Coal tar overruns: tests help clear up controversy

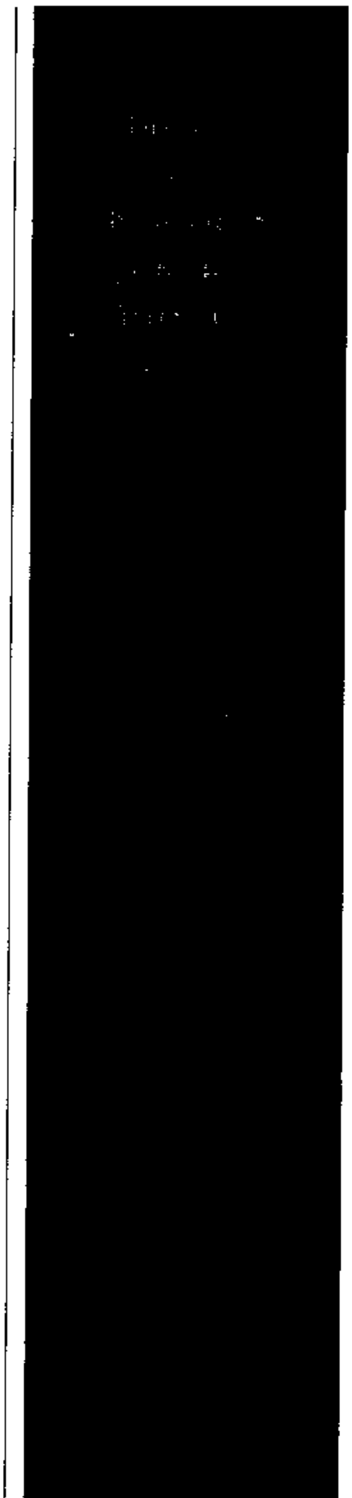
The Koppers Co., Inc., and the National Roofing Contractors Association (NRCA) are conducting a two-phase joint program to determine the relationship between heating and application temperatures, application viscosity and the amount of interply moppings of hot-applied coal tar products used in the construction of built-up roofing membranes. The first phase, using hand-mopping application techniques, has been completed and the results are given in this interim report. The second phase will address mechanical application procedures, which probably account for the majority of the roofs applied.

Twenty-four test-roof sections, 3 feet wide by 16 to 20 feet long, were constructed. Three major variables were studied: temperature at point of application; materials (coal tar pitch, which for this report refers to ASTM D-450, Type I and coal tar bitumen, which refers to ASTM D-450, Type III); and application methods (broomed roofing was compared with not-broomed roofing). All other variables were held constant.

A total of 144 1-foot-square sample coupons were cut from the test roof panels. These coupons were weighed and the applied weight of the coal tar material was calculated. Other tests, including physical properties, viscosity, tensile strength and elongation, were conducted for control and comparison purposes.

The data show that application temperature ranges of 300F to 425F resulted in average interply mopping weights of 15.2 to 31.3 pounds per 100 square feet, depending on the material, temperature and whether the felt was broomed or not broomed.

The test results indicate that the viscosities of coal tar roofing products in the temperature range of 300F to 425F varied from about 10 to 100 centipoise (7.9 to 79.4 centistokes).



Based upon the data presented, the viscosity range for coal tar products at the point of application to achieve appropriate interply quantities would be 15 to 35 centipoise (11.9 to 27.8 centistokes). This equates to an equiviscous temperature (EVT) for coal tar bitumen of 375F ±25F and for coal tar pitch of 360F ±25F.

Introduction

NRCA has received complaints of overruns during the application of coal tar products, that is, more material being required than was specified. Overruns as high as 45 percent above the specified amount have been reported. This led to claims that manufacturer-published coverage specifications appeared to be too low to be achievable at the recommended application temperatures. This point has been the subject of controversy in the industry.

In an effort to clear up this uncertainty, NRCA and Koppers have joined in carrying out a two-phased test program on coal tar bitumen and coal tar pitch to determine the relationship of temperature, viscosity and interply rates during the application of built-up roofing membranes, using both hand-mopping and mechanical laying techniques. The tests and their results and conclusions of the hand-mopping phase are presented in this interim report.

Prior test experience

The NRCA/Koppers test program was precipitated by a laboratory test program sponsored by NRCA at Chicago Testing Laboratory, Inc. The test results were published as "Contractors prompt coal tar tests; results show ASTM standards inadequate," by William C. Cullen, NRCA research associate, in *Roofing Spec*, February 1984. The NRCA program objectives were: 1) to provide leads to the cause of the apparent overruns and other alleged problems associated with the use of coal tar

Three variables studied under consistent test conditions

Three variables were examined in the NRCA/Koppers study—materials, temperature and application method. Samples were prepared and tested using identical equipment, procedures and personnel.

Variables

Materials—two materials were included in the program: coal tar roofing pitch, ASTM D-450 Type I and coal tar bitumen, ASTM D-450 Type III.

Before 1970, coaltar built-up roofing systems were installed in the United States using roofing pitch described in ASTM D-450, Type I.

Since 1970, an increasing number of installations have used coal tar bitumen, ASTM D-450, Type III, a modified formulation developed by Koppers for low-fume evolution and to improve environmental and working conditions during application.

Temperatures—tests were conducted at six point-of-application temperatures, two below Koppers' recommended range and one above the recommended range. These point-of-application test temperatures were: 300F, 325F, 350F, 375F, 400F and 425F.

Application methods—in the test, built-up roof specimens were constructed in two ways: 1) with the felt rolled in; 2) with the felt rolled and broomed in.

To cover several possible combinations of the variables (material, temperature and application methods) under study, 24 built-up roof specimens were prepared (2 bitumens x 2 application methods x 6 temperatures = 24).

Test equipment

Site—the tests were conducted in Building 37 at Verona, Pa., an auxiliary unit of Koppers Science & Technology Center, Monroeville, Pa., both in the vicinity of Pittsburgh. This test site is an enclosed area capable of controlling inside air temperature between 60F and 80F.

Kettle—a 125-gallon Garlock kettle was selected. It was large enough to supply adequate quantities of bitumen for each test, generate the typical heat history, and easy to maneuver or empty when changing from one type of bitumen to the other.

The primary objective was to determine the relationship between application temperature, viscosity and interply mopping weight.

products; 2) to measure the physical property differences between coal tar pitch and coal tar bitumen and how the differences relate to on-the-roof performance; and 3) to investigate the strengths and weaknesses of the current ASTM Standards Specification ASTM D-450 as they relate to performance under service conditions.

NRCA/Koppers study objectives

Cullen's article noted the need for additional field research to address the overrun complaints. The subsequent NRCA/Koppers study addressed the overrun problem. Therefore, the primary objective was to determine the relationship between application temperature, viscosity and interply mopping weight application rates of coal tar products.

Study parameters

Three fundamental variable factors affect the application rate of hot-applied interply roofing coal tar products:

- physical characteristics of the material;
- point-of-application temperature; and
- method of application.

The application temperature is dependent on several other factors that occur on the jobsite. 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

Specimen preparation—before the start of the tests, 24 four-square rolls of felt were prepared by removing the first 50 feet, then sequentially numbering the rolls one through 24 (one roll for each test). From the last 15 feet of each 50-foot section, 10- to 12-inch-by-12-inch samples were removed, weighed, labeled, packaged and retained for later examination. Felt weights used in calculating interply quantities were based on the actual weights of these samples.

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 2½-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 12-inch-by-12-inch, flat, steel template with a handle was positioned flat on the membrane and the coupons were carefully cut with utility knives.

Digistrip temperature recorder (Kay Instruments)—this temperature recorder had a capacity to measure and record temperatures at up to 16 locations on an intermittent basis. The temperature and locations were recorded on tape, and could be fed into a computer programmed to analyze the recorded temperature at each location as a function of time.

Thermocouples—J-type thermocouples were used for their quick response to temperature change.

Scale—a Sartorious 30,000-gram balance with two-decimal accuracy was used to weigh the bitumen, felt and membrane samples.

Test surface

The deck was 22-gauge steel with a 2½-inch-wide flute on wood framing. Flake board ½ inch thick was laid over the steel decking and nailed to the wood framing through the steel sheet. No. 15 coal tar saturated felt was rolled out and stapled at each end to serve as a separator sheet. Overall dimensions of each test strip were approximately 36 inches wide and 16 feet long.

Roofing personnel

The roofing crew consisted of a mop man, roll man and kettle operator. All were employees of Pennsylvania Roofing Systems, Inc., a member contractor of NRCA. All crew members were experienced in hand-mopping of felts for built-up roof systems and belonged to the United Union of Roofers, Waterproofers, and Allied Workers Association, Local No. 37 (AFL/CIO).

The test sequence provided a broomed and not-broomed membrane at each temperature. Application was started at the low temperature and progressed to the high temperature.

In preparation for each test, the kettle temperature was raised to approximately 25F above the designated point-of-application temperature. The bitumen was transferred to the insulated mop cart and allowed to cool to within 5F of the application temperature. While the bitumen was cooling, a thermocouple was placed on top of the separator sheet and the first layer of felt was rolled into place. When the bitumen in the mop cart reached the desired temperature, mopping began. For all even-numbered tests the felt was broomed in.

Additional thermocouples were placed between subsequent plies (see Figure 1), and the temperature was recorded at 10-second intervals by the recorders. The membrane consisted of one ply of No. 15 coal tar saturated felt stapled to the deck

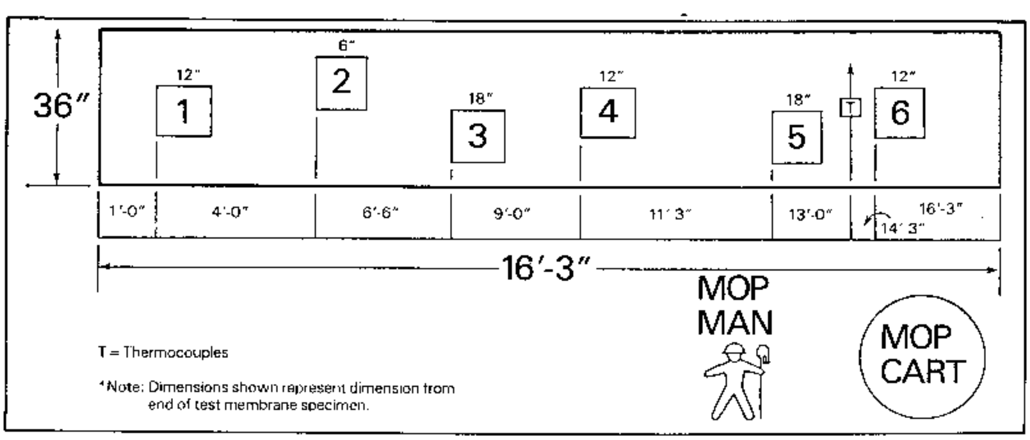


FIGURE 1: Sample coupon locations

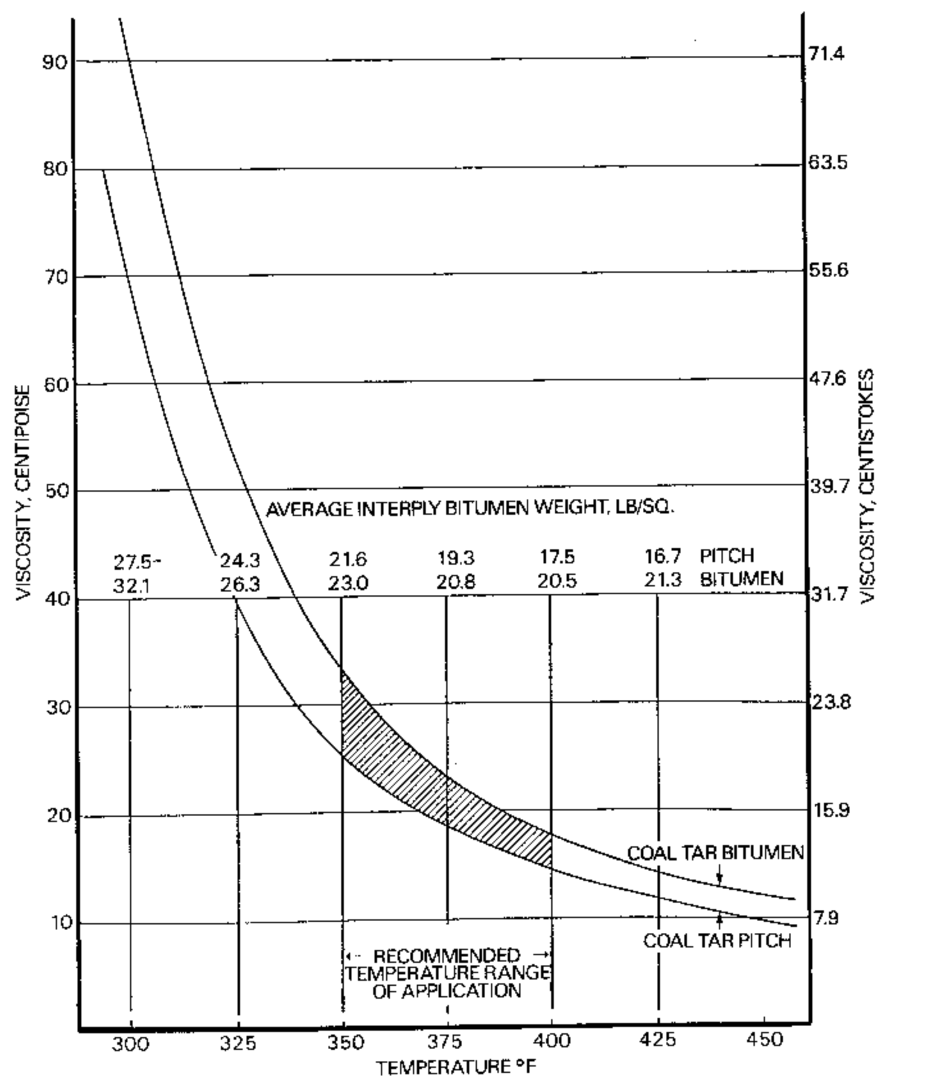
Measurement of the interply bitumen by the optical method was found to be difficult.

and three additional plies of No. 15 coal tar saturated felt mopped on with hot bitumen (either coal tar pitch or coal tar bitumen) and recorded. When the membrane was completed, 1-foot-square test coupons were cut from the membrane and labeled so their locations could be identified (Figure 1) and weighed. These coupons were packaged and retained for laboratory evaluation. The average interply quantity was calculated by subtracting the known felt weight from the total coupon weight.

Optical measurement of interply thickness—a machinists microscope was used in an attempt to make thickness measurements of the bitumen from the test coupons. A cross section of each membrane was cut to fit the stage of the microscope.

Thickness measured by the optical method did not agree with the theoretical thickness calculated from the quantity of interply bitumen as determined by the weight method. Measurement of the interply bitumen by the optical method was found to be difficult and could possibly be misleading because the interface between the felt and bitumen was not clearly defined due to the texture of the felt and the penetration of the bitumen into the felt. Membranes produced at the higher temperature have a measured (optical) thickness lower than the thickness calculated from the interply quantities by weight. The membranes produced at lower temperatures measured closer to the theoretical. It was concluded that the actual amount of coal tar interply quantities is better measured by determining the weight of the sample coupon and subtracting the weight of the felts from the coupon weight and dividing by the number of layers of bitumen.

FIGURE 2: Viscosity at recommended application temperatures



Test results

Physical properties—Table 1 shows that both Type I and Type III materials essentially met the requirements of ASTM D-450-78 except that:

- Type I material exceeded the ASTM maximum for total percentage of bitumen soluble in carbon disulfide by .5 percent; and
- Type I was not tested for specific gravity of distillate due to insufficient residue sample derived from the distillation.

Viscosity determinations—results of viscosity determinations over the range of temperatures used in the test program for both coal tar pitch and coal tar bitumen are plotted in Figure 2. It is noted that both materials demonstrate similar viscosity curves over the temperature range of 300F to 450F.

The viscosities of the respective coal tar products at the Koppers' recommended application temperatures between 350F and 400F are shown in the shaded areas of Figure 2, that is 18 to 34 centipoise (14.3 to 27 centistokes) for bitumen and 13 to 25 centipoise (10.3 to 19.8 centistokes) for pitch.

The values for the average interply mopping weights at the six mopping temperatures, which are superimposed in Figure 2, show that the Koppers' recommended application temperature, indicated by the shaded area, resulted in interply mopping weights of about 18 to 22 pounds per square for pitch and 21 to 23 pounds per square for bitumen.

The rates at the lower temperatures of 300F and 325F resulted in interply mopping weights of 25 and 30 pounds per square for coal tar pitch and bitumen, respectively.

An analysis of the data with respect to the viscosity/temperature relationship of coal tar bitumen shows a viscosity of 25 ±10 centipoise (20 ±8 centistokes) is required to attain interply mopping weights of somewhere between 18 and 23 pounds per square. Assuming this is a valid conclusion, the EVT range for coal tar bitumen used in this study would be from 350F to 400F.

For coal tar pitches, the viscosity is somewhat lower at a given temperature, which is reflected in the lower interply quantities. Therefore, based upon a viscosity of 25 ±10 centipoise (20 ±8 centistokes) the EVT for coal tar pitch would range between 335F and 385F.

Discussions with the mop man during the sample preparation phase revealed that it was a difficult and tiring task to mop these coal tar products at the 300F and 325F temperatures where the materials have viscosities somewhere above the 50 centipoise (39.7 centistokes) range.

Discussion with the mop man revealed that it was difficult to mop these coal tar products at the 300F and 325F temperatures.

TABLE 1: Physical properties of bitumen

REQUIREMENTS/ASTM D450-78			TEST DATA		ASTM TEST
	Type I	Type III	Type I	Type III	METHOD
Water, max., %	0	0	0	0	D-95
Specific gravity, 25/25C (77F)	1.22–1.34	1.22–1.34	1.26	1.26	D-70
Softening point (R&B), °C	52–60	56–64	58.5	62.0	D-36
Softening point (R&B), °F	126–140	133–147	134	146	D-36
Flash point (COC), min., °F	248	248	420	415	D-92
Total bitumen soluble in carbon disulfide, %	72-85	72–85	85.57	82.90	D-4
Ash, max., %	0.5	0.5	0.14	.06	D-2415
Total distillate:					
0–300C, max., % (32–572F, max., %)	10	0	0.99	0	
0–315C, max., % (32–599F, max., %)	—	0	—	0	
0–360C, max., % (32–680F, max., %)	—	5	–	2.0	
Specific gravity of distillate from 0–300C, min., (32–572F min.) 38/15.5C	1.03	N.A.	*	N.A.	
Softening point (R&B) of residue from distillation to 300C max.,	80°C	—	61.9°C	—	
to 572F max.,	176°F	—	142°F		

N.A.—Not applicable
* Insufficient sample for test from distillation

Larger quantities of both bitumen and pitch were applied as the temperature decreased.

Application rates of interply mopping material—Tables 3a and 3b give the interply weight of bitumen and pitch for each coupon prepared at the respective test temperature. The weights are expressed in pounds per 100 square feet per ply. Figure 3 illustrates that a definite correlation exists between the interply mopping weight and the application temperature. As expected, larger quantities of both bitumen and pitch were applied as the temperature decreased. Further, slightly larger quantities of bitumen were applied at identical temperatures to those of pitch. Figure 3 also shows no apparent correlation between interply mopping weight and whether or not the sample was broomed during the application procedure.

Table 4 summarizes the average interply mopping weights of bitumen and pitch at the test application temperatures.

A rather interesting finding from the data in Tables 3a and 3b was the nonuniformity of weights among the individual test coupons taken at preselected locations from the test samples in spite of the close control of temperature and other variables, which are often not controllable on an actual jobsite. Since the tests were performed under carefully controlled conditions, with accurate measurement methods, the weight differences between

TABLE 3: NCRA/KOPPERS coal tar bitumen/coal tar organic felt four plies—three interply moppings

TEST NO.	1	2	3	4	5	6	7	8	9	10	11	12
Temp. at mop (°F)	300	300	325	325	350	350	375	375	400	400	425	425
Broomed	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Interply, lb/100 ft.^{2}												
Cut #1	27.9	40.1	19.9	22.5	15.3	20.1	20.4	20.8	20.4	22.6	33.2	12.6
Cut #2	27.2	31.3	28.2	31.3	26.6	23.0	22.6	22.6	19.9	21.6	17.6	17.4
Cut #3	39.8	44.4	27.3	39.6	33.0	32.0	22.3	22.1	26.1	26.0	26.0	27.5
Cut #4	32.2	31.0	27.2	33.1	25.9	19.8	20.6	21.8	16.0	17.1	18.5	22.1
Cut #5	21.5	27.4	25.4	22.8	20.0	22.5	16.1	14.8	13.1	16.9	18.1	20.6
Cut #6	–	–	20.4	17.6	17.5	21.1	23.4	21.8	22.4	23.4	21.1	21.2
Average	29.7	34.5	24.7	27.8	23.0	23.1	20.9	20.6	19.7	21.3	22.4	20.2

TABLE 3: *(continued)*

TEST NO.	13	14	15	16	17	18	19	20	21	22	23	24
Temp. at mop (°F)	300	300	325	325	350	350	375	375	400	400	425	425
Broomed	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Interply, lb/100 ft.^{2}												
Cut #1	18.3	30.2	28.3	19.1	15.1	14.3	15.1	16.1	12.7	16.0	16.9	16.4
Cut #2	24.6	33.6	25.8	23.0	21.8	21.4	19.7	20.0	19.1	16.8	17.6	14.6
Cut #3	28.7	38.9	32.7	35.0	31.0	21.0	24.0	23.4	21.6	22.8	26.4	20.2
Cut #4	26.5	30.6	22.1	19.3	23.0	21.9	16.4	19.0	13.9	16.6	11.4	14.1
Cut #5	24.9	33.6	23.6	22.4	25.6	21.1	20.1	22.2	18.4	13.4	18.3	15.0
Cut #6	18.7	21.0	20.8	18.7	20.7	21.3	17.6	17.8	19.54	19.3	18.8	10.8
Average	23.6	31.3	25.6	23.0	22.9	20.2	18.8	19.8	17.5	17.5	18.2	15.2

TABLE 4: Consolidated interply applied weight averages

	BROOMED		NOT BROOMED	
Temp. °F	Bitumen Type III	Pitch Type I	Bitumen Type III	Pitch Type I
300	34.5	31.3	29.7	23.6
325	27.8	23.0	24.7	25.6
350	23.1	20.2	23.0	22.9
375	20.6	19.8	20.9	18.8
400	21.3	17.5	19.7	17.5
425	20.2	15.2	22.4	18.2

samples from some sections indicate the difficulty of applying roofing material with any degree of uniformity, particularly under jobsite conditions where the other factors, which were held constant in the test, will also affect the application rate.

Tensile properties of membrane specimens—as an additional benefit of the research program, tests on tensile properties were measured on selected specimens taken from the samples prepared at the test temperatures. The specimens were selected on the basis of those whose weights were closest to the group average interply weight. The specimens were tested in accordance with ASTM method D-2523 in the across-machine direction at a temperature of 0F. Table 2 reports the test data as well as other pertinent information on the test specimens.

The test data indicate that there was little scatter in tensile strength properties regardless of the application temperature, the interply mopping weights, or whether or not the samples were broomed during application. All values essentially met the suggested 200-pound-per-inch requirement described in National Bureau of Standards Building Science Series No. 55, "Preliminary Performance Criteria for Bituminous Built-up Membrane Roofing."

The tensile strength of the coal tar bitumen specimens averaged approximately 212 pounds per inch, which was slightly higher than the value of 205 pounds per inch for coal tar pitch specimens. On the other hand, the average strain for the pitch specimens was 2 percent as opposed to 1.6 percent for the bitumen specimens. All specimens exceeded elongation values generally accepted by the roofing industry as adequate for bituminous built-up roof membranes.

Summary and conclusions

- The application of coal tar pitches and bitumens in a viscosity range of 15 to 25 centipoise (11.9 to 27.8 centistokes) resulted in interply mopping rates of 18 to 23 pounds per square, which approximates the minimum average mopping weights of 20 pounds per square as currently recommended by Koppers.
- The EVT for coal tar products may be considered as that temperature at which the viscosity of the material is 25 centipoise (19.8 centistokes). For the products used in this study, the EVT for coal tar bitumen would be 375F ±25F, and the EVT for coal tar pitch, 360F ±25F.
- Hand-mopping of hot-applied coal tar products at viscosities exceeding 50 centipoise (39.7 centistokes) is difficult and tiring for the mop man.
- Point-of-application temperatures in the range of 335F to 400F appear to be an acceptable range for hand-mopping operations involving coal tar products, depending on the specific material used.

The weight differences indicate the difficulty of applying roof material with any degree of uniformity.

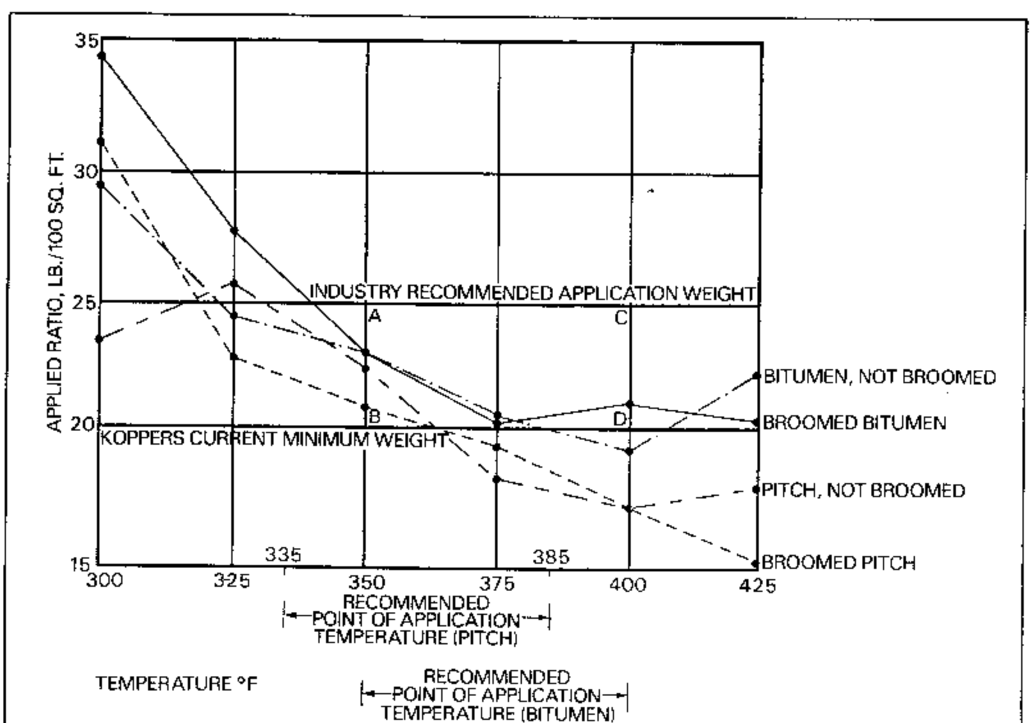


FIGURE 3

NRCA and Koppers plan to conduct additional tests involving mechanical equipment.

- The lower the point-of-application temperature, the greater the quantity of interply mopping material.
- The variances in interply mopping weights among specimens taken from same run were considerably higher than anticipated.
- When the "roll-in" felt application technique is used, there are no apparent differences in interply mopping weights between those broomed and those not broomed at constant application temperatures.
- Essentially all specimens prepared at the six mopping temperatures met the 200-pound-per-inch breaking load requirement described in NBS BSS 55.
- The average ultimate breaking load for the 12 bitumen specimens was approximately 212 pounds per inch, while the 12 pitch specimens averaged about 205
- The average ultimate elongation was 2 percent for the pitch specimens and 1.6 percent for the bitumen specimens. pounds per inch.
- The amount of interply mopping material had no significant impact on the value of the breaking load.
- Optical measurement performed in the laboratory of interply material thickness is not practical.

Additional tests and data to come

The data presented here apply to hand-mopping techniques only. Coal tar membranes applied by mechanical means may well produce different results. Therefore, NRCA and Koppers plan to conduct additional tests involving mechanical equipment used in the application process.

In addition to the application temperature/viscosity data, this study produced more information such as bitumen cooling rates, etc. The data are being analyzed and evaluated in order to provide a better understanding of built-up roofing application characteristics.

TABLE 2: BUR membrane tensiles @ 0°F(1)

	Membrane ID(2)	Peak load lbs.	Tens. prop. @ peak load: stress lbs./in.^{2}	strain, %	Modulus @ break, lbs./in.^{2}	Interply mopping, lbs/sq.: @ test cut	test avg.	Membrane application test temp. °F
Coal Tar Bitumen ASTM D-450, Type III	1-NB-1	217.2	1357.7	6.7(3)	19619	27.9	29.7	300
	2-B-2	202.0	1262.4	1.7	22877	31.3	34.5	300
	3-BN-5	204.0	1274.9	1.5	20594	25.4	24.7	325
	4-B-5	211.1	1319.4	1.7	25174	22.8	27.8	325
	5-NB-2	218.4	1364.7	1.8	23049	26.6	23.0	350
	6-B-2	212.1	1325.7	1.7	21664	23.0	23.1	350
	7-NB-4	225.1	1407.0	1.6	25255	20.6	20.9	375
	8-B-1	207.7	1298.3	1.7	18684	20.8	20.6	375
	9-NB-2	203.5	1271.7	1.6	21388	19.9	19.7	400
	10-B-2	210.6	1316.3	1.7	19754	21.6	21.3	400
	11-NB-6	209.6	1310.0	1.4	18649	21.1	22.4	425
	12-B-5	216.1	1350.8	1.6	14124	20.6	20.2	425
Coal Tar Pitch ASTM D-450, Type I	13-NB-2	199.6	1247.5	1.8	18720	24.6	23.6	300
	14-B-4	203.0	1268.8	1.7	20722	30.6	31.3	300
	15-NB-2	212.8	1329.7	1.6	23617	25.8	25.6	325
	16-B-2	205.3	1282.8	1.7	19843	23.0	23.0	325
	17-NB-4	208.4	1302.3	1.8	15744	23.0	22.9	350
	18-B-3	205.3	1282.8	1.9	13728	21.0	20.1	350
	19-NB-2	205.4	1283.6	2.0	14229	19.7	18.8	375
	20-B-2	200.0	1250.0	2.1	17034	20.0	19.8	375
	21-NB-5	205.8	1285.9	1.7	14478	18.4	17.5	400
	22-B-2	186.1	1163.3	1.9	17591	16.8	17.5	400
	23-NB-5	205.8	1285.9	5.0(3)	18213	18.3	18.2	425
	24-B-5	216.4	1352.3	1.8	21163	15.0	15.2	425
	Avg. for Type III CT bitumen, test no's. 1–12	211.5	1321.6	1.6	20902.6	23.5	24.0	—
	Avg. for Type I CT pitch, test no's. 13–24	204.5	1277.9	2.0	17923.5	21.4	21.1	—

Notes:

(1) BUR membrane samples were preconditioned at 0F for two hours prior to testing in cold chamber.

(2) Sequence in Membrane ID represents test number—brooming/not brooming—sample no. ("B" = broomed); ("NB" = not broomed).

(3) These values not used in determining average for coal tar type (sample insufficiently restrained in the test equipment).