METHODS FOR MEASURING APPLICATION RATE OF LIQUID MEMBRANE-FORMING CURING COMPOUNDS ON CONCRETE PAVEMENTS

Toy S. Poole
U.S. Army Corps of Engineers Research and Development Center,
Vicksburg, MS

ABSTRACT

Several method of measuring application rates of liquid membrane-forming curing compounds were investigated. For non-pigmented compounds, a direct mass determination using sampling coupons appears to be the only plausible method. For white-pigmented compounds, reflectance was found to be a reasonably accurate, field applicable, method. Also, visual estimation of degree of whiteness was given a quantitative basis.

INTRODUCTION

Liquid membrane-forming curing compounds are normally the only practical material that can be used to aid in curing of large placements of portland cement concrete pavements. Various standards direct the amount of application, but there isn't much guidance on methods for verifying the application rate. The purpose of this paper is to review the existing methods and to report on recent work on development of additional methods. This work is part of a research project funded by the Federal Highway Administration (FHWA) on development of guidance on curing portland cement concrete pavements.

EXISTING METHODS

An information search revealed three methods that address the problem of assuring curing compound application. One of these is a visual method for white-pigmented curing compounds, and the other two rely on calculations based on measures of curing compound used.

The visual method often cited in guidance for assuring application of white-pigmented curing compound is to apply the compound until the treated surface appears uniformly white. It is apparently assumed that a visual perception of less whiteness is then indicative of an area of under application. However, it is possible that areas of maximum whiteness represent over application and the less white areas represent the specified application. Without some quantitative estimation of the curing compound application, this method cannot be used to verify any quantitative specification requirements.

The Corps of Engineers quality assurance guidance on curing compound application (CWGS 03300, section 3.17.9) directs that applications be verified by measuring the amount of curing compound used in a particular operation and then calculating coverage from the surface area to which it was applied. This method is plausible, but leaves considerable room for variation in the details, such as effects of blowing wind and non-uniform distribution.

The Minnesota DOT has published a method (Vandenbossche, 1999) in which the output rate of curing compound application nozzles is measured, then the rate of movement of the curing train is adjusted to give a prescribed application rate. The quality control activity would then presumably be to check on the rate of movement of the application equipment. This appears to be a useful way to engineer curing compound application, but it doesn't actually verify that the compound is actually applied at the prescribed rate.

NEW METHODS INVESTIGATED

In our work for the FHWA, several methods have been investigated for estimating in-place curing compound application, as described below.

Scratch Test

An instrument called a Tooke Paint Inspection Gage is used in the paint industry to measure the thickness of paint on surfaces (ASTM D 4138). This instrument has a scoring blade that scratches groove in the coating, such that the cross section of the scratch is a "V" shape. The groove must pass completely through the paint and at least slightly into the substrate. The instrument contains a magnifying lens with a built in measuring scale. The width of the wall of the groove, as measured from directly overhead, is then measured using the scale on the lens, and the thickness of the coating calculated from a simple trigonometric relationship. The instrument is sensitive to coating thicknesses ranging up to about 1 mm in thickness. Curing compound thickness varies from about 25 to 80 micrometres, depending on application rate (Dhir, Levitt, and Wang, 1989).

Attempts to use this instrument to measure the thickness of a curing compound membrane were unsuccessful because of the relatively soft and granular nature of the substrate (concrete), the soft nature of the curing compound, and perhaps also due to the relatively poor bond between the curing compound and the concrete. As a result, the groove was not smoothly made, so that the cross section of the coating could not be clearly visualized through the viewing lens.

Direct Measurement of Mass

Direct measurement of curing compound application by weighing sampling devices placed in the path of the curing compound application equipment is plausible. A typical application rate for curing compounds is 5 m^2/L. At this rate, a 10 x 10 cm coupon would then receive 2.0 grams of curing compound. To verify curing compound application to within 10% accuracy, one would need to measure the mass of application to within 0.2 g of wet curing compound. These limits are reasonably attainable, even with field usable balances. However, a significant source of error is in the loss of solvent due to evaporation between the time when the curing compound is applied and the sampling coupon retrieved for weighing. Under relatively severe drying conditions (e.g. 1 kg/m^2/hr) 0.8 g would evaporate in 5 minutes, assuming the evaporation rate follows Menzel's formula for evaporation of water from a free-water surface. Even under less intense evaporation rates, sizable measurement error could occur unless

considerable attention is paid to collecting the sample and protecting it from evaporation relatively quickly.

One solution to the evaporation problem is to measure dry mass. However, since curing compound contains 70 to 85% solvent, a somewhat larger sample would be required to collect enough material to give a precise measurement on the dried material. A 10 x 10 cm sampling device would contain from 0.3 to 0.6 g of dry material at the above described application rate and solvent content. This procedure would be easily done in a laboratory setting, but probably would be awkward in a field setting because of the necessity to dry the material to constant weight, need for a constant temperature oven, and the need for a relatively precise balance to weigh the relatively smaller amounts of material.

This is basically a plausible method, but considerable care would be required to eliminate sources of error. It is the only method that would appear to work on non-pigmented curing compounds.

Infrared Thermometer

The concept behind this technique is that concrete that has a poorly formed or thin coat of curing compound will allow more water to evaporate that concrete on which a well formed and adequately thick curing compound has been applied. This difference in evaporation would then result in a surface temperature difference that could be detected by an infrared thermometer or an infrared camera. The plausibility of this approach was examined using laboratory specimens. Three mortar specimens were prepared according the ASTM C 156. No curing compound was applied to one, and curing compound was applied to the other two at a rate of 5 m^2/L at different application times. If useful temperature differences could be demonstrated under these conditions, then the concept could be further investigated for its ability to detect more subtle variations in treatment. The specimens were exposed to C 156 conditions (evaporation rate of 0.6 to 1.1 kg/m^2/hr) and surface temperatures measured with a infrared surface-temperature thermometer. Results are shown in Figure 1.

A measurable temperature difference was observed. The temperature of the coated specimens rose above the temperature of the uncoated specimen almost as soon as the curing compound had dried (about 2 hours after specimen fabrication), reaching a maximum of 4 ^{o}C after 5 hours. However, this temperature difference persisted only for a short while, becoming indistinguishable by about 7 hours.

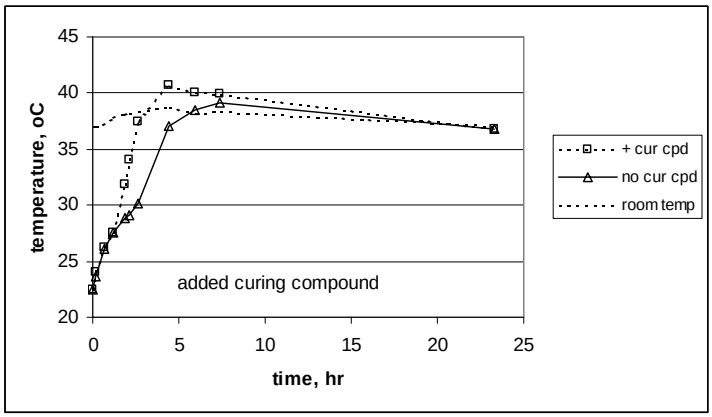

Figure 1. Comparison of surface temperature of mortar with and without curing compound application.

The conditions of this experiment were relatively simple and did not include the effect of sunlight. Incident radiation might tend to obscure the observed temperature effect, particularly with white-pigmented curing compounds. The high level of reflectance of these materials would tend to have the opposite effect on surface temperature relative to the evaporative effects. This same effect would not appear to apply to clear curing compounds.

Given the relatively small temperature and transient difference that was observable under relatively high levels of evaporation, this technique does not appear to have promise for general field use, given the complicating effects of sunlight, and variable evaporation conditions that might exist there.

Visual Estimation

As discussed above, visual examination is a common method for verifying application of white-pigmented curing compound. The purpose of this investigation was to give this practice some quantitative basis. The investigation was conducted on fresh mortar specimens and on black paper specimens coated with different levels of a white-pigmented curing compound (resin based).

The mortar specimens were 10.2-cm diameter and 5-mm thick. The mortar was proportioned as in ASTM C 156. Curing compound was applied using a paint sprayer to four specimens at variable application rates that gave a visual effect varying from relatively grey to relatively white. Actual application rates were then determined by weighing the specimens. Application rates were 3.2, 5.4, 7.9, and 15.2 m^2/L. An application rate of 5 m^2/L is commonly cited by manufacturers as being appropriate. These four specimens were used to develop a visual standard curve. Three more specimens were coated with variable amounts of curing compound and treated as unknowns. An estimate the actual amount of the application was made by visual comparison with the standard curve. The person making the comparison did not know the actual application rate.

Figure 2. shows photographs of the specimens. Table 1 shows the comparison of the actual and estimated application rates. The visual estimation was within about 2 m^2/L of the actual application rate.

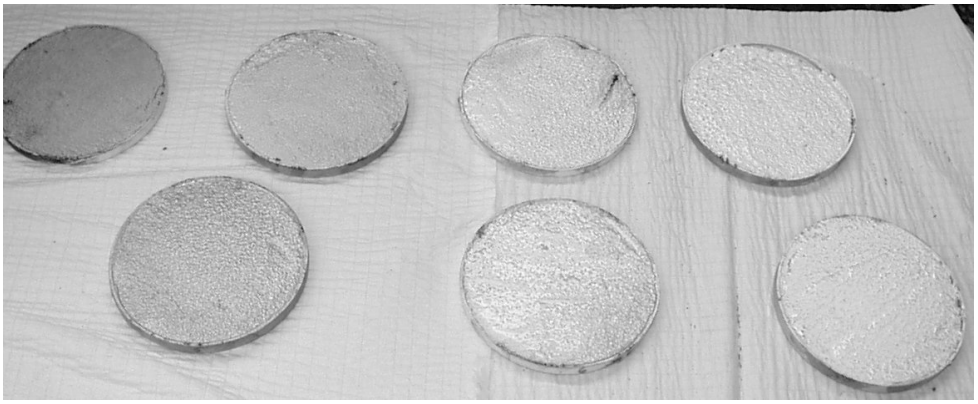

Figure 2. Fresh mortar specimens with variable applications of white-pigmented curing compound. The top four specimens contained 15.2, 7.9, 5.4, 3.2 m^2/L (L to R). The bottom 3 specimens were treated as unknowns (see Table 1).

Table 1. Comparison of actual and visually estimated curing compound application on fresh mortar specimens.

Actual application rate (m^2/L)	Visually estimated (m^2/L)
12.5	9
6.5	5
3.8	3

The experiment was repeated using black construction paper glued to a stiff cardboard as the sampling device. The rationale for this variation was that the black background might provide a better contrast for visual estimation. If this turns out to be true, then a test method based on examination of paper coupons might reasonably be developed involving dispersing the coupons on a concrete surface before application of curing compound, and then collecting them for analysis.

Figure 3 is a photograph of the specimens. Table 2 shows the comparison of the actual and estimated curing compound application.

The enhanced contrast of the black-paper specimens relative to the mortar specimens was not conspicuous when the mortar specimens were fresh, since they were also very dark. However, the mortar specimens containing light applications of curing compound tended to show an increase in whiteness when they had surface dried, which tended to reduce the contrast on these specimens.

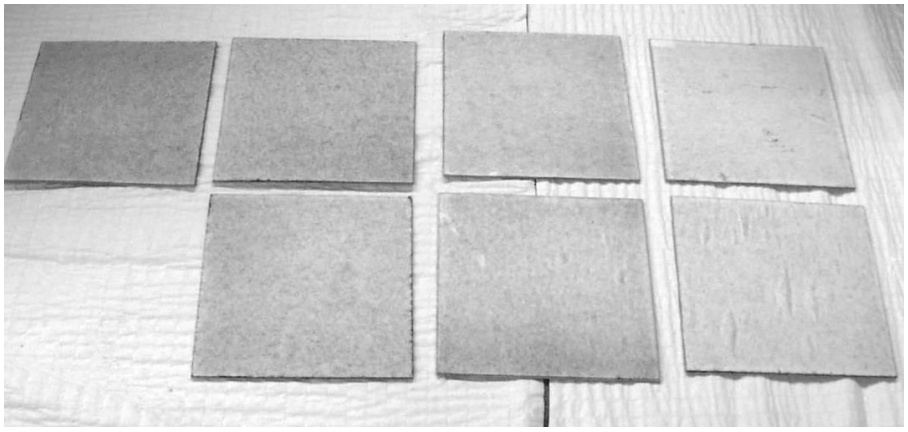

Figure 3. Black construction-paper specimens with variable applications of white-pigmented curing compound. The top four specimens contained 10.1, 7.5, 5.9, 4.5 m^2/L (L to R). The bottom 3 specimens were treated as unknowns (see Table 2).

Table 2. Comparison of actual and visually estimated curing compound application on black construction paper.	
Actual application rate (m^2/L)	Visually estimated (m^2/L)
4.2	4
6.1	7
9.2	6

Reflectance

Reflectance is a measurement commonly used in the paint industry to measure degree of whiteness (ASTM E 1347). It is also a specification-requirement test in ASTM C 309. A portable reflectometer was used to measure the reflectance of the specimens made in the experiment described above. Figure 4 shows the graphical representation of the reflectance vs curing compound application of the "standard" specimens. A non-linear curve was fitted to the data and used to calculate the curing compound application of the unknown specimens. Table 3 shows the results of the comparison. The average accuracy of the three determinations within 15%.

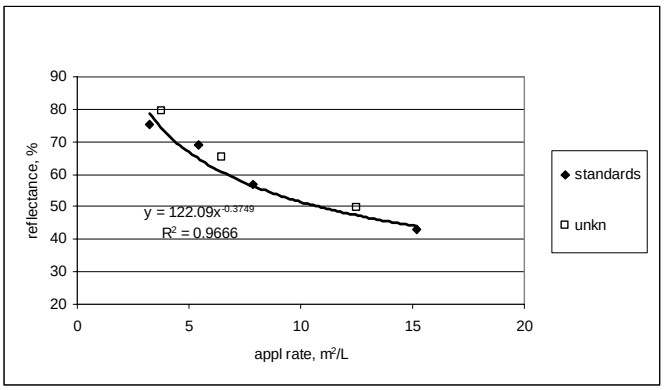

Figure 4. Reflectance vs. application rate for white-pigmented curing compound applied to fresh mortar at different rates. Data points represented by open symbols were treated as unknowns.

Table 3. Comparison of actual and reflectance-estimated curing compound application on fresh mortar, using the power equation in Figure 4.	
Actual application rate (m^2/L)	Estimated from Reflectance (m^2/L)
12.5	11.0
6.5	5.3
3.8	3.2

Figure 5 and Table 4 show results obtained using the black-paper specimens. Two of the three unknown determinations were accurate to better than 10% of the true value. The other was off by 33%. This may be a statistical outlier, but there is insufficient replication to conclude this definitively.

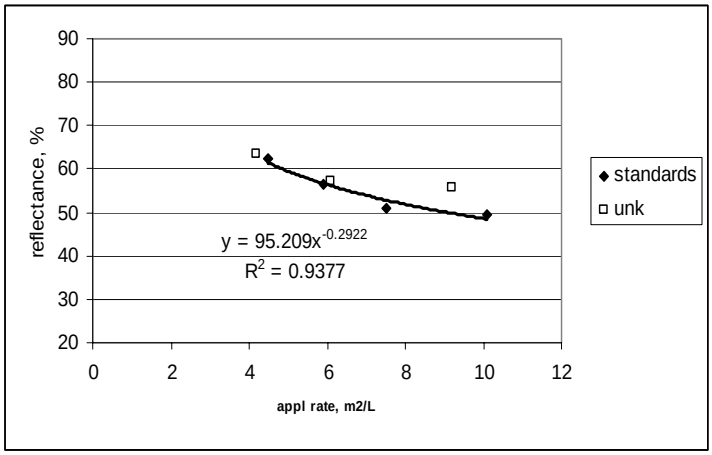

Figure 5. Reflectance vs. application rate for white pigmented curing compound applied to black-paper specimens at different rates. Data points represented by open symbols were treated as unknowns.

Table 4. Comparison of actual and reflectance-estimated curing compound application on black paper, using the power equation in Figure 5.	
Actual application rate (m^2/L)	Estimated from Reflectance (m^2/L)
4.2	4.0
6.1	5.7
9.2	6.2

DISCUSSION AND CONCLUSIONS

Of the methods investigated, only the direct weighing appeared to be reasonably suited for non-pigmented curing compounds.

The visual estimation of white-pigmented curing compound appears to give reasonable results when a standard set of specimens is available for comparison. The visual detection limit (difference detectable in a side-by-side comparison) appears to be about 2 m^2/L. The sensitivity of this estimation would probably be substantially reduced if this frame of reference were not available, particularly if spatial variation in application rate was gradual. However, it is clear from this work that a concrete that is noticeably grey on visual examination is probably substantially under coated, perhaps containing only half of the specified application rate.

The portable reflectometer appears to be a good tool for use in a method for quantitatively measuring curing compound application. The field portability of this instrument allows spot checking with minimal setup requirements. The instrument is battery operated and measures 10x15x5 cm. It measures reflectance on a spot approximately 2 cm in diameter. One approach to field QA would be to develop a standard curve using job materials and then determine a reflectance value that corresponds with the desired application rate. Then that reflectance could be used as a criterion for evaluating the quality of application of curing compound in a field situation.

In conclusion, visual estimation of the application rate of white-pigmented curing compound can be useful where a suitable reference comparison is available. Visual estimation is probably also reliable to detect areas of very low application rate in close proximity to areas of proper application rate. However, visual estimation is not a strong method for detection of low application rates when the under-application is slight or the low-application membrane is uniform. Measuring reflectance with a field reflectometer provides a useful tool for objectively determining subtle variation in application rates.

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