Flexural Strength Behavior of Composite UHPFC – Existing Concrete

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Flexural Strength Behavior of Composite UHPFC - Existing Concrete

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Abstract. Ultra high performance fiber concrete (UHPFC) is an advanced formula concrete that is proven to be more superior than conventional concrete because it embrace the qualities of steel and concrete. Therefore UHPFC properties which include high durability and strength are fully exploited in the research of rehabilitation and strengthening in concrete and even non-concrete structures. This article presents the findings of an experimental study carried out to examine the bonding strength behaviour between normal concrete (NC) substrate and UHPFC as a repair material, under flexural strength test by using third-point loading beam test method. Three types of NC substrate surface preparation were used: as-cast (without surface preparation) as a reference, wire-brushed, and sand-blasted. The flexural test results clearly indicated that all failures occurred through the NC substrate and no de-bonding was observed in the interface between NC substrate and UHPFC. The results of the flexural strength confirmed that adhesion bond strength between NC substrate and UHPFC was stronger than the substrate regardless, the substrate roughness. This proves that UHPFC is able to link and bond strongly with the substrate.

Introduction:

The deterioration of reinforced concrete structures is a major social problem. To minimize this problem and ensure effective structural management, the number and extent of repair interventions must be kept at the lowest probable level [1].

In the field of rehabilitation, the bond strength between the new and existing concrete generally presents a weak link in the repaired structures [2]. Good bond is one of the paramount importance for the success in repair works [3].

The extremely low permeability characteristic of UHPFC jointly with their outstanding mechanical properties reinforce the idea to use UHPFC to rehabilitate and strengthen the zones where the structures are exposed to high mechanical loading and severe environmental [4]. UHPFC could be used as a repair materials as it has strong mechanical bond, which formed between the UHPFC as an overlay material and the substrate material [5].

A number of studies have used UHPFC as a repair or composite material to strengthen normal concrete (NC) members. However, few recent studies have evaluated the slant shear and splitting tensile strength of the bond between UHPFC and NC as repair material and substrate material, respectively [5-7]. Thus, the objective of the present study is to examine the bonding strength behaviour between normal concrete (NC) substrate and UHPFC as a repair material, under flexural strength test by using third-point loading beam test method. Three types of NC substrate surface preparation were used: as-cast (without surface preparation) as a reference, wire-brushed, and sand-blasted.

Experimental Programme

Normal concrete substrate and UHPFC properties. Normal concrete substrate (NC) was used as an existing concrete. The mixing design of NC used in this study ensures average compressive strengths 45MPa at 28 days. The NC used contains Type-I ordinary Portland cement, river sand with fineness modulus of 2.4, coarse aggregate (granite) with a maximum size of 12.5mm, a water-to-cement ratio of 0.5 and a slump value between 150-180 mm. The mix proportion of the NC substrate is presented in Table 1. A prism with dimensions 100 mm × 100 mm × 400 mm was used as a control. The NC prisms were tested for 28 days strength and experimental results showed the NC has an average flexural strength of 4.76 MPa.

Table 1. NC substrate mix design

Item	Mass (kg/m^3)
OPC	400
Coarse Aggregate	930
Fine Aggregate	873
Water	200
Superplasticizer	4

Table 2. UHPFC mix design

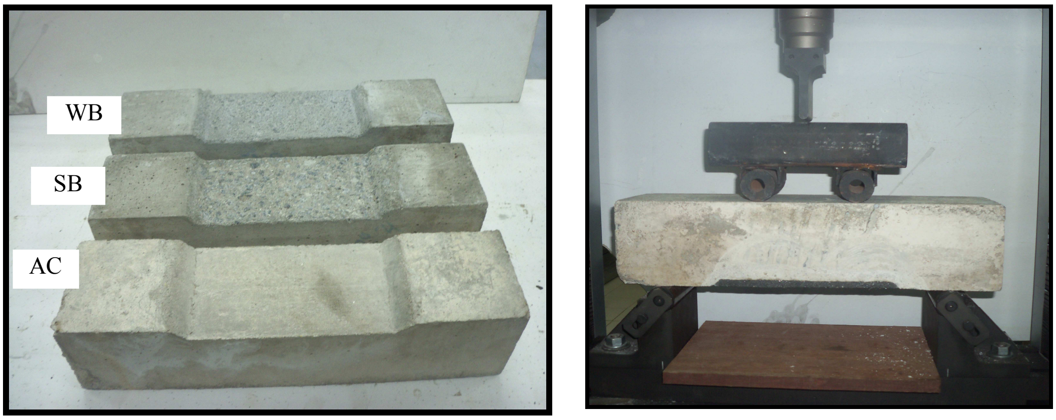
Item	Mass (kg/m^3)
OPC	768
Silica Fume	192
Sieved Sand	1140
Micro-Steel Fiber	157
Superplasticizer	40
Free Water	144

The mix design of UHPFC used as a repair material contains Type-I ordinary Portland cement, densified silica fume, well graded sieved and dried mining sand, very high strength micro-steel fiber and polycarboxylate ether based (PCE) superplasticizer. The steel fiber used has a fiber length and fiber diameter of 10mm and 0.2mm, respectively, and the steel fiber has ultimate tensile strength of 2500 MPa. The UHPFC used has achieved an average 3 days cube compressive strength of f_c' = 165 MPa. The mix design of the UHPFC is presented in Table 2. A prisms of UHPFC with dimensions 100 mm × 100 mm × 400 mm were tested for 3 days strength and experimental results showed the UHPFC has an average flexural strength of 18.90 MPa.

Specimens Preparation. Each of the tested specimen comprised of two different materials, being the NC as a substrate and UHPFC as a repair material. To fabricate the composite UHPFC/NC substrate, the NC substrate prism was cast with similar dimensions as the control prism, with an additional wide-mouthed notch of 200 mm (length) 100 mm (width) 10 mm (depth). The fresh NC was sealed and left to set in its moulds for 24 hours after casting. After 24 hours the NC specimens were demoulded and were cleaned and cured for another two days in a water curing tank. At the age of three days, the NC substrate specimens were taken out from the water tank for surface preparation. In this study, the experimental parameter is the surface texture of the substrate. Three different types of surface were prepared, that is (i) as cast without roughening (AC), (ii) sand blasting (SB) and (iii) wire brushing (WB).

Fig. 1.a, shows the roughened surfaces of the NC substrate specimens. These specimens represent the substrate for the flexural test. Prior to the casting the UHPFC onto this roughened NC surfaces, the NC specimens were further cured in a water tank until the age of 28 days since the casting date. At the age of 28 days, the NC substrate specimens were left to dry for two months.

Before casting the UHPFC, the surfaces of the NC substrate specimens were moistening for 10 minutes and wiped dry with a damped cloth. The NC substrate specimens were then placed into their respective moulds with the roughening side facing upward to be overlaid with the UHPFC. Mixing of the UHPFC was carrying out using a pan mixer. The moulds were then filled with UHPFC. The composite UHPFC/NC substrate specimens were steam cured for 48 hours at a temperature of 90°C. At age 3 and 7 days, the third point bending strength test was performed for the composite UHPFC/NC substrate specimens using AUTOGRAPH AG-X, having a capacity of 100 kN and loaded at the rate of 1 MPa/min. Fig. 1.b shows the flexural test set-up for composite UHPFC/NC substrate specimens.



(a) (b)

Fig. 1: (a) NC substrate with different surface treatment and (b) the third-point loading beam test set-up for the composite UHPFC/NC substrate specimen.

Third Point Loading Beam Test Method (Flexural Strength). This test was performed to investigate the bonding behavior between UHPFC and NC substrate. In this test, the UHPFC is applied to a recess made on bottom of a prismatic NC substrate. A third point bending strength test, according to ASTM C 78 [8] was used to test the composite specimens. Flexural strengths of NC and UHPFC was tested by a third point bending strength test, according to ASTM C 78 [8] and ASTM C 1018 [9] respectively. In this test method, the geometry of concrete prisms 400 mm in length with a cross sectional area of 100 mm x 100 mm was used. The test procedure requires that the prism span length to be at least three times it's depth as indicated in Fig.1.b. The load is applied through two points that are located at one-third of the span length from each support. As a result, the maximum stress is induced in the middle third of the prism.

$$F = \frac{PL}{bd^2}$$

F flexural strength, (MPa),
P maximum applied load indicated by the testing machine, (N)
L span length, (mm)
b average width of specimen, (mm)
d average depth of specimen, (mm)

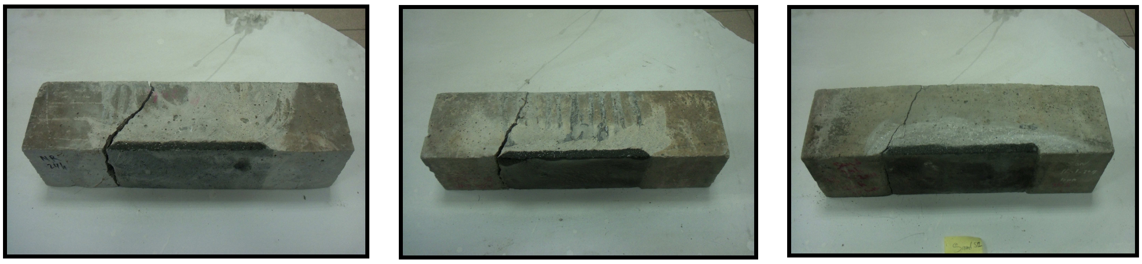
Results and Disscusion

The results of flexural test are shown in Table 3. The results clearly showed that all failures occurred via the NC substrate, as shown in Fig. 2. This behaviour was the same for the test ages 3 and 7 days, and for all types of surface roughness, as-cast, wire-brushed and sand-blasted. These results in general agreed with those of R.R. Pattnaik et al. [10], who studied the bonding between normal concrete and different types of epoxy, for very rough substrate surface. In that study, when the compressive strength of the epoxy was stronger than the normal concrete substrate, the failure mode was through the normal concrete. Likewise, the UHPFC used in this study had a compressive strength stronger than the NC substrate, so the failure occurred through the substrate. This proved that UHPFC was able to link and bond strongly with the substrate, particularly the bonded surface located in tension side. The failure generally occurred at the middle of the prism as in monolithic prism of NC substrate and UHPFC. These results also proved that binder materials would not be needed if UHPFC is used as overlay material.

The results of the flexural strength confirmed that adhesion bond strength between NC substrate and UHPFC was very strong, and was stronger than the substrate regardless the substrate roughness. In case of as-cast surface, although the substrate surface was not rough, the adhesion bonding was stronger than the substrate, with evidence the failure occurred via the substrate as shown in Fig. 2.a. This can be attributed to the chemical adhesion bond due to the action of the silica fume in the UHPFC along with the calcium exist in the substrate surface which together forms the calcium silicate, leading to improvement in the interface [11,12]. In addition, the application of steam curing significantly improves the hydration process [13] as well as the properties of silica fume thereby leading to the formation of more densified cement matrix microstructure.

Table 1: Flexural strength and failure modes of composite UHPFC/NC substrate specimens

Test age	Surface Treatment	Sample No.	Max. Load (kN)	Max. Stress (MPa)	Average (MPa)	Standard deviation (MPa)	COV (%)	Failure Mode
3 days	As-cast surface	AC1	14.24	4.27	4.27	0.00	0.04	Substrate
		AC2	14.23	4.27				Substrate
	Wire-brushed	WB1	19.19	5.76	5.34	0.60	11.18	Substrate
		WB2	16.38	4.91				Substrate
	Sand-blasted	SB1	13.84	4.15	4.64	0.69	14.84	Substrate
		SB2	17.08	5.12				Substrate
7 days	As-cast surface	AC1	16.52	4.96	5.07	0.17	3.30	Substrate
		AC2	17.31	5.19				Substrate
	Wire-brushed	WB1	13.61	4.08	4.74	0.92	19.49	Substrate
		WB2	17.96	5.39				Substrate
	Sand-blasted	SB1	18.74	5.62	5.09	0.75	14.80	Substrate
		SB2	15.19	4.56				Substrate



(a) (b) (c)

Fig. 2: Flexure failure of composite UHPFC/NC substrate, (a) as-cast surface, (b) wire-brushed surface and (c) sand-blasted surface.

Summary

As a conclusion, it can be said that:

The results of the flexural test clearly indicated that all failures occurred through the NC substrate and no de-bonding was observed in the interface between NC substrate and UHPFC. The results of the flexural strength confirmed that adhesion bond strength between NC substrate and UHPFC was very strong, and was stronger than the substrate regardless the substrate roughness. In case of as-cast surface, although the substrate surface was not rough, the adhesion bonding was stronger than the substrate, with evidence the failure occurred via the substrate. This proves that UHPFC is able to link and bond strongly with the substrate, although the bonded surface located in tension side, no separation between the NC substrate and the UHPFC which indicates that superior bond behaviour of UHPFC.

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