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Stress Strain Behaviour of Concrete Elements Retrofitted Using Organic and Inorganic Binders

P. Bhuvaneshwari, K. Saravana Raja Mohan and R. Kirthiga
School of Civil Engineering, SASTRA University, Thanjavur, India

Corresponding Author: P. Bhuvaneshwari, School of Civil Engineering, SASTRA University, Thanjavur, India

ABSTRACT
Concrete has been widely used as construction material for most of important structures worldwide. Age of many of these structures has reached the end of their service life. Necessity arises for repair and rehabilitation to strengthen these structures. A technique used for strengthening concrete structures is retrofitting. In present study retrofitting is done by wrapping the cylinder specimens with Glass Fiber Reinforced Polymer sheet (GFRP) using binders. Two types of binder are used namely organic epoxy and inorganic cementitious composites. Generally epoxy has a good bonding capacity to strengthen the structures. The demerit of epoxy is its incompatibility with the base concrete. To overcome this Difficulty Mineral Based Composites (MBC) are being used. The retrofitting of damaged specimens gives a clear view of effect of strengthening in terms of restoration to original strength. Study focuses on the comparison of stress strain behaviour of control and retrofitted damaged cylinders obtained using above mentioned two binders. It is concluded that compressive strength and stiffness for concrete members using inorganic binders are comparable with epoxy binders in bringing back the specimens to original strength apart from being non hazardous. It is also inferred that strength increases with increase in number of layers of wrapping. The reduction in strength due to mineral based binders could be increased by adding fibers in composites namely engineered cementitious composites.

Key words: Cylinder, wrapping, organic binders, inorganic binders, stress-strain behavior

INTRODUCTION
Most of the buildings existing worldwide were constructed with reinforced concrete. The unexpected increase in load affects the strength and serviceability of these structures. Taljsten and Blanksvard (2007) suggested that retrofitting using fiber reinforced polymer with epoxy as binder is the recent technique adopted to strengthen ruined buildings. They concluded that demerits of epoxy as binders could be overcome with Mineral Based Composites (MBC) as binders. MBC use cement based mortar as a bonding matrix. It have excellent bond with the base concrete, good workability and cost effective. This conclusion was arrived through the study carried out by them, on slabs strengthened with CFRP using epoxy binders and mineral based composite binders. The slabs with mineral based binders showed enhanced performance with ductile failure. Di Ludovico *et al.* (2010) found that the BRM (Basalt reinforced Mortar) confining system could provide a good solution to enhances the compressive strength and ductility of concrete members and it helps to overcome the limitations of epoxy-based FRP laminates. Wu *et al.* (2010) concluded that it is feasible to make cement-based composite sheets for in-situ structural retrofit

with effective bonding and without any delamination. Blanksvard *et al.* (2009) suggested that compatibility with base concrete could be ensured by using mineral based composites as binders. It was recommended to include fibers with high stiffness to increase the performance of mineral based composites. Basalo *et al.* (2009) suggested for effective impregnation of cement mortar using less density fiber sheets. Hashemi and Al-Mahaidi (2008) concluded that micro cement added mortar gives better flexural performance and load carrying capacity for any type of FRP sheet. Bournas and Triantafillou (2008) suggested that TRM (Textile reinforced mortar) jacketing provides good confinement of poorly detailed reinforced concrete columns in seismic regions. Johansson and Taljsten (2005) found that the analytical equation which predicts the maximum shear stress in FRP systems can be used for the mineral based systems and similar results can be obtained. Kurtz and Balaguru (2001) found that the post yield stiffness is high for inorganic binders. Deflection of the beam with the inorganic binders was 25% less than that of the beam with the organic binders and no delamination is noted.

This study aims in quantifying the efficiency of wrapping technique using glass fiber sheet and cementitious composites as binders for strengthening damaged cylinder specimens. Control specimens were damaged, repaired, cured, wrapped and tested for its strength. The strength of wrapped control and damaged cylinders using mineral based composites as binders were compared with those using epoxy binders. The comparison of compressive strength between control specimen and damaged specimen with wrapping was done.

MATERIALS AND METHODS

Materials: Portland Pozzolana Cement (PPC) is used, which is obtained by adding Ordinary Portland Cement (OPC) clinker with 10 to 25% of pozzolanic material. The pozzolanic materials generally used for manufacture of PPC are calcined clay or fly ash. Sand was locally procured and it confirms to Indian Standard Specifications (IS 383, 1970). Testing of fine aggregate was carried out according to IS 2386, (1963). The fine aggregate confirms to grading zone II. Coarse aggregate having the maximum size of 20 mm was used. The aggregate was tested as per IS 2386, (1963).

Metakaolin is obtained from kaolinite. Compared to cement the particle size of metakaolin is small. Highly reactive aluminosilicate pozzolana reacts with slaked lime to form strong slow-hardening cement. Super plasticizers are chemicals used as admixtures to increase the workability of concrete. These polymers avoid particle aggregation and improve the flow characteristics of concrete. GLENEIUM B233 admixture used in this project is based on polycarboxylic ether and it is compatible with all types of cements. GLENIUM STREAM 2 is an organic viscosity-modifying admixture for making concrete with enhanced viscosity.

Woven roving glass fiber sheets are made from glass fiber roving and they are compatible with most resin systems. It is used to increase the material strength. The durability and cost effectiveness increases its application. The properties of the sheet are as provided by the manufacturer and given in Table 1.

Epoxy is a two part system with resin and hardener. The flexural strength of epoxy as given by manufacturer is 45 N mm^{-2}. Properties of the materials are given in Table 2.

Specific gravities of cement, fine aggregate and coarse aggregate are 3.1, 2.63 and 2.65, respectively. The sieve analysis for fine and coarse aggregate gave the fineness modulus as 3.24 and 6.78. The design of concrete mix was according to IS 10262, (2009) to achieve a characteristic compressive strength of 30 Mpa with w/c ratio 0.37 and slump of 60 mm. The design mix proportion arrived was 1: 0.96: 2.33.

Table 1: Mechanical properties of Bi-directional glass fiber sheet

Properties	Values
Standard weight (g m^{-2})	610
Thickness per layer (mm)	0.6
Tensile strength (N mm^{-2})	4200
Modulus of elasticity (N mm^{-2})	75000

Table 2: Physical properties for materials nsed in study

Properties	Cement	Fine aggregate	Coarse aggregate	Metakaolin	Super plasticizer	Viscosity modifying agent
Fineness modulns	-	3.24	6.78	-	-	-
Specific gravity	3.1	2.63	2.65	2.5	1.08	1.01

Experimental investigation: The strength properties such as compressive strength, stress-strain relationship for cylinder were studied. For cubes 150×150×150 mm and cylinders 300×150 mm specimens were cast in three layers. Each layer received 25 manual strokes and vibrated for 10 sec on a vibrating table. After casting, the test specimens were left to air dry in ambient conditions for 24 h. Then the specimens were removed from the mould and cured for 28 days. After curing, testing of specimens were carried out. The cylinder specimens were labelled as C: Control, CSW: Control with single wrap, CDW: Control with double wrap, FSW: First crack with single wrap, FDW: First crack with double crack, FFSW: Full failure with single wrap, FFDW: Full failure with double wrap.

Testing of specimens

Cube compressive strength: For cube compression test, the cubes were tested in saturated condition, after wiping out the surface moisture. Testing was carried in compression testing machine of 3000 kN capacity with a uniform stress of 10 kg cm^2 min^{-1}, after the specimen had been centred in the testing machine. Loading was continued till the readings were reversed from the incremented values. The reversal in the reading value indicated that the specimen has failed. The machine was stopped and the reading at that instant was noted which was the ultimate load from which the ultimate cube compressive strength was calculated.

Cylinder compressive strength: Cylinder compressive strength tests were carried out compression testing machine of 3000 kN capacity. The cylinder compressive strength is around 0.8 times cube compressive strength.

Wrapping the cylinder with GFRP sheet: The surface was prepared by rubbing with sand paper and loose particles were removed using brush. Resin and hardener of epoxy binder are mixed in proportion of 100: 35 by weight and mixed continuously for 5 min to have uniform colour. One coat of epoxy is applied on the surface of cylinder. Cylinder is wrapped with glass fiber sheet having an overlap of 75 mm to avoid failure in overlap region. Top and bottom 15 mm of cylinder is left free to avoid direct loading of glass sheet. One more layer of epoxy was applied and specimen was cured for 7 days. The glass sheet is cut to the required dimension as shown in Fig. 1.

Using cement composites as binder: Surface was made smooth by rubbing with sand paper and loose particles were removed using brush. Cement and Metakaolin were mixed with water and super plasticizers and Viscous Modifying Agent (VMA) were added to increase the workability. The water to cement-metakaolin ratio (w cm^{-1}) was 0.28. Amount of Super plasticizers and VMA used

Fig. 1: E-Glass sheet cut for required dimension

Fig. 2: Preparation of cementitious composites

were 0.3 and 0.004% of weight of cement. One coat of cement composites is applied on the surface of cylinder. Cylinder is wrapped with glass fiber sheet having an overlap of 75 mm to avoid failure in overlap region. Top and bottom 15 mm of cylinder is left free to avoid direct loading of glass sheet. One more layer of composites was applied and specimen was cured for 7 days. The preparations of composite and wrapped cylinder using cementitious composites are given in Fig. 2 and 3, respectively.

Stress-strain curve: The cylinder specimen is loaded in universal testing machine of 1000 KN capacity available with automatic data acquisition system as shown in Fig. 4. The stress strain behaviour of cylinder specimen is plotted. Damaged specimens are obtained by loading the cylinders upto first crack and to ultimate load as given in Fig. 5 and 6, respectively.

Testing of wrapped cylinders: Wrapped control specimens are tested upto failure. Stress strain plot are obtained from automatic data acquisition system. The Specimens are loaded upto first crack as given in Fig. 5, repaired with epoxy putty, cured for 7 days and wrapped with one and two layers of glass sheet and tested. Separate specimens are utilized for organic and inorganic binders.

Fig. 3: Wrapped cylinder specimen

Fig. 4(a-b): (a) Load setup for cylinder specimen and (b) Automatic data acquisition system

The specimens are loaded upto full failure as shown in Fig. 6, repaired, cured for seven days and wrapped with one and two layers of glass sheet using epoxy and cementitious composites and tested.

RESULTS AND DISCUSSION

The stress-strain behaviour of wrapped cylinders was studied. From the graph, for the wrapped specimens stress is linear upto the ultimate load of concrete, after that the sheets start to take load. Failure of sheet was accompanied by cracking sound which indicates the failure of fiber glass sheets.

Fig. 5: Initiation of crack in cylinder specimen

Fig. 6: Failed specimen after ultimate load

Epoxy as binder: Using epoxy as a binder, the stress strain plot for strengthened cylinders were compared. Compressive strength and stiffness of specimens were increased considerably compared to control specimen. The increase in strength of cylinder specimens was 65 and 121.14% when wrapped with single and double layer of glass sheet. For the similar binder the testing of strengthened cracked cylinders showed an increase of 18.25 and 34.85% for single and double wrapping, respectively. The percentage increase in strength of strengthened full failure specimens was about 17.13% for double wrapping. Full failure specimen with single wrapping was not showing significant restoration of strength. Strength and stiffness enhancement of both undamaged and damaged strengthened specimens were achieved using this organic epoxy binder, as suggested by earlier studies. The demerits of using epoxy as binder as discussed by Taljsten and Blanksvard (2007) is overcome with inorganic cementitious composites as binders. Ultimate compressive strength for different specimens was produced in Table 3.

Cementitious composites as binder: Using cementitious composites as a binder, the stress strain plot for strengthened cylinders were compared. Compressive strength and stiffness of specimens obtained is comparable to that of epoxy binder. Ultimate compressive strength for different specimens were produced in Table 4. The increase in strength of cylinder specimens were 37.66 and 109.59% when wrapped with single and double layer of glass sheet. Testing of strengthened cracked cylinders showed an increase of 14.93% for double wrapping. The increase in strength of strengthened full failure specimens was not significant even with double wrapping. Bonding of mineral based composites to base concrete, noted in this study is excellent, as suggested by Taljsten and Blanksvard (2007). It is also noticed that cementitious composites overcome the

Table 3: Compressive strength of cylinder specimens with epoxy as binder

Specimen	Load (kN)	Compressive strength (N mm^{-2})
C	431.479	24.407
CSW	712.373	40.296
CDW	953.330	53.974
FCSW	495.311	28.850
FCDW	518.852	32.913
FFSW	396.417	22.440
FFDW	505.393	28.588

C: Control, CSW: Control with single wrap, CDW: Control with double wrap, FCSW: First crack with single wrap, FCDW: First crack with double crack, FFSW: Full failure with single wrap, FFDW: Full failure with double wrap

Table 4: Compressive strength of cylinder specimens with cementitions binder

Specimen	Load (kN)	Compressive strength (N mm^{-2})
C	431.479	24.407
CSW	593.460	33.600
CDW	903.535	51.160
FCSW	408.180	23.110
FCDW	495.432	28.049
FFSW	321.980	18.230
FFDW	392.107	22.24

C: Control, CSW: Control with single wrap, CDW: Control with double wrap, FCSW: First crack with single wrap, FCDW: First crack with double crack, FFSW: Full failure with single wrap, FFDW: Full failure with double wrap demerits of organic binders, as they are easy to handle and have compatibility to base concrete, as mentioned in earlier studies. The enhancement of compressive strength using mortar confinement as discussed by Di Ludovico *et al.* (2010) is achieved in this work. Post yield stiffness for strengthened specimen is found to be more compared to control specimen, as concluded by Kurtz and Balaguru (2001). The result demand for increase in number of layers of glass sheet to have further enhancement in strength and stiffness.

CONCLUSION

The work has been carried out for strengthening damaged concrete surface with glass fibre sheet using cementitious composites as a binder and it is compared with epoxy binders. The compressive strength results were observed and stress-strain characteristics of cylinder were plotted. Following conclusions have been arrived:

- Strengthening of control specimens showed enhanced strength characteristics whereas the strengthened damaged specimens restored the specimens to its original strength
- The compressive strength of the wrapped cylinder increases with increase in number of layers of wrapping, for both types of binders
- The compressive strength of cylinders using inorganic cementitious composites is less when compared to the organic epoxy binders. For damaged specimens with cementitious composites as binders, increase in number of layers is required to restore the strength
- The stiffness of the damaged and strengthened specimens are similar to that of control specimens
- The reduction in strength due to cementitious composites could be enhanced by adding fibers to composites namely engineered cementitious composites

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