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Repair of Corroded Reinforced Concrete Beams using Glass Fibre Sheets and Cementitious Composites

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Abstract: Steel rebars undergoing corrosion play a major role against durability of reinforced concrete components. This project investigates the viability of using externally bonded glass fiber sheet along with cementitious composites to rehabilitate beam members with corroded rebars. Steel rods were corrodedthrough alternate wetting and drying condition. Following the corrosion phase, twelve reinforced concrete beams were cast and grouped as B1, B2, B3 and B4. The beam members were strengthened and repaired externally. Three control beams of B1 were cast without any repair to corroded rebars and without any strengthening. B2 beams were cast without repair of corrosion but they were strengthened externally with fiber sheets using cementitious composites. In group B3, rebars were applied with protective epoxy coating and strengthening was carried out. Procedure in B4 was similar to B3, except epoxy was used as binder for fiber sheets. Four point bending test were carried out on all beams and results were compared. Flexural behaviour of beams showed that the effect of strengthening in corroded beams increased the ultimate load carrying capacity, stiffness and energy absorption. Percentage increase in ultimate load for beams B2, B3 and B4 are 20.9%,66.16% and 75.72%s compared with beam B1. Wrapping in beams reduced the deflection. Percentage decreases in deflection are 10% for B1, 20% for B2 and 35% for B3 respectively compared to beam B1.Percentage increase in stiffness is 14.2% for B2, compared with control beam B1.Similar improvement in percentage of stiffness is noted as 74.9% and 121.8% for B3 and B4 respectively. Energy absorption in B2 is enhanced by 47.02% compared with control beam B1.Whereas beam B3 and B4 shows 77.33% and 107.6% increase in energy absorption respectively.Present strengthening technique using cement based composites as binder is found to be efficient, similar to epoxy binder in retrofitting reinforced concrete members with corroded bars.
Keywords : Beams, Corroded rebar, flexure, glass sheets, cement based composites, Epoxy.

1.Introduction

Durability of reinforced concrete structures get affected due to corrosion of embedded steel bars. Corrosion of bars reduces its tensile strength and deteriorates the grade of concrete. One of promising methods to overcome the problem is by retrofitting. Among the various strengthening techniquesavailable,like altering the cross section, span reduction, pre stressing and addition of steel plates,wrapping glass fibre sheet is the most effective technique in present scenario.Experiments were carried out on the characteristics of bond between steel and concrete for different corrosion environment and suggestion were given for addition of polypropylene fiber to concrete to enhance the bonding (1).The action of corrosion of steel bars on concrete in RC structures was studied and the bond stress and serviceability loss were quantified by (2)

Investigation on the effect of mix design and cracking of concrete specimens for corrosion rate was conducted and found that improved quality of concrete with or without cracks reduces the rate of corrosion

(3).The effects of CFRP laminates were studied for repairing RC beams under active rebar corrosion (4). They concluded that, beams wrapped using CFRP laminates performed wellandretained 92% of the control beam strength. The effect of corrosion in large scale RC columns were simulated and damaged specimenswere repaired with CFRP sheets. Water with mixed sodium chloride was used as a medium for accelerated corrosion. They confirmed that the repair using CFRP improved the strength of the damaged members (5).

The use of FRP sheets as wrapping forRC beams with corroded rebars was very much effectivein improving the structural strength was proved through experimental studies (7). The monotonic strength of strengthened corroded beams were compared and found that the strength of un strengthened – un corroded and un strengthened - corroded beams were 87% and 37% more compared to reference specimens. It was also concluded that the fatigue life of strengthened specimens were improved significantly (8).

The various parameters in strengthened reinforced concrete beams under corrosion were studied and found that the glass fibre along with epoxy binder had wonderful effects in strengthening damaged beam members. It was concluded that there were significant increase in ultimate strength and ductility (9).

The different effective techniques for setting up accelerated corrosion of rebars in RC specimens were suggested (10). The corrosioninrebars for RC beams adoptingthree different strengthening schemes were studied and was concluded that CFRP strips along with CFRP anchors are effective in aggressive environment (11).

The effectiveness of cementitious compositesfor in-situ strengthening of structural members was proved (12).The effect of confinement provided by CFRP sheets on the bond strength of corroded rebars in concrete was studied and confirmed that wrapping improved the bond strength and the ductility of beams (13).

The effect of fibre reinforced polymer (FRP) and textile reinforced mortar (TRM) on corrosion damaged reinforcement bars was researched and was found that both systems are equally effective in terms of increasing the cracking load. It was proved that the TRM strengthened beams having different reinforcement ratio showed slightly lower value for ductility than the FRP beams, at all corrosion levels (14).

Epoxy is the common binder used along with glass fiber sheets. Since the use of epoxy has restriction in the working environment, cement based composites is used as binder in the present study.Present study aims in confirming the effectiveness of glass fiber sheet with cementitious composites as binder compared to epoxy binder, forstrengthening deteriorated reinforced concrete beams with corroded rebars.

2. Experimental Analysis

2.1 Materials

The materials used in the study namely cement, sand, coarse aggregates and steel bars possessed the following properties as per relevant Indian Standard testing methods.Ordinary Portland cement of 43 grade with specific gravity 3.1 is used. It confirms with IS 1727-1967[14].Fine aggregate confirm to IS: 383-1970[15].The fine aggregates confirm zone II grading and have fineness modulus 3.24. Coarse aggregate having the maximum size of 20 mm with fineness modulus 6.78 was used in the work. Testing of aggregates was as per IS: 2386-1963[16].

Metakaolin has specific gravity 2.5. Glass fiber woven roving is compatible with most binder systems. The physical properties of E-glass sheet have standard weight of 610g/m^2 with elastic modulus 75000MPa.

The Gelenium B233 a water reducing admixture has specific gravity 1.08 with pH > 6. The viscosity-modifying admixture Gelenium stream 2 has specific gravity 1.01. In order to simulate deteriorated concrete, the grade adopted was M15.The design of concrete mix confirmswith IS 10262-1982[16],to achieve a characteristic compressive strength of 15MPa with w/c ratio 0.37 and slump of 60mm, the concrete mix proportion arrived is 1:2.5:5.

2.2 Corrosion of Rebars

Reinforcement cages were tied and corrosion of the reinforcement was done by alternate wetting and drying process. The cages were kept under water for one day and outside the water for two days, until complete corrosion takes place. Chemical reaction during corrosion is as mentioned in below equations.

$2Fe(s) \rightarrow 2Fe^{2+}(aq) + 4e^-$ (1)
$4e^- + 4H^+(aq) + O_2(g) \rightarrow 2H_2O$ (2)
$2Fe(s) + 4H^+(aq) + O_2(g) \rightarrow 2Fe^{2+}(aq) + 2H_2O$(3)
$4Fe^{2+}(aq) + O_2(g) + 7H_2O(l) \rightarrow 2Fe_2O_3 \cdot 3/2H_2O(s) + 8H^+(aq)$ (4)
Fe^{2+} (aq)flow through the solution to the rebar and precipitate.

2.3 Mass loss

Mass loss was calculated to ascertain the level of corrosion took place in the reinforcement cage. Unit for measurement was Kg.

Mass loss=

$$\frac{\text{Initial weight of gauge-final weight of gauge}}{\text{Initial weight of gauge}} \times 100$$

$$= \frac{7.860-7.020}{7.860} \times 100 = 10.6\ \%$$

The value of mass loss of 10.6% assures that the level of corrosion is moderate. Present study aims in strengthening reinforced concrete beams corroded up to moderate level.

2.4 Casting and Curing of Specimens

Cubes (150mm x150 mm x 150mm) and cylinders (150mm diameter and 300mm height) were cast and moist cured for 28 days.The beams members are 100 mm x 150 mm x1500 mm.The top and bottom reinforcement consists oftwo numbers of 10mm diameter. Reinforcements were tied with 6 mm stirrups with spacing of 100 mm c/cfor whole span of thebeam.The rusted cages were usedas reinforcements.

For casting the beams, oiled moulds werechecked for correct dimensions. Group B1 and B2 were cast with corroded cages. Group B3 and B4 were cast with cages cleaned and coated with epoxy. In order to avoid splitting bond failure a clear cover 25 mm was adopted. After casting the specimens were allowed to remain in mould for the first 24 hours at ambient conditionas shown in Fig.1. Then the specimens were demoulded and were allowed to moist cure for 28 days.

Fig.1 Demoulded Cast beams

2.5 Repair of Beams

The beams samples after curing were surface dried for repair. For group B3 cement based composite was used as binder. Cement and metakaolin were mixed with water and super plasticizers of 0.3% and viscous modifying agent of 0.004% were added to increase the workability. The ratio W/ (C+M) was maintained as 0.28. [12].

Group B4 used epoxy as binder. The proportion followed for resin and hardener was 100:35 by weight and mixed continuously for 5 minutes to have uniform colour. Using sand paper the surface was made uniform before wrapping. Beams in all groups were wrapped with glass fiber sheet as shown in Fig.2.Glass sheet was stopped at a depth of 75mm from top to avoid direct loading.

Fig.2 Wrapping of beams using glass fiber sheet and cementitious binder

2.6 Testing of Specimens

All the cubes were tested using compression testing machine of 3000 kN capacity. The tests were carried out at a uniform stress of 10 kg/cm^2/minute after the specimen has been centered in the testing machine. Loading was continued till the readings were reversed from the incremental values. The reversal in the reading value indicates that the specimen has failed. The machine was stopped and the ultimate load was noted. The average compressive strength is 19.65N/mm^2

Repaired and cured beams were tested under two point bending in the universal testing machine of 1000KN capacity as shown in Fig 3. This load case was adopted to have uniform moment without shears between the loads. Steel plates were used to distribute the load for entire width of the beam. Deflectometers were used to measure the deflection at midpoint and below the pointof loading.

a) Strengthened beam with glass fiber sheet and epoxy binders

b) Strengthened beam with glass fiber sheet and cement composite binders

Fig.3 Flexure test on beams

3. Results and Discussion

The load deflection plot obtained for the different beams are as shown in Fig.4. The ultimate moment, stiffness, energy absorption are compared as shown in table 1.

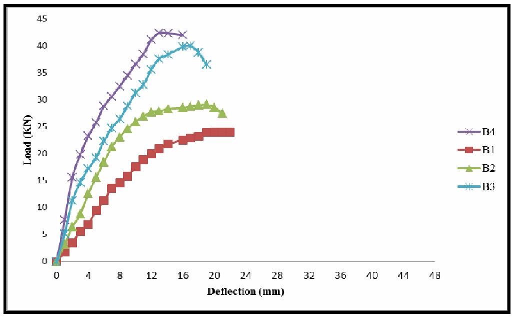

Fig.4 Load vs Deflection plotfor the beams

3.1 Load Carrying Capacity

Strengthened beam without any repair of corroded reinforcement using cement based composites as binders is 20.9% more efficient as compared with control beam. Strengthened reinforced concrete beam after respective treatment of corroded bars using cement based composites as binders is 66.16% more efficient as compared with control beam. Strengthened reinforced concrete beam after respective treatment of corroded bars using epoxy as binders is 75.72% more efficient as compared with control beam.

3.2 Stiffness

Stiffness of strengthened beam without any repair of corroded reinforcement using cement based composites as binders is increased by 14.2% compared with control beam. Similar increase was noticed in other two beams and the values are 74.9% and 121.8% respectively.

3.3 Energy Absorption

Energy absorption capacity is enhanced by 47.02% for strengthened beam without any repair of corroded reinforcement using cement based composites as binders. Increase in energy absorption is even better in other two beams. Percentage increase is 77.33% and 107.6% respectively as compared with control beam.

Table.1. Flexure behavior of unstrengthened and strengthened corroded beams

Beam	Strengthening Technique	Maximum bending moment (kNm)	Stiffness (N/m)	Energy absorption (Nm)
B1	No epoxy coating for corroded bars and no strengthening	4245.50	1118.7	88250
B2	No epoxy coating for corroded bars. Strengthened with glass sheet and cement composite binders	5110.00	1277.8	129750
B3	Epoxy coating for corroded bars. Strengthened with glass sheet and cement composite binder	6665.75	1957.3	156500
B4	Epoxy coating for corroded bars. Strengthened with glass sheet and epoxy binder	6877.50	2482.2	183250

4. Conclusions

- The beam B1 showed ultimate load carrying capacity as 24.1kN with ultimate moment as 4245.5KNm.
- Ultimate load for beam B2 is increased by 20.9% as compared with beam B1.The corresponding increase of 66.16% and 75.72% are noted in beams B3 and B4.
- Wrapping in beams reduced the deflection. Percentage decreases in deflection are 10% for B1, 20% for B2 and 35% for B3 respectively compared to beam B1.
- Percentage increase in stiffness is 14.2% for B2, compared with control beam B1.Similar improvement in percentage of stiffness is noted as 74.9% and 121.8% for B3 and B4 respectively.
- Energy absorption in B2 is enhanced by 47.02% compared with control beam B1.Whereas beam B3 and B4 shows 77.33% and 107.6% increase in energy absorption respectively.
- Present strengthening technique using cement based composites as binder is found to be efficient, similar to epoxy binder in retrofitting reinforced concrete members with corroded bars.

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