Repair of Pre-Cracked RC Beams Using Several Cementitious Materials

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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.

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.

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.

**Materials**

**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.

**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>
<thead>
<tr>
<th>Components</th>
<th>UHPC</th>
<th>UHPFRC</th>
<th>NSC</th>
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<tr>
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<td></td>
<td></td>
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<td>Steel fibers</td>
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</table>

**Table 1. Concrete composition**

**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.

**Test Specimens**

**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.

**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.

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

**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.

Results and Discussion

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.

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.

Crack Patterns

The crack patterns of the repaired beams are flexural cracks outside the repair area. The beams repaired using UHPFRC

<table>
<thead>
<tr>
<th>Load, kN</th>
<th>C.B</th>
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<th>UHPFRC</th>
<th>NSC</th>
<th>CRM</th>
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</table>

Table 2: Mid-span deflections
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.

**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.

**References**


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**MC-EINPRESSHILFE – EH**

**Expansive Plasticized Grouting Admixture**

M C-Einpresshilfe EH is an admixture in powder form for grouting ducts in post tensioned or pre-stressed concrete structures using cementitious grout. It ensures permanent contact and an excellent bond with the grouted surfaces. The expanding properties decrease the natural settlement of the fines before the starting of initial set and reduces shrinkage of the grout so that a good workability and a proper grouting operation is achieved. Within 3 days after grouting a high frost- resistance is obtained which fulfills the regulations for grouting pre-stressed structures. The plasticizing effect helps the grout to attain a good workability and thus a proper grouting operation is achieved.

Before admixing MC-Einpresshilfe EH the cement grout powder component should be thoroughly mixed with water for about 2 to 3 minutes. After that MC-Einpresshilfe EH should be added to the mix at a ratio of 0.5 to 1% by cement weight. The whole mixing to ensure complete dispersion, should last at least 4 minutes. Due to high dispersion of MC-Einpresshilfe EH it is possible to reduce the w/c ratio in order to get a denser mix. A preliminary test is necessary to determine optimum dosage. The grouting operation can be carried out easily and effectively into very narrow cross-section without increasing the water content of the mix.

MC-Bauchemie (India) Pvt. Ltd. Manufactures this product along with a host of other Construction Chemicals in technical and financial collaboration with MC-Bauchemie, Germany. MC-Bauchemie (India) Pvt. Ltd. is an ISO 9001:2008 certified Company.

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