REPORT OF COMMITTEE ON CURING OF CONCRETE PAVEMENT SLABS

SYNOPSIS

This report summarizes the opinions of the Committee with respect to the various curing methods that have been used as alternates to curing with wet coverings and presents chapters reviewing the available information relative to the following curing methods, with calcium chloride admixture, with bituminous coatings, (also relation of temperature to curing methods), with sodium silicate, with paper and intermittently with water

The efforts of the Committee will be concentrated in the future upon such fundamentals as methods of test for quality of curing, the phenomena of the action between water and cement and the effects of subgrade

INTRODUCTION

Since the organization of this committee in 1928 the principal effort has been toward the evaluation of the commonly used methods of curing

In the 1929 committee report the following statement was quoted: [1]

> "By good 'Curing' is meant the setting up of favorable conditions for chemical action during the setting and early hardening period
>
> The general opinion at the present time is that the most favorable conditions exist when the concrete is warm and moist throughout Temperatures that are regarded as favorable in practice range from 70° F to somewhat above 100° F"

In view of the committee's acceptance of this definition, curing by means of ponding or wet coverings of earth, sand, straw, etc , has been used as the basis of reference in appraising the other methods

Although wet curing best fulfills the requirements set up in the foregoing definition, experience has shown that it cannot always be used efficiently and therefore there is room for methods which do not require so much water and so much labor and inspection far behind the mixer

The Committee has now decided that it is no longer practicable to study individually each of the ever increasing number of methods for curing concrete pavements and although additional research data will be studied as they become available, the efforts of the Committee will be concentrated on such fundamentals as·

1 Development of tests with suitable limits by which the efficacy of proposed curing methods can be determined

[1] Report of Committee C-9, Proceedings A S T M , Volume 29, page 303

2 Study of the phenomena of the action between cement and water.

3 Study of the effects of subgrade characteristics upon volume changes and curing processes

Preliminary study of the subgrade problem indicates that the effects of subgrade soils as related to curing methods are difficult to measure

The amount of checking or hair cracking in concrete pavement slabs may be materially influenced by the type of subgrade soil In numerous cases the checking which has occurred on absorptive soils has been prevented by placing the concrete on a layer of waterproof paper, which may be considered to be a part of the curing process However, in some instances other factors have been discovered to be the causative agents Checking and hair cracking may be influenced not only by the subgrade and by the curing method, but by other independent factors such as materials and construction methods.

Although conclusive data are not available it appears that the degree of curing as measured by the volume changes that causes checking and hair cracking may be influenced by the character of the subgrade soil, but also that in many cases the effects of other variables may completely overshadow this influence

The purpose of this report, is to summarize the Committee's findings concerning curing with calcium chloride, sodium silicate, bituminous coatings, paper coverings and intermittent curing with water and to present further information concerning these methods that has not been previously reported by the Committee

Chapter 1

COMMITTEE FINDINGS

Calcium Chloride

Calcium chloride used either as a surface coating or as an admixture has been used satisfactorily as a curing medium Since calcium chloride depends upon its deliquescent properties for its efficacy as a curing medium, it should not be used in arid or semi-arid regions, nor under high temperatures [1] nor unless the relative humidity is expected to exceed 50 at normal temperatures

When used as a *surface coating* it should not be applied until the concrete has hardened in order to guard against scaling Fresh concrete should be protected with wet burlap until ready for the application of calcium chloride The American Society for Testing Materials Tentative Specification for Curing Portland-Cement Concrete Slabs by Surface Application of Calcium Chloride (C83-31T) requires that, "The burlap shall remain until the concrete will bear the weight of the workman without damage but in no case less than 12 hours"

When calcium chloride is used as an *admixture* the concrete should be protected with wet burlap for the first 24 hours The acceleration in early strength that accompanies the use of calcium chloride as an admixture may be an added advantage A review of data on the calcium chloride admixture method is given in Chapter 2 of this report

Bituminous Coatings

Satisfactory strength and surface texture is in general secured in concrete cured with bituminous coatings, however, measurements have shown that the use of these coatings is accompanied by greater total temperature changes and greater daily variations in volume than are shown by other curing methods under similar conditions It has been found that these greater variations in slab temperatures and volumes may be avoided by changing the color of the black coating by application to the surface of whitewash, stone dust, cement or other light colored substances Some further study of the effects of such colorings upon the permeability of the bituminous films is desirable

A summary of the available research data concerning this method is given in Chapter 3 of this report

[1] Report of Committee on Curing of Concrete Pavement Slabs, Proceedings Highway Research Board, Vol 10, page 370

Sodium Silicate

The tests reviewed by the Committee, including data previously reported by the Committee [1] and data from Louisiana, Missouri and Ohio, show that the strength and volume change characteristics of concrete slabs cured in the field with sodium silicate were, for the conditions encountered, similar to those of moist cured concrete. For best results the sodium silicate should not be applied until the concrete has set, and the concrete should be protected with wet burlap until the sodium silicate is applied. The ability of the concrete to sustain the weight of the workman without damage is a good criterion for the time of removing the burlap, but in any case good practice requires that it remain in place for at least 12 hours.

Strength data from three experimental projects are given in Chapter 4 of this report, together with some information bearing upon the factors that control the effectiveness of sodium silicate as a curing agent. The available evidence indicates that the sodium silicate does not form an impervious film upon the concrete although it does offer an impediment to the loss of moisture. The degree of impediment to the evaporation of water which it affords or upon which its effectiveness as a curing medium depends has not yet been entirely determined.

The Use of Paper for Curing Concrete Pavements

A report on this subject by Mark Morris was published in the Twelfth Proceedings of the Highway Research Board. A further report is included in this report as Chapter 5. The Committee agrees with Mr Morris in his conclusion that "... there are strong indications that suitably prepared papers may be used satisfactorily as curing agents, under some restrictions as to manner of application and number of repetitions of use, and that in these circumstances, such papers will provide a satisfactory curing condition for concrete pavement slabs."

Intermittent Curing of Concrete

This subject was investigated for the purpose of determining the required length of time of the curing period with water in humid regions. A preliminary report by F. C. Lang was published in the Twelfth Proceedings of the Highway Research Board, and his final report is included in this report as Chapter 6.

The Committee had noticed in studying research data from field experiments that very frequently a short initial period of wet curing

[1] Report of Committee on Curing of Concrete Pavement Slabs, Proc Highway Research Board, Vol 10, page 370

without other artificial curing gave good results The effects of intermittent or natural curing seem to offer an explanation of such results After consideration of the extensive laboratory investigation conducted by Lang the Committee concluded that. When the conditions are such that practically all of the mixing water present, when the placing and finishing operations are completed, is retained for three days no additional curing is necessary Keeping the surface wet by saturated burlap would assure such a condition

Chapter 7

DISCUSSION

Professor J S Crandell, *University of Illinois* There are two items of interest to this Committee which I would like to state During the past year I have run some tests on calcium chloride on fresh concrete, taking the weight of the specimens each hour on the hour A curious thing resulted I found that the concrete loses weight up to about the tenth hour and then begins to gain weight At the 26th hour it again has the same weight as when started I do not know whether anybody else has discovered this or not We have not run enough tests yet to be sure of our data It appears that the calcium chloride takes the water out of the concrete. The water is evaporated by the air, and then goes back again from the air into the concrete

Another item is the matter of curing concrete with paper I had an excellent opportunity last year to see just what that would do. Some concrete was cured in Urbana, Illinois, with felt roofing paper The paper was placed late in the afternoon, and during the night the temperature dropped to 18 degrees I wondered what would be the effect Would the concrete freeze? The paper was laid perfectly flat During the curing period the paper of course takes up moisture, or it is wetted beforehand It usually dries on the surface but, in this particular instance, it froze Some of you may have observed that when clothes are washed and hung on the line in the winter they first freeze and then dry By the end of the day the laundry may be brought in and it is perfectly dry That is exactly what happened here The paper froze, and underneath it the temperature did not drop below 33 or 34 degrees, although the temperature of the outside air was 18 degrees I tried it out in the laboratory—and it works Apparently, as long as that paper rises from the concrete and maintains an air space, the concrete underneath does not freeze

Professor H. J Gilkey, *Iowa State College* Much research has been devoted to the curing of concrete but our knowledge of curing phenomena admittedly remains so inadequate as still to justify elaborate investigations such as this one on "Intermittent Curing" So little research has been devoted to the oven-drying of concrete that it would be presumptuous to say whether its effects may not be as pronounced as are the effects of moisture itself It seems unfortunate therefore that the results of this investigation should all have been linked intimately to a technique, the possible effects of which are quite unexplored

During the past ten years the writer has conducted a number of curing investigations, some of which have included limited oven-drying experiments. Representative data from these may best serve to explain the fear that the technique adopted may have added a whole family of variables which, when better understood may materially alter some of the conclusions reached from these carefully executed tests

Series A consisted of 3 by 6 inch compressive cylinders (maximum size of aggregate ½ inch) After 2 3 years of continuous moist curing (by immersion) some specimens were placed in an electric oven at 171° F. (well below the boiling point of water) and were dried to constant weight which was attained in five days Others were dried to constant weight at 257° F. (well above the boiling point of water). More moisture was driven out and seven days were required to reach constant weight at the higher temperature Both groups were allowed

TABLE I—SERIES A

Time in Oven	Oven Temperature	Test Condition	Ultimate Strength	Strength Ratio to Standard Cured	Moisture Lost by Drying Per Cent	Remarks
None	—	Saturated	6035	1 00	None	Standard Cured
5 days	171°F	Dry	5350	0 89	45 5	
7 days	257°F	Dry	5425	0 90	64 0	
5 days	171°F	Saturated	4210	0 70	As above	
7 days	257°F	Saturated	3873	0 64	As above	

to cool gradually for a day in the air of the laboratory after which half of each group was saturated by immersion to constant weight (in water from 15 to 24 hours) The data are shown in Table I

It is evident that oven-drying punishes the specimen severely In this particular series the pronounced gain in strength by virtue of the dry condition as tested was more than offset, while the oven-dried specimens which were resaturated prior to testing had strengths which were but 60 or 70 per cent of that of the specimens which were standard cured and tested wet without being dried In all series, oven-dried specimens re-soaked prior to test gave the characteristic falling off of 20 to 30 per cent in strength which represents the usual difference between the strength of concrete dry and that which is saturated

Undoubtedly part of the weakening from oven-drying is due to shrinkage stresses and cracking Weakening from this cause should take on added importance with increased size of specimen, more rapid heating and higher temperatures Not infrequently cracks can be detected with the naked eye although the surface roughness of mortar and concrete specimens often makes this difficult However well-cured neat cement specimens (which have smoother surfaces) as small as 2 by 4 inch develop visible cracks from gradual air-drying at ordinary temperatures Under a microscope these cracks show as great chasms When 2 by 4 inch neat cement cylinders will develop important cracks under ordinary air-drying, there seems to be no question about the structural havoc that oven-drying should create in either concrete or mortar in spite of decreased tendency to shrink because of a lower cement factor

It was thought that the severity of the punishment from oven-drying might be lessened by air-drying the specimens prior to placing them in the oven and that was done under two different humidities for periods ranging from one day up to a month These specimens were all of the 2 by 4 inch size but of the same mixture and total age (2 3 years) as those of Series A cited above The oven tempera-

TABLE II—SERIES B

Time in Air	Time in Oven	Oven Temperature	Test Condition	Ultimate Strength	Strength Ratio to Standard Cured	Moisture Lost by Air-Drying Per Cent	Total Moisture Lost Per Cent
None	None	—	Saturated	5435	1 00	None	None
29 days	None	—	Dry	6300	1 16	11 0	11 0
28 days	None	—	Saturated	5450	1 00	As above	As above
25 days	3 days	210°F	Dry	5440	1 00	As above	45 6
25 days	3 days	210°F	Saturated	4290	0 79	As above	As above

ture was 210° F (slightly above the boiling point of water at the elevation of 5,000 feet where the tests were conducted), and only three days were required for oven-drying to constant weight because of the preliminary drying in air. A few representative results are given in Table II

While the oven-dried specimens have strengths almost identical with those in Series A, the standard cured strength for Series B is lower than that for Series A and the percentage weakening is less Whether the smaller apparent injury from oven-drying is due in part to the previous air drying is questionable since the Series B specimens were also smaller (2 by 4 inch instead of 3 by 6 inch) and shrinkage stresses should be correspondingly less severe

It is also questioned whether specialists on cement, colloidal chemistry and crystallography would support the assumption that the water retained after oven-drying indicates, even approximately, the amount of water held in chemical combination If this were true, herein might lie a very simple method for the determination of the amount of cement present in hardened concrete In fact several years ago the writer conducted a series of mortar tests, using both neat cement and Ottawa sand in mixtures ranging from the neat cement to 1 · 5 by weight and with water-cement ratios over the full range of workable mixtures Cured specimens were oven-dried at various temperatures to see whether the amount of water driven off was proportional to the cement present No satisfactory agreement could be found. It was then suspected that the water loss due to an added increment of temperature after constant weight was reached below the boiling point might prove significant No useable relationship was discovered

While the assumption made by the author is appealing in its apparent reasonableness, it seems possible and even probable that the matter is not so simple and that there is no one way in which water is fixed in a mass of hardened concrete Drying out is probably effected by colloidal and capillary phenomena, as well as those due both to crystallization, and chemical unions Partial dehydration can doubtless occur at temperatures well below that of chemical break-down.

The data given in Series A and Series B appear to supply some evidence of the apparent fallacy in the assumption which has been made If it is correct to assume that the water lost in oven-drying measures the amount not combined, then there should be no added loss of moisture for increases in the drying temperature between the boiling point of water and that at which breakdown occurs. At both 171 and 210° F the water loss was 46 per cent while at 257° F the loss was 64 per cent. The tests were conducted at an altitude of 5,000 feet and both 210 and 257° F. lay well above the boiling point of water while 171° F was well below it These observations are consistent with the findings from several other series which seem to indicate rather definitely that there is no abrupt end-point in moisture loss but rather that each added increment of temperature brings an increased moisture loss before constant weight is attained

Surely the results would be more satisfying had all strength tests been performed on saturated specimens and had some such method as measuring the heat of solution been used to determine the stage of hydration which had been attained More uniformity of the results of tests on companion specimens does not prove necessarily that the findings are either the same as or parallel to those which would have been obtained had the oven-drying features been omitted.

The extensiveness of the series, the fact that a single mixture and size of specimen were used throughout and that so many of the tests were at an advanced age when strength increases from normal curing are not rapid gives these tests a permanent value for subsequent study as the new variables are explored further. Nevertheless it is felt the investigation, as a practical study of relative curing methods, leaves much to be confirmed because adequate interpretations are not now possible

Professor F C Lang, *University of Minnesota* At the time the procedure to be followed in this investigation was decided upon, it was realized that the single drying of the specimens in the oven might be somewhat injurious to the concrete It was thought however, that it would show relative values for the different curing periods It was also considered desirable to get some data on the amount of retained or combined water The Committee has, at times, considered the relationship between the amount of retained water and the strength of concrete The punishment in the oven could not have been very severe as none of the specimens showed any cracking or checking, and the compressive strengths for the water-cement ratio used are quite satisfactory It is of interest to note the increase in strength for Series Nos 12 and 13 as shown on Figures 5 and 6 The specimens in these series were alternately immersed in water and dried in an oven at 150° F

Professor Gilkey questions the use of the term "combined water" The author of this paper realizes that the amount of water which can be driven off varies with the temperature and perhaps retained water would be a better term, but water which cannot be evaporated off must be in some other state than free water McMillan uses the term "combined water" in his book "Basic Principles of Concrete Making" and states that "the quantity of combined water may vary over a wide range, being influenced by the fineness and composition of the cement, the quantity of water mixed with the cement, the age and curing conditions"

As a possible measure of the efficiency of the various curing methods, the amount of combined or retained water under an identical drying condition was measured.

The primary purpose of this investigation was to get additional data which would be of value when deciding how long an initial wet curing period for concrete pavements is necessary in humid areas It is not very important whether the strengths shown are the most favorable or not, or at what temperatures the combined or retained water was measured so long as the relationships between the different series is not seriously disturbed

Professor F E Richart, *University of Illinois*. Is there any explanation why the water curing showed three fourths as much water as the other ones with intermittent curing?

Professor F C Lang, *University of Minnesota* The relationship between the strength of the concrete and the amount of retained water is fairly consistent for all the intermittent series but is somewhat different for the water cured specimens (Series No 19)

It is possible as pointed out in the report, that there might have been some entrained air in the intermittent cured specimens which affected the computations for combined water and also that some solids were dissolved out when specimens were continuously in water, and perhaps the intermittent curing is more favorable for the solidification of the cement paste

Mr L C Stewart· I would like to ask Professor Crandell if the calcium chloride he used was smooth or flaky Was the concrete freshly made or had it acquired its initial set? I would also like to ask if he noticed how soon the calcium chloride went into solution?

Professor J S Crandell, *University of Illinois* It went into solution very quickly—I should say fifteen minutes

Mr Searcy B Slack· A novel method of sealing the surface of concrete pavement for curing has been proposed by Mr P H. Hipple of Atlanta, Georgia The process consists essentially of spraying the surface of the concrete just after finishing with a thin layer of neat cement paste The claim is made that the fine particles of cement will be driven into the surface pores of the concrete and will serve both to close these openings and to harden the surface of the concrete As the surface is sealed with this paste the moisture will be retained and cure the concrete and the concrete will not in the future so readily absorb moisture

The machinery for applying the cement spray consisted of a small air compressor and a mixing tank In the mixing tank there was an agitator for keeping the cement paste at uniform consistency About 45 pounds air pressure was used to force the cement paste out of the mixing tank through the hose and nozzle At the nozzle the cement paste was broken up into a fine spray by a stream of compressed air The amount of cement used was one sack for each 100 square yards of surface sprayed Too heavy an application would cover the surface sand grains and give a slick surface while too little would not properly cover the surface

As considerable work had been done in developing the equipment and on small scale tests it was decided to try out this method on curing on a concrete paving job under the direction of the State Highway Board of Georgia.

Arrangement of Test Sections

The concrete pavement on which the tests were carried out was the usual 9-6-9 section with dowelled longitudinal center joint and transverse expansion joints at fifty foot intervals The aggregates were quartz sand and crushed granite proportioned by weight for a mix of approximately 1 2 . 3½ (1 45 bbls cement per cu yd of concrete) Curing on all of the project except the test sections was done by covering the concrete just after finishing with wet burlap which stayed in place about 24 hours and as soon as removed the pavement was covered with a three inch layer of earth and kept wet for ten days

The sections on which the tests were made were all constructed during the first week in June, a very hot dry week And on Monday, Wednesday and Friday the pavement laid was cured by cement spray while on Tuesday and Thursday the pavement was cured by earth and water in the usual way At the beginning of each day's run during this week a section 100 feet long was cured by covering with wet burlap for 24 hours with no further curing

Method of Testing

Four cores six inches in diameter were drilled from each long section and two cores were drilled from the 100 foot sections All cores were taken when the concrete was 28 days old and were tested the same day. The averages of the results of the compression tests on these cores are as follows

Cured by earth and water	3388 lbs per square inch
Cured by cement spray	2981 lbs per square inch
Cured by wet burlap 24 hours	2716 lbs per square inch

The strength of the cores from sections cured with earth and water and wet burlap for 24 hours was very consistent The cores from the cement spray sections poured on Monday and Wednesday were somewhat stronger than the cores from the section poured on Friday

Another method of comparing results of the different methods of curing was used on this project It is generally assumed that an effective cure holds the moisture in the concrete As the electrical resistance of concrete varies with the amount of moisture in the concrete, the resistance being low for moist concrete and high for dry concrete, measurement of the electrical resistance of the concrete will give some measure of the moisture and hence of the curing

The resistance measurements were made between points three feet from the edge of the pavement and three feet apart Quite a number of points were used in each section so that the average would be fairly representative Two methods of getting contact with the concrete were tried The first by using electrodes made from strips of galvanized iron ½ inch wide and embedded in the concrete two inches This method was not satisfactory as the electrodes were hard to place uniformly and would be kicked loose by persons walking on the concrete The second method of making contact was by two 4 by 4 in wooden blocks one end of which had been covered with sheet copper and the sheet copper covered with 8 layers of cheese cloth The cheese cloth was dipped into a solution of salt water and placed on the surface of the pavement The cheese cloth would take up irregu-

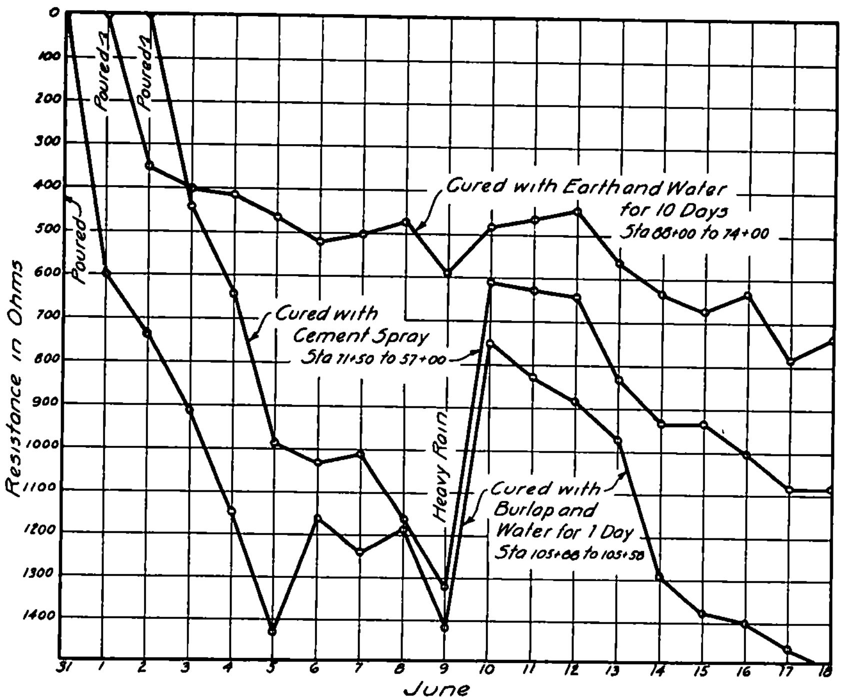

Figure 1. Relation Between Curing of Concrete and Electrical Resistance

larities in the surface and through the salt water give good contact with the copper plate Reasonably uniform results could be secured with contacts made in this way.

In measuring the resistance of the sections being cured with earth and water the pavement was uncovered for some distance on each side of the points between which the measurements were to be made The surface of the concrete was allowed to dry out until no surface moisture showed before the measurements were taken

The results of these resistance measurements on three of the sections cured by different methods are shown in the curves on Figure 1 These curves are typical of the results on other sections

It is interesting to note the effect of the heavy rain which fell during the afternoon and night of June 9th

These results indicate that a resistance method of measuring moisture in concrete or curing has interesting possibilities

Mr A R Evarts. I am curious to know whether the resistance measured by the method described by Mr Slack is surface resistance or whether it goes down through the concrete A check on that would disclose whether the metal reinforcement used made any difference in the resistance in comparison to its distance from the surface

Mr Searcy B Slack The section we tested was plain concrete—no reinforcement—and we started far enough away from the dowel bars and edge reinforcement so that the resistance was not affected Reinforced concrete does have considerably less resistance than plain concrete

CURING CONCRETE PAVEMENTS

A REVIEW

R W Crum,
Director, Highway Research Board

It is generally agreed that after concrete is laid in a road slab there is a critical period, of uncertain length, during which the conditions surrounding the concrete will have a decided influence upon its quality The measures that are taken during this time to protect the concrete against detrimental influences constitute that part of the manufacturing process commonly called "Curing" The primary object of the protection is to assure the presence of an excess of curing moisture and as favorable temperature conditions as practicable This should produce the greatest strength attainable under the prevailing production conditions, and should minimize volume changes in the mass during the critical period

The Committee on "Curing" of the Highway Research Board has accepted the conclusion that the most favorable conditions for curing prevail when the concrete is kept warm and moist (1), (7).[1]

In practice the method that most nearly provides this condition consists in keeping the slab covered with an excess of moisture during the critical period This is accomplished by first covering the concrete before it begins to dry out with a saturated porous fabric such as burlap which is kept soaked as long as it is in place; then, during the day following the placing this fabric is removed and the concrete is covered either with water held in place by dikes or by a layer of earth, sand, sawdust, straw, etc, which is kept thoroughly wet until the end of the curing period There is no general agreement as to how long this period should be This uncertainty is caused by the fact that the hardening of concrete is a slow and gradual process Formerly it was thought that concrete should be kept wet for 28 days, because the most rapid gain in strength usually takes place in that period However, with the attainment of the necessary load bearing strength at much shorter periods that has become possible in recent years, it is now generally thought sufficient to continue wet curing only until the strength is such that the pavement can be opened to use In many cases this is found to be in seven days or less

As the use of concrete pavements became widespread and improvements in construction methods greatly expedited the laying of the concrete, certain difficulties in the use of the conventional curing process began to appear Cover material is sometimes scarce or nonexistent It became more difficult to keep the earth or other covering

[1] Figures in parenthesis refer to list of references at end

wet, as specified Even a period as short as seven days might mean keeping a mile of pavement wet behind the active concreting operation, and often it is difficult or impossible to provide the quantities of water needed Also proper supervision and inspection are costly and may be difficult to secure

As the result of this situation a number of methods have been proposed which do not require any further watering or other attention after application If results as good as those secured by the conventional wet methods can be secured the advantages are obvious

A great amount of research information has been accumulated in many localities respecting the various curing methods Most of the data have been studied and reported upon by the Committee on Curing of Concrete Pavement Slabs of the Highway Research Board (1), (2), (3), (4) Thus far the principal work of the Committee has consisted in comparing the results secured by wet curing with those of the following extensively used methods:

Calcium chloride surface application
Calcium chloride admixture
Sodium silicate surface application
Bituminous material surface application
Waterproof paper covering

Differentiation between the results of different curing methods has been found to be difficult, for during the early life of the concrete the ranges of those properties affected by " Curing " are not large and are often complicated by such uncontrollable variables as weather, water supply, workmanship, etc

The primary purpose of all of the methods mentioned is to maintain a favorable curing condition by the retention of enough of the mixing water to meet the condition that the concrete should be moist during the curing period This has been generally interpreted to require an excess of water over that required for hydration of the cement, but inasmuch as it is not yet known just how much water is needed for this purpose, the significance of tests of the water conserving properties of the various methods is not entirely understood In addition to the water holding properties the principal bases for comparison of curing methods have been the effects upon strength and volume changes that could be traced to the method of curing

The general conclusions of the writer, based on study of the data summarized in the reports of the Highway Research Board Committee—with due regard in individual cases to the peculiar characteristics of the different methods—are that: 1. In reasonably humid regions, including most of the United States, and in seasons when the normal climatic conditions prevail, covering with wet burlap or other porous fabric until the morning of the day after placing followed by any of the treatments previously mentioned should give satisfactory results; 2 Keeping the pavement wet continuously for three or four days will also be satisfactory in these regions except under especially adverse conditions, 3 In arid regions such as parts of the west and southwest, the use of positive seal coats will be necessary if thorough moist curing is not used

These conclusions are partly influenced by the fact that under normal conditions in the humid regions referred to, reliance may be placed upon some replenishment of the water supply by rain during the curing period and upon conservation of moisture due to high relative humidity. The effects of intermittent curing have been investigated by Lang and reported by the Highway Research Board (3), (4).

CHARACTERISTICS OF CURING METHODS (8), (2)

Calcium Chloride Surface Application This method, which usually calls for spreading two pounds of calcium chloride per square yard upon the surface, depends upon the ability of calcium chloride to absorb moisture from the air for its efficacy in curing concrete. If sufficient moisture is present in the air to dissolve the flakes of the salt it will tend to keep the original water in the concrete by forming a surface layer that will resist the evaporation of the interior moisture Under these conditions the strength and volume change characteristics (1), (2) of the concrete have been found to be equivalent to those of wet cured concrete Extensive surveys (2) have not revealed significant damage from surface scaling This method is not suitable for those regions where by reason of comparatively high temperatures and dry air the salt will not readily deliquesce (2)

Calcium Chloride Admixture The presence of this deliquescent salt in solution in the mixture is intended to restrain evaporation of the water and to accelerate the hardening of the concrete Satisfactory strength has been reported for extensive use under suitable conditions (1), (2), (4). The data concerning effects of this salt admixture upon volume changes are contradictory (4) In some cases more frequent shrinkage cracks have appeared to follow the use of this method: In others no such effect has been noticed In Pennsylvania where it has probably been most extensively used, the pavements have been satisfactory in this respect. Extensive studies at the National Bureau of Standards on the reactions of calcium chloride on portland cement have been reported (5) Since the evaporation of mixing water is not entirely prohibited by this method best results cannot be expected in arid regions where moisture replenishment or conservation will not occur

Sodium Silicate This process consists in spraying the surface with a solution of sodium silicate which, upon hardening, forms a film upon the surface and in the surface pores As this film is an evaporation retarding medium rather than a preventive of evaporation (4) some subsequent conditions of high humidity or moisture replenishment by rain are needed for best results Extensive satisfactory use, under suitable conditions, as respect strength and volume change has been reported (1), (2), (4)

Bituminous Coatings Coverings of both emulsions and cut-back products have been found to form seal coats that retain the mixing water and produce concrete of satisfactory strength (1), (2), (4) However, the black color of the surface promotes the absorption of heat during the day and radiation at night thus causing large temperature differentials The corresponding large volume changes (2), (4), usually result in frequent shrinkage cracks When the concrete is laid on a subgrade of very low frictional resistance such as fine sand, the slab can accommodate itself to the expansion and contraction without more than normal cracking On other subgrades the cracking may be obviated by covering the black surface with some light colored material such as whitewash (2), (4) This has the effect of changing the heat absorptive power of the surface so that the excessive volume changes do not occur

Waterproof Paper Blankets of waterproof paper or other material form effective seal coats and produce concrete of satisfactory strength and volume change characteristics (3), (4) This method involves some subsequent labor in removing and reusing the paper and some inspection to see that it is unbroken when used again

Intermittent Curing It has been shown by Lang (3), (4) that continuous wet curing is not necessary but that good results will ensue if the pavement is intermittently wetted at not too long intervals In view of this fact it is expected that if the slab is kept wet for three or four days there will be enough subsequent intermittent wetting under normal climatic condition in the humid areas to provide satisfactory curing At times under adverse local atmospheric conditions it may be advisable to maintain the initial curing period for from 3 to 7 days

Future Research

Effects of Subgrade Thus far the evaluation of curing methods has been principally from the standpoint of conditions affecting the surface, and a narrow interpretation of "Curing" as that part of the manufacturing process immediately following placement would restrict consideration to methods that can be applied to the surface Nevertheless the character of the subgrade may have important effects upon the factors that make for favorable conditions during the curing period Concrete that is laid upon soil capable of extracting moisture from the concrete should probably be protected against that action At least further investigation of the possible extent and results of such action should be made

In the case of a certain highly absorptive soil in Iowa, effective use has been made of a layer of waterproof paper upon the soil for preventing loss of moisture Extensive hair cracking was avoided by this means (6) Waterproof paper is also used upon the subgrade in Kansas and Nebraska

We lack as yet certain knowledge of the relations between subgrade soil characteristics and those factors that provide favorable curing conditions

Methods of Testing Evaluation of curing methods by comparison with other methods is at best somewhat indefinite in results What we need is certain knowledge of the characteristics of concrete that indicate whether or not it has been subjected to favorable conditions during the critical period If these characteristics were definitely known it should be easily possible to devise tests by which the value of a proposed method could be determined For instance, it is generally agreed that the amount of mixing water retained for a given time under the prevailing curing condition is an important indication of the efficacy of the treatment. A standard method of test of this factor is therefore needed

Function of Water in Concrete It is apparent that the primary factor in the curing problem is water But the functions of water in concreting are only imperfectly understood It is probable therefore that not much more progress can be made in studying " Curing " until these functions are revealed by scientific inquiry

REFERENCES

1 Report of Committee on Curing of Concrete Pavement Slabs, *Proceedings, Highway Research Board,* Vol 9, page 369

2 Report of Committee on Curing of Concrete Pavement Slabs, *Proceedings, Highway Research Board,* Vol 10, page 370.

3 Report of Committee on Curing of Concrete Pavement Slabs, *Proceedings, Highway Research Board,* Vol 12, page 331.

4 Report of Committee on Curing of Concrete Pavement Slabs, *Proceedings, Highway Research Board,* Vol 13, Part II (This Volume)

5 " Progress Report on Reaction of Calcium Chloride on Portland Cement," Rapp and Wells, *Proceedings, Highway Research Board,* Vol 13, page 291, final report, *Proceedings, Highway Research Board,* Vol. 14

6 " Tar Paper on Loess Subgrade Lessens Hair Cracks in Concrete Pavements," *Public Roads,* Vol 6, page 127, August, 1925

7. Report of Sub-Committee on Curing of Concrete, Committee C-9, A S T.M , *Proceedings A S T M ,* Vol 29, Part I, page 303.

8 Report of Sub-Committee on Curing of Concrete, Committee C-9, A S T M , *Proceedings A S T M ,* Vol. 31, Part I, page 331