

Bond Strength of Shotcrete Repair

by Denis Beaupré, Ph.D.

A good concrete or shotcrete repair must possess three prime characteristics: 1) the repair material must be durable in an aggressive environment, 2) the repair must be well bonded to the substrate and 3) the repair must be as crack free as possible to efficiently protect any embedded steel reinforcement from corroding.

This article deals only with the second issue: the bond strength of the repair. Before discussing bond strength of shotcrete, it may be helpful to look at bond strength of concrete repairs. In 1956 Felt wrote:

"...it became apparent that factors influencing bond of new and old concrete were not easily isolated and controlled. The most important factor was the condition of the old surface—its cleanness, roughness and strength or soundness. If the surface was clean, slightly rough and free of weak outer skin, good bond was generally obtained, otherwise relatively poor bond was obtained." (1)

In 1988, our understanding of shotcrete bond strength was much the same as it was for concrete in 1956. Very little information was available concerning the parameters that influence the long term bond strength of shotcrete, particularly the influence of mixture composition and surface preparation. In 1987, Schrader and Kaden reported that the bond between shotcrete and an old concrete surface

is generally very good, due to the shotcrete compaction process and the normally low water/cement ratio of this material, particularly for dry-mix shotcrete (2). It is most probable that the phenomenon of rebound plays a more important role than compaction or mixture composition on bond strength than is recognized. When shotcrete starts impacting on the receiving surface only the cement paste sticks to the surface. The other components rebound until a sufficient thickness of paste is built up. A well-compacted layer of low water/cement ratio Portland cement paste is thus formed at the interface between the old concrete and new shotcrete layer.

This paper summarizes the results of a study on the influence of surface preparation and mixture composition on long term bond strength of shotcrete repairs. This paper also presents the results of a new study, carried out in 1998, on the influence of multi-layer applications on shotcrete interlayer bond strength.

Bond Strength of Shotcrete Repairs

In a study carried out by Laval University in 1988 (3), many pull-out tests (over 700) were performed to evaluate the capacity of different shotcrete mixtures to produce an acceptable and durable bond to concrete. A secondary objective of this study was to evaluate the influence of surface preparation on shotcrete bond strength. Twenty-one different concrete slabs were cast, cured and allowed to dry for

one year. Then several different methods of surface preparation were used to prepare the slabs: sandblasting, jackhammering, jackhammering followed by sandblasting, grinding, and hydro-milling. Following this, slabs were covered with a thin layer of shotcrete. Six dry-mix and four wet-mix shotcrete mixtures of different compositions were used (some mixtures contained silica fume, latex, steel fibers, high early strength cement, or a combinations of some of these variables). All these mixtures were comprised of good quality shotcrete.

Pull-out tests were performed to evaluate the repair bond strength. A 3 3/4 in. (95 mm) diameter core was drilled with the

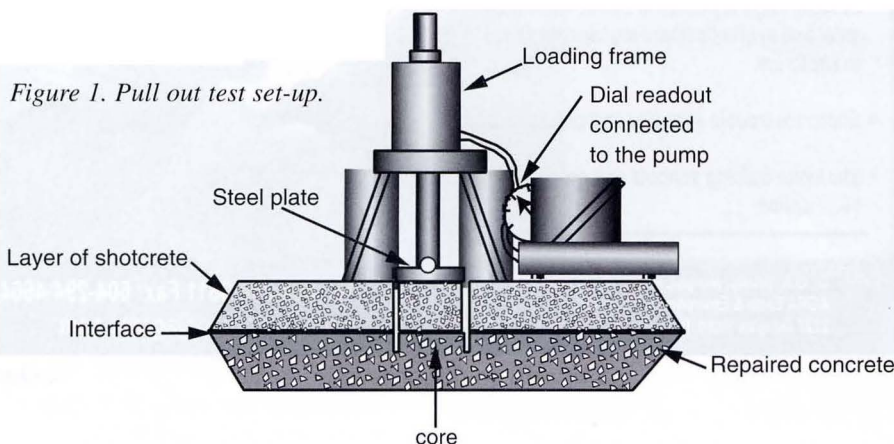


Figure 1. Pull out test set-up.

cut extending beyond the bonded interface into the original substrate concrete. A circular steel plate was attached to the top of the unbonded core by means of a fast setting epoxy. The test sample was then placed on the testing mechanism and a tensile force applied until failure occurred. A minimum of six pull-out tests were performed at the ages of two and six months for each panel tested.

The results of these tests are grouped and summarized in Table 1. This data is now included in the ACI 506 Guide to Shotcrete. Reference 3 of this paper lists further details of individual test results. Each result presented in Table 1 is the average of at least 12 pull-out tests (6 tests at two months and 6 tests at six months).

Apart from the improvement in bond strength evident from the combined use of fibers and silica fume, statistical analysis revealed no significant influence of the mixture compositions on the bonding strength obtained for a given surface preparation. However, the type of surface preparation had a significant influence on the bond strength of the shotcrete repair.

The highest bond strength was obtained with sandblasted surfaces. While this is not a very practical method for removal of much concrete, it was a very effective method to improve bond strength of shotcrete to concrete. The next highest bond strengths were obtained with surfaces prepared by hydro-milling, or by jackhammering followed by sandblasting. Jackhammering alone did not seem to produce sufficient bond strength because it left a great deal of unsound cracked particles that weakened the interface. Ground surfaces produced very poor results compared to other preparation techniques.

Hydro-milling seems to have the advantage of removing the damaged concrete, leaving the surface clean without weakening the surface layer of the old concrete. It is fast, efficient, and requires less labor than other methods. Chipping with jackhammers can potentially weaken the surface, but in this case, this phenomenon was not significant. Low-mass hammers (15 kg/33 lb.) were carefully used, and sandblasting further helped clean the surfaces by removing some of the residual fractured concrete particles. These two methods of concrete surface preparation are presently the only ones accepted by the Quebec Department of Transport for concrete or shotcrete repairs.

Study on Multi-Layer Shotcrete Bond

The bond characteristic of shotcrete is an important issue for the engineer because it has important implications for repair durability. It can have practical

Table 1. Summary of repair bond strength in MPa.

Type of shotcrete	Hydromilling	Sandblasting	Grinding	Jackhammer	Jackhammer + Sandblasting
Dry-Mix	1.6*	2.0	0.2	1.3	1.7
Dry-Mix + silica fume + fibers	2.0	2.3	0.8	1.1	1.9
Wet-Mix	1.6	n/a	n/a	n/a	n/a

*average from tests at 2 and 6 months

implications for the shotcrete contractor because the quality of surface preparation, which is a costly operation, can make the difference between good and bad shotcrete bond. Sometimes, contractors need to place shotcrete in more than one layer. Engineers, seeing bond between layers as a potential source of trouble, and not knowing the best way to accomplish this bond, are sometimes reluctant to allow the placing of shotcrete in more than one layer.

The one-layer operation can sometimes cause logistics problems for overhead application: when a thick layer of shotcrete is placed overhead, there is a risk of "fresh decohesion" (delamination) (Figure 2) during the finishing operation even if the shotcrete does not actually fall from the surface. When decohesion is detected after the shotcrete has set, the contractor must then remove the unsound shotcrete and reapply new shotcrete.

In order to obtain data on this issue, the Industrial Chair on Shotcrete and Concrete Repair at Laval University has undertaken a series of tests on the multi-layer bond strength of shotcrete. The results presented in this section are the results of the first phase test program.

During the study, twelve concrete base slabs were coated with two layers of shotcrete. The first layer was applied to a sand blasted concrete surface and produced excellent bonding characteristics. That layer was finished in different ways: 1) no finish, 2) scratched with a steel trowel (but not finished), 3) scratched and finished with a wood trowel, and 4) roughened with a broom. Half of each panel was coated with a curing compound, either by spray or by using a brush. The second half of the panel of shotcrete was either water-cured or left ot dry. Af-

Figure 2. Pull-off test for multi-layer shotcrete.

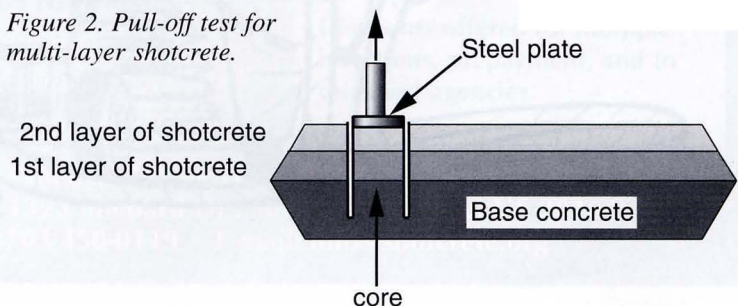


Table 2. Multi-layer bond strength in MPa.

Time	Type of finish between layers (results with no curing compound)			
	None	Scratch	Scratch + Wood	Roughen with Broom
4 hours	2.1	1.8	2.1	1.9
1 day	n/a	2.1*	2.1	n/a
28 days	n/a	1.8	n/a	2.0

*average of 8 tests instead of 4 tests

ter different periods of waiting (4 hours, 1 day and 28 days) the second layer of shotcrete was applied and finished with a wood trowel. Pull-out tests were performed 28 days after placing of the second layer of shotcrete.

Figure 2 shows the geometry of the sample used for this study. Table 2 summarizes the results of the bond pull-out tests for the half panel made without curing compound. From Table 2 it can be seen that, for the waiting period and the types of finish studied, there is no significant influence of these parameters on bond strength. The average bond strength results from Table 2 is (190 psi) 2.0 MPa.

Table 3 compares the average test results from Table 2 with the corresponding average bond strength results for the curing compound condition and for the single shotcrete layer condition. One can see that there is little reduction in bond strength when placing shotcrete in more than one layer if curing compound is not used; however, there can be significant reduction, in the order of 50%, if curing compound is used. The results presented in Table 3 were obtained without removing the curing compound before the application of the second layer of shotcrete. However, if the curing compound was removed with efficient sand blasting, the bond strength would

probably be similar to the results from the first study, i.e. be as good as a single layer shotcrete application. For technical and practical reasons the author does not recommend using curing compounds between layers, even if the waiting period before applying the second layer is long.


Conclusions and Recommendations

The test results described in this paper indicate that the bonding achieved between good quality shotcrete mixtures and concrete surfaces prepared by hydro-milling or chipping with light jackhammers, followed by sandblasting, is generally strong and durable. The other types of concrete removal (grinding, chipping with jackhammers without sandblasting) resulted in either lower bonding strengths or a reduction in bonding strength over time (see reference 3 for more information on bond durability). No significant differences were observed between the bond strength of dry or wet process shotcrete applied on hydro-milled surfaces.

With respect to the multi-layer bond strength of shotcrete, the presence of

shotcrete/shotcrete interfaces does not seem to create a large reduction in shotcrete quality in terms of mechanical bond if no curing compound is used. However, in saturated conditions and in the presence of freezing and thawing, engineering practice typically requires that the bond interface should be contained between the base concrete and the outermost reinforcing layer.

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Conditions	Average Bond Strength
No curing (from Table 2)	2.0 MPa
Curing Compound	1.2 MPa
One layer (no joint)	2.4 MPa

Table 3. Average bond strength.

References:

1. Felt, E.J., "Resurfacing and Patching Concrete Pavement with Bonded Concrete," Proceedings of Highway Research Board, 1956, pp. 444-479.
2. Schrader, E. and Kaden, R., "Durability of Shotcrete," (SP-100-57), Detroit, ACI SP-100: Concrete Durability, 1987, pp. 1071-1102 .
3. Talbot, C., Beaupré, D., Gendreau, M., Lamontagne A., and Pigeon, M. "Durabilité des réparations en béton projeté (Durability of shotcrete repairs)," Report submitted to the Depart-

ment of Transportation of Québec, 1992, 86 p.

Conversion factors: 1 MPa = 145 psi

Denis Beaupré is an associate professor in the department of civil engineering at Laval University in Québec City. His main research topics are shotcrete, both wet and dry processes, as well as pumping and rheology. He also works as a consulting engineer with the "Service d'Expertise en Matériaux" (S.E.M.) in Québec City where his work primarily involves shotcrete projects.