ADHESION OF A UHPFRC COVER TO A REGULAR CONCRETE AS PROTECTION FOR MARINE STRUCTURES

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Abstract

The marine exposure class imposes high cement content in concrete mix design to justify durability criteria which only concern concrete cover exposed to external attacks. The objective of this paper is to present an alternative approach designed by Bouygues Travaux Publics to solve this problem. It consists of modifying the cover properties for durability requirements, creating a protective layer against chloride or CO2 ingress, while prescribing a regular structural concrete for the remaining part of the structure.

This approach is based on a double wall structure as used for buildings. The external skin is prefabricated with a UHPFRC's thin concrete, maintained against the formwork and providing a good resistance to chloride or CO_2 ingress. The characterization of the coating adhesion with the structural concrete as well as the durability and the adhesion of joints are presented and detailed in this article.

Résumé

Les classes d'exposition imposent des minima de dosage en ciment souvent élevés uniquement pour répondre à des critères de durabilité qui ne concernent uniquement que la zone d'enrobage, seule partie de l'ouvrage sujette aux agressions extérieures. L'objectif de cet article est de présenter une solution conçue par Bouygues Travaux Publics pour résoudre ce problème. Elle consiste à faire pleinement jouer l'effet barrière de l'enrobage pour qu'il réponde aux critères de durabilité imposés, en conservant pour le reste du volume un béton structural uniquement.

Le principe est celui du double mur déjà utilisé dans le bâtiment. La peau extérieure est préfabriquée avec un béton mince de type BFUP, quasi imperméable à la diffusion des ions chlorures ou du CO_2, plaquée contre le coffrage. Le travail présenté consiste en l'étude de caractérisation de l'accroche de l'enrobage avec le béton de structure ainsi que la durabilité et l'accroche des joints.

1. INTRODUCTION

The exposure class for marine structures requires concrete mixes with high cement content for justifying the required durability criteria. So, over the years and regulation evolutions [1-4], a strong difference appeared between the mandatory design strength and the effective higher strength, leading to potential pathologies or problems like fragile behaviors. However durability issues only affect the concrete cover and not the entire structure. Furthermore the mix design cost and the environmental footprint increase with the amount of cement and additives like fly ash or silica fume.

UHPFRC is well suited for such applications. The very low porosity and chloride migration property of this material, compared to regular concrete, provide high durability to external aggressive environments. The new standard NF P18-470 recommends the use of UHPFRC to prevent chemical aggression [5]. The purpose of this study is to create a UHPFRC cover coating that could be maintained against a formwork or used as a formwork itself for satisfying durability requirements.

The full coating is in fact made of UHPFRC panels. They have been sized for a better human handling. To seal each panel together, the joints must provide a sufficiently high durability. Several options exist such as epoxy, polyurethane, adhesive or mortar products:

- Epoxy sealants have good technical performances in terms of bond, shear stress, tensile stress or chemical ingress [6],
- Polyurethane sealants have good bond, hardness and ageing properties [6],
- Cementitious mortar have similar behavior than concrete. Additives can be added to modify the porosity and reducing permeability to increase durability,
- Adhesives have good resistance to shear stress, temperature and humidity. The implementation is made by compression of a thin sheet of monomers [7]

Bonding has to have a low surface tension during the setting time of the concrete and the failure must remain cohesive in the concrete or in the UHPFRC coating. These products are characterized in terms of durability and bond properties.

The main objective of this paper is to detail the adhesion results between regular concrete and UHPFRC.

2. MATERIALS AND METHODS

After several preliminary studies for selecting sealants, a full-scale test has been designed to study "scale 1" bond strengths. A 1.90×1.20×0.10 m wall (Figure 1) has been fabricated with different UHPFRC panel sizes (0.02 m thick): 0.20×0.95 m for the smallest panels and 0.94×0.95 m for largest panels. The addition of polyvinyl alcohol fibres (PVA) is required for handling in order to control their fragility.

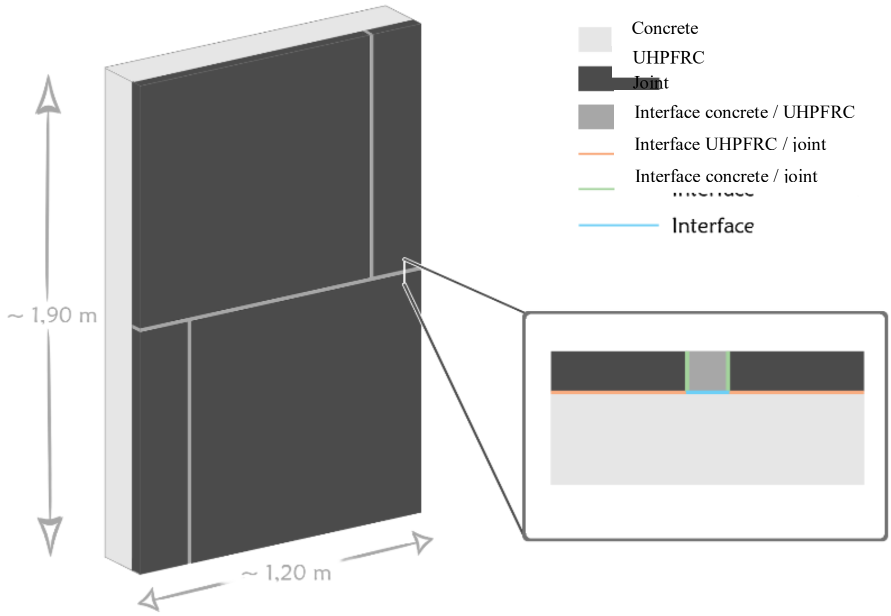


Figure 1: Shell design

To increase the adhesion between the UHPFRC panels and the structural concrete, different surface treatments were studied.

- Smooth surface: no preparation of the surface
- Rough surface: a textile is placed on fresh concrete to scar it. This textile is then removed before hardening.
- Geotextile surface: a humid geotextile is applied to cure the UHPFRC panels. After the concrete setting, the geotextile is not totally removed. Textile fibres remaining at the UHPFRC surface would improve the connection between both concretes.
- Scratch surface: the panel surface is scratched with a proper tool.
- Fibre surface: metallic fibre are perpendicularly placed on the fresh UHPFRC. These fibres are intended to improve the connection between UHPFRC panels and the structural concrete.
- Special design: UHPFRC is marked with a bubble wrap before hardening. The surface is printed by the bubbles.

A formwork is prepared with assembled panels and a C40/50 structural concrete, without additives, is cast to complete the wall. The adhesion between the coating layer and the structural concrete has to be characterized in order to avoid delamination. The main test is the bond test as described in NF EN 1542 [9]. Failure modes (Figure 2) indicate the relative cohesion between the coating and the structural concrete. For each surface texture, 15 to 20 samples are tested.

Between the different panels, joints must be included to insure the durability of the system. They need to be efficient enough to prevent chloride ingress and the risk of delamination. To do so, different types of joints were tested: mortar (marine or not), tapes between or under panels, marine adhesive, polyurethane adhesive and multipurpose epoxy adhesive.

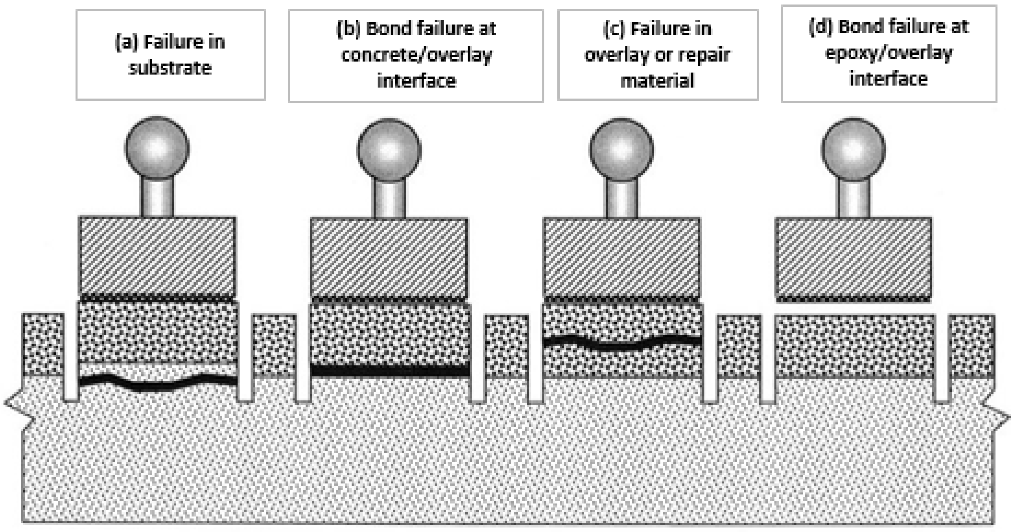


Figure 2: Schematic view of failure modes (from ASTM C1583/C 1583 M-04)

After 28 days, the formwork is removed and joints are set up between the panels. The interstice is generally cleaned. For the adhesive sealant, in addition to cleaning, the supplier requires to prepare the surface with a primer to increase the adhesion between support and adhesive. Then 28 days later, the pull-off test according to NF EN 1542 is made to verify the adhesion between the 3 components: coating, structural concrete and joint. 3 samples are prepared on each joint (horizontal, vertical top, vertical bottom). The characterization of the system is completed with the measurement of the chloride migration coefficient according to NTB 492 test [10].

3. RESULTS

The connection between the UHPFRC coating and the structural concrete strongly depends on the surface texture and the roughness homogeneity, as illustrated in Figure 3.

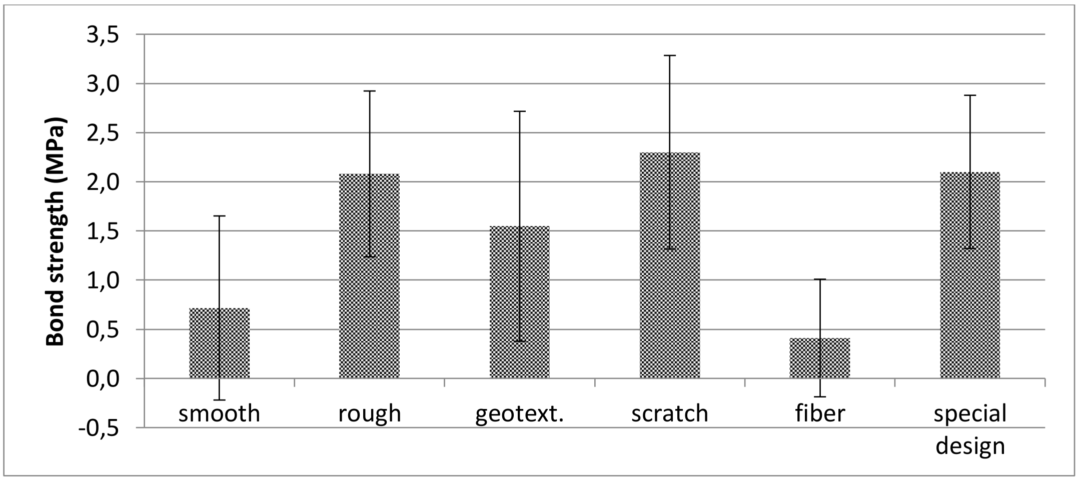
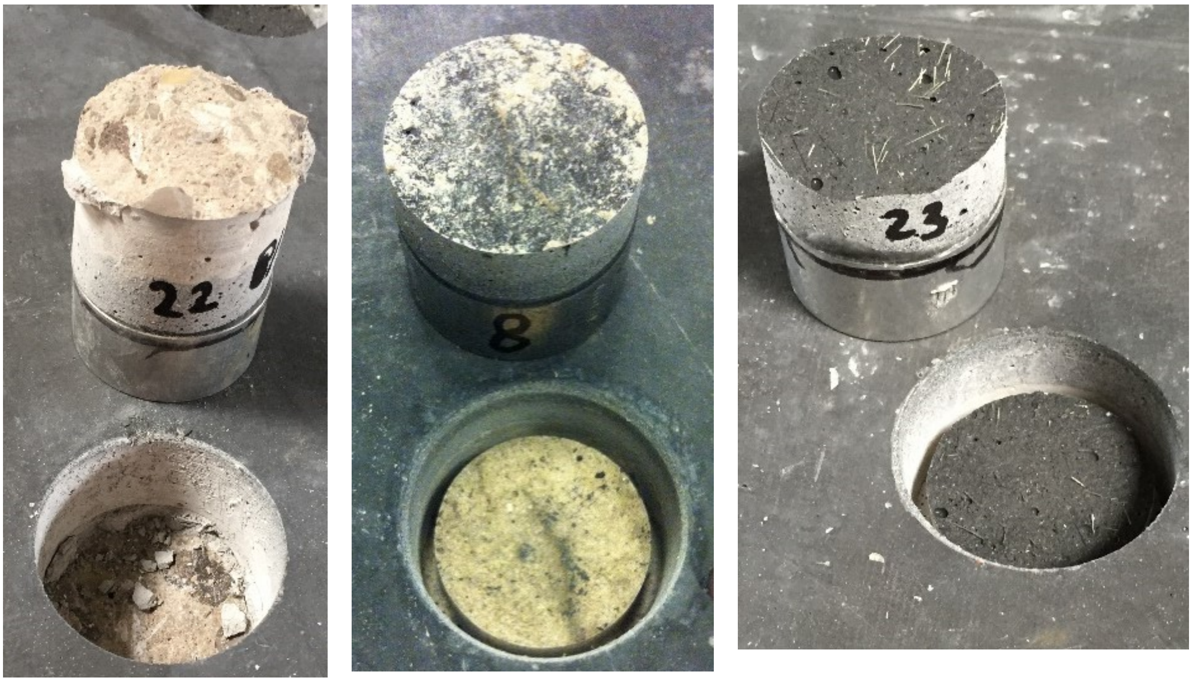


Figure 3: Bond strength according to the surface texture of UHPFRC panels

Smooth and fibre surfaces present a low adhesion with the structural concrete. The failure for smooth surface is represented in Figure 4(b). For fibre surface, the value obtained is due to the fibres preparation. They were painted to prevent corrosion during heat treatment. The presence of painting between fibres and the structural concrete does not allow to have a correct bond failure, mainly because of fibres slipping.

Special design, rough and scratch surface, with a bonding strength around 2 MPa, present higher values than smooth surface (0.7 MPa). This value is in good agreement to the 1.5 MPa bond strength required for concrete floor layers. The failures observed are similar to those given in Figures 4(a) and 4(c) and prove a high adhesion between coating and structural concrete. The failure in 4(c) can be produced by the presence of air bubbles in the UHPFRC.



(a) Failure in concrete

(b) Failure at concrete / overlay interface

(c) Failure in overlay material

Figure 4: Failure patterns

With the geotextile surface, the value obtained is approximatively 1.5 MPa as criteria for concrete floor layers. But the results present a large variability. The repartition of fibres is too random and the adhesion between the coating and the structural concrete is not representative. For the metallic fibres, the same behaviour is observed.

Joints are necessary to prevent chloride aggression. As illustrated in Figure 5, it is not sufficient just to lay 2 panels side by side, no matter how close they are, since the tiniest imperfection can help chloride ingress. Adhesives' chloride migration cannot be measured. During the preparation for sampling, a delamination occurs caused by the non-adhesion between adhesive and concrete. For some adhesives, the same phenomena of delamination appears for the bond test. This kind of product does not present an appropriate behaviour.

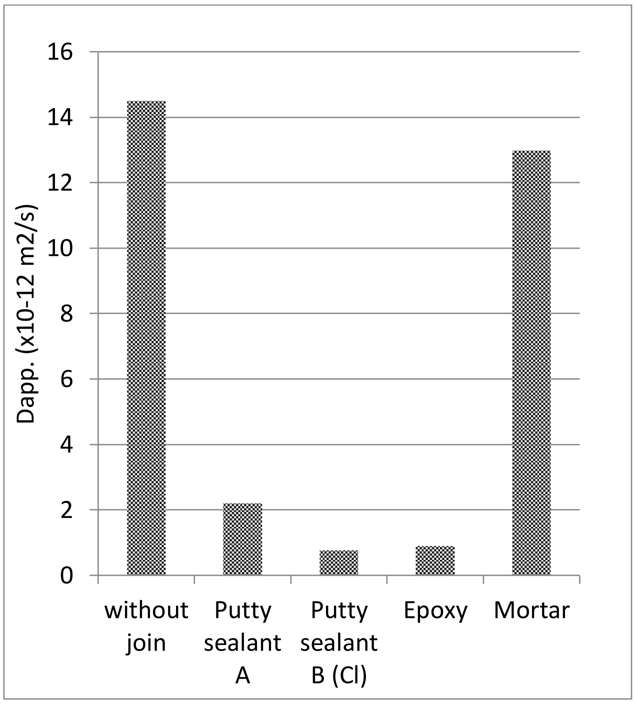


Figure 5: Chloride migration coefficients

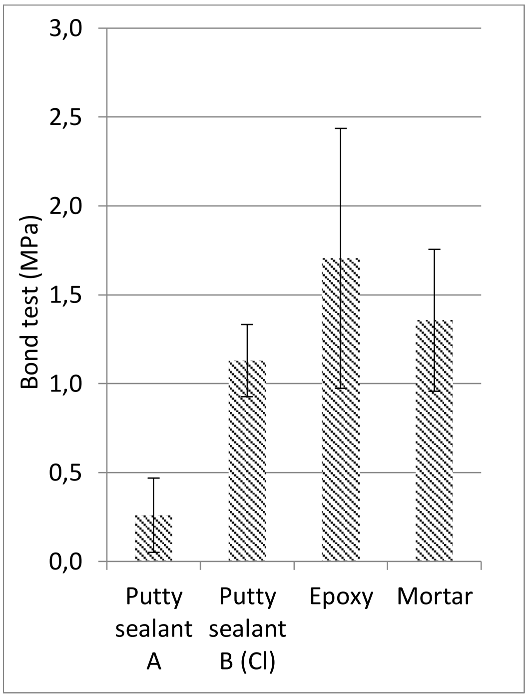


Figure 6 : Bond test for main joints

For the current study, joints are applied vertically after pouring. It will be similar for a real application on site.

For putty and epoxy sealants, chloride migration coefficients have the best results, less than 2.10^{-12} m^2/s. The difference between putty A and B is coming from the fact that putty sealant B is recommended for marine applications. The value obtained for sealant B is in good agreement.

Conversely, mortar recommended for marine applications has a chloride migration coefficient similar to the case without joint. The different mortars tested present shrinkage with the UHPFRC panels. This cracking help the chlorides to penetrate up to the structural concrete. Some of them have different rheology which makes easier the setting on small spaces but will modify the durability properties.

Figure 6 illustrates bond tests strength. Epoxy gives the best performance for this test compare to other joints. For pull-off tests, the results show the difference of adhesion between the 2 putty sealants although the setting is similar for both products. The adhesion between the putty sealant and the concrete is higher for sealant B than A.

Epoxy gives the best performance results. The adhesion with coating and concrete is satisfactory and the chloride migration coefficient too. The application on site should be revisited. The setting time is only 30 minutes: it can be too short for high shells.

The joint implementation on the same shell gives different results on bond tests and chloride migrations. The application method seems to be the same for all the joints but Figure 7 gives another point of view. The horizontal joint presents the smallest variability of chloride migration coefficients compared to vertical top joints. Their coefficients are three times larger for vertical bottom joints than for vertical top joints. The vertical position of the shell can modify the joint behavior and its efficiency.

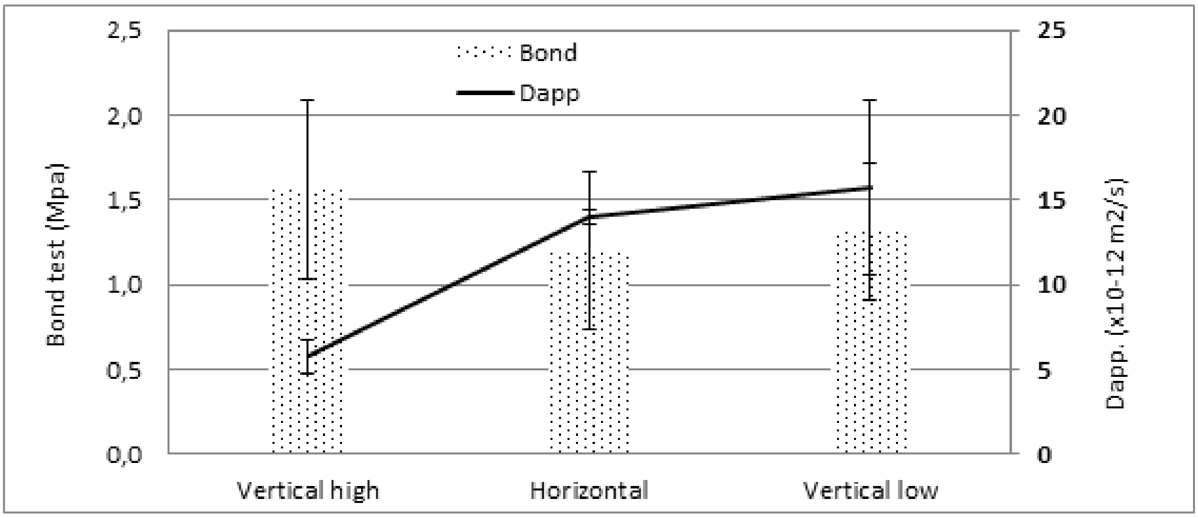


Figure 7: Results of chloride migration and bond tests for mortar joint

Chemical or organic joints seem to be sensitive to setting. Mechanical joints may be an interesting alternative to study.

4. CONCLUSION

UHPFRC could be an interesting approach for protecting the structural concrete against aggressive environments. This paper presents an original double wall system and details the characteristics of the adhesion between the UHPFRC coating layer and the regular structural concrete to prevent chloride ingress. The durability depends on the surface roughness. The material used for the sealing joint and their locations is also influencing the adhesion properties. The problem is therefore not reduced to the right choice of a joint type, but special attention for the setting methods is also required. The characteristics of each component is not sufficient. The system coating/concrete/joint should be considered as a whole system.

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