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TECHNICAL ASPECTS OF MEASUREMENTS USING THE PULL-OFF METHOD

TECHNICZNE ASPEKTY POMIARÓW METODĄ PULL-OFF

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Abstract

The article presents an analysis of the technical use aspects of the pull-off method for testing the repair layers applied to concrete elements, based on the standards requirements. The use of non-destructive testing methods is the only option in some cases. However, it is very important to pay attention to their proper use or even preparation for research. The pull-off method requires just such diligence to be able to properly interpret the obtained results. The article compares the results of the research in which the pull-off method was used in various configurations. The obtained measurement results were compared with each other and analyzed in terms of their usefulness.

Keywords: pull-off method, tensile strength, reprofiling mortar, PCC layer, non-destructive metod

Streszczenie

W artykule przedstawiono analizę technicznych aspektów użytkowania metody pull-off do badania warstw naprawczych nakładanych na elementy betonowe w oparciu o wymagania norm. W niektórych przypadkach jedyną opcją jest zastosowanie nieniszczących metod badawczych. Bardzo ważne jest jednak, aby zwracać uwagę na ich właściwe stosowanie, a nawet samo przygotowanie do badań. Metoda pull-off wymaga właśnie takiej staranności, aby móc właściwie zinterpretować uzyskane wyniki. W artykule porównano wyniki badań, w których zastosowano metodę pull-off w różnych konfiguracjach. Otrzymane wyniki pomiarów porównano ze sobą i przeanalizowano pod kątem ich przydatności.

Słowa kluczowe: metoda pull-off, wytrzymałość na rozciąganie, zaprawa naprawcza, zaprawa PCC, metoda nieniszcząca

1. INTRODUCTION

From the moment the first buildings were erected, durability was the main factor taken into account. Over the years, the concept of durability has changed its essence, because nowadays buildings are not erected ”for centuries” but for a specific period of time, called the period of use. The need to carry out all kinds of repairs and renovations is more and more frequent nowadays. Damage to buildings is completely natural. The important issue is finding the cause, solution and prevention. In order for the object to be preserved in the condition of its use as long as possible, it is first of all necessary to design it properly and then execute it. All maintenance procedures during use and protection against corrosion are also extremely important. If any element is damaged, it should be repaired immediately and then properly protected. In the initial stages, it is important to choose the right repair method and materials. For this purpose, repair mortars of the PCC type are used.

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PCC mortars are ready-made mortars (polymer cement concrete) manufactured at the factory, in which, apart from cement binder, aggregates and mineral additives or pigments, powdered polymers play an important role, playing the role of modifiers improving the adhesion of mortars to the substrate, bending and tensile strength, workability, tightness, chemical resistance [1].

The purpose of the performed tests and comparisons was to illustrate the results obtained in the pull-off tests carried out in accordance with the standards in question, and the results of tests that are often performed on construction sites under real conditions.

2. METHODOLOGY – PULL-OFF METHOD

When determining the strength of a concrete element, it is not always possible to rely on the test results of control elements, i.e. cubes and cylinders, due to the various conditions of their production and maturation, as well as the lack of appropriate control elements. Then, non-destructive methods of concrete strength testing are used, thanks to which additional information is obtained on the distribution of concrete strength in the analyzed element [2]. Non-destructive methods of concrete testing are very helpful in cases where taking samples for testing would damage the structure of the tested elements [3]. Because of non-destructive testing, it is possible to obtain information on the strength characteristics, homogeneity and moisture of the concrete built into the tested object, without disturbing its current structure and further usability. These tests are also widely used in quality control and detection of defects in concrete products during their production, as well as in experimental tests, such as the assessment of changes in concrete properties after a specific time or under the influence of specific external factors [4, 5].

As can be seen in the publications of other authors, the influence of tested variables is relatively large [6-8]. Based on the results of the pull-off test, the methods of repairing objects, the possibility of the repair itself or even the selection of appropriate repair materials are determined. However, in order for the test to obtain results appropriate for the analysis, particular attention should be paid to all factors related to it. This article only discusses two variables: different substructure (concrete and aerated concrete) and two ways of test preparation (notched and non-incised). Additional parameters that should also be taken into account when performing the pull-off test are, for example: the temperature of the substrate and measuring discs, their humidity, surface cleanliness, age, environmental conditions in which they work, etc. A large number of factors that directly or indirectly affect test result causes that the pull-off method – commonly recognized as relatively simple – gives appropriate results only for skilled engineers who are aware of the conditions that affect the obtained results [9, 10]. The authors are also aware of their importance, while the article focuses only on the two combinations presented.

The pull-off method is classified as semi-destructive. It consists in measuring the tensile strength, which is necessary to tear off the metal disc glued to the tested surface. The disc diameter should be 50 mm, minimum thickness 20 mm – for steel discs, or 30 mm – for aluminum ones. The test area is determined by the appropriate drilling of the surface [11-13]. The peel-off adhesion test allows the peel strength of coatings, plasters, floors, plasters, weldable roofing membranes etc. on concrete and steel to be assessed. Thanks to this method, it is easy to estimate whether a given surface requires repairs. It is also used immediately before laying all types of repair layers, in order to check the quality of concrete substrate preparation, as well as after the application of repair layers [12, 14].

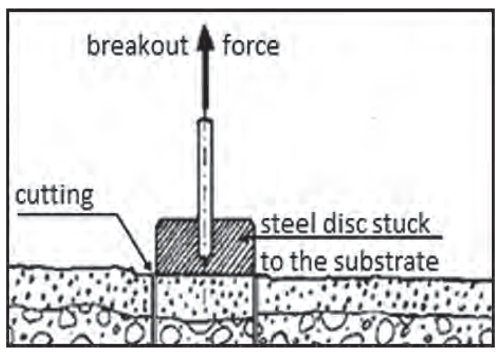

Fig. 1. Pull-off adhesion test – the essence of the measurement [14]

A detailed description of the course of the study is presented in the standard [15]. Before starting the test, the concrete sample should be cleaned of all kinds of dust, preferably with compressed air. According to the standard, the samples should have dimensions of 300 mm × 300 mm × 100 mm with the maximum grain size of the aggregate 8 mm or 10 mm. It is required to make five measurements of adhesion on at least one sample of a given product. The arrangement of the measuring discs is shown in Figure 2. A repair layer should be evenly applied to the concrete sample, prepared according to the manufacturer's recommendations. After a three-day curing period, the sample should be additionally stored for a period of seven days under standard laboratory conditions. After this time, the specimen should be drilled with a diamond core bit at an angle (90 ±1)° to the surface. The borehole should be drilled to a depth of (15 ±5) mm into the concrete substrate. The next step is to glue the discs, which must be properly prepared by grinding and degreasing the surface that will be in contact with the adhesive. Then apply a thin layer of quick-drying two-component epoxy adhesive to the surface of the sample and place the disc so that its center is aligned with the center of the drilled cylinder. After the glue has hardened, you can start to tear off the discs. Various devices for pull-off testing are available on the market, devices with an automatic pump, such as DeFelsko PosiTest AT-A, Elcometer 510 or Proceq Dyna DY-2, are characterized by extremely high accuracy. The tear-off device should be used based on the manufacturer's recommendations. It is placed concentrically over the disk, perpendicular to the drilled surface. The disc should be torn off continuously and evenly, at a speed of (0.05 ±0.01) MPa/s, until failure occurs [15]. The result of the test measurement is the value expressed in MPa, determined from the strength at which the layer of the cut material is broken, to which the disc tearing off the sample fragment is glued, in relation to the surface of the cut layer. The test is reliable if the entire surface of the disc is covered with a stripped layer. The type of sample failure should be determined visually. If there are different types of damage on one sample, their percentage should be specified. Possible types of failure are presented below [15]:

– A: cohesive failure in concrete substrate,
– A/B: failure of the adhesive between the substrate and the first layer (e.g. primer or tie coat),
– B: cohesive failure in the first layer,
– B/C: adhesion failure between the first and second layer,
– C: cohesive failure in the second layer (etc. according to the type of product or system tested),
– – /Y: adhesive failure between the last layer and the adhesive layer (e.g. C/Y with a two-layer repair system),
– Y: cohesive failure in the adhesive layer,
– Y/Z: adhesive failure between the adhesive layer and the disc (marked as Z).

Of course, a completely unreliable result is the failure in the adhesive layer (Y) or between the adhesive and the disc (Y/Z). Obtaining such results proves only the incorrect preparation of the material for testing (bad mixing of the two-component adhesive, non-degreasing of the disc surface, ect). Destruction in the concrete layer (A) shows that the individual re-profiling or repair layers are sufficiently firmly bonded to the substrate. Damage between one of the layers requires additional analysis, e.g. the peel strength obtained in the measurements or even the test repeated.

The test result is influenced by: the type of tear-off device used; thickness, diameter and type of material from which the disc was made; well depth and angle; the method of attaching the holder to the disc; thickness of the substrate and top layer; sample moisture during measurement; the tearing speed [13].

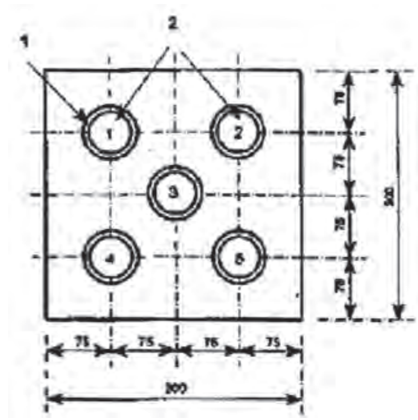

Fig. 2. View of the sample for testing with the arrangement of the discs, dimensions in millimeters; 1 – ring around the test site, formed during drilling, 2 – steel or aluminum discs with a diameter of 50 mm [15]

Fig. 3. Correctly performed adhesion measurement using the pull-off method [14]

3. MEASUREMENTS

The aim of the study was to compare the adhesion between concrete layer and re-profiling system on two variables: two types of substructure (strong, i.e.

concrete, and weak – aerated concrete), and two ways of test preparation (notched and non-incised). Adhesion tests are characterized by a large dispersion of results, therefore 20 tests were prepared and performed (the standard [15] indicates that a minimum of 5 tests should be performed) for each concrete.

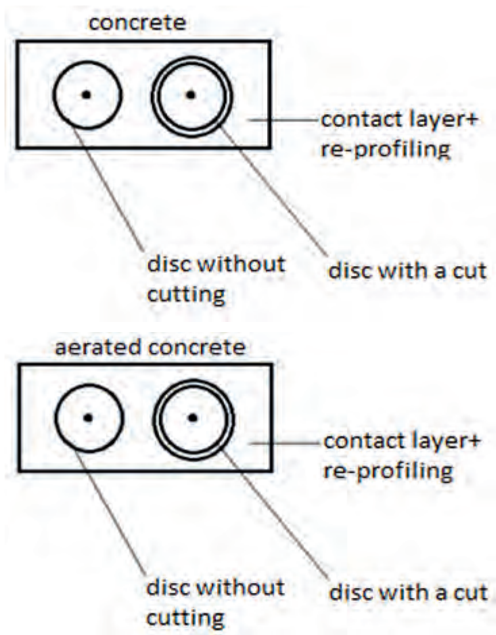

Fig. 4. Diagram showing the materials used and the method of performing the adhesion test (own elaboration)

Eight concrete slabs and eight aerated concrete slabs were used for the test. A mix was made, consisting of a ready-made dry mix of the contact layer of the PCC repair system. The mortar was evenly applied to the cleaned surface of the boards, then another layer of PCC re-profiling mortar was applied to it. The samples were left for 28 days. After this time, another stage of research took place – gluing metal discs. The specimens were trimmed according to the standard [16] with a distinction between non-notched and non-notched adhesion tests.

Fig. 5. Preparation of samples for adhesion tests – mortar application

The surface of the discs has been thoroughly polished and degreased. After applying the two-component epoxy glue, the discs were glued to the boards as shown in Figure 6. At this stage of the research, no drillings were made, and 4 concrete slabs and 4 aerated concrete slabs were used. The authors used the material without cutting in the research, because very often in real conditions on the construction site, during the pull-off tests, the substrate is not cut. This is due to various reasons, but often it is just ignorance.

The adhesion tests were performed with a Proceq dy-216 pull-off tester 72 hours after the metal discs had been glued.

Fig. 6. Metal discs torn off on the surface of the plates

The second stage of the research consisted in carrying out an adhesion test on the surface with making an incision. Before gluing the discs, 4 concrete slabs and 4 aerated concrete slabs were notched with a crown drill until the depth penetrated the concrete layer. On one of the aerated concrete samples, the structure of the material was damaged during cutting, which made it possible to stick only 3 discs. The further procedure is the same as for peeling discs without notches.

Fig. 7. Discs torn off from the aerated concrete surface with cuts

Fig. 8 Discs detached from the concrete surface with cuts

4. RESULTS

The Table 1 summarizes all the obtained results of PCC mortar adhesion tests to the surface of concrete samples and aerated concrete without incisions and with incisions.

Table 1. Results of adhesion tests

No.	Breakout strength in non-incised samples [MPa]		Breakout strength in notched samples [MPa]	
	concrete	aerated concrete	concrete	aerated concrete
1	2.04	1.47	1.54	
2	2.56	0.71	1.82	1.06
3	2.49	1.46	2.79	0.63
4	2.59	1.80	0.73	1.12
5	2.95	1.78	2.90	1.02
6	3.36	1.77	2.55	0.63
7	4.23	1.59	3.44	1.00
8	1.92	2.02	2.04	1.35
9	1.76	2.20	2.50	0.98
10	0.87	2.00	2.71	0.37
11	2.28	1.22	3.40	0.92
12	2.53	1.47	2.78	0.30
13	3.55	1.40	1.42	1.00
14	2.55	1.73	2.89	0.76
15	1.13	1.96	2.06	0.90
16	5.02	2.33	2.97	0.98
17	3.80	2.21	2.88	1.51
18	5.13	2.12	1.57	0.76
19	4.12	2.11	3.19	0.68
20	1.81	1.81	2.69	
avg.	2.83	2.44	1.76	0.89
standard deviation	1.1522	0.7065	0.3843	0.2951

For better understand the standard deviation, results are presented in Figure 9.

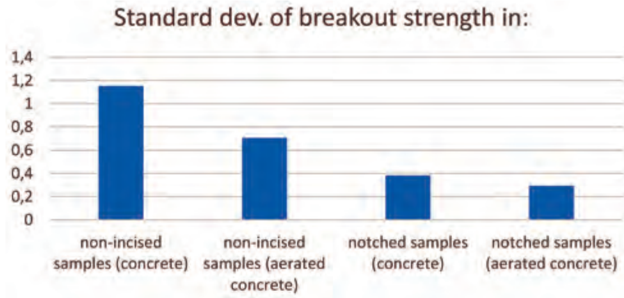

Fig. 9. Standard deviation of breakout strength in non-incised and notched samples

As can be seen in the diagram (Fig. 9), notching the coating before the measurement has a relatively large impact on the scatter of the obtained results.

Figures 10 and 11 presents a breakdown of the damage depending on the material and test method.

Fig. 10. Damage during adhesion tests on non-incised samples of concrete (left) and aerated concrete (right)

Fig. 11. Damage during adhesion tests on notched samples of concrete (left) and aerated concrete (right)

By analyzing the above photos, we can see differences in the way the material is detached. In the case of concrete, the damage occurs in the repair layers. In aerated concrete, which is a weak material, the measuring disc with repair layers also tears off a fragment of the substrate. In addition, during the tests without cutting, the aerated concrete showed complete destruction of the material structure, as shown in the photo.

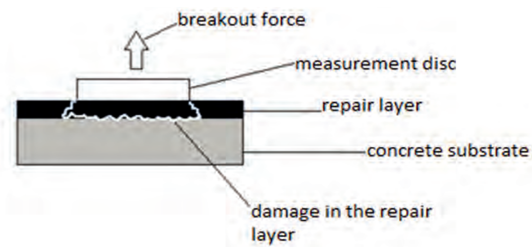

Fig. 12. Diagram showing the method of failure in a concrete sample without incising

The above figure shows the observed pattern of failure occurring in a concrete sample without an incision. The damage is visible in the repair layers, it extends slightly beyond the area where the measuring disc is attached and does not reach the concrete substrate, which is a strong material. The failure type that occurs is cohesiv e failure.

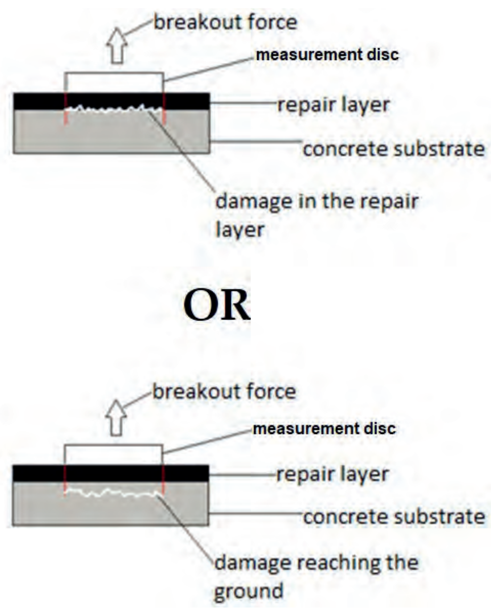

Fig. 13. Diagram showing the method of destruction in a concrete sample with an incision

Figure 13 shows the observed pattern of damage occurring in a concrete sample with cuts. Damage manifests itself in two ways. They can only occur in the repair layer as well as in the concrete layer at the depth of the cut. The types of failure are cohesive failure (first scheme) and adhesive failure (second scheme).

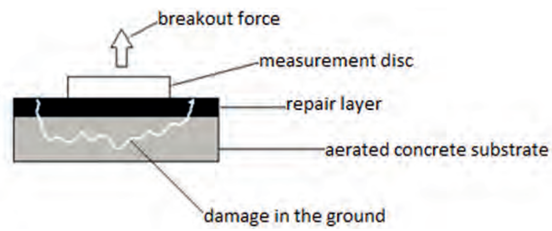

Fig. 14. Diagram showing the method of destruction in an aerated concrete sample without incision

Figure 14 shows the observed damage pattern in an aerated concrete sample without cuts. The damage goes deep into the layers of the material, damaging to a large extent the structure of the substrate and causing it to cracks all over the surface. The failure type that occurs is adhesive failure.

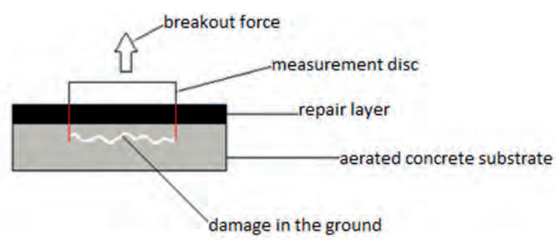

Fig. 15. Diagram showing the method of destruction in an aerated concrete sample with cuts

In Figure 15, the observed pattern of damage in an aerated concrete sample with notches is presented. The damages are visible in the substrate along the width of the previously made incision. The failure type that occurs is adhesive failure.

5. CONCLUSIONS

The test of adhesion without cutting gives results with a larger spread than in the case of notched materials.

By analyzing the results summarized in Table 1, it can be seen that the average adhesion on concrete samples is lower in the case of notched samples by 0.39 MPa (about 14%). The dispersion of the individual measurement results is significantly smaller in the case of notched concrete.

When analyzing the results summarized Table 1, it can be seen that the average adhesion on aerated concrete samples is much lower in the case of notched samples. The difference is 0.87 MPa (approximately 50%). The dispersion of the individual measurement results is slightly smaller in the case of incised aerated concrete.

The variety of results may indicate the heterogeneity of the substrate or the inaccuracy of the test itself due to the method of sample preparation or the uneven application of the detachable strength. It is more visible in the case of tests on concrete samples. The results contain information not only about adhesion to the substrate, but also about the cohesion, i.e. cohesion, of the repair material itself. The method of detaching the material from the tested samples shows a much greater cohesive effect in concrete particles compared to aerated concrete. The introduction of a cut with a diamond core drill simplifies the tested state of stress to uniaxial detachment, and the then observed nature of the damage allows to determine whether it was an adhesive or a cohesive failure.

From the point of view of ease of interpretation of the results, notching the substrate is desirable, however, testing without incision corresponds to the conditions in which the substrate and repair layers work. Because of that and in connection with the need for an appropriate interpretation of the results, in Authors opinion, it is recommended to incise the samples before pull-off testing.

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