF MINERAL FILLER IN THE COATING ON CONTINUED BENDING RESISTANCE.

range of 25 to 50 per cent filler where most of them fall. The slope of the line, or in other words the regression coefficient, was determined to a large extent by the four shingles containing no filler in the coating, because of the location of the four plotted values to the extreme left where they would automatically control the direction of the line. It is, however, significant to note that the bending index of these shingles was above 70 where the average of the others with about 40 per cent filler was only about 67 per cent.

The negative correlation coefficients and reverse slopes of the regression lines for both the portion of filler and portion of total mineral indicate that as the amount of mineral increases, either as filler or in total amount, there is a reduction in the continued bending resistance of the asphalt shingles. The pattern of the regression line representing total mineral by per cent as shown in Fig. 84 is very similar to the one for portion of filler. This would be expected as the correlation coefficients were similar and also with a high correlation one for the other.

Thick-butt Asphalt Shingles

Index of design

Since a majority of the asphalt shingles being applied are of the thick-butt type, it was felt desirable to attempt to analyze in somewhat more detail the behavior of this type of shingles tested. The test results and consequently the behavior of the thick-butt shingles in bending was somewhat more eratic and less predictable than the other types of shingles, particularly the uniform-thickness type.

From the observations made of the tests as well as numerous field observations and the previous analyses described, an attempt has been made to set up an index of design for thick-butt shingles based on what was felt to be the pertinent criterion for such.

Felt. The felt as verified by an overall correlation with performance was found to be highly significant in predicting continued bending resistance, so has been listed as one of the primary factors to be considered in the design. Column 1 of Table 21 shows the portion of felt in per cent by weight and the next column adjacent to it lists the order of the 14 shingles on the basis of felt, the one with the highest proportion being listed as No. 1, etc.

Filler. In the previous analysis the filler was found to be significant to the 5 per cent level in prediction of the continued bending resistance of all the asphalt shingles tested, so it too has been included here as a factor to be considered in wind resistant design. Column 2 of Table 21 lists the percentage of filler in the coatings as determined by the composition analysis. They varied from 23.2 to 47.6

Table 21

Design Indexes for Thick-butt Asphalt Shingles

	1 Per cent of felt	Index	2 Per cent of filler	Index	3 Per cent of total mineral	Index	4 Total wt/108 sq ft	Index	5 Dist. of trans. line ins	Index	6 Top as per cent of butt	Index	Total indexes	7 Design index
1	8.8	14	34.9	5	53.3	10	130.0	1	6.50	5	47.7	14	49	9
3	11.5	1	23.2	1	44.9	4	106.8	13	6.25	8	79.6	3	30	2
4	10.0	8	33.8	4	47.1	7	123.8	4	6.75	2	68.6	7	32	4
9	10.8	3	46.0	13	50.1	9	115.9	9	6.25	8	57.5	12	54	12
10	10.0	8	44.4	12	53.7	11	111.3	12	6.63	4	68.6	7	54	12
11	9.7	10	41.8	11	57.4	14	118.6	6	6.75	2	52.3	13	57	14
13	9.7	10	39.4	8	44.4	2	116.0	8	6.25	8	62.3	10	46	6
14	10.8	3	36.9	6	44.4	2	105.5	14	6.87	1	78.9	4	30	2
16	10.9	2	38.5	7	42.7	1	125.9	3	6.00	11	83.1	2	26	1
17	10.1	6	47.6	14	46.6	5	113.8	10	5.12	14	83.3	1	50	10
19	10.4	5	40.6	9	49.9	8	111.6	11	5.63	13	73.6	6	52	11
21	9.2	12	41.5	10	47.0	6	127.5	2	6.00	11	74.1	5	46	6
24	9.1	13	29.0	3	53.9	12	123.8	4	6.50	5	59.6	11	48	8
26	10.1	6	28.6	2	55.8	13	118.2	7	6.31	7	65.1	9	45	5
Sum							1648.7		87.81					
Mean	10.0		37.5		51.8		117.8		6.28		68.0			

per cent for the 14 shingles and have been indexed accordingly with the lowest percentage as 1 and on up to the highest as 14.

Total mineral. The significance of total mineral was similar to that for filler; however, it was felt desirable to include it because adding extra mineral as top surfacing beyond an adequate amount may also reduce the continued bending resistance as does additional filler. The thick-butt shingles varied in total portion of filler from a low of 42.7 per cent to a high of 57.4 per cent. The respective amounts for the 14 shingles are listed in Column 3 of Table 21. Considerable correlation is noted between the indexes for this mineral column and the filler column; however, not one hundred per cent by a long way, indicating that some of the mineral loading is with granules as well as filler but not particularly together.

Total weight. All other things being fairly equivalent, total weight is as shown in previous correlations a good criterion for estimating a shingle's behavior. With thick-butt shingles, however, just what weight to use becomes a problem because of the varying weight throughout the shingle's cross section. In this case the weight of the butt portion of the shingles figured on a 108 square foot basis was used. The weights are shown in Column 4 of Table 21 and it is noted they vary from 130.0 lbs per 108 square feet down to 105.5 lbs.

<u>Transition lines</u>. A new characteristic has been brought in here that has not been considered previously in the analysis. It is the distance of the transition line from the butt of the shingle. From the observation of the tests and the test results it is evident that the bending resistance drops off very rapidly as the nail approaches the thinning-out portion of the thick-butt, thin-top shingles. The closer this transition line is to the specified position for the nails the more nails that are going to be applied near or on it in ordinary application. Figures 39 to 65 show one shingle of each of the 27 studied, including the 14 thick-butts here concerned with, nailed with the nails one-half of an inch higher than specified. In observing these it is noticed that on a number of the thick-butts the nails are very close or right on this line that can be detected in the photographs. In normal field application one-half an inch more or less one way or the other in the spotting of a nail is not very much, assuming the applicator is actually trying to put the nail where specified. On the other hand, if the applicator is not aware of the significance of placing the nail as low as possible it might well end up one inch higher than specified.

The distances of the transition lines from the butts of the 14 shingles are given in Column 5 of Table 21, and are noticed to vary from 5.12 inches for Shingle No. 17 to 6.87 inches for Shingle No. 14.

Thinness of top. Somewhat analogous with the position of this thinning line in the thick-butt shingles is how great is the transition from the thick-butt to the thin-top. This has been shown in Table 21 as the weight of the top part of the shingle figured in pounds per 108 square feet, as a per cent of the bottom part figured on the same basis. A great variance is noticed here and a very significant factor too if the shingles are going to be thinned out down where there is a chance of the nails being in the thin portion of the shingle or close enough so the shingle tears past the nail heads in bending so the bend takes place on this transition line.

In an attempt to arrive at a representative index from which the behavior of a thick-butt shingle in bending may be predicted all of the above described indexes have been weighted equally for the 14 shingles and an overall index obtained. These indexes are compared with similar behavior indexes in the following section.

Index of behavior

Initial resistance. Naturally the higher the resistance of a shingle to being blown up initially, the lower the probability of damage in a windstorm. The totals of the initial bending resistances for the 18 tests on each of the shingles has been included in Table 22 as one of the measurements of behavior of thick-butt shingles when

Table 22

Bending Resistance Indexes for Thick-butt Asphalt Shingles

	1		2		3		4		5		6	7
	Total initial forces	Index	First five forces	Index	Fifth force as % of 1st	Index	Total bends to 10#	Index	No. tearing past nails	Total index	Behavior index	Design index
1	443	4	1511	5	51.6	13	589	2	6	30	4	9
3	332	14	1286	14	63.8	5	225	14	0	47	12	2
4	446	2	1532	4	53.4	11	305	11	3	31	5	4
9	394	7	1466	7	59.2	8	476	6	6	34	7	12
10	368	10	1468	6	62.3	6	520	5	4	31	5	12
11	380	9	1295	13	51.9	12	252	13	9	56	14	14
13	444	3	1617	2	57.9	9	600	1	4	19	3	6
14	346	13	1370	10	67.1	1	260	12	0	36	10	[illegible]
16	457	1	1772	1	64.6	3	570	3	1	9	1	1
17	361	12	1398	9	64.5	4	386	9	0	34	7	10
19	366	11	1324	12	56.5	10	440	8	4	45	11	11
21	406	6	1592	3	66.0	2	553	4	00	15	2	6
24	416	5	1357	11	47.9	14	369	10	11	51	13	8
26	391	8	1460	8	60.6	7	455	7	4	34	7	5
Sum	5550		20448				6000					
Mean	397		1460		58.9		429					

subjected to bending stresses. As listed in some of the previous analyses these totals vary from 332 pounds to 457 pounds.

Continued resistance. Two factors have been included under this heading inasmuch as they both bring out to some extent the same characteristic. One is the total of the first five forces as used previously in some of the comparisons, and the other is the per cent the fifth force is of the first, all tests included. They both measure in effect the ability for a shingle to maintain high bending resistance after it has been bent up once. Inasmuch as shingles have been observed in many cases to be flapping in windstorms of velocities that can be expected every few years, this characteristic of continued resistance is of importance along with the initial resisting ability.

Fatigue factor. As a measure of the fatigue of the asphalt shingles the total number of bends that each shingle would sustain prior to dropping to a bending resistance of only 10 pounds was recorded. These totals for the 18 tests on each thick-butt are included in Column 4 of Table 22. A large variance is noted in this measurement. The recorded bends for the 14 shingles varied from a low of 225 bends up to a high of 600.

Tearing past nails. The times out of the 18 tests for each thick-butt shingle that the shingles were observed to definitely tear past the nails were recorded and included in Table 22 as a partial measurement of the bending resistance of asphalt shingles.

Comparison of indexes

An overall index for behavior measurement was determined similar to the one for design of thick-butt shingles. The two are shown in adjacent columns (6 and 7) in Table 22. It is realized that these indexes are not perfect ways of comparing data; however, due to the eratic nature of the data and the numerous factors contributing in varying amounts to the bending resistance of thick-butt shingles, they are felt worthwhile.

It is noticed that Shingle No. 16 rated as No. 1 with both the design and behavior index. In checking its design it is noted that it is a fairly heavy shingle being No. 3 in the weight of its butt; however, it is also noticed that the decrease to its thin-top section is not large, the top being 83.1 per cent as heavy as the butt. This means that its thin-top is nearly as heavy as the butt of the lightest shingle of the group. The transition line of this shingle was 6 inches from the butt edge; however, it is of little importance when considering the thickness of the top. In checking its composition further by Fig. 30 it is noticed that the only difference between the thick-butt and thin-top of this shingle is in its back coating, and also that it has a heavier than average felt. In checking the behavior of Shingle No. 16 it is noticed that it was fairly high in all respects.

In observing the other extreme, Shingle No. 11 showed up as the low one of the group for both indexes. The butt of Shingle No. 11 is of average weight; however, the thin-top is only 52.3 per cent of that by weight. From Fig. 48 it is seen to be a smooth surfaced shingle, which is not implied to mean that that is bad. However, in checking its composition further it is noticed that it contained 57.4 per cent mineral, which was the highest mineral content for the group. The per cent of filler is not extremely high as compared with some of the others but from Fig. 30 it is seen that the amount of surface granules is extremely high, and the bitumen coating quite light. In checking the behavior of this shingle, the outstanding factor which gave it such a low overall bending resistance index was the number of times the shingle tore past the nails. Nine of the 18 tests showed the shingle tearing past which, of course, lowered its continued bending resistance in each case to nearly zero.

Shingle No. 1, for example, is seen to be an extremely heavy butted shingle but the top of it is less than one-half as heavy. It is also seen to be very high total mineral but not quite up to the average in filler. The felt is light on a proportion basis because of the heavy weight of the loaded butt. Even though it was a heavy shingle the design index showed up worse than its actual performance under bending tests. The 4 and 5 inch nailing patterns held the resistance figures up pretty well because of its weight when the nails were not placed too near the transition line. Its continued resistance was very low, however, dropping off to 51.6 per cent by the fifth bend. Six of the tests tore past which were the ones in which the nails were placed a little higher than specified. In the photograph of Fig. 39 the shingle has torn past the nails.

Shingle No. 3 presents a case where the indexes do not match. The main reason the design index shows up pretty well is because practically all the factors except shingle weight were pretty high; however, they show high, mainly because they are percentages of the total weight and that is small so the per cents are consequently high. The transition line is fairly low at 6.25 inches; however, the top is 79.6 per cent as heavy as the butt. In checking the behavior it is noticed that no tear-pasts were observed. The shingle was possibly just too light to hold up well. Another factor that might enter the picture here, however, is as noticed from Fig. 41, the shingle has deep straight vertical grooves embossed into its surface. It could be that these deep cuts actually weaken the shingle in bending rather than strengthen it as claimed by some.

Shingle No. 14 was similar to No. 2 in being light, but having a good design index and a poor behavior index. In checking closely it is seen that Shingle No. 14 is very similar to No. 16 in composition, only on the light side. Shingle No. 16, however, as mentioned above, behaved the best of the group and No. 14 and No. 10 out of 14.

Shingle No. 24, a smooth surfaced shingle, also performed very poorly according to the behavior index; however, the design index is about in the middle of the group. The shingle is seen to be fairly heavy in the butt but drops off to less than 60 per cent in weight at a line 6.5 inches from the butt edge. The shingle is seen to be loaded with mineral on a total weight basis, but to have a fairly small percentage of filler in the coating. In checking the behavior of this shingle it is seen that it was low in all respects except initial resistance which can be gained by merely loading a shingle; however, the lasting resistance was low. The resistance after the fifth bend was less than half that of the first which as shown in previous analyses goes hand in hand with high amounts of mineral and low-weight felts.

In summary, it is believed that these brief discussions of some individual shingles and their performances emphasize some of the correlations previously made, as well as bring out other factors that must be considered in designing a thick-butt shingle so it will have a satisfactory wind resistance.

Performance of thick-butt shingles as compared to the uniform-thickness type

In Table 21 it was found that the weight of the butt portions of the thick-butt shingles investigated averaged 117.8 pounds per 108 square feet, while the top portions averaged 68 per cent of that or 80 pounds per 108 square feet. The average distance from the butt edge of the transition line for the 14 shingles was 6.28 inches, meaning that an average of 52.3 per cent of the shingle was of the thickened composition. On this basis the average weight of the group of thick-butt shingles, considering the above proportioning, was 100 pounds per 108 square feet.

There were three individual uniform-thickness shingles (Nos. 12, 23, and 28) of around 100 pounds per 108 square feet each in weight, which this mythical (average of 14 shingles) thick-butt shingle might be compared to. The three weighed 114.0, 94.2, and 98.0 pounds per 108 square feet, respectively, and averaged 102.1 pounds per 108 square feet.

For comparison purposes the average of the thick-butt shingles and its performance is here compared with the average of the above three uniform-thickness shingles. The total amount of materials going into each of the two types was nearly the same; however, it is granted that the total amounts of the individual ingredients was some different. The following table gives some pertinent comparative data:

Table 23

Performance Comparison of Thick-butt and Uniform-thickness Shingles

	Average of 14 thick-butts	Average of 3 uniform shingles
Wt/108 sq ft	100.0	102.1
Wt of felt/108 sq ft	11.75	11.50
Initial resistance	398	418
Resistance after 5 bends (total)	1460	1695
Bends prior to 10 lb. resistance	427	1335
Fif bend as per cent of first	58.9	70.0

From Table 23 it is evident that, from the standpoint of wind resistance characteristics, the materials put into thick-butt shingles could be used more efficiently in a shingle designed with a uniform-thickness cross section.

SUMMARY

This study consisted of a composition analysis of 27 types of new tab-type asphalt shingles and physical tests on these types of shingles to determine the comparative bending resistance of them under varying conditions of application. It was a part of the overall project entitled "An Investigation of Farm Building Losses Due to Wind and Fire", which has been carried on by the Iowa Agricultural Experiment Station since 1930. Such a study of roofing materials and particularly asphalt shingles was undertaken because of the findings of previous statistical studies of loss experiences of the major wind insurance companies in Iowa as well as numerous field observations which brought to light the very rapidly increasing trend of wind damage to asphalt shingles on farm buildings in Iowa.

The 27 types of asphalt shingles investigated included various weights of three main types of tab shingles. They were (1) 14 thick-butt shingles, (2) 7 hex-tab shingles, and (3) 6 uniform-thickness-shingles. The composition analysis of the shingles, which were products of 13 manufacturers, determined the following: (1) weight of the dry felt, (2) amount of felt saturation, (3) amount of top coating bitumen, (4) amount of back coating bitumen, (5) per cent

of filler in coating, (6) amount of top surface granules, and (7) amount of back dusting mineral.

A method was developed for determining the comparative wind resistance of tab-type asphalt shingles. As a part of the method for measuring the bending resistance of asphalt shingles under controlled laboratory conditions, a bending machine was designed and constructed. The mechanical application of the bending stresses at uniform rates decreased to a minimum the variations in the test results.

A factorial experiment was designed for the physical tests on the 27 types of asphalt shingles tested. With such an arrangement it was possible to obtain significant information on six types of nailing patterns and three temperature levels without impairing the precision of the overall bending resistance index desired for each individual type shingle as well as for the three groups of shingles. The field application of asphalt shingles covers a wide range of conditions, therefore, it was felt desirable to run the tests under conditions assimilating those extremes. From the standpoint of nailing patterns, information was desired on the advantage of six nails per strip shingle over four, if any, and the significance of the distance of the nails from the butt edge of the shingle. The six nailing patterns tested were as follows: (1) six nails at 5-5/8 inches from the butt, (2) four nails at 5-5/8 inches from the butt, (3) six nails at 6-5/8 inches from the butt,

(4) four nails at 6-5/8 inches from the butt, (5) six nails at 4-5/8 inches from the butt, and (6) six nails at 6-1/8 inches from the butt. The three temperature levels at which the tests were run were as follows: (1) 55° F, (2) 70° F, and (3) 85° F.

The measurement data recorded from the physical tests consisted of (1) the initial bending resistance, (2) the resistance on each of the successive five bends, (3) the number of bends at bending resistances divisable by five until the resistance decreased to 10 pounds, and (4) whether the shingle tore past the nail heads in bending or not.

The total of the initial bending resistances for each type of shingle tested as well as the totals of the first five bending forces were used as indexes for the running of an analysis of the variance on the factorial data to determine the statistical significance of the various types of nailing patterns and levels of temperature. Correlations were also made the wind-resisting behavior and the composition of the shingles.

CONCLUSIONS

1. From the preliminary analysis of variance of the factorial experiment the following conclusions were drawn:

   a. Nailing patterns, different than the standard specifications, affect the bending behavior of thick-butt asphalt shingles far more than either hex-tab or uniform shingles (Tables 8, 9 and 10).

   b. Temperature variations affect the bending behavior of hex-tab shingles the most; however, the interaction effect between temperature level and nailing pattern is highest with the thick-butt type shingles (Tables 8 and 9).

2. From the detailed analysis of application with different numbers of nails the following conclusions were drawn:

   a. No advantage in bending resistance is gained with the use of six nails as compared to four in the application of hex-tab and uniform-thickness shingles when nailed not higher than the standard specifications of 5-5/8 inches (Fig. 70).

   b. Six nails per strip shingle are advantageous over four in applying thick-butt shingles, as added assurance against tearing past the nail heads in bending (Fig. 70).

c. Six nails offer added bending resistance over four with all types of tab-type asphalt shingles when the nails are placed higher than the specified distance of 5-5/8 inches (Fig. 71).

3. From the detailed analysis of application with various nailing distances the following conclusions were drawn:

a. Higher nailing than the specified 5-5/8 inches for thick-butt shingles is very critical as it results in the nails being placed near, on, or above the weak transition lines (Fig. 72).

b. Lower nailing of asphalt shingles at the 4-5/8 inch distance will increase bending resistances about 25 per cent with thick-butt shingles and over 10 per cent with those of uniform-thickness cross sections (Figures 72, 73 and 74).

c. There is no significant reduction in the bending resistance of uniform-thickness shingles, either hex or square tab, when the nails are placed up to one inch higher than the specified 5-5/8 inches (Figures 73 and 74).

4. From the detailed analysis of the effect of temperature level on bending resistance the following conclusions were drawn:

a. There is a non-linear relation between bending resistance of asphalt shingles and temperature. The resistance increases at a faster rate as the temperature drops from 70° F than it increases as the temperature rises from that point (Fig. 79).

b. Lower temperatures cause the bending resistance of thick-butt shingles to drop off more rapidly than the other types because of more frequent tearing failures around the nail heads (Fig. 76).

c. The advantage in bending performance of uniform-thickness shingles over thick-butt types increases as the temperature drops from 85 to 55° F (Figures 76, 77 and 78).

5. From the standpoint of overall weight of asphalt shingles there is a highly significant correlation between it and the initial bending resistance with a somewhat lower correlation with the resistance after five bends, which indicates that factors other than mere weight affect the ability of asphalt shingles to sustain bending stresses (Figures 80 and 81).

a. The rate of increase of sustained bending resistance with the addition of weight to asphalt shingles is 2.5 times greater for uniform-thickness shingles than for the thick-butt types (Figure 81).

6. From the study of the effect of the various constituents of asphalt shingles on bending resistance, the following correlations were derived:

a. The effect of the per cent of felt on sustained bending resistance is highly significant and may be represented by the following linear regression equation:

$$Y = 1.0516X + 56.4154$$ (Figure 82).

b. The effect of per cent of filler in the coating and the total portion of mineral matter on sustained bending resistance is significant at the 5 per cent level and may be represented respectively by the following linear regression equations:

$$Y = -0.0872X + 70.8327$$ (Figure 83)

$$Y = -0.1875X + 76.6672$$ (Figure 84)

7. In comparing the overall wind resisting performance of the various types of asphalt shingles the following conclusions were drawn:

a. On a weighted basis the uniform-thickness shingles will resist bending stresses 23 per cent higher initially and 55 per cent higher after five bends than the thick-butt types (Figure 75).

b. Uniform-thickness asphalt shingles make more efficient use of the materials from which they are ordinarily manufactured than do the thick-butt types (Table 23).

DISCUSSION

It is the writer's opinion, based on observations during the past five years and the findings and conclusions of this investigation, that minimum wind resistant specifications for asphalt shingles should be set up. Such specifications should apply to the design as well as the application of the shingles.

It is believed that a big step towards proper nailing would be attained if the manufacturers would mark the strip shingles where the nails should be placed. This would do more towards getting the proper number of nails applied in the right positions than all the specification sheets that are now placed in the bundles of shingles.

If thick-butt shingles are to be considered as wind-resistant roofing, the design of them should be quite rigidly controlled. The following minimum specifications are suggested:

1. Butt weight: 115 pounds per 108 square feet
2. Top weight: 75 per cent of the butt weight
3. Thick portion to extend up 7 inches from lower edge
4. Felt weight: 12 pounds per 108 square feet
5. Filler: not over 35 per cent of coating by weight
6. Total mineral: not over 50 per cent of total weight

7. Applied with six nails per strip shingle
8. Nails placed 5-5/8 inches from butt edge
9. Applied over smooth solid deck

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APPENDIX

Appendix A

CORRELATION OF WEIGHT OF SHINGLE
AND INITIAL BENDING RESISTANCE

No. of Shingle	X	Y	x	y	x^2		xy	y^2
1	130.1	443	+18	+ 29	324	+	522	841
2	107.1	372	- 5	- 42	25	+	210	1754
3	106.8	332	- 5	- 82	25	+	410	6704
4	123.8	446	+12	+ 32	144	+	384	1024
5	94.2	326	-18	- 88	324	+	1584	7720
7	131.8	716	+20	+302	400	+	6040	91000
8	151.8	790	+40	+376	1600	+	15040	141000
9	115.9	394	+ 4	- 20	16	-	80	400
10	111.3	386	- 1	- 28	1	+	28	783
11	118.6	380	+ 7	- 34	49	-	238	1156
12	114.0	514	+ 2	+100	4	+	200	10000
13	116.0	444	+ 4	+ 30	16	+	120	900
14	105.5	346	- 6	- 68	36	+	408	4600
15	88.0	283	-24	-131	576	+	3144	17100
16	125.9	457	+14	+ 43	196	+	602	1849
17	113.8	361	+ 2	- 53	4	-	106	2809
18	85.0	286	-27	-128	729	+	3456	16360
19	111.6	366		- 48				2300
20	92.1	351	-20	- 63	400	+	1260	3950
21	127.5	406	+16	- 8	256	-	128	64
22	94.0	327	-18	- 87	324	+	1566	7540
23	94.2	415	-18	+ 1	324	-	18	1
24	123.8	416	+12	+ 2	144	+	24	4
25	88.9	365	-23	- 49	529	+	1127	2401
26	118.2	391	+ 6	- 23	36	-	138	529
27	127.6	533	+16	+119	256	+	1904	14161
28	98.0	325	-14	- 89	196	+	1246	7921
Sum	3,018	11,171			6,934		+38,567	344,871
Mean	112	414						

$$b_x = Sxy/Sx^2 = \frac{38567}{6934} = 5.56$$

$$y = \bar{y} + b\,(X - \bar{x}) = 414 + 5.56\,(X - 112)$$

$$y = 414 + 5.56X - 622 = 5.56X - 208$$

$$b_y = Sxy/Sy^2 = \frac{38567}{344871} = .1118$$

$$r = \sqrt{(5.56)(.1118)} = \sqrt{.622} = .79$$

Appendix B

REGRESSION AND CORRELATION COEFFICIENTS OF WEIGHT OF SHINGLES AND TOTAL INITIAL FORCES

Thick-butts	X	Y	x	y	x^2	y^2	xy
1	130	443	+12	+45	144	2025	+ 540
3	107	332	-11	-66	121	4356	+ 726
4	124	446	+ 6	+48	36	2304	+ 288
9	116	394	- 2	- 4	4	16	+ 8
10	111	386	- 7	-12	49	144	+ 84
11	119	380	+ 1	-18	1	324	- 18
13	116	444	- 2	+46	4	2116	- 92
14	106	346	-12	-52	144	2704	+ 624
16	126	457	+ 8	+59	64	3481	+ 472
17	114	361	- 4	-37	16	1369	+ 148
19	112	366	- 6	-32	36	1024	+ 192
21	128	406	+10	+ 8	100	64	+ 80
24	124	416	+ 6	+18	36	324	+ 108
26	118	391		- 7		49	
Sum	1,651	5,568			755	20,300	+3,160
Mean	118	398					

$b_x = Sxy/Sx^2 = \frac{3160}{755} = 4.19$ $b_y = Sxy/Sy^2 = \frac{3160}{20300} = .1555$

$r = \sqrt{4.19 \times .1555} = \sqrt{.651} = .815$ *

$Y = \bar{y} + b\,(X-\bar{x}) = 398 + 4.19\,(X-118) = 4.19\,X - 96.42$

Hex Tabs	X	Y	x	y	x^2	y^2	xy
2	107	372	+14	+42	196	1764	+ 588
5	94	326	+ 1	- 4	1	16	- 4
15	88	283	- 5	-47	25	2209	+ 235
18	85	286	-10	-44	100	1936	+ 440
20	92	351	- 1	+21	1	441	- 21
22	94	327	+ 1	- 3	1	9	- 3
25	89	365	- 4	+35	16	1225	- 140
Sum	649	2,310			340	7,600	1,095
Mean	93	330					

$b_x = \frac{1095}{340} = 3.22$ $b_y = \frac{1095}{7600} = .144$

$r = \sqrt{3.22 \times .144} = \sqrt{.464} = .682$

$Y = 330 + 3.22\,(X-93) = 3.22X + 30.5$

Appendix B (Cont'd)

REGRESSION AND CORRELATION COEFFICIENTS OF WEIGHT OF SHINGLES AND TOTAL INITIAL FORCES

Uniform Thickness	X	Y	x	y	y^2	x^2	xy
7	132	716	+12	+166	144	27556	+ 1992
8	152	790	+32	+240	1024	57600	+ 7680
12	114	514	- 6	- 36	36	1296	+ 216
23	94	415	-26	-135	676	18225	+ 3510
27	128	533	+ 8	- 17	64	289	- 136
28	98	325	-22	-225	484	50625	+ 4950
Sum	718	3,293			2,428	155,591	+18,212
Mean	120	550					

$$b_x = \frac{18212}{2428} = 7.5 \quad b_y = \frac{18212}{155{,}591} = .1172$$

$$r = \sqrt{7.5x\ .1172} = \sqrt{.88} = .94^{*}$$

$$y = 550 + 7.5\ (X-120) = 7.5X-350$$

Appendix C

CORRELATION OF WEIGHT OF SHINGLES WITH TOTAL OF FIRST FIVE BENDING FORCES

No. of Shingle	X	Y	x	y	xy	y^2
1	130	1511	+18	- 79	- 1422	6241
2	107	1475	- 5	- 115	+ 575	13225
3	107	1286	- 5	- 304	+ 1520	92416
4	124	1532	+12	- 58	- 696	3364
5	94	1290	-18	- 300	+ 5400	90000
7	132	2830	+20	+ 1240	+ 24800	1537600
8	152	2978	+40	+ 1388	+ 55520	1926544
9	116	1466	+ 4	- 124	- 496	15376
10	111	1468	- 1	- 122	+ 122	14884
11	119	1295	+ 7	- 295	- 2065	87025
12	114	2042	+ 2	+ 452	+ 904	204304
13	116	1617	+ 4	+ 27	+ 108	729
14	106	1370	- 6	- 220	+ 1320	48400
15	88	1142	-24	- 448	+ 10752	200704
16	126	1772	+14	+ 182	+ 2548	33124
17	114	1398	+ 2	- 192	- 384	36864
18	85	1177	-27	- 413	+ 11151	170569
19	112	1324		- 266		70756
20	92	1406	-20	- 184	+ 3680	33856
21	128	1592	+16	+ 2	+ 32	4
22	94	1331	-18	- 259	+ 4662	67081
23	94	1707	-18	+ 117	- 2106	13689
24	124	1357	+12	- 233	- 2796	54289
25	89	1484	-23	- 106	+ 2438	11236
26	118	1460	+ 6	- 130	- 780	16900
27	128	2193	+16	+ 603	+ 9648	363609
28	98	1337	-14	- 253	+ 3542	64009
Sum	3,018	42,840			+138,722	5,176,798
Mean	112	1,590				

$$Sx^2 = 6934 \qquad b_x = \frac{138722}{6934} = 20$$

$$by = \frac{138722}{5176798} = .0268$$

$$r = \sqrt{byxb_x} = \sqrt{(20)(.0268)} = \sqrt{.5360} = .732*$$

$$Y = \bar{y} + b\ (X - \bar{x}) = 1590 + 20\ (X - 112)$$

$$= 1590 + 20X - 2240 = 20X - 650$$

Appendix D

REGRESSION AND CORRELATION COEFFICIENTS OF WEIGHT OF SHINGLES AND TOTAL OF FIRST FIVE FORCES

Thick Butts	X	Y	x	y	x^2	y^2	xy
1	130	1511	+12	+ 51	144	2601	+ 612
3	107	1286	-11	-174	121	30276	+ 1914
4	124	1532	+ 6	+ 72	36	5184	+ 432
9	116	1466	- 2	+ 6	4	36	- 12
10	111	1468	- 7	+ 8	49	64	- 56
11	119	1295	+ 1	-165	1	27225	- 165
13	116	1617	- 2	+157	4	24649	- 314
14	106	1370	-12	- 90	144	8100	+ 1080
16	126	1772	+ 8	+312	64	97344	+ 2496
17	114	1398	- 4	- 62	16	3844	+ 248
19	112	1324	- 6	-136	36	18496	+ 816
21	128	1592	+10	+132	100	17424	+ 1320
24	124	1357	+ 6	-103	36	10609	- 618
26	118	1460					
Sum	1651	20,448			755	245,852	+7,753
Mean	118	1460					

$b_x = Sxy/Sx^2 = \frac{7753}{755} = 10.28 \quad by = \frac{7753}{245852} = .0315$

$r = \sqrt{10.28 \times .0315} = \sqrt{.323} = .569$*

$Y = \bar{y} + b\ (X-\bar{x}) = 1460 + 10.28\ (X-118) = 10.28X + 247$

Hex Tabs			x	y	x^2	y^2	xy
2	107	1475	+14	+145	196	21025	+2030
5	94	1290	+ 1	- 40	1	1600	- 40
15	88	1142	- 5	-188	25	35344	+ 940
18	85	1177	-10	-153	100	23409	+1530
20	92	1406	- 1	+ 76	1	5776	- 76
22	94	1331	+ 1	+ 1	1	1	+ 1
25	89	1484	- 4	+154	16	23716	- 616
Sum	649	9305			340	110,871	+3769
Mean	93	1330					

$b_x = \frac{3769}{340} = 11.07 \quad by = \frac{3769}{110871} = .034$

$r = \sqrt{11.07 \times .034} = \sqrt{.376} = .614$

$y = 1330 + 11.07\ (x-93) = 11.07x + 300.49$

Appendix D (Cont'd)

REGRESSION AND CORRELATION
COEFFICIENTS OF WEIGHT OF SHINGLES
AND TOTAL OF FIRST FIVE FORCES

Uniform Thickness			x	y	x^2	y^2	xy
7	132	2830	+12	+650	144	422500	+ 7800
8	152	2978	+32	+798	1024	636804	+ 25536
12	114	2042	- 6	-138	36	19044	+ 828
23	94	1707	-26	-473	676	223729	+ 12298
27	128	2193	+ 8	+ 13	64	169	+ 104
28	98	1337	-22	-843	484	710649	+ 18546
Sum	718	13,087			2,428	2,012,895	65,112
Mean	120	2,180					

$$b_x = \frac{65112}{2428} = 26.8 \quad b_y = \frac{65112}{2,012,895} = .0324$$

$$r = \sqrt{26.8 \times .0324} = \sqrt{.868} = .933*$$

$$Y = 2180 + 26.8\,(X-120) = 26.8X-1036$$

Appendix E

BENDING RESISTANCE OF ASPHALT SHINGLES FOR FIRST FIVE BENDS & NUMBER OF BENDS PRIOR TO A RESISTANCE OF 10 LBS.

Shingle No. 1

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	37	31	29	27	26	150	15	38	125
55 4 5-5/8	36	27	23	19	15	120			10
55 6 6-5/8	19	10	8	7	6	50			2*
55 4 6-5/8	16	7	6	6	5	40			1
55 6 4-5/8	43	37	34	32	31	177	27	71	110
55 6 6-1/8	35	15	10	7	6	73			[illegible]
Sub-total	186	127	110	98	89	610			
70 6 5-5/8	27	24	22	21	20	114		22	78
70 4 5-5/8	27	21	18	16	15	97			10
70 6 6-5/8	17	9	6	6	5	43			2*
70 4 6-5/8	15	7	6	5	5	38			1*
70 6 4-5/8	29	24	22	21	20	116		22	80
70 6 6-1/8	29	22	18	16	14	99			8
Sub-total	144	107	92	85	79	507			
85 6 5-5/8	22	18	16	15	15	86			23
85 4 5-5/8	21	16	14	12	11	74			7
85 6 6-5/8	15	9	6	5	4	38			2*
85 4 6-5/8	11	5	4	4	3	27			1*
85 6 4-5/8	26	21	20	19	18	104		9	48
85 6 6-1/8	18	14	12	11	10	65			5
Sub-total	113	87	72	66	61	394			
Grand total	443	316	274	249	229	1511			589

Shingle No. 3

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	24	20	18	17	16	95		7	28
55 4 5-5/8	23	18	16	15	14	86			19
55 6 6-5/8	22	18	16	15	14	85			16
55 4 6-5/8	20	16	14	13	12	75			11
55 6 4-5/8	27	23	21	19	18	108		11	48
55 6 6-1/8	23	20	17	16	15	91			21
Sub-total	139	115	102	95	89	540			
70 6 5-5/8	18	16	15	14	13	76			12
70 4 5-5/8	18	15	13	12	11	69			8
70 6 6-5/8	17	14	13	12	11	67			8
70 4 6-5/8	15	12	11	10	9	57			
70 6 4-5/8	22	18	16	15	14	85			21
70 6 6-1/8	19	15	14	13	13	77			11
Sub-total	107	91	83	77	71	431			
85 6 5-5/8	14	11	10	10	9	54			4
85 4 5-5/8	13	11	10	10	9	54			4
85 6 6-5/8	15	11	10	9	9	54			3
85 4 6-5/8	11	9	8	7	7	42			1
85 6 4-5/8	15	12	12	11	10	62			5
85 6 6-1/8	13	10	9	8	8	48			2
Sub-total	84	65	59	55	52	315			
Grand total	332	271	244	227	212	1286			225

Shingle No. 5

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	23	19	18	17	16	93		7	39
55 4 5-5/8	24	20	18	17	16	95		8	36
55 6 6-5/8	24	19	17	16	15	91			27
55 4 6-5/8	23	19	17	[illegible]	15	90			25
55 6 4-5/8	22	19	17	16	15	89			25
55 6 6-1/8	23	20	18	17	16	94		7	35
Sub-total	139	116	105	99	93	552			
70 6 5-5/8	16	14	13	12	11	66			9
70 4 5-5/8	17	14	13	12	11	67			32
70 6 6-5/8	17	14	13	12	11	67			9
70 4 6-5/8	17	14	13	12	11	67			8
70 6 4-5/8	19	16	15	14	13	77			13
70 6 6-1/8	20	17	15	14	14	80			15
Sub-total	106	89	82	76	71	424			
85 6 5-5/8	13	10	9	9	8	49			2
85 4 5-5/8	13	11	10	9	9	52			3
85 6 6-5/8	15	12	10	10	9	56			3
85 4 6-5/8	13	11	10	9	9	52			3
85 6 4-5/8	14	12	11	10	9	56			4
85 6 6-1/8	13	10	9	9	8	49			2
Sub-total	81	66	59	56	52	314			
Grand total	326	271	246	231	216	1290			289

Shingle No. 2

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	27	24	22	21	20	115		15	63
55 4 5-5/8	27	23	21	20	19	110		11	48
55 6 6-5/8	28	24	22	21	20	115		14	63
55 4 6-5/8	26	21	19	18	17	101		8	35
55 6 4-5/8	22	20	19	17	15	102		9	43
55 6 6-1/8	25	22	20	19	19	107		13	59
Sub-total	153	136	123	117	111	630			
70 6 5-5/8	20	17	16	15	14	82			24
70 4 5-5/8	19	16	15	14	13	77			17
70 6 6-5/8	21	17	15	15	14	83			22
70 4 6-5/8	21	17	16	15	14	83			8
70 6 4-5/8	15	12	11	11	10	59			5
70 6 6-1/8	22	16	17	16	15	88			17
Sub-total	117	97	91	86	80	472			
85 6 5-5/8	15	13	11	11	10	60			5
85 4 5-5/8	15	11	10	10	9	54			4
85 6 6-5/8	16	13	12	11	11	63			7
85 4 6-5/8	15	12	11	10	10	58			4
85 6 4-5/8	15	12	10	10	9	56			4
85 6 6-1/8	15	13	12	11	10	62			5
Sub-total	91	74	66	63	59	353			
Grand total	372	307	280	266	250	1475			451

Shingle No. 4

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	33	25	22	20	19	119		12	29
55 4 5-5/8	32	10	8	6	5	61			2*
55 6 6-5/8	25	18	16	14	13	86			10
55 4 6-5/8	22	11	10	9	8	60			3*
55 6 4-5/8	41	32	28	26	24	151	9	21	70
55 6 6-1/8	39	25	21	18	17	120		8	30*
Sub-total	192	121	105	93	86	597			
70 6 5-5/8	21	18	16	15	15	96		7	25
70 4 5-5/8	25	19	16	15	14	89			14
70 6 6-5/8	18	16	15	14	13	76			9
70 4 6-5/8	17	13	11	11	10	62			5
70 6 4-5/8	27	21	19	18	17	102		8	34
70 6 6-1/8	29	23	20	17	16	101		6	20
Sub-total	141	109	95	90	85	520			
85 6 5-5/8	20	15	14	13	12	74			9
85 4 5-5/8	20	15	13	12	11	71			8
85 6 6-5/8	16	13	12	11	10	62			5
85 4 6-5/8	14	11	9	8	8	50			2
85 6 4-5/8	24	18	16	17	15	88			22
85 6 6-1/8	19	15	13	12	11	70			7
Sub-total	113	87	77	71	67	415			
Grand total	446	317	277	254	238	1532			305

Shingle No. 6

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	52	44	40	[illegible]	37	211	62	148	350
55 4 5-5/8	58	46	41	39	37	221	49	115	280
55 6 6-5/8	49	40	37	34	[illegible]	193	31	72	185
55 4 6-5/8	44	35	32	30	[illegible]	169	[illegible]	50	160
55 6 4-5/8	55	50	[illegible]	[illegible]	[illegible]	243	131	175	375
55 6 6-1/8	51	41	38	35	33	[illegible]	[illegible]	76	175
Sub-total	309	256	236	221	213	1235			
70 6 5-5/8	38	31	29	27	26	151	18	52	210
70 4 5-5/8	41	33	30	28	26	158	17	49	170
70 6 6-5/8	35	29	26	25	24	139	11	29	95
70 4 6-5/8	34	27	25	23	22	131	6	20	85
70 6 4-5/8	44	36	33	31	30	174	27	73	245
70 6 6-1/8	39	31	29	27	26	151	13	35	114
Sub-total	231	187	172	161	153	904			
85 6 5-5/8	31	25	23	21	20	120		21	95
85 4 5-5/8	32	26	24	22	21	125	7	20	94
85 6 6-5/8	27	23	21	19	18	108		11	43
85 4 6-5/8	27	22	20	19	18	106		10	37
85 6 4-5/8	32	26	24	22	21	125	6	19	92
85 6 6-1/8	27	23	21	19	17	107		10	43
Sub-total	176	145	133	122	115	691			
Grand total	716	588	541	504	[illegible]	2830			2614

Shingle No. 8

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	60	48	44	41	39	232	49	90	111
55 4 5-5/8	60	47	43	40	38	228	38	65	96
55 6 6-5/8	57	45	40	38	35	215	23	42	88
55 4 6-5/8	54	42	38	35	32	201	22	47	115
55 6 4-5/8	64	48	42	39	37	230	50	95	125
55 6 6-1/8	62	47	41	38	35	223	33	54	83
Sub-total	357	277	248	231	216	1329			
70 6 5-5/8	42	33	30	28	27	160	16	45	121
70 4 5-5/8	45	35	31	29	27	167	15	40	100
70 6 6-5/8	38	32	29	27	25	151	13	39	125
70 4 6-5/8	38	30	27	25	24	144	9	28	113
70 6 4-5/8	44	35	32	30	29	170	20	50	115
70 6 6-1/8	42	33	30	28	26	159	15	36	103
Sub-total	249	198	179	167	158	951			
85 6 5-5/8	31	24	22	20	19	116		12	53
85 4 5-5/8	33	26	24	22	21	126	6	15	54
85 6 6-5/8	28	24	22	21	20	117		14	56
85 4 6-5/8	29	23	20	18	17	107		8	35
85 6 4-5/8	32	26	23	21	20	122		15	55
85 6 6-1/8	29	23	21	19	18	110		10	45
Sub-total	184	146	132	121	115	698			
Grand total	790	621	559	519	489	2978			1593

Shingle No. 10

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	30	26	23	22	21	122	6	19	87
55 4 5-5/8	30	26	24	22	21	123	7	20	84
55 6 6-5/8	24	16	15	11	10	76			5
55 4 6-5/8	16	9	8	7	6	46			2*
55 6 4-5/8	34	29	26	25	24	138	11	39	70
55 6 6-1/8	29	24	22	20	19	114		13	49
Sub-total	163	130	118	107	101	619			
70 6 5-5/8	23	19	18	17	16	93		7	42
70 4 5-5/8	22	19	17	16	15	89			34
70 6 6-5/8	19	14	11	10	9	63			4
70 4 6-5/8	14	9	8	7	7	45			2*
70 6 4-5/8	24	20	18	17	16	95		8	42
70 6 6-1/8	25	21	19	18	17	100		9	32
Sub-total	127	102	91	85	80	485			
85 6 5-5/8	18	15	13	12	12	70			11
85 4 5-5/8	18	15	13	12	12	70			11
85 6 6-5/8	14	11	10	9	8	52			3*
85 4 6-5/8	11	8	7	6	5	37			1*
85 6 4-5/8	19	15	14	13	12	73			13
85 6 6-1/8	16	13	12	11	10	62			5
Sub-total	96	77	69	63	59	364			
Grand total	386	309	278	255	240	1468			520

Shingle No. 12

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	37	31	28	27	26	149	14	[illegible]	59
55 4 5-5/8	37	30	28	26	24	145	9	12	21*
55 6 6-5/8	36	30	27	25	24	142	10	20	47
55 4 6-5/8	31	25	22	21	19	118		12	49
55 6 4-5/8	42	36	33	31	29	171	19	45	145
55 6 6-1/8	37	30	27	26	25	145	11	28	56
Sub-total	220	182	165	156	147	870			
70 6 5-5/8	27	24	21	20	19	111		19	80
70 4 5-5/8	27	22	20	19	18	106		11	52
70 6 6-5/8	27	22	20	19	18	106		12	57
70 4 5-5/8	25	20	18	17	16	96		7	26
70 6 4-5/8	32	27	25	24	23	131	12	37	145
70 6 6-1/8	29	24	22	20	19	114		12	37
Sub-total	167	139	126	119	113	664			
85 6 5-5/8	21	18	17	16	15	87			31
85 4 5-5/8	23	20	17	16	16	92		7	30
85 6 6-5/8	20	16	15	14	13	78			15
85 4 6-5/8	19	16	14	13	13	75			13
85 6 4-5/8	23	20	18	17	16	94		7	41
85 6 6-1/8	21	17	16	15	13	82			16
Sub-total	127	107	97	91	86	508			
Grand total	514	428	388	366	346	2042			937

Shingle No. 9

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	32	28	26	24	23	133	11	34	112
55 4 5-5/8	33	25	22	18	15	114		6	17*
55 6 6-5/8	17	11	9	8	7	52			3*
55 4 6-5/8	16	12	10	9	6	53			3
55 6 4-5/8	38	33	31	29	28	159	24	69	120
55 6 6-1/8	29	20	16	13	11	89			6*
Sub-total	165	129	114	101	91	600			
70 6 5-5/8	25	21	20	19	18	103		12	75
70 4 5-5/8	25	20	18	17	16	96		7	28
70 6 6-5/8	14	10	8	7	6	45			2
70 4 6-5/8	14	8	7	7	6	42			2*
70 6 4-5/8	28	23	22	21	20	114			30
70 6 6-1/8	23	18	16	15	14	86			10*
Sub-total	129	100	91	86	80	486			
85 6 5-5/8	20	17	15	15	14	81			25
85 4 5-5/8	20	16	14	14	13	77			14
85 6 6-5/8	12	9	7	6	5	39			1*
85 4 6-5/8	10	7	6	5	5	33			1*
85 6 4-5/8	22	18	17	16	15	88			29
85 6 6-1/8	16	13	12	11	10	62			1
Sub-total	100	80	71	67	62	380			
Grand total	394	309	276	254	233	1466			475

Shingle No. 11

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	29	24	21	19	18	111		11	51
55 4 5-5/8	27	20	17	15	13	92			7*
55 6 6-5/8	24	8	6	5	4	47			2*
55 4 6-5/8	17	6	5	4	4	36			2*
55 6 4-5/8	36	30	27	25	24	142	11	29	55
55 6 6-1/8	28	21	18	17	16	100		6	16
Sub-total	161	109	94	85	79	528			
70 6 5-5/8	22	18	16	15	14	85			20
70 4 5-5/8	22	18	15	14	13	82			13*
70 6 6-5/8	15	9	7	5	5	41			2*
70 4 6-5/8	15	6	5	4	4	34			2*
70 6 4-5/8	25	21	19	18	17	100		9	36
70 6 6-1/8	24	19	17	15	14	89			15
Sub-total	123	91	79	71	67	431			
85 6 5-5/8	17	13	11	11	10	62			5
85 4 5-5/8	19	15	13	12	11	70			7*
85 6 6-5/8	13	8	7	6	5	39			2*
85 4 6-5/8	11	6	4	4	3	28			1*
85 6 4-5/8	19	15	14	13	12	73			11
85 6 6-1/8	17	14	12	11	10	64			5
Sub-total	96	71	61	57	51	336			
Grand total	380	271	234	213	197	1295			252

Shingle No. 13

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	37	29	25	23	22	136	6	[illegible]	[illegible]
55 4 5-5/8	37	26	12	10	9	94			4*
55 6 6-5/8	22	20	12	11	10	75			[illegible]
55 4 6-5/8	18	11	9	8	8	54			2*
55 6 4-5/8	45	39	35	34	33	[illegible]	45	[illegible]	[illegible]
55 6 6-1/8	30	21	18	16	15	100			18
Sub-total	189	146	111	102	97	645			
70 6 5-5/8	25	21	19	16	17	100		8	37
70 4 5-5/8	26	21	19	17	16	99		7	30
70 6 6-5/8	20	15	13	12	11	71			8
70 4 6-5/8	16	12	10	9	8	55			3*
70 6 4-5/8	33	28	26	24	23	134	12	43	145
70 6 6-1/8	24	19	17	16	15	91			16
Sub-total	144	116	104	96	90	550			
85 6 5-5/8	21	17	15	14	14	81			19
85 4 5-5/8	22	18	16	15	14	85			14*
85 6 6-5/8	15	12	10	9	9	55			3
85 4 6-5/8	12	9	8	7	7	43			2
85 6 4-5/8	25	20	19	17	16	97		[illegible]	[illegible]
85 6 6-1/8	16	13	12	[illegible]	10	61			4
Sub-total	111	89	80	72	70	422			
Grand total	444	351	295	270	257	1617			630

Shingle No. 14

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	26	22	20	19	18	105		10	41
55 4 5-5/8	26	22	20	18	17	103		8	32
55 6 6-5/8	22	18	16	15	14	85			13
55 4 6-5/8	20	16	14	13	12	75			9
55 6 4-5/8	28	24	22	21	20	115			15
55 6 6-1/8	25	21	19	18	17	100		8	28
Sub-total	147	123	111	104	98	583			
70 6 5-5/8	18	15	14	13	13	73			14
70 4 5-5/8	19	15	13	13	12	72			15
70 6 6-5/8	19	15	13	12	12	70			8
70 4 6-5/8	15	12	11	10	9	57			4
70 6 4-5/8	23	20	18	17	16	94		7	32
70 6 6-1/8	21	17	16	15	14	83			18
Sub-total	114	94	85	80	76	449			
85 6 5-5/8	16	13	12	12	11	64			8
85 4 5-5/8	15	12	12	11	12	62			7
85 6 6-5/8	12	10	9	8	8	47			2
85 4 6-5/8	12	10	8	8	8	46			2
85 6 4-5/8	15	12	11	11	11	63			4
85 6 6-1/8	14	12	11	10	9	56			4
Sub-total	85	71	64	60	58	338			
Grand total	346	288	260	244	232	1370			260

Shingle No. 16

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	32	26	[illegible]	22	21	125	6	15	50
55 4 5-5/8	33	27	24	22	21	127	6	13	43
55 6 6-5/8	32	27	24	21	20	124		12	33
55 4 6-5/8	27	21	18	17	16	99		6	19
55 6 4-5/8	40	34	31	29	28	162	15	33	110
55 6 6-1/8	35	28	25	23	22	133	7	17	44
Sub-total	199	163	146	134	128	770			
70 6 5-5/8	27	23	21	20	19	110		14	62
70 4 5-5/8	23	19	17	16	15	90			21*
70 6 6-5/8	23	19	17	15	14	88			16
70 4 6-5/8	19	15	12	11	11	68			7
70 6 4-5/8	28	24	22	21	20	115		16	68
70 6 6-1/8	25	20	17	15	14	91			14
Sub-total	145	120	106	98	93	562			
85 6 5-5/8	21	18	16	15	14	84			23
85 4 5-5/8	23	19	17	16	15	90			20
85 6 6-5/8	16	13	11	10	10	60			4
85 4 6-5/8	15	12	10	9	9	55			3
85 6 4-5/8	21	18	16	15	15	85			25
85 6 6-1/8	17	14	13	11	11	66			8
Sub-total	113	94	83	76	74	440			
Grand total	457	377	335	308	295	1772			570

Shingle No. 18

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	21	16	17	16	15	87			51
55 4 5-5/8	22	20	18	17	17	94		9	62
55 6 6-5/8	24	20	19	18	17	98		8	63
55 4 6-5/8	20	17	16	15	14	82			28
55 6 4-5/8	19	17	16	15	14	81			33
55 6 6-1/8	23	19	18	17	17	94		11	56
Sub-total	129	111	104	98	94	536			
70 6 5-5/8	14	12	11	11	11	59			7
70 4 5-5/8	15	12	11	11	10	59			5
70 6 6-5/8	15	13	12	12	11	63			9
70 4 6-5/8	14	12	11	10	10	57			4
70 6 4-5/8	14	12	11	11	11	59			7
70 6 6-1/8	17	15	14	14	13	73			15
Sub-total	89	76	70	69	66	370			
85 6 5-5/8	11	9	8	8	7	43			2
85 4 5-5/8	13	10	10	9	9	51			2
85 6 6-5/8	11	9	8	8	7	43			2
85 4 6-5/8	11	10	9	8	8	46			2
85 6 4-5/8	11	9	8	8	8	44			2
85 6 6-1/8	11	9	8	8	8	44			2
Sub-total	68	56	51	49	47	271			
Grand total	286	243	225	216	207	1177			353

Shingle No. 15

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	21	18	17	16	15	87			14
55 4 5-5/8	22	19	17	16	15	89			31
55 6 6-5/8	22	19	17	16	16	90		6	32
55 4 6-5/8	19	16	15	14	14	78			17
55 6 4-5/8	19	16	15	14	13	77			16
55 6 6-1/8	23	19	18	17	16	93		6	25
Sub-total	126	107	99	93	89	514			
70 6 5-5/8	15	12	11	11	10	59			5
70 4 5-5/8	15	13	11	10	9	58			4
70 6 6-5/8	16	14	12	12	11	65			9
70 4 6-5/8	13	11	10	9	9	52			3
70 6 4-5/8	16	13	12	12	11	64			9
70 6 6-1/8	17	14	13	12	12	68			10
Sub-total	92	77	69	66	62	366			
85 6 5-5/8	10	9	8	7	7	41			1
85 4 5-5/8	11	9	9	8	8	45			2
85 6 6-5/8	12	10	9	9	8	48			2
85 4 6-5/8	11	9	8	8	7	43			2
85 6 4-5/8	10	9	8	7	7	41			2
85 6 6-1/8	11	9	8	8	8	44			2
Sub-total	65	52	50	47	45	262			
Grand total	283	239	218	206	196	1142			207

Shingle No. 17

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	25	21	18	17	16	97		10	28
55 4 5-5/8	26	20	18	17	15	96			23
55 6 6-5/8	24	20	18	18	17	97		9	49
55 4 6-5/8	21	18	16	15	14	84			22
55 6 4-5/8	33	27	25	23	22	130	8	21	100
55 6 6-1/8	25	20	18	17	16	96		8	32
Sub-total	154	126	113	107	100	598			
70 6 5-5/8	20	16	14	13	12	75			12
70 4 5-5/8	17	13	12	11	11	64			7
70 6 6-5/8	19	16	14	14	13	76			18
70 4 6-5/8	17	14	12	12	11	66			7
70 6 4-5/8	24	20	18	17	16	95		9	48
70 6 6-1/8	20	16	15	14	13	78			13
Sub-total	117	95	85	81	76	454			
85 6 5-5/8	16	13	11	10	10	60			4
85 4 5-5/8	16	13	12	11	10	62			5
85 6 6-5/8	13	10	9	8	8	48			2
85 4 6-5/8	13	10	9	9	8	49			2
85 6 4-5/8	18	15	13	12	12	70			11
85 6 6-1/8	14	12	10	10	9	55			3
Sub-total	90	73	64	60	57	344			
Grand total	361	294	262	248	233	1398			386

Shingle No. 19

Number of test	1st	2nd	3rd	4th	5th	Sum total	20#	15#	10#
55 6 5-5/8	30	25	22	21	20	118		52	146
55 4 5-5/8	31	24	20	17	15	107			11*
55 6 6-5/8	17	12	10	9	8	56			3
55 4 6-5/8	14	10	9	8	8	49			2
55 6 4-5/8	39	33	30	28	27	157	19	53	120
55 6 6-1/8	24	15	12	10	9	70			4*
Sub-total	155	119	103	93	87	557			
70 6 5-5/8	21	18	16	15	14	84			18
70 4 5-5/8	22	18	15	14	13	82			11*
70 6 6-5/8	13	10	8	7	7	45			2
70 4 6-5/8	13	9	7	7	6	42			2*
70 6 4-5/8	27	22	20	19	18	106		13	75
70 6 6-1/8	20	13	10	9	8	60			7
Sub-total	116	90	70	71	66	419			
85 6 5-5/8	18	15	13	12	11	69			9
85 4 5-5/8	18	15	13	12	11	69			7
85 6 6-5/8	11	8	7	5	5	36			1
85 4 6-5/8	10	8	6	5	5	34			1
85 6 4-5/8	22	18	16	15	14	85			19
85 6 6-1/8	16	12	10	9	8	55			3
Sub-total	95	76	65	58	54	340			
Grand total	366	285	244	222	207	1324			440

* Shingle tore past nails in bending

Appendix E (Cont'd)

BENDING RESISTANCE OF ASPHALT SHINGLES FOR FIRST FIVE BENDS & NUMBER OF BENDS PRIOR TO A RESISTANCE OF 10 LBS.

Shingle No. 20

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	24	20	19	17	16	96		9	48
55 4 5-5/8	25	22	20	19	18	104		10	60
55 6 6-5/8	23	20	18	17	17	95		8	45
55 4 6-5/8	22	19	17	16	15	89			31
55 6 4-5/8	28	25	23	22	21	119	7	30	120
55 6 6-1/8	29	24	22	21	20	116		18	75
Sub-total	151	130	119	112	107	619			
70 6 5-5/8	17	15	14	13	12	71			12
70 4 5-5/8	17	15	13	12	12	69			12
70 6 6-5/8	17	15	13	12	12	69			10
70 4 6-5/8	16	13	12	11	11	63			7
70 6 4-5/8	20	16	15	14	14	79			25
70 6 6-1/8	24	20	18	17	16	95		7	17
Sub-total	111	94	85	79	77	446			
85 6 5-5/8	15	11	10	10	9	55			3
85 4 5-5/8	14	11	10	10	9	54			3
85 6 6-5/8	13	11	9	9	8	50			2
85 4 6-5/8	14	11	10	9	8	52			3
85 6 4-5/8	16	13	12	11	11	63			8
85 6 6-1/8	17	14	13	12	11	67			9
Sub-total	89	71	64	61	56	341			
Grand total	351	295	268	252	240	1406			491

Shingle No. 22

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	24	21	20	19	18	102		12	59
55 4 5-5/8	23	21	20	18	17	99		11	61
55 6 6-5/8	24	21	19	18	17	99		9	64
55 4 6-5/8	22	19	17	15	15	88			21
55 6 4-5/8	22	19	17	16	15	89			24
55 6 6-1/8	24	20	18	17	17	96		9	57
Sub-total	139	121	111	103	99	573			
70 6 5-5/8	17	15	14	14	13	73			18
70 4 5-5/8	18	16	15	14	13	76			19
70 6 6-5/8	19	16	14	13	13	75			16
70 4 6-5/8	17	13	12	11	10	63			4
70 6 4-5/8	17	15	14	13	12	71			16
70 6 6-1/8	19	16	15	14	14	78			20
Sub-total	107	91	84	79	75	436			
85 6 5-5/8	13	11	10	10	9	53			3
85 4 5-5/8	14	11	10	10	9	54			3
85 6 6-5/8	14	11	10	10	9	54			3
85 4 6-5/8	12	10	9	9	8	48			2
85 6 4-5/8	14	12	11	10	10	57			4
85 6 6-1/8	14	12	11	10	9	56			4
Sub-total	81	67	61	59	54	322			
Grand total	327	279	256	241	228	1331			399

Shingle No. 21

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	26	21	19	18	17	101		8	32
55 4 5-5/8	28	23	21	19	18	109		10	40
55 6 6-5/8	26	21	19	18	17	101		7	27
55 4 6-5/8	23	20	17	16	15	91			20
55 6 4-5/8	37	30	28	26	25	146	10	33	130
55 6 6-1/8	34	28	25	24	23	134	9	25	87
Sub-total	174	143	129	121	115	682			
70 6 5-5/8	20	17	15	14	13	79			16
70 4 5-5/8	20	17	14	14	13	78			17
70 6 6-5/8	19	16	15	14	13	77			13
70 4 6-5/8	17	14	12	11	11	65			6
70 6 4-5/8	26	22	20	19	18	105		11	48
70 6 6-1/8	28	24	21	20	19	112		14	68
Sub-total	130	110	97	92	87	516			
85 6 5-5/8	18	15	13	12	12	70			9
85 4 5-5/8	16	13	12	11	11	63			7
85 6 6-5/8	15	11	10	10	9	55			3
85 4 6-5/8	14	12	10	9	9	54			3
85 6 4-5/8	20	16	15	14	13	78			15
85 6 6-1/8	19	16	14	13	12	74			12
Sub-total	102	83	74	69	66	394			
Grand Total	406	336	300	282	268	1592			553

Shingle No. 23

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	30	26	24	23	22	125	10	40	220
55 4 5-5/8	32	28	25	24	23	132	11	53	200
55 6 6-5/8	29	25	23	22	21	120	7	27	145
55 4 6-5/8	26	22	21	19	18	106		11	62
55 6 4-5/8	32	28	26	25	24	135	13	53	160
55 6 6-1/8	29	25	24	23	22	123	9	35	135
Sub-total	178	154	143	136	130	741			
70 6 5-5/8	23	20	18	17	17	95		9	77
70 4 5-5/8	22	19	18	17	16	92		8	66
70 6 6-5/8	20	16	15	14	14	79			23
70 4 6-5/8	20	16	15	14	14	79			23
70 6 4-5/8	24	21	19	18	17	99		13	86
70 6 6-1/8	25	21	20	19	18	103		12	67
Sub-total	134	113	105	99	96	547			
85 6 5-5/8	17	15	14	13	12	71			16
85 4 5-5/8	18	15	14	13	13	73			19
85 6 6-5/8	15	12	11	11	10	59			5
85 4 6-5/8	16	13	12	11	11	63			8
85 6 4-5/8	20	17	16	15	14	82			27
85 6 6-1/8	17	15	14	13	12	71			15
Sub-total	103	87	81	76	72	419			
Grand total	415	354	329	311	298	1707			1353

Shingle No. 24

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	35	28	25	24	22	134	8	19	62
55 4 5-5/8	35	19	10	8	6	78			3*
55 6 6-5/8	20	9	8	7	6	50			2*
55 4 6-5/8	16	9	7	6	6	44			2*
55 6 4-5/8	40	34	30	29	28	161	16	40	135
55 6 6-1/8	31	16	12	10	8	77			4*
Sub-total	177	115	92	84	76	544			
70 6 5-5/8	27	21	19	18	17	102		9	34
70 4 5-5/8	26	18	15	13	12	84			8*
70 6 6-5/8	15	9	7	6	5	42			2*
70 4 6-5/8	13	7	6	5	5	36			2*
70 6 4-5/8	30	24	22	21	20	117		14	60
70 6 6-1/8	25	17	13	11	10	76			5*
Sub-total	136	96	82	74	69	457			
85 6 5-5/8	20	16	14	13	12	75			9
85 4 5-5/8	20	14	12	11	10	67			4*
85 6 6-5/8	11	6	5	4	4	30			2*
85 4 6-5/8	10	5	4	4	3	26			1*
85 6 4-5/8	24	20	18	17	16	95		6	24
85 6 6-1/8	18	14	12	10	9	63			4
Sub-total	103	75	65	59	54	356			
Grand total	416	286	239	217	199	1357			369

Shingle No. 26

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	20	16	15	14	13	78			11
55 4 5-5/8	[illegible]	[illegible]	14	13	12	79			10*
55 6 6-5/8	20	17	16	15	14	82			21
55 4 6-5/8	[illegible]	15	[illegible]	13	12	72			12
55 6 4-5/8	40	34	31	29	28	162	20	[illegible]	180
55 6 6-1/8	34	26	25	22	20	133		11	11*
Sub-total	[illegible]	126	115	106	99	[illegible]			
70 6 5-5/8	19	[illegible]	12	11	11	69			7*
70 4 5-5/8	18	15	12	11	10	65			5*
70 6 6-5/8	15	12	11	10	[illegible]	56			4
70 4 6-5/8	[illegible]	13	11	10	9	58			4*
70 6 4-5/8	30	25	23	22	21	121	6	20	77
70 6 6-1/8	30	23	20	18	17	108		8	27*
Sub-total	127	100	93	[illegible]	78	479			
85 6 5-5/8	[illegible]	12	10	[illegible]	8	58			1
85 4 5-5/8	14	10	9	[illegible]	[illegible]	49			2*
85 6 6-5/8	11	9	[illegible]	7	7	42			2
85 4 6-5/8	[illegible]	9	[illegible]	7	7	41			1
85 6 4-5/8	24	20	18	17	16	96		7	31
85 6 6-1/8	23	17	16	15	14	85			29*
Sub-total	[illegible]	77	[illegible]	63	60	367			
Grand total	391	307	273	252	237	1460			455

Shingle No. 25

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	28	24	23	21	20	116		25	112
55 4 5-5/8	28	25	23	22	21	119	6	21	120
55 6 6-5/8	24	20	19	18	17	98		8	44
55 4 6-5/8	23	20	18	17	16	94		8	41
55 6 4-5/8	24	20	19	18	17	98		12	75
55 6 6-1/8	31	26	24	23	22	126	7	24	102
Sub-total	158	135	126	119	113	651			
70 6 5-5/8	20	17	16	15	14	82			26
70 4 5-5/8	20	16	15	14	14	79			23
70 6 6-5/8	17	14	13	12	12	68			9
70 4 6-5/8	17	14	13	12	12	68			10
70 6 4-5/8	19	16	15	14	13	77			27
70 6 6-1/8	24	21	19	18	17	99		12	62
Sub-total	117	98	91	85	82	473			
85 6 5-5/8	15	13	12	11	11	62			7
85 4 5-5/8	15	12	11	10	10	58			4
85 6 6-5/8	15	12	11	10	10	58			4
85 4 6-5/8	12	10	9	9	8	48			2
85 6 4-5/8	16	13	12	11	11	63			7
85 6 6-1/8	17	15	14	13	12	71			13
Sub-total	90	75	69	64	62	360			
Grand total	365	308	286	268	257	1484			688

Shingle No. 27

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20#	15#	10#
55 6 5-5/8	37	34	31	30	28	162	23	67	200
55 4 5-5/8	[illegible]	[illegible]	31	29	[illegible]	160	30	93	225
55 6 6-5/8	36	32	30	29	27	153	26	61	260
55 4 6-5/8	[illegible]	30	[illegible]	26	24	143	12	28	150
55 6 4-5/8	[illegible]	36	[illegible]	33	32	179	40	116	200
55 6 6-1/8	[illegible]	35	30	29	28	158	25	68	115
Sub-total	[illegible]	200	[illegible]	[illegible]	167	955			
70 6 5-5/8	27	[illegible]	22	21	20	115		24	150
70 4 5-5/8	27	[illegible]	21	[illegible]	18	[illegible]		17	102
70 6 6-5/8	25	23	21	20	20	111		19	110
70 4 6-5/8	[illegible]	22	20	19	[illegible]	105		14	89
70 6 4-5/8	[illegible]	29	[illegible]	25	24	136	6	52	160
70 6 6-1/8	31	[illegible]	24	23	22	[illegible]	8	11	111
Sub-total	172	[illegible]	[illegible]	132	127	701			
85 6 5-5/8	22	[illegible]	[illegible]	[illegible]	16	90		7	42
85 4 5-5/8	[illegible]	[illegible]	[illegible]	[illegible]	15	78			40
85 6 6-5/8	17	[illegible]	[illegible]	[illegible]	15	88			36
85 4 6-5/8	[illegible]	17	[illegible]	[illegible]	[illegible]	80			23
85 6 4-5/8	[illegible]	22	20	19	[illegible]	105		12	71
85 6 6-1/8	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			39
Sub-total	133	112	[illegible]	[illegible]	[illegible]	[illegible]			
Grand total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2193			2125

Shingle No. 28

Number of test	1st	2nd	3rd	4th	5th	Sum total	Force in pounds 20	15#	10#
55 6 5-5/8	23	19	19	17	16	93		10	83
55 4 5-5/8	24	22	20	19	18	103		16	88
55 6 6-5/8	[illegible]	21	20	19	18	103		14	95
55 4 6-5/8	23	20	18	17	16	94		8	47
55 6 4-5/8	25	22	20	19	18	104		15	
55 6 6-1/8	25	22	20	19	18	104		16	91
Sub-total	[illegible]	128	116	110	[illegible]	601			
70 6 5-5/8	16	[illegible]	17	12	12	67			13
70 4 5-5/8	16	13	12	11	10	62			5
70 6 6-5/8	19	16	15	14	13	77			26
70 4 6-5/8	16	14	13	12	11	66			9
70 6 4-5/8	17	16	16	14	13	75			23
70 6 6-1/8	20	17	15	16	15	84			30
Sub-total	[illegible]	90	83	79	74	431			
85 6 5-5/8	12	10	9	9	[illegible]	48			
85 4 5-5/8	12	10	10	9	9	50			
85 6 6-5/8	14	12	11	10	10	57			
85 4 6-5/8	11	9	8	8	8	44			
85 6 4-5/8	14	12	11	10	10	57			
85 6 6-1/8	12	10	9	9	9	49			
Sub-total	75	63	58	55	54	305			
Grand total	325	279	257	244	232	1337			610

* Shingle tore past nails in bending