NEW DEVELOPMENTS IN THE CURING OF CONCRETE PAVEMENTS

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Experience and investigation in the past few years have developed many refinements and improved methods in the construction of concrete pavements. Increased traffic on the highways has demanded that every effort be made to improve conditions affecting the convenience as well as the safety and comfort of the travelling public.

In accordance with this policy attention has been given to such matters of design and construction as that of obtaining smoothness of surface, increasing the radius of curves, widening of curves and the enforcement of regulations with regard to advertising signs on highways, elimination of grade crossings, and extension of vision at railroad crossings and highway intersections.

State Highway Departments, Technical Societies and Engineering Universities have made studies and investigations on problems affecting the quality of pavements such as design of mix, rules of proportioning, suitability of various types of sands, stone, and cement, durability of concrete, stress phenomena, admixtures, accelerators, and methods of curing.

Possibly one of the most interesting problems at the present time is the development of new processes in curing concrete pavements. Old blanket methods of curing by dirt, water and straw are reliable if properly carried out. However, an increasingly important factor in daily business and personal conduct is that of time, and as a result it has been asked, "Can we speed up construction" and "Can we cut down the curing period on concrete pavement?"

Early in the history of Portland cement it was known that certain chemicals accelerated the set of cement. Calcium chloride and allied compounds were found to be the best for this purpose. Reliable tests have been made which indicate that the time required for proper curing may be reduced 25 to 50 per cent, representing to the public an enormous saving in travel cost as well as convenience. As given in a table compiled recently by Prof. T. R. Agg, of Iowa State College, the cost of operating a passenger automobile over ordinary earth roads is 12.6 cents per ton-mile as compared with a cost of 9.3 cents over a good concrete pavement, making the difference in cost of operation 3.3

cents per ton-mile, or an average of 4.1 cents per care-mile considering the average weight per car to be 2,500 pounds. In the construction of 1,000 miles of pavement in one year necessitating 1,500 miles of detour with the average daily traffic of 500 cars, there is a saving of $900,000 to the motorists, if the construction period is cut down 15 days. This astounding sum, as well as many of the worries incident to detouring, is saved to the motorist and the cost of detour maintenance is saved to the State, if the time required for the proper curing of concrete can be reduced from 30 to 15 days. A further advantage in this method of curing is realized in cases where water for curing is not readily available and, therefore, must be piped or hauled at great cost, where dirt in sufficient quantities is likewise costly.

The surface application of calcium chloride may be properly called a recent development in curing of concrete pavements. Its importance is reflected in the fact that several state highway departments have, during the past two years, adopted as alternative the curing of pavements by calcium chloride and others are investigating and considering the method. Nearly three years ago as a result of tests made up to that date instructions were issued to engineers of the Illinois Division of Highways covering the use of calcium chloride as a curing agent applied dry to the surface of the concrete and used in solution as an admixture. The instructions issued were as follows:

"**Use on the Surface of Pavements for Curing.**—Calcium chloride may be used in connection with curing of pavements, taking the place of the usual curing with earth and water, or the curing with water by what is known as the 'pounding method.' Two and one-half (2½) pounds of the flaked or granular material (the flaked is preferred as it is more easily distributed and less easily removed by wind or rain) shall be applied to each square yard of pavement and it shall be distributed uniformly over the surface of the finished pavement by means of a mechanical drilling device or by the use of shovels and long handled brooms. The material shall not be spread upon the pavement until the latter has thoroughly set, ordinarily from six to eight hours after laying the pavement. Care shall be taken that the material is uniformly spread and if, in the opinion of the engineer, a uniform distribution is not obtained from the shovels, a thorough brooming shall be required. All lumps shall be broken up and uniformly distributed over the surface.

Calcium chloride shall not be applied during rains and experiments have definitely determined that, if a rain follows the placing of the calcium chloride after a period of two or three hours there will have been enough absorption of the calcium chloride by the new pavement preceding the rain that there will not be required additional applications of the material.

Incorporating in the Mix to Hasten the Set.—The Department will permit the use of calcium chloride in the concrete mix for pavement construction during cold weather. When used, the solid, granulated, flaked or powdered materials shall be thoroughly dissolved in water. It is recommended that the proper amount of calcium chloride solution should enter the mixer drum just before the water is added to mix the aggregates, or the solution may be added direct to the stone or sand when in the skip, but in either case the method of handling this solution shall be approved by the engineer.

When used in the pavement work, not more than **two per cent (2%) by weight of the cement shall be used.**

Calcium chloride should not be used in a pavement that crosses an electric railroad but its use should be discontinued approximately one-quarter of a mile from the electric railroad crossing. There is no objection to using the material when the highway parallels an electric line.

It is not definitely known at what temperature concrete will freeze when the two per cent of calcium chloride is mixed with the concrete and it will, therefore, be necessary to arrange to cover the pavement with loose straw or earth as soon as it has taken sufficient set to prevent marring of the surface. In other words, calcium chloride hastens the setting of the concrete, but is in no sense a protective. It makes possible an earlier application of a straw or earth covering.

Due to its action on reinforcing steel, calcium chloride shall not be used in bridge or culvert construction; therefore, the usual precautions should be taken when placing concrete in culverts and bridges during temperatures around the freezing point."

The above instructions cover in general those issued by highway departments of the various other state and municipalities permitting the use of calcium chloride.

The investigations that have determined the action and suitability of various materials as curing agents have been conducted by several laboratories, including the U. S. Bureau of Public Roads, the Structural Materials Laboratory of the Lewis Institute, and the Illinois Highway Laboratory. The results of these experiments are available in publications and although a detailed discussion would be somewhat cumbersome pertinent conclusions may be quoted.

1. "In the use of calcium chloride no advantage was gained for percentage of the commercial product greater than 2 or 3 per cent of the weight of cement (Chlorine content 1

to 1½ per cent). This amount when used in mixes of about 1:5 and in consistencies suitable for building construction, showed an increase in compressive strength of from 100 to 200 pounds per square inch, which increase was practically constant at ages of 2 days to 3 years. For richer mixes and drier consistencies the strength increase was greater and for leaner mixes and wetter concretes it was less." (Bulletin 13, by Duff A. Abrams, Structural Materials Research Laboratory, Lewis Institute.)

2. "Concrete cured with a surface application of calcium chloride of suitable intensity will attain approximately the same strength in 14 days as concrete cured by wet dirt or other similar methods in 28 days." (Can We Cut Down the Curing Period for Concrete Roads? by H. F. Clemmer, A. R. B. A. Convention, 1924.)

Investigations in curing of concrete were begun by the Illinois Highway Laboratory about three years ago, shortly after construction of the Bates Experimental Road. Tests were made to determine the effects of its use, in the dry form, as a surface curing agent, and in solution as an admixture. A review of the results is included in the Proceedings of the American Society for Testing Materials (1923) under the title, "An Investigation in the Use of Calcium Chloride as a Curing Agent for Concrete," and a later paper entitled, "Can We Cut Down the Curing Period for Concrete Roads," presented at the 1924 convention of the American Road Builders' Association at Chicago.

The investigations were conducted in several series, a general review of which follows:

Over 2,000 specimens were used, including 500 beams 8″x 12″x30″, 100 cylinders made to serve as a check on quality of the concrete, 1,000 cylinders and tensile briquettes of 1:3 mortar and neat mixtures, and in addition slabs of various sizes for determination of wear and other surface phenomena. A volumetric mix of 1:2:3½ standard in Illinois for highway work, was used and all stone, sand and cement were tested in accordance with state specifications.

External Treatment

Since the primary interest was in strengths obtained at 14 and 28 days the greater number of specimens were tested at these ages. Tests were also made at 60-day, 90-day, 6 month, 1 year and 2 year periods.

Series 1.—Series 1 included 260 specimens, 100 poured in forms made by excavating to the desired depth in the ground and placing wooden sides, 60 poured in oiled wood forms and 100 poured in concrete forms. Canvas protection against weather conditions was provided. The purpose of using the concrete forms as shown was to duplicate as nearly as possible pavement conditions. Specimens in this series were given the following treatments: 2 inch dirt wet, 3 days; 2 inch dirt wet, 7 days; 2 inch dirt wet, 14 days; 1 pound per square yard calcium chloride, 1 pound per square yard calcium chloride with 1 inch dirt, 3 pounds per square yard calcium chloride, 3 pounds per square yard calcium chloride with 1 inch dirt, ½ to 2/3 gallon per square yard asphalt.

Series 2.—The specimens in this series were poured both in oiled wood forms and in concrete forms. The effect of an oiled sub-grade, as well as the use of magnesium calcium chloride and sodium silicate as curing agents was investigated in this series.

The specimens in this series were given the following treatments: 3 pounds per square yard calcium chloride after 10 hours, 3 pounds per square yard calcium chloride after 24 hours, 3 pounds per square yard calcium chloride after 10 hours washed off 12 hours later, 3 pounds per square yard magnesium calcium chloride after 10 hours, 3 pounds per square yard magnesium calcium chloride after 24 hours, 1/5 normal solution of sodium silicate after 10 hours, 1/5 normal solution of sodium silicate after 24 hours, 2 inch dirt wet, 7 days; 2 inch dirt wet, 14 days; 2 inch dirt wet 7 days (Sub-grade oiled). These specimens were tested at the ages of 14 and 28 days.

Series 3.—In this series specimens were cured with surface treatments of various forms of calcium chloride in order to compare the effect of using dry calcium chloride with that of using solutions of the chemical.

Results

These results may be interpreted from several angles but considering the subject of this paper, the most valuable and significant comparisons to be drawn are those that demonstrate the ability of calcium chloride curing to secure as great a strength in 14 days as is obtained by the use of wet earth in 28 days.

For the purpose of a practical interpretation of the results of Series 1, Fig. 1 has been included, showing the 28-day transverse strength of the specimens in per cent, using as 100 per cent, the transverse strength obtained from the specimens cured with earth wet 14 days. This comparison is especially significant since wetted earth curing is universally considered as satisfactory.

As a second interpretation of the Series 1 tests, Fig. 2 shows a chart illustrating the fact that greater transverse strength is obtained by the use of calcium chloride in 14 days than by the other methods in 28 days.

Results of experiments confined to the comparison of the effects of surface application of dry calcium chloride as compared with the external use of solutions of the chemical show the dry chemical to be far superior. Specimens cured with dry chemical applied externally had moduli of rupture averaging approximately 760 while those treated externally with 60 per cent solutions averaged approximately 590, and 30 per cent solutions

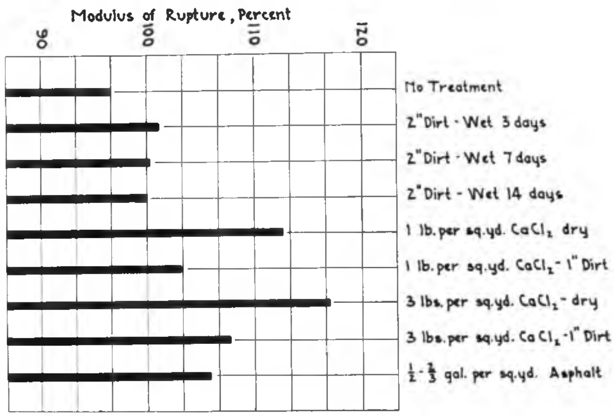

Fig. 1. Transverse strength of specimens at 28 days.

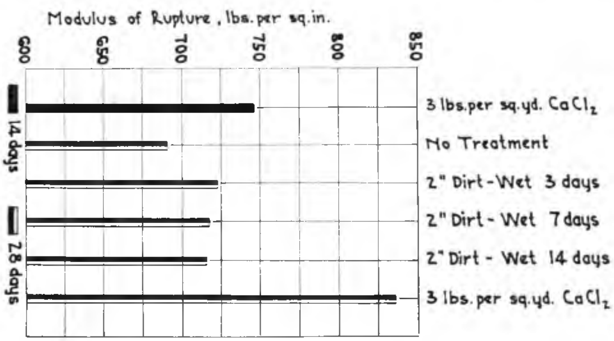

Fig. 2. Transverse strength at 14 and 28 days.

averaged approximately 545. It was thought at the time that if the method was found satisfactory the application of a concentrated solution of calcium chloride would be somewhat more convenient and uniform than treatment with the dry material.

Properties of Calcium Chloride Applied Externally:

In order to study the hygroscopic properties of calcium chloride and the extent of moisture attraction, mortar specimens of uniform weight were made and treated with varying quantities of calcium chloride, including a series of specimens having no treatment. After being treated, these samples were weighed at intervals of one hour and the loss or gain in weight calculated.

A weight greater than the original was observed on all treated specimens for a period of as high as 45 hours, the untreated specimens, however, exhibiting an immediate loss. The fact that this action is proportional to the strength of the treatment is also apparent and leads to the theory that the hygroscopic chemical freshly applied attracts moisture from the air in proportion to the amount used until the absorbed moisture is in equilibrium with that of the air, after which by absorption into the concrete and loss by mechanical means, the amount of chemical, and necessarily water, gradually decrease. The property of calcium chloride of maintaining the moisture content of the concrete at a higher percentage during the first 48 hours, leads to the belief that the chemical serves to prevent the formation of transverse cracks caused by shrinkage. General observation indicates that fewer transverse cracks occur in concrete pavements cured with calcium chloride than in those cured by ponding or wetted earth. This is being definitely investigated in Illinois at the present time.

Calcium Chloride on Concrete Surfaces:

Laboratory investigation was made to determine the effect of excessive amounts of calcium chloride on concrete surfaces. To illustrate the various effects, tensile briquettes of 1:3 mortar were made and treated. Specimens treated with a surface application of dry calcium chloride such as would be equivalent to 10 pounds per square yard of surface indicated slight puffing due to this excessive use of the chemical. It was noted that the tensile strength of these briquettes at the age of 28 days was not affected by the excessive amount of calcium chloride. In practice, however, contractors are cautioned against the use of excessive quantities and are instructed to break all lumps and spread the material evenly on the surface.

Wear of Surface:

To gain an insight into the wearing value of the treated surface of concrete pavements, several slabs have been cast and tested at various ages in a machine designed especially to approximate the wear of a concrete pavement. A wear machine is used in which the specimen is clamped horizontally to the frame of the apparatus and wear effected by the abrasion of two metal weights with the aid of a constant flow of standard abrasive material. The depth of wear is determined by Ames dials, using reference points on the specimen.

The treated surface using 2½ pounds per square yard of calcium chloride, shows an almost imperceptible wear of 0.024

inch, while the untreated surface shows a distinct depth of abrasion of 0.20 inch under the same number of revolutions of the apparatus.

The ease with which calcium chloride in proper condition may be spread is apparent, very little labor being required for the operation. The method of application has been left to the contractor or resident engineer and there have been developed as a result several implements and methods by which the material may be applied. One requirement of the department, however, is that a uniform application be made.

The results obtained so far by no means limit the extent to which further investigation may be continued or the problems to which chemical curing may be applied. Several laboratories, as well as the Illinois Highway Laboratory, are conducting work on the curing of concrete which will no doubt prove of great value in the future. Experiments have progressed to a point, however, where the question of cutting down the curing period for concrete pavement can be definitely answered.