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Compressive Stress-Strain Behavior of Composite Ordinary and Reactive Powder Concrete

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Abstract: 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. Good bond is one of the main requirements for successful repair. The main aim of this study was to investigate the compressive stress-strain behaviour of the composite specimens consist of ordinary concrete (OC) substrate as old concrete and reactive powder concrete (RPC) as a retrofitting material, by using different types of OC substrate surface preparation methods. The results showed that the composite OC/RPC specimens were able to behave closely to individual OC, in the case of using OC substrate with surface prepared by sand blasted.

Key words: Reactive powder concrete · Bond strength · Repair material · Substrate · Compressive stress-strain

INTRODUCTION

Reduction in the useful service-life of reinforced concrete construction is a major problem confronting the construction industry worldwide. Repair and rehabilitation of deteriorated concrete structures are essential not only to utilize them for their intended service-life but also to assure the safety and serviceability of the associated components.

A good repair improves the function and performance of the concrete structure, whether the structure is a pavement, or a bridge, or a building. On the other hand, poor repair fails early or deteriorates the adjoining sound concrete material in a relatively short period of time. Selection of appropriate repair materials depends on the material properties and behaviour of composite section under anticipated service exposure conditions [1-3].

The reactive powder concrete (RPC) has a remarkable flexural strength and very high ductility; their ductility is greater than 250 times that of conventional concrete [4, 5]. Their extremely low porosity gives them low permeability and high durability and makes them potentially suitable for being used in a new technique for retrofitting reinforced concrete structures [6, 7].

A number of studies [8-11] have used RPC as a repair or composite material to strengthen OC structural members. However, very little information on the behavior of the compressive stress-strain behavior of the composite specimens OC/RPC bond between RPC as repair material and old concrete substrate is available.

The main aim of the work presented here is to investigate the compressive stress-strain behavior of the composite specimens consist of ordinary concrete (OC) substrate as old concrete and reactive powder concrete (RPC) as a retrofitting material, by using different types of OC substrate surface preparation methods.

Experimental Programme

Ordinary Concrete Substrate and RPC Properties: The mixing design of OC used in this study ensures average compressive strengths 45MPa at 28 days. The OC used contains Type-I ordinary Portland cement, river sand with

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Table 1: OC substrate mix design

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

Table 2: RPC mix design

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

Fig. 1: Specimen for OC compression test

Fig. 2: Slant shear test specimens with the different surface textures

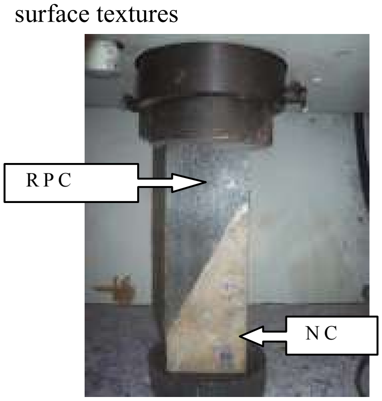


Fig. 3: Slant shear test specimens

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 OC substrate is presented in Table 1. As shown in Figure.1, the control specimen used consists of 100mm x 100mm x 300mm tall prism for uniaxial compression strength test with an average compression strength 38MPa at 28 days.

The mix design of RPC 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) super-plasticizer. 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 RPC used has achieved an average 28 days cube compressive strength of f_{cu} = 170 MPa. The mix design of the RPC is presented in Table 2.

Specimens Preparation: Each of the tested specimen comprised of two different materials, being the OC as a substrate and RPC as a repair material. The fresh OC was sealed and left to set in its moulds for 24 hours after casting. After 24 hours the OC specimens were demoulded and were cleaned and cured for another two days in a water curing tank. At the age of three days, the OC 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. Five different types of surface were prepared, which are (i) as casted without roughening (AC), (ii) sand blasted (SB), (iii) wire brushed (WB), (iv) drill holes (DR) and (v) grooves (GR).

Figure 2 shows the roughened surfaces of the OC substrate specimens. These specimens represent the first half substrate for the slant shear test. Prior to the casting the RPC onto this roughened OC surfaces, the OC 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 OC substrate specimens were left to dry for two months [12].

Before casting the RPC, the surfaces of the OC substrate specimens were moistured for 10 minutes and wiped dry with a damped cloth. The OC substrate specimens were then placed into steel-made moulds with the slant side face upward. Mixing of the RPC was carrying out using a pan mixer. The moulds were then filled with RPC. Figure 3 shows the complete composite specimens for the split cylinder strength tests and slant shear strength tests.

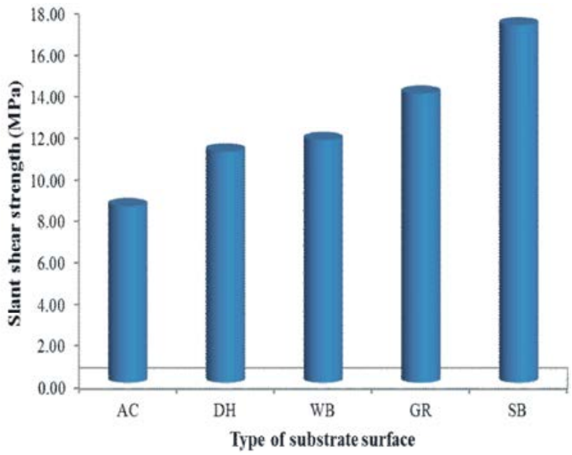


Fig. 4: Slant shear strength for each type of substrate surface

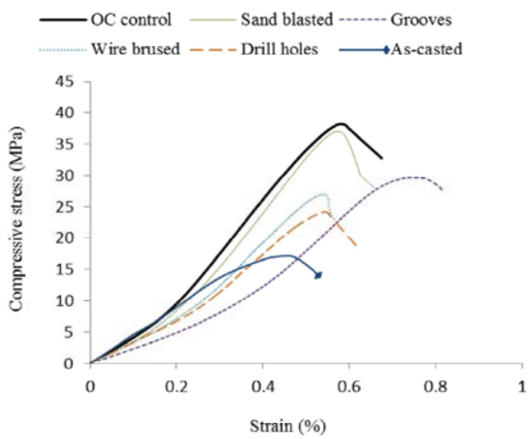


Fig. 5: Compressive stress-strain curves.

The composite specimens were steam cured for 48 hours at a temperature of 90°C [13, 14]. At age 7 days, slant shear test was performed.

Test Method: Slant shear test as per the specification of ASTM C882 [15] was used to investigate the behavior of compressive stress-strain of the composite specimens OC substrate and RPC repair material. the bond strength between OC substrate and RPC repair material also calculated. The RPC was casted and bonded to the OC substrate specimens on a slant plane inclined angle of 30° from the vertical axis to form a 100mm x 100mm x 300mm composite prisms specimens [7] as shown in Figure 3.

Discussion of Results: The bond strength for the slant shear strength was calculated by dividing the maximum load by the bond area which can be expressed as:

$$S = \left\{ \frac{P}{A_L} \right\} \quad (1)$$

where S is the slant shear strength (in MPa); P is the maximum force recorded (in kN) and A_L is the area of the slant surface (in mm^2). The experimental slant shear strength test results were presented in Figure 4.

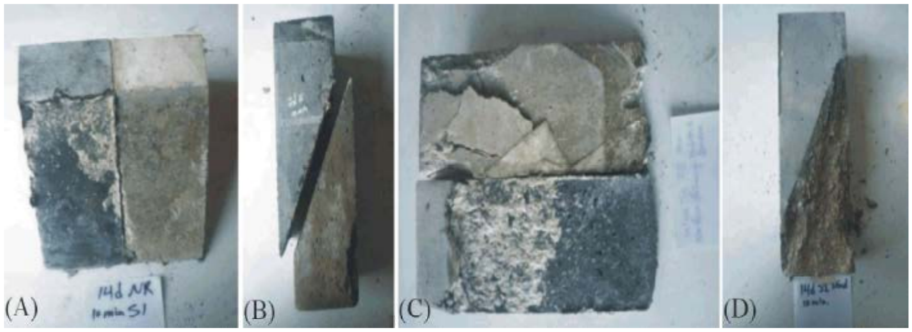
As shown in Figure 5., the type of substrate surface preparation affects on the compressive stress-strain behavior of the composite specimens, the recorded compressive strength increases in the order of as casted surface < drill holes surface < wire brush surface < grooved surface < sand blasted surface. Hence, the differently prepared surfaces of the substrates provide significant improvement in bond strength of the composites in comparison to no preparation surface (as casted), the different substrate surfaces provide a relative increase of 31.1, 37.5, 64.0 and 102.7%, for drill holes surface, wire brush surface, grooved surface and sandblasted surface, respectively. Thus, the different substrate surfaces enhance the bond strength by between 31.1 to 102.7%, with the sand blasted surface exhibiting the highest enhancement; since in case of the substrate surface prepared by sand blasted, the compressive stress-strain of the composite specimens behaved closely to individual OC.

The failure modes for the slant shear specimens can be categorized into four types as shown in Figure 6:

- Type A is the interfacial bond failure;
- Type B is the interfacial failure and substrate cracks or small parts broken;
- Type C is the interfacial failure and substrate fracture;
- Type D is the substratum failure.

The lowest shear bond strength was recorded in the case of the as casted surface due to no surface preparation of the substrate. Again, the observed trend further emphasizes the necessity for appropriate surface preparation to ensure improved the bond strength of the composites. The drill holes and wire brush surfaces exhibit combination of type B (Figure 6b) and C (Figure 6c) failure modes from 3 samples tested, while the grooved and sand blasted surfaces exhibit type C and D failure mode, respectively. Thus, the highest bond strength recorded by the sand blasted surface is concurrent with the observed failure mode; i.e. complete substratum failure with no interfacial de-bonding (Figure 6d). The average slant shear test was the highest in the surface sand blasted substrate (i.e. S_{av} = 17.18 MPa).

The ACI Concrete Repair Guide specifies the acceptable bond strength for repair work shall within the ranges of 6.9 – 12MPa for slant shear strength at 7 days



A= Interface failure, B = Interface failure & substrate cracks, C = Interface failure & substrate fracture, D = Substratum failure.
Fig. 6: The failure modes for the slant shear specimens

test age [16]. This guideline is particularly useful for the selection of appropriate repair material. the tested specimens in this study were tested at 7 days. Comparison shows that most of slant shear strength of this study near or more than the ACI requirement at 7 days [17].

CONCLUSION

This paper discusses the experimental results of the compressive stress-strain behavior of composite specimens consist of ordinary concrete OC substrate (with a cube compression strength of 45MPa) as an old concrete and reactive powder concrete RPC (with a cube compression strength of 170MPa) as a repair material, by using different types of OC substrate surface preparation methods. The experimental results can be summarized by the following points:

- The results showed that, at early ages the composite OC/RPC specimens were able to behave closely to individual OC, in case of OC substrate surface was prepared by sand blasted.
- The results of slant shear test showed that the bond strength between RPC and the substrate depended on the type of surface preparation of the substrate.
- Long-term test for bond strength between the RPC and OC substrate should be carried out to collect statistical data and review the performance of RPC against time effects.

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REFERENCES

1. Vaysburd, A. and P. Emmons, 2000. How to make today's repairs durable for tomorrow—corrosion protection in concrete repair. Construction and Building Materials, 14(4): 189-97.
2. Tayeh, B.A., B.H. Abu Bakar, M.A. Megat Johari and Y.L. Voo, 2013. Utilization of ultra high performance fibre concrete (UHPFC) for rehabilitation – a review. Procedia Engineering, 54: 525-38.
3. Courard, L., F. Michel, D. Schwall, A. Wielen, A. Garbacz and T. Piotrowski, 2009. Surfology: concrete substrate evaluation prior to repair. Materials Characterization IV: Computational Methods and Experiments, 64: 407-16.
4. Richard, P. and M. Cheyrezy, 1995. Composition of reactive powder concretes. Cement and concrete Research, 25(7): 1501-11.
5. Graybeal, B.A., 2007. Compressive behavior of ultra-high-performance fiber-reinforced concrete. ACI Materials Journal, 104(2): 146-52.
6. Bruhwiler, E., 2012. Rehabilitation and strengthening of concrete structures using ultra-high performance fibre reinforced concrete. International Conference on Concrete Repair, Rehabilitation and Retrofitting, 02-05 September 2012. Cape Town, South Africa.
7. Tayeh, B.A., B.H. Abu Bakar, M.A. Megat Johari and Y.L. Voo, 2012. Mechanical and permeability properties of the interface between normal concrete substrate and ultra high performance fiber concrete overlay. Construction and Building Materials, 36: 538-48.
8. Brühwiler, E. and E. Denarié, 2008 Rehabilitation of concrete structures using Ultra-High Performance Fibre Reinforced Concrete. The Second International Symposium on Ultra High Performance Concrete, 05-07 March 2008. Kassel University, Germany.

9. Habel, K., E. Denarié and E. Brühwiler, 2006 Structural response of elements combining ultrahigh-performance fiber-reinforced concretes and reinforced concrete. Journal of Structural Engineering, 132: 1793.
10. Tayeh, B.A., B.H. Abu Bakar, M.A. Megat Johari and M.M. Ratnam, 2013. The Relationship between substrate roughness parameters and bond strength of ultra high- performance fiber concrete. Journal of Adhesion Science and Technology, http:// dx.doi.org/ 10.1080/01694243.2012.761543.
11. Tayeh, B.A., B.H. Abu Bakar, M.A. Megat Johari and A.M. Zeyad, 2013. Flexural Strength Behavior of Composite UHPFC - Existing Concrete Advanced Materials Research, 701: 32-6.
12. Tayeh, B.A., B.H. Abu Bakar and M.A. Megat Johari, 2012. Mechanical properties of old concrete - UHPFC interface.. International Conference on Concrete Repair, Rehabilitation and Retrofitting III (ICCRRR 2012), 02-05 September 2012. Cape Town, South Africa, pp: 1035-40.
13. Tayeh, B.A., B.H. Abu Bakar and M.A. Megat Johari, 2013. Characterization of the interfacial bond between old concrete substrate and ultra high performance fiber concrete repair composite. Materials and Structures, 46(5): 743-53.
14. Tayeh, B.A., B.H. Abu Bakar, M.A. Megat Johari and Y.L. Voo, 2013. Evaluation of bond strength between normal concrete substrate and ultra high performance fiber concrete as a repair material. Procedia Engineering, 54: 554-63.
15. ASTM-C882. Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear. American Society for Testing and Materials, West Conshohocken, PA 19428-2959, United States1999.
16. Chynoweth, G., R.R. Stankie, W.L. Allen, R.R. Anderson, W.N. Babcock and P. Barlow, 1996. Concrete Repair Guide. ACI Committee, Concrete Repair Manual, 546: 287-327.
17. Tayeh, B.A., B.H. Abu Bakar, M.A. Megat Johari and A.M. Zeyad, 2013. The role of silica fume in the adhesion of concrete restoration systems.. Advanced Materials Research, 626: 265-9.