Effect of concrete substrate texture on the adhesion properties of PCC repair mortar

Luc Courard[1], Damien Schwall[2]

Université de Liège, Département GéomaC
Civil Engineering Institute, Chemin des Chevreuils, 1
B – 4000 Liège, Belgium

Andrzej Garbacz[1], Tomasz Piotrowski[2]

Warsaw University of Technology, Faculty of Civil Engineering
Department of Building Materials Engineering
Al. Armii Ludowej 16, 00-637 Warsaw, Poland

ABSTRACT

The study of adhesion of repair materials on concrete structures implies a good knowledge of the influence of concrete surface characteristics. A large research project has been realized with regards to the influence of concrete substrate strength and preparation technique efficiency. Three types of concretes and four types of surface preparation have been combined in order to obtain twelve different concrete slabs. They have been characterized according different destructive and non destructive techniques: Schmidt hammer, compressive strength, superficial cohesion (pull-off tests), Impact Echo measurements and cracking quantification (microscopical observations). Finally, a polymer cement concrete mortar has been applied and adhesion has been evaluated by means of pull-off and laboratory tensile tests. The relationships between parameters describing surface quality (roughness, cracking), adhesion strength and stress wave propagation have been analysed.

1. INTRODUCTION

Before any repair operation, an effective assessment of the concrete substrate has to be performed. Usually next to the surface reparation of concrete, evaluation of the cohesion of the superficial concrete is requested for adhesion and durability reasons. Many authors describe the influence of the surface preparation technique on the superficial cohesion of concrete (Silfwerbrandt 2005, Courard et al. 2005) or the adhesion (Pretorius and Kruger 2001, Garbacz et al. 2005). However, the real effects of surface preparation technique only begin to be investigated in terms of superficial microcracking or roughness quantification (Czarnecki et al. 2003, Courard et al. 2005, Courard et al. 2004, Silfwerbrand 1998).

---

[1] Assistant Professor
[2] Research Assistant

This project was performed with regards to the influence of concrete substrate strength and preparation technique efficiency. Three types of concretes and four types of surface preparation have been combined in order to obtain twelve different concrete slabs. The quality of the superficial concrete has been characterized according different destructive and non destructive techniques: Schmidt hammer, compressive strength, superficial cohesion (pull-off tests), Impact Echo measurements and cracking quantification (microscopical observations).

Finally, a self-compacting PCC mortar has been applied and adhesion has been evaluated by means of pull-off and laboratory tensile tests. The relationships between parameters describing surface quality (roughness, cracking), adhesion strength and stress wave propagation have been analysed.

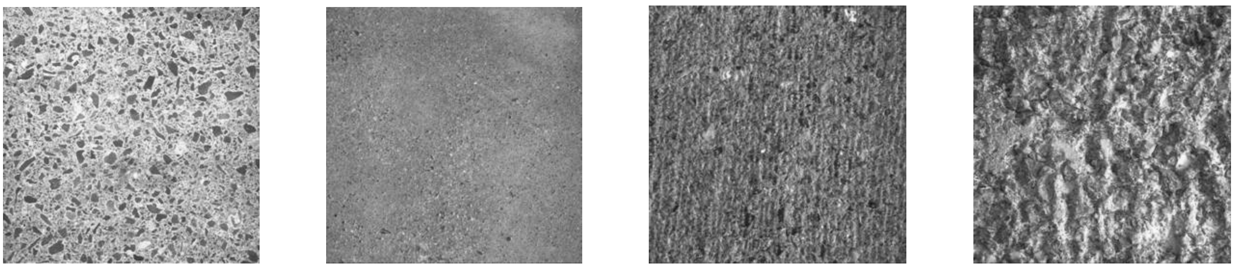
2. DESCRIPTION OF MATERIALS AND SURFACE PREPARATIONS

The effect of the concrete removal/preparation technique is most likely dependent upon the nature and the quality of the concrete substrate. Three types of concrete were designed in order to obtain C30/37, C40/50 and C50/60 concrete, respectively (Table 1).

Table 1 - Composition of concretes

	C30/37	C 40/50	C50/60	Unit
Cement CEM I 52,5 N	275	325	375	kg/m^3
Rhine Sand (0/2 mm)	765	729	676	kg/m^3
Rounded aggregate (2/8 mm)	255	230	206	kg/m^3
Rounded aggregate (8/14 mm)	569	576	601	kg/m^3
Rounded aggregate (14/20 mm)	390	401	412	kg/m^3
Water	197	192	188	$10^{-3} m^3$
W/C ratio	0.72	0.59	0.50	

Four types of surface preparation techniques were investigated: sandblasting, scabbling, water jetting (250 MPa of pomp pressure during 5 min) and polishing (Schwall 2005). Polishing is obtained by means of two abrasive and rotative wearing plates until obtaining smooth touch surface. The visual observation of the concrete surfaces indicates that the high pressure water jetting technique induces a particular texture characterized by large waves mostly parallel to the water flow (Fig.1).



polishing | sandblasting | scabbling | hydro-jetting

Figure 1 – Examples of concrete surface after preparation

The concrete slabs have been covered by a Self-Compacting commercial PCC mortars (5-cm thick) characterized by a flexural strength of 7.27 MPa and a compressive strength of 54.61 MPa (24-hours old).

3. MECHANICAL CHARACTERISTICS OF SUPERFICIAL CONCRETE

3.1. Schmidt Hammer test (before repair)

The cohesion of the superficial concrete has been first evaluated by means of Schmidt hammer. Ten measures have been taken in vertical direction; only polished surfaces strictly present adequate conditions to perform the test (Piotrowski 2005), which requires flat and leveled surface and only results on polished slabs are presented (Table 2). Other surfaces are theoretically too rough for this test method.

The Schmidt Hammer results on polished samples are lower than compressive strength evaluated through compression test on cylinders. These values can be used for calibration of Schmidt Hammer for this kind of concrete: the normative coefficient varies from 1.30 to 1.41 (Table 2).

Table 2 - Schmidt hammer test results for concretes of various strength classes after polishing

Concrete type	Mean rebound number, R	Estimated compressive strength on the base of Producer's reference curve, f_{ck}, [MPa]	Compressive strength determined on the cube $f_{ck,cube}$ [MPa]	$\gamma = f_{ck,cube} / f_{ck}$
C30/37	34.3	35.32	45.88	1.30
C40/50	36.2	38.75	53.29	1.38
C50/60	39.3	44.15	62.12	1.41

3.2. Pull-off test before repair

Pull-off test is usually performed in order to evaluate the bond strength between concrete substrate and repair material; if the test is made in absence of repair layer, it can be adopted as a cohesion measurement of the superficial concrete (Courard, et Bissonnette 2004).

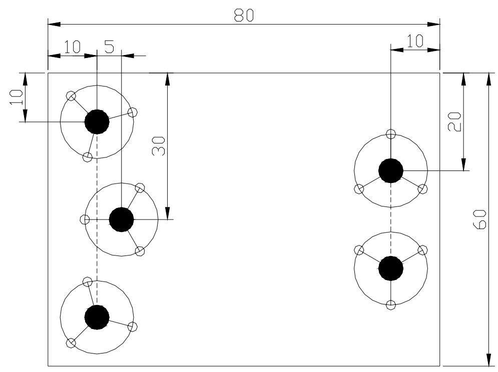


Figure 2 - Distribution of pull-off points after surface treatment

The test conditions (Fig.2) have been defined according to the practice (Courard and Bissonnette 2004):

- Diameter of the steel dolly: 50-mm;
- Depth of coring: 15-mm;
- Number of tests: 5;
- Loading rate: 0.05 MPa/s

The pull-off test results show higher strength values in comparison with the calculated values of $f_{ctm} = 0,3 \cdot \left(f_{ck,cyl}\right)^{2/3}$ (Table 3). Moreover, the next partial conclusions can be given:

- there seems to be a correlation between the degree of aggressiveness and the reduction of strength: while sandblasting only induces a small decrease of pull-off strength, hydro jetting and scabbling, which are more energetic surface treatments, produce a larger decrease of resistance (12 and 13 %, respectively);
- the concrete quality – in terms of characteristic compressive strength – doesn't seem to have a major influence on the cohesion of the superficial concrete. The less influence on the pull-off strength reduction was observed for the C50/60. However, the high strength rates of the concretes probably limit the influence of the surface treatment on the quality of the surface.

Table 3 - Pull-off test results after surface treatment

pull-off strength [MPa]				
$f_{ck,\,cyl}$	C30/37	C40/50	C50/60	Mean
Polishing	4.29	4.07	3.71	4.02
Sandblasting	3.70	3.93	3.76	3.80
Scabbling	3.39	3.51	3.58	3.49
Hydro jetting	3.53	3.54	3.59	3.55
Mean	3.73	3.76	3.66	-
f_{ctm}	2.90	3.51	4.07	-

Three types of rupture (Fig.3) have been considered in the analysis: superficial, middle and deep. The last mode means that the rupture happened at the depth coring (15-cm). In the case of polished and sandblasted slabs, main failures appeared in the middle or in the bottom of cores. Otherwise, for scabbling and hydrojetting techniques, ruptures have been observed mainly in near-to-surface area, that means 75 and 33%, respectively; this is probably due to microcracks developed in this zone during surface preparation (see chapter 5).

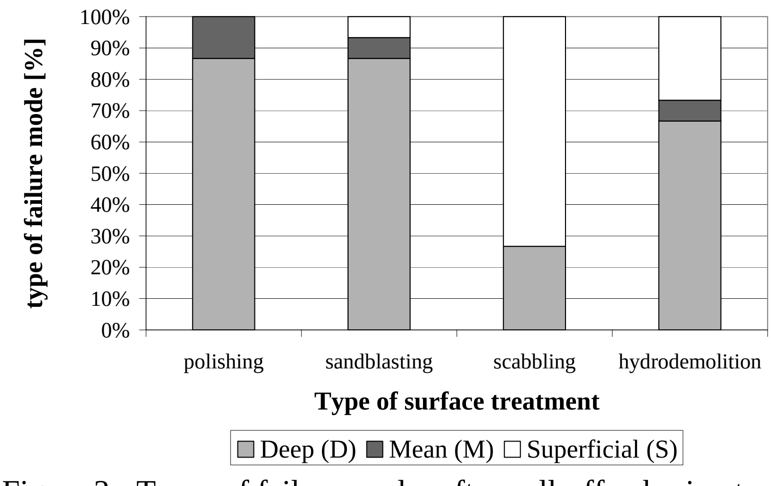


Figure 3 - Types of failure modes after pull-off cohesion test

4. ROUGHNESS AND WAVINESS QUANTIFICATION

A first evaluation of the surface roughness has been realized by means of Average Texture Depth test, according to prEN 13036-1 (2000): a defined volume of specific sand is sprayed on the concrete surface, the diameter of the "circle" is measured and Average Texture Depth calculated from $ATD = \frac{4 \cdot V}{\pi \cdot d^2}$. The larger the diameter, the lower ATD, the smoother the surface (Fig.4).

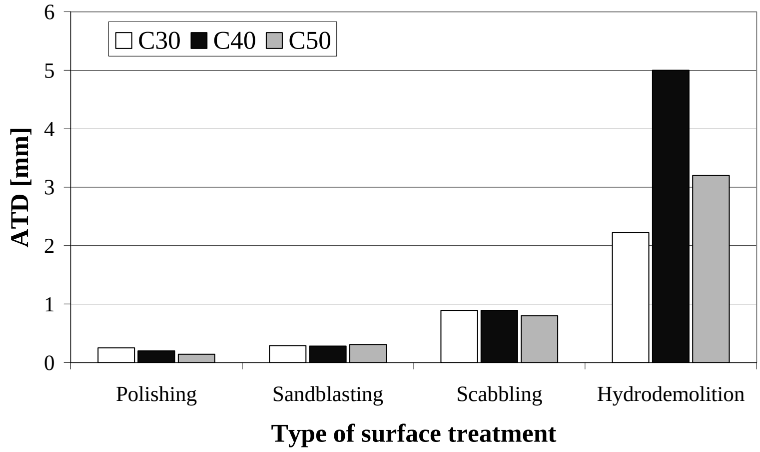


Figure 4 – Average Texture Depth values after surface preparations on different concretes

The validity of the test is between 0.25 mm and 5 mm: the results are consequently at the level of the inferior limit value for polished surfaces.

Opto-morphology technique (Perez et al., 2005) has also been used afterwards in order to calculate amplitude and statistic parameters; they have been evaluated with RugoDS program (Schwall, 2005), based on MatLab 7.0, that permits to process numeric data from representation of Moiré projection (Fig.5).

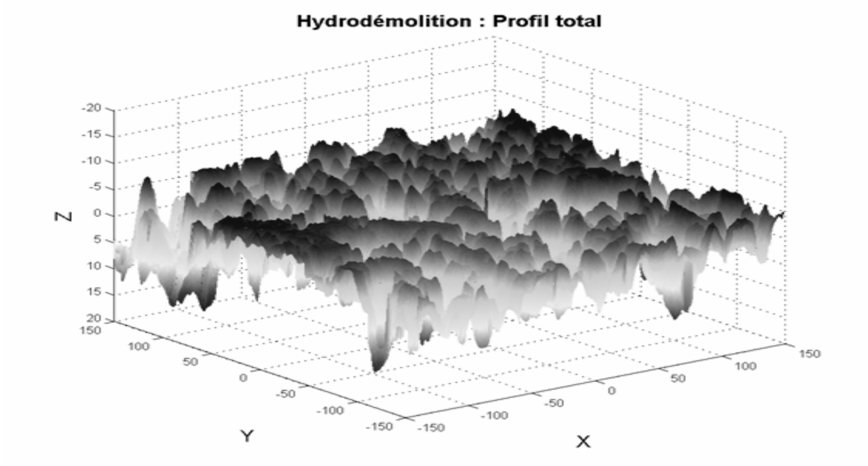


Figure 5 – total profile obtained after hydro demolition technique

One of the information coming from surface analysis is the bearing ratio and the Abbott's curve (Courard and Nélis, 2003). The surface parameters defined on the basis of this curve let us to analyse not only the depth of the holes but also the shape of the profile: C_F represents the depth of the profile, excluding high peaks and holes; C_L is the relative height of the holes and C_R the relative height of the peaks. The C_F parameter gives an idea of the flatness of the surface: the lower it is, the more flat the profile is. Parameter C_L gives an idea of the volume of voids, beneath the mean line of the profile, which could be fulfilled by the bond coat or the repair material.

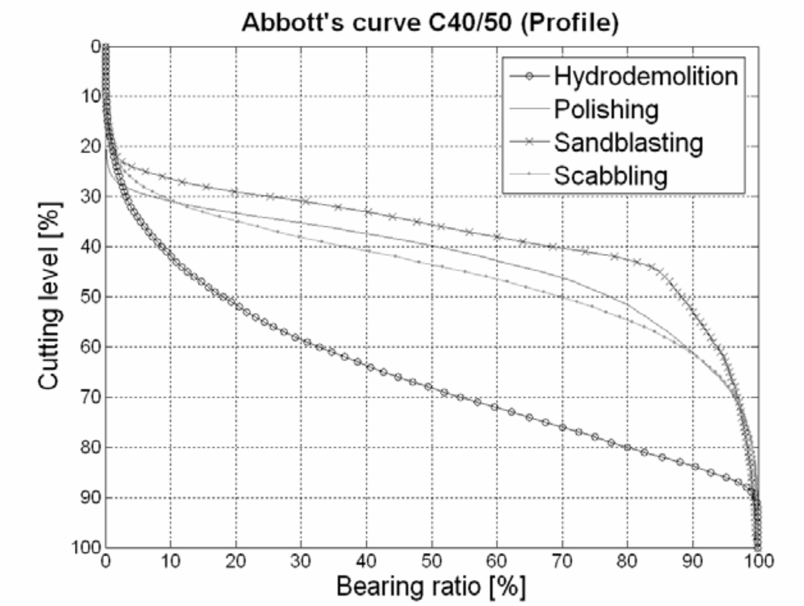


Figure 6 - Abbott's parameters for the surface preparation techniques on C40/50 concrete

Figure 6 clearly shows the effects of two groups of technique: the first group – polishing, sandblasting, scabbling – is giving surface without big peaks and deep holes, while waterjetting induces a very irregular surface, which is confirmed by the values of C_F parameter (Table 4). Analysis of C_R parameter also shows the larger quantity and amplitude of peaks for hydrojetting surface preparation.

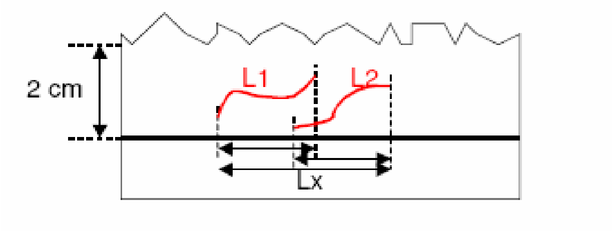
Table 4 - Abbott's parameters for the surface preparation techniques on C40/50 concrete

Parameter [mm]	Polishing	Sandblasting	Scabbling	Hydro-jetting
C_R	0.34	0.56	0.87	5.46
C_F	0.76	1.17	1.31	5.7
C_L	0.27	3.1	1.83	2.61

5. MICROCRACKING

The samples used for microscope observations (80 mm in diameter and approximately 150 mm in length) were cored from the concrete substrates. The cores were sawn in two parts along their main axis. The surfaces to be observed were then polished with abrasive powders (Courard et al., 2005).

An optical binocular microscope was used for the investigation (Fig.7). The surface of investigation was delimited by drawing a straight reference line parallel to the prepared surface plane. The line was drawn approximately 20 mm from the surface, since in any case no more cracks could be observed below. The samples have been polished with a grain sand paper nr 400 (Schwall, 2005).



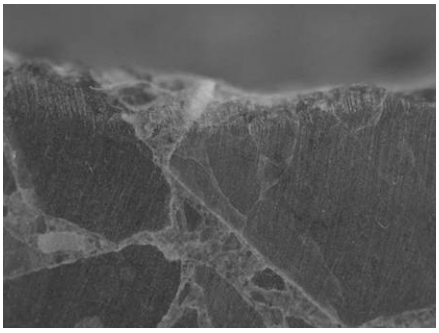


Figure 7 - Evaluation of the length (L_i) of the cracks
and their projection on horizontal reference (L_x)

Number and length of microcracks have been systematically registered on the three types of concretes and four types of surface preparation (Fig.8).

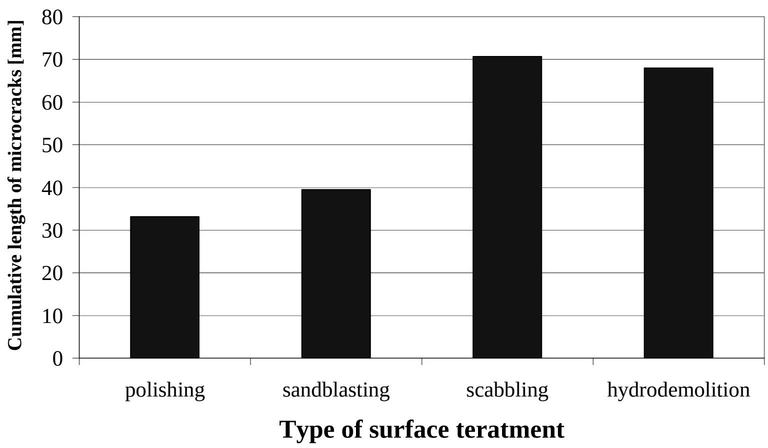


Figure 8 – The mean of microcracks cumulative length for three types of concrete after various surface treatment

The results we obtained do not allow to point out any effect of the quality of concrete; the surface preparation technique seems however to influence the length of the cracks observed on the first 2 centimetres. Scabbling induces almost 75% and 100% more cracks than sandblasting and polishing, respectively. The similar results obtained for water jetting and scabbling are more surprising, even if they show relatively low quantity of cracks. These results follow however the same classification than for the pull-off test and the Schmidt hammer test.

Another interesting information is coming from L_{total} / L_X ratio calculation (Table 5), where L_{total} represents the cumulative length of the cracks. This parameter gives an idea of the slope of the cracks in relation to the surface. In the case of polished slabs, the cracks are more parallel to surface, while they seem more perpendicular oriented for scabbling. The conclusion is aggressive type of surface preparation, with the highest number of cracks, have the lowest L_{total} / L_X ratio.

Table 5 – Evaluation of the slope of the cracks

Technique	L total/ Lx
Polishing	0.653
Sandblasting	0.527
Scabbling	0.439
Water jetting	0.527

6. BEHAVIOUR OF CONCRETE REPAIRED SLABS

6.1. Pull-off test after repair

When repair was 28 days old, pull-off tests were performed in order to evaluate the bond strength between concrete substrate and repair layer. The test conditions were the same as for cohesion test. Surface preparation effect can be again divided in two groups with regards to EN 1504-10: bond strength after hydrodemolition and sandblasting is greater than the threshold minimum values for laboratory performance: 2.0 MPa for structural repair, 1.5 MPa for non structural. The bond strength for polishing and scabbling is close to or below the limit (Table 6).

Table 6 - Pull-off test results after repair

pull-off strength [MPa]				
$f_{ck, cyl}$	C30/37	C40/50	C50/60	Mean
Polishing	1.91	2.36	0.86	1.71
Sandblasting	2.04	2.19	2.16	2.13
Scabbling	1.02	1.42	1.66	1.36
Hydro jetting	2.51	2.54	2.30	2.45
Mean	1.87	2.13	1.74	-

It can be also concluded from pull-off results that sandblasting and hydrodemolition techniques produce a better surface preparation, taking into consideration the bond strength criteria (Fig.9). Moreover, the class of concrete has no influence on bond strength for sandblasting or hydrodemolition but it could have an effect in case of polishing and scabbling.

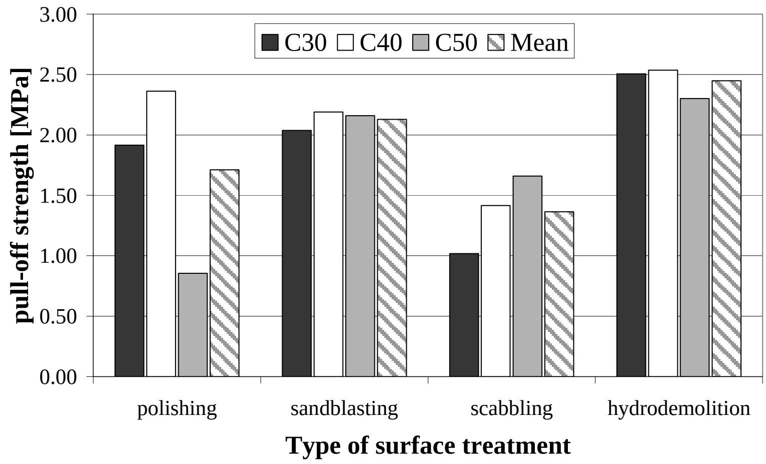


Figure 9 - Pull-off strength for tested repair systems

On the base of a visual assessment, the type of failure was registered for each specimen. In case of slabs treated by polishing, all failures appeared at the interface between concrete substrate and repair mortar. Scabbled surfaces present ruptures near to interfacial zone, due to microcracks. Situation is more unclear for sandblasting and hydrodemolition techniques: in both cases, cohesive A and interface A/B failures were observed (Fig.10).

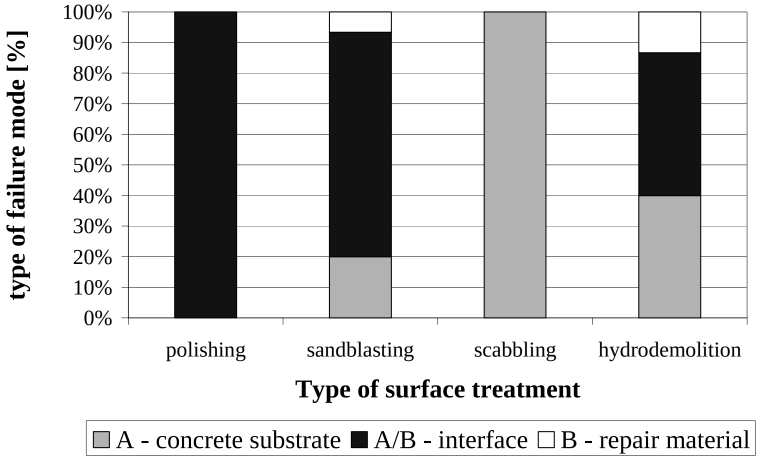


Figure 10 - Types of failure modes after pull-off adhesion test

6.2. Schmidt Hammer test (after repair)

The Schmidt Hammer test was performed on repaired slabs (three classes of concrete and four types of surface preparation) - Table 7. These results of rebound number measurements obtained for polished samples before repair were treated as the reference ones.

Table 7 – The mean rebound number for samples (after repair)

Rebound number	Type of concrete substrate											
	polishing			sandblasting			scabbling			hydrodemolition		
	C30	C40	C50	C30	C40	C50	C30	C40	C50	C30	C40	C50
R_{after}	34.7	35.5	35.0	36.1	34.7	35.5	34.9	34.8	33.1	34.5	34.9	33.3
Comparison												
R_a/R_b	1.01	0.98	0.89	1.05	0.96	0.90	1.02	0.96	0.84	1.01	0.96	0.85

The results obtained showed that surface treatment influenced the rebound number value for repair systems with concrete substrate of higher strength – the rebound number decreased about 15% in the case of more aggressive treatments like scabbling or hydrodemolition. However this decrease did not correspond to pull-off strength. This indicates that a rebound number method is not suitable for an assessment of bond quality in repair systems.

6.3. Impact-echo test

Impact-Echo method is based on mechanical, high energy impact of a steel ball of given diameter used to generate the stress waves that penetrate the concrete. The displacement of the surface of the element is registered by a piezoelectric oscillation converter set next to the impact point. The amplitude vs time is generated and transformed by Fast Fourier Transformation (*FFT*) into the frequency spectrum. Analysis of this spectrum allows for inside discontinuity of concrete structure detection.

The analysis of graphics coming from repaired concrete slabs shows that there is one clear and high peak in area of frequencies from interface (around 75 kHz) in case of polishing (Fig.11). Spectrums of sandblasted samples do not have any peak apart from the bottom one. For scarification, there is no specific peak at the level of interface frequencies but a wide plateau located on depth < 10 mm from the interface – probably an effect of near-to-surface highly cracked area. Finally, for hydrodemolition, there are a lot of medium high peaks corresponding to the depth from 29 to 50 mm, what is probably due to very rough surface and air voids in this area.

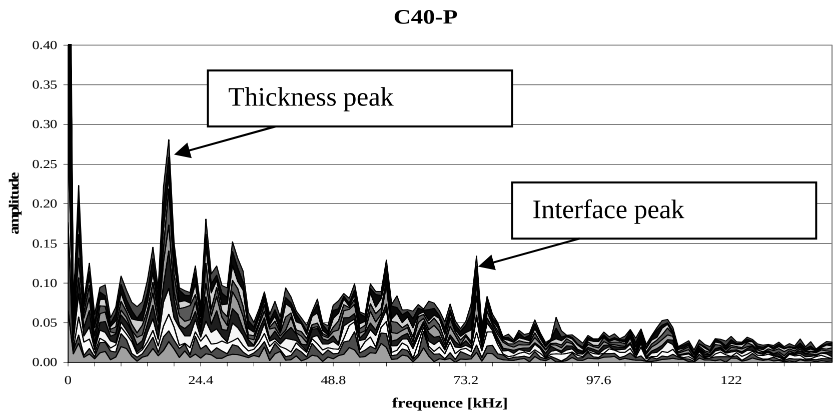


Figure 11 – Impact-echo principle and frequency spectrum for polished slab of C40/45

7. CONCLUSIONS

The following conclusions may be reached from the present investigations concerning the concrete substrate evaluation and the adhesion of repair systems:

- polishing, sandblasting, scabbling give surfaces without big peaks and deep holes, while hydrojetting induces a very irregular surface, which is confirmed by the values of C_F;
- surface preparation technique influence microcracking observed in superficial zone of concrete (2-cm): scabbling and hydrodemolition induce almost two times higher number of microcracks than sandblasting and polishing and they are more perpendicular to the surface;
- the concrete quality did not have a major influence on the cohesion of the superficial concrete;
- bond strength after hydrodemolition and sandblasting is greater than the threshold minimum values for laboratory performance, while it is close to limit for polishing and scabbling;
- in the case of polishing, all failures during pull-off test appeared at the interface between concrete substrate and repair mortar. Scabbled surfaces present ruptures near to interfacial zone, due to microcracks;
- the class of concrete has no influence on bond strength for sandblasting or hydrodemolition but it could have an effect in case of polishing and scabbling;
- quality of interface had effect on the character of high frequency part (corresponding to interface frequency peak) of frequency spectrum specific for a given type of surface treatment;
- surface treatments influence the rebound number value for repair systems – the rebound number decreased about 15% in the case of more aggressive treatments like scabbling or hydrodemolition for concrete substrate of higher strength. However this decrease did not correspond to pull-off strength.

These conclusions lead to the next consideration: microcracking is really an essential parameter in the evaluation of the quality of concrete substrate before repairing. However, it remains a very difficult property to clearly evaluate, which necessitate long preparation and laboratory investigations: on-site test like surface permeation should be soon developed in order to help concrete surface assessment.

8. REFERENCES

Courard L., Bissonnette B., Essai dérivé de l'essai d'adhérence pour la caractérisation de la cohésion superficielle des supports en béton dans les travaux de réparation : analyse des paramètres d'essai.. *Mater. Struct.*, 37, 342-350 (2004).

Courard, L., Bissonnette, B. and Belair, N. Effect of surface preparation techniques on the cohesion of superficial concrete: comparison between jack-hammering and water-jetting. In: ICCRRR 2005 International Conference on Concrete Repair, Rehabilitation and Retrofitting (Eds. H. Beushausen, F. Dehn and M.G. Alexander), Cape Town, South Africa, 1027-1031 (2005).

Courard, L. and Nélis, M. Surface analysis of mineral substrates for repair works: roughness evaluation by profilometry and surfometry analysis. *Magazine of Concrete Research.* **55**(4), 355-366 (2003).

Courard L., Garbacz, A. and Gorka, M. Concrete surface treatments quantification by means of mechanical profilometry. in: ICPIC, XIth International Congress on Polymers in Concrete (Ed. M. Maultzsch, Federal Institute for Materials Research and Testing), Berlin, Germany (2-4 June 2004), 125-132 (2004).

Czarnecki, L., Garbacz, A., Kostana, K., "The Effect of Concrete Surface Roughness on Adhesion in Industrial Floor Systems", 5th Colloquium Industrial Floors, Esslingen, 2003.

Garbacz, A., Gorka, M. and Courard, L. Relationship between surface characteristics and superficial cohesion of concrete. In: ICCRRR 2005 International Conference on Concrete Repair, Rehabilitation and Retrofitting (Eds. H. Beushausen, F. Dehn and M.G. Alexander), Cape Town, South Africa, 1021-1026 (2005).

Garbacz, A., Courard, L., and Gorka, M. On the effect of concrete surface treatment on adhesion in repair systems. *Magazine of Concrete Research*. **57**(1), 49-60 (2005).

Perez, F., Bissonnette, B. et Courard, L. Outils de caractérisation paramétrique de la rugosité des surfaces en béton : nouveaux développements. In : Journées scientifiques du RF²B, 25-26 août, Sherbrooke, Canada (2003).

Pretorius, J. and Kruger, D. The influence of surface roughness on the bond strength of concrete repairs. In: Xth International Congress on Polymers in Concrete (ICPIC 01, Ed. D. Fowler), Honolulu, Hawaï, p13 (2001).

Perez, F., Courard, L., Bissonnette, B., Garbacz, A. and Gorka, M. Comparison of two different techniques for the evaluation of concrete surface roughness. In: ICCRRR 2005 International Conference on Concrete Repair, Rehabilitation and Retrofitting (Eds. H. Beushausen, F. Dehn and M.G. Alexander), Cape Town, South Africa, 1015-1020 (2005).

Piotrowski, T. Effect of concrete quality on stress wave propagation in repair systems. M.Sc. Thesis at the Warsaw University of Technology (2005).

Silfwerbrand J., Beushausen H., Bonded concrete overlays – bond strength issues, In: ICCRRR 2005 International Conference on Concrete Repair, Rehabilitation and Retrofitting (Eds. H. Beushausen, F. Dehn and M.G. Alexander), Cape Town, South Africa, 53-61 (2005).

Silfwerbrand J. and Paulsson J., Better bonding of bridge deck overlays, Concrete International, 20, 56-61 (1998).

Schwall, D, "Analyse de l'effet des techniques de préparation sur la rugosité des surfaces en béton", Travail de fin d'études en vue de l'obtention du grade d'Ingénieur civil des constructions, 2005 (in French).

9. ACKNOWLEDGMENTS

The authors are thankful to Professor L.Czarnecki, Head of the Building Materials Engineering Department at the Warsaw University of Technology for his valuable discussion and remarks. The research project was financially supported by the Government of Poland (KBN) and the Regional Government of Wallonia (DRI), Belgium, through the Scientific

Cooperation Project "Etude des mécanismes et caractérisation de l'adhésion au moyen de méthodes destructives et non-destructives" (2005). Part of experiments have been done in the framework of project granted by Polish Scientific Research Committee - grant number KBN 4T07E02727 (2004-2006)