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Repair of Pre-Cracked RC Beams Using Several Cementitious Materials

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Authors' contributions

This work is carried out in collaboration between the two authors. Author SMS has designed the study and written the first and final drafts of the manuscript. Author YMO has executed the experimental program and helped in literature review. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

This study investigates the use of four cementitious repair materials in terms of restoring the flexural capacities of pre-cracked reinforced concrete shallow beams. Fifteen reinforced concrete beams are cast, pre-cracked, repaired and then tested under four point-loading. The repair materials used include Ultra High Performance Concrete (UHPC), Ultra High Performance Fiber Reinforced Concrete (UHPFRC), Normal Strength Concrete (NSC) and Cement-based Repair Material (CRM). Added to this, three beams are cast, tested and considered as control beams. The outcome of this study shows that the four repair materials can achieve flexural capacities ranging from 97 % to 111% of the control beam capacities. In addition, mid-span deflections and crack patterns are also compared.

Keywords: Pre-cracked; shallow beams; UHPFRC; UHPC; flexural capacity; stiffness.

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ABBREVIATIONS

***NSC**: Normal strength concrete; **UHPC**: Ultra high performance concrete; **UHPFRC**: Ultra high performance fiber reinforced concrete; **CRM**: Cement-based repair material; **C.B:** Control beams.*

1. INTRODUCTION

Reinforced concrete is generally considered a good durable material, when compared to other competing construction materials [1]. Nevertheless, a large number of concrete structures deteriorate due to inadequacy of design, overloading due to change in use, chloride attack, corrosion, exposure to elevated temperatures, bombardment, etc [2,3].

In the European Union about 84,000 reinforced and prestressed concrete bridges need to be maintained, repaired and strengthened at an annual cost of £215 M, while in the USA, about 27% of highway bridges require repair or replacement [4]. Due to the high cost associated with reconstruction of the damaged elements, repair and strengthening techniques have become a priority in the recent years due to its much lower cost.

Traditional techniques using steel plates have been used in the past to improve flexural and shear capacities of damaged concrete beams [5-7]. However, high installation cost and corrosion of the plates focused the attention on using fiber-reinforced polymers, suitable in terms of low costs and fast in execution, as new repair materials.

Carbon fibre reinforced polymer sheets have been successfully used to repair and strengthen reinforced concrete structures. The success may be attributed to their high strength-to-weight ratio, high stiffness, ease in installation and corrosion resistance of the material [8,9].

A large number of researchers concluded that using bonded CFRP sheets can enhance the flexural capacities of the repair/strengthened beams in addition to reducing their deflections [8,10,11,12]. On the other hand, some researchers stated that strengthening by means of CFRP turn the ductile behavior of the original beams into brittle one due to debonding between concrete and CFRP sheets [10,13].

Ultra high performance concretes have been used for improving flexural behavior of damaged concrete beams. Flexural tests showed that these composites can improve the flexural behavior of reinforced concrete beams, including flexural strength and ductility [14-16].

Epoxy resins prepared by different manufactures are also used in restoring flexural capacities of pre-cracked beams. Repaired beams are tested to failure and compared with the control beams. In general, the results obtained show that the repaired beams yielded flexural strengths larger than those of the control beams. In addition, deflections of the repaired beams are much smaller [17-18]. A study carried out at King Saud University showed that commercial repair materials subjected to tensile stresses had no significant contribution to beam response compared to normal concrete. However, significant contribution was observed when commercial repair materials are subjected to compressive stresses [19].

The objective of this research is to investigate the flexural performance of pre-cracked reinforced concrete beams repaired using several cementitious materials, including Ultra High Performance Concrete. The importance of this study stems from the fact that a large number of concrete buildings have been damaged due to the effect of air bombardment caused by outbreak of violence in the Gaza Strip and need to be repaired/strengthened efficiently at low cost.

2. EXPERIMENTAL PROGRAMS

The main objective of the testing program is to study the flexural capacities of beams repaired using four different cementitious materials. In addition, crack patterns and mid-span deflections are to be evaluated.

2.1 Materials

2.1.1 Concrete

All the beams are cast using normal strength concrete that has a 28-day compressive strength of 25 MPa. Then, the beam specimens, used in the study, are wet cured for a 28-day period.

2.1.2 Repair materials

Beams are repaired using four cementitious materials. Normal strength concrete having a 28-day compressive strength of 25 MPa, Ultra High Performance Concrete having a 28-day compressive strength of 120 MPa and Ultra High Performance Fiber Reinforced Concrete having a 28-day compressive strength of 134 MPa and a tensile splitting strength of 7.82 MPa are used. In addition, a commercial repair material “BETONREP 250” manufactured by YASMO MISR, Egypt having a 7-day compressive strength of 30 MPa is also used. Concrete composition is shown in Table.1.

Table 1. Concrete composition

Components	UHPC	UHPFRC	NSC
	Kg/m^3		
Cement (CEM I52.2 R)	600	600	300
Water	180	180	188
Aggregates	1605	1605	1880
Silicafume	93	93	0
Superplasticizer	18	19.8	18
Steel fibers	0	0.50	0

2.1.3 Steel reinforcement

The yield strengths of the deformed reinforcement used in preparing the test specimens are 420 MPa and 280 MPa, for 12 mm and 8 mm bars, respectively.

2.2 Test Specimens

2.2.1 Dimensions and reinforcement

Test beams are 150 mm wide, 200 mm deep and 1100 mm long. The actual span is limited to 900 mm, as shown in Fig. 1. Each of the 15 beams is reinforced on the tension side with 2 bars, 12 mm in diameter and on the compression side with 2 bars, 8mm in diameter. All beams are overdesigned in shear to avoid shear failure using 8 mm stirrups spaced at 50 mm. The beams are designed according to the requirements of ACI 318-11M [20] as tension-controlled.

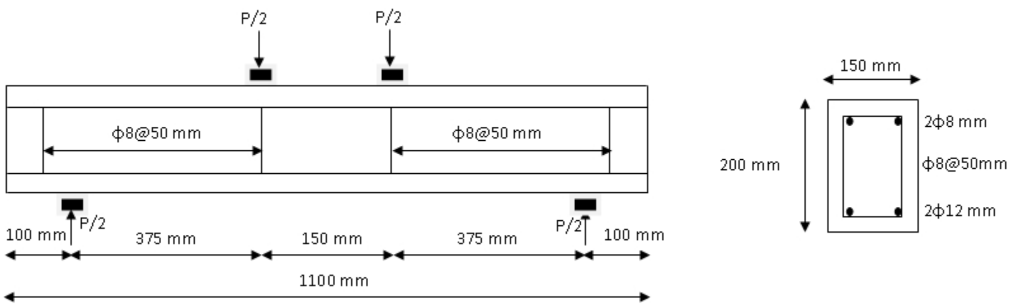


Fig. 1. Beam dimensions and reinforcement details

2.2.2 Pre-crackinf and repair

Twelve beams are tested in a loading frame under four point-loading to two thirds of their ultimate load capacities in order to induce initial cracks and be ready for application of the repair materials, Fig. 2. The cracks are then grooved to form a V-shape using a chisel in order to replace the damaged concrete for widths ranging from 2-3 cm at the extreme tension fiber to zero width around the tension reinforcement level. Then, water is sprinkled on the formed groves to remove any loose materials, Fig. 3.

Fig. 2. Pre-cracks are marked

Fig. 3. Cracked beams are V-shaped grooved

Four beam groups (3 beams each) are then repaired using the four repair materials and wet cured for another 7 days, Fig. 4.

Fig. 4. Cracked beams after application of the repair materials

2.2.3 Flexural testing

Three undamaged beams are tested to failure under four point loading and considered as control specimens. Ultimate loads are recorded, crack patterns are traced and mid-span deflections are measured using dial gauges. In addition, the 12 repaired beams are loaded to failure. Ultimate loads are recorded, crack patterns are traced and mid-span deflections are measured.

3. RESULTS AND DISCUSSION

3.1 Flexural Capacities

The ultimate loads for beams repaired using NSC are 4% less than those for the control beams. Beams repaired using UHPC showed an increase of 7% in flexural capacity. Beams repaired using UHPFRC and CRM showed the best results with increases in flexural capacities over the control beams of about 18% and 11%, respectively, Fig. 5.

In general, the four repair materials proved effective in restoring the flexural capacities of the repaired beams. Someone may be deceived by the fact that beams repaired using NSC cannot restore the flexural capacities, forgetting that the repaired beams are tested 7 days only after the repair process.

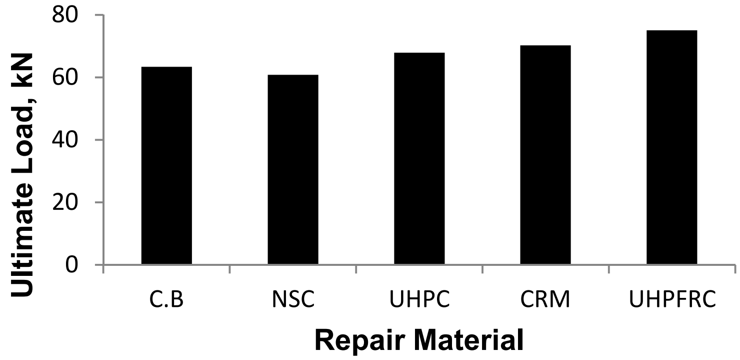


Fig. 5. Ultimate loads for control and repaired beams

3.2 Mid-Span Deflections

The repaired beams, with no exception, show less mid-span deflections than the control beams. This may be attributed to the increase in stiffness of the repaired beams (increase in their moduli of elasticity). The least deflection values are obtained from the beams repaired using UHPFRC and CRM, as shown in Table 2 and Fig. 6.

Table 2. Mid-span deflections

Load, kN	Mid-span deflections (mm)				
	C.B	UHPC	UHPFRC	NSC	CRM
4.5	1.6	1.2	0.83	1.5	1
4.5	1.6	1.2	0.83	1.5	1
9	2.4	1.8	1.25	2.3	1.5
13.5	3.1	2.325	1.6	2.9	2
18	3.7	2.775	1.9	3.5	2.3
22.5	4.2	3.15	2.2	4	2.6
27	4.7	3.525	2.5	4.5	3
31.5	5.1	3.825	2.6	4.8	3.2
36	5.6	4.2	3	5.3	3.5
40.5	6	4.5	3.1	5.7	3.8
45	6.5	4.875	3.4	6.2	4.1
49.5	7	5.25	3.6	6.6	4.4
54	7.4	5.55	3.8	7	4.6
58.5	7.9	5.925	4.1	7.5	5
63	8.6	6.45	4.5	8.2	5.4
67.5	---	6.90	5.05	---	5.95
72	---	---	5.5	---	---
75	---	---	6.15	---	---

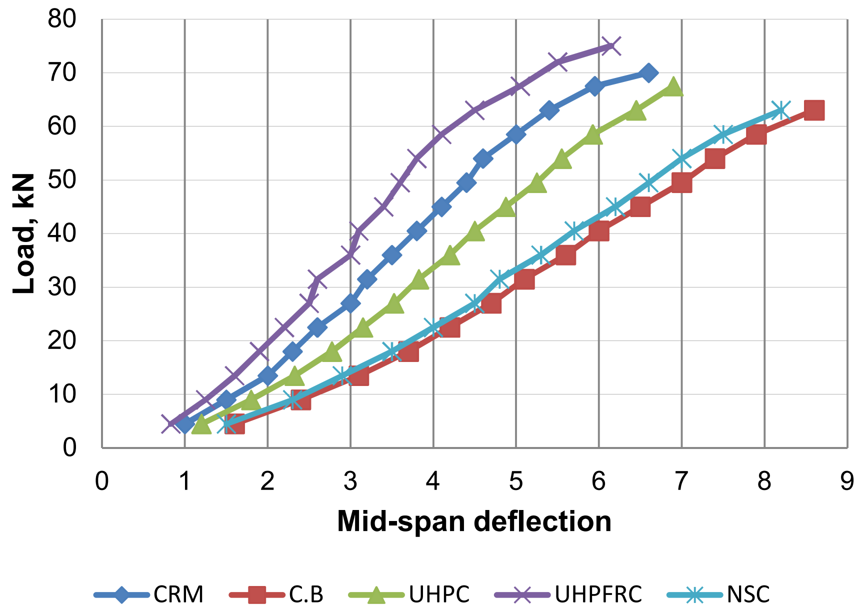
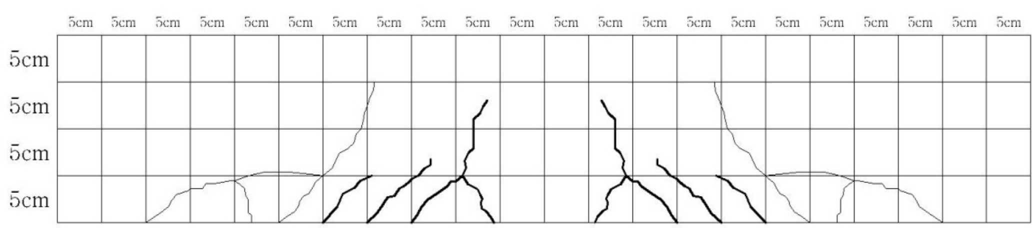


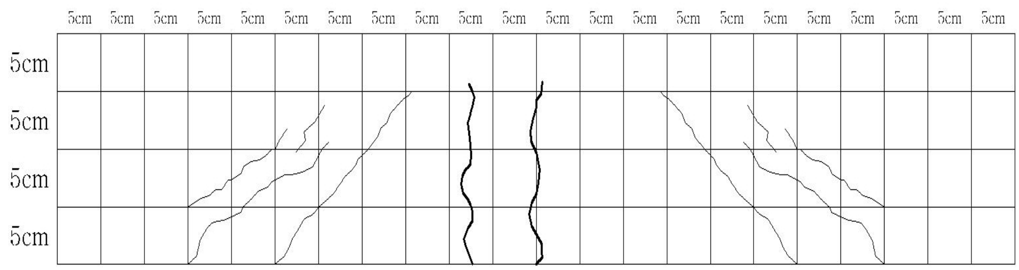
Fig. 6. Load vs. mid-span deflection

3.3 Crack Patterns

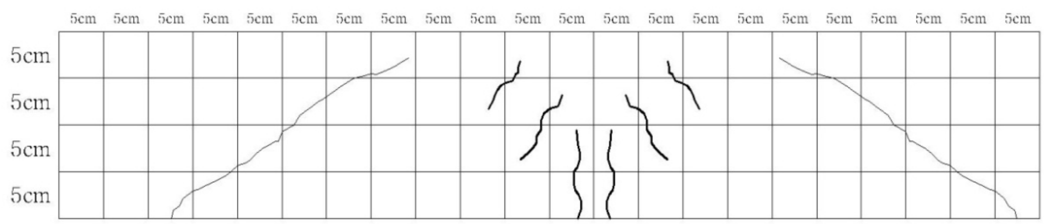
The crack patterns of the repaired beams are flexural cracks outside the repair area. The beams repaired using UHPFRC and CRM showed less crack widths and lengths compared to the beams repaired using UHPC and NSC. Furthermore, web shear cracks are more significant for the repaired beams, which proves the effectiveness of the adopted repair technique in general, Fig. 7.



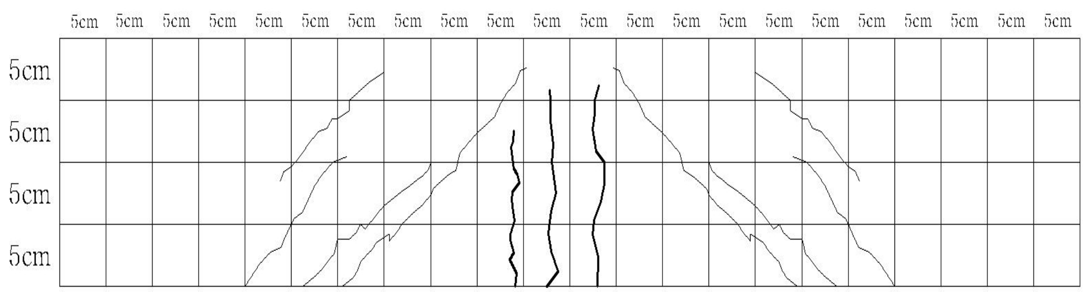
a- Crack pattern of control beams



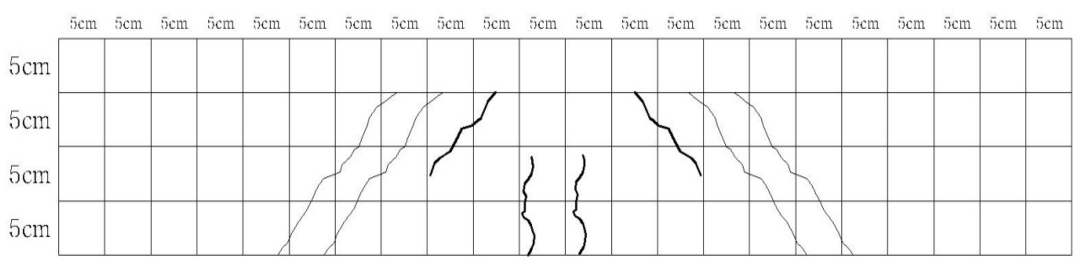
b- Crack pattern of UHPC-repaired beams



c- Crack pattern of UHPFRC-repaired beams



d- Crack pattern of NSC-repaired beams



e- Crack pattern of CRM-repaired beams

Fig. 7. Crack patterns of all of the tested beams

4. CONCLUSION

Based on the results of the executed experimental program, the following may be drawn out

- It is recommended to use UHPFRC or CRM "BETONREP-250" for repair of beams damaged in the form of excessive cracking.
- Smaller mid-span deflections are recorded when UHPFRC and CRM repair materials are used.
- The crack patterns of the beams repaired using UHPFRC and CRM show less flexural cracks compared with the rest of the beams.
- It is not recommended to use NSC in repair of damaged beams.
- Future investigations are needed in order to assess the performance of repaired beams when submitted to blast loads.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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