Effect of water-vapor emissions on floor-covering adhesives

Though pull-off tests show that higher emission rates reduce adhesive strength, they also indicate that adhesive properties are as important as emission rate

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According to the construction schedule, floor coverings for the multiplex theater you're building should be installed this week. But the 16,000-square-foot concrete floor isn't cooperating. The flooring installer says water-vapor emission rates are still too high, so if you want the flooring installed now, you'll be responsible for any subsequent moisture-induced problems.

The theater owners' message is equally adamant: Get the floor covering installed so we can start generating some revenue instead of waiting for the concrete to dry.

This scenario illustrates a common dilemma. To stay on schedule, especially for fast-track projects, general contractors may be tempted to have the flooring installed regardless of water-vapor emission rate. But before assuming responsibility for floor-covering performance, they should assess the probability of distress, which may include loss of adhesion between the covering and the concrete.

Some flooring installers try to determine the effect of water-vapor emission rates on flooring adhesives by conducting bond-and-moisture tests. Small flooring mats are adhered to the floor, and, if after three days, an unusual amount of force is required to lift them from the subfloor, the mats are considered to be securely bonded (Ref. 1). However, the results of bond-and-moisture tests are qualitative rather than quantitative. To gather measurable data, The Aberdeen Group studied the effect of water-vapor emissions on the bond strength of several different floor-covering adhesives by using a pull-off testing method that was developed to evaluate adhesion of epoxy compounds to concrete surfaces (Ref. 2).

Tests on a dry floor

To establish the bond strength under dry conditions, we initially tested nine flooring adhesives by adhering sections of vinyl composition tile (VCT) to a 20-year-old concrete floor at a testing laboratory. Six of the adhesives were water-based, two were solvent-based and one was a two-component epoxy (Table 1). All were taken from single containers purchased off the shelf at a building-supply center. The VCT was also an off-the-shelf product. A first set of tests was made with the water-, solvent- and epoxy-based adhesives marked #1 in Table 1. A second set was made with water-based adhesives #2 through #6 and solvent-based adhesive #2.

Tile installation. Because water beaded on the floor surface where the adhesives were to be applied, indicating that the floor had been sealed, we sandblasted the surface

Figure 1. Steel discs glued to 2-inch-diameter plugs of vinyl composition tile were later pulled off to measure the strength of adhesives bonding the tile to concretes with varying water-vapor emission rates.

and vacuumed areas that were to receive the adhesive.

Test specimens were 12-inch-square, ⅛-inch-thick tiles cut into thirds to produce three 4x12-inch strips, which were core-drilled to produce three 2-inch-diameter tile plugs. This allowed lab technicians to perform three pull-off tests for each adhesive tested. The technicians spread each adhesive on the concrete surface, covering an area approximately the size of the tile strip and following the manufacturer's recommendations for adhesive thickness, trowel size and open time. After waiting until the recommended open time had been reached, they placed the 4x12-inch strips on the adhesives and pounded the strips into place. Then they placed the 2-inch-diameter tile plugs back into the drilled holes and pounded them down.

Figure 2. Using a manually operated screw piston, a technician applies pressure from a hydraulic ram to pull off vinyl-composition-tile plugs.

Water-vapor emission and pH tests. After the test tiles were placed, technicians put two calcium-chloride cup-test kits in the area where each set of initial pull-off tests was to be conducted. They used these kits to measure water-vapor emission rate. At the end of the three-day testing period, they also measured the pH of the concrete surface just outside the test-kit lid. Average emission rates for the first and second pull-off test sets were 1.4 and 1.8 lbs/1,000 sf/24 hrs, respectively. The pH of the concrete surface was 9 for both of these test sets.

Pull-off tests. After the adhesive had cured for three days, technicians placed a string in the small gap between the tile plug and the rest of the tile, applied a fast-setting epoxy to the plug and attached a 2-inch-diameter steel disc that had a ½-inch-diameter threaded rod welded to the top (Fig. 1). The string prevented epoxy from being squeezed out from beneath the disc and into the gap, where it could have affected pull-off test results.

To conduct the tests, a technician placed a tripod over the disc, centered a 500-pound-capacity hydraulic ram over the threaded rod and connected the rod to the ram (Fig. 2). Using a manually operated screw piston, the technician applied hydraulic pressure, which was measured on a dial gauge and converted to a load using a calibration chart. The maximum load was used to calculate the applied stress at failure.

Results of the dry-floor tests are shown in Table 2. As expected, the epoxy-based adhesive yielded the highest average pull-off strength of 128 psi. The two solvent-based adhesives yielded strengths of 11.0 and 29.5 psi. Average strengths for the six water-based adhesives also varied widely, ranging from 7.0 to 38.5 psi.

Tests on slabs with higher emission rates

Based on the dry-floor test results, we selected three water-based adhesives with average, above-average and below-average pull-off strengths, each made by a different manufacturer. Using the same testing procedure, we applied these three adhesives, the two solvent-based adhesives and the epoxy to two 3-foot-square concrete test slabs with higher water-vapor emission rates.

The test slabs were more than six months old, had received an initial hand-float finish and had been cured for three days under plastic sheeting. To achieve an initial high moisture emission, we added water to the slab surfaces and allowed it to dry. After three days of drying, we performed the first tile adhesive tests, and, as the concrete slabs continued to dry, performed other tile adhesive tests at lower water-vapor emission rates.

Table 3 shows the average failure stress of three individual pull-off tests for the six different tile adhesives at different water-vapor emission rates. The reported emission

Table 1 Tile adhesives tested

Water-based	
#1.	Tile adhesive for vinyl composition and asphalt tile; clear-spread.
#2.	Resilient-tile adhesive; water-based/rubber-resin.
#3.	Multipurpose flooring adhesive for sheet goods, carpet and resilient tile; white latex.
#4.	Tile adhesive for vinyl composition and asphalt tile; clear-spread latex resin.
#5.	Resilient-tile adhesive; water-based/latex-resin.
#6.	Resilient-tile adhesive; water-based/asphalt-rubber.
Solvent-based	
#1.	Tile adhesive for vinyl composition and asphalt tile.
#2.	Resilient-tile adhesive; solvent-based asphalt/cut-back.
Epoxy	
#1.	Two-component epoxy for resilient tile.
Tile	
All tests: 12-inch-square by ⅛-inch-thick vinyl composition tile.	

Table 2 Pull-off strength (psi) of adhesives placed on a dry floor

Water-vapor emission rate (lbs/1,000 sf/24 hrs)	Water-based #1	#2	#3	#4	#5	#6	Solvent-based #1	#2	Epoxy #1
1.4	11.4						29.5		128
1.8		36.6	24.0	7.0	8.7	38.5		11.0	

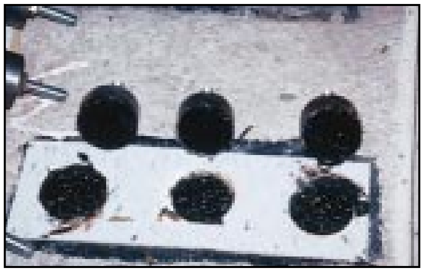

Figure 3. Pull-off tests usually resulted in cohesive failures within the tile adhesive.

rate is an average value from two calcium-chloride cup-test results. The pH shown is the average of two measurements made on the dry concrete surface adjacent to the cup-test lid.

The pull-off tests usually resulted in cohesive failures within the tile adhesive (Fig. 3), with a few failures occurring at the adhesive/tile interface. Of the 75 pull-off tests performed on the test slabs, a portion of the failure plane (typically 20%) occurred at the concrete surface only four times.

For many of the tests, the adhesive was still gummy or tacky after the three-day curing period and could be indented by fingertip pressure or easily scraped. Figure 4 shows the adhesive strings typical in many of the tests. In the dry-concrete tests, we had also noted that a few adhesives were tacky or soft even though the water-vapor emission rate was below 3 lbs/1,000 sf/24 hrs.

Test results were erratic for some of the adhesives tested. Note that the pull-off strength for solvent-based adhesive #1 *increased* when the emission rate increased from 1.4 to 4.0 and 4.7 lbs/1,000 sf/24 hrs. The pull-off strength for water-based adhesive #3 also increased when the emission rate increased from 1.8 to 4.7 lbs/1,000 sf/24 hrs. However, most of the test data indicate decreased adhesive strengths at higher emission rates. When adhesive strength is expressed as a percentage of the dry-floor value, as shown in Figure 5, a significant percentage of adhesive strength is lost for both water- and solvent-based adhesives when the emission rates exceed 5 lbs/1,000 sf/24 hrs.

Adhesive properties make a difference

For the three types of adhesives we tested, the greatest strength reduction at higher emission rates was for the water-based adhesives and the lowest strength reduction was for the epoxy adhesive. One solvent-based adhesive yielded better results than the water-based adhesives but didn't perform as well as the epoxy adhesive. The other solvent-based adhesive didn't perform as well as some of the water-based products.

Because of the variable test results within a given type of adhesive, we couldn't identify a water-vapor emission rate below which a secure bond would be obtained for a specific adhesive. Some flooring manufacturers suggest a maximum acceptable emission rate of 5 lbs/1,000 sf/24 hrs before applying VCT flooring (Ref. 1). But two of the adhesives we tested

What pull-off strength is needed?

Guidelines are needed to evaluate the pull-off strengths we measured for flooring adhesives. To assess the soundness of concrete surfaces that will receive an overlay, some engineers require pull-off strengths of 150 to 200 psi, as measured by the method described in Reference 2. Based on our data, that's overkill because none of the adhesives we applied to a dry floor reached a 150-psi pull-off strength.

ASTM C 1315-95, "Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete," includes requirements for a test used to determine if a curing membrane is compatible with tile adhesives. In this test, mortar panels are coated with the membrane-forming compound and allowed to dry for three days at 73° F (±4° F) and 50% (±10%) relative humidity. Tile adhesive is applied in ¾-inch-diameter areas per the manufacturer's instructions and is tested as described in ASTM D 4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers."

ASTM C 1315 requires a pull-off strength of at least 145 psi. But interlaboratory pull-off data in ASTM D 4541 show that pull-off results depend on the type of device used. The data indicate that for a device with a 2-inch-diameter loading fixture (similar to what we used), a 20-psi pull-off strength is roughly equivalent to a 145-psi pull-off strength for a ¾-inch-diameter loading fixture. This 20-psi value falls within the range of pull-off results we obtained.

Table 3 Pull-off strength (psi) of adhesives placed on concretes with differing water-vapor emission rates

Water-vapor emission rate (lbs/1,000 sf/24 hrs)	Water-based #1	Water-based #2	Water-based #3	Solvent-based #1	Solvent-based #2	Epoxy #1
3.7	10.0	23.3				
4.0				59.2	9.6	
4.5	10.4	18.1				
4.7			31.4	62.6	13.6	
5.1			4.3	27.2	0.0	
5.8	0.0	0.0				
6.1	5.6	11.8				105.9
6.4				13.8	0.0	
7.2	0.0	0.0				27.8
7.8			0.0	23.1	0.0	

Note: Each pull-off test result is the average of three individual tests. Each water-vapor emission test result is the average of two tests. The pH of the concrete surface was tested at two locations at the end of each test. The concrete surfaces were at a pH of 9 during the adhesive testing.

Figure 4. Even though the adhesives had cured for three days, pull-off tests revealed many were still gummy or tacky, forming the adhesive strings shown.

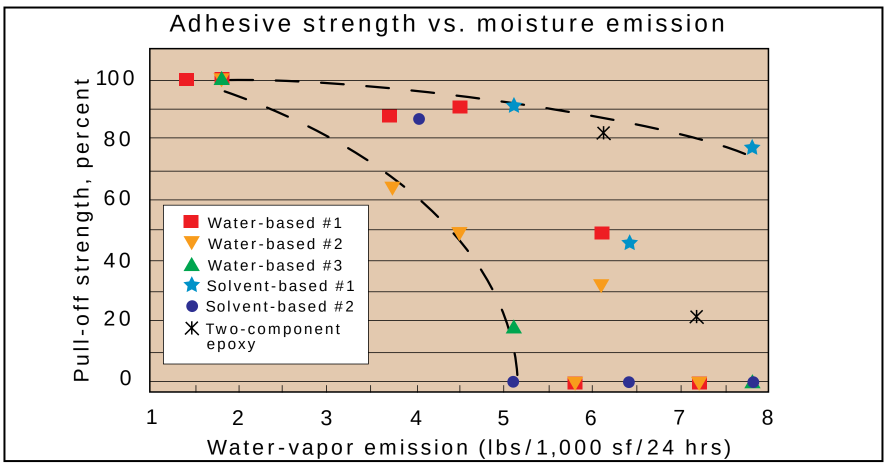

Figure 5. Pull-off strength for most adhesives drops dramatically when the water-vapor emission rate exceeds 5 lbs/1,000 sf/24 hrs.

had little or no pull-off strength when applied to concrete with this emission rate. Based on our tests, secure bond is a function of adhesive properties and water-vapor emission rate. Adhesive manufacturers could assist general contractors and flooring installers by providing data that relate a quantitative measure of bond strength to water-vapor emission rate. Some measure of batch-to-batch product variability would also be useful.

Some flooring installers require a concrete surface pH of 9 or lower before floor coverings can be applied. In all of our tests, the pH didn't exceed 9 when the adhesives were applied, but this pH level didn't prevent adhesive-strength reduction as water-vapor emission rates increased.

References

1. *Armstrong Techniques,* No. 2, Armstrong World Industries, Lancaster, Pa., January 1998.

2. ACI 503R-93, "Use of Epoxy Compounds with Concrete," Appendix A, Test Methods, American Concrete Institute, Farmington Hills, Mich., 1993.

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