Two different techniques for the evaluation of concrete surface roughness

L. Courard
GeomaC Department, Université de Liège, Liège, Belgium

F. Perez and B. Bissonnette
CRIB - Civil Engineering Department, Université Laval, Québec, Canada

M. Gorka and A. Garbacz
Institute of Construction Engineering & Management, Faculty of Civil Engineering, Warsaw University of Technology, Poland

ABSTRACT: The study of adhesion of repair materials on concrete structures implies a good knowledge of the influence of concrete surface treatment. The effects of surface preparation technique is rarely clearly described and parameterised: it is consequently difficult to point out the real influence of roughness on adhesion results. A first step was made by using mechanical profilometry to differentiate concrete surfaces prepared by shot blasting, sand blasting and hand or mechanical milling. This technique is very accurate for investigations in laboratory, on a limited surface area. If Quality Control is requested or if it is impossible to core samples from the site, other procedures should be followed. That the reason why opto-morphometry analysis has been developed, in order to analyse larger surfaces. The comparison of the two techniques shows clearly the advantages of each one and the precision that can be achieved.

1 INTRODUCTION

The study of adhesion of repair materials on concrete structures implies a good knowledge of the influence of concrete surface treatment (Courard 2000). Many authors describe the influence of the surface preparation technique on the superficial cohesion of concrete (Courard et Bissonnette (a) & Courard et al. 2005) or the adhesion (Silfwerbrand 1990, Pretorius et Kruger 2001 & Courard et al. (b)). However, the effects of surface preparation technique is never clearly described or quantified: it is consequently difficult to point out the real influence of roughness on adhesion results, as this is disturbed by other effect like microcracking or bond coating (Pretorius and Kruger 2001 & Courard et Bissonnette (a)).

A first step was made by using mechanical profilometry to differentiate polished and sandblasted concrete surfaces (Courard 1998, Courard and Nélis 2003 & Courard and Garbacz 2004). This technique is very accurate for investigations in laboratory, on a limited surface area. If Quality Control is requested or if it is impossible to core samples from the site, other procedures should be followed. That the reason why optical analysis has been developed (Perez et al. 2003) in order to analyse larger surfaces. The comparison between the two techniques is presented hereafter.

2 DESCRIPTION OF MATERIALS AND SURFACE PREPARATION

The effect of the concrete removal/preparation technique is most likely dependent upon the nature and the quality of the concrete substrate. The concrete mixture selected to cast the test specimens (substrate) for the purpose of this study is a 0.40 W/C micro-concrete (10-mm maximum size aggregate) used as a reference material in many on-going research projects conducted at Laval University in relation with repair and rehabilitation (Courard et al. 2005).

Table 1. Test specimens and surface preparation

Reference	Type of preparation
PTW	Polished troweled surface
HPW	High pressure water jetting
SC2	Scarifying

Three types of surface preparation techniques were investigated (Table 1): scarifying, high pressure water jetting (18000 psi pressure and 6 gal/h water flow) and polishing. 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 while scarifying will generally induce some oriented macro-roughness (grooved surface); though in this study it was intentionally eliminated by the operator by means of successive transverse and perpendicular operations.

The samples used for mechanical profile investigations (100-mm in diameter) were cored from concrete blocks specimens. The cores were sawn in two parts (identified a and b), along their main axis.

3 SCALE EFFECT AND ROUGHNESS PARAMETERS

After treatment, concrete surfaces present fractal topography. As for any fractal object, it is possible to break up this surface or this profile in a sum of under-profiles. Each under-profile can be differentiated in terms of wavelengths; there is however no limit or precise criterion to validate the choice of decomposition method.

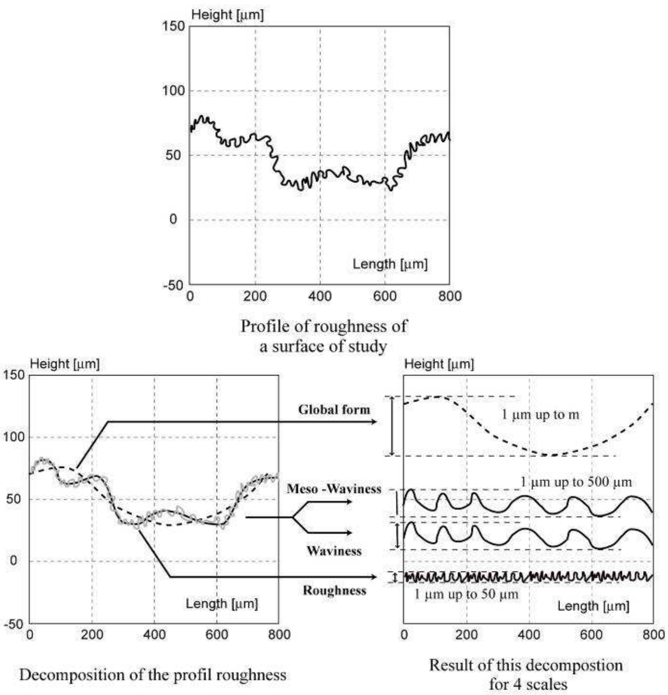


Figure 1. Scale effect on profile decomposition

In the two applications presented hereafter, two distinct methods of decomposition are used. Nevertheless, they use the same approach principles and they have the same objective. As the two methods have different resolutions, they make it possible to reach complementary scales of topography. The method with mechanical stylus (chapter 4) and high resolution reaches two scales of roughness named: roughness (R) and waviness (W). The optical method, (chapter 5) with a resolution of 0.200-µm, makes possible to reach two higher scales named meso-waviness (M) and form (F).

A series of parameters make it possible to break up a total wave into two waves. The determination of surface parameters (Table 2) is realised on the basis of the mean line as a reference line (Courard 1998).

Table 2. Profile amplitude and statistic parameters.

Parameter	*Definition*
X_t	total height of the profile
X_v	maximum depth of the profile (holes)
X_p	maximum height of the profile (peaks)
X_a	arithmetic mean of the deviation of the profile from the mean line
X_q	quadratic mean of the deviation of the profile from the mean line
S_k	skewness of surface height distribution
S_m	mean spacing between profile peaks at the mean line, measured over the assessment length

Another interesting information from surface analysis is the bearing ratio (Courard & Nélis 2003) and the Abbott's curve (Fig. 2). 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.

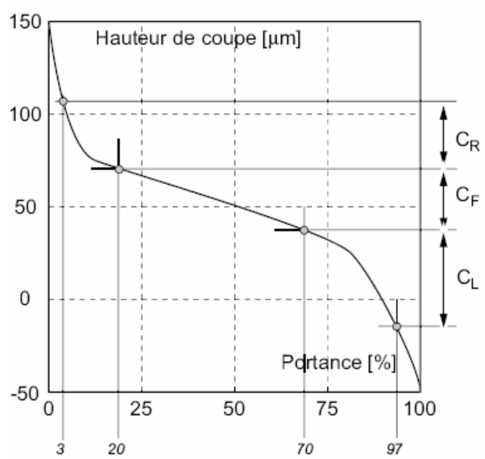


Figure 2. Abbott's curve (curve of bearing ratio) and curve parameters.

By definition, calculation of the parameters is realized as follows:

$$C_R = H_{20\%} - H_{3\%}$$
$$C_F = H_{70\%} - H_{20\%}$$
$$C_L = H_{97\%} - H_{70\%}$$

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.

4 EVALUATION OF THE PROFILE ROUGHNESS BY MECHANICAL SURPHOMETRY

The technique has been already described in details (Sherrington and Smith 1988 & Courard and Nélis 2003) and is only here rapidly remembered. A stylus is walked along the surface to be analysed and the profile is continuously registered (Fig. 2).

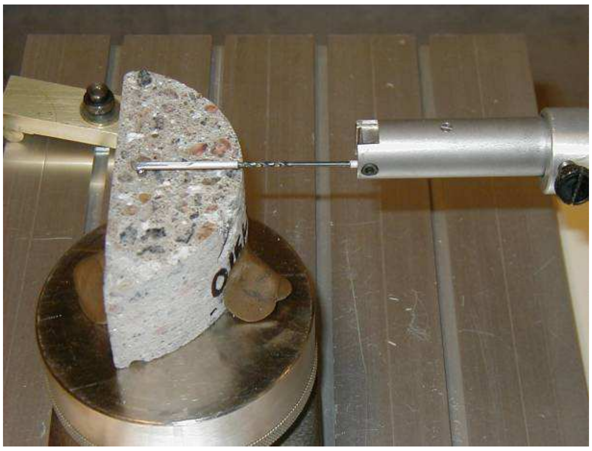


Figure 2. Stylus walking on the concrete surface.

The total registered profile is filtered in high and low frequencies in order to separate roughness and waviness, respectively (Courard 1998). Filtering will reduce to 50 % of the initial amplitude of a wave when its wavelength corresponds to the filter characteristic.

5 EVALUATION OF THE PROFILE ROUGHNESS BY OPTO-MORPHOMETRY

The projection “moiré” technique is an interferometrical measurement method. The “moiré» phenomenon appears when two networks of light rays, made of equidistant lines - alternatively opaque and transparent -, are superimposed. This phenomenon may occur naturally in the everyday life when daylight passes through at least two thicknesses of curtains. The networks used are generally transparent, with a transmittance given by square functions. When the network is linear, the fringes take the shape of periodically transparent and coloured crenels.

The technique of identification of relief is based on the deformation’s measurement of a parallel fringes pattern projected on a surface (Figure 3). The moiré’s fringes are similar to level lines representing the variations height of the object. By projecting a network of parallel fringes on a plane surface, this network will not be deformed, as shown on Fig. 3. When projected on an unspecified form, this same network will be deformed according to the level of rise in this form (Fig. 3). Moreover, there is a relation between rise in the form and distance between each level line. The main principle of the test consists in the comparison of two images having two different moiré networks. The first image is the image reference: it is an image of the network of not deformed parallel fringes. The second image contains the projected network deformed according to the analyzed form. An algorithm analyzes the image and compares the grid of calibration and the deformed grid. This treatment is based on the indices of grey which express the level of color in black and white. The variation of the color is treated like the displacement of this color.

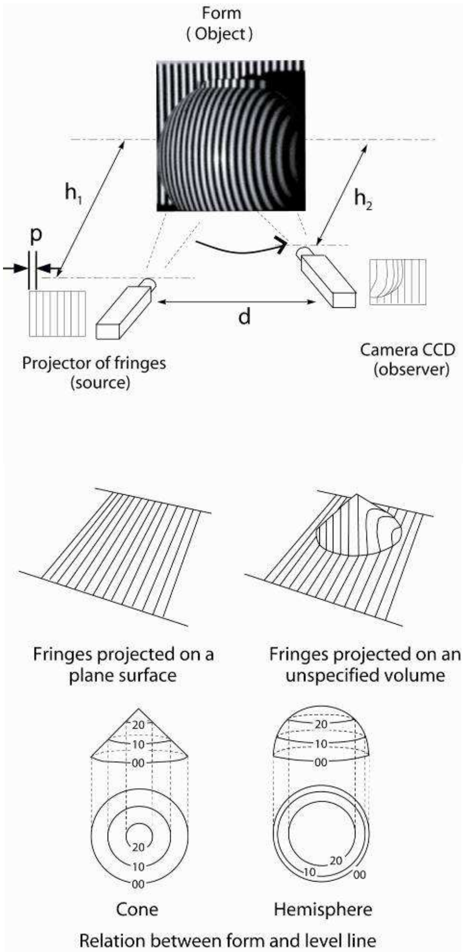


Figure 3. Principles of the Moiré projection technique.

A set of equation can be written to describe this process (Perez 2005). From these equations and with known phase shift values, the phase value and the modulation can be evaluated for every pixel of the image. It is then possible to build a continuous surface from the phase’s values.

The measurement accuracy is directly related to the density of the fringes network, and the capacity of differentiation of the network by the system of image analysis. Theoretically, with an illumination angle of 45^{o} and a camera CDD of 512x512-pixels, the resolution will be approximately 1/5000 of the size of the object. With a camera of 1000x1000-pixels, the resolution is 1/10000 of the size of the object. In our application, the resolution is of 200 µm in the three directions of space for one surface of 350x350-mm (Fig.4). The measurable maximum vertical amplitude could be about 100 mm.

A profile can be divided into several scales of roughness. Each scale can be dissociated from the precedent by carrying out a decomposition process. Fig. 1 indicates the three principal scales of roughness for the concrete surfaces. Because of the vertical resolution of the device, it is impossible to separate roughness from waviness. A profile obtained through this approach will consequently give the description of meso-waviness and global form. The signal treatment is based on the principle of decomposition by wavelets: this type of filtration does not modify sampling, on the contrary of median methods. This is a considerable advantage, knowing that sampling has a major influence to the measurement of fractals surfaces.

Figure 4. Example of setup to obtain optical evaluation.

6 RESULTS

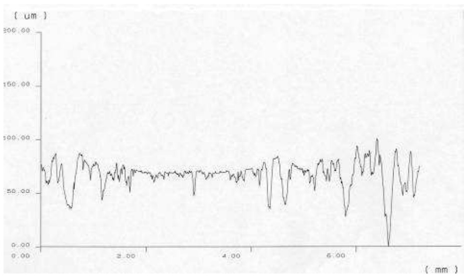
6.1 *Mechanical evaluation*

A first evaluation by mechanical profilometry has been realized by means of a stylus with diamond sphere radius of 6 µm. The length of measurement was 8 mm and the filter used to separate roughness from the profile was fixed to 0.8 mm. Three profiles were registered on one sample of each kind of preparation; each profile on the sample was made in different directions. A second measurement was made with stylus of 79 mm long and a diamond of 1.5 mm radius, in order to point out waviness. The length of the measurement was enlarged to 30mm or more. The filter was again chosen at 0.8mm and the filter to separate shape from the profile was 16mm (two times the dimensions of the aggregates). Observation of the values of the roughness amplitude parameters (Table 4) clearly shows that R_a, R_q, R_t parameters is between1.5 and 3 times smaller for the polished concrete profile than for water jetting and scarification, and that the values of amplitude and statistical roughness parameters are equal for water jetting and scarification.

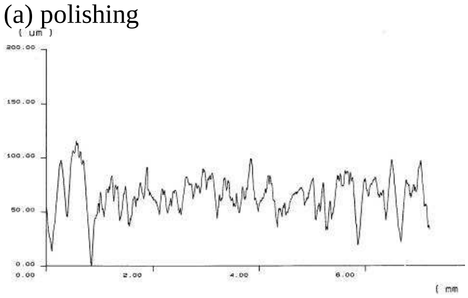
Table 4. Waviness (W) and roughness (R) parameters for mechanical evaluation (dimension en µm)

Treatment	*Polishing*	*Water jetting*	*Scarification*
Wa	6	420	127
Wp	13	1003	346
Wq	9	501	158
Wv	47	923	445
Wt	60	1926	791
Ra	5	14	15
Rq	7	17	19
Rt	70	96	102
C_R	4	152	412
C_F	10	228	827
C_L	14	231	537

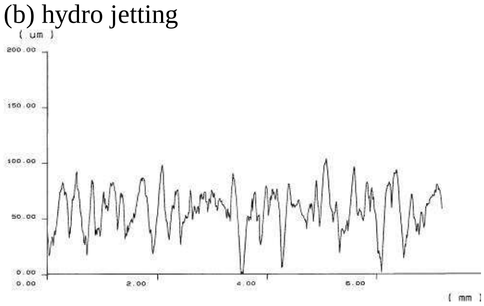
It is here confirmed that the surface treatment technique (Fig.5) has no major influence on the micro-roughness (“high frequencies waves”) of the profile. However, the differences are more effectives for waviness parameters.



(a) polishing

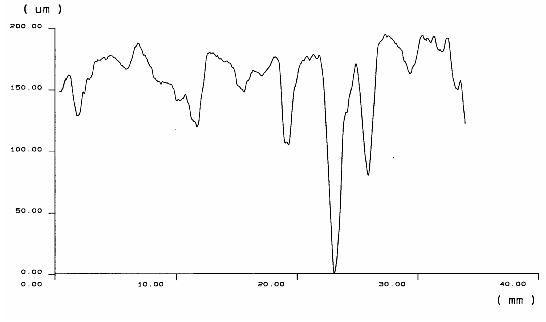


(b) hydro jetting

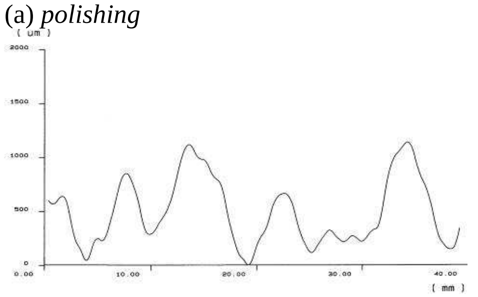


(c) grinding

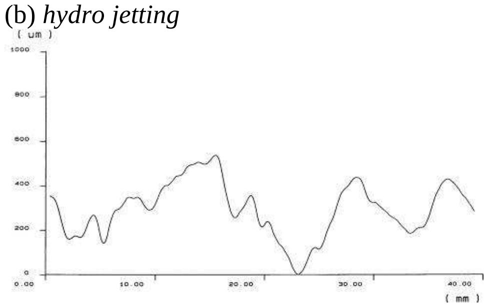
Figure 5. Roughness profile after different surface treatments



(a) *polishing*



(b) *hydro jetting*

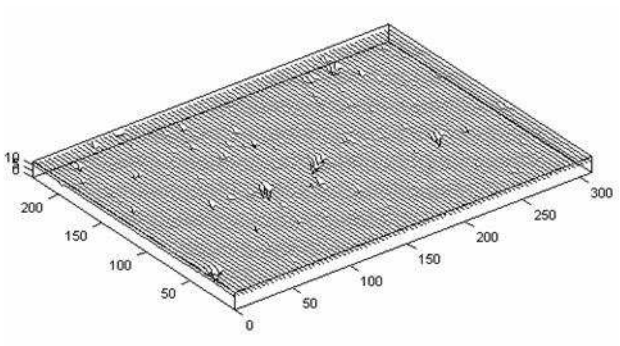


(c*) grinding*

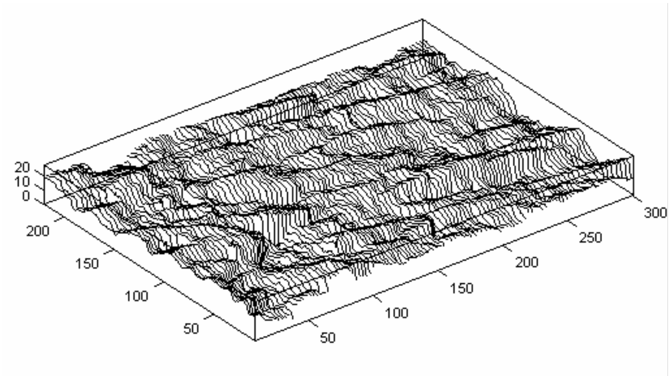
Figure 6. Waviness profile after different surface treatments

6.2 *Opto-metrical evaluation*

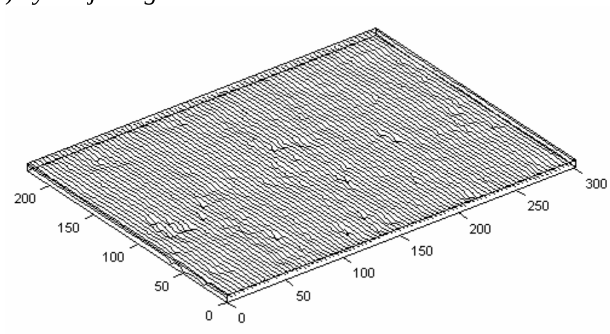
As the same way to mechanical evaluation, 3 opto-metric topography evaluations have been made. The figure 8 presents the statements of the optical measurement. At this scale, water jetting seems to induce the bigger ”roughness”. Polishing and scarification are quite similar. It’s due to the bubble effect at the surface which gives roughness aspect.



(a) *polishing*



(b) *hydro jetting*



(c) *Scarification*

Figure 7. Meso-waviness profile after different surface treatments (dimension in mm)

Observation of the values of the roughness amplitude parameters (Table 5) clearly shows that M_a parameter is 20 times more important for water jetting than for scarification and polishing. At this scale, the others treatments induce smooth surface. Polishing surface is the less rough surface. The major part of apparent roughness of polishing surface comes from the bubble. At this day, it’s not possible to cut off bubble from the meso-waviness.

Table5. Global form (F) and meso-waviness (M) parameters.for opto-metric evaluation (dimension en mm)

Treatment	*Polishing*	*Water jetting*	*Scarification*
Fa	0.137	0.358	0.326
Ft	4.1	10.8	12.6
F Sm	129	85.3	102.3
Ma	0.169	2.85	0.315
Mt	19.7	27.8	10.2
M Sm	15.3	36.5	22.5
C_R	0.30	4.65	0.41
C_F	0.29	5.76	0.55
C_L	0.35	5.71	0.81

7 CONCLUSIONS

The use of these two methods to evaluate the profiles of concrete presents some limitations:

for mechanical technique,

- Stylus : because of the shape of the stylus it is impossible to make measurements on very rough surfaces prepared by hydro-jetting for example;
- Air bubbles : some of the air bubbles in concrete are so large that the stylus falls and the measurement is interrupted. That means that the selection of the zone to be investigated is very important;
- Dimensions: this measurement is very high time consuming and it is the reason why the surface of investigation is limited. Moreover, this system is not usable on site.

for opto-metric technique,

- Vertical resolution: it's impossible to evaluate micro-roughness and waviness.
- Air bubbles: future version of logarithm will be able to remove bubble effect in order to obtain real roughness.

But the combination of these two methods let us to have a very good description of "roughness" at all scales. The accuracy of the method that is used is fundamental for the quality of the description of the surface.

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9 ACKNOWLEDGMENTS

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