Effect of Method of Curing On Internal Temperatures of Concrete Pavements In North Carolina

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This study was undertaken to evaluate the relative merits of four curing methods not involving the use of applied water: (a) white pigmented liquid membrane, (b) clear liquid membrane with fugitive red dye, (c) tan waterproof paper, and (d) white waterproof paper. Moisture retention was not measured. Variations in temperature at three depths in the pavement slab under the curing media were recorded from the time of placement until 72 hours. Compression strengths of concrete cores taken from the test sections were determined at approximately 12 months and 18 months.

From the data presented in this report and under the conditions investigated, the following conclusions are drawn: Considering the temperature variables, lowest temperatures are obtained with white waterproof paper, followed in order by, white pigmented liquid membrane, tan waterproof paper, and clear liquid membrane with fugitive red dye.

● CURING has been defined as the process of maintaining a satisfactory moisture content and a favorable temperature in concrete immediately following placement so that hydration of the cement may continue until the desired properties are developed to a sufficient degree to meet the requirements of service. Until recently, applications of water were used to maintain the satisfactory moisture content and this method provided a considerable amount of inherent temperature control. With the advent of the use of waterproof membranes of paper, quick-drying liquid compounds, plastic films, or "sealers," the cooling effects of evaporation and the insulating effect of thick layers of earth, straw, cotton mats, etc., were largely eliminated.

Curing compounds have been favored by the contractors on pavement construction for economic reasons, and construction engineers have been satisfied because of the ease of field inspection and the comparatively long period of moisture retention and curing. Waterproof paper has been found to be the second most favored method for curing.[1]

A survey of performance in North Carolina about four years ago showed that concrete pavement placed in the morning on days of high atmospheric temperature and sunshine, when cured by clear liquid membrane compounds with fugitive dye, developed more uncontrolled cracks than pavements cured by other means. For this reason the use of clear compounds has been prohibited since 1953 and only the white pigmented compounds permitted. This change will be found to have been adopted by many concrete paving agencies.

The study was undertaken to evaluate the relative merits of four curing methods not involving the use of applied water: (a) white pigmented liquid membrane, (b) white waterproof paper, (c) tan waterproof paper, and (d) clear liquid membrane with fugitive red dye. Moisture retention was not measured. Varia-

[1] Report of Committee on Curing of Concrete Pavements. Proceedings, HRB, Vol. 32, pp. 335-342 (1953).

tions in temperature at three depths in the pavement slab under the curing media were recorded from the time of placement until 72 hours. Compression strengths of concrete cores taken from the test sections were determined at approximately 12 months and 18 months.

Differences among the first three were generally of minor importance, as indicated by the maximum range in temperatures at top and bottom of the slab (Table 7) and maximum differences between the highest and lowest temperature at the top of the slab during the first 72 hours (Table 6).

TWO PROJECT LOCATIONS

Data were secured from two concrete pavement construction projects during the summer of 1954. One project is located in mid-eastern North Carolina and the other in the mid-western part of the state. Both are 8-in. uniform, non-reinforced, 24-ft wide with contraction joints at 30-ft intervals, without dowel load transfer. White pigmented curing compounds were used as the general curing method for both jobs.

Project 4839 is located on US 70 between Raleigh and Durham and is the north, or west-bound, lane of the dual-lane highway, 16.96 mi long. The stations, permanently marked in the pavement, at which each round of comparisons was made are given in Table 1.

Project 6375 is located on US 64 and is the Statesville by-pass. There is only one 24-ft width of pavement and this was placed in one operation the same as project 4839. The station numbers and other data are given in Table 1. The total project is 7.10 mi long.

APPARATUS

The testing equipment involved in the conduct of the experimental work was simple. The essential apparatus was a supply of about 36 glass thermometers, −30 F to 120 F, and the metal tube wells that were inserted in the fresh concrete to protect the thermometers from breakage. The technicians had wrist watches for timing the operations. In addition there were three recording thermometers, at a location about the middle of project 4839, with bulb and tubing installed to record continuously the temperature in the concrete pavement at 1-in. and 7-in. depths and also the atmospheric temperature. The Raleigh-Durham Airport Weather Bureau Station is 1-mi from the project, and the monthly reports gave the other hourly atmospheric data which might have affected the tests. The facilities of the State Highway Division of Materials were available for taking concrete cores and testing them.

TABLE 1

LOCATIONS AND CONDITIONS FOR TEST SECTIONS

Order of Installation	Stations	Installation Date	Max. Air Temp.*, °F	Pavement Grade %
		(a) PROJECT 4839		
Round 1	154 + 11 - 155 + 31	6-23-54	92	−2.5
Round 2	169 + 20 - 170 + 40	6-24-54	89	+7.0
Round 3	195 + 37 - 196 + 57	6-28-54	86	−2.2
Round 4	281 + 29 - 282 + 49	7- 5-54	97	0.0
Round 5	332 + 11 - 333 + 31	7- 9-54	80	+5.0
Round 6	442 + 38 - 443 + 28	7-20-54	97	−7.0
Round 7	623 + 22 - 624 + 12	8-23-54	84	−0.6
		(b) PROJECT 6375		
Round 8	238 + 08 - 239 + 28	9-27-54	85	+1.6
Round 9	239 + 28 - 240 + 48	9-27-54	85	+1.6

* From records of U.S. Weather Bureau, Raleigh-Durham Airport.

PROCEDURE

Curing three of the first four 30-ft slabs the first thing in the morning was the only interference with the contractor's normal paving operations. The technicians recorded the time and temperature of the concrete and air for the first batch placed. As the pavement was finished and before any curing was applied, three of the metal tubes were inserted at convenient points, about 1 ft from the edge of the slab, to secure the temperatures at 1-in., 4-in. and 7-in. depths. Temperatures at these depths were recorded at 2-hr intervals from the time of placing until midnight for the first day, and each day until the concrete was 72 hours old when paving operations were resumed. These measurements were made for the first four slabs only, as these were the slabs cured for comparison purposes. The order of placing the four different methods of curing was changed for each round to minimize the effect of construction operations. Table 4 is a partial summary of the records kept by the technician.

The liquid membrane seal was mechanically applied by the contractor at the normal rate of 200 sq ft per gal. Table 2 shows the actual rate as checked by the technician at several points during construction. White and tan waterproof paper was applied by technicians from the Research Department of the Division of Materials. White pigmented liquid membrane type 2, ASTM Designation C 309-53T was used throughout the project as a specification item except where other methods were used as test sections.

The two types of paper were applied in the approved manner; that is, folded over the edge after removal of forms and secured with windrows of dirt. The paper was applied 1 to 2 hours after placing and finishing the concrete, depending on atmospheric conditions and concrete consistency. All paper was rolled back after 72 hours (the standard curing period) and made available for re-use.

The waterproof paper was re-used for all nine comparisons covering both job locations. Its condition at the end of the tests was excellent, with no holes, tears or loss of moisture retention properties being apparent.

TABLE 2

RATE OF APPLICATION OF LIQUID COMPOUNDS

Station	Application Rate, sq ft per gal.
(a) LOCATION 1, PROJECT 4839	
172 + 23 to 189 + 98	194.5
108 + 76 to 122 + 94	190.9
202 + 27 to 238 + 05	203.4
Average	196.3
(b) LOCATION 2, PROJECT 6375	
253 + 18 to 274 + 54	204.2
172 + 23 to 189 + 98	194.5
223 + 11 to 238 + 06	196.6
Average	198.4

Computed rate of application of liquid membrane seal by mechanical spreader.

Rate of application determined by starting with full 55-gal. drum of compound and recording yardage covered when empty.

CONCRETE DESIGN

Location 1, Project 4839

Concrete for the pavement for both projects was designed for a flexural strength of 550 psi at 14 days when tested in accordance with ASTM Method C-78.

The coarse aggregate of crushed granite, 1½-in. maximum size, tested at 31 percent in accordance with the Los Angeles wear method. The fine aggregate was a natural silica sand with a fineness modulus of approximately 2.40, and the cement was type 1A air-entraining. A cement content of 5.2 sacks per cu yd was used with 6.2 gal. of water per sack of cement.

The compacted 4-in. coarse aggregate sub-base was filled with stone screenings and sprinkled with water before paving started. The concrete was compacted by vibrating pans attached to the rear of the mechanical spreader.

The air content of the fresh concrete varied from about 4.0 to 6.5 percent with a majority of the tests made showing a range of 4.5 to 5.5 percent.

Cores were drilled from the roadway beyond the limits of the test sections when the pavement was approximately one month old. They were stored in the laboratory in an air-dry condition from 2 to 3½ months and 50 of these cores were tested in an air-dry condition at an age of 3 to 4½ months. The average strength was 3956 psi.

Twenty-eight cores were drilled from the test sections when the pavement was approximately three months old. They were stored in the laboratory in an air-dry condition. At the end of that period, they were capped on both ends with neat cement paste and tested without soaking in water at 12 and 18 months of age (Table 11).

Location 2, Project 6375

The crushed granite coarse aggregate, 1½-in. maximum size, for this project tested at 24 percent in accordance with the standard Los Angeles wear method. The fine aggregate was a natural silica sand with a fineness modulus of approximately 2.20, and the cement was type 1A air-entraining. A cement content of 5.20 sacks per cu yd and a water content of 6.0 gal. per sack of cement was the design used to secure 550 psi flexural strength at 14 days.

The air content of the fresh concrete varied from about 3 to 5 percent with a majority of the tests showing a range of 4.5 to 5.0 percent air.

The compacted 4-in. crushed granite coarse aggregate sub-base was filled with natural silica sand and sprinkled with water before paving started. The concrete was compacted by vibrating pans attached to the rear of the mechanical spreader.

Fourteen of the cores which were drilled from the roadway beyond the limits of the test sections when the pavement was two months old were stored in laboratory air for 18 months. At the end of that period, they were capped on both ends with neat cement mortar and immersed in water for 48 hours before testing. The average compressive strength was 2712 psi.

Sixteen cores drilled from test sections on this project at an age of approximately 18 months were in the laboratory air 30 days before testing. At the end of that period, they were capped on both ends with neat cement paste and tested without soaking. Their average compression strength was 4245 psi (Table 11).

RESULTS

The maximum temperatures 1 in. below the surface of the pavement that occurred in test slabs during the 72-hr curing period are shown in Table 3. When all nine comparisons are averaged, white waterproof paper shows two degrees lower temperature than white pigmented liquid membrane and four degrees lower than tan waterproof paper. The clear compound was eleven degrees higher than the white curing paper.

The maximum temperature differences (at the top of the slab for each of the nine rounds) in test slabs during 72-hr curing period are shown in Table 6. The order of effectiveness in maintaining low and uniform temperatures is (1) white waterproof paper, 26.7 degrees; (2) tan waterproof paper, 30.7 degrees; (3) white pigmented liquid membrane, 32.5 degrees; and clear membrane with red dye, 38.8 degrees.

The maximum range in temperature between top and bottom in the test slabs during the curing period is shown in Table 7. The order of effectiveness is (1) white paper, 23.1 degrees; (2) tan paper, 27.3 degrees; (3) white pigmented liquid membrane, 27.8 degrees; and clear membrane with red dye, 34.1 degrees.

The relative air and pavement temperatures (Table 8) show the order of effectiveness to be (1) white waterproof paper, (2) white pigmented liquid membrane, (3) tan waterproof paper and the clear membrane with red dye. The difference between the first and the third is only 4 F, but between the first and the fourth the difference is 11 F.

The maximum range in air temperature and pavement temperature in test slabs

TABLE 3
MAXIMUM TEMPERATURE 1-IN. BELOW PAVEMENT SURFACE IN TEST SLABS DURING 72-HR CURING

Treatment	Location 1, Project 4839							Location 2, Project 6375		Average
	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Round 9	All Rounds
White waterproof paper	112	112	111	97	115	108	108	97	99	106
White pigmented liquid membrane	115	113	114	101	119	103	108	100	104	108
Tan waterproof paper	120	114	119	101	122	108	108	99	100	110
Clear liquid membrane	128	115	126	108	131	115	115	104	109	117

1 in. below the surface of the pavement during the curing period (Table 9) shows white waterproof paper to be 13.1 F, white pigmented liquid membrane 15.1 F, and tan paper 16.7 F. Clear membrane with red dye had the greatest average variation with 23.3 F difference.

Table 6 shows the maximum temperature differences at 1 in. below the pavement surface. For the purpose of comparison, these values are expressed as degrees of temperature variations above those in the nine white waterproof paper rounds(Table 10).

A comparison of compressive strengths of concrete cores drilled from the road beyond the limits of curing method tests with cores drilled from test sections is shown in Table 11. The fourteen cores drilled from the roadway beyond the limits of the test sections on location 2, Project 6375, indicate excessively low compressive strength. They were drilled when the pavement was two months old, then stored in laboratory air for 18 months and finally immersed in water for 48 hours before testing. The immersion in water may be partly to blame for the low value.

The test results of cores drilled from the pavement indicate that the concrete is satisfactory insofar as the strength is concerned, but there is no apparent corre-

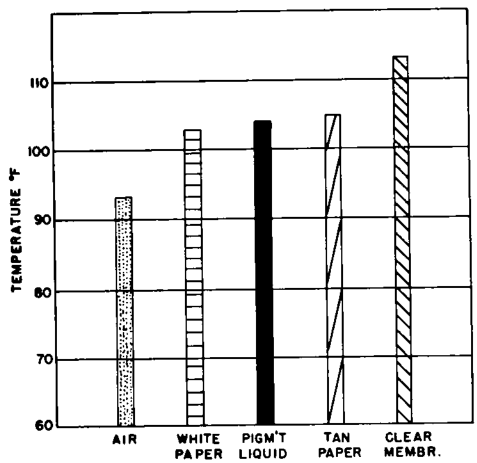

Figure 1. Comparison of maximum temperature of pavement 1 in. below surface as related to air temperature.

TABLE 4

SUMMARY OF DATA PREPARED FROM FIELD NOTES

Type of Curing	Slab Position Temperature °F					
	Top		Middle		Bottom	
	High	Low	High	Low	High	Low
Round 1, Air: high 95 - low 59*						
White pigmented liquid membrane	115	74	115	75	115	75
Clear liquid membrane	128	79	117	81	117	81
Tan waterproof paper	120	75	113	82	113	81
White waterproof paper	112	78	110	78	110	79
Round 2, Air: high 104 - low 59*						
White pigmented liquid membrane	113	78	105	80	106	81
Clear liquid membrane	115	79	114	81	109	84
Tan waterproof paper	114	82	112	81	102	82
White waterproof paper	112	79	109	78	100	85
Round 3, Air: high 104 - low 59*						
White pigmented liquid membrane	114	80	101	82	106	83
Clear liquid membrane	126	83	120	84	118	84
Tan waterproof paper	119	80	113	78	111	78
White waterproof paper	111	84	111	85	106	86
Round 4, Air: high 88 - low 57*						
White pigmented liquid membrane	101	73	101	79	100	79
Clear liquid membrane	108	75	110	79	105	80
Tan waterproof paper	101	78	104	81	97	81
White waterproof paper	97	76	99	80	98	78
Round 5, Air: high 88 - low 57*						
White pigmented liquid membrane	119	73	118	77	111	79
Clear liquid membrane	131	75	127	79	120	80
Tan waterproof paper	122	78	117	81	115	82
White waterproof paper	115	78	113	79	108	81
Round 6, Air: high 94 - low 63*						
White pigmented liquid membrane	103	81	102	86	101	87
Clear liquid membrane	115	84	113	90	108	90
Tan waterproof paper	108	86	106	90	103	90
White waterproof paper	108	86	106	90	104	91
Round 7, Air: high 84 - low 66*						
White pigmented liquid membrane	108	80	102	86	103	86
Clear liquid membrane	115	84	113	90	109	90
Tan waterproof paper	108	86	104	90	103	90
White waterproof paper	108	86	106	90	104	91
Round 8, Air: high 92 - low 58*						
White pigmented liquid membrane	100	72	100	73	99	77
Clear liquid membrane	104	71	100	77	98	76
Tan waterproof paper	99	75	97	77	95	80
White waterproof paper	97	75	97	77	96	79
Round 9, Air: high 92 - low 58*						
White pigmented liquid membrane	104	73	104	77	99	80
Clear liquid membrane	109	72	108	77	101	79
Tan waterproof paper	100	75	100	79	97	81
White waterproof paper	99	77	99	81	99	81

* Temperatures recorded at job site by technicians using max.-min. thermometer over a 72-hr period.

TABLE 5

ATMOSPHERIC CONDITIONS

Date	Max. Temp., °F	Min. Temp., °F	Precipitation	Remarks
PROJECT 4839, LOCATION 1, Raleigh-Durham U.S. Weather Bureau Station				
6-23-54	92	68	None	Placing 1st test section
6-24-54	89	64	None	Placing 2nd test section
6-25-54	95	59	None	
6-26-54	99	69	None	
6-27-54	104	72	None	
6-28-54	86	62	None	Placing 3rd test section
6-29-54	89	56	None	
6-30-54	95	58	None	
7- 1-54	99	70	None	
7- 2-54	101	72	0.37	
7- 3-54	96	68	None	
7- 4-54	94	70	None	
7- 5-54	97	68	0.65	Placing 4th test section
7- 6-54	89	68	None	
7- 7-54	97	63	None	
7- 8-54	87	70	None	
7 -9-54	80	66	None	Placing 5th test section
7-10-54	86	67	None	
7-11-54	87	59	None	
7-12-54	88	57	None	
7-13-54	97	61	None	
7-20-54	97	70	1.07	Placing 6th test section
7-21-54	90	69	0.07	
7-22-54	81	70	None	
7-23-54	87	65	None	
8-23-54	84	66	None	Placing 7th test section
8-24-54	86	60	None	
8-25-54	91	65	None	
8-26-54	96	71	None	
PROJECT 6375, LOCATION 2, Hickory U.S. Weather Bureau Station				
9-25-54	84	49	None	
9-26-54	88	50	None	
9-27-54	85	52	None	Placing 8th and 9th test sections
9-28-54	90	54	None	
9-29-54	93	56	None	
9-30-54	88	60	None	

lation between the compressive strength of the pavement concrete and the method used to cure it.

These field data indicate that white and tan waterproof paper and, also white pigmented liquid membrane curing, may provide satisfactory concrete with no abnormal cracking due to summertime temperature changes.

The data are not presented for the purpose of establishing a fact with respect to the total efficiency or inefficiency of a curing method, but rather to show what may be determined in the field by this procedure.

Since the deterioration of paper with use can be measured only by an accurate moisture test, the data here fail to establish clearly the effect of use. The occurrence of holes, breaks and tears can be seen and remedied by patching. The paper in these tests was re-used nine times and shows few signs of deterioration.

RECOMMENDATIONS

It still remains to be determined how much rise or change in temperature can be safely tolerated, although it will be agreed that a minimum is desirable. Economic considerations and the practical business of inspection are involved in the determination of safe tolerances. Attention is called, also, to the limited amount of data included in this report and the relatively narrow scope of conditions covered. It is recommended that other investigators conduct similar practical comparison tests and, perhaps, in-

TABLE 6

MAXIMUM TEMPERATURE DIFFERENCE AT TOP OF SLAB*

Treatment	Location 1, Project 4839							Location 2, Project 6375		Average
	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Round 9	All Rounds
White waterproof paper	34	33	27	21	37	22	22	22	22	26.7
Tan waterproof paper	45	32	39	23	44	22	22	24	25	30.7
White pigmented liquid membrane	41	35	34	28	46	22	28	28	31	32.5
Clear liquid membrane	49	36	43	33	56	31	31	33	37	38.8

* Difference between highest and lowest temperature °F 1-in. below top in test slabs during 72-hr curing period.

TABLE 7

MAXIMUM RANGE IN TEMPERATURE BETWEEN TOP AND BOTTOM OF SLABS

Treatment	Location 1, Project 4839							Location 2, Project 6375		Average
	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Round 9	All Rounds
White waterproof paper	33	27	25	19	34	17	17	18	18	23.1
Tan waterproof paper	39	32	41	20	40	18	18	19	19	27.3
White pigmented liquid membrane	40	32	31	22	40	16	22	23	24	27.8
Clear liquid membrane	47	31	42	28	51	25	25	28	30	34.1

clude a study of the reverse condition where temperatures are comparatively low at night and some insulation effect against loss of heat may be desirable.

ACKNOWLEDGMENTS

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TABLE 8
RELATIVE AIR AND PAVEMENT TEMPERATURES*

Treatment	Maximum Pav't Temp.	Av. Maximum Air Temp.	Diff.
White waterproof paper	106	94	12
White pigmented liquid membrane	108	94	14
Tan waterproof paper	110	94	16
Clear liquid membrane	117	94	23

* Comparison of maximum temperatures of the pavement 1 in. below the surface for the individual curing methods with the average of the air at its maximum for the 72-hr curing period for all 9 rounds.

TABLE 9
MAXIMUM RANGE IN AIR TEMPERATURE AND PAVEMENT TEMPERATURE IN TEST SLABS 1 IN. BELOW THE SURFACE DURING 72-HR. CURING PERIOD.*

Rounds	White-Waterproof Paper	White Liquid Membrane	Tan Paper	Clear Liquid Membrane
1	17	20	25	33
2	8	9	10	11
3	7	10	15	22
4	9	13	13	20
5	27	31	34	43
6	14	9	14	21
7	24	24	24	31
8	5	8	7	12
9	7	12	8	17
Av. Range °F	13.1	15.1	16.7	23.3

* Data secured from Table 4 by subtracting high air temperature from high top temperature for each round of each curing medium.

TABLE 10
MAXIMUM TEMPERATURE VARIATIONS*

Treatment	Rounds									Average
	1	2	3	4	5	6	7	8	9	
White waterproof paper	0	0	0	0	0	0	0	0	0	0.0
Tan waterproof paper	11	−1	12	2	7	0	0	2	3	4.0
White pigmented liq. membrane	7	2	7	7	9	0	6	6	9	5.9
Clear liquid membrane	15	3	6	12	19	9	9	11	15	11.0

* In °F during 72-hr curing period 1 in. below pavement surface in all rounds of test slabs based on white waterproof paper rounds.

TABLE 11

COMPARISON OF STRENGTHS OF CONCRETE CORES DRILLED FROM TEST SECTIONS WITH THOSE DRILLED FROM THE ROAD BEYOND THE LIMITS OF THE EXPERIMENT.*

Type of Curing	No. of Cores	Average Strength, psi 12 Mo.	18 Mo.
(*a*) Location 1, Project 4839			
White waterproof paper	7	4629	4986
White pigmented liquid membrane	7	4800	5213
White pigmented liquid membrane	†50	3956‡	—
Tan waterproof paper	7	4821	5045
Clear liquid membrane	7	5090	5021
(*b*) Location 2, Project 6375			
White waterproof paper	4	4232	—
White pigmented liquid membrane	4	4303	—
White pigmented liquid membrane	**14	—	2712
Tan waterproof paper	4	4210	—
Clear liquid membrane	4	4275	—

* Tested in air dry condition except as otherwise noted.
† Cores drilled from the road beyond the limits of test sections when pavement was approximately 30 days old. Tested in air dry condition.
‡ At 3 to 4½ months.
** Cores drilled from the road beyond the limits of test sections when pavement was approximately 2 months old. Soaked 48 hours prior to testing.

DISCUSSION

M. G. Brown, *Chemical Research Engineer, Michigan State Highway Department*—The subject of this paper is of interest to all concerned with the proper curing of portland cement concrete and with the temperature build-up in fresh concrete poured at the beginning of hot summer days. The temperature data are significant and further substantiate the difference found by previous investigators between white and clear sprayed membranes in their ability to reflect radiant heat from the sun. Michigan has required the use of a white pigmented membrane since 1949.

In August, 1955, the Michigan State Highway Research Laboratory made a series of field measurements similar to the North Carolina tests in connection with a study of polyethylene films for curing concrete. In this study temperatures were measured under the following curing media: (1) curing paper, white side up; (2) curing paper, buff side up; (3) white polyethylene film, 0.004 in. thick; and (4) white membrane, 200 sq ft per gal.

A small test area was picked out at station 175 + 30 on the south 11-ft widening strip of construction project F 41-42, C6R, on US 16 at Cascade. This pavement was of uniform 9-in. thickness with standard steel mesh reinforcing of 75.9 lb per 100 sq ft and ½-in. contraction joints spaced at 99-ft intervals. The test area was divided into four sections, each consisting of 10 lineal feet of 11-ft single-lane pavement. Copper-constantan thermocouples were placed at the midpoint of each section about 18 in. from the edge and at depths of ¼ in. and 8 in. below the surface. A total of eight thermocouples from the pavement and one suspended in the air and sun were connected to an automatic 10-point temperature recorder for a printed record of temperatures. The concrete was finished at 8:00 a.m., August 1, 1955, and the four areas were

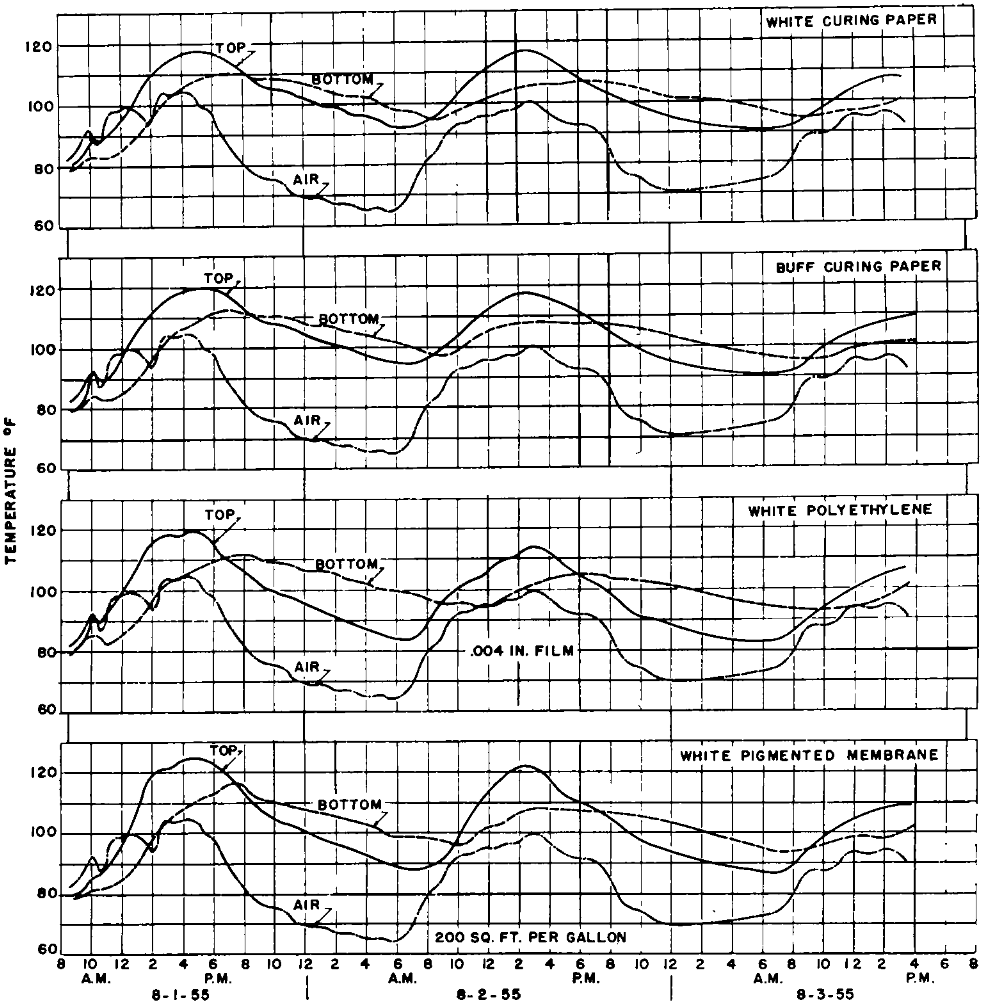

Figure 2. Effect of curing method on pavement temperatures.

covered about three hours later. Temperatures were recorded for three days but the curing was carried on for seven days, the specified time for paper curing in Michigan. These data are shown in Figure 2. The weather was very hot and sunny for the first three days and there was no precipitation.

A comparison of maximum and minimum readings follows to compare with results obtained by Proudley and Morgan:

COMPARISON WITH TABLE 6.

Treatment	Max. Top Temp. °F	Min. Top Temp. °F	Difference
White paper	117	89	28
Buff paper	119	89	30
White polyethylene	119	83	36
White membrane	124	86	38

COMPARISON WITH TABLE 7.

Treatment	Max. Top Temp.	Min. Bot. Temp.	Difference
White paper	117	93	24
Buff paper	119	94	25
White polyethylene	119	93	26
White membrane	124	93	31

COMPARISON WITH TABLE 8.

Treatment	Max. Top Temp.	Max. Air Temp.	Difference
White paper	117	104	13
Buff paper	119	104	15
White polyethylene	119	104	15
White membrane	124	104	20

The temperature differences obtained for the sections covered with the white and buff curing papers agree very closely. The white membrane section, however, developed somewhat higher temperatures, probably because the top thermocouple junction was just beneath the surface rather than 1 in. below. Another factor may have been a difference in the water retaining properties of the two membranes. The method of using glass thermometers in metal wells set in the pavement probably would not be as discriminating as the thermocouple method and the metal wells would tend to average the effect of a thermal gradient within the concrete. This difference in location of temperature measurement apparently did not change the results beneath the white and buff paper appreciably because of the insulating air layer between the pavement surface and paper.

The white polyethylene sheet material performed almost as well as the curing papers in holding the surface temperatures down. However, the concrete surface under the plastic cooled down about 6 F more than the paper-covered areas during the night. This seemed to be due to a layer of moisture between the plastic and concrete which caused the plastic to grip the surface and make intimate contact thus promoting transfer of heat to the night air. By comparing the concrete surfaces after seven days when the curing sheets were removed, it was found that the polyethylene held moisture in the concrete better than the curing paper. The plastic was somewhat harder to apply to the fresh concrete when it was windy because it was much lighter and more flimsy. It also tended to deform and stretch in the heat of the sun when it was pulled with any force. Possibly a heavier film or one in combination with a reinforced, waterproof paper would prove more advantageous.

Proudley and Morgan's method of comparing maximum and minimum temperatures for the whole 72 hour initial curing period does not give a true picture of temperature differentials significant in causing warping stresses although it does provide a measurement of the over-all uniformity of temperature. Stresses within the concrete pavement would actually be due to simultaneous temperature differences between the top and bottom surfaces. It can be seen (Figure 2) that the maximum top to bottom differentials obtained on this project for both day and night conditions were:

Treatment	Top-Bottom Differentials °F Day	Night
White paper	14	− 7
Buff paper	16	− 7
White polyethylene	20	−16
White membrane	22	−11

It is apparent from these values that the maximum night time tensile stresses in the top surface would occur in the section cured with the white polyethylene.

Proudley and Morgan's paper clearly describes a worthwhile and important phase of concrete pavement construction. They are to be commended for their efforts in obtaining temperature data of a large enough scope to bring out the effects of the various curing methods, along with weather variations, on the internal temperatures of pavement poured in the early morning hours.