Cement & Concrete Composites 46 (2014) 73–80

Contents lists available at ScienceDirect

Cement & Concrete Composites

journal homepage: www.elsevier.com/locate/cemconcomp

Near-to-surface properties affecting bond strength in concrete repair

Luc Courard [a,*], Tomasz Piotrowski [b], Andrzej Garbacz [b]

[a] University of Liège, Faculty of Applied Sciences, ArGEnCO Department, Chemin des Chevreuils, 1, 4000 Liège, Belgium

[b] Warsaw University of Technology, Faculty of Civil Engineering, Department of Building Materials Engineering, Al. Armii Ludowej 16, PL 00637 Warsaw, Poland

ARTICLE INFO

Article history:
Received 7 June 2012
Received in revised form 27 September 2013
Accepted 20 November 2013
Available online 28 November 2013

Keywords:
Concrete
Surface treatment
Adhesion
Mechanical interlocking
Repair
Roughness
Microcracking
Pull-off test

ABSTRACT

One of the main processes for repairing concrete structures is patch repair. Efficiency and durability of a repaired system depends on the bond between concrete substrate and repair material. By increasing the surface roughness, the surface treatment of concrete substrate can promote mechanical interlocking that is one of the basic mechanisms of adhesion. Nevertheless, some problems may arise from "co-lateral" effects of the treatment, especially due to the development of microcracks inside the substrate. In the presented paper, the effect of concrete substrate surface preparation has been characterized by roughness measurement, description of microcracking in the near-to-surface layer and a pull-off cohesion test. After repair, pull-off bond strength has been evaluated. It is concluded that selection of a suitable surface treatment technique should be preceded by the analysis of its aggressiveness in relation to the concrete substrate strength. A procedure for bond strength estimation using multiple regression approach, based on parameters describing surface quality really generated from various roughening techniques, is then proposed.

1. Introduction

A good quality bond between an overlay and concrete substrate is an important requirement for assuring efficiency of repair [1]. According to Silfwerbrand (see Fig. 1), the creation and the durability of the bond depends on several factors, each acting with different degrees of influence [2] and can be divided into three main groups [3]. From these, Silfwerbrand pointed out five major factors: microcracking, absence of laitance layer, cleanliness before to overlay placement, compaction and curing procedures. The three first parameters are directly related to substrate characteristics, which can be modified by surface treatment. Treatment of concrete substrate is commonly used for cleaning, removing laitance layer and roughening the surface. However, it can induce microcracking if it is not well operated with regard to the quality and the strength of concrete [4–6]. Even if roughening is not considered as the most important factor for interface quality [2], it seems however to influence bond strength.

Bond quality is usually characterized by a fracture stress related to the process of breaking the bond between bodies that are already in contact [7]: another approach considers the process through which two bodies are brought together and attached (bonded) to each other: in this case, the kinetics of contact is of prime importance. Creation of the bond can be explained in terms of specific and mechanical adhesion. Specific adhesion can be evaluated by studying the interfacial and surface forces acting at the interface, specifically the conditions for good wettability and spreading [8]. Good wettability contributes to a better fulfilling of the concrete surface profile by the repair material. Mechanical adhesion is coming from interlocking effect induced by roughening concrete surface. Analyses already made [8,9] showed that the roughness of the substrate prior to repair is a common factor influencing both specific and mechanical adhesion.

According to EN 1504 [10] and RILEM recommendations [11,12], preparation of the concrete substrate is the fundamental operation which is considered for every "principle" related to concrete repair. Damaged and deteriorated concrete and, where necessary, sound concrete should be removed by means of a surface treatment operation [13,14]. In selecting the most appropriated surface treatment method, it is possible to take off only specific quality of concrete. Moreover, increasing roughness promotes adhesion due to better mechanical interlocking for high strength concrete substrates [5]. This is confirmed by Santos et al. [6] for concrete-to-concrete systems with two concretes of 50 MPa and 46 MPa compressive strengths, respectively. Many authors (e.g. [2,4,15,16]) indicate that microcracking may be a problem, especially in weak substrates. That is why EN 1504 [10] stated: "*microcracked or delaminated concrete including that caused by the techniques of cleaning, roughening or removal which reduces bond or structural integrity, shall be subsequently removed or remedied*".

* Corresponding author. Tel.: +32 4 366 93 50; fax: +32 4 366 95 20.
E-mail address: Luc.Courard@ulg.ac.be (L. Courard).

0958-9465/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cemconcomp.2013.11.005

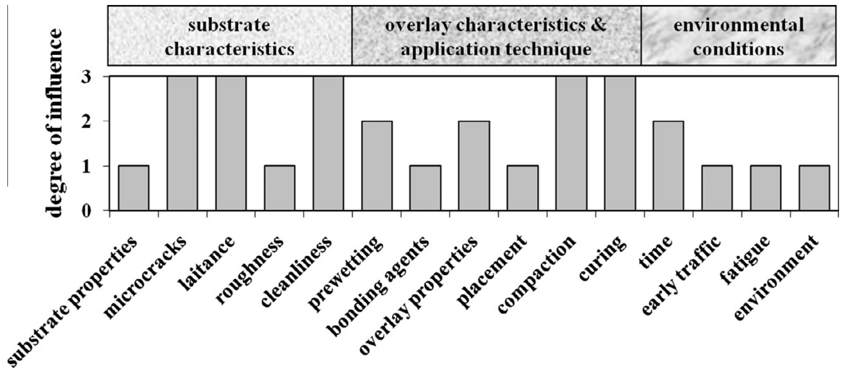

Fig. 1. Factors affecting bond between concrete substrate and repair material.

The fundamental objective of this research project is to estimate the quality of concrete substrate and to evaluate its surface roughness by means of quantitative parameters with regard to adhesion. In the present paper, influence of substrate quality resulting from different surface treatments is particularly analyzed and mathematical relations between surface properties and bond strength are established.

2. Materials

Several repair systems have been tested with different concrete substrate qualities. The research program was divided in two stages. In a first step, performed at the University of Liege (Group A), three different types of concrete and four types of surface treatment techniques were used in order to obtain differences in profile development, surface roughness and level of microcracking in the near-to-surface layer [15]: polishing (PL) as a reference smooth surface, dry sandblasting (SB-D), jack hammering (JH) and high pressure waterjetting (250 MPa) called "hydrodemolition" (HD). Jack hammering is using here a hammer with a special head used for roughening (JH): it is called "sccrabling" in ACI Repair Manual [17]. In a second step, performed at the Warsaw University of Technology (Group B), concretes with other compressive strengths and less aggressive techniques were best suited to obtain similar profiles and low-level microcracking. Brushing (BR) with a metallic brush, wet sandblasting (SB-W), scarification (SC) and waterjetting with a low pressure of 12 MPa (LC) were used for concrete surface preparation. Mix proportion and compressive strengths (f_{ck}) are presented in Table 1 for each concrete and concrete substrate samples after surface treatment are listed in Table 2. After substrate quality evaluation, concrete slabs were covered by commercial polymer cement repair mortar (PCC) with specific technical characteristics presented in Table 3.

3. Substrate surface characterization – test methods and results

3.1. Roughness

Many approaches are valuable to quantify surface roughness [6,16,18]. EN 1504 [10] recommends visual observation, the use of a profile meter or sand test for this purpose. An original visual surface quantification is also proposed by ICRI (ACI) [17]: nine reference rough plates are placed near to actual concrete and compared to the surface roughness [19,20]. These Concrete Surface Profile (CSP) chips allow a classification from 1 to 9 but are really limited to surface preparation suited for coatings: maximum proposed roughness is smooth and do not represent more aggressive surface preparation like water jetting or jack hammering. One of the most common method for roughness measurement is the volumetric sand patch technique presented in Fig. 2. It is also recommended by EN 1766 [21] for measurement of surface macrotexture depth of concrete substrate prior to repair: a constant volume of specific sand is sprayed on the concrete surface and the diameter of the "circle" is measured. Surface Rough Index (SRI) is calculated using the following Eq. (1):

$$\mathrm{SRI} = \mathrm{V}/\mathrm{d}^2 \cdot 1272\ (\mathrm{mm}) \tag{1}$$

where d is the mean sand patch diameter [mm], V is the volume of sand used in the test (ml).

A lower value of SRI indicates a smoother concrete surface.

Profilometry methods commonly used in surface engineering have also been recently implemented for concrete surface characterization. Calculation of statistical and amplitude distribution parameters of the profile allows a quantitative and objective evaluation of the surface geometry [22]. Profile can be obtained by means of profilometers (mechanical and laser) or digitalization of the cross-section image [6,16]. A combination of profiles can be also extended onto surfometry, resulting in a 3D image of the real surface [23]. More recently, a new way of surfometry quantification has been developed. Optomorphology, a technique of relief identification is based on the deformation's measurement of a parallel fringes pattern projected on a surface [24] and allows for a digitalization of the surface, as presented in Fig. 3.

Garbacz et al. [11] showed that the surface geometry of the substrates tested is discriminated by similar parameters, whatever the filtration level is. Authors' investigations [16,23,24] show similar relationship for C40-A when comparing results of SRI and mean arithmetic deviation of total profile (Pa) obtained by optomorphology. Relation between Pa vs. SRI is presented in Fig. 4. Results obtained for laser profilometry and optomorphology are different in values while the same SRI: this is due to the fact that the filtration of the signal was not applied in case of optomorphology. This was already observed in previous research [23]. However, conclusions remain the same: the higher SRI increases, the higher Pa.

The results of substrate surface roughness measurement are presented in Table 4. The substrates of Group A can be ranked from polished smooth surface (PL) to very rough hydrodemolished surfaces (HD) and intermediate like dry sandblasted (SB-D) and jack hammered (JH). In Group B, surface treatment techniques had relatively low influence on profile roughness.

3.2. Microcracking

In the case of concrete of relatively low quality, beside the surface roughness, the presence of cracks in the near-to-surface layer is a very important factor that may affect the adhesion of repair systems. As the aggressiveness of the surface treatment techniques was low for the samples of Group B, no significant microcracking