RESEARCH REPORT

TEMPERATURE AND VISCOSITY EFFECTS ON THE APPLICATION OF ASPHALT DURING THE CONSTRUCTION OF BUILT-UP ROOFING SYSTEMS

SPONSORED BY:

Trumbull

Division of Owens-Corning Fiberglas

NATIONAL ROOFING CONTRACTORS ASSOCIATION

Research Report

Temperature and Viscosity Effects On The Application Of Asphalt During The Construction Of Built- Up Roofing Systems

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CONTENTS

Temperature and Viscosity Effects on the Application of Asphalt During the Construction of Built-up Roofing Systems

1. Introduction

This report gives the results of a two-phased research program sponsored jointly by the National Roofing Contractors's Association and the Trumbull Division of the Owens-Corning Fiberglas Corporation. The primary objective was to study the relationship among application temperature, asphalt viscosity and the interply quality of asphalt used in the construction of built-up roof membranes. Phase I addressed hand-mopping and mechanical-spreader applications under controlled ambient conditions in Summit, Illinois. Phase II was conducted under actual on-the-roof ambient conditions on industrial buildings located in Tulsa, Oklahoma, and Lyman, South Carolina. The complete and detailed reports of the two phases are included as Attachment I and Attachment II of this report, Each report contains: (1) Description of Tests; (2) Test results including Tables and Figures; (3) Conclusions; and (4) Recommendations.

A total of 29 test sections were prepared using accepted roofing practices to apply interply asphalt over a temperature range from 400 F to 500 F. One hundred and sixty one (161) one-square foot test cut samples were taken from the test sections for observation and analysis. All samples were weighed to calculate interply asphalt weights. Selected samples from each test run were sent to a commercial laboratory to be tested for load-strain characteristics and analyzed to determine area of interply voids.

The physical properties of asphalts and reinforcing felts, used to prepare the test sections, were measured for compliance with appropriate ASTM standards. Viscosity measurements were made of the original, unheated asphalts as well as on samples taken during and after the tests were completed. Viscosities were determined over a temperature range of 350 F to 500 F at 25 F intervals.

The conclusions and recomendations ensuing from the project are contained in the Attachment I and Attachment II reports. They are based on the overall analysis of the data reported. However, supplementary observations and experiences of project personnel, both on the test sites and in the laboratory, were also considered in drawing conclusions and making recommendations.

2. Primary conclusions

2.1 The analysis of the data and information obtained in Phase I of the project suggests that a viscosity of 75 centipoise is the more suitable value for defining the Equiviscous Temperature (EVT) base for roofing asphalts.

2.2 The relatively high interply asphalt quantities measured for the mechanical-spreader applied test sections in Phase II of the project support a need for the modification of the Equiviscous Temperature (EVT) as suggested in the Phase I conclusion above.

3. Primary Recommendation

3.1 The recommendation is made that the viscosity base of 125 centistokes now used to define the Equiviscous Temperature (EVT) of roofing asphalt in the United States be changed to 75 centipoise. The following definition is recommended:

“The Equiviscous Temperature (EVT) range of roofing asphalts is the recommended temperature at which the viscosity of asphalt is 75 centipoise plus or minus 25 F at the mop cart or felt layer immediately prior to application to the substrate. "

ATTACHMENT I

REPORT ON

Temperature and Viscosity Effects On The Application Of Asphalt During The Construction Of Built-Up Roofing Systems

PHASE I
CONTROLLED CONDITIONS

A report prepared jointly by representatives of the
National Roofing Contractors Association and the
Trumbull Division, Owens-Corning Fiberglas Corporation

1. Introduction

This report describes a research program to determine the relationship between heating and application temperatures, application viscosity and the amount of interply moppings of hot-applied asphalt used in the construction of built-up roofing membranes. Both hand-mopping application and mechanical-spreader application were addressed in this study. This study also included the use of both organic felts (ASTM D 226, Type II) and glass fiber felts (ASTM D 2 178, Type IV).

A total of twenty test runs were prepared over an application temperature range of 400 F to 500 F. One-hundred ten (110) test cut samples were taken for observation and analysis.

The test sections were constructed under controlled ambient conditions to study the effect of the following variables on applied interply weights: (1) temperature at point of application: (2) types of asphalt: and (3) hand mopping and mechanical equipment application procedures.

Generally, 9-inch x 16-inch test coupons were taken from each test roof section. These coupons were weighed to calculate the asphalt interply quantities. In addition, selected coupons were tested for interply voids, tensile strength and elongation.

The physical properties of the asphalt used were determined for compliance with appropriate ASTM Standards. Viscosity measurements of the asphalts used were also determined over a temperature range of approximately 350 F to 500 F.

A supplementary test run prepared with aggregate surfacing was also constructed to determine the level of perfection that could be achieved by an experienced crew applying a bituminous membrane under essentially ideal application conditions and close supervision.

This test section, approximately 5-feet wide and 13-feet long, was constructed of four plies of fiberglass felts hand mopped and laid shingle fashion. ASTM D 312, Type II asphalt was used for the interply mopping and pour coat and was applied at the asphalt’s EVT. Aggregate surfacing was applied into the pour coat of asphalt to an area 5-feet by 10-feet, leaving an area 3-feet by 5-feet unsurfaced.

Samples 12-inches by 12-inches from the aggregate surfaced area were taken in accordance with ASTM D 2829 and samples from the unsurfaced area were 4-inches by 40-inches and were taken in accordance with ASTM D 3617.

The purpose of these tests was to determine:

- The weight of the interply asphalt
- The weight of the surfacing asphalt
- The weight of the aggregate surfacing
- The percent of aggregate adherence
- The area of interply voids

2. Conclusions and Recommendations

The conclusions and recommendations presented here are based on the results of tests and observations made during this study and will be useful to the entire built-up roofing industry. Supplemental analysis of test, data, measuring such parameters as cooling rates, load-strain properties, and interply voids, are also considered in the conclusions.

2.1 General Conclusions

1. The data suggests that a viscosity of 75 centipoise may be the more appropriate base for defining the Equiviscous Temperature (EVT) of asphalt in lieu of the 125 centistokes value now used in the ASTM definition.
2. The membranes prepared with glass felts and Type II asphalt combinations indicated the more desirable and consistent results with respect to uniformity of interply bitumen weights, incidence of interply void areas and better breaking loads than the other felt-asphalt combinations used in the program.
3. In general, the measured values of individual test cut specimens sampled from identical test runs were not reproducable for interply mopping weight or interply void areas. The lack of uniformity challenges the validity of using test cut samples as quality control parameters for interply weight and void areas during the application of built-up roof membranes.
4. The data and information gained in this program with respect to the viscosity and temperature effects on the application of asphalts used in roofing under quasi laboratory conditions suggest the need for conducting a similar project under field conditions during the construction of a built-up roof.

2.2 Specific Conclusions

2.2.1 Viscosity

1. Type II asphalt (SP = 170 F) used in the project exhibited a viscosity range of 266 to 22 centipoise over temperatures of 350 F to 500 F.
2. The type III asphalt (SP = 198 F) exhibited a viscosity of 620 to 37 centipoise over temperatures of 350 F to 500 F.
3. Asphalt samples taken from the kettle after completion of each days application indicated only an insignificant viscosity change as compared to samples taken initially.
4. The Equiviscous Temperature (EVT) based on the ASTM defined viscosity of 125 centistokes was 383 F and 420 F for the Type II and III asphalts respectively.
5. The current ASTM basis of 125 centistokes to define EVT may be somewhat high for optimum application viscosity. The overall program results suggest that the more desirable alternative may be 75 centipoise.
6. Assuming 75 centipoise were adopted as the EVT base, the EVT of the asphalts used in the program would be 417 F and 457 F for the Type II and III respectively.

2.2.2 Interply Mopping Rates

1. The average interply weight of all 72 specimens of glass felts applied with both types of asphalt over the 400 F to 500 F range was 26 lb./100 sq. ft. The weights of the individual test cut specimens varied from 14 to 49 lb./100 sq. ft. giving a standard deviation of 9.3 among the values of the 72 specimens.
2. The average interply weight of glass felt specimens applied with Type II asphalt at 400 F, 450 F, and 500 F, at viscosities of 88, 40, and 22 centipoise was 21 lb./100 sq. ft. The weights of the individual test cuts ranged from 14 to 31 lb./100 sq. ft. with a standard deviation of 5.1.
3. The average interply weight of glass felt applied with Type III asphalt at 400 F, 450 F, and 500 F, at viscosities of 190, 75, and 37 centipoise, was 29 lb./100 sq. ft. The individual values for individual test cuts varied from 15 to 49 lb./100 sq. ft. giving a standard deviation of 10.4.
4. The average interply weight of all 33 organic felt and Type III asphalt specimens applied at 400 F, 450 F, and 500 F was 29 lb./100 sq. ft. The individual values for test cuts ranged from 16 to 51 lb./100 sq. ft. with a standard deviation of 9.0.
5. The average interply weight for 45 hand mopped specimens was 22 lb./100 sq. ft. The individual test cut values varied from 15 to 33 lb./ 100 sq. ft. with a standard deviation of 4.4 as opposed to the machine applied specimens which averaged 35 lb./100 sq. ft. while individual specimens varied from 19 to 50 lb./100 sq. ft. showing a standard deviation of 9.0.
6. The glass felt and Type II asphalt combination applied at the range of 400-500 F produced specimens of more uniform interply weight as indicated by the standard deviation.
7. Uniformity of samples constructed with Type II asphalt was attributable to the fact that all Type II asphalt was applied at temperatures above the EVT for that asphalt. When the temperature became too high, application quantities became more erratic, suggesting the need for an application temperature range to provide consistant, satisfactory results.
8. In general, glass and organic felt specimens prepared at application temperature at or above the EVT, produced the more uniform interply mopping weights when compared to the specimens prepared at lower application temperatures.

2.2.3 Breaking Load

1. The average breaking load of all organic felt specimens at 0 F was approximately 205 lb./in. The average elongation was about 1.4 % .
2. The average breaking load of all glass felt specimens at 0 F was aproximately 335 lb./in. with the average elgonation being 2.5 % .
3. Both organic and glass felt applied with Type III asphalt using hand mopping techniques produced specimens with higher breaking loads (in the order of 25 to 40 lb./in.) than those applied by machine application.
4. The mechanical and hand applied specimens prepared with glass felt and Type II asphalt produced specimens that tested to approximately the same breaking loads.
5. In general, the higher application temperatures produced specimens with the higher breaking loads.

2.2.4 Interply Voids

1. All 36 specimens tested for interply voids varied in void area measured from a few square inches (less than 1%) to areas as high as 18 % of the total interply area.
2. Membranes prepared with glass felts and Type II asphalt consistently indicated the fewer number of void areas.
3. Little or no correlation was apparent between the interply void areas measured among specimens prepared with either organic or glass felts and Type III asphalt.
4. Little or no correlation was apparent between the interply void areas measured and the temperatures at which the specimens were applied.
5. Wide variatons in interply void areas were frequently found between specimens taken from the same test runs.

2.3 Recommendations

Following are the more important recommendations derived from this research program. They primarily concern the heating and application of hot-applied asphalt products during the job-site construction of built-up roof membranes.

2.3.1 Equiviscous Temperature (EVT)

1. Equiviscous application temperature should be used to achieve proper interply quantities of hot-applied asphalt in the construction of built-up roof membranes.
2. The recommended asphalt EVT range for asphalt should be based on a viscosity of 75 centipoise, plus or minus 25 F.
3. It is recommended that asphalt product suppliers identify the EVT range of the material on the product label.

2.3.2 Heating of Asphalt Products

1. Asphalt products should be heated to a sufficiently high temperature so that they may remain at or above the recommended EVT of the asphalt at the point of application.
2. For safety reasons, the temperature of asphalt in the kettle or tanker should not be heated to or above the actual COC (Cleveland Open Cup) flash point.
3. The temperature of the material in the kettle or tanker should be monitored.
4. Asphalt temperature should be monitored in the dispenser or mop cart at the point of application immediately prior to application.
5. Precautions should be taken to limit the temperature drop when transporting the asphalt between the kettle and point of application.

2.3.3 Application Practices

Although not investigated in this testing, the following is recognized as good roofing practice:

1. The roofing felts should be placed in the hot asphalt immediately after it is applied to compensate for the rapid surface cooling of the asphalt and to insure bonding between felt and bitumen.

3. Observations From Supplementary Tests on Aggregate Surfaced Test Run

1. The quantity of membrane components currently stated in job specifications appear to be based on many years of application experience rather than on in-service performance behavior.
2. The quality of built-up roofing membrane depends more on good application practices than on the quantity of the membrane components specified.
3. Test cut results probably are not representative of the total roof area and are not indicative of the membrane quality.

4. Acknowledgements

Both NRCA and Trumbull Asphalt Products wish to thank the many people who helped in the various phases of this project.

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APPENDIX I

Phase I Report

Controlled Conditions

APPENDIX I

Phase I Report
Controlled Conditions

NRCA/Trumbull Asphalt Study

Introduction

The National Roofing Contractors Association (NRCA) and the Trumbull Division, Owens-Corning Fiberglas conducted a joint program to determine the relationship between heating and application temperatures, application viscosity and the amount and uniformity of interply moppings of hot-applied asphalt products used in the construction of built-up roofing membranes.

Twenty test-roof sections, approximately 6-feet wide and either 18 or 50-feet long, were constructed. Four major variables were studied: temperature at point of application; asphalt, ASTM D 312, Type II and Type III: organic felt, ASTM D 226, Type II, and glass fiber felt, ASTM D 2178, Type IV; and application methods, hand mopping and mechanical application. All other variables were held essentially constant.

A total of 110 9-inch by 16-inch rectangular sample coupons were cut from the test roof sections. These coupons were weighed and the weight of the applied asphalt material was calculated. Other tests including physical properties, asphalt viscosity, tensile strength and elongation, and void analysis were conducted.

The NRCA/Trumbull test program was precipitated by a test program conducted by NRCA and the Koppers Company on coal tar roofing products. The test results were published in the report, "Temperature and Viscosity Effects on the Application of Coal Tar Products during the Construction of Built-up Roofing Systems" and also appeared in *Roofing Spec* magazine (now *Professional Roofing).*

Objective of the Study

The primary objective was to determine the relationship between application temperature, viscosity, interply mopping weight, and uniformity of application of asphalt products. A secondary objective was to relate application parameters to the quality of samples with respect to interply voids and load-strain properties.

Study Parameters

Four fundamental factors that affect the application rate of hot-applied asphalt rooting products were studied:

- Physical characteristics of the reinforcing felt
- Physical characteristics of the asphalt
- Point-of-application temperature
- Method of application

The application temperature is dependent on several other factors which occur on the job site. Ambient temperature, wind velocity, nature of the substrate, atmospheric conditions, kettle temperature, speed of application and insulation of luggers and pipes are among the important factors that influence the application temperature. Method of application, experience and teamwork of the work crew, and competence of supervision are also important factors.

Test Procedures Examine Variables

Four variables were examined in the study – asphalt type, felt type, application temperature, and application method. Samples were prepared and tested using identical equipment, procedures, and personnel.

Variables

Asphalt Types: Two grades of asphalt were included in the program: ASTM D 312, Type II; and ASTM D 312, Type III.

Reinforcing felt: Two types of felt were used in the study: Organic felt, ASTM D 226, Type II, and glass fiber felt, ASTM D 2178, Type IV.

Temperature: Tests were conducted at three point-of-application temperatures: 400 F, 450 F, and 500 F.

Application Method: Specimens were constructed: (1) by hand mopped application with the felt rolled, and (2) by machine application. Organic felt specimens were broomed in immediately after the felt was rolled into the hot asphalt, and glass fiber felt specimens were drag broomed.

Test Equipment

Date: August 18 and 19, 1986.

Site: The tests were conducted in a warehouse building at the Trumbull facilities in Summit, Illinois. This test site is an enclosed area where the inside air temperature remained between 60 F and 80 F.

Kettle: A 125-gallon kettle was used. It was large enough to supply adequate quantities of bitumen for each test, and easy to maneuver or empty when changing from one type of asphalt to the other.

Mechanical Felt Layer: A reverse-rolling felt layer with integral bitumen dispenser and felt carrier was used. It had an insulated aluminum body, 40-gallon capacity, hand-controlled flow, safety lids with latches and a parking brake. The felt layer weighed approximately 98 pounds empty.

Mop Handle:The mop man used a 10-foot aluminum mop handle which allowed him to spread the bitumen with mop strokes commensurate with his on-the-job experience.

Mop Head: A 2-l/2 pound, single-ply cotton mop head was selected by the mop man. Each mop head was weighed before use to insure uniformity.

Mop Cart: A round insulated mop cart was used to maintain the bitumen temperatures at the desired mopping temperature.

Brooms: Brooms 36-inches wide were used for brooming in the felts.

Template for cutting coupons: A 9-inch × 16-inch flat steel template with a handle, positioned flat on the membrane for the purpose of cutting samples with utility knives.

Scale: A 30,000-gram balance with 0.1 gram accuracy was used to weigh the asphalt, felt and membrane samples.

Thermometer: A hand-held digital thermometer with thermocouple probe was used for measuring asphalt temperatures and for monitoring the temperature of the asphalt in the mop bucket or mechanical felt layer reservoir.

Test Surface

A raised test platform 64-feet by 40-feet constructed of 15/32-inch thick flakeboard over a nominal 2 by 4 wood framing was used as a simulated deck for the assembly of the test specimens. For the specimens constructed using Type III asphalt, a layer of No. 15 asphalt-saturated felt was rolled out and fastened to the deck to serve as a separator sheet. For the specimens constructed using Type II asphalt, the Type 15 felt was replaced with a layer of rosin paper and glass fiber felt.

Roofing Personnel

The roofing crew consisted of a mop man, a roll man, a helper, and a kettle operator. All were employees of Hans Rosenow Roofing Company, Chicago, Illinois, a member contractor of NRCA. All crew members were experienced in all aspects of constructing built-up roof systems and belonged to the United Union of Roofers, Waterproofers, and Allied Workers Association, Local No. 11 (AFL/CIO).

Test Procedures

Specimen preparation: Before the start of each run, the rolls of felt were prepared by removing the first 5 feet. A second 5 feet of felt was removed from the roll immediately after each specimen was constructed. When more than one roll of felt was used to assemble a specimen, samples were taken from the beginning and end of each roll. These samples were identified and retained for later examination. Felt weights used in calculating interply quantities were based on the actual weights of the felt used.

The test sequence provided for the construction of a hand-mopped and machine applied membrane test run at each temperature.

In preparation for each test run, the kettle temperature was raised to approximately 25 F above the designated point-of-application temperature. The asphalt was transferred to the insulated mop cart or mechanical spreader reservoir and allowed to cool to within 5 F of the application temperature. When the bitumen reached the desired temperature, application began.

When the test run was completed, 9-inch by 16-inch test coupons were cut from the membrane and labeled so their locations could be identified (Figure 1). The templates were placed on the specimen so that the 16-inch dimension was aligned parallel to the lap edge, and so that the cut included approximately l-inch of headlap. The coupons were weighed, packaged and retained for laboratory evaluation. The average interply quantity was calculated by subtracting the known felt weight from the total coupon weight.

Test Results

Physical Properties of Asphalt: Table 1 shows that both Type II and Type III asphalts used in the study met the requirements of ASTM D 312, and remained essentially unchanged throughout the study.

Viscosity Determinations: Results of viscosity determinations over a range of temperatures used in the test program for both Type II and Type III asphalt are plotted in Figure 2.

Figure #2 represents the viscosities of the respective asphalt types at the current recommended 125 centistokes EVT .

Physical Properties of Reinforcing Felt: Table 2 shows the test results for a typical roll of asphalt saturated organic felt and the basic weight for the roll sections furnished from each membrane application.

The net mass of the felts is less than the current ASTM D 226 minimum of 13 lb./100 sq. ft. The basic weight of the 21 sections taken during the membrane application averaged 12.44 lb./100 sq. ft. which is in agreement with the value obtained on the roll that was tested. The tests on the roll do meet the proposed revision of D 226 which requires a minimum of 11.5 lb./100 sq. ft.

Table 3 gives the test results for one roll of asphalt glass fiber felt and the basic weight for the roll sections furnished from each membrane application.

All test results are in compliance with the requirement for Type IV felt of ASTM D 2178. The average basic weight of the 38 sections was 8.03 lb./100 sq. ft. which is the same as obtained on the roll.

Application Rates of Interply Mopping Material: Table 4 gives the interply mopping weights for each coupon prepared at the respective test temperatures. The weights are expressed in lb./100 sq. ft./ply.

Table 5 summarizes the average interply mopping weights of bitumen at the test application temperatures.

Load-strain Properties of Membrane Specimens: Tensile properties were measured on selected samples from each specimen. The sample closest to the average interply weight for the specimen were selected for this purpose. The specimens were tested in accordance with ASTM D 2523 in the across-machine direction at a temperature of 0 F. Table 6 reports the test data as well as other pertinent information on these test samples.

Voids Within Membrane Specimens: Selected samples from each specimen were analyzed for the presence of interply voids. Two samples were arbitrarily selected from each specimen for analysis. The specimens were chilled to -10F and separated into individual plies by fracturing the interply asphalt. The void area was then measured by use of a grid. Table 7 reports the test data as well as other pertinent information on these test samples.

Supplemental Testing — Project Perfect Square

In an attempt to determine what level of perfection could be achieved by an experienced crew applying a bituminous membrane under ideal application conditions and close supervision, this NRCA/Trumbull Study was expanded to include one additional test section.

This test section, approximately 5-feet wide and 13-feet long, was constructed of four plies of fiberglass felts, hand mopped, and laid shingle fashion. ASTM Type II asphalt was used for the interply mopping and pour coat and was applied at the EVT of the asphalt being used. Aggregate surfacing was applied in a pour coat of asphalt to an area 5-feet by 10-feet, leaving an area 3-feet by 5-feet unsurfaced.

The test equipment, test surface, and roofing personnel used in this supplemental test were as described for the original testing of the NRCA/Trumbull Study.

Figure 3 indicates the pre-selected sampling locations. Samples (12-inches by 12-inches) from the aggregate surfaced area were taken in accordance with ASTM D 2829 and samples from the unsurfaced area were 4-inches by 40-inches and were taken in accordance with ASTM D 3617.

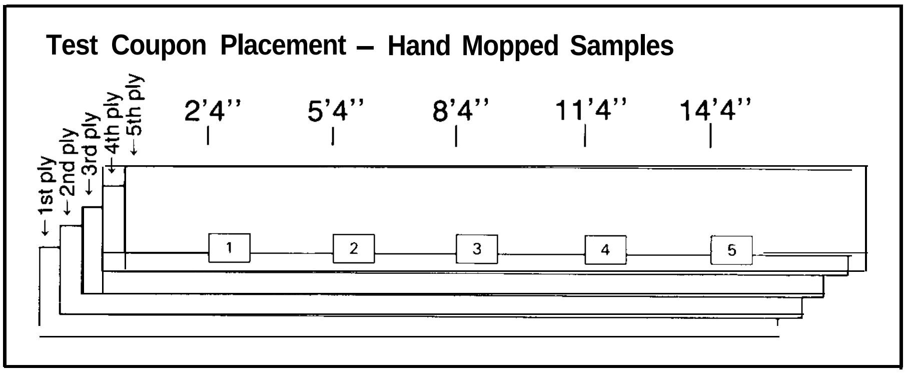
The purpose of these tests was to determine:

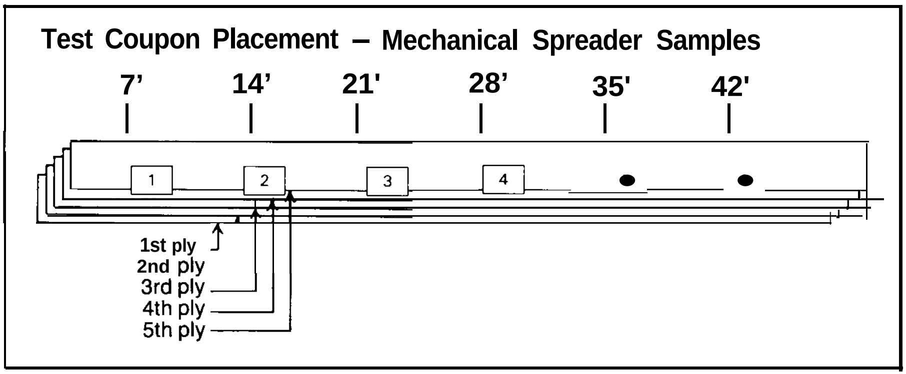
- The weight of the interply asphalt
- The weight of the surfacing asphalt
- The weight of the aggregate surfacing
- The percent of aggregate adherence
- The area of interply voids

Table 8 gives the membrane component weights measured from the test cut samples and Table 9 gives the interply void analysis of the test cut samples.

NRCA and the Trumbull Division of Owens-Corning Fiberglas plan to conduct additional tests to verify the findings of this controlled study under field application conditions.

FIGURE 1 – Test Coupon Locations





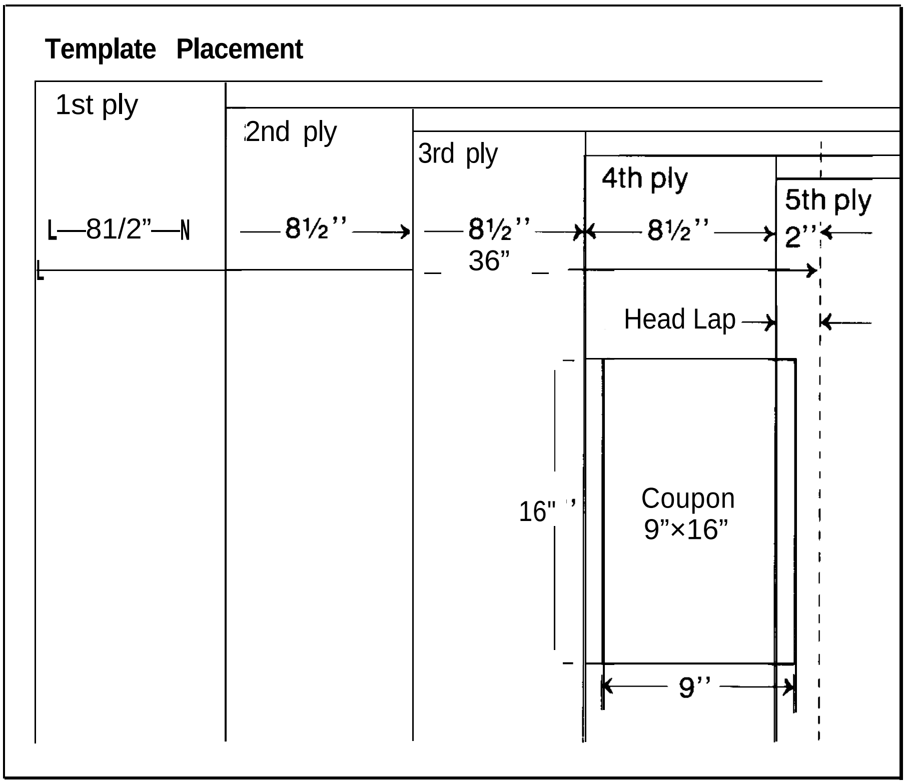


FIGURE 2 — Viscosities Of Asphalts Used in Phase I

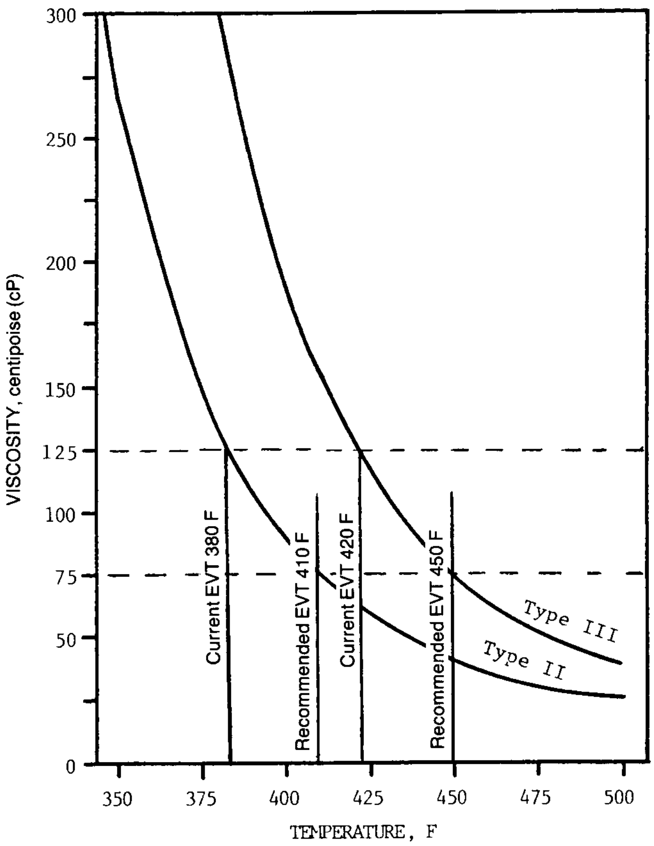


FIGURE 3 — Perfect Square Test Coupon Locations

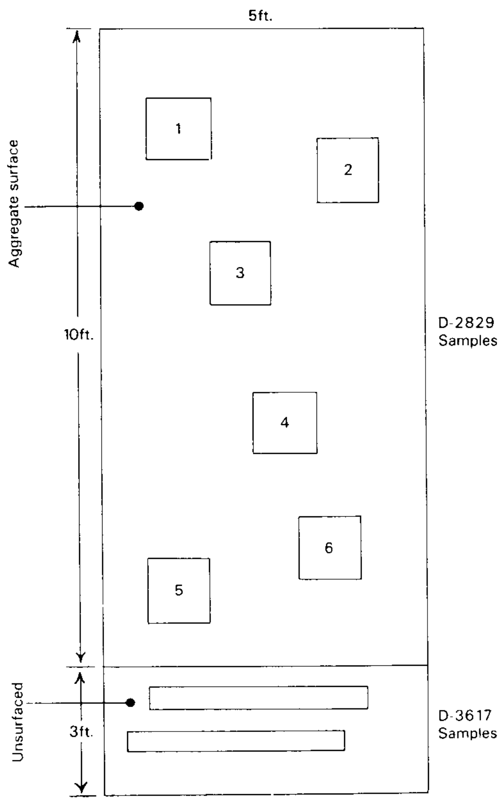


TABLE 1 — Physical Properties Of Asphalts Used In This Study

	Type II Asphalt			Type III Asphalt		
	ASTM Standard	Start of test	End of test	ASTM Standard	Start of test	End of test
Softening Point, F	158-176	170	167.5	185-205	198	195
Penetration @ 77F	18-40	30	31	15-35	18	18.5
Penetration @ 115F, max.	100	53	56	90	30	32
Penetration @ 32F, min.	6	14	15	6	11	12
Flash Point COC, F, min.	475	595	595	475	585	590
Ductility @ 77F, cm., min.	3.0	3.75	4.0	2.5	3.0	3.0

TABLE 2 — Physical Properties Of Organic Felts Used In This Study

	ASTM Standard D-226	Test Results
Width of roll, in.	36+1-0.25	36.25
Area of roll, sq. ft., min	432	437
Net mass of saturated felt, lb.1100 sq. ft., min.	13	12.7
Mass of saturant, lb.1100 sq. ft., min.	7.3	7.35
Mass of desaturated felt, Ib./l00 sq. ft., min.	5.2	5.35
Ash, %, max.	10	3.9
Perforated felt, avg. area of individual hole, sq. mm., max.	32	0.64
Average venting area, %, min.	0.1	0.18
Average breaking strength, lbf./in.		
with fiber grain, min.	30	46
across fiber grain, min.	15	15.3
Pliability @ 77F, 1/2 in. radius	no breakage	pass
Loss on heating at 221 F for 5 hours, %, max	4	2.8

TABLE 3 — Physical Properties Of Glass Felts Used In This Study

	ASTM Standard D-21 76	Test Results
Width of roll, in.	36 + I- 0.25	36.06
Area of roll, sq. ft., min.	540	543
Moisture, %, max.	1.0	0.2
Net dry mass of felt, lb./100 sq. ft., min. (average of all rolls)	7.0	7.99
Bituminous saturant, lb./1100 sq. ft., min.	3.0	6.01
Mass of desaturated felt, lb./100 sq. ft., min.	1.7	1.99
Detached comminuted surfacing, lb./100 sq. ft., max.	0.7	0.02
Adherent comminuted surfacing, lb./100 sq. ft., max.	2.5	0.01
Ash, %	70 to 88	81.1
Average breaking strength, lbf./in.		
with fiber grain, min.	44	75.7
across fiber grain, min.	44	57
Pliability @ 77F, 1/2 in. radius	no breakage	pass

TABLE 4 — Asphalt Interply Mopping Weight Test Results

Test Number	1	2	3	4	5	6	7	8	9	10
Felt Type	organic	organic	glass	glass	organic	organic	glass	organic	glass	organic
Test Temperature, F	400	400	400	400	450	400	450	450	450	500
Application Method	handmop	handmop	handmop	machine	machine	machine	machine	handmop	handmop	machine
Asphalt Type	III	III	III	III	III	III	III	III	III	III
Interply Weight (lb./100 sq. ft.)										
Coupon 1	30.5	23.7	24.8	49.1	36.9	44.3	41.1	29.0	20.5	23.9
Coupon 2	31.3	21.6	21.3	47.4	41.2	44.7	35.7	24.9	18.3	22.1
Coupon 3	24.1	18.7	19.5	45.3	40.6	41.4	32.1	24.8	21.4	21.7
Coupon 4	30.8	26.4	22.9	44.7	33.9	38.3	32.4	21.6	20.4	20.7
Coupon 5	28.6	24.7	23.1	49.4	39.5	39.6	34.9	24.1	21.7	22.6
Coupon 6	—	—	—	47.0	36.1	50.9	39.1	—	—	25.9
Average	29.0	23.0	22.3	47.1	38.0	43.2	35.9	24.9	20.4	22.8
Standard Deviation	2.9	3.0	2.0	1.9	2.9	4.5	3.6	2.7	1.3	1.9

Test Number	11	12	13	14	15	16	17	18	19	20
Felt Type	glass	glass	organic	glass	glass	glass	glass	glass	glass	glass
Test Temperature, F	500	500	500	400	500	500	450	400	450	400
Application Method	machine	handmop	handmop	machine	machine	handmop	handmop	machine	machine	handmop
Asphalt Type	III	III	III	III	II	II	II	II	II	II
Interply Weight (lb./100 sq. ft.)										
Coupon 1	25.6	17.2	19.4	36.2	22.0	17.7	15.0	31.1	21.7	24.1
Coupon 2	21.4	16.6	17.9	33.0	20.9	15.0	16.8	30.4	18.8	20.8
Coupon 3	21.8	18.2	17.0	32.5	18.7	15.8	25.3	30.1	20.2	22.6
Coupon 4	19.3	14.9	17.9	33.8	19.9	13.7	15.2	29.7	19.0	22.0
Coupon 5	26.5	16.6	16.1	34.3	18.1	15.5	16.8	30.5	20.4	21.8
Coupon 6	25.5	—	—	39.9	21.9	—	—	30.2	22.3	—
Average	23.3	16.7	17.6	34.9	20.4	15.5	17.8	30.3	20.4	22.3
Standard Deviation	2.9	1.2	1.2	2.7	1.9	1.5	4.3	0.5	1.4	1.2

TABLE 5 — Asphalt Interply Mopping Weight Summary

Felt Type	Test Temp F	Application Method	Asphalt Type	Tests	Interply Mopping Weights (lb.1100 sq. ft.) Average	Minimum	Maximum	Deviation
glass	all	handmop	II	3	18.5	13.7	25.3	3.7
glass	all	machine	II	3	23.7	18.1	31.1	4.9
glass	400	both	II	2	26.7	20.8	31.1	4.1
glass	450	both	II	2	19.2	15.0	25.3	3.0
glass	500	both	II	2	18.2	13.7	22.9	2.9
glass	all	both	II	6	21.4	13.7	31.1	5.1
glass	all	handmop	III	3	19.8	14.9	24.8	2.7
glass	all	machine	III	4	35.3	19.3	49.4	8.8
glass	400	both	III	3	35.5	19.5	49.4	10.2
glass	450	both	III	2	28.9	18.3	41.1	8.1
glass	500	both	III	2	20.3	14.9	26.5	3.9
glass	all	both	III	7	29.4	14.9	49.4	10.4
glass	all	both	both	13	25.7	13.7	49.4	9.3
organic	all	handmop	III	4	23.6	16.1	31.3	4.7
organic	all	machine	III	3	34.7	20.7	50.9	9.2
organic	400	both	III	3	32.5	18.7	50.9	9.3
organic	450	both	III	2	32.1	21.6	41.2	7.0
organic	500	both	III	2	20.5	16.1	25.9	3.0
organic	all	both	III	7	28.9	16.1	50.9	9.0
both	all	handmop	III	7	22.0	14.9	31.3	4.4
both	all	machine	III	7	35.1	19.3	50.9	9.0
both	400	both	III	6	34.1	18.7	50.9	9.8
both	450	both	III	4	30.5	18.3	41.2	7.8
both	500	both	III	4	20.4	14.9	26.5	3.5
both	all	both	III	14	29.1	14.9	50.9	9.7

TABLE 6 — Load-Strain Test Results

Test Number	Felt Type	Test Temp F	Application Method	Asphalt Type	Tensile @ 0 F (lb./in.)	Percent Elgonation	Modulus Of Elasticity @ 0 F (lb./in. x 10^4)
1	organic	400	handmop	III	201.7	1.71	0.5898
2	organic	400	handmop	III	208.7	1.37	0.7617
6	organic	400	machine	III	170.5	1.28	0.6660
3	organic	450	handmop	III	223.0	1.54	0.7240
5	organic	450	machine	III	191.8	0.84	1.1417
13	organic	500	handmop	III	222.7	1.53	0.7278
10	organic	500	machine	III	211.6	1.46	0.7243
3	glass	400	handmop	III	291.5	2.15	0.6779
4	glass	400	machine	III	351.5	2.59	0.6786
14	glass	400	machine	III	332.5	2.59	0.6786
9	glass	450	handmop	III	322.0	2.31	0.6970
7	glass	450	machine	III	349.7	2.62	0.6674
12	glass	500	handmop	III	313.5	2.91	0.5378
11	glass	500	machine	III	353.2	2.86	0.6175
21	glass	400	handmop	II	341.0	2.46	0.6931
18	glass	400	machine	II	325.8	2.62	0.6217
17	glass	450	handmop	II	337.8	2.32	0.7280
20	glass	450	machine	II	345.7	2.57	0.6726
16	glass	500	handmop	II	338.0	2.49	0.6787
15	glass	500	machine	II	358.2	2.19	0.8178

TABLE 7 — Summary of Void Measurements

Felt Type	Test Temp F	Application Method	Asphalt Type	Average Sq. In. Voids/ Ply
glass	all	handmop	III	**10.1**
glass	all	machine	III	**1.9**
glass	400	both	III	**7.0**
glass	450	both	III	**6.8**
glass	500	both	III	**1.7**
glass	all	both	III	**5.4**
organic	all	handmop	III	**12.2**
organic	all	machine	III	**5.0**
organic	400	both	III	**8.6**
organic	450	both	III	**6.6**
organic	500	both	III	**12.4**
organic	all	both	III	**9.1**
all	all	handmop	III	**11.3**
all	all	machine	III	**3.2**
all	400	both	III	**7.8**
all	450	both	III	**6.7**
all	500	both	III	**7.0**
all	all	both	III	**7.3**
glass	all	handmop	II	**1.7**
glass	all	machine	II	**2.1**
glass	400	both	II	**1.3**
glass	450	both	II	**1.8**
glass	500	both	II	**2.6**
glass	all	both	II	**1.9**
glass	all	both	both	**3.8**

TABLE 8 — Perfect Square Sample Weight Test Results

	Total Membrane Weight (lb.1100 sq. ft.)	Aggregate Surfacing Weights (lb.1100 sq. ft.) Total	Loose	Embedded	Percent Embedment	Asphalt Weights (lb./100 sq. ft.) Pourcoat	Interply
Coupon 1	617.0	449.9	168.1	276.8	61.5	42.6	22.2
Coupon 2	649.5	470.6	203.0	267.6	56.9	47.0	23.6
Coupon 3	681.3	504.4	226.7	277.7	55.1	48.0	22.2
Coupon 4	587.0	417.2	117.4	299.8	71.9	50.4	20.6
Coupon 5	741.5	542.7	141.5	401.2	72.9	75.9	21.5
Coupon 6	671.8	449.0	131.1	317.9	70.8	62.3	17.5
Average	649.0	472.3	164.6	306.8	64.9	54.4	21.3
Minimum	587.0	417.2	117.4	267.6	55.1	42.6	17.5
Maximum	741.5	542.7	226.7	401.2	72.9	75.9	23.6
Standard Deviation	55.6	44.9	43.0	49.7	8.0	12.5	2.1

TABLE 9 — Perfect Square Void Analysis Results

	Interply Void Area (sq. in.) Ply 1&2	Ply 2&3	Ply 3&4	Total Area	Percent Voids
Coupon 1	3.0	1.0	6.0	10.0	2.3
Coupon 2	7.0	1.0	3.5	11.5	2.7
Coupon 3	0.0	2.0	1.5	3.5	0.8
Coupon 4	3.5	4.5	3.0	11.0	2.5
Coupon 5	7.0	4.5	0.0	11.5	2.7
Coupon 6	10.0	3.0	2.5	15.5	3.6

ATTACHMENT II

REPORT ON

Temperature And Viscosity Effects On The Application Of Asphalt During the Construction of Built-Up Roofing Systems

PHASE II
FIELD CONDITIONS

A report, prepared jointly by representatives of the
National Roofing Contractors Association and the
Trumbull Division, Owens-Corning Fiberglas Corporation

1. Introduction

This report describes the field test portion of a research program to determine the relationship between heating and application temperatures, application viscosity and the amount of interply moppings of hot-applied asphalt used in the construction of built-up roof membranes. Both hand-mopping application and mechanical-spreader application were addressed in this study. This study used glass fiber felts (ASTM D 2178, Type IV) and asphalt (ASTM D 226, Type III).

The first portion of these tests was conducted in Tulsa, Oklahoma, and, because of the small size of the roof area being used, only the hand-mopping application was performed. The temperature was approximately 37 F with a wind of 20 mph from the northwest.

The second portion of these tests was conducted in Lyman, South Carolina, and both mechanical-spreader application and hand-mopping application were carried out. The temperature was approximately 71 F with a slight breeze.

A total of nine test runs were prepared over an intended application temperature range of 400 F to 500 F. Fifty-one (51) test cut samples were taken for observation and analysis.

The test sections were constructed under field conditions to study the effect of the following variables on applied interply weights: (1) temperature at point of application: (2) types of asphalt: (3) hand mopping and mechanical equipment application procedures: and (4) to compare these field test results to the controlled tests performed under Phase I of this test program.

Test coupons, 12-inch x 12-inch, were taken from each test roof section. These coupons were weighed to calculate the asphalt interply quantities. In addition, selected coupons were tested for interply voids, tensile strength and elongation.

The physical properties of the asphalt used were determined for using test cut samples as quality control parameters for compliance with appropriate ASTM Standards. Viscosity measurements of the asphalts used were also determined over a temperature range of approximately 350 F to 500 F.

2. Conclusions and Recommendations

The conclusions and recommendations presented here are made on the basis of the data and information obtained in this research project and should be useful to the entire built-up roofing industry. Supplemental analysis of test data, measuring such parameters as cooling rates, load-strain properties, and interply voids, are also considered in the conclusions.

2.1 General Conclusions

2.1.1 Equiviscous Temperature (EVT)

1. The results of the hand-mopped samples of the Tulsa and Lyman test series indicate that a viscosity 125 centistokes is suitable for the construction of built-up roofing membranes. However, the relatively high interply weights of the spreader applied samples of the Lyman tests support a need for a modification of the Equiviscous Temperature (EVT) .
2. The "fallback" in an asphalt's softening point which may occur during heating will cause a decline in the EVT of the asphalt in use. For example, during the Lyman test series, the EVT of the asphalt declined from approximately 420 F for the unheated sample to about 395 F for the asphalt samples at the conclusion of the test.

2.1.2 Interply Asphalt Weights

1. In general, the correlation between the interply mopping weights of the Tulsa/Lyman field samples and those obtained from the controlled test series at Summit, Illinois, was fairly good.
2. The uniformity of interply weights of samples taken from any one test run of the Tulsa/Lyman test series was considered good. The standard deviation was about 1 to 4.
3. With some notable exceptions, the higher the application temperature of the test run, the lower the interply weight and the more uniform the application.

2.1.3 Breaking Load

1. The breaking load of all specimens tested was above the 200 lb./in. value suggested in the National Bureau of Standards Building Science Series No. 55. In general, the lower the interply asphalt weight, the higher the breaking load, but, the breaking load was more influenced by the tensile strength of the felt used.

2.1.4 Interply Voids

1. The results of the samples tested indicate that no clear correlation existed between the area of voids measured in any ply, the location of the ply, the application temperature and the interply weight.

2.2 Observations and Comments

1. The initial test sample taken from any test run generally had the lightest interply weight of all specimens taken from the run. The reason for this has not been established.
2. Some differences were noted in the readings between the different types of thermometers used in these tests, thus indicating a need to insure the accuracy of the thermometers before they are used at a jobsite.
3. On average, the hand-mopped samples from the Tulsa test series had a higher interply weight than those from the Lyman test series. A contributing factor was the ambient climatic conditions. In Tulsa, the temperature was approximately 37 F with a 20 mph wind as opposed to the Lyman climate of over 70 F with little or no wind.
4. A "fallback" in the softening point of asphalt of approximately 15 F was measured before and after completion of testing with a subsequent decline in the actual Equiviscous Temperature (EVT). In other words, an asphalt's EVT may also change, more or less depending on the asphalt, as the job progresses. As an example, the asphalt used in Lyman changed from Type III to Type II during the jobsite heating whereas the Tulsa asphalt remained in spec for Type III.

2.3 Specific Conclusions

2.3.1 Viscosity

1. The Type III asphalt (SP = 185 F) used in the Tulsa tests exhibited a viscosity range of 920 to 35 5 centipoise over temperatures of 350 F to 500 F.
2. The Type III Asphalt (SP = 178-183 F) used in the Lyman tests exhibited a viscosity range of 620 to 25 centipoise over temperatures of 350 F to 500 F.
3. Asphalt samples taken from the kettle after completion of each days application indicated viscosity changes as compared to samples taken initially. Because of this change, the asphalt used in the Lyman tests did not meet the Type III softening point criteria of ASTM D 226 at the conclusion of the tests.
4. The equiviscous temperature (EVT) based on the ASTM defined viscosity of 125 centistokes was 418 F for Tulsa and 419 F for Lyman.
5. The Current ASTM basis of 125 centistokes to define EVT may need some modification for optimum application viscosity.

2.3.2 Interply Mopping Rates

1. The average interply weight of all 50 specimens applied over the 400 F to 500 F range was 27.7 lb./100 sq. ft. The weights of the individual test cut specimens varied from 13.2 to 50.3 lb./100 sq. ft. giving a standard deviation of 7.8 among the values of the 50 specimens.
2. The average interply weight for 32 hand mopped specimens was 24.1 lb./100 sq. ft. The individual test cut values varied from 13.2 to 35.1 lb.000 sq. ft. with a standard deviation of 4.6 as opposed to the 18 machine applied specimens which averages 34.1 lb./100 sq. ft. while individual specimens varied from 24.0 to 50.3 lb./100 sq. ft. showing a standard deviation of 8.3.
3. In most instances, specimens prepared at application temperature at or above the EVT produced the more uniform interply mopping weights when compared to the specimens prepared at lower application temperatures. Machine application at temperatures below the EVT becomes irratic and difficult.

2.3.3 Breaking Load

1. The average breaking load of all specimens at 0 F was approximately 259 lb./in. The average elgonation was about 2.35 % .
2. The specimens applied by hand mopping and the specimens made by machine mopping had almost identical average tensile strengths for all specimens that used glass felt by the same manufacturer.
3. For glass felts from different manufacturers, both meeting ASTM D 2178, Type IV, no correlation between the actual weight of the felt and an increase in the tensile strength of the specimen. In the specimens tested, the heavier glass felt produced the lowest tensile strength. The breaking load of the test sample correlates with the tensile strength of the felt used.
4. In general, the higher application temperatures produced specimens with higher breaking loads.

2.3.4 Interply Voids

1. All 18 specimens tested for interply voids varied in void area measured from a few square inches (less than 1 %) to areas as high as 12 % of the total interply area.
2. No correlation existed between the area of voids measured in any ply, the location of the ply, the application temperature and the interply weight.
3. Wide variations in interply void areas were frequently found between specimens taken from the same test runs.
4. These tests demonstrate the improbability of producing a void free membrane under good working conditions.

2.4 Recommendations

Following are the more important recommendations derived from this research program. They primarily concern the heating and application of hot-applied asphalt products during the job-site construction of built-up roof membranes.

2.4.1 Equiviscous Temperature (EVT)

1. Equiviscous application temperature should be used to achieve proper interply quantities of hot-applied asphalt in the construction of built-up roof membranes.
2. The Equiviscous Temperature (EVT) of asphalt be based on a maximum viscosity of 75 centipoise with an allowable variance of plus or minus 25 F.
3. It is recommended that asphalt product suppliers identify the EVT range of the material on the product label.

2.4.2 Heating of Asphalt Products

1. Asphalt products should be heated to a sufficiently high temperature so that they may remain at or above the recommended EVT of the asphalt at the point of application.
2. For safety reasons, the temperature of asphalt in the kettle or tanker should not be heated to or above the actual COC (Cleveland Open Cup) flash point.
3. The temperature of the material in the kettle or tanker should be monitored.
4. Asphalt temperature should be monitored in the dispenser or mop cart at the point of application.
5. Precautions should be taken to limit the temperature drop when transporting the asphalt between the kettle and point of application.

2.4.3 Application Practices

Although not investigated in this testing, the following is recognized as good roofing practice:

1. The roofing felts should be placed in the hot asphalt immediately after it is applied to compensate for the rapid surface cooling of the asphalt and to insure bonding between felt and bitumen.

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APPENDIX I

Phase II Report

Field Conditions

APPENDIX I

Phase II Report

Field Conditions

NRCA/Trumbull Asphalt Study

Introduction

The National Roofing Contractors Association (NRCA) and the Trumbull Division, Owens-Corning Fiberglas conducted a joint program to determine the relationship between heating and application temperatures, application viscosity and the amount and uniformity of interply moppings of hot-applied asphalt products used in the construction of built-up roofing membranes.

Nine test-roof sections, approximately 6-feet wide and either 20 or 60-feet long, were constructed. Two major variables were studied: temperature at point of application and application methods, hand mopping and mechanical application. All other variables were held essentially constant.

Glass fiber felt, ASTM D 2178, Type IV and Asphalt, ASTM D 312, Type III were used in this study.

A total of 51 12-inch by 12-inch sample coupons were cut from the test roof sections. These coupons were weighed and the weight of the applied asphalt material was calculated. Other tests including physical properties, asphalt viscosity, tensile strength and elongation, and void analysis were conducted.

The NRCA/Trumbull test program was precipitated by a test program conducted by NRCA and the Koppers Company on coal tar roofing products. The test results were published in the report, "Temperature and Viscosity Effects on the Application of Coal Tar Products during the Construction of Built-up Roofing Systems" and also appeared in *Roofing Spec* magazine (now *Professional **Roofing***).

Objective of the Study

The primary objective was to determine the relationship between application temperature, viscosity, interply mopping weight, and uniformity of application of asphalt products. A secondary objective was to relate application parameters to the quality of samples with respect to interply voids and load-strain properties.

Study Parameters

Four fundamental factors that affect the application rate of hot-applied asphalt roofing products were studied:

- Physical characteristics of the reinforcing felt
- Physical characteristics of the asphalt
- Point-of-application temperature
- Method of application

The application temperature is dependent on several other factors which occur on the job site. Ambient temperature, wind velocity, nature of the substrate, atmospheric conditions, kettle temperature, speed of application and insulation of luggers and pipes are among the important factors that influence the application temperature. Method of application, experience and teamwork of the work crew, and competence of supervision are also important factors.

Test Procedures Examine Variables

Two variables were examined in the study — application temperature and application method. Samples were prepared and tested using identical equipment, procedures and personnel.

Variables

Asphalt Types: One grade of asphalt was included in the program: ASTM D 312, Type III, however, different manufacturers were used in Tulsa and in Lyman.

Reinforcing Felt: One type of felt was used in the study: ASTM D 2178, Type IV, however, a different manufacturer's felts were used in Tulsa and in Lyman.

Temperature: Tests were conducted at three point-of-application temperatures: 400 F, 450 F, and 5OO F.

Application Method: Specimens were constructed: (1) by hand mopped application with the felt rolled, and (2) by machine application. All felt applications were drag broomed.

Test Equipment

Date: Tulsa, Oklahoma, March 9, 1988

Lyman South Carolina, April 14, 1988

Site: The first tests were conducted on a manufacturing plant addition in Tulsa, Oklahoma. The temperature at the start of the tests was approximately 37 F, with a wind approximately 20 mph from the northwest.

The second tests were conducted on a textile mill re-roofing project in Lyman, South Carolina. The temperature at the start of the tests was approximately 71 F, with a slight breeze.

Kettle: A *265* gallon Garlock pumper kettle was used for the Tulsa tests and a 600-gallon Garlock pumper kettle was used for the Lyman tests.

Mechanical Felt Layer: A Redi forward pushing felt layer with integral bitumen dispenser and felt carrier was used. It had an aluminum body, 40-gallon capacity, hand-controlled flow, safety lids with latches and a parking brake.

Mop Handle: The mop man used a lo-foot wooden mop handle, which allowed him to spread the bitumen with mop strokes commensurate with his on-the-job experience.

Mop Head: 2-l/2 pound, multi-ply fiberglass mop head was selected.

Mop Curt: A round insulated mop cart was used to maintain the bitumen temperatures at the desired mopping temperature.

Brooms: Brooms 36 inches wide were used for brooming in the felts.

Template for cutting coupons: A 12-inch by 12-inch flat steel template with a handle, positioned flat on the membrane for the purpose of cutting samples with utility knives.

Scale: A 30,000-gram balance with 0.1 gram accuracy was used to weigh the asphalt, felt and membrane samples.

Thermometer: A hand-held digital thermometer with thermocouple probe was used for measuring asphalt temperatures and for monitoring the temperature of the asphalt in the mop bucket or mechanical spreader reservoir. In addition, a 0 F to 600 F, Cooper 3270-05 hand held thermometer was used in the Lyman tests.

Test Surface

Tulsa: The roof area, approximately 30-feet x 44-feet, consisted of a standard metal deck over which 3-feet x 4-feet x 1 l/2-inch phenolic foam insulation with a fiberglass facer was mechanically fastened with insulation clips at the rate of 1 (one) fastener per each 2 sq. ft. of roof area. In order to facilitatethe removal of the samples a venting base sheet (the type with holes) was randomly spot mopped to the insulation with Type III asphalt.

Lyman: The roof area consisted of a plywood deck over which the original roofing had been removed and a vapor retarder had been installed. The vapor retarder was composed of a red rosin paper and a fiberglass rooting felt had been nailed and then 2 (two) plies of #15 organic felt had been mopped with Type III asphalt. The top surface had also been mopped with Type III asphalt. Just prior to the start of our tests, a fiberglass type roof insulation in 3-feet x 4-feet x 1 5/8-inch sheets was applied to the vapor retarder in a mopping of Type III asphalt.

Roofing Personnel

All members of the roofing crew were experienced in all aspects of constructing built-up roofing systems and were employees of Empire Roofing & Insulation Company for the Tulsa tests and of CRS, Inc., for the Lyman Tests.

Test Procedures

Specimen Preparation: Before the start of each run, the rolls of felt were prepared by removing the first 5-feet. A second 5-feet of felt was removed from the roll immediately after each specimen was constructed. When more than one roll of felt was used to asemble a specimen, samples were taken from the beginning and end of each roll. These samples were identified and retained for later examination. Felt weights used in calculating interply quantities were based on the actual weights of the felt used.

The test sequence provided for the construction of a hand-mopped and machine-applied membrane test run at each temperature in the Lyman tests and of a hand-mopped membrane test at each temperature for the Tulsa tests.

Tulsa Tests

In preparation for each test run, the kettle temperature was raised to approximately 25 F above the designated point-of-application temperature. The asphalt was transferred to the mop cart or mechanical spreader reservoir and allowed to cool to within 15 F of the application temperature. When the asphalt reached the desired temperature, application began.

When the test run was completed, 12-inch by 12-inch test coupons were cut from the membrane and labeled so their locations could be identified (Figures 1 and 1A). The templates were placed on the specimen so that it was aligned parallel to the lap edge, and so that the cut included at least l-inch of headlap. The coupons were weighed, packaged and retained for laboratory evaluation. The average interply quantity was calculated by substracting the known felt weight from the total coupon weight.

Test Results

Physical Properties of Asphalt: Tables 1 and 1A show the physical properties of the Type III asphalts used in Tulsa and Lyman respectively and indicate the physical property changes that resulted from heating during the tests.

Viscosity Determinations: Results of viscosity determinations over a range of temperatures used in the test program for Type III asphalt are shown in Figure 2 for Tulsa and figure 3 for Lyman.

Physical Properties of Reinforcing Felt: Tables 2 and 2A show the test results for the glass felts used in the tests at Tulsa and Lyman respectively. All test results are in compliance with the requirements for Type IV felt of ASTM D 2 178.

Application Rates of Interply Mopping Material: Tables 3 and 3A give the interply mopping weights for each coupon prepared at the respective test temperature for Tulsa and Lyman respectively. The weights are expressed in lb. / 100 sq. ft. /ply.

Tables 4 and 4A summarize the average interply mopping weights of bitumen at the test application temperatures for Tulsa and Lyman respectively.

Load-strain Properties of Membrane Specimens: Tensile properties were measured on selected samples from each specimen. The sample closest to the average interply weight for the specimen were selected for this purpose, The specimens were tested in accordance with ASTM Method D 2523 in the across-machine direction at a temperature of 0 F. Tables 5 and 5A report the test data on Tulsa and Lyman respectively, as well as other pertinent information on these test samples.

Voids Within Membrane Specimens: Selected samples from each specimen were analyzed for the presence of interply voids. Two samples were arbitrarily selected from each specimen for analysis. The samples were chilled to -10 F and separated into individual plies by fracturing the interply asphalt. The void area was then measured by use of a grid. Tables 6 and 6A report the test data for Tulsa and Lyman respectively as well as other pertinent information on these test samples.

FIGURE 1 — Test Coupon Locations At Tulsa, OK

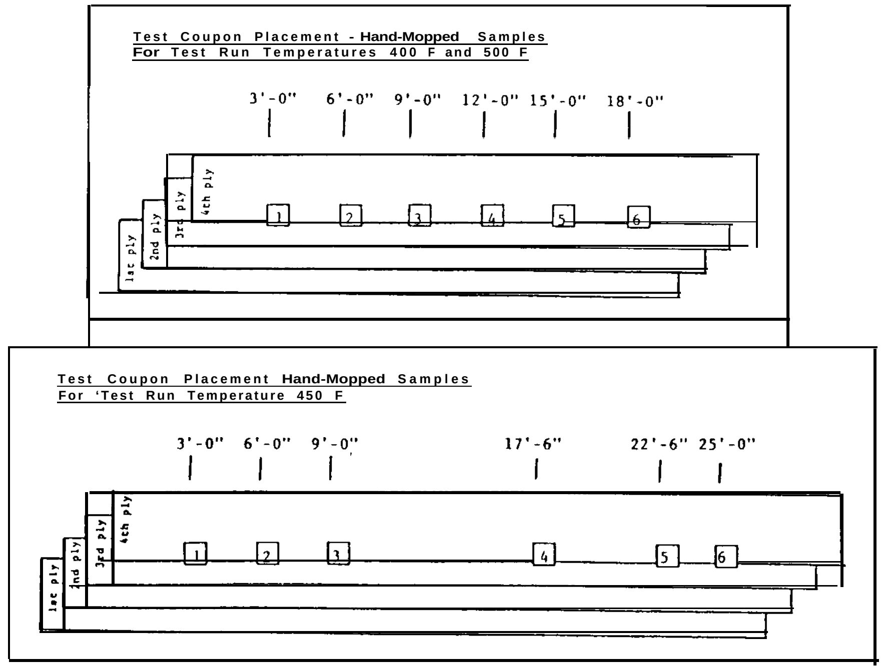


FIGURE1A — Test Coupon Locations At Lyman, SC

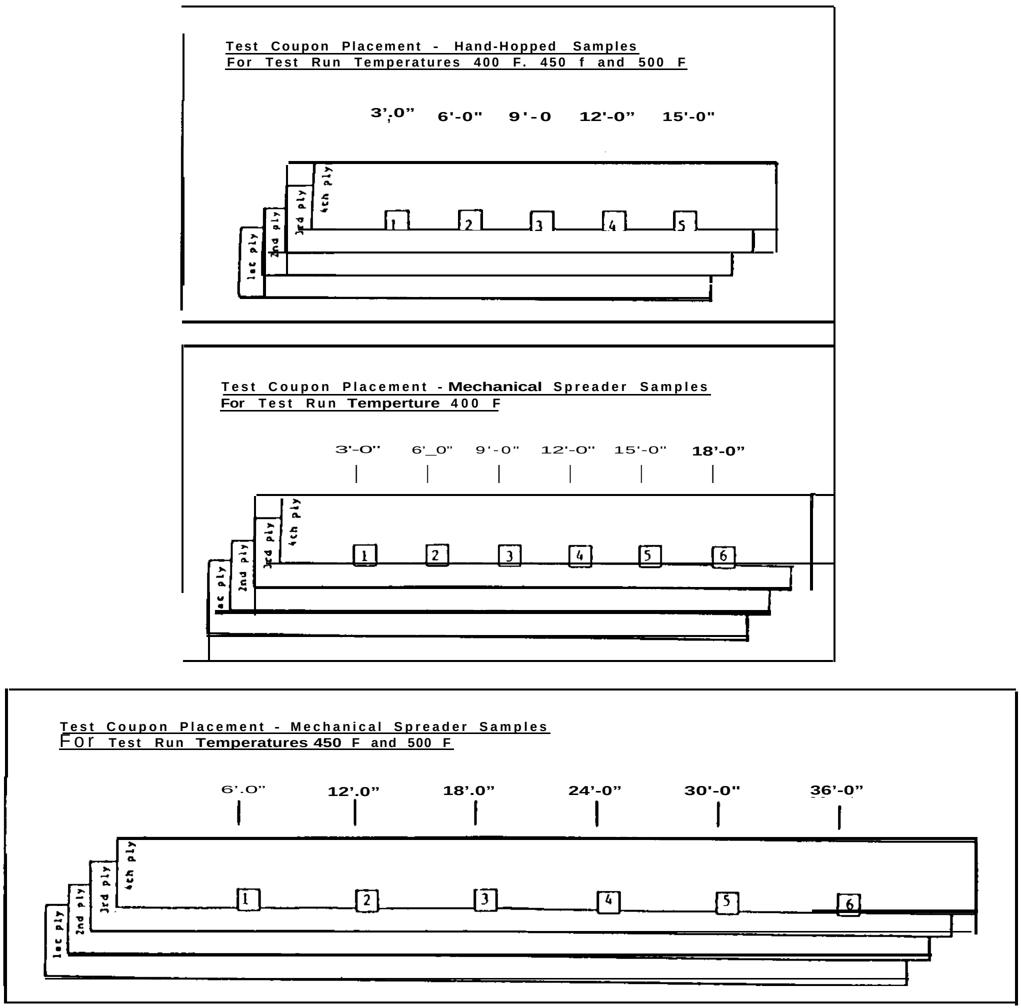
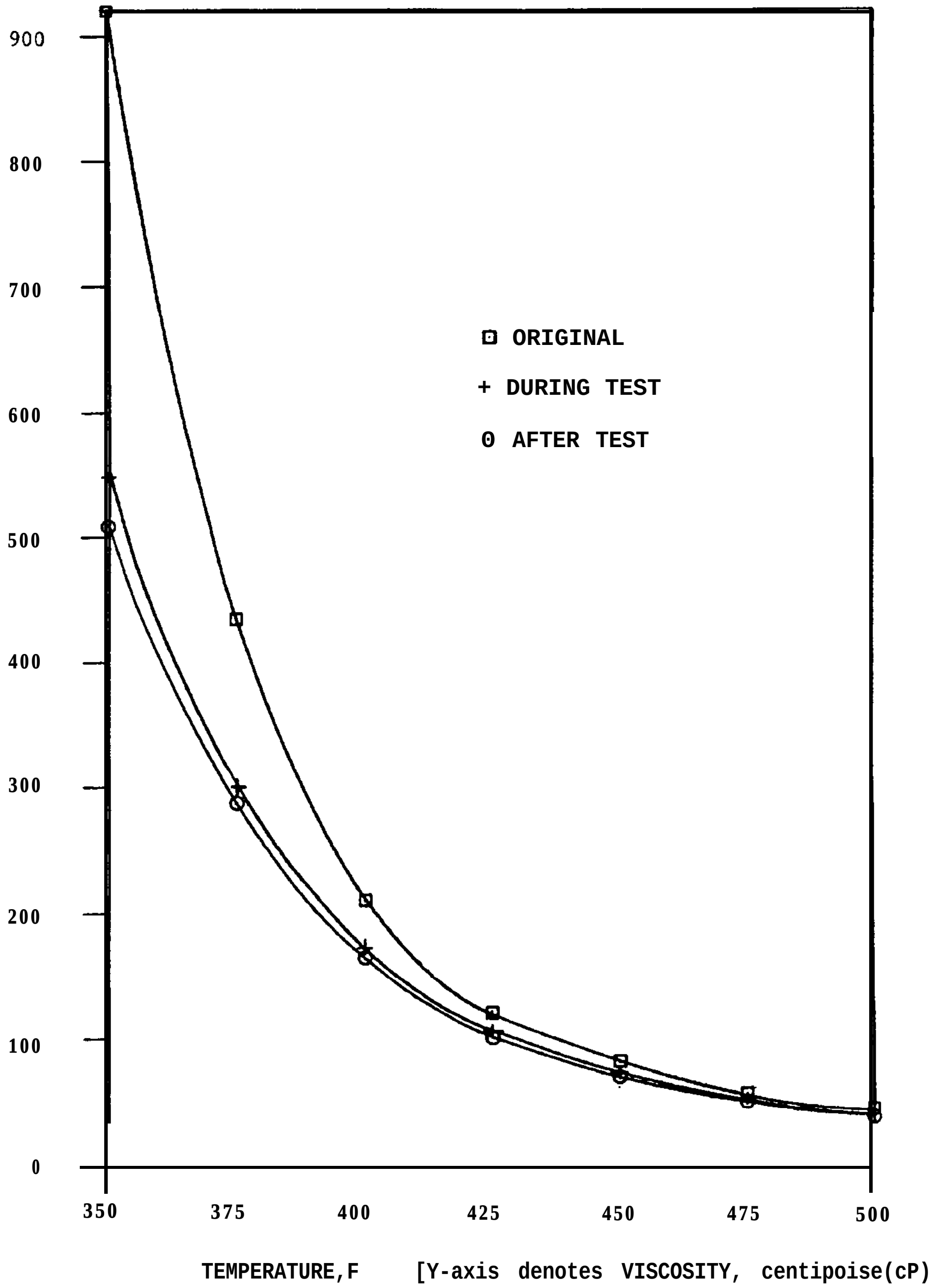
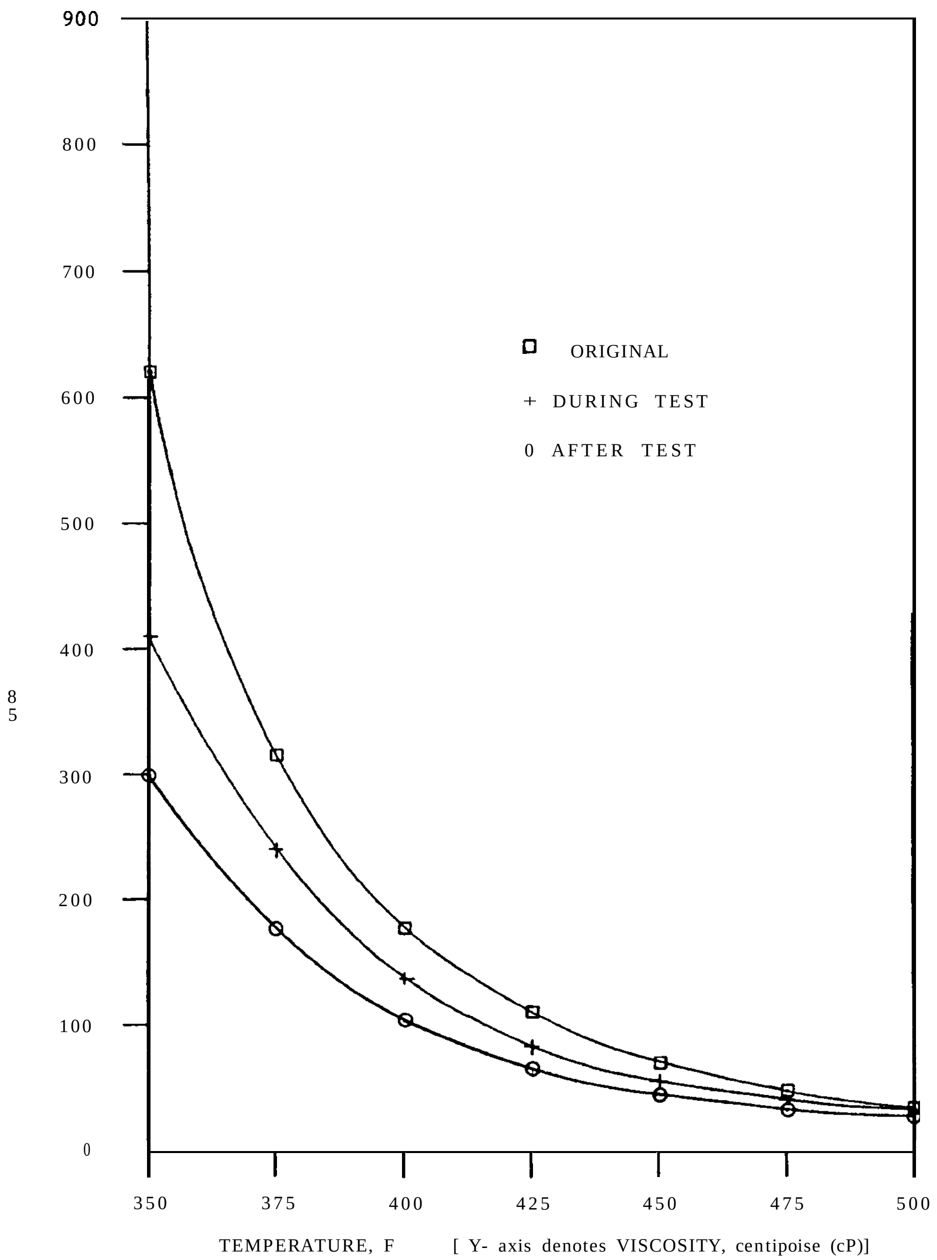


FIGURE 2 — Viscosities Of Asphalt Used At Tulsa, OK



Temperature, F	Viscosity, cP Original	Viscosity, cP Start Of Test	Viscosity, cP End Of Test
350	920	544	510
375	435	300	290
400	210	172	165
425	120.5	106.5	102
450	80	73.5	70.5
475	55.5	53	49
500	41	36.5	35.5

FIGURE 3 — Viscosities Of Asphalt Used At Lyman, SC



Temperature, F	Viscosity, cP Original	Viscosity, CP Start Of Test	Viscosity, cP End Of Test
350	620	410	300
375	31	240	173
400	178	136	103
425	110	83.5	65.5
450	69.5	58.5	45
475	48	40	32
500	33	28	25

TABLE 1 — Physical Properties Of Asphalt Used In This Study At Tulsa, OK

	ASTM Standard	Type III Asphalt Original	Start Of Test	End Of Test
Softening Point, F	185-205	**203**	**188**	**188**
Penetration @ 77F	15-35	**16**	19	19
Penetration @ 115F, max.	90	31	38	38.5
Penetration @ 32F, min.	6	9	11	11
Flash Point COC, F, min.	475	600	590	590
Ductility @ 77F, cm., min.	2.5	3.00	3.50	3.50
EVT@125cP,F		420	420	420

TABLE 1A — Physical Properties Of Asphalt Used In This Study At Lyman, SC

	ASTM Standard	Type III Asphalt Original	Start Of Test	End Of Test
Softening Point, F	185-205	192	185	177
Penetration @ 77F	15-35	24	25	27
Penetration @ 115F, max.	90	48	53	57
Penetration @ 32F, min.	6	12	13	15
Flash Point COC, F, min.	475	575	575	575
Ductility @ 77F, cm., min.	2.5	3.75	4.00	4.25
EVT @ 125 cP, F		420	405	395

TABLE 2 — Physical Properties Of Glass Felts Used In This Study At Tulsa, OK

	ASTM Standard D-2178	Test Results
Moisture, %, max.	1.0	0.44
Net dry mass of felt, lb./100 sq. ft., min. (average of all rolls)	7.0	9.59
Bituminous saturate, lb./100 sq. ft., min.	3.0	5.9
Mass of desaturated felt, lb./100 sq. ft., min.	1.7	2.1
Ash, %	70 to 88	83.7
Average breaking strength, lbf./in.		
-with fiber grain, min.	44	58.2
-across fiber grain, min.	44	66.2
Pliability @ 77F, 1/2 in. radius	no breakage	None

TABLE 2A — Physical Properties Of Glass Felts Used In This Study at Lyman, SC

	ASTM Standard D-2178	Test Results
Moisture, %, max.	1.0	0.30
Net dry mass of felt, lb./100 sq. ft., min. (average of all rolls)	7.0	10.89
Bituminous saturate, lb./100 sq. ft., min.	3.0	6.7
Mass of desaturated felt, lb./100 sq. ft., min	1.7	2.5
Ash, %	70 to 88	79.1
Average breaking strength, lbf./in.		
-with fiber grain, min.	44	47.3
-across fiber grain, min.	44	44.1
Pliability @ 77F, 1/2 in. radius	no breakage	None

TABLE 3 — Asphalt Interply Mopping Weight Test Results At Tulsa, OK

Test Number	1	2	3
Felt Type	glass	glass	glass
Test Temperature, F	400	450	500
Application Method	handmop	handmop	handmop
Asphalt Type	III	III	III
Interply Weight (lb./l00 sq. ft.)			
Coupon 1	24.8	22.8	25.7
Coupon 2	28.7	35.1	24.0
Coupon 3	28.	* 48.3	28.3
Coupon 4	29.6	27.8	26.0
Coupon 5	27.3	24.5	26.0
Coupon 6	25.4	29.3	23.9
Average	27.4	27.9	25.6
Standard Deviation	2.0	4.8	1.6

** This coupon was not included in the average because of it's large value .*

TABLE 3A — Asphalt Interply Mopping Weight Test Results At Lyman, SC

Test Number	1	2	3	4	5	6
Felt Type	glass	glass	glass	glass	glass	glass
Test Temperature, F	400	450	500	400	450	500
Application Method	handmop	handmop	handmop	machine	machine	machine
Asphalt Type	III	III	III	III	III	III
Interply Weight (lb.1100 sq. ft.)						
Coupon 1	16.5	19.4	13.2	37.6	36.3	26.4
Coupon 2	21.8	21.2	18.2	50.3	40.3	25.1
Coupon 3	20.2	25.7	17.7	45.9	33.4	26.6
Coupon 4	24.4	25.1	23.6	44.1	30.5	24.0
Coupon 5	23.6	26.0	16.4	31.5	34.1	25.8
Coupon 6		—	—	45.9	30.4	25.4
Average	21.3	23.5	17.8	42.6	34.2	25.6
Standard Deviation	3.1	3.1	3.8	6.8	3.8	1.0

TABLE 4 — Asphalt Interply Mopping Weight Summary At Tulsa, OK

Test Temp F	Application Method	Asphalt Type	Interply Mopping Weight (lb./100 sq. ft.) Tests	Average	Minimum	Maximum	Deviation
all	handmop	III	3	26.9	22.8	35.1	3.0

TABLE 4A — Asphalt Interply Mopping Weight Summary At Lyman, SC

Test Temp F	Application Method	Asphalt Type	Interply Mopping Weight (lb./100 sq. ft.) Tests	Average	Minimum	Maximum	Deviation
all	handmop	III	3	20.9	13.3	26.0	3.9
all	machine	III	3	34.1	24.0	50.3	8.3
400	both	III	2	32.9	16.5	50.3	12.2
450	both	III	2	29.3	19.4	40.3	6.5
500	both	III	2	22.0	13.2	26.6	4.7
all	both	III	6	28.1	13.2	50.3	9.4

TABLE 5 — Load-Strain Test Results At Tulsa, OK

Temp Number	Test Temp F	Application Method	Asphalt Type	Tensile @0F (lb./in.)	Percent Elongation	Modulus Of Elasticity @0F (lb./in. x 10^4)
1	400	handmop	III	279	2.20	0.6355
2	450	handmop	III	279	2.44	0.5810
3	500	handmop	III	324	2.24	0.7230

TABLE 5A — Load-Strain Test Results At Lyman, SC

Temp Number	Test Temp F	Application Method	Asphalt Type	Tensile @0F (lb./in.)	Percent Elongation	Modulus Of Elasticity @0F (lb./in. x 10^4)
1	400	handmop	III	234	2.22	0.5270
4	400	machine	III	225	1.91	0.5890
2	450	handmop	III	252	2.26	0.5575
5	450	machine	III	238	2.58	0.4610
3	500	handmop	III	233	2.10	0.5550
6	500	machine	III	264	3.23	0.4090

TABLE 6 – Summary Of Void Measurements At Tulsa, OK

Sample Numbers	Test Temp F	Application Method	Number Of Samples	Interply Voids, (square inches) Base Sheet &1stPly	1st& 2nd Ply	2nd & 3rd Ply	3rd & Top Ply	Average per Ply
2	400	handmop	1	8.0	4.0	4.0	3.0	4.8
5	400	handmop	1	3.0	8.0	4.0	----	3.8
5	450	handmop	1	----	----	1.0	---	0.2
6	450	handmop	1	----	3.0	5.0	---	2.0
2	500	handmop	1	5.0	----	3.0	---	2.0
6	500	handmop	1	6.0	----	----	----	1.5
	all	handmop	6					2.4

TABLE 6A – Summary Of Void Measurements At Lyman, SC

Sample Numbers	Test Temp F	Application Method	Number Of Samples	Interply Voids, (square inches) Facer & 1st Ply	Ist& 2nd Ply	2nd & 3rd Ply	3rd & Top Ply	Average per Ply
3	400	handmop	1	__	3.0	---	3.5	1.6
5	400	handmop	1	0.5	__	1.0	5.5	1.8
1	450	handmop	1	4.0	__	7.5	---	2.9
4	450	handmop	1	0.5	__	·_	6.5	1.8
3	500	handmop	1	1.0	__	8.0	2.0	2.8
5	500	handmop	1	2.5	__	1.0	---	0.9
4	400	machine	1	2.5	1.5	1.5	---	1.4
6	400	machine	1	----	__	1.5	1.0	0.6
4	450	machine	1	0.5	12.0	7.5	0.5	5.1
6	450	machine	1	5.5	3.5	10.0	---	4.8
3	500	machine	1	5.0	5.5	3.5	---	3.5
6	500	machine	1	2.5	0.5	0.5	0.5	1.0
	all	handmop	6					1.9
	all	machine	6					2.7
	400	both	4					1.3
	450	both	4					3.6
	500	both	4					2.0
	all	all	12					2.3