CHAPTER 3

REVIEW OF DATA ON BITUMINOUS COATINGS AND RELATION OF TEMPERATURE TO CURING METHODS

H F GONNERMAN,
Manager, Research Laboratory, Portland Cement Association

It was pointed out in the reports of the Curing Committee in the Ninth and Tenth Proceedings of the Highway Research Board, that in general, satisfactory strength and surface texture were obtained by curing with bituminous coatings but that measurements of temperatures and volume changes in the slabs showed that these coatings as used, caused greater total temperature changes and greater daily variations in volume than other curing methods under similar conditions Crack surveys of pavements in several states revealed that, except in localities where fine sand subgrades were encountered, transverse cracks were in general more numerous in pavements cured with bituminous coatings Data studied by the Committee indicated that considerably greater daily temperature fluctuations occurred in concrete cured with bituminous coatings than with other methods due to the fact that the black surface is a good absorber of heat when cold and a good radiator of heat when hot The large temperature variations occurring at the top of the pavement slab and between the top and bottom produce changes in volume which tend to warp and crack the slabs especially at early ages when the tensile resistance of the concrete is low

Additional information on the temperature variations, volume changes and cracking of pavements cured with bituminous coatings in comparison with other methods has since become available through tests carried out by the U S Bureau of Public Roads and by the Missouri and Iowa State Highway Departments. In some of these tests the use of whitewash, light colored powders or other materials as an added covering was investigated This was done in the belief that the heat absorbed would be decreased by reason of the reflection of heat from the white surface, or the insulating effect of the added covering material, and thus the ill-effects of the bituminous coatings would be minimized

It was found that the use of light colored applications substantially decreases the total daily temperature changes and makes it possible to avoid the bad effects due to the black color of bituminous coatings used as curing agents

Bureau of Public Roads Tests

In an unpublished investigation of the effect of various surface coverings on the temperature of concrete slabs exposed directly to the sun's rays, it was found that

(1) The use of bituminous coatings on concrete exposed to the sun's rays caused variations in temperature greater than those in unprotected concrete and very much greater than those in slabs whose surfaces were covered with burlap, earth or straw

(2) The temperature differential between the upper and lower surfaces of a concrete slab exposed to the sun's rays was greater for a slab whose surface was coated with bitumen than for an uncoated slab and was much greater than for slabs covered with burlap, earth or straw

(3) Three inches of dry straw was a more effective heat insulator for the surface of a concrete slab than an equal thickness of dry earth

(4) Increasing the thickness of either earth or straw increases the heat insulating value

(5) Dry earth is a somewhat better heat insulator than wet earth

Missouri State Highway Department Tests

During the 1930 construction season, the Missouri State Highway Department carried out extensive field studies on two projects along lines suggested by this Committee in which the relative merits of twelve methods of curing were investigated The important results regarding temperature variations, volume changes and cracking abstracted from the June, 1932, report on this investigation by F V Reagel, T F Willis and F N Wray of the Missouri Highway Commission are as follows

Temperature in Concrete Regardless of the method of curing, the time temperature curve for the concrete at the top surface of the pavement was found to follow the general contour of the corresponding curve of air temperatures measured in the shade The concrete at the bottom of the slab was found to have a considerably smaller daily range in temperature than that near the top, and the maximum and minimum temperatures at the bottom lagged from 2 to 3 hours behind those at the top

Although the concrete temperature depended primarily on the temperature of the air, simultaneous measurements of concrete temperatures in sections cured by different methods showed differences of as much as 40° F

Since constancy of temperature during the early hardening period was considered important to the proper curing of the concrete, the various methods were compared on the basis of (1) the differences between the maximum temperature of concrete at the top surface of pavement and the corresponding maximum air temperature, and (2) the maximum daily drop in temperature of concrete at top surface relative to the drop in air temperature On these bases the curing methods are rated as shown in Table XI When rated on the basis of the total daily change in temperature of the top surface relative to that of the bottom surface, the various curing methods had practically the same grouping

TABLE XI

MISSOURI DATA

Group	Curing Methods	Max Temp at Top Surface Compared with Corresponding Air Temperature	Max Daily Drop in Temp of Concrete at Top Surface Compared with Drop in Air Temperature
1 (Best)	72 hr of wet burlap Hunt process coated with whitewash Curcrete covered with lime Ponding	0 to 5°F less	9 to 15°F less
2	24 hr wet burlap (minimum) Moisture-proof paper Calcium chloride, surface application Sodium silicate	14 to 19°F greater	2 to 4°F greater
3	Calcium chloride admixture Curcrete dusted with dry portland cement	21 to 23°F greater	8 to 9°F greater
4 (Poorest)	Hunt Process Curcrete	32 to 34°F greater	13°F greater

The authors summarize the relative effects of the various curing methods on the temperature of the concrete as follows:

"Any curing method which caused the concrete to attain a higher maximum temperature during the day caused larger temperature differentials between the top and bottom surfaces of the pavement, and indirectly was responsible for a greater drop in the temperature of the concrete at night"

Volume Changes in Pavement Expansion and contraction of the pavement was measured over a ten inch gage length The transverse contractions were found to be consistently greater than the longitudinal and hence were used in studying the effect of curing method on volume change In general, the maximum readings were obtained in the afternoon at or near the time when the maximum temperature at the top surface was recorded Minimum readings occurred at night when the temperature was at or near the minimum The data indicated that temperature change was the dominating factor causing the daily repetitions of expansion and contraction.

Results of tests made when the weather was fair and when no interruptions or irregularities occurred are plotted in Figure 9 This

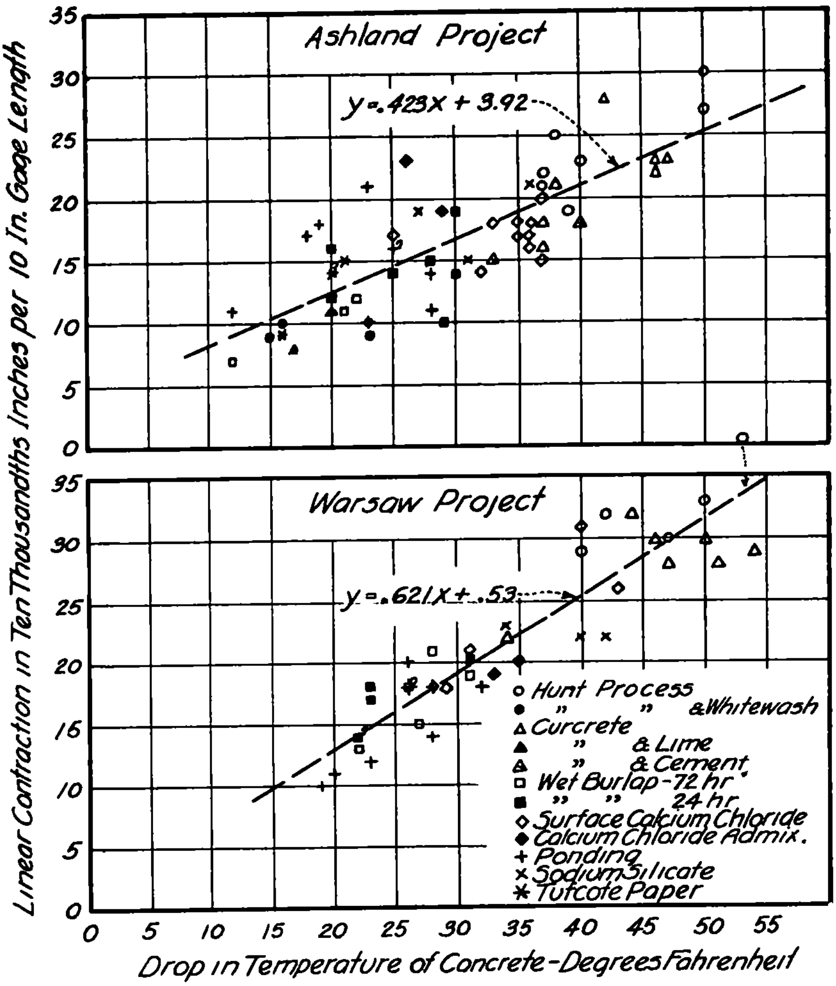

Figure 9. Relation Between Temperature Drop and Measured Contraction Data from Tables VII and IX of "An Investigation of Methods of Curing Concrete Pavements," Missouri State Highway Department

figure shows the relation between the total daily drop in temperature of the top surface of certain of the test sections on one or more days and the corresponding amount of contraction which accompanied the temperature drops It reveals a fairly definite linear relationship between contraction and temperature drop showing that temperature change was the dominant factor causing volume change This being true, the various curing methods from the standpoint of their effects on volume change may be rated according to their effects on concrete temperatures which would place them in the same groupings as shown previously

Curling of Pavement Measurements of the curling or warping of the pavement were taken in both longitudinal and transverse directions on several test sections Transverse measurements were made at points along a transverse butt joint from the pavement edge to the center joint Longitudinal measurements were made at points along the center joint for a distance ten feet back of the butt joint The general conclusion drawn from the data on curling was that the temperature differential between top and bottom of pavement was the controlling factor in the daily vertical movement of the edge on the end of the slab The greater the temperature differential the greater was the curling which emphasizes the importance of the effect of the curing method on temperature changes in the concrete

It is of interest to note that measurements comparing the longitudinal curling on each side of a butt joint showed that the vertical movement of the slab cured with Hunt process sprayed with whitewash was only about one-half that of the slab cured with Hunt process without the whitewash

Cracking and General Condition of Pavement Surface Periodical condition surveys were made to determine the relative effects of the different curing methods on the cracking and surface condition of the concrete

Cracking was subject to the influence of a number of variables which tended to obscure the effects of a given controlled factor such as artificial curing As a result the data show relatively large variations in the amount of contraction cracking in sections which were intended to be cured alike and particularly at the early ages, the principal causes were variations in weather conditions and subgrade

Effect of Weather Conditions on Cracking The weather conditions through their influence on temperature history of the concrete affected the extent of cracking It was found that the magnitude of the temperature drop had a marked effect on cracking as may be seen from Figure 10 This figure shows the relation between the maximum drop in temperature of the top surface of the concrete (at instrument stations located at about the middle of the morning paving) and the number of transverse cracks per 100 feet of pavement in the corresponding portions of the test sections The graphs indicate an increase in the number of cracks with increasing temperature drop

It was found at the early ages that for practically every test section the concrete placed in the afternoon had fewer contraction cracks than that placed in the morning This is believed to be due to the fact that the concrete placed in the afternoon was exposed to sunshine and high atmospheric temperature a shorter time, attained a lower maximum temperature, underwent smaller temperature drop the first

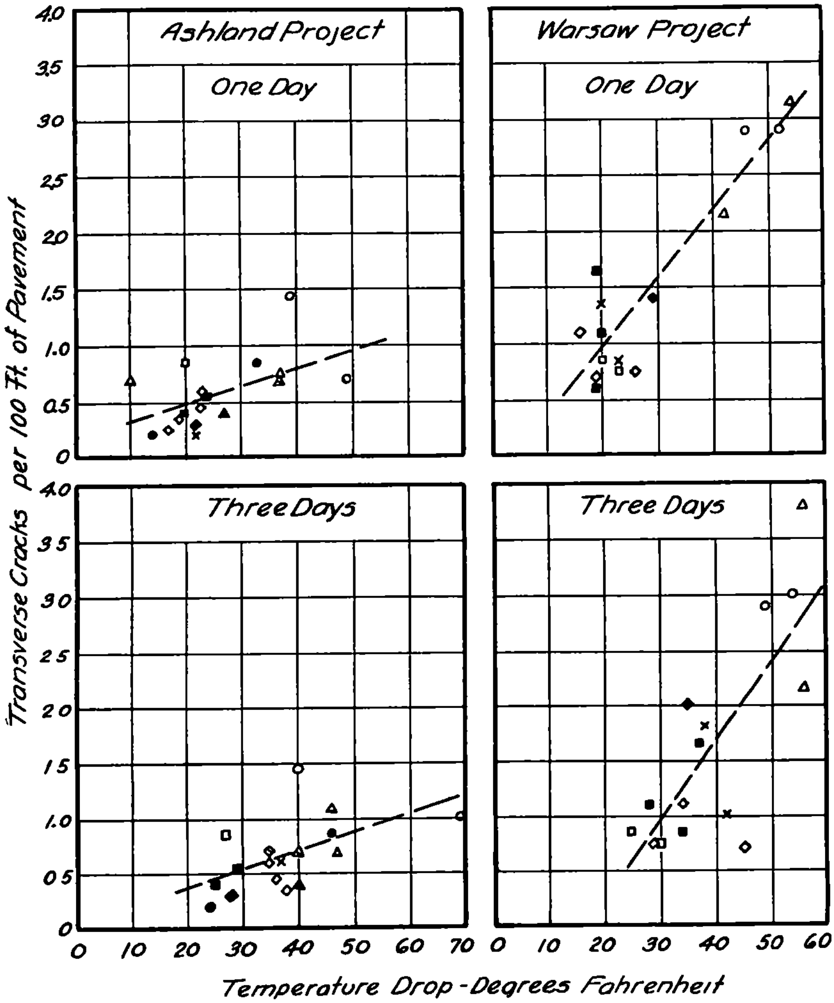

Figure 10. Relation Between Maximum Temperature Drop of Concrete and Extent of Cracking. Missouri Data Symbols for Curing Methods Same as on Figure 1.

night and consequently was subjected to smaller temperature stresses Furthermore the concrete placed in the latter part of the day remained plastic while a considerable amount of contraction due to daily temperature drop occurred and hence may have yielded to the tensile stresses by plastic flow

TABLE XII

Summary of Core Strengths

MISSOURI TESTS

All specimens tested wet

Each value is average of tests on ten cores

The figures in parentheses are ratios of the average strengths for a given method of curing to the corresponding average strength for the ponding method, expressed as a percentage

Method of Curing	Compressive Strength of Cores, lb per sq in									
	Ashland Project					Warsaw Project				
	14d	28d	3m	1yr	Av for All Ages	14d	28d	3m	1yr	Av for All Ages
Ponding	3400	3350	4240	4410		4170	4070	5160	5000	
	3380	4190	4390	4710		4650	4370	5050	4980	
	3800	3600	4610	4470		3780	3850	4280	4400	
	3180	3350	4720	4260		3480	4110	4020	3950	
	3440	3620	4490	4460		3940	3740	5070	4080	
						4000	4030	4720	4480	
	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Wet Burlap 24 hours	3130	3620	3310	4150		3810	4430	4520	4480	
	2820	3620	3850	3810		3310	3860	3670	3940	
	3300	3210	3680	3740		3470	3870	3570	4200	
	3080	3480	3610	3900		3530	4050	3920	4210	
	(90)	(96)	(80)	(87)	(88)	(88)	(100)	(83)	(94)	(91)
Sodium Silicate	3130	3665	3550	4090		3920	3890	3980	3630	
	3010	2800	3830	3700		3630	3790	3870	4280	
	3070	3230	3690	3900		3770	3840	3920	4470	
	(89)	(89)	(82)	(87)	(87)	(94)	(95)	(83)	(100)	(93)
Surface Calcium Chloride	3290	3580	4530	4520		4090	4570	4380	4420	
	2860	3980	4140	4490		3550	3590	3450	3700	
	3140	3470	4330	4450		3820	4080	3920	4060	
	3210	2810	4180	3860						
	3120	3460	4290	4330						
	(91)	(96)	(96)	(97)	(95)	(95)	(101)	(83)	(91)	(92)
Wet Burlap 72 hours	2940	3750	4270	4440		3780	3920	3620	5000	
	3660	3210	4770	4140		3870	3870	4750	4160	
	2510	3120	4250	3600		3820	3900	4180	4580	
	3040	3360	4430	4060						
	(88)	(93)	(99)	(91)	(93)	(95)	(97)	(89)	(102)	(96)
Hunt Process	3720	3420	4310	3890		3920	4570	3690	4540	
	2980	3890	4175	3980		3600	3930	4600	4410	
	2880	3600	4060	3950		3760	4250	4150	4480	
	3190	3640	4180	3940						
	(93)	(100)	(93)	(88)	(94)	(94)	(105)	(88)	(100)	(97)

TABLE XII—*Continued*

SUMMARY OF CORE STRENGTHS

MISSOURI TESTS

All specimens tested wet

Each value is average of tests on ten cores.

The figures in parentheses are ratios of the average strengths for a given method of curing to the corresponding average strength for the ponding method, expressed as a percentage

Method of Curing	Compressive Strength of Cores, lb per sq in									
	Ashland Project					Warsaw Project				
	14d	28d	3m	1yr	Av for All Ages	14d	28d	3m	1yr	Av for All Ages
Curcrete	3460	3470	4010	4470		3770	3540	3550	3740	
	3020	3410	4010	4570		3290	4030	3840	3730	
	3240	3440	4010	4520		3530	3790	3700	3740	
	(94)	(95)	(89)	(102)	(95)	(88)	(94)	(78)	(83)	(86)
Calcium Chloride Admixture	2420	2900	3460	3520		3430	3720	3600	4280	
	(70)	(80)	(77)	(79)	(77)	(86)	(92)	(76)	(95)	(87)
Hunt and Whitewash	3400	3770	4580	4210						
	2910	3810	4410	4230						
	3160	3790	4500	4220						
	(92)	(102)	(100)	(95)	(94)					
Tufcote	3000	3560	3900	4220						
	3610	3360	4610	4090						
	3300	3460	4260	4160						
	(96)	(96)	(95)	(93)	(95)					
Curcrete and Cement	3540	4110	4150	4380						
	(103)	(113)	(93)	(98)	(102)					
Curcrete and Lime	3590	3470	4530	4370						
	(104)	(96)	(101)	(98)	(100)					

Instances were noted where entire test sections, placed on cool and shady days had less than average cracking up to ages of three days Experimental sections of pavement cured by the Curcrete and Hunt methods were benefited more by construction on cloudy days and by late afternoon placing than were sections cured by other methods

Effect of Subgrade on Cracking The effect of subgrade in causing variations in the cracking of sections cured alike was not so easily discerned Test sections on the Warsaw project placed in a soft-, spongy uniform top soil containing very little granular material developed considerably fewer transverse cracks than similarly cured sections in other locations It was considered probable that the lesser cracking of these sections was due to the differences in some property of the subgrade, as for example, frictional resistance to the movement of the pavement

Average Crack Intervals for Different Curing Methods Because of apparent similarity in the cracking of test sections cured by cer-

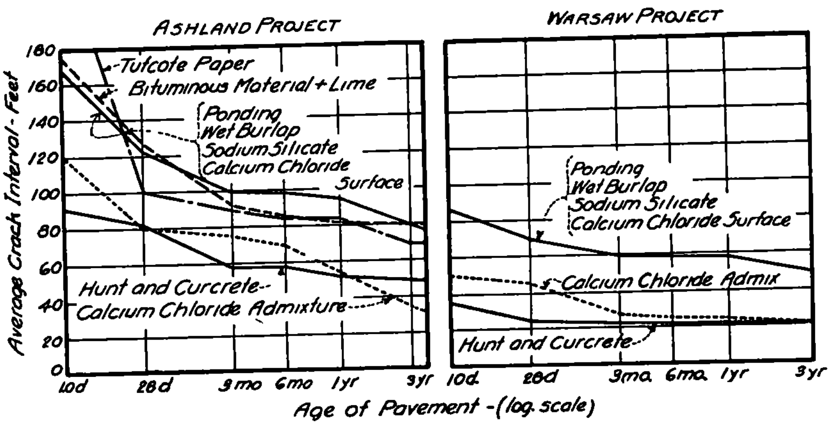

Figure 11. Extent of Cracking of Pavements Cured by Different Methods—Missouri Data

tain methods, the average crack intervals were grouped according to age, curing and construction project The average values for the various groups which represent the most significant portion of the data on cracking are shown in Figure 11 Hunt process and Curcrete gave the shortest crack intervals The difference between them and the average intervals for the group which included ponding, wet burlap, sodium silicate and surface calcium chloride (methods which permitted the pavement to retain its natural color) was approximately 40 feet on both projects for ages between 28 days and 1 year A coating of dry lime or whitewash applied on top of the bituminous curing materials was effective in reducing contraction cracking The average crack interval for the whitened surfaces compared favorably with the test sections cured by ponding, wet burlap, sodium silicate, surface calcium chloride While whitening might be considered capable of completely eliminating the bad effect of asphaltic curing agents, the report points out the possibility of rains and traffic destroying the white coating This would leave the pavement bearing the characteristic black color which might cause it to crack about as much as it would have had the whitening not been applied

Effect of Curing Method on Strength In the Missouri experiments, cores were drilled at each of ten different locations on each test section The cores were taken four days prior to each age of test. They were capped with a strong mortar, soaked in water for 24 hours and tested at ages of 14 days, 28 days, 90 days and 1 year The core strengths are summarized in Table XII

Assuming that the effect of uncontrolled variables are "ironed out" by the repetitions of the curing methods, the data (excluding the calcium chloride integral method which was used on only one test section on each project and the use of which required considerable additional mixing water to overcome the quick set which otherwise would have occurred) gave certain indications respecting strength which the authors summarized as follows

"1 All the test sections, regardless of the curing method, had satisfactory strength
2 Sections cured by 'ponding' had the highest strength
3 The poorest curing methods did not decrease the strength in excess of 15 per cent as compared with the best
4 None of the curing methods showed any economically justifiable advantage over 24 hours wet burlap"

Moisture Retention A few data on moisture retention of bituminous cured surfaces are given in Table XIX, Chapter 4

Tests by the Iowa State Highway Commission

1929 Tests The Iowa State Highway Commission has made crack surveys of a number of sections of projects cured with Curcrete and wet earth Data comparing the average crack intervals for earth and bituminous coverings on adjacent one-mile strips of road built in Iowa at each of several locations during the construction season of 1929 are plotted in Figure 12 The data in this figure are based on surveys conducted at three different periods in the life of the pavement and have been arranged according to the kind of coarse aggregate (gravel or stone) and mix

The bituminous curing on these projects was performed in the manner prescribed for Curcrete by the producer In the earth curing method, wet burlap for the first 24 hours was followed by a covering of moist earth for seven to ten days

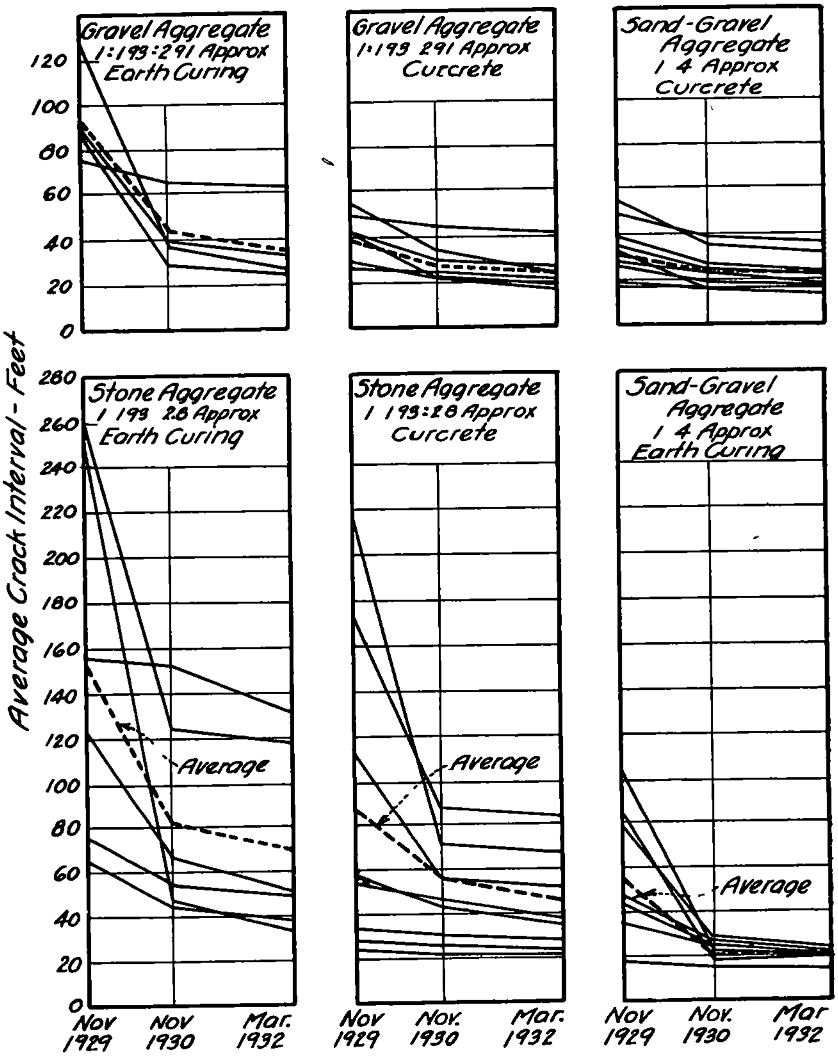

Figure 12 Average Crack Intervals on Iowa Projects Constructed in 1929. Surveys Made on Dates Shown

Figure 12 gives the average slab length in feet at the time of the November–December, 1929, the November–December, 1930 and the February–March, 1932 inspections Separate diagrams are shown for a given method of curing, mix, and type of aggregate The full lines on each diagram show the average crack intervals for each section of several projects and the dash lines represent the averages of all the sections in the group

It appears from these diagrams that in general the crack intervals for both methods of curing tend to approach the same value with age, although at the early ages the earth-cured concrete shows a much greater uncracked slab length than similar pavement cured with Curcrete

1932 Tests Field tests on two different projects were made late in August and early in September, 1932, by the Iowa Highway Commission which had for the principal objectives the determination of

1 The relative length of the time interval between the placing of the concrete and the practical application of (a) Curcrete and (b) Wet burlap upon the fresh concrete
2 The time interval between the application of Curcrete upon either fresh or hardened concrete and the practical application of a whitewash coating
3 The relationship between air temperature and that of the concrete throughout the day for each method of curing.
4 The relationship between the strengths obtained for each method of curing

The experimental pavement sections were placed beginning at noon of one day and extending until noon of the following day, so that each method was subjected to the conditions of an afternoon and a forenoon run For each method of curing three sections 1000 and 2000 ft in length were employed

Time of Application of Curcrete and Whitewash It was found that Curcrete may be applied as soon as or a little earlier than the wet burlap after completion of the final finishing processes, furthermore, that the whitewash may generally be applied to the bituminous coating on fresh concrete about as soon as on concrete which is 12 to 30 hrs old The fine spray now obtainable with the better spray tips permits the application of the bituminous coating somewhat earlier than previously It was found that with care the bituminous coating or the burlap covering could be applied slightly before the water-sheen left the surface of the concrete

Temperature of Concrete Little difference was found in the temperature of the concrete for the two methods of curing The time interval between the application of Curcrete and the whitewash covering was apparently small enough to prevent any great absorption of heat at the time of the year that the tests were carried out. No visible effects of possible greater heat absorption were noted upon pavement built on the same projects earlier in the season

Strength of Cores from Pavement Compressive strengths of cores from each of the two projects for the two methods of curing were as follows

Project	Method of Curing	No of Cores	Age at Test Days	Average Comp Str lb per sq in	Strength Ratio per cent
F-350	Wet Burlap 18-30 hr —Curcrete—Whitewash	20	28	5439	100
F-350	Curcrete—Whitewash	15	28	4982	93
F-45	Wet Burlap 11-30 hr —Curcrete—Whitewash	25	28	4597	100
F-45	Curcrete—Whitewash	18	28	3944	86

The lower strength exhibited by the concrete cured with the whitewashed Curcrete but without the initial application of wet burlap is considered to be due to the greater moisture loss from the concrete during the early curing period—the first 24 hours—occurring with this method This conclusion was arrived at from a careful review of the data and direct observations of the field tests and the results of extensive laboratory tests under controlled conditions to determine the relationship between strength and moisture loss for different methods of curing