Evaluation of the mechanical integrity of a concrete surface by means of combined destructive methods

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ABSTRACT: As a good bond between the repair and the old concrete is required, the soundness of the prepared surface has to be carefully assessed. This paper presents the results of an investigation intended to assess and compare quantitatively different test methods, namely the rebound hammer and the pull-off test, to evaluate superficial mechanical integrity of a prepared substrate. Although it does not yield a precise evaluation of compressive strength, the rebound hammer test is recognized as a useful tool for performing quick surveys to assess concrete uniformity. The pull-off test is very well correlated with the splitting-tensile test, but it is not suited for vertical and overhead surfaces. It appears from the results generated in this study that the combination rebound hammer / pull-off test could very well fill the needs for the evaluation of prepared horizontal surfaces.

1 INTRODUCTION

As part of the concrete repair process, in order 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 (Bissonnette *et al.* 2006; Courard *et al.* 2009). 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 (Vaysburd *et al.* 2000; Garbacz *et al.* 2005). This issue could become even more critical than the condition evaluation carried out before undertaking the repair project (Courard *et al.* 2012).

Although the effect of substrate condition on bond is widely recognized (Silfwerbrand 1990; Courard *et al.* 2011), there is still no standard method intended for characterizing the integrity of a concrete substrate after concrete removal. For one, Belgian guidelines (2007) explicitly recommend performing a pull off test (EN1542, 1999) directly on the substrate, especially if doubt exists about the quality of surface preparation; a minimum value of 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 has been conducted by the authors (Bissonnette *et al.* 2004) to evaluate the influence of various parameters on the measured cohesion of a concrete surface by means of pull off 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.

Test location and interpretation of test results (Bungey 2000) must consider the possible variations of material properties within structural members and differences between in-situ 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 5 and 8 locations are tested.

This paper presents the results of an investigation intended to assess and compare quantitatively different test methods, namely the rebound hammer and the pull off test, to evaluate the integrity of a substrate after concrete removal operations.

2 TEST METHODS AND MATERIALS

2.1 *Schmidt rebound hammer (ASTM C 805 and) EN 12504-2 determination of rebound number*

Due to its simplicity of use and low cost, the rebound hammer is a most widely used device for non-destructive testing of concrete (Figure 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 (Carino 2003). While the test may be simple to perform, the relationship between measured rebound number 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 (Courard *et al*. 2011; Carino 2003). Since 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 the present study, the test results are expressed in terms of strength.

Figure 1. The Schmidt rebound hammer

2.2 *Pull off test (EN 1542-4,)*

The pull off test is commonly used to assess the adhesion of repair systems to concrete.

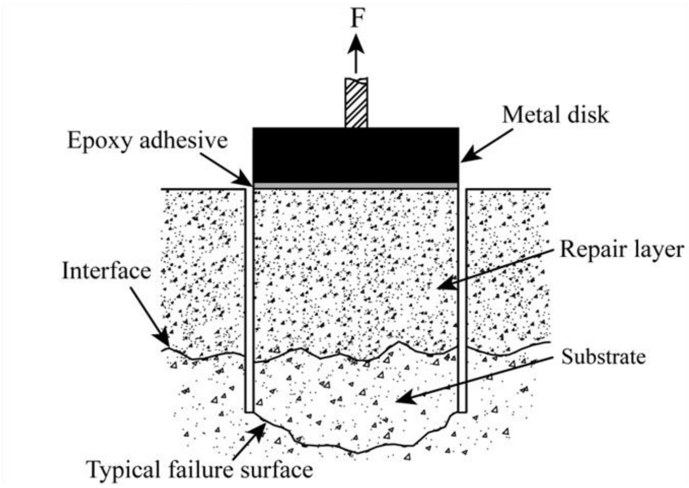

Figure 2. Pull off test

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 (Figure 2).

The pull off test can also be used to evaluate the cohesion and integrity of a concrete surface to be repaired (Bungey *et al*. 2001; Hindo 1990; Emberson *et al*. 1990; Austin *et al*. 1995). An experimental program was conducted in a previous study (Bissonnette *et al*. 2004) 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 (Figure 2), which actually depend on the maximum aggregate size.

In order to yield low standard deviation and satisfactory level of confidence in the results (maximum coefficient of variation of 12 %), a minimum of 5 tests is recommended. Other authors (Bungey 2000) recommend a minimum of 6 pull off tests in a specific area to be assessed.

It was proved that up to a certain misalignment limit angle (about 5°), load and coring misalignments were not found to yield significantly value of pull-off strength (Courard *et al.*, 2014).

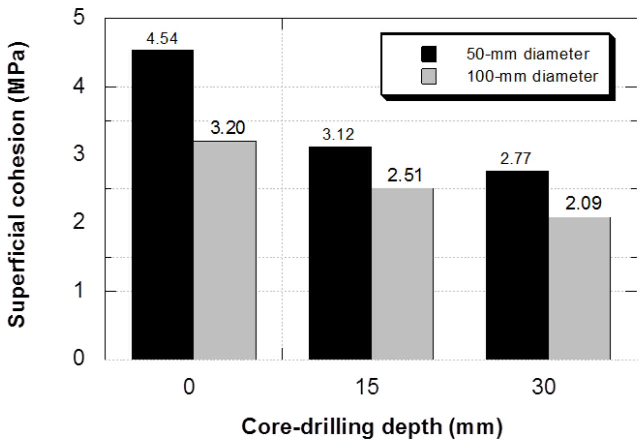

Figure 3. Effects of core-drilling depth and metal disk diameter on surface concrete cohesion (loading rate < 0.05 MPa/s)

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 (Bissonnette *et al*. 2006).

2.3 *Materials*

Experiments have first been performed on untreated concrete surfaces in order 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 test specimens were cast using concrete with 0.40 and 0.48 water/cement ratios, respectively. The former was made using 10-mm crushed granite as coarse aggregates, while the latter used 20-mm aggregates from the same source. Table 1 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. Two different slab configurations were cast: type S1 (500 × 500 × 90 mm) and type S2 (730 × 730 × 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 23 °C and 50-70 % RH for 26 days. A relatively good quality of concrete was obtained due to compaction and low w/c ratio: an even higher w/c ratio (S2 *vs* S1) but smaller aggregates offered a good resistance to splitting.

Table 1. Concrete mixture composition and properties

Mixture design	S1	S2
Cement CSA type 10 (kg/m³)	384	383
Water (l/m³)	156	187
Sand (kg/m³)	736	734
Coarse aggregate 10 mm (kg/m³)	-	916
Coarse aggregate 20 mm (kg/m³)	918	-
Air-entraining (ml/m³)	78	76
Superplasticizer (ml/m³)	980	1269
W/C	0.40	0.48
Slump (mm)	145	75
Compressive strength (MPa)	32.3	46
Splitting tensile strength (MPa)	3.3	4.0

3 EXPERIMENTAL PROGRAM

3.1 *Rebound hammer test*

The rebound hammer tests were performed on cast surfaces, before any treatment. To estimate the required number of data for statistical significance, a large number of tests were carried out. Based on the results summarized in Table 2, it seems that the average compressive strength estimated with the rebound hammer is not significantly influenced by the number of tests, at least beyond 25 replicas. It thus appears that 25 tests are sufficient (but also necessary) for the surface investigated.

The rebound hammer results obtained for all concrete slabs are presented in Figure 4. 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 (2 wood lumbers), which offer different rigidities.

Table 2. 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		
	Number of tests					
	61	36	25	61	36	25
Ave. value (MPa)	32.3	32.1	32.5	30.9	30.9	30.8
Coefft. of var. (%)	10.1	10.8	9	8.3	9.3	6.8

Variability, which was evaluated with the coefficient of variation (CV), was lower when the concrete specimen was placed on a continuous support.

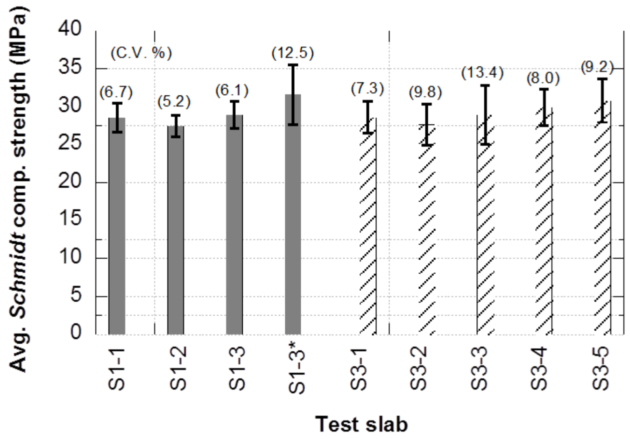

Figure 4. Average compressive strength values estimated from the rebound hammer tests on flat finished slab specimens

3.2 *Pull-off test*

The pull-off tests were performed on the S1- and S2-series slabs using a core-drilling depth of 20 mm. The test results are summarized in Table 3. 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 size aggregate concrete.

Table 3. Pull off test results (S1- and S2-series test slabs)

Test nr.	Pull off stress (MPa)	
	S1-series slabs	S2-series slabs
1	3.42	3.92
2	3.06	3.60
3	3.35	4.19
4	3.24	4.10
5	3.30	3.92
6	3.30	3.67
7	3.12	4.05
8	3.40	4.01
Average value	3.27	3.93
Coefficient of Variation (%)	3.91	5.12

Overall, the recorded values are very close to the corresponding splitting tensile strength data (Table 1). This is consistent with the results of a previous program (Bissonnette *et al.* 2004), where pull off 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.

4 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 concrete surface. The investigation reported in this paper intended to evaluate different test methods for that purpose: the rebound hammer and the pull off test.

Although the 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. The rebound hammer method is thus recognized as a useful tool for performing quick surveys to assess concrete uniformity and mechanical integrity over substrates.

The pull off test provided results that are very close to the actual splitting-tensile strength of the material. Moreover, it was shown in a previous study (Bissonnette *et al.* 2006) that it can effectively capture the presence of bruising. Still, it is difficult to perform adequately 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 rebound hammer / pull off tests can fulfill the needs for the evaluation of horizontal surfaces. For quality control purposes, acceptance criteria could be specified for both the hammer soundings (ex. C.V. < 20 %) and cohesion strength test results (ex. pull off test: cohesion strength > 0.75 fst.

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