Diagnosing slab delaminations

Is improper finishing the only cause?

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The experienced contractor saw no signs of trouble when his crews started placing 8,000 square feet of 10-inch-thick floor slab directly on compacted soil. The 5- to 6-inch-slump concrete contained a Type A water-reducing admixture and an air-entraining agent. Air temperature was in the mid-thirties the night before the pour but rose to the mid-fifties during the day. Finishers used double-rider trowels equipped first with pan floats then with steel trowel blades to achieve the required hard-troweled finish.

Within a day after slab placement, large patches of the surface, ¼ to ⅜ inch deep, started to come off. Sounding with chain drags indicated that most of the surface had delaminated. To determine the cause of this large-scale delamination, the owner sent cores to a petrographer, who concluded that premature steel troweling had densified the concrete surface while air bubbles and some mix water were still moving upward in the slab. He also reported that the total measured air content of the concrete approached 8%.

Because premature steel troweling was identified as the major delamination cause, the contractor had to pay about $90,000 to repair the slab.

Variations on this story are being played out across the country, with delaminations being noticed immediately after finishing or soon after a floor is placed in service. When petrographers' reports list premature finishing as the primary cause, the petrographers imply that finishers should be able to manipulate their tools, equipment, procedures or timing to prevent such problems. This focus on finishers ignores other critical factors that affect the finishers' ability to prevent delaminations. Unfortunately, when one or more of these factors are present, the deck is stacked against the finisher. But responsibility for delaminations isn't that clear cut.

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When delaminations form in floors, thin layers of the surface break away from the base concrete. Several factors contribute to the problem.

In this article, the first in a series on delamination of troweled concrete surfaces, we'll discuss how bleeding, surface setting and delamination are interrelated. Future articles will examine the specific effects variations in bleeding and setting have on delamination.

Delamination mechanisms

Delaminations are separations in a slab, parallel to and generally near

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Figure 1. In this photomicrograph of an incipient delamination the connected elongated voids are 1 mm below and parallel to the finished surface. Each hatch mark on the left side of the slab is 1 mm.

the upper surface. Although the separations can be caused by rebar corrosion or freezing and thawing, on floors they're caused by a buildup of water and air beneath a dense layer of surface mortar (Fig. 1). Because the water and air create a weakened zone, traffic causes the surface layer to break away from the base concrete. Typically the delaminated surface mortar is ⅛ to ⅜ inch thick and the affected area from a few square inches to more than a hundred square feet (Refs. 1, 2).

Premature troweling can, indeed, produce a dense layer of surface mortar by sealing the surface so air and water can't escape. But similar effects can be produced by atmospheric conditions that affect setting and bleeding. When concrete bleeds, the paste and aggregates settle at different rates. Aggregate particles settle only until they develop a point-to-point contact (sometimes called bridging); cement particles, however, continue to settle between the stabilized aggregate particles, allowing bleedwater to rise.

If, due to hot weather conditions, the concrete's surface mortar sets faster than the rest of the concrete, but the concrete is still bleeding internally, the surface will settle at a slower rate (Ref. 3). Klieger hypothesized that if setting interrupts the bleeding process before the surface mortar reaches the underlying material, a plane of weakness may result (Ref. 4).

In laboratory tests of concretes exposed to temperatures and wind velocities up to 90°F and 20 mph, respectively, Klieger was unable to verify his hypothesis with scaling test results. But a few years later, a bridge deck placed under hot-weather conditions exhibited flaking, or delamination (Ref. 5). Set-retarded concrete for the 8-inch-thick deck was screeded with an oscillatory screeding machine, floated by hand with a longitudinal float and smoothed with a scraping straightedge. Final surface texturing was done with a burlap drag, followed by curing with a white-pigmented curing compound. Workers noted flaking four days after the first bay was placed. The first eight bays of the deck exhibited general surface flaking, and almost all of the surface was affected on some bays. Flakes were up to 3⁄16-inch thick.

This field behavior wasn't duplicated in subsequent laboratory tests. Because so many variables are involved, we believe it's difficult to reproduce delaminations in the lab.

Factors that stack the deck

Because delamination, bleeding and surface setting are interrelated, the factors that affect bleeding and setting are keys to understanding delamination. Generally, jobsite factors that affect bleeding and surface setting rate in slabs also affect the probability of delamination.

Factors that affect bleeding include:

- A cold subgrade
- A vapor retarder directly under the slab
- Thick slabs
- A high water content
- Entrained air
- Some water-reducing admixtures, fly ashes and slags

Factors that affect surface setting rate include:

- High wind velocity
- Low relative humidity
- Rising air temperature
- Exposure to direct sunlight

Even if we know that one or more of these factors will be present, we don't yet know enough about delaminations to consistently predict when they will occur. But we do know that increasing the number of these risk factors stacks the deck against finishers, decreasing the probability that they can create the desired surface quality without producing delaminations

The use of air-entrained concrete in hard-troweled floors is one such risk factor. Although air-entrained concrete has been machine-troweled without producing delaminations, the probability of success is low (see box). That's why ACI 302.1R-96, *Guide for Concrete Floor and Slab Construction* (Ref. 6) and ACI 301-96, *Specifications for Structural Concrete* (Ref. 7) don't recommend using air-

Timing isn't everything

More than 40 finishers and observers gathered at Allen Engineering facilities in Paragould, Ark., to participate in a slab delamination study sponsored by ACI Committee 302. Workers placed and finished four 20x40-foot, 6-inch-thick concrete panels with different tools, techniques and materials. *Concrete Construction* helped fund this industry-supported investigation into practical concrete construction problems.

In June 1997, ACI Committee 302, Construction of Concrete Floors, sponsored a study of factors that contribute to slab delamination. Workers placed four 20x40-foot, 6-inch-thick panels on a compacted granular subgrade with no vapor retarder. One panel contained air-entrained concrete, and the other three contained non-air-entrained concrete. A truss-type vibratory screed struck off and consolidated all panel surfaces. To assess the effect of finishing equipment, experienced finishers used float, combination and trowel blades and pan floats mounted on both rider and walk-behind power trowels.

Although several factors were varied, only the air-entrained concrete surface delaminated. Two 8-cubic-yard truckloads of concrete were used in the air-entrained panel. The concrete contained an average of 465 pounds of Type I cement and 109 pounds of Class C fly ash. The average water-cementitious materials ratio was 0.44. The mix contained 1,805 pounds of limestone coarse aggregate (1½-inch nominal maximum size) and 1,251 pounds of fine aggregate (fineness modulus = 2.99). A Type A water reducer and an air-entraining agent were added. Based on field tests, average concrete properties were:

- Air content — 5.3%
- Slump — 7 inches
- Unit weight — 143 pounds per cubic foot
- Temperature — 77°F

The average 28-day compressive strength was 4280 psi.

For the panel containing this concrete, the subgrade, concrete and air temperatures were all within 5°F at the time of placement. It was a cool, cloudy day, and during the concrete pour the air temperature varied from 60°F to 75°F and the relative humidity, from 50% to 95%. The measured wind speed varied from ½ to 2½ mph.

When floating passes were started four hours after strike-off, there was no bleedwater on the surface and the finishers' footprints were about ¼ inch deep. The power float passes went smoothly, but the first signs of trouble appeared during troweling. The surface started to peel (Fig. 1). A chain-drag survey 24 hours later revealed that 1.4% of the slab surface had delaminated (Fig. 2). Based on another survey at 28 days, the delaminated area had doubled. Delaminations occurred throughout the panel and didn't follow any tool or equipment pattern, thus ruling out float blades or pans as the cause.

Could it be the timing? The combined finisher experience totaled more than 100 years. All of the finishers and onsite observers represented more than 500 years of experience. No one believed the timing was inappropriate. The most likely cause of the delaminations was the entrained air. However, the air content at which entrained air became a problem wasn't clearly defined. Cores were taken from the panel and the 11.5% average air content of the hardened concrete was significantly higher than that of the fresh concrete. Based on fresh-concrete unit weight tests, the calculated air content was about 6.5%. Thus, the results of this test show that entrained air can cause surface delamination, but they don't define a threshold air content or shed any light on factors that affect that threshold.

Figure 2. After 24 hours, a chain-drag survey revealed that 1.4% of the slab surface was delaminated (spray-painted areas). A worker marks the delaminated area with spray paint.

entrained concrete in slabs that require a machine-troweled surface.

To shed more light on the relationship among bleeding characteristics, setting times and delamination potential, we studied literature on the subject and did some bleeding and setting tests of our own. The next two articles will present the results of our research.

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