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The effect of the porosity within the interfacial zone between layers on pull-off adhesion

Łukasz Sadowski *, Damian Stefaniuk, Jerzy Hoła

Faculty of Civil Engineering, Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

HIGHLIGHTS

- X-ray micro computed tomography was used to evaluate the porosity of concrete.
- The porosity in the concrete within the interfacial zone between layers differ.
- The relation between the porosity and the pull-off adhesion was shown.
- Sphericity of pores and pore diameter are not related to the pull-off adhesion.
- Grinding of the substrate causes a decrease of the thickness of the interphase zone.

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ABSTRACT

The article focus on the effect of the porosity within the interfacial zone on pull-off adhesion using X-ray micro computed tomography. The study shows that grinding of the concrete substrate causes a decrease of the thickness of the interfacial zone. However, shotblasting does not cause such decrease. It was shown that the fraction and the number of pores in the material within the interfacial zone between layers is different in three divided zones. Moreover, the relation between the fraction and the number of pores in the three zones and the pull-off adhesion f_b between the layers was also shown.

1. Introduction

Layered concrete elements are often used in the construction industry. They are usually made of two heterogeneous layers: overlay (also known as top layer, coating, added layer or topping) and existing concrete substrate. Their durability, including the safety of their exploitation, substantially depends on the bond between the overlay and the existing concrete substrate [1–6]. A macroscopic measure of this bond is the value of the pull-off adhesion f_b. The higher the value of f_b, the better the bond is considered to be [7,8]. The pull-off adhesion is tested in practice using the destructive pull-off method [7,8]. However, an assessment of the bond between concrete layers is also possible using non-destructive testing (NDT) methods and artificial neural networks (ANNs). For this purpose, *Garbacz* [9] used impact-echo and ultrasound echo methods and *Hoła* et al. [10] used impulse response and impact-echo methods. It is also possible to determine the value of the pull-off adhesion between concrete layers with the aid of NDT methods, which was proved by *Sadowski and Hoła* [11–15].

Many researchers indicate that the bond between concrete layers largely depends on the parameters that characterize the concrete of the existing concrete substrate and their surface morphology [16–20]. Thus, *Siewczynska* showed that the pull-off adhesion value f_b depends on the compressive strength and the humidity and temperature of the concrete of the substrate [21]. *Sadowski* et al. [22] found that the pull-off adhesion f_b depends on the grain size of the aggregate used in the concrete of the substrate. *Abu-Tair* et al. [23,24], *Siewczyńska* [25] *Santos* et al. [26–32]

* Corresponding author.
E-mail address: lukasz.sadowski@pwr.edu.pl (Ł. Sadowski).

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Garbacz et al. [33,34] *Courard* [35–37] *Mansour* et al. [38] and *Hoła* et al. [39] proved that there is a relation between the concrete surface morphology of the substrate and the adhesion of this concrete surface to the overlay. *Silfwerbrand and Beushausen* [40] showed that the porosity of the concrete of the substrate has a significant effect on the bond with the overlay. *Zhou* et al. [41] point to the fact that the structure of pores in the interfacial zone of layers may be different to the structure of pores away from this zone, which may have an effect on the interlayer bond. In recent years, researchers have noticed that the mechanical properties of cementitious composites at macro-scale are highly dependent on porosity. Special emphasis is placed on small pores, which can be associated with air voids and have a diameter larger than 10 μm [42–46]. There have only been a few attempts to evaluate the interfacial zone of concrete layers using scanning electron microscopy (SEM) [47–55]. However, these attempts were of qualitative character.

At this point, with reference to studies [56–59], it should be noted that literature refers to the interfacial zone of concrete layers, which is understood as the near surface layer (NSL) of the substrate. *Courard* et al. [56] describe the NSL with a thickness of about 100–150 μm, which according to [56] is formed due to the wall effect in the subsurface zone of the concrete substrate. In turn, *Courard* et al. [57] and *Kreijger* [58] refer to the concrete skin in which the thickness is equal to of half a grain size of the maximum aggregate D_{max} contained in the concrete that was used to form the substrate. However, *Pigeon and Saucier* [59] believe that this zone should be understood as the interfacial transition zone (ITZ), occurring in concrete at the interface between aggregate and the cement matrix. They also stated that the thickness of this zone depends on the method of treating the surface of the substrate. At this point it is worth noting the work of *Bissonnette* et al. [60], in which it is highlighted that within the interfacial zone, as a result of curing of the material of the overlay, an interphase is formed and is opposed to the interface which is formed at the time of laying the overlay onto the existing concrete substrate [61]. According to the authors of this article, when considering the structure of pores of the material within the interfacial zone of the existing substrate and the overlay placed on its surface, it is better to talk about the interfacial zone, which is divided into:

- the near surface zone of the concrete substrate (NSZ-CS),
- the meso-interphase zone of concrete layers (meso-IZ)
- the near surface zone of the overlay mortar (NSZ-OM).

When summing up the above considerations, it should be emphasized that at present it is not yet known if and how structure of pores changes within the interfacial zone of layers, whether the fraction and number of pores, their sphericity and pore diameter differ in the specific zones and also how they influence pull-off adhesion. The answer to these scientific questions is the purpose of this article.

It should be mentioned that the quantification of the structure of pores, which is understood as the fraction, number, diameter and shape of pores within the interfacial zone of concrete layers, is currently possible with the use of modern methods that illustrate a microstructure in 3D such as the high resolution X-ray micro-computed tomography (micro-CT) method [62–65].

2. Description of conducted research

A layered concrete element with dimensions of 600 × 900 mm and a total thickness of 150 mm (Fig. 1) was subjected to tests. The substrate had a thickness of 125 mm and the overlay had a thickness of 25 mm. Table 1 shows the weight composition of the mixes that were used to make the concrete substrate (CS) and the overlay mortar (OM). Table 2 shows a summary of the mean values of the physical and mechanical parameters of these materials. These parameters were determined after 28 days of curing. Both concretes cured naturally at an air temperature of 20 °C (±3 °C) and relative humidity of 60% (±5%).

After the existing concrete substrate was made, its surface was divided into four equal parts with dimensions of 300 mm × 450 mm each, as shown in Fig. 1. Each part was treated in a different way. This resulted in 4 different surfaces in terms of morphology, namely:

- T1 – the surface received directly after concreting (raw),
- T2 – the surface received directly after concreting – formed after contact with the formwork (as cast),
- T3 – the mechanically grinded surface (ground),
- T4 – the shotblasted surface.

The overlay was then laid on the existing concrete substrate, which was two years old.

Tests of the pull-off adhesion f_b between the overlay and the substrate were carried out after 28 days using the pull-off method (Fig. 2). These tests included the execution of boreholes in the

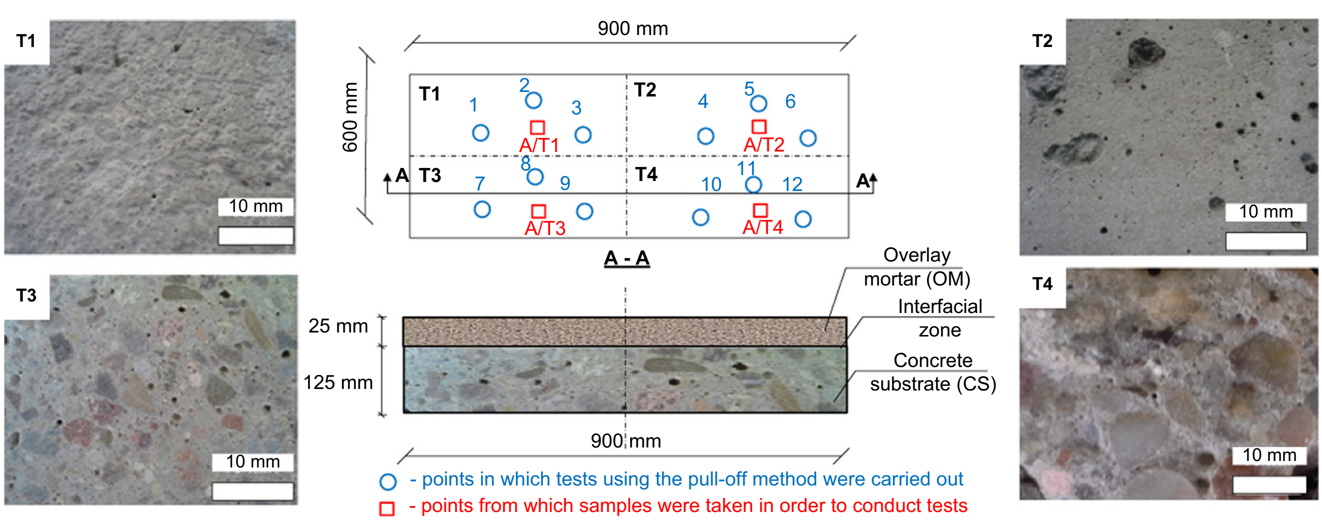

Fig. 1. Scheme presenting the tested element with a distribution of points in which tests using the pull-off method were carried out and from which samples were taken in order to conduct tests using the micro-CT method, and also optical views of the existing concrete substrate surface.