DEVELOPMENT OF CONCRETE CURING PRODUCTS AND PRACTICES

Don L. Spellman and R. W. Ford, Transportation Laboratory,
California Department of Transportation

The historical development of curing materials and practices in the California Division of Highways since 1967 is discussed. Greater demand on the performance of pavement texture because of earlier use, greater volumes of high-speed traffic, and increased emphasis on skid resistance created a need for better quality curing. The cost and effectiveness of compounds formulated play the major role in their adoption. Chlorinated rubber compounds, while more expensive than other types investigated, had some superior properties that justify their use on structures. Availability of raw materials and air pollution laws have required some adjustments. Laboratory tests used to compare performance are not very satisfactory. Alternatives to the standard mortar pan test method were explored, and a field test to measure spread rate was developed.

•THE beneficial effects of good curing are well known (1-6, 8, 9). Although compressive strength has often been a criterion for comparing curing methods, other important factors are involved. For example, craze cracking, plastic shrinkage, and full-depth transverse or map cracking are undesirable. These conditions may result from delays in application of curing procedures but do not necessarily reduce compressive strength to any significant degree. Some types of cure provide temperature control (sometimes by cooling and sometimes by heating) to minimize adverse effects. Surface abrasion resistance is a particularly important factor for floors and pavements, yet compressive strength tests of cores will not usually reflect surface conditions.

As the need for better surface textures increased, the whole operation of curing and texturing was critically examined to determine areas of possible improvement. Factors such as increased traffic, higher speeds (resulting in the need for greater initial and longer lasting skid resistance), earlier use of pavement after construction (and even during construction), and an awareness of lack of texture durability prompted a search for improvements in construction and in materials used to form the texture of the pavement. Upgrading of curing appeared to be a way to help overcome some of the problems caused by loss of surface texture.

Liquid types of curing compounds for concrete pavement have been used for a long time, perhaps born from the desire to get away from the messy, more complicated and expensive "water cure" recognized by early concrete technologists as necessary for best results. While liquid-type curing membranes are not as effective as wet-type curing, they are in many cases adequate, much lower in cost to use, and more convenient. Maintaining wet mats is both messy and inconvenient. Water supplies must be developed and inspection maintained during the whole curing period. Removal and replacement of mats for sawing operations on pavements require a considerable amount of extra labor. One significant plus factor, however, is the cooling effect of a wet cure, which is important on bridge decks. A small outdoor "laboratory-type" test program confirmed the relative effectiveness of the more common types of curing

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used. Curing temperatures and compressive strengths were compared for concrete cured with a liquid compound, a reinforced plastic sheet, and wet mats; the results are given in Table 1.

Curing studies have been numerous and it is difficult to say when the idea of a liquid seal first came about. In the late 1950s asphaltic emulsions were in common use, and the ASTM committee concerned was busy developing a performance specification for "nonbituminous liquid compounds for curing concrete" (2). The 1944 specification for liquid materials was developed for bituminous-type products, and other types could not successfully be tested under this specification. In his report to the ASTM committee, Proudley stated, "The method of test is of special importance and should be simple, so that almost any laboratory can perform it satisfactorily, and comprehensive, so that it will simulate a practical range of field conditions, and finally, the test should be reproducible so that a well-equipped laboratory with reasonable care can agree with the findings of other acceptable laboratories and can repeat the tests on the same material ... with only a minor tolerance for test errors."

Although some of these goals have been partially achieved after more than 20 years of effort, it seems fair to conclude, based on recent correspondence of the present ASTM subcommittee, that there is yet a lot to do. Development of a generally acceptable test has been painfully slow.

Until about 1968, the so-called wax or wax/resin type of curing compound, pigmented to give it ability to reflect heat and thereby lower concrete curing temperature, was most often used for curing pavements. Considering its cost and effectiveness, it was regarded as adequate. As the demand for deeper and more durable texture increased, it became evident that some upgrading of the product would be desirable. Typical properties that were considered deficiencies were the tendency of the wax to crystallize during temperature changes, high pigment settling rates, the fact that the cured "film" did not impart any strength or toughness to the surface at early ages (tracked), and viscosity characteristics that allowed it to sag or run off the peaks of the deeper textures that resulted from switching from burlap drags to brooming.

An early concern developed about use of new and different curing compounds and increased rates of application. The increased application rate and tougher films suggested a reduction in early skid resistance that could create a slick pavement. In one case, the pavement, after receiving an application of a new chlorinated rubber product, appeared to be slick because of its sheen and light reflectance. Skid tests made on one project approximately 2 weeks after application showed that initial skid resistance was indeed reduced but, because a heavier, deeper texture (brooming) had been used, the initial values did not create any skid hazard. If a heavy application of the new material were made to a pavement having initially a borderline skid resistance, it could conceivably cause a skid hazard. The newer materials have now been in use for several years, with no problem with skid resistance reported. The new curing compounds may be expected to prolong better skid resistance because of the toughness of the compounds and better cures. Laboratory abrasion testing indicated that the new materials could

Table 1. Comparison of curing methods, temperatures, and strength.

Type of Cure	14-Day, Percent Relative Core Strength	Maximum Temperature[a] During First 24 Hours (deg F)
Wet mats (7 days, then air-cured)	100	103
No cure (allowed to air-dry)	56	98
Chlorinated rubber type of membrane	77	116
Reinforced plastic sheet (7 days, then air-cured)	75	110

[a]½ in. below surface; maximum air temperature on first day was 98 F, and ambient temperature during curing period ranged from 58 F to 105 F.

be expected to reduce surface wear. Field testing for skid resistance over a 7-year period, however, showed no significant differences among curing compounds for prolonging the period of good skid resistance.

Basically, curing compounds specified were required to meet the performance specifications defined in AASHTO Specification M-148. A review of tests on samples from jobs showed a large variation in performance. No doubt some of the wide variations were the result of test method deficiencies, inasmuch as a number of highway departments had expressed dissatisfaction with the test. Thus, as part of a broader plan, work was initiated to find ways of improving the test procedure. New approaches were explored and the existing test method was modified in an attempt to improve it also. As testing was moved out to the field, it was found that, even there, problems developed because of inability to measure spread rates accurately. Various procedures were developed in an attempt to improve field measurements.

CURING COMPOUNDS

A search for alternatives to the wax/resin type of compound led to two general types: a resin/varnish type and a chlorinated rubber type. A commercial chlorinated rubber compound was being marketed for curing concrete to improve durability of surface textures, in recognition of a national problem. The commercial product conformed basically to Federal Specification TT-C-00800. Its relatively high cost, however, limited its use to structures where, because of physical conditions, a better grade material could be justified. The chlorinated rubber product had good moisture-retention properties and, equally important to bridge construction, had good drying and scuff-resistance qualities, which made it particularly desirable for deck and box girder construction. Typically there is much construction activity on decks and inside box girders as soon as the concrete is hard enough to walk on without damage.

By specification, damaged sealant must be repaired immediately. The chlorinated rubber type of seal provided a fairly tough membrane that could take a reasonable amount of "traffic" without damage. Another factor that justifies higher curing sealant cost for structures is the fact that almost all of the curing a structure will get during its lifetime is the formal curing it gets the first few days after construction. Because some parts of a bridge are up in the air instead of in contact with the ground, the concrete not only tends to dry out more but also is deprived of some additional moisture that could be supplied at ground levels.

By applying coatings technology acquired through paint formulation activities, modified chlorinated rubber compounds were developed that not only retained the desirable physical properties but also were lower in cost than commercially available products. Even so, the cost of this type of curing compound is still relatively high, and it is not generally used for curing pavements. Various formulations of chlorinated rubber compounds were developed to meet other specific needs. For example, a somewhat thixotropic version was developed for use on median barriers and other vertical surfaces. Both clear and gray formulations were developed for use where a white was not wanted for aesthetic reasons. As air pollution rules came into effect, the solvent systems had to be altered to comply.

The solvency and relative evaporation rates of solvents had to be considered since those properties affect the continuity of film, pigment suspension, and sag and flow characteristics of the curing compounds. Faster evaporating solvents were required for formulations designed for use on vertical surfaces.

Curing compounds with a petroleum hydrocarbon resin base, being lower in cost, were developed for use primarily on pavements. Although they may not have properties equal to the chlorinated rubber compounds, they are adequate for the purpose. Generally speaking, a good curing seal that lasts at least 2 or 3 weeks is probably all that is necessary because pavements, being in contact with the ground and subject to wetting during rainy periods, continue to cure indefinitely.

In addition to being tough enough to resist some tire traffic from joint saws and the profilograph, the compounds had to be able to remain on the ridges left by broom texturing without running down into the low areas.

Several formulations were devised and lab-tested. Alternatives to the resin type were also investigated. For example, a compound using a limed tall oil base was developed that equaled the resin type. Although a specification for this product was used as an alternate to the resin type, it was never made commercially, possibly because of some significant differential in manufacturing cost. An acrylic-base product also was formulated. Literally dozens of formulations were made and tested, with each succeeding one that was adopted having slightly better properties than the former. The number discarded, however, is formidable.

One difficulty in formulating products such as curing compounds, whether supplied by composition or performance specifications, is the changes that can occur in raw materials available. Although earlier resins supplied were fairly color-stable, later supplies turned quite yellow after a few days of exposure to the sun. Of course, the specifications can include restrictions on yellowing, but a few "colored" pavements resulted in some adverse comments before being corrected.

Later, materials shortages required many other changes in composition. Formulations involving solvent substitutions required extensive testing because solvent release is a major factor in the formation of impermeable films.

Many combinations of titanium dioxide with various extender pigments and antisettling agents have been tested in an effort to conserve limited supplies of TiO_2 while retaining good reflectance and pigment suspension.

Choice of additives is not indicated in our specifications because the selection is dependent on process variables such as pigment dispersal equipment, which differs among curing compound manufacturers. This policy has occasionally caused problems. As an example, after a new specification was issued, a factory sample from one of our curing compound suppliers failed to meet requirements for water retention. The sample complied with all other chemical and physical requirements. Upon investigation, we learned that bentone had been used as an antisettling agent. That addition produced a porous film through which an excessive amount of water vapor was transmitted.

Table 2 gives the curing compound formulations developed at the Transportation Laboratory that are included in the 1975 California Standard Specifications.

Lab Testing and Evaluation

Dissatisfaction with the ASTM and AASHTO test methods for measuring moisture loss has been voiced by nearly everyone having to rely on them for product control. Despite the many refinements made over the years, reproducibility is poor and comparison of results between laboratories is most difficult. Particularly troublesome has been the effect of time of application of the compound to the portland cement mortar, the effect of surface texture, and the difficulty in securing a seal between the mortar and the pan forms. All this could be avoided, however, if the general principle of the test were changed; i.e., the compounds should be tested on mortar that is representative of conditions existing in actual use. This argument, of course, has great merit. It would, for example, show up products that might react adversely with the highly alkaline mortar. It would also, if texturing is properly carried out, measure the ability of the compound to remain and protect the higher points and not run down into the valleys.

One test condition related to equipment requirements is the 32 ± 2 percent relative humidity (at 100 ± 2 F) specified in AASHTO T-155. Temperature can be readily controlled, but relative humidity is another matter and, to our knowledge, no equipment is commercially available at reasonable cost that can consistently comply with these requirements. Various studies have been made to isolate the relative effects of test variables, and about the only conclusion that can be made is that there are a lot of them. However, as with some other tests, a specific operator can get a "feel" for the test and, by careful control, use it successfully. By replicate testing and experience, for example, a defect such as failure of the seal between the mortar and the pan will be easily recognized. Operator skill in applying the membrane must be at a high level because the amount of sealant sprayed and the method of spraying some materials are critical.

To overcome some of the difficulties and cost of conventional AASHTO testing, other means of evaluation were explored. For example, liquid membranes were applied to filter paper, which in turn was used to cap a jar containing water. The loss of water through the coated paper was determined by weighing the jars, which were stored in an oven at 137 F. Unfortunately, the test results did not always correlate with moisture losses determined by the AASHTO method. This method, nevertheless, has better repeatability and may be useful in comparing curing products. Some typical test results are given in Table 3.

Other paper or filter-type base materials are still being considered, however, and means of obtaining a uniformly reproducible film are being explored.

Another approach investigated was the drawing down of a film of predetermined thickness on a transparent base. After drying, the films were examined with a microscope. Although the method was not considered suitable for a control test, we did find that wax-base or wax/resin material usually failed the moisture retention test if the dried film appeared sandy or gritty.

Other measures of compound efficiency explored were flexural strength of coated concrete specimens and abrasion resistance. These tests, while a measure of what the curing compound does, are difficult and time-consuming to perform and are, therefore, considered unsuitable for routine acceptance testing.

Field Testing

Field testing is generally limited to sampling and determining rate of application. Usually the application rate was checked by counting the number of barrels of compound used over some measured distance and calculating the coverage in square feet per gallon (as specified). This procedure, of course, does not tell us anything about uniformity of coverage, nor does it reflect the amount of compound lost in the wind or overspray. Despite the fact that spray rigs are required to have "shields", there are often conditions under which shields are not effective. Some protect the spray only if the wind is from the front or rear. Side winds can carry much of the compound away. To improve the accuracy of measuring, a procedure was developed to measure the compound at different points on the pavement surface. Absorbent pads were made that were preweighed, then placed at various points in front of the spray rig. Immediately after the sprayer passed, the pads were folded (wet sides together) to prevent loss of weight through evaporation, and then reweighed. Knowing the area of the pad and the gain in weight, coverage could be readily calculated. Some typical results are given in Table 4. These data show some rather nonuniform application rates on actual jobs and point up the inadequacy of a specification calling for a single application rate.

Later, the test method (California 535) called for "Pampers" as the absorbing medium. The method required field-weighing of the pads, which were recovered immediately after application of the compound and sealed in small plastic bags.

Although the pad-weighing method was shown to be operational, an even simpler test procedure was desired. The use of a wet film thickness gauge used in paint inspection was developed. For this procedure, wet films are collected on a metal or glass base and a specially made gauge is used to measure the thickness (Figure 1). Rigid paint-can lids were substituted for the thicker metal and glass plates, which eliminated cleaning of plates.

Some measurements on the dried film were also made. Theoretically, if the percentage of solids of the compound is known, the dried film thickness should be directly related to wet film thickness. In the case of one field test, the relationship was not good because the compound was not adequately stirred before use and the actual solids content was low compared to what was specified. Since this was measurable, the test might be used as a gross check on the solvent/solids ratio.

Some skill is required to handle the gauge because slight tipping or failure to hold the base flat to prevent flow will cause erroneous results. A magnet fastened to the

Table 2. California curing compound formulations.

Specification Number	Nature of Compound	Intended Uses
742-80-71	Pigmented petroleum hydrocarbon resin	General use, chiefly pavements
741-80-100	Pigmented chlorinated rubber base	Bridge decks and horizontal surfaces where abrasion resistance during construction is required
741-80-101	White or gray pigmented chlorinated rubber base	Vertical surfaces, median barriers where nonsagging pigmented finish is desired
722-80-102	Clear chlorinated rubber base	Colored concrete, exposed aggregate concrete, or where natural color is to be retained

Table 3. Comparison of test results from mortar and water vapor transmission methods.

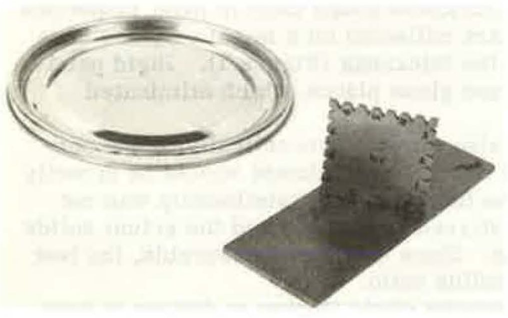
	Water Loss at 24 Hours (grams)	
Sample No.	AASHTO Mortar Method	Water Vapor Transmission Through Filter Paper
TK-26, gray	10	5.2
TK-26-1	6	3.4
70-006	41	15.2
70-007	21	12.2

Table 4. Curing compound spread-rate determination.

	Spread Rate (ft^2/gal)	
Test	Determined by Volume Method	Deposited on Test Pads
Laboratory	132	129
	132	130
	150	145
	150	152
	200	195
	200	220
	100	96
Laboratory, 8 × 18-ft slab	200[a]	160
		200
		185
		195
		210
Field, 24-ft pavement, first day	123[b]	310
		310
		242
		165
		235
		235
		225
Field, 24-ft pavement, second day	128	165
	98	170
	134	195
	120	175
	—	165

[a]Average for whole slab. [b]Average for day's paving.

Figure 1. Equipment used for wet film thickness determination.



end of a pole proved to be a simple yet effective means of collecting the plates when placed more than an arm's length in from the edge of the pavement. Such placement is, of course, necessary to check transverse spread rates.

CONCLUSIONS

1. Curing compounds used to cure pavements and structures have been formulated to have better overall properties (i.e., moisture retention, viscosity, sag, and uniformity) than those available in the past. Chlorinated rubber curing compounds were designed for use on decks and other surfaces where scuff resistance is important and for use on vertical surfaces where sagging is detrimental. Resin-type compounds of lower cost were developed for pavements where long-lasting curing seals are not necessary.

2. A moisture vapor permeability test using filter paper as a substrate could be used in lieu of AASHTO T-155 for comparing water retention characteristics of curing compounds. The AASHTO method should be used as a referee procedure until an acceptance limit can be established for each type of material tested.

3. Field tests for determining spread rates of curing compounds at the time of application have been developed. The use of these spread rate methods is effective in encouraging contractors to apply uniform coatings of adequate thickness.

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