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Bond strength of underwater repair concretes under hydrostatic pressure

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HIGHLIGHTS

- Effect of hydrostatic pressure on the properties of underwater repair concrete.
- Pressure weakens the grip of concrete repair for the top vertical substrates.
- The best adhesion of repair concrete was obtained for the sand-blasting surface.
- The possibility of test UWC properties in a special pressure tank.

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ABSTRACT

Complex investigation of the influence of hydrostatic pressure on the bond strength of underwater concretes (UWC) to the concrete substrate was carried out. A new-developed apparatus made possible to cast the repair concrete under water on the previously prepared concrete substrate and use hydrostatic pressure 0.5 MPa. This pressure corresponds with placing of the repair concrete at the depth of 50 m. The bond strength of the repair layers of the concrete to horizontal and vertical surfaces was investigated; this was possible by using the specially formed concrete substrates. The bond strength was determined using pull-off methods according to the European Standard EN 1542. Favourable effect of the pressure on the bond strength of underwater repair concretes was observed for the horizontal substrates. In the case of vertical substrates (a vertical wall model), however, decrease of the bond strength of UWC was observed in the layers near the water surface. The most effective method of the surface treatment during the placement of the underwater repair concrete under hydrostatic pressure appeared to be sand-blasting.

1. Introduction

Repairs of the hydraulic concrete structures are complicated construction works due to the constant dynamic action of water on these structures. In the case of repairs of hydraulic objects requiring application of reinforced concrete, the use of underwater concrete (UWC) is increasing [1–4]. The repaired surface should be properly prepared before applying concrete repair. Concrete repaired area should have a uniform strength over the entire surface and be free of loose concrete layers shattered soil and contamination of foreign materials in the form of [5–7]. The surface should have the proper roughness, enabling the use of the proposed concrete or surface protection system [8,9]. In the case of repairing the hydraulic concrete structures, the hydrodynamic method is most often used for preparation of the substrate. The works are performed "In-the-Dry" or "In-the-Wet" [10]. Working "In-the-Dry" is often preferred by the contractors due to economical reasons and easier inspection of the repair. However, when the repair object is large, the costs of installing the cofferdams, portable dams or constructing dikes can appear too high. Repair works done "In-the-Wet" are performed under water. They usually involve the necessity of use of commercial divers and special equipment for preparation of the substrate to repair [10]. In the dry environment, the surface of the repaired concrete is usually prepared using sand- or grit-blasting, milling or hammering [11]. In the case of the repairs of the hydraulic structures performed "In-the-Wet", the most often used methods are high-pressure water jetting, abrasive blasting and mechanical scrubbers [12]. The methods are differentiated regarding to aggressiveness, therefore the geometrical structures of the prepared surface are various. For description of the

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Table 1
Compressive strength of underwater repair concrete.

Hydrostatic pressure (MPa)	Compressive strength[a] (MPa)		
	After 7 days	After 28 days	After 28 days (7 days cured in the pressure tank and 21 days cured in water)
0	48.7	60.5	59.7
0.1	48.4	59.3	57.8
0.2	48.1	59.0	57.1
0.3	51.9	60.6	58.7
0.4	52.7	61.5	59.7
0.5	50.2	60.7	59.3

[a] The specimens for the strength tests, which were the cubes 100 × 100 × 100 mm, have been cut from the elements after curing of the repair concrete in the pressure tank.

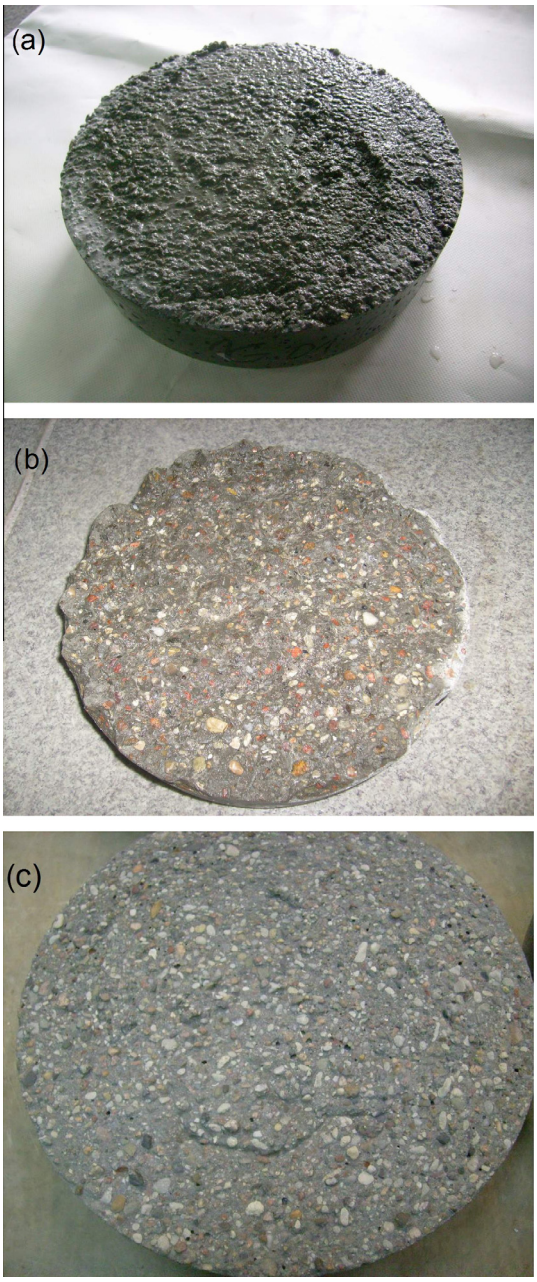

Fig. 1. Three types of the surface preparation of the horizontal substrates: (a) low-pressure washing, (b) manual hammering with pneumatic hammer, and (c) sand-blasting.

geometrical structure, the deviations of the shape and position are determined as well as unevenness, roughness and cracks. Selection of the suitable method of surface preparation depends on the desirable effect and should be adjusted to the material properties of the repaired member and environment in which it is used [13]. The selection of the method depends on the technical possibilities and economical factors. In the case of the underwater repairs of the hydraulic objects in Poland, the most often methods of preparation of the repaired surface are: low-pressure and high-pressure hydro-mechanical method, mechanical or manual hammering and sand-blasting [14].

The methods of testing materials for repair of concrete structures are designed for the materials placed on the dry substrate [15]. The basic use requirements for repair products cover, among other, compressive strength, bond strength, modulus of elasticity, control of shrinkage and creep or thermal expansion. The physical and mechanical properties of the underwater concretes are tested with the methods used for ordinary cement concretes.

The underwater concretes tested in situ show the lower properties than the cast concretes hardening without water access. The typical underwater concretes, placed using tremie method, reach in the structure 80–90% of the designed and laboratory tested strength [16]. In the case of self-consolidated UWC, the fall can be even 50–70% if the concrete mix is subject to the vortices and turbulences [17]. Decrease of UWC strength can be attributed to the combination of factors like washing out of the cement paste particles by the water, leading to growth of water–binder ratio (w/b), segregation of the aggregates during casting of the mix, hydrostatic pressure of the water, erosion of the concrete surfaces and insufficient consolidation of the components. Complex investigation of the influence of the hydrostatic pressure and rate of placing the mix on the repair UWC features have been conducted by Assaad et al. [18]. The results showed that the washout loss increases with the depth of the work (i.e. hydrostatic pressure). For the given rates of concrete mix placing it is possible to determine the boundary values of hydrostatic pressure, above which the rapid growth of the washout loss is observed. Simulation of the influence of water pressure on the mechanical features of cement concretes and pastes were performed by Tashiro and Urushima [19] and Clayton [20]; they observed the negative effect of the high water pressure on the mechanical characteristics and structure of the concrete. However, they investigated the hardened cement concretes and pastes without anti-washout admixtures (AWA). The influence of high hydrostatic pressure on the mechanical properties was investigated by van der Wegen [21]. Tests were performed on the hydraulic concretes and mortars by placing the hardened specimens, after demoulding, in the special chamber where they subjected to the water pressure 10 MPa for 7, 28 and 185 days. No negative effect of such high pressure on the compressive strength of the tested concretes and tensile strength and flexural strength of the mortars was observed. Small number of investigations on the influence of hydrostatic pressure on UWC properties is caused by the necessity of construction of the special testing stands. They are, generally, pressure tanks of special structure, enabling investigation on very small samples of concrete or mortar.