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The Effect of Texturing of the Surface of Concrete Substrate on the Pull-Off Strength of Epoxy Resin Coating

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Abstract: This paper describes a study conducted to evaluate the effect of texturing of the surface of concrete substrate on the pull-off strength (f_b) of epoxy resin coating. The paper investigates a total of seventeen types of textures: after grooving, imprinting, patch grabbing and brushing. The texture of the surface of the concrete substrate was prepared during the first 15 min after pouring fresh concrete into molds. The epoxy resin coating was laid after 28 days on hardened concrete substrates. To investigate the pull-off strength of the epoxy resin coating to the concrete substrate, the pull-off method was used. The results were compared with the results obtained for a sample prepared by grinding, normative minimal pull-off strength values and the values declared by the manufacturer. During this study twelve out of fifteen tested samples achieved a pull-off strength higher than 1.50 MPa. It was found that one of the imprinting texturing methods was especially beneficial.

Keywords: concrete substrate; texturing; adhesion; cohesion; epoxy resin; coating; pull-off strength

1. Introduction

The construction industry is growing intensively, especially in the field of large area floors. This is mainly due to the growth of the production and transport industries and the fact that larger areas are being adapted for storage. To ensure a suitable floor for more significant loads, epoxy resins are mainly used as concrete surface coatings [1,2]. This usually allows a satisfactory pull-off strength (f_b) of coatings to be obtained [3]. The destruction of epoxy resin coating occurs during freezing and thawing processes [4], chemical compound aggression [5], erosion and corrosion [6,7], or resistance against thermal shock [8]. As pointed out by Garcia and de Brito [9], the major advantages of epoxy resin coatings are: its high chemical and mechanical resistance, being easy to clean, and its watertightness. Epoxy resin coatings are used to enhance the durability properties of a floor [10,11]. They increase the service life of a floor and decrease its failure [12]. They may also be used as preventive repair [13] and surface protection.

Before the application of epoxy resin coating, the manufacturer recommends preparing the surface of the concrete substrate using sandblasting or grinding, cleaning it, and then using a bonding agent to achieve a guaranteed pull-off strength (usually 2.0 MPa). Usually, grinding is the most effective method of mechanically treating the surface of the concrete substrate before the application of the epoxy resin coating. This was quantified by using 3D roughness parameters of the concrete substrate [14]. However, these steps are labor-intensive and expensive. Moreover, there is a higher probability of failure during these steps. In the authors' opinion there is a need to search for a way to avoid these steps during the construction process of epoxy resin coating floors. One recent example of such a procedure is to modify the composition of the epoxy resin coating using nanosilica [15], carbon nanotubes [16], glass powder [17], polymers [18] or diacrylate monomers [19]. These attempts were successful in increasing the pull-off strength of the epoxy resin coating to the concrete substrate. However, these kinds of modifications usually have a negative effect on the other important properties of epoxy resins, e.g., mechanical strength and viscosity. Thus, there is a need to find another way to improve the pull-off strength of the epoxy resin coatings [20]. It seems sensible to search for a proper method of treating the concrete substrate before the application of the epoxy resin coating.

Texturing of the surface of the concrete substrate is a promising method [21]. It may be especially effective when carried out on the surface of the fresh and liquid material of the substrate. For example, He et al. [22] used brushing to obtain a satisfactory coarseness of the surface of the concrete substrate. Alternatively, Mirmoghtadaei et al. [23] textured the surface of the concrete substrate using grooving and brushing in order to obtain a satisfactory coarseness. According to the authors, there have been no attempts to investigate the effect of texturing of the surface of concrete substrate on the pull-off strength of the epoxy resin coating. The following questions also remain unanswered: Which method of texturing is the most useful? Will imprinting or patch grabbing be effective?

When considering the above, the purpose of this manuscript is to evaluate the effect of texturing of the surface of concrete substrate on the pull-off strength of the epoxy resin coating. The paper also aims to ensure a proper pull-off strength of the epoxy resin coating by treating the surface of the concrete substrate using different texturing methods. For this purpose, four different texturing methods were used: grooving, imprinting, patch grabbing and brushing. Pull-off strength results were compared with the value obtained for the grinded concrete substrate surface, the value of the normative minimal pull-off strength and the value declared by the manufacturer.

2. Materials and Methods

2.1. Concrete Substrate

The concrete substrate samples were prepared in wooden forms measuring $150 \times 150 \times 40$ mm^3. To decrease the friction between the wood and sample, internal walls were covered with oil. The 40 mm thick substrate was prepared using a ready mix concrete of class C16/20 (Baumit, Wrocław, Poland). This composition consists of Type 1 Portland cement, quartz aggregate, limestone powder, sand with a grain size of 0–4 mm, and other additives. In this study the weight water-binder ratio of the ready-mix was 0.1 and the mixing time was 3 min. This kind of concrete is commonly used in civil engineering as a concrete substrate for epoxy resin coatings.

2.2. Texturing of the Surface of the Concrete Substrate

The surface of a freshly laid and liquid concrete mixture of the substrate was textured in four basic ways: grooving, imprinting, patch grabbing and brushing. The names and the descriptions of applied texture methods have been summarized in Table 1. All of these four methods are also shown in Figures 1–4.

Finally, for the grooving, widely available nets (No. 1) or grids (No. 2) with different size holes and thicknesses were used (Figure 1).

The imprinting was created using small cross spacers with thicknesses of 2, 4 and 6 mm. Moreover, two pattern types were designed for the plastic spacers: type "+" with crosses in regular spacing (Nos. 3, 5, 7), and type "x" with an additional rotated (45°) cross in the middle of four regular spacers (Nos. 4, 6, 8). The general view of the applied imprinting method is shown in Figure 2.

The patch grabbed textures were created with the use of a flooring trowel with different square sizes (Nos. 10–12), and also with a 2 mm rotated corrugated nylon tube along the concrete substrate surface (No. 9). The third designed surface method is shown in Figure 3.

The brushing was prepared with the use of brushes of three hardness levels: delicate bristles (No. 13), medium delicate bristles (No. 14.) and wire bristles (No. 15). After brushing, a texture depth between 2 and 3 mm has been obtained. The fourth method with medium delicate bristles is presented in Figure 4.

Table 1. The names and the descriptions of applied textured methods.

Name of the Texturing Method	Sample Number	Description of Applied Texturing Method
Grooving	1	Grooving using a building net to produce a series of grooves with a depth of 1 ± 0.5 mm and a gap from 7 to 9 mm between each other
	2	Grooving using a painting grid to produce a series of grooves with a depth of 8 ± 0.5 mm and with a gap from 9 to 11 mm between each other
Imprinting	3	Imprinting using small cross plastic spacers type "+" with a thickness of 2 mm in regular spacing of 34 mm
	4	Imprinting using small cross plastic spacers type "x" with a thickness of 2 mm in regular spacing of 24 and 34 mm
	5	Imprinting using small cross plastic spacers type "+" with a thickness of 4 mm in regular spacing of 34 mm
	6	Imprinting using small cross plastic spacers type "x" with thickness of 4 mm in regular spacing of 24 and 34 mm
	7	Imprinting using small cross plastic spacers type "+" with a thickness of 6 mm in regular spacing of 34 mm
	8	Imprinting using small cross plastic spacers type "x" with thickness of 6 mm in regular spacing of 24 and 34 mm
Patch grabbing	9	Patch grabbing with a rotated corrugated nylon tube with the diameter of 2 mm
	10	Patch grabbing with a flooring trowel with size of 4 × 4 mm^2
	11	Patch grabbing with a flooring trowel with size of 6 × 6 mm^2
	12	Patch grabbing with a flooring trowel with size of 12 × 12 mm^2
Brushing	13	Brushing with a painting brush with width of 150 mm
	14	Brushing with a wire brush with width of 190 mm
	15	Brushing with a normal brush with width of 140 mm

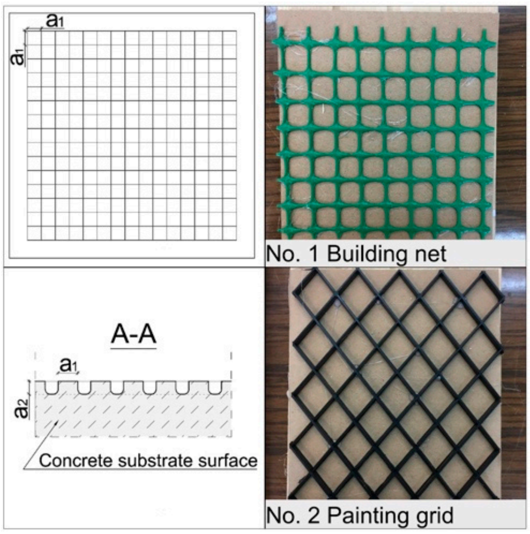


Figure 1. The applied grooving method for texturing the surface of the concrete substrate (dimensions: a_1 = 8, 10 mm; a_2 = 1.0, 8 mm).

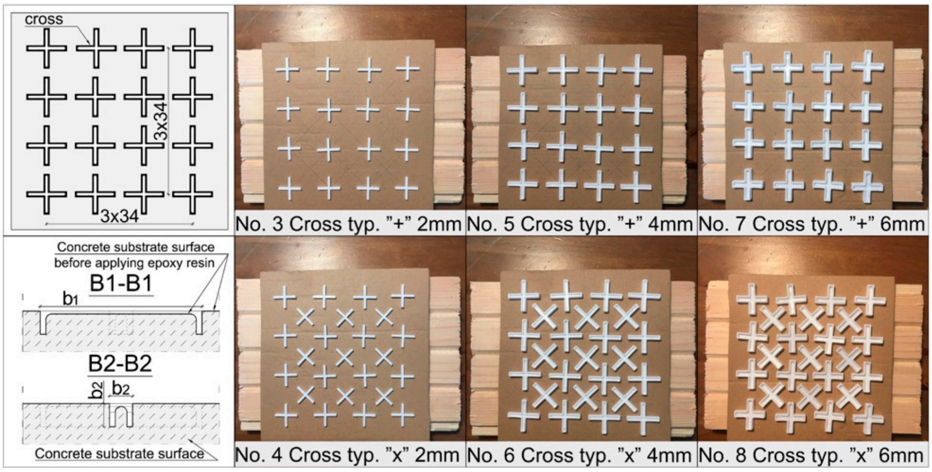


Figure 2. The applied imprinting method for texturing the surface of the concrete substrate (dimensions: b_1 = 20, 28 mm; b_2 = 2, 4, 6 mm).

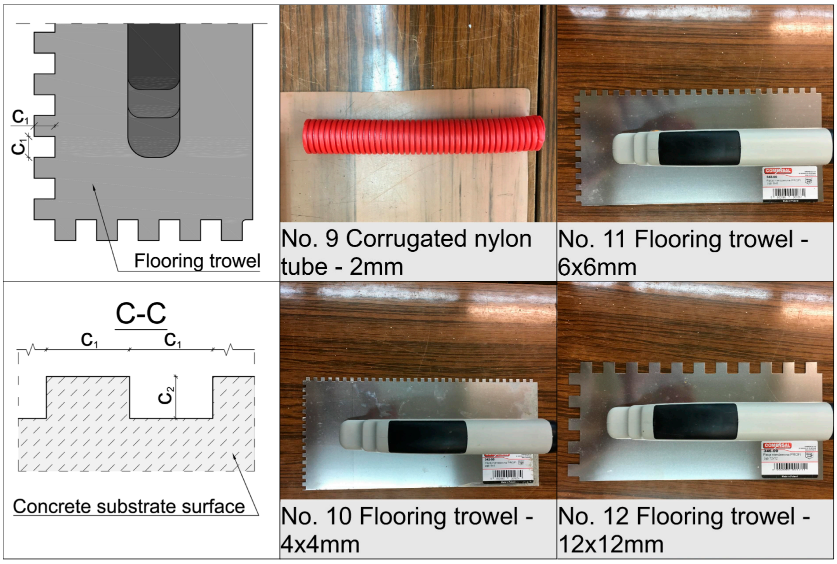


Figure 3. The applied patch grabbing method for texturing the surface of the concrete substrate (dimensions: c_1 = 2, 4, 6, 12 mm; c_2 = 1, 4, 6 mm).

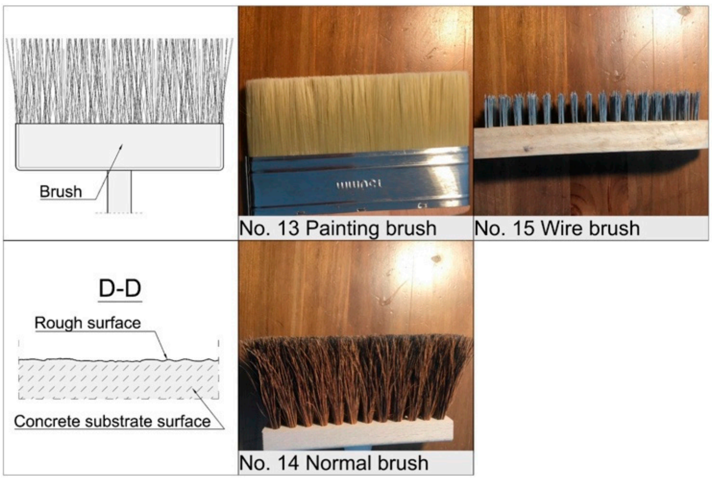


Figure 4. The applied brushing method for texturing the surface of the concrete substrate.

The exemplary optical views of the surfaces of the concrete substrates after 28 days of maturation are presented in Figure 5.

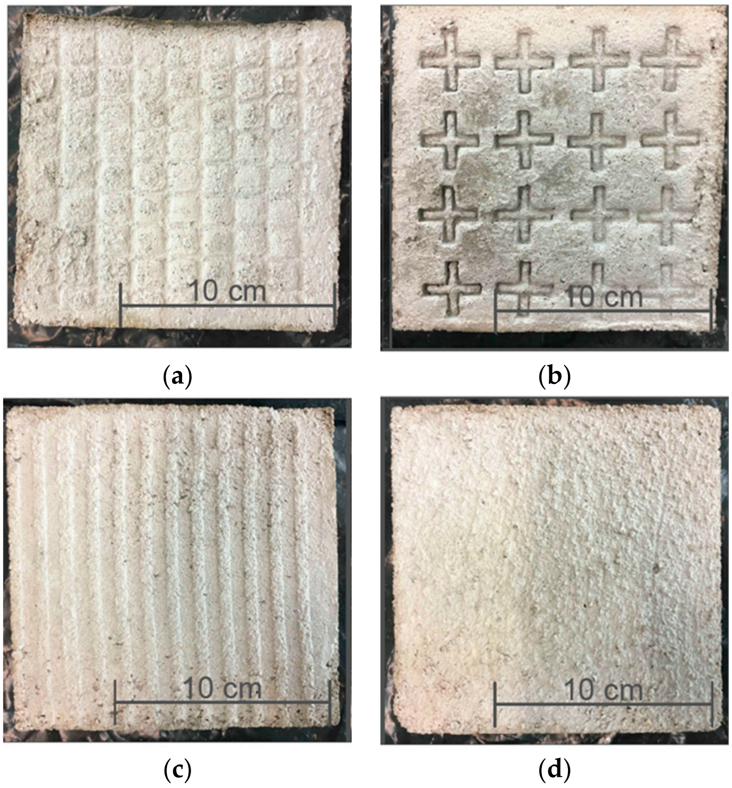


Figure 5. Exemplary optical views of the surfaces of the concrete substrates after 28 days of maturation: (**a**) grooved; (**b**) imprinted; (**c**) patch grabbed; (**d**) brushed.

The manufacturer of the epoxy resin recommended that the concrete surface be treated in two steps: grinding and applying a bonding agent. These actions allow the value of the pull-off strength higher than 2.0 MPa to be obtained after the epoxy resin coating is hardened for seven days. In this study, the concrete substrates were only textured without grinding and applying a bonding agent. For comparative purposes, one sample surface was grinded manually using a grinding stone with ceramic abrasive grain (No. X) in order to compare the obtained values with the textured forms and the pull-off strength declared by the manufacturer ($f_b > 2.0$ MPa). The exemplary optical view of the surface of the concrete substrate after grinding has been presented in Figure 6. On this surface no bonding agent has been applied. These values were also compared to the minimum value of the pull-off strength required by the standard EN 1542 [24] ($f_b > 1.5$ MPa).

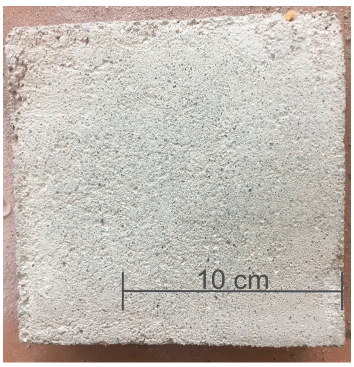


Figure 6. Exemplary optical view of the surface of the concrete substrate after grinding.

2.3. Epoxy Resin Coating

Commercially available epoxy resin (StoPox BB OS, Sto-ispo Sp. z o.o., Wrocław, Poland) was prepared from two components. The first, which is a base, is an epoxy resin based on bisphenol (Component A). The second component is a hardener based on aliphatic polyamines (Component B). The weight ratio of A:B is 100:25. A plastic knife was used to mix the two components together for 3 min in order to obtain a uniform consistency (Figure 7).

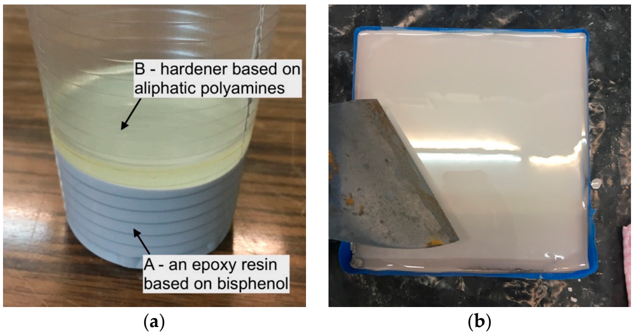
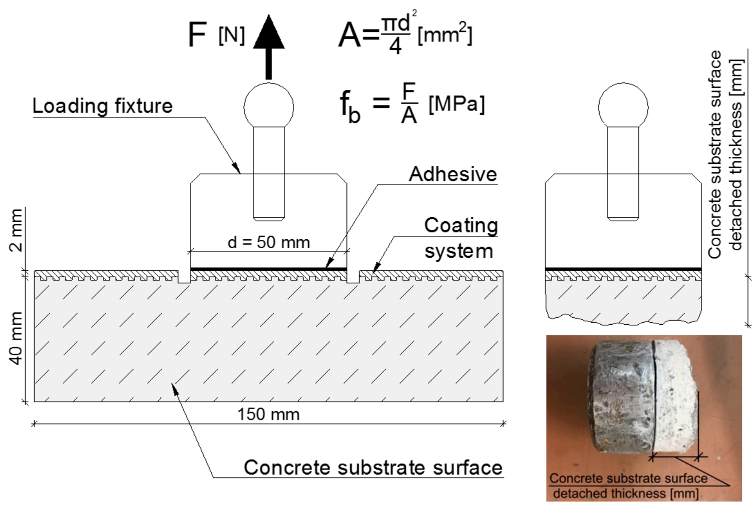


Figure 7. Epoxy resin coating: (**a**) Components–A & B; (**b**) sample after pouring fresh epoxy resin.

30 min after mixing, the material is suitable to be applied at 20 °C. The viscosity of the epoxy resin after mixing with the hardener was in a range between 1400 to 2300 MPa. The epoxy resin was aged in a controlled laboratory environment at the temperature of 20 ± 2 °C and a relative humidity less than 65%. The epoxy resin obtains enough strength for the pull-off strength tests seven days after being poured.

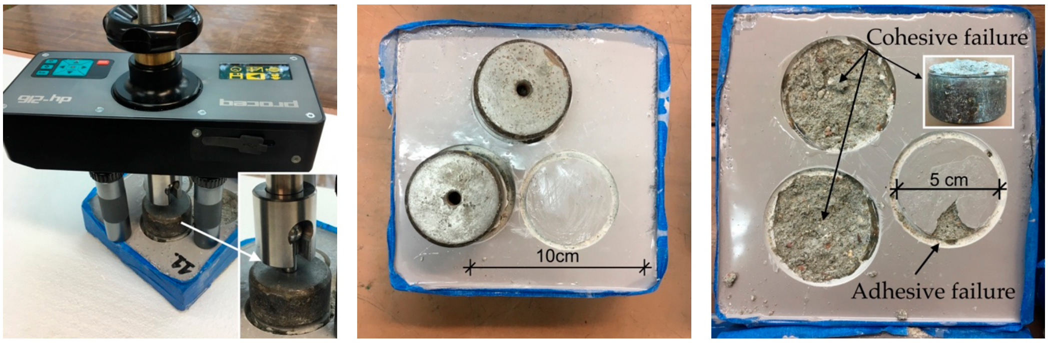
2.4. Pull-Off Strength Tests

The automatic adhesion tester (DY-216, Proceq, Schwerzenbach, Switzerland) was used for the pull-off strength test according to ASTM D4541 [25]. This method has recently become very popular in assessing the pull-off strength of polymer modified coatings [26]. For each sample one specimen was tested in three places. During the test, the load on the fixture was increased in a manner that was as smooth and continuous as possible. The rate of the load was 0.05 MPa/s in order for failure to occur or so that the maximum stress was reached in about 100 s or less. After obtaining the test results, the type of failure and concrete substrate detached thickness were also analyzed (Figure 8).



(**a**)

Figure 8. *Cont.*



(**b**) (**c**) (**d**)

Figure 8. Pull-off method: (**a**) scheme of the pull-off strength test; (**b**) Proceq dy-216 measuring the pull-off strength; (**c**) view of the discs glued to the coating; (**d**) cohesive and adhesive failure.

3. Results

Due to the different texturing methods of the surface of the concrete substrate, the analysis was carried out separately for each method. The results are the mean values of the pull-off strength and the concrete substrate surface detached thickness, which were obtained for each surface. From all 51 tests, one adhesive failure was observed (in this case 15% of the coating was detached). For the rest of the samples, the cohesive failure was observed in the concrete substrate surface (Figure 8d).

3.1. Pull-Off Strength

It is visible from Figure 9 that only sample No. 1 from the grooving methods obtained values of f_b higher than 1.5 MPa. On the other hand, for all of the imprinting texturing methods, the values of f_b were higher than 1.5 MPa. It was observed that the values of the pull-off strength for sample No. 5 were higher than those declared by the manufacturer (f_b = 2.00 MPa). Half of the patch grabbed samples obtained pull-off strength values higher than 1.5 MPa. The observed values of pull-off strength for brushing were in a range from 1.65 to 1.91 MPa. The pull-off strength result for No. 13 is 1.74 MPa, and for the reference (grinded) surface of the concrete substrate it was equal to 1.82 MPa (No. X).

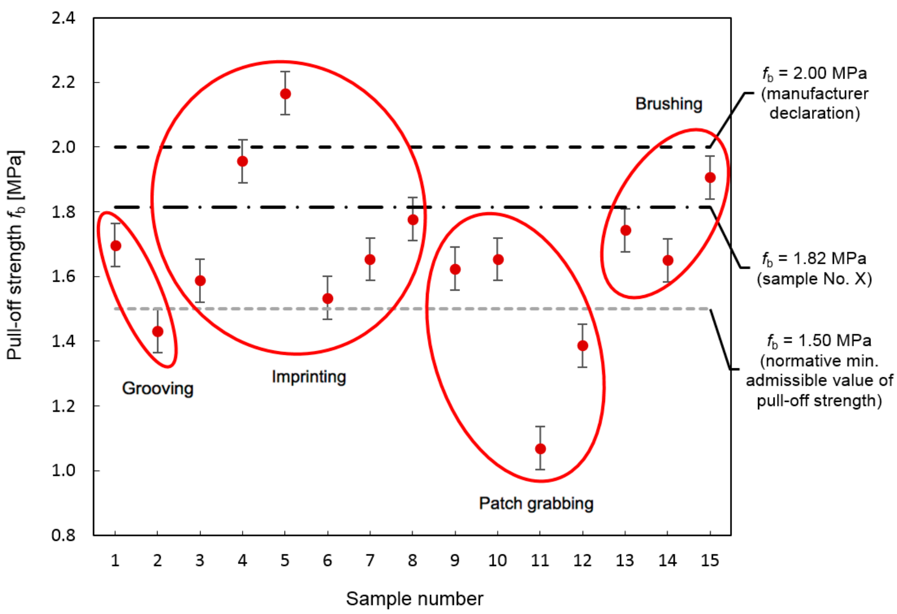


Figure 9. The effect of texturing of the surface of the concrete substrate on the pull-off strength of the epoxy resin coating.

3.2. Detached Thickness

Figure 10 presents the impact of concrete substrate surface detached thickness on the pull-off strength of the epoxy resin coating for grooving (samples from 1 to 2), imprinting (samples from 3 to 8), patch grabbing (samples from 9 to 12) and brushing (samples from 13 to 15).

It is visible from Figure 10a that for the grooved samples the surface of the concrete substrate detached thickness was higher for the painting grid (No. 2) than for the building net (No. 1). Figure 10b shows that in the case of imprinted surfaces, the concrete substrate surface detached thickness increases with the thickness of the cross and the number of crosses that were used on one texturing plank. The greatest result of depth after the pull-off strength test was obtained using the cross with a thickness b_2 = 6 mm. The concrete substrate surface detached thickness for the patch grabbed samples Nos. 10–12. increases proportionately to the size of the textured longitudinal stripes (Figure 10c). The concrete substrate surface detached thickness is almost the same as the pull-off strength for samples No. 13 (13.03 mm) and No. X (13.68 mm). Moreover, for the concrete textured by brushing, a smaller concrete substrate surface detached thickness was observed (Figure 10d). The pull-off strength results for the first three methods are the best when the concrete substrate surface detached thickness value is close to 12 mm.

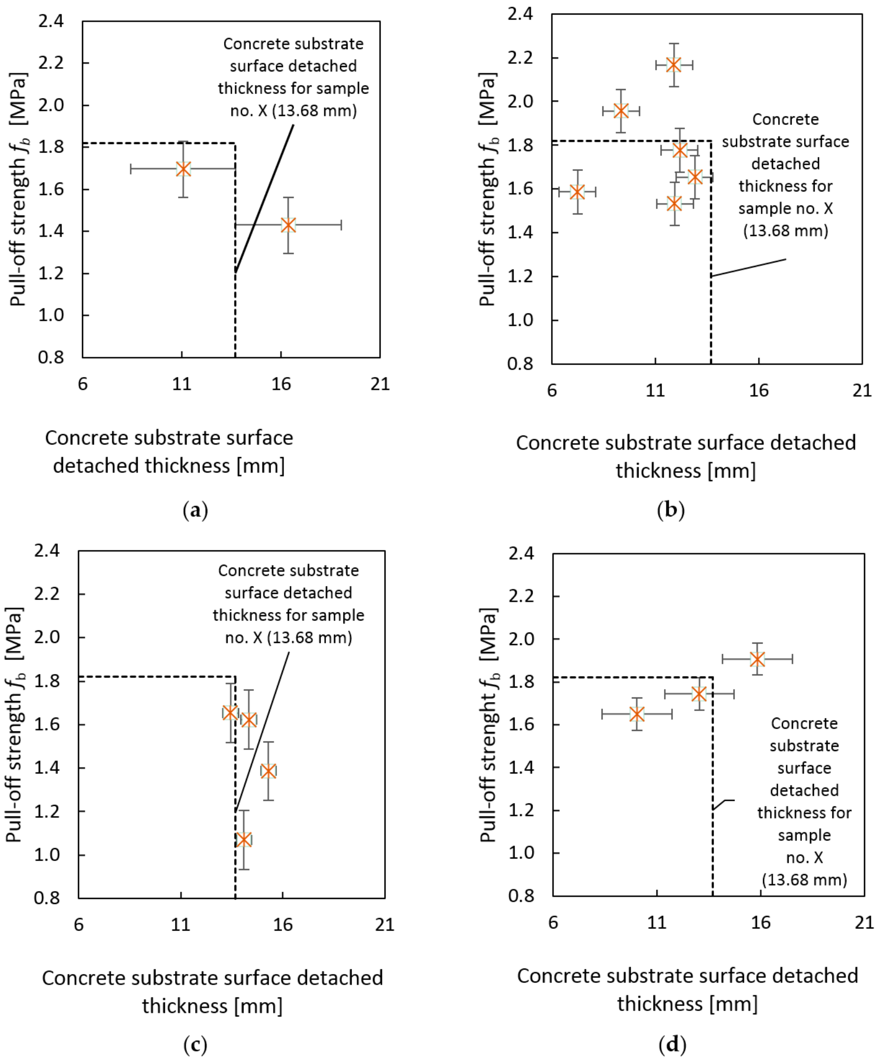


Figure 10. Impact of concrete substrate surface detached thickness on the pull-off strength of the epoxy resin coating for: (**a**) grooving (samples from 1 to 2); (**b**) imprinting (samples from 3 to 8); (**c**) patch grabbing (samples from 9 to 12); (**d**) brushing (samples from 13 to 15).

4. Conclusions

The purpose of this article was to evaluate the effect of texturing of the surface of concrete substrate on the pull-off strength of the epoxy resin coating. The research also aimed to ensure a proper pull-off strength of the epoxy resin coating by preparing the surface of the concrete substrate using different texturing methods. Based on the performed tests, the following conclusions can be drawn:

- The treatment of the surface of the concrete substrate by grinding, cleaning, and applying a primer can be replaced by many different texturing methods that can give similar pull-off strength results.
- Brushing with a painting brush achieved the most similar results to those obtained for the sample after grinding (No. X). It shows that a simple brushing method should be used instead of grinding.
- The best texturing method turned out to be imprinting (No. 5. with crosses type "+"). The pull-off strength for this sample was equal to 2.17 MPa. This is more than that declared by the manufacturer when the surface of a concrete substrate was prepared according to their recommendations (2.00 MPa). Imprinting can be easily used for texturing a concrete substrate surface, as it creates a higher pull-off strength of the epoxy resin coating.
- The concrete substrate surface detached thickness depends on the depth and area of the textured surface. The surface of concrete substrate should be prepared using a method in which the concrete substrate surface detached thickness value is close to 12 mm. This enables the best possible pull-off strength results to be obtained. Such information can be used during the design and construction stage.

The study shows an alternative way to treat the concrete substrate. In further studies, the best concrete substrate texturing methods should be used with modified epoxy resin coating in order to increase the pull-off strength. Some actions should focus on analyzing the concrete substrate surface detached thickness and the impact of texturing depth on the pull-off strength of coatings.

This study also evidenced the technical difficulties for measuring the real adhesion between concrete substrate and epoxy resin. It is proper to note that the pull-off strength test results cannot be used to differentiate the adhesion properties of the epoxy coating to the differently prepared concrete substrates. This is due to the fact that all of the pull-off strength test results resulted in a cohesive failure. Thus, for future studies the development of an adequate method to measure real adhesion between coatings and substrates is required.

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