

Cracks in Latex-Modified Concrete Overlays—How They Get There, How Serious They Are, and What To Do About Them

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The cause, effect, and prevention of cracks in latex-modified concrete (LMC) overlays were investigated. The types of cracks that occur in concrete, whether the concrete is LMC or conventional, are divided into two categories: internally caused and externally caused. Internally caused cracks are plastic and shrinkage cracks. As in any quality concrete, LMC is subject to both of these if good construction practices are not followed. In addition, because LMC has a low water content, it has little bleed water available to evaporate and thus should be protected during placement if extreme drying conditions exist. Externally caused cracks include cracks caused by physical tearing, and flexural, reflective, and thermal cracks. All of these processes can be minimized or avoided by following proper construction practices. If cracking occurs in an LMC overlay, it is necessary first to determine the extent of the cracking before deciding on the remedy. Cracks that are shallow, $\frac{1}{8}$ in. deep or less, do not affect the permeability performance of the overlay. Deeper cracks, however, should be sealed. Laboratory studies of crack-sealing techniques indicate that the low-viscosity sealers are capable of filling most cracks and are recommended when full-depth penetration is required.

Because overlays are designed to provide protective concrete layers on bridge and parking garage decks, it is desirable to produce a concrete layer that has integrity and uniformity, and minimize any condition that will cause cracks, thus compromising the barrier properties of the overlay. Latex-modified concrete (LMC), like any other concrete, will crack when the tensile stresses exerted on it exceed the tensile strength of the material itself. Like any other concrete, these tensile stresses can be produced both by external and internal sources. Typical of these internal sources are plastic and drying shrinkage. Examples of external sources are structural movement, reflective cracks from the deck, thermal expansion, and tearing while finishing.

These cracking influences are addressed—how to attempt to avoid them, and what to do about cracks if they occur. An attempt is made to understand how cracks occur and how to try to prevent them. In addition, factors that are blamed for cracks but in fact have nothing to do with them are also discussed.

CRACKS IN LMC OVERLAYS—HOW DO THEY GET THERE?

Internally Caused Cracks

Plastic Shrinkage

Plastic shrinkage in concrete is caused by water evaporating from the exposed surface faster than it can be replaced by bleed water before the concrete has hardened. As drying occurs, moisture leaves the surface of the concrete and shrinkage stresses develop before the concrete gains sufficient strength to resist them. The solution, of course, is to prevent this evaporation until the concrete gains proper strength.

Like most quality concretes, LMC mixes have a low water-cement ratio (typically less than 0.40) and there is little bleed water available to replenish that which is lost to evaporation. This is particularly critical for thin overlays where there is a high surface area per unit volume of concrete. Reduction of this plastic shrinkage can be accomplished in two ways:

1. Place concrete when the evaporation rate is low, i.e., less than $0.15 \text{ (lb/ft}^2\text{)/hr}$. This evaporation rate is a function of concrete and air temperature, wind speed, and relative humidity, and can be determined from the chart, shown in Figure 1, published in The American Concrete Institute's *Recommended Practices for Hot Weather Concreting (1)*.

2. Install the curing cover close behind the finishing operation. The cure cover is typically damp burlap and polyethylene film, and they both should be held down with suitable weights to prevent them from being blown off. (The polyethylene films should be white to minimize solar heat gain and increase in the temperature of the fresh concrete too quickly.)

The effect of bleed water on early plastic shrinkage cracking of these systems was demonstrated on $12 \times 12 \times 1$ -in. samples of latex-modified mortars made with two different water-cement ratios. The samples were exposed to a wind of 9 mph at 81°F and 18 percent relative humidity [at an evaporation rate of $0.22 \text{ (lb/hr)/ft}^2$] for over 2 hr. The sample with a water-cement ratio of 0.26 cracked; the one with a water-cement ratio of 0.45 did not, indicating that the former had insufficient bleed water to resist initial plastic shrinkage (Table

1). These findings do not imply that the evaporation chart is in error, or that increasing the water content is an answer to cracking. These relatively small samples were made from mortar, so the data may not translate directly to large areas of concrete normally associated with overlays. More testing needs to be done on this subject. However, what the data confirm is that concrete is a complex material and that many factors need to be considered when working with it. It will continue to be important to monitor environmental conditions while placing LMC, and to take precautionary measures during hot, dry, and windy conditions.

Drying Shrinkage

Like any other concrete, the drying shrinkage of LMC is affected by the amount of water in the mix. It is the water-cement interaction that influences the drying shrinkage of the concrete, not the latex. Comparative tests (2) have indicated that LMC and conventional concrete with the same water-cement ratio have the same shrinkage characteristics. Whether the concrete is latex-modified or conventional, excess shrinkage will result from excess water in the mix. The key, then, is to make sure that excess water is not added. This precaution is best accomplished by making a trial mix of the proposed

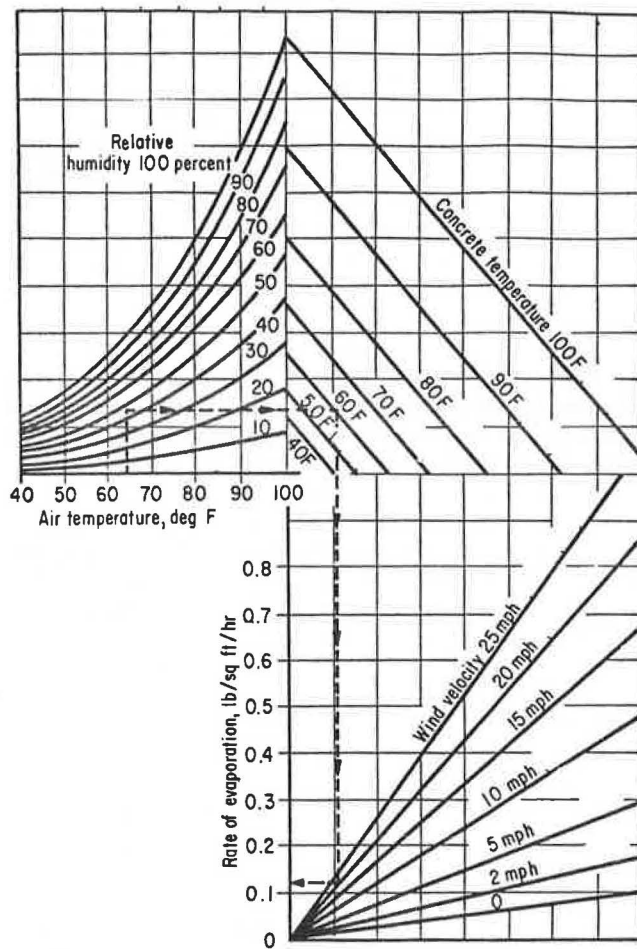


FIGURE 1 Nomograph for determining rate of evaporation (1).

TABLE 1 EFFECT OF WATER-CEMENT RATIO ON CRACKING OF LATEX-MODIFIED MORTAR EXPOSED TO WIND

Water-cement Ratio	Appearance of Cracks?
0.26	yes
0.45	no

NOTE: Wind 10 mph, temperature 72°F, relative humidity 50 percent.

ingredients in a laboratory where all the components can be accurately measured, mixed, and tested. This procedure will relate slump to water-cement ratio, so that in the field, slump measurements will be accurate indications of water content.

By making a trial mix, it is possible to evaluate the various components that are used. Use of the wrong sand, for instance, can result in a concrete mix that requires excess water to achieve a workable slump. In LMC mixes, where the sand content is relatively high, it is particularly important that this component be chosen carefully. Figure 2 (3) shows the surface imperfections that are present on many sand particles. These surface imperfections have a detrimental effect on the mix because the macrosurface voids first have to be filled with paste, i.e., cement, water, air, (and latex if appropriate), before the concrete begins to flow. Thus, a sand with many of these macrosurface voids demands extra water before the concrete has a workable slump, thus producing an overwatered concrete with inferior properties. Obviously, if slump alone is used to monitor water content of a field mix, the concrete can easily have extra water added inadvertently.

This surface phenomenon is confirmed by the data in Table 2 where the surface areas of two different sands are shown to be different by a factor of over 4, even though both met ASTM C 33 for gradation. In laboratory tests, the high surface area of the Maryland sand produced a concrete of much lower slump than the control mix, both at the same water-cement ratio. Or put the other way, to achieve the same slump, more water would be required by the concrete made with the Maryland sand so that if slump were the only test conducted, the mix would easily be overwatered and produce low-quality concrete. Permeability results from laboratory tests of LMC made with the sand confirmed these findings.

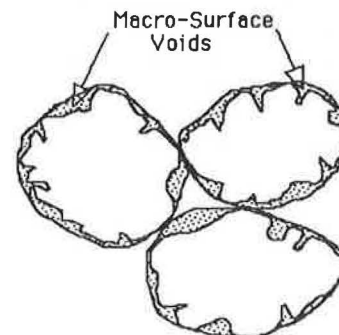


FIGURE 2 Macrosurface voids of sand particles.

TABLE 2 SURFACE AREAS OF TWO DIFFERENT CONCRETE SANDS

Sand Source	Surface Area ^a (m ² /g)
Michigan ^b	0.477
Maryland	2.093

^aBy Nitrogen absorption test.

^bControl.

Externally Caused Cracks

This process is caused by externally applied stresses on the surface of LMC before it has set but after a crust has formed.

Particular care must be exercised when finishing LMC to avoid tearing the surface and causing cracks. LMC is different from conventional concrete in that a crust, i.e., a relatively firm material caused by the drying of the latex, will form on its surface if exposed too long to the air while in the plastic state. When this crust forms, the working life of the LMC has expired, while underneath, the concrete will be quite plastic until the setting time has expired. The difference between these two could be as much as 2 hr, depending on the drying conditions of the air and the temperature of the LMC. This surface crust can be torn and cause surface cracks if the finishing operation continues. On bridge deck overlays, where a rake is commonly used for applying grooves, these tears will appear as short and shallow (typically $\frac{1}{2}$ - \times $\frac{1}{8}$ -in.) cracks oriented 90° to the direction of the grooves. (The effect of this type of crack on the permeability properties of LMC is discussed later.)

Flexural cracks are caused by excessive tensile stress applied to the overlay by flexural movement over negative moment areas. Excess deflection of a bridge deck under traffic can cause cracks to appear in an overlay at the negative moment region. The pattern of such cracks would be transverse, approximately in straight lines, and probably spaced 2 to 4 ft apart. These cracks can occur in any concrete overlay, including LMC. Even though the flexural strength of LMC is greater than conventional concrete, it is not designed to resist these excess tensile stresses.

In new two-course construction, the overlay should be placed after removing the forms from the base concrete, so that stresses caused by the weight of the overlay are borne by the underlying concrete. If placed before the forms are removed, the overlay will have to carry a portion of its own weight and may crack in negative-moment regions.

Reflective cracks are caused by movement of the underlying concrete reflecting through the overlay. Any time there is a crack in a concrete deck that is to be overlaid with a well-bonded, rigid material such as LMC, it is imperative to determine beforehand whether the crack is stable. If the underlying concrete on either side of the crack continues to move after the overlay is applied, whether from load deflection or temperature change, it is certain that the crack will be reflected into and through the overlay. In order to address this problem, a soft joint should be installed in the overlay right over the crack in the deck.

Expansion joints in the deck can cause the same problem. They should not be overlaid at the time of placement of the overlay, with the expectation of cutting them with a saw the following day. Doing so would result in a crack in the overlay

over the joint, and possibly some debonding adjacent to the joint. The proper procedure is to form the overlay joint with an expandable material (i.e., plastic foam) and pour the overlay against it. After cure, the material can be removed and replaced with the final joint material.

Temperature-related cracks are caused by temperature differences between the newly-placed overlay and underlying concrete creating excessive differential expansion. Because many overlays are placed during the summer, there is concern about the proper time of day to place the overlay to avoid differential expansion between the deck and the overlay. Both early morning and late evening placements are commonly used to address this problem (as well as to avoid working during midday, when the temperature and wind can aggravate crusting). There are no definitive studies comparing cracking performance with time of placement, but the argument for early morning is persuasive and is presented here for consideration.

Early in the morning, i.e., just before dawn, the deck is cool. As the overlay is placed and the temperature rises, both the deck and the overlay warm and expand together, minimizing differential movement between the two. The heat received by the overlay in the morning hours accelerates cure, producing additional strength to resist subsequent drying shrinkage. (The procedure of prewetting the deck before overlay placement will also help this situation by cooling the deck even more.) Traffic-related cracks are caused by vibration from traffic in adjacent lanes that loosens the finished but not yet hardened LMC. Where the grade of the deck is severe, i.e., greater than 6 percent, and there is vibration from adjacent traffic, freshly placed LMC may move downhill slightly, creating cracks. This process can happen even hours after placement if the temperature of the LMC is low. The best solution is to reroute or reduce traffic. If this can't be done, reducing the slump of the LMC or utilizing Type III cement to accelerate cure, will help the situation.

Other Possible Causes of Cracks

There have been some instances where transverse cracks have appeared in overlays placed while traffic is on adjacent lanes. Because the cracks have some order, i.e., they are relatively straight and in a specific direction, the question has been raised as to whether the traffic vibration has caused cracking by flexing the bridge. Field data on this issue, however, are inconclusive. In any case, because there is the possibility that maintaining traffic during overlay construction may adversely affect the movement of the deck, consideration should be given to placing the overlay when the traffic count is low or when vehicle speed is restricted.

It has been reported (4) that screeding and finishing operations—particularly, the rate of movement of the screed—can have an effect on cracking of conventional mixes. Roller finishers are typically used to finish LMC overlays; to date, there has been no research to determine if there is a relation between roller speed and cracking. Clearly, this subject needs more study.

HOW SERIOUS ARE CRACKS IN LMC OVERLAYS?

Although having cracks in LMC overlays is not desirable, when they do occur it is important to understand the impact

that a particular type of crack has on performance of the overlay. The overlay should not be assumed to be a total loss needing replacement. Rather, it is important to know what impact the cracks might have on the performance of the overlay. This can only be determined by examining the cracks in detail, preferably by cores taken from the deck, to determine their width and depth. For instance, a shallow crack ($\frac{1}{8}$ in. deep) has little effect on the permeability of the overlay, whereas a deeper one ($\frac{1}{2}$ in.) has a significant effect. Tests conducted on cores taken from an LMC overlay had both of these types of cracks. The shallow cracks had the appearance of tears that are typically caused by late timing, when the crust has begun to form on the surface, whereas the deep crack appeared to be from plastic shrinkage. Using the rapid permeability test (15) (AASHTO T 277-83), chloride permeability was measured on the cores with cracks, and compared to a core without cracks. The results (Table 3) indicate that the core with shallow tears in the surface had the same low permeability (260 coulombs) as the core without cracks, indicating that these shallow tears do not affect the permeability performance of the overlay. The core with the deep crack, however, had a significantly higher permeability (700 coulombs), and thus required sealing. For this particular overlay, the treatment was to seal the deep cracks with a low-viscosity polymer, and treat the shallow tears as cosmetic blemishes by covering them with a latex-cement slurry. These treatments are discussed further later.

WHAT TO DO ABOUT CRACKS

Even with the best of intentions, cracks do occasionally appear in LMC overlays. If the degree of cracking is not severe, where severe refers both to size and frequency, the cracks can be treated so that the overlay is restored to serviceable condition. (The degree of cracking that requires replacement of the overlay rather than crack treatment is not addressed here because it would need to be determined on an individual basis.)

Two studies (5,6) have reported on the effect of sealers on filling cracks in LMC. Both consisted of slabs of LMC that were intentionally cracked by exposure of the fresh concrete to heat and wind to induce plastic shrinkage cracks. In one case, the sample was $3\frac{1}{2}$ in. thick; in the other it was 1 in. thick. In both cases, cracks of various widths and depths were created.

After the LMC cured, the cracks were sealed with a variety of materials, including epoxy and methacrylate (both of low viscosity), sodium silicate, and latex-cement slurry. Samples were then cut from the slabs and the cross sections examined to determine depth of penetration of the various sealant materials. The results are presented in Table 4.

TABLE 3 PERMEABILITY TEST RESULTS OF CORES FROM AN LMC OVERLAY

Core	Type of Crack	Permeability (Coulombs)
Control	None	260
Sample 1	Tears; $\frac{1}{8}$ in. deep	260
Sample 2	Shrinkage; $\frac{1}{2}$ in. deep	700

TABLE 4 EVALUATION OF MATERIALS FOR SEALING CRACKS IN LMC

Sealer	Viscosity	Cracks Penetrated?
Study A—LMC Slab Thickness 1 in. (6)		
Methacrylate	10–20 cps	yes
Epoxy	10–20 cps	yes
Latex-cement-sand slurry ^a	"pancake batter"	no ^b
Study B—LMC Slab Thickness 3.5 in. (7)		
Methacrylate A	60 cps	yes
Epoxy	175 cps	yes
Epoxy	not reported	yes
Sodium-silicate	not reported	no
Latex-cement-slurry ^c	"pourable"	yes ^d

^aCement/sand = 0.33; latex solids/cement = 0.15; water/cement = 0.38.

^bSlurry was well bonded but only covered the surface of the crack.

^cLatex solids/cement = 0.15; water/cement = 0.67.

^dOnly at bottom of wide cracks.

These studies indicate that the methacrylate and epoxy sealers were effective in penetrating and filling cracks and should be used for repairing cracked overlays. Two different latex-cement mixes were studied and neither of them appeared to be particularly suitable for filling cracks. The mix in Study A consisted of sand, cement, latex, and water, whereas the other was just cement, latex, and water. The former had the lower water-cement ratio and thus less flow. The slurry used in Study A did not penetrate but tended to bridge the cracks and bond to the top surface of the overlay. The mix used in Study B was of low enough viscosity to flow into the cracks but it did not fill them significantly. In addition, the high water-cement ratio of this mix would make the long-term performance of such a grout suspect. Use of these slurry mixes should be limited to treatment of the shallow tears and cracks. The sodium silicate product that was tested did not indicate any effect on filling the cracks.

HOW TO PREVENT CRACKS IN LMC OVERLAYS

The obvious first step in addressing a problem is to try and prevent it from occurring in the first place. Preventing cracks in LMC overlays can best be accomplished by following proper construction practices for quality concrete. This means having a specification that is appropriate for the project; using high-quality materials and equipment that is in good operating order; employing people who are experienced, quality conscious, and interested in producing good work; and making decisions on the job that will benefit the long-term performance of that job. In particular, for LMC, it means keeping close control of the water in the mix; avoiding placement of LMC when the evaporation rate is above 0.10 (lb/ft²/hr); and applying the burlap cover appropriately to avoid plastic shrinkage cracking.

Another possible crack prevention measure is related to the curing schedule. Typically LMC is cured for 1 day damp and the remaining days open to air drying. Under normal conditions, this procedure is good but if temperature and wind conditions are not favorable, 1 day of damp curing may not be long enough to prevent shrinkage cracking during drying. Recent research (7) on the effect of curing schedule on shrink-

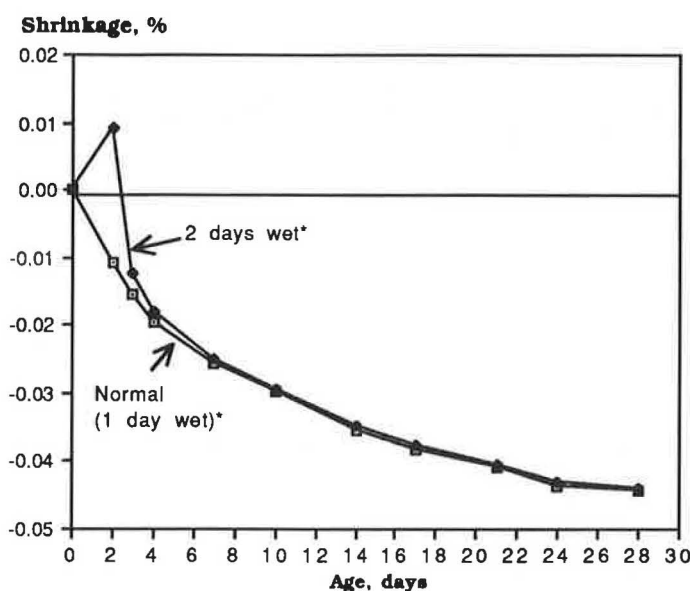


FIGURE 3 Shrinkage of LMC versus initial cure time, lower curve, normal (1 day wet), upper curve, 2 days wet, remaining days at 72°F, 50 percent relative humidity.

age of LMC indicates that during the initial wet-cure period, slight expansion of the concrete occurs, and that by extending the wet cure beyond 1 day there is potential to offset shrinkage stresses that occur during the dry-cure period.

Results of shrinkage studies with 1 day versus 2 days of damp cure are shown in Figure 3. These data indicate that by extending the damp cure time to 2 days, slight expansion of the LMC will occur, thus putting the overlay into compression and reducing the tendency to create shrinkage cracks. The compressive strength properties were essentially unaffected by this extra day of wet cure.

CONCLUSIONS

1. Cracks in LMC are not always detrimental to the long-term performance of the material. Shallow tears from late-finishing operations need not be sealed. Deep cracks should be sealed, using low-viscosity epoxy or methacrylate sealers.

2. Cracking in LMC can be controlled by proper attention to the quality of the materials used in the mix as well as the construction procedures used to place it.

RECOMMENDATIONS

- Placement of LMC overlays should be limited to conditions for which the evaporation rate is less than 0.10 (lb/ft²)/hr.

- Two days of wet cure should be considered as a standard curing procedure for LMC.

- Care should be exercised during placement of overlays where the grade exceeds 6 percent and traffic is maintained

on adjacent lanes. Traffic should be rerouted or slowed, or Type III cement should be incorporated in the mix design.

- Research should be conducted on the roller finisher to determine if there is a relationship between speed of the roller and cracking.

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