# COMPARISON OF DESTRUCTIVE METHODS TO APPRAISE THE MECHANICAL INTEGRITY OF A CONCRETE SURFACE

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The concrete repair industry is constantly searching for improved methods available to assess the condition of existing structures and adequately interpret the related data.[1,2] Beyond the stage of visual examination and hammer-sounding (tapping), questionable areas can be subjected to further investigation using a variety of techniques.[3-5] In Table 1, a list of methods to assess in-place concrete strength and/or physical integrity is provided.

As part of the concrete repair process, to promote optimal adhesion of the repair material, the concrete substrate must be prepared to yield a rough surface that is free from defects and contaminants.[7-8] Depending on the technique being used, the concrete removal operation can be harmful to the residual concrete substrate. Whenever bond is key to the success of a repair, the soundness of the prepared surface should be assessed after surface preparation. This issue could become even more critical than the condition evaluation carried out before undertaking the repair project.

Although the effect of substrate condition on bond is widely recognized,[1,5,7] there is still no standard method intended for characterizing the integrity of a concrete substrate after concrete removal. For one, Belgian guidelines[9] explicitly recommend performing a pulloff test[10] directly on the substrate, especially if doubt exists about the quality of surface preparation; a minimum value of 290 psi (2 MPa) is usually recommended. This must be seen as a guiding value. For low-strength concrete, a lower value could be specified.

An experimental program was conducted by the authors[11] to evaluate the influence of various parameters on the measured cohesion of a concrete surface by means of a pulloff test. The test method shows good potential for a sound quantitative evaluation of a concrete surface mechanical integrity prior to repair, provided that the test parameters are selected properly.

The test location and interpretation of test results[12] must consider the possible variations of material properties within structural members and differences between in-place and standard specimen strengths. The proper testing layout actually depends on whether it is intended to determine average values for a member (for specification compliance) or to assess the substrate condition in critical areas (for structural adequacy assessment). Furthermore, the number of test locations would vary with the objectives of the test and the expected level of confidence for the overall strength estimates. Typically, between five and eight locations are tested.

This article presents the results of an investigation intended to assess and compare quantitatively different test methods—namely, the Schmidt rebound hammer, the pullout test, and the pulloff test—to evaluate the integrity of a substrate after concrete removal operations.

### TABLE 1: TEST METHODS TO EVALUATE IN-PLACE CONCRETE[6]

| Strength assessment | Integrity assessment |
|---|---|
| Rebound hammer | Visual inspection |
| Ultrasonic pulse velocity | Stress wave propagation methods |
| Probe penetration | Ground-penetrating radar |
| Pullout | Electrical/magnetic methods |
| Break-off | Nuclear methods |
| Maturity method | Infrared thermography |

## EXPERIMENTAL PROGRAM

### TEST METHODS AND PARAMETERS

#### SCHMIDT REBOUND HAMMER (ASTM C805 AND BS 1881, PART 202)

Due to its simplicity of use and low cost, the Schmidt rebound hammer (ASTM C805) is the most widely used device for nondestructive testing of concrete (Fig. 1). It operates as follows: a spring-loaded hammer impacts (with a given amount of energy) a steel plunger in contact with the concrete surface, and the distance that the hammer rebounds is recorded. The rebound value is primarily influenced by the elastic modulus and strength of the concrete near the surface.[6] While the test may be simple to perform, the relationship between measured rebound and in-place concrete strength is sensitive to a number of parameters. In particular, the results are influenced by the moisture condition, carbonation, and surface texture of the concrete, as well as hammer inclination.[5,6] Because the plunger's rebound depends on the energy being restituted from the substrate, it is expected that incidence of bruising and cracking in the surface layer will reflect in the recorded values. Although the evaluation of strength is not an issue in this study, the test results are expressed in terms of strength.

## PULLOUT TEST

Post-installed test procedures were selected for evaluation in this study, as they are well-suited for the intended purpose. In this method, a metallic insert is embedded in the concrete. The insert and surrounding conical volume of concrete are pulled out by a tension jack, which pushes against the peripheral concrete surface through a concentric reaction ring. The device records the ultimate force required to pull out the insert, whose values provides an indirect evaluation of the concrete strength. Obviously, the recorded value does not correspond to any fundamental mechanical property of the material, but it definitely reflects the material's compressive and tensile strengths and it is likely to be affected by the presence of damage or defects at the surface, above the expanded steel ring. Among a variety of pullout test procedures,[6] two were investigated in this study. The first one is the standardized Capo pullout test (ASTM C900 and BS 1881, Part 207), adapted from the Lok test,[1] and where a groove in the predrilled hole allows a compressed steel ring to expand and confine the concrete (Fig. 2). The other investigated test, referred to herein as the accelerated cohesion test, is a nonstandard procedure that uses a two-component adhesive anchor consisting of a self-contained adhesive capsule and a threaded rod with a nut and washer. For such experiments, it has been found that a minimum of five tests is recommended to yield reliable results.[12]

## PULLOFF TEST (EN 1542 AND BS 1881, PART 207)

The pulloff test is commonly used to assess the adhesion of repair systems to concrete. It measures the direct tensile force required to pull off a metallic disk, together with a layer of concrete, from the surface to which it has been epoxy-glued (Fig. 3).

The pulloff test can also be used to evaluate the cohesion and integrity of a concrete surface to be repaired.[9-11,14-16] An experimental program was

*Fig. 1: The Schmidt rebound hammer*

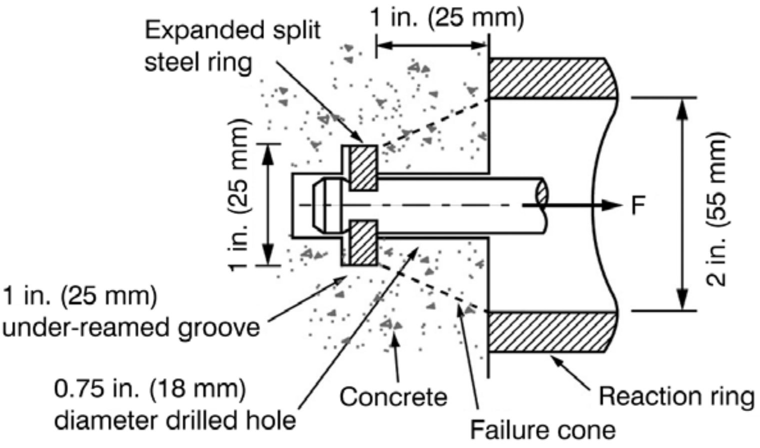


*Fig. 2: Pullout: Capo test[13]*

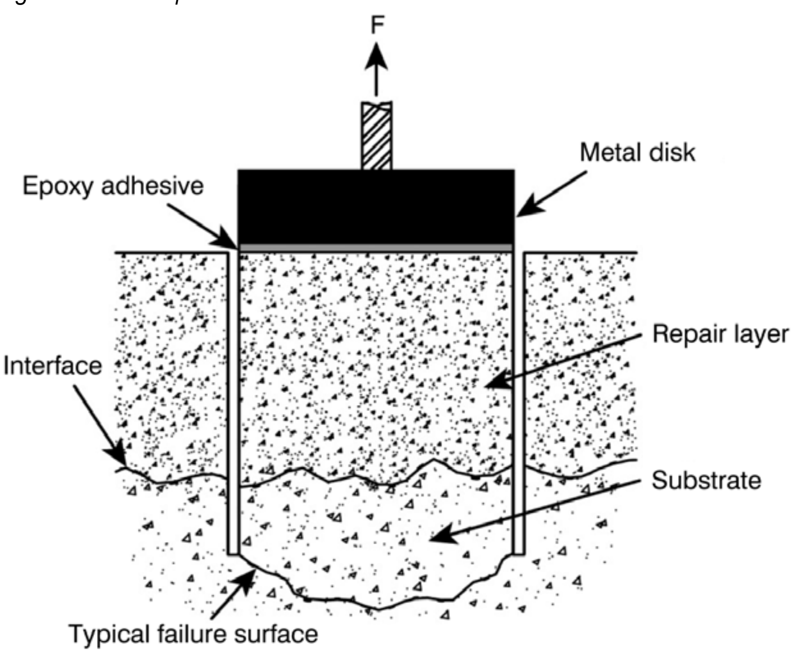


*Fig. 3: Pulloff test*

conducted in a previous study[11] to evaluate the influence of various test parameters—metal disk thickness and diameter, core drilling depth, loading rate, adhesive type and thickness, and number of tests—to measure the cohesion of a reference concrete surface. A statistical results analysis revealed that disk diameter and core-drilling depth are the most significant parameters, presumably with threshold values (Fig. 4), which actually depend on the maximum aggregate size.

To yield low standard deviation and satisfactory level of confidence in the results (maximum coef-

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*The insert is installed against the concrete form before casting.

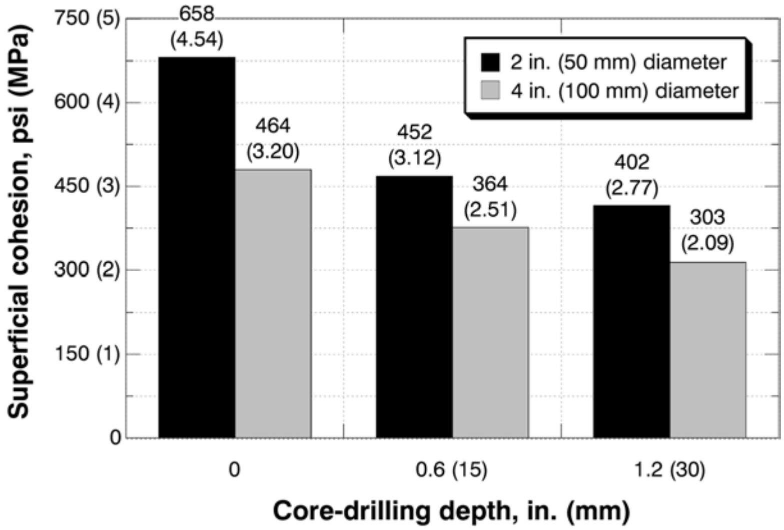


*Fig. 4: Effects of core-drilling depth and metal disk diameter on surface concrete cohesion (loading rate <7.25 psi/s [0.05 MPa/s])*[11]

ficient of variation [COV] of 12%), a minimum of five tests is recommended. Other authors[12] recommend a minimum of six pulloff tests in a specific area to be assessed.

After testing, and depending on the failure mode or value, concrete integrity may need to be assessed further to examine the presence of cracks near the failure surface (mostly parallel to the surface) as a result of surface preparation operations.[7]

## TEST SERIES AND MATERIALS

Experiments were first performed on untreated concrete surfaces to study the significance and sensitivity of test parameters. Then, test series intended to evaluate the cohesion of concrete after various surface treatments were carried out.

Slab and block test specimens were cast using concrete with 0.40 and 0.48 water-cement ratios (*w/c*), respectively. The former was made using 0.4 in. (10 mm) crushed granite as coarse aggregates, whereas the latter used 0.8 in. (20 mm) aggregates from the same source. Table 2 presents the concrete mixture designs, which had been used as reference materials in other related research projects devoted to repair and rehabilitation issues.

Three concrete batches were prepared for the fabrication of 13 concrete slabs and three concrete blocks. Two different slab configurations were cast: Type S1 was 20 x 20 x 3.5 in. (500 x 500 x 90 mm) and Type S2 was 29 x 29 x 3.5 in. (730 x 730 x 90 mm). After casting, the slabs were covered with wet burlap and a polyethylene sheet for 48 hours. They were then stored in the laboratory at 73°F (23°C) and 50 to 70% relative humidity (RH) for 26 days. The three 24 x 24 x 3.5 in. (610 x 910 x 610 mm) block specimens (B-series) were cured for 7 days in a humidity chamber and then air-stored in the laboratory for 21 more days.

## COMPARISON AND STATISTICAL EVALUATION OF METHODS ON FLAT FINISHED CONCRETE SURFACES

### SCHMIDT REBOUND HAMMER TEST

The Schmidt rebound hammer tests were performed on cast surfaces before any treatment. To estimate the required number of data for statistical

### TABLE 2: CONCRETE MIXTURE COMPOSITIONS, PLASTIC CONCRETE PROPERTIES, AND MECHANICAL PROPERTIES AT THE AGE OF 28 DAYS

| | Slab specimens | | Block specimens |
|---|---|---|---|
| Mixture design | S1-series | S2-series | B-series |
| Cement (CSA Type 10), lb/yd³ (kg/m³) | 647 (384) | 645 (383) | 684 (406) |
| Water, gal./yd³ (L/m³) | 31.5 (156) | 33 (187) | 33 (165) |
| Sand, lb/yd³ (kg/m³) | 1241 (736) | 1237 (734) | 1313 (779) |
| Coarse aggregate, lb/yd³ (kg/m³)<br>0.1 to 0.4 in., (2.5 to 10 mm) | — | 1544 (916) | 1638 (972) |
| Coarse aggregate, lb/yd³ (kg/m³)<br>0.4 to 0.8 in. (10 to 20 mm) | 1547 (918) | — | — |
| Air-entraining admixture, oz/yd³ (mL/m³) | 2 (78) | 2 (76) | 2 (78) |
| High-range water-reducing admixture<br>Polycarboxylate-based, oz/yd³ (mL/m³)<br>Naphthalene-based, oz/yd³ (mL/m³) | 25 (980)<br>— | 33 (1269)<br>— | —<br>61 (2352) |
| *w/cm* | 0.40 | 0.48 | 0.40 |
| Air content, % | 11 | 9 | 5.8 |
| Slump, in. (mm) | 5.7 (145) | 3 (75) | 1.4 (35) |
| Compressive strength ($f_c$), psi (MPa) | 4685 (32.3) | 6672 (46.0) | 7005 (48.3) |
| Splitting tensile strength ($f_{st}$), psi (MPa) | 479 (3.3) | 580 (4.0) | — |

TABLE 3: SCHMIDT REBOUND HAMMER TEST RESULTS—INFLUENCE OF THE NUMBER OF TESTS PERFORMED UPON STATISTICAL PARAMETERS (S2 SLAB SPECIMENS)

| Statistical parameter | S2-5 slab | | | S2-6 slab | | |
|---|---|---|---|---|---|---|
| | No. of tests | | | No. of tests | | |
| | 61 | 36 | 25 | 61 | 36 | 25 |
| Average value, psi (MPa) | 4685 (32.3) | 4655 (32.1) | 4714 (32.5) | 4482 (30.9) | 4482 (30.9) | 4467 (30.8) |
| COV, % | 10.1 | 10.8 | 9.0 | 8.3 | 9.3 | 6.8 |

TABLE 4: CAPO PULLOUT TEST RESULTS (S1- AND S2-SERIES SLABS)

| Test no. | Compressive strength, psi (MPa) | |
|---|---|---|
| | S1-series slabs | S2-series slabs |
| 1 | 3858 (26.6) | 5410 (37.3) |
| 2 | 4380 (30.2) | 4786 (33.0) |
| 3 | 4627 (31.9) | 3989 (27.5) |
| 4 | 3756 (25.9) | 4264 (29.4) |
| 5 | 4743 (32.7) | 5134 (35.4) |
| 6 | 4351 (30.0) | 4888 (33.7) |
| 7 | 4235 (29.2) | 5004 (34.5) |
| 8 | 4830 (33.3) | 5628 (38.8) |
| Average value | 4351 (30.0) | 4888 (33.7) |
| COV, % | 9.0 | 11.2 |

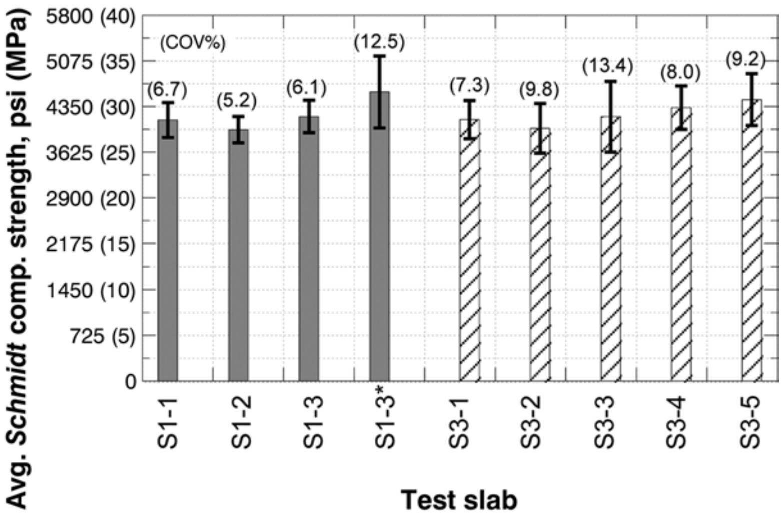


*Fig. 5: Average compressive strength values estimated from the Schmidt rebound hammer tests on flat finished slab specimens*

significance, a large number of tests were carried out. Based on the results summarized in Table 3, it seems that the average compressive strength estimated with the Schmidt hammer is not significantly influenced by the number of tests, at least beyond 25 replicas. Thus, it appears that 25 tests are sufficient for the surface investigated.

The Schmidt hammer results obtained for all concrete slabs are presented in Fig. 5. The differences between S1-3 and S1-3* appear to be mostly related to the nature of the support provided underneath the test slabs—either continuous (wooden platform) or discontinuous (two wood lumbers). Variability, which is evaluated with the COV, is lower when the concrete specimen is placed on a continuous support (Fig. 6).

## CAPO PULLOUT TEST

Capo pullout test series were performed on slabs from both series to account for the coarse aggregate size effect. Results are presented in Table 4.

Strictly from the test result data, no specific trend could clearly be associated to the coarse aggregate size. Nevertheless, the observation of the extracted concrete fragments (conical-shape failure) revealed that larger aggregate size in the S1-series slabs altered the cracking pattern, resulting in a much more irregular conical shape (Fig. 6(a) and (b)).

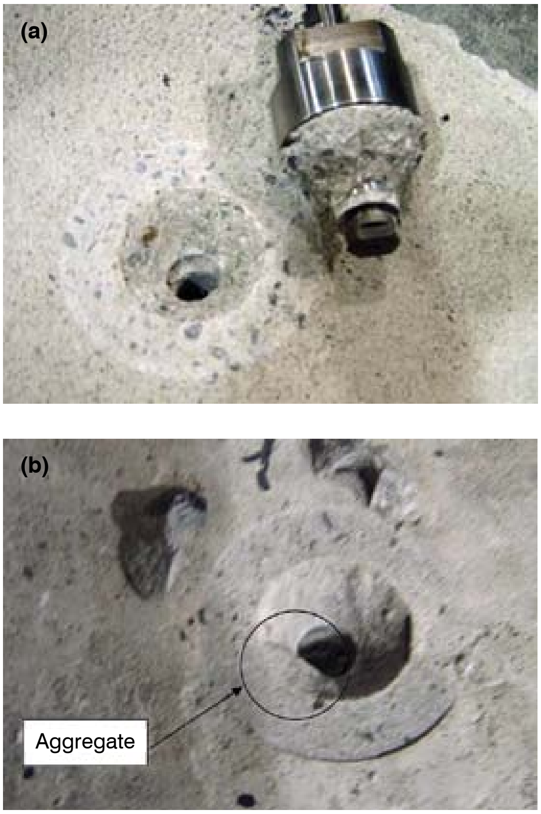


*Fig. 6: Typical pullout conical-shape failure after Capo pullout tests*

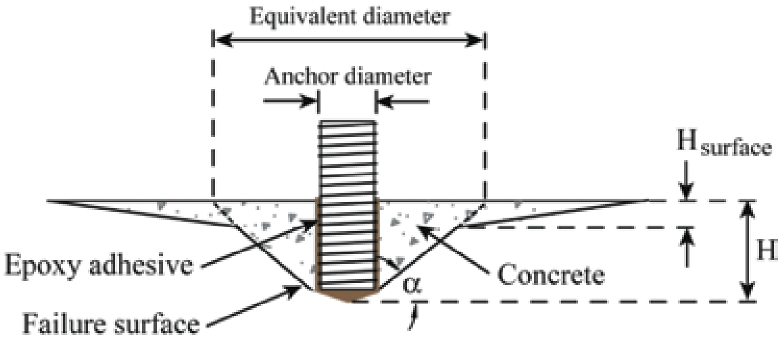


*Fig. 7: Schematic diagram of the conical-shape failure observed in accelerated cohesion tests*

## ACCELERATED COHESION TEST

The first step was to conduct a parametric study, taking into account the diameters of the anchors 0.25 and 0.37 in. (6.4 and 9.5 mm) and the anchorage depths of 0.6 and 0.8 in. (15 and 20 mm). Along the test program, two failure modes were encountered:

1. Type 1: The failure mode is characterized by anchor extraction with little or no concrete near the surface. This can be the result of insufficient polymerization of the adhesive or by the presence of interfacial defects (air bubbles or lack of adhesion between the adhesive and concrete), which cause a weak bond between the adhesive and concrete and ultimately trigger failure.
2. Type 2: The failure mode leads to the extraction of a cone-shaped concrete fragment along with the anchor. This type of rupture is known as conical-shape failure. Figure 7 illustrates this type of failure and the corresponding geometrical parameters. In many cases, the extracted cone exhibited two segments, the angle α decreasing sharply near the surface.

The test results are presented in Table 5. Overall, the recorded variability is quite low for such a test in concrete. Taking into consideration both the COV and the percentage of cone-type failures, the most effective combination appears to be a 0.4 in. (9.5 mm) diameter anchor embedded down to a depth of 0.6 in. (15 mm).

To compare the results of the pulloff and accelerated cohesion tests, the surface area of the failure cone in the latter was evaluated to determine the effective tensile cohesion stress. The tensile load-bearing surface was calculated by evaluating the horizontal projection of the cone area, less the steel anchor cross section. In determining the equivalent diameter at the surface, the assumption was made that the cone angle α was constant from the bottom up to the surface (enlargement near the surface neglected). Equivalent surfaces and corresponding stress values for tests conducted with 0.4 in. (9.5 mm) diameter anchors at a depth of 0.8 in. (20 mm) are presented in Tables 6 and 7.

While recorded pullout load values again exhibit little dispersion, the corresponding cohesion stress values are quite variable owing to the variability of the calculated surface values. Again, the use of larger coarse aggregates clearly induces a wider dispersion of results. Larger aggregates alter crack propagation, particularly at the base of the cone, yielding a greater angle α and a smaller failure surface. This limits the interpretation of the near-to-surface characteristics, given the observed dispersion. In the remainder of this study, accelerated cohesion test results will therefore be analyzed based on the raw pullout load values.

### TABLE 5: ACCELERATED COHESION TEST RESULTS (B-SERIES SPECIMENS)

| Test no. | Pullout load lb force (kN) | | | |
|---|---|---|---|---|
| | 0.25 in. (6.4 mm) ϕ anchor | | 0.4 in. (9.5 mm) ϕ anchor | |
| | Anchorage depth | | Anchorage depth | |
| | 0.6 in. (15 mm) | 0.8 in. (20 mm) | 0.6 in. (15 mm) | 0.8 in. (20 mm) |
| 1 | 899 (4.0) | 1304 (5.8) | 967 (4.3) | 1506 (6.7) |
| 2 | 967 (4.3) | 1349 (6.0) | 922 (4.1) | 1596 (7.1) |
| 3 | 787 (3.5) | 1394 (6.2) | 1012 (4.5) | 1439 (6.4) |
| 4 | 922 (4.1) | 1236 (5.5) | 877 (3.9) | 1619 (7.2) |
| 5 | 967 (4.3) | 1281 (5.7) | 1012 (4.5) | 1686 (7.5) |
| 6 | 809 (3.6) | 1304 (5.8) | 1012 (4.5) | 1619 (7.2) |
| 7 | 967 (4.3) | 1461 (6.5) | 1012 (4.5) | 1709 (7.6) |
| 8 | 832 (3.7) | 1484 (6.6) | 1079 (4.8) | 1484 (6.6) |
| Average value | 899 (4.0) | 1349 (6.0) | 989 (4.4) | 1574 (7.0) |
| COV, % | 8.4 | 6.5 | 6.4 | 6.1 |
| Conical-shape failure, % | 38 | 50 | 100 | 63 |

## TABLE 6: ACCELERATED COHESION TEST RESULTS (S1-SERIES SLABS)

| Test no. | Pullout load, lb force (kN) | Angle α, degrees | *H*, in. (mm) | Equivalent diameter, in. (mm) | Equivalent surface, in.² (mm²) | Pullout stress, psi (MPa) |
|---|---|---|---|---|---|---|
| 1 | 1169 (5.2) | 29.6 | 0.41 (10.3) | 1.8 (45.8) | 2.4 (1576) | 479 (3.3) |
| 2 | 1079 (4.8) | 25.5 | 0.57 (14.4) | 2.8 (69.9) | 5.8 (3768) | 184 (1.27) |
| 3 | 1147 (5.1) | 39.8 | 0.69 (17.6) | 2.0 (51.7) | 3.1 (2032) | 364 (2.51) |
| 4 | 1484 (6.6) | 31.5 | 0.67 (16.9) | 2.5 (64.6) | 5.0 (3204) | 299 (2.06) |
| 5 | 1394 (6.2) | 33.6 | 0.53 (13.5) | 2.0 (50.1) | 2.9 (1900) | 473 (3.26) |
| 6 | 1281 (5.7) | 19.2 | 0.79 (20.0) | 4.9 (125) | 18.7 (12,093) | 68 (0.47) |
| 7 | 1124 (5.0) | 23.1 | 0.46 (11.6) | 2.5 (63.9) | 4.8 (3136) | 231 (1.59) |
| 8 | 1281 (5.7) | 39.1 | 0.66 (16.8) | 2.0 (50.8) | 3.0 (1956) | 422 (2.91) |
| Average value | 1236 (5.5) | 30.2 | 0.59 (15.1) | 2.6 (65.2) | 5.7 (3708) | 315 (2.17) |
| COV, % | 11 | 24 | 22 | 39 | 94 | 47 |

## TABLE 7: ACCELERATED COHESION TEST RESULTS (S2-SERIES SLABS)

| Test no. | Pullout load, lb force (kN) | Angle α, degrees | *H*, in. (mm) | Equivalent diameter, in. (mm) | Equivalent surface, in.² (mm²) | Pullout stress, psi (MPa) |
|---|---|---|---|---|---|---|
| 1 | 1596 (7.1) | 30.2 | 0.76 (19.4) | 3.0 (76.2) | 7.0 (4494) | 229 (1.58) |
| 2 | 1439 (6.4) | 36.1 | 0.67 (17.1) | 2.2 (56.5) | 3.8 (2435) | 380 (2.62) |
| 3 | 1619 (7.2) | 13.6 | 0.76 (19.2) | 6.6 (168) | 34.1 (22,030) | 48 (0.33) |
| 4 | 1619 (7.2) | 20.0 | 0.81 (20.5) | 4.8 (122) | 18 (11,623) | 90 (0.62) |
| 5 | 1709 (7.6) | 20.0 | 0.77 (19.6) | 4.6 (118) | 16.7 (10,765) | 103 (0.71) |
| Average value | 1596 (7.1) | 24.0 | 0.76 (19.2) | 4.3 (108) | 15.9 (10,269) | 170 (1.17) |
| COV, % | 6.1 | 38 | 6.5 | 40 | 75 | 80 |

## TABLE 8: PULLOFF TEST RESULTS (S1- AND S2-SERIES TEST SLABS)

| Test no. | Pulloff stress, psi (MPa) | |
|---|---|---|
| | S1-series slabs | S2-series slabs |
| 1 | 496 (3.42) | 569 (3.92) |
| 2 | 444 (3.06) | 522 (3.60) |
| 3 | 486 (3.35) | 608 (4.19) |
| 4 | 470 (3.24) | 595 (4.10) |
| 5 | 479 (3.30) | 569 (3.92) |
| 6 | 479 (3.30) | 532 (3.67) |
| 7 | 453 (3.12) | 587 (4.05) |
| 8 | 493 (3.40) | 582 (4.01) |
| Average value | 474 (3.27) | 570 (3.93) |
| COV, % | 3.91 | 5.12 |

## PULLOFF TEST

The pulloff tests were performed on the S1- and S2-series slabs using a core-drilling depth of 0.8 in. (20 mm). The test results are summarized in Table 8. The aggregate size appears to have a limited influence on cohesion strength and variability. Nonetheless, the location and shape of the failure surface were more variable for the larger-sized aggregate concrete.

Overall, the recorded values are very close to the corresponding splitting tensile strength data (refer to Table 2). This is consistent with the results of a previous program,[11] where pulloff testing was shown to be an effective technique for evaluating the mechanical integrity of horizontal surfaces after concrete removal. For quality control purposes, an acceptance criterion corresponding to a fraction of the average splitting-tensile strength $f_{st}$ result could be specified.

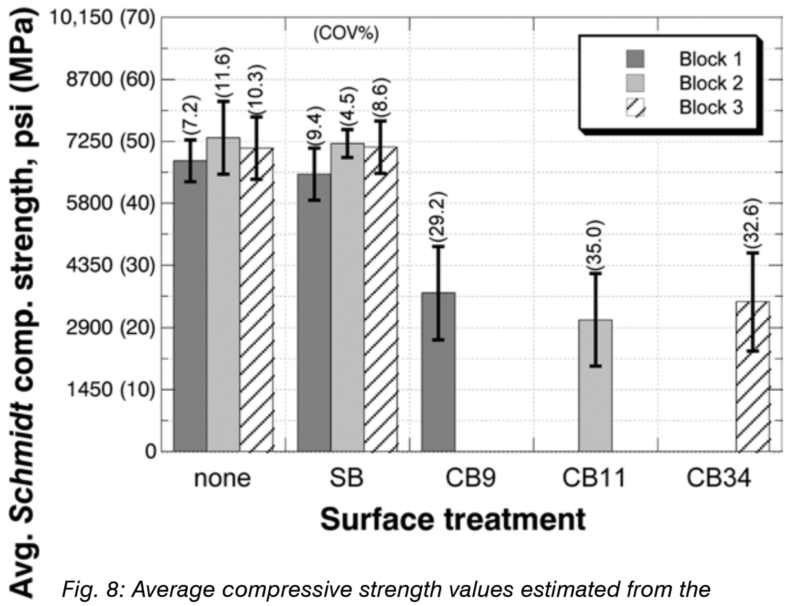


*Fig. 8: Average compressive strength values estimated from the Schmidt rebound hammer tests on slab specimens after different surface treatments (SB: sandblasting; CB9: 19.8 lb (9 kg) concrete breaker; CB11: 24.3 lb (11 kg) concrete breaker; CB34: 75 lb (34 kg) concrete breaker)*

## COMPARISON OF METHODS FOR ASSESSMENT OF PREPARED CONCRETE SURFACES

### SURFACE PREPARATION TECHNIQUES

The following concrete surface treatments were performed on the B-series specimens to carry out in this part of the experimental program:

- Sandblasting (SB);
- Concrete cover removed using a 19.8 lb (9 kg) handheld concrete breaker;
- Concrete cover removed using a 24.3 lb (11 kg) handheld concrete breaker; and
- Concrete cover removed using a 75 lb (34 kg) handheld concrete breaker.

On all three block specimens, two lateral surfaces were prepared by SB while the two other ones were left unprepared (none) to provide a reference. The top surface of each of the three blocks was then prepared using a different concrete breaker (CB): a 19.8 lb (9 kg) breaker (CB9), a 24.3 lb (11 kg) concrete breaker (CB11), and a 75 lb (34 kg) concrete breaker (CB34). The resulting surface roughness characteristics and the influence on the repair material bond strength were not addressed in this part of the project. Information in that regard can be found elsewhere.[17,18]

Schmidt rebound hammer tests and accelerated cohesion tests were conducted for a comparative assessment of physical integrity on the treated and reference surfaces. The Capo pullout test and the pulloff test were left out of that part of the program, as the former absolutely requires a flat surface, whereas the latter has already been investigated in-depth for the same purpose in a previous study.[11]

### SCHMIDT REBOUND HAMMER

Figure 8 presents the average results and COVs, respectively, of the Schmidt hammer soundings performed on all testing surfaces (average of 60 results for reference and SB treatment; average of 25 results for CB treatments).

Again, the compressive strength values calculated from the recorded Schmidt hammer rebound data are strictly used herein on a comparative basis. As shown in Fig. 8, the results obtained for the surfaces prepared with concrete breakers exhibit much more variability, which can be attributed to the following:

- Variability in the procedure (applied force, duration);
- Angle between the axis of the hammer and the concrete surface; and
- Surface topology (the hammer tip can hit an aggregate, cement paste, or both).

Although this test can yield significant average values when performed over large surfaces, the data recorded in this study suggest that variability, not in as much as the absolute values, provide a reliable indication of the presence and importance of defects in the substrate. Based on the results generated with the various investigated surface preparation methods (refer to Table 3 and Fig. 5 and 8), it appears that a threshold COV value of the order of 15 to 20% could discriminate between prepared surfaces where significant bruising has been left or not.

### ACCELERATED COHESION TEST

Table 9 summarizes the results obtained on side and top faces of the concrete block specimens (B1, B2, and B3), which had received the different surface treatments as described previously.

No statistical differences were found between the reference and SB surfaces. The coefficients of variation are relatively low and the test method appears to be suitable for vertical surfaces. Although the average pullout strength values obtained for the surfaces prepared with concrete breakers are only slightly lower than those obtained on the reference and SB surfaces, the COVs are substantially higher.

The higher pullout strength result variability observed in the case of the surfaces prepared with concrete breakers can obviously be explained by their irregular profile induced by this type of surface preparation. Moveover, microcracking within the surface concrete layer has also been observed. In previous investigations,[7] it was found that the number of cracks and total crack length are usually significantly higher (two to four times and four to 25 times, respectively) on substrates prepared with concrete breakers than on those prepared with most other common techniques. Moreover, increasing the hammer weight—and therefore its impact

## TABLE 9: ACCELERATED COHESION TEST RESULTS (BLOCK SPECIMENS)

| Surface treatment | Average pullout load, psi (kN) | | | COV, % | | |
|---|---|---|---|---|---|---|
| | B-series specimen | | | B-series specimen | | |
| | B1 | B2 | B3 | B1 | B2 | B3 |
| None* | 1102 (4.9) | 1236 (5.5) | 1214 (5.4) | 8.4 | 2.4 | 7.1 |
| SB* | 1214 (5.4) | 1259 (5.6) | 1124 (5.0) | 6.9 | 4.7 | 12.7 |
| CB9† | 1124 (5.0) | — | — | 24.7 | — | — |
| CB11† | — | 1102 (4.9) | — | — | 18.0 | — |
| CB34† | — | — | 1102 (4.9) | — | — | 24.9 |

*Each reported value is the average of eight test results
†Each reported value is the average of 12 test results

energy—significantly increases both length and number of cracks.

Overall, the COVs of the data generated with the accelerated cohesion test are comparable to those characterizing the Schmidt hammer data. Again, a threshold COV value of the order of 15 to 20% could discriminate between prepared surfaces where significant bruising has been left or not.

## CONCLUSIONS

Surface preparation is often a critical step in concrete repairs. While it is well-acknowledged that the concrete removal operation can induce bruising and cracking in the substrate, there are still no simple practical means available to assess the integrity of a prepared surface. The investigation reported in this article intended to evaluate different test methods for that purpose: the Schmidt rebound hammer, the Capo pullout test, the accelerated cohesion test, and the pulloff test.

Although the Schmidt rebound hammer test cannot systematically yield a reliable evaluation of the in-place compressive strength of concrete, it was shown to provide valuable comparative data for detecting superficial defects on a concrete surface.[5] The rebound hammer method is thus recognized as a useful tool for performing quick surveys to assess concrete uniformity and mechanical integrity over freshly prepared substrates.

The Capo pullout test has limited interest for surface preparation, as it can only be carried out on smooth surfaces.

Conversely, the accelerated cohesion test exhibited interesting potential as a simple tool for assessing the mechanical integrity of a concrete surface prior to repair. Not only can it be used on any concrete surface but it is also simpler and much faster than the pulloff test. Obviously, the test procedure requires some optimization; within the variables investigated in this study, the most reproducible results were obtained with a steel threaded rod having a diameter of 0.4 in. (9.5 mm) and anchored in a 0.6 in. (15 mm) deep drilled hole. In the quest of such a test for the field evaluation of surface concrete integrity, the use of commercially available chemical anchors would certainly be desirable.

The pulloff test provided results that are very close to the actual splitting tensile strength of the material. Moreover, it was shown in a previous study that it can effectively capture the presence of bruising. Still, it is difficult to adequately perform on vertical or overhead surfaces and, in practice, its use is essentially limited to horizontal surfaces.

Finally, it appears from the results generated in this study that the combination Schmidt hammer/pulloff tests can fulfill the needs for the evaluation of horizontal surfaces after concrete removal, whereas the combination Schmidt hammer/accelerated cohesion tests can be used effectively on any surface, irrespective to its inclination. For quality control purposes, acceptance criteria could be specified for both the hammer soundings (for example, COV < 20%) and cohesion strength test results (for example, pulloff test: cohesion strength $> 0.75 f_{st}$; accelerated cohesion test: COV < 20% ).

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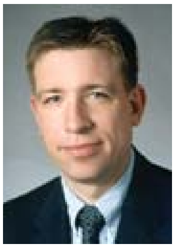

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