ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 18 (2018) 573–582

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Multi-sensor evaluation of the concrete within the interlayer bond with regard to pull-off adhesion

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ARTICLE INFO

Article history:
Received 19 March 2017
Accepted 26 September 2017
Available online

Keywords:
Concrete
Surface morphology
Interlayer bond
Pull-off adhesion
Structural assessment

ABSTRACT

The article presents the results of multi-sensor evaluation of the concrete within the interphase between overlay and existing substrate with regard to pull-off adhesion. It has been shown that both the effective surface area of the existing concrete substrate and the contribution of the exposed aggregate on this substrate, as a result of concrete substrate surface treatment, have a significant impact on pull-off adhesion. The highest adhesion was obtained when the surface of the existing concrete substrate was shot-blasted. This method of surface treatment provides both a high coarseness of the surface of the existing concrete substrate and considerable exposure of the aggregate on this surface. In order to clarify why this method of surface treatment of existing concrete substrate is advantageous with regard to the possibility of obtaining high adhesion, scanning electron microscopy (SEM) was used. SEM microstructural analysis was performed on concrete cubic specimens taken from the interphase zone between the overlay and existing concrete substrate. The results of these studies, including the contact type between the overlay made of cement mortar and the existing concrete substrate, are presented in the study.

1. Introduction

A fundamental measure of the interlayer bond between an overlay and existing substrate is the value of the pull-off adhesion f_b [1]. The value of f_b is evaluated using the pull-off method and standardized according to EN 1542 [2] and ASTM D7234 [3]. A higher value of f_b corresponds to a better bond between the overlay and existing substrate [4]. This bond is related to mechanical and physical adhesion [5]. In recent years, it has been shown that mechanical adhesion is mainly influenced by the pore structure [6] and micro-cracking [7] of the existing concrete substrate. It is also important during hardening of the material of the overlay [8]. The morphology of the existing concrete substrate [9] and its surface treatment [10] is also important. This has been demonstrated using selected 3D amplitude [11] and volume morphological parameters [12]. An increase in the developed (effective) area of the existing concrete substrate has a positive impact on the mechanical adhesion [13]. The developed area is

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http://dx.doi.org/10.1016/j.acme.2017.09.008
1644-9665/

influenced by the surface treatment of the existing concrete substrate (e.g. shot-blasting or grinding). According to [14], it can be characterized by the developed interfacial area ratio S_{dr}:

$$S_{dr} = \frac{1}{A} \times \left[\int\int \left(\sqrt{\left[1 + \left(\frac{\partial z(x,y)}{\partial x} \right)^2 + \left(\frac{\partial z(x,y)}{\partial y} \right)^2 \right]} - 1 \right) dxdy \right]. \quad (1)$$

As stated in ISO 25178 [14], S_{dr} is the ratio of the increment of the interfacial area within the definition area (A) over the definition area. According to [14], S_{dr} reflects the hybrid property of surfaces, and a large value of the parameter indicates the significance of the amplitude, spacing or both. In relation to [15], the surface area is the total area of all triangles formed over the texture. The value of S_{dr}, equal to 0%, represents a perfectly flat surface.

In turn, the compressive strength, humidity and temperature of the existing concrete substrate have an impact on physical adhesion [16]. It has been shown, for example, that wetting of the surface of the existing concrete substrate prior to the application of an overlay has an impact on the physical adhesion [17]. As already noted in [18], penetration of the fresh cement paste into the porous structure of the existing concrete substrate is also significant. This process creates the interface as a result of the hydration and microstructure changes [19] and moisture exchange between hardening overlay and existing substrate [20]. As a result of hardening of the overlay, a specific border is formed, over which the local density displays a spatial gradient between two phases [21] or in contact with formwork [22]. It is placed in the context of the phase transformation of concrete [23], especially at early ages [24]. This border is known as an interphase [25]. As pointed out in [26], the interphase becomes less evident after contact between the overlay and existing concrete substrate is made and this is because the hardening overlay is interconnected with the existing concrete substrate.

According to the authors, within the interphase between the overlay and existing concrete substrate, the following types of contacts, which are relevant with regard to an interlayer bond, can be distinguished: cement matrix of the overlay – cement matrix of the substrate (MM), cement matrix of the overlay – aggregate of the substrate (MA) and aggregate of the overlay – cement matrix of the substrate (AM). It should be expected that the contribution of individual types of contacts depends on the size of the aggregate that is exposed on the differently treated surface of the existing concrete substrate.

This raises the question of how the developed surface area of the existing concrete substrate and the contribution of its exposed aggregate, as a result of the concrete substrate surface treatment, influence the pull-off adhesion. It is not known if there are visible differences in the microstructure of the concrete within the interphase between the overlay and substrate. How does it change in the case of different concrete substrate surface treatments and for divided types of contacts between the material of the overlay and substrate? These are questions that are considered in the article.

Until now, there have not been any studies on how the chemical composition of the concrete within the interphase is affected by different types of contacts between the material of the overlay and substrate. It is not well known what thickness of the interphase zone (IZ) should be considered as important from the point of view of the migration of oxides between the overlay and substrate. The answer to these fundamental scientific questions is the purpose of this article.

The multi-sensor approach is required in order to answer these questions [27]. Sensor analysis has recently become more popular in engineering practice [28]. Thus, different techniques have been used to evaluate the concrete within the interphase between the overlay and substrate with regard to pull-off adhesion. This was done at different observation length scales. First, the pull-off method was employed to obtain the macroscopic value of the pull-off adhesion. Then, 3D Light Amplification using Stimulated Emission of Radiation (LASER) scanning and a light stereo microscope were used to evaluate the developed surface area of the existing concrete substrate and the contribution of exposed aggregate on this substrate. Finally, microstructural tests were performed using scanning electron microscopy (SEM).

The paper is organized as follows: Section 2 presents the description of experimental procedure, its background, materials and methods used and also data acquisition; Section 3 condenses the significant results and Section 4 presents the final conclusions.

2. Experimental procedure

To evaluate the developed surface area of the existing concrete substrate and the contribution of exposed aggregate on this substrate, tests were performed on the existing concrete substrate with dimensions of 600 mm × 900 mm and a thickness of 125 mm (Fig. 1). The weight composition of the concrete mixes in (/m^3) was as follows: 352 kg of Portland cement type CEM II A-LL 42.5 R, 165 l of water, 724.4 kg of fine aggregate with a maximum grain size of 2 mm and bulk density of 2.60 Mg/m^3, 1086.6 kg of coarse aggregate with a maximum grain size of 8 mm and bulk density of 2.62 Mg/m^3 and 40 kg of fly ash. In order to obtain an adequate workability of the concrete mix, 2.0 l of polycarboxylate plasticizer Sika® ViscoFlow®-6920 with a density of 1.07 g/cm^3 was used. The concrete substrate matured naturally for 28 days at an air temperature of +18 °C (±3 °C) and relative air humidity of 60% (±5%). During this time, the surface of the concrete substrate was divided into four equal parts of 300 mm × 450 mm, as shown in Fig. 1. Then, the surface of each of the four parts was prepared in an alternative way (Fig. 1). This resulted in four areas with different morphology.

On each of the surfaces (T1–T4), the 12 testing areas with dimensions of 50 mm × 50 mm were randomly selected to evaluate the developed surface area of the existing concrete substrate using non-contact 3D LASER triangulation scanning (Fig. 2a). This method is based on the determination of the position of a target by measuring the reflected light from the target surface [29]. Since the methods offer high accuracy, the optical parameters of the lenses and its vertical resolution must be taken into account [30]. From each of the surfaces (T1–T4), the samples with a size of 50 mm × 50 mm × 10 mm were taken to evaluate the contribution of exposed aggregate