Shear Characteristic Study of RC beams Retrofitted with FRP and Cement matrix Composite

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***Abstract*— The shear behavior and ductility property of beams, retrofitted with cement matrix composite and epoxy binder are compared in this study. Ten shear deficient beams were casted out of which eight beams were retrofitted. Four beams were retrofitted with epoxy binder, and remaining four beams with cement matrix composite. Glass fiber and sisal fiber were used for retrofitting. Cement matrix was prepared with silica fume and superplastisizer. The fibers were diffused in the cement matrix. Four point bending test was performed to analyze the ultimate load and deflection at the mid span of each beam. All the beams were cracked at the shear span. Retrofitted beams showed a considerable increase in shear carrying capacity. A maximum 64% and a minimum 25% of increase in ultimate load were observed in retrofitted beams. Cement matrix composite was found to be effective in shear strengthening, if fibers with good tensile strength are provided.**

Keywords—Retrofitting; Shear; Cement Matrix Composite; Epoxy Binder;

I. INTRODUCTION

Structures after their expected design period start to develop cracks and deflections which make them unusable. Complete demolition and reconstruction of such structures require considerable time and money. Rehabilitation and strengthening is an alternative solution for this problem. In monumental structures, strengthening is the only possible option rather than reconstruction. Retrofitting is the most common strengthening method used in these days. Beams can fail under shear or flexural loading. Shear failure occurs without much warning. Study on flexural strengthening is getting more concern in current scenario. Structures already retrofitted against flexural failure are more likely to fail under shear. In this situation, retrofitting for shear strengthening deserves much attention.

Retrofitted structures act as composites. Composites are combinations of two materials with different physical properties but acting together for a common purpose. Fibers are the commonly used material for retrofitting. Earlier, steel plates where used for retrofitting. Steel plate increases the self weight of structures, and is highly corrosive. Introduction of artificial fibers was a major progress in the field of retrofitting. Carbon fibers, glass fiber etc. are the commonly used artificial fibers; while jute, coir, sisal etc. are used as natural fibers. Artificial fibers are found to be having more tensile strength and durability, but are costly. Natural fibers are preferred in structures with short design period and low economy. Fibers can be attached either on the surface of the structure or by making grooves on the surface and inserting. In former case it is known as ‘external binding’ and in later case it is ‘near surface mounting’. Binders are used to stick the fibers to the structures. Binding materials should be strong enough to transfer the load from the structure to the fibers. Resins such as epoxies, vinyl esters, polyurethanes, are commonly used as binders. Recent years have witnessed an increased use of epoxies, which raised serious environmental issues. Even though it shows good structural properties, epoxies are having a wide range of disadvantages. Chemical reactivity and unpleasant odor of epoxies create problems. It loses its binding properties at higher temperature and is highly flammable. All the disadvantages of epoxies in addition to its increased cost demand some alternative binding materials.

Cementitious binding materials with different ingredients are being developed during the last two decades. Anders Wiberg conducted studies based on strengthening of concrete beams using cementitious binder and carbon fiber. The cementitious composite provided 65% increase in strength.

The compressive behavior of confined concrete was analyzed by H C Wu and P Sun. Fiber sheets impregnated in cement slurry and wrapped around concrete cylinders were tested in this study. The same material was applied to strengthen flexural behavior of concrete beams also. Compressive and flexural strength of the retrofitted structures were analyzed. A significant increase in strength and ductility was observed in the specimens after retrofitting.

A state of the art study on fiber cement composite was made by B J Mohr, N H El-Ashkar and K E Kurtis. Wood pulp fiber was added in cement matrix composite. The composites were made by adding various percentages of silica fume, slag content and rice husk ash in cement slurry. Cement matrices were found to be compatible with the fiber. The beams retrofitted with these matrices showed an increase in load carrying capacity.

Siavash Hashemi and Riadh al Mahaidi prepared three different mixes of cement based bonding material for retrofitting. Silica fume, adhesive containing SBR latex and microcement were used for flexural strengthening of beams. The load carrying capacity was increased up to 2.5 times, after retrofitting. Microcement was found to be more efficient in retrofitting.

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Study on textile reinforced cementitious composite(TRCC) for retrofitting of concrete structures was carried out by A Katz, M Tsesarsky, A Peled and I Anteby. Impact test and static flexural test were conducted to analyze load deflection behavior in static and dynamic loading. Glass fiber, polyethylene and carbon fiber were used for retrofitting. The retrofitted beams showed remarkable increase in stress resistance.

Textile reinforced engineered cementitious composite (TR-ECC) was used by J G Dai, B Wang and S L Xu. Ten control beams and strengthened beams each were prepared for testing. As an adhesive, ECC was observed to be suppressing crack formation in beams. Fly ash and fiber were mixed in cement mortar in different proportions. The retrofitted beams showed an increase in flexural and shear load carrying capacity.

Literature on cement matrix composites was found to be rare compared to that on epoxy binders. So study on this field deserves much importance.

From previous experiments, it is observed that cement matrix composites can overcome all the disadvantages of epoxies. It creates a comfortable working environment for the labors. It is more fire resistant, less corrosive and chemically inert compared to epoxies. Cemetitious binder shows better homogeneity with concrete so that differential expansions due to temperature changes will not arise. Beams retrofitted with cementitious composite require no further plastering. Preparation and application of cementitious composite is simpler. However, the commercial use of cement matrix as a binder is still uncommon. A thorough research study is required to use cement matrix composites in retrofitting.

Objective of the present study includes the preparation of a cement matrix composite, for strengthening of beams under shear loading. Further a comparative study is made, between the beams retrofitted with epoxy binder and cement matrix composite. Ultimate shear load carrying capacity and ductility property are analysed in this paper. Glass fiber and Sisal fiber are used for retrofitting.

II. MATERIALS USED

M 25 concrete and Fe 500 steel were used for casting of beams. The cement was OPC 43 grade, manufactured by Crown Cements. Steel was manufactured by Tata Steels. Naturally available river sand of zone IV and coarse aggregate of nominal size 10 mm were used for concreting.

Retrofitting was done by using glass fiber and sisal fiber. Epoxy binder and cement matrix composite were used to stick the fiber on the surface of the beams. Sikadur 32 LP, manufactured by Sika Company was used as epoxy binder. Cement matrix composite was prepared by cement, silica fume, superplastisizer and water. Viscocrete was used as superplastisizer to reduce the water content.

III. METHODOLOGY

Ten beams were casted, out of which two beams were used as control beams and the remaining eight beams were retrofitted. Retrofitting was carried out as per the retrofitting scheme shown in Table 1.

TABLE I. RETROFITTING SCHEME

Beams	Specifications		
	Binder	*Fiber*	*No. of beams*
B1, B2	-	-	2
B3, B4	Epoxy	Glass	2
B5, B6	Epoxy	Sisal	2
B7, B8	Cement matrix	Glass	2
B9, B10	Cement matrix	Sisal	2

A. *Detailing of Beams*

All the beams were designed to fail under shear. The beams were one meter long and having an area of cross section of 100 mm X 135 mm. Three bars each with 8 mm diameter were used at the tensile side of the beam. A clear cover of 15 mm was provided. Shear stirrups with 6 mm diameter were provided across the main bars at a spacing of 450 mm. Two corner bars of 8mm diameter were provided at the top.

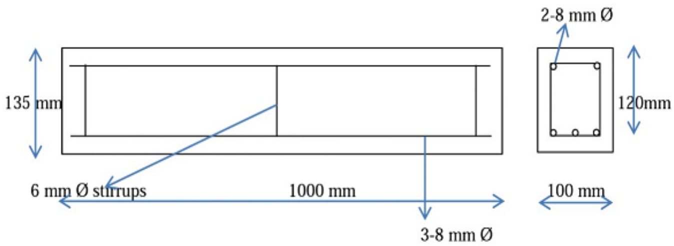

Fig. 1. Detailing of the beam.

B. *Casting of Beams*

Testing of cement, sand and coarse aggregate were conducted to formulate the mix design for M 25 grade concrete. Fine aggregates were sieved using 4.75 mm passing and 0.075 mm retaining IS sieves. Coarse aggregates were crushed angular stones, from the nearby quarry. Coarse aggregates were thoroughly washed and dried. Concreting was performed in the rotating mixer with 100 kg capacity. Aggregates and cement were measured by weight and mixed thoroughly. A satisfactory slump of 100 mm was obtained while using a water cement ratio of 0.5. Three test cubes were casted and tested to ensure that the mix was having proper strength. Reinforcement bars were measured, cut, bent and tied to form the reinforcement cages. Beams were casted in wooden molds. After 24 hours of hydration, the unmolded beams were labeled and were immersed under the curing tank for 28 days.

C. *Retrofitting of Beams*

The beams were taken out of the curing tank and surface dried. The total span of the beam was divided into three equal zones of 30 cm each. When the beams are loaded at two points, shear cracks are expected to develop at the first and third zones. These zones were marked as shear zones. Lateral sides of both the shear zones were thoroughly chiseled. It provides an increase in effective surface area and thereby provides an increased adhesion.

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1) Retrofitting using Epoxy binder: The epoxy binder Sikadur 32 LP, consists of two components, component A and component B. Two components were mixed at a ratio of 1:2 by volume. Mixing was performed until getting a uniform yellow resin. The resin was applied at the chisseled beam surfaces. Fiber mat was measured and cut as per the dimensions. The fiber sheets were attached to the glued beam surfaces. The surface of the fibers were thoroughly pressed to remove entrapped air bubbles. After retrofitting, the beams were allowed for a hardening of seven days.

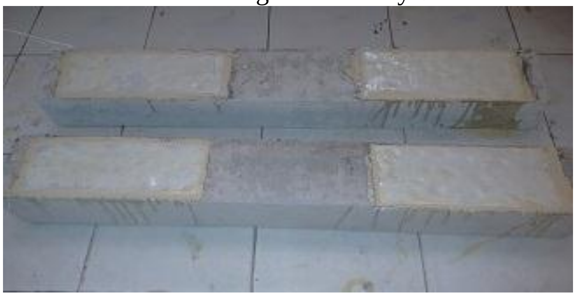

Fig. 2. Beams retrofitted using epoxy binder and glass fiber.

2) Retrofitting using Cementitious binder: Cementitious binder was prepared using cement, silica fume, superplastisizer and water. Percentage of silica fume was 10% by weight of cement. Different trial mixes were prepared with different silica fume contents. Viscocrete, the superplastisizer was taken upto 2% by weight of cement. A workable cement composite slurry was obtained by adding water. Glass fiber and sisal fibers were measured, cut and diffused into fibrous form. Length of individual fiber was 3 cm. The fiber content in the mix was 5% by weight of cement. Fiber was thoroughly mixed in cement matrix composite. The composite was then applied on the chisseled beam surfaces upto a thickness of 4 mm. The retrofitted area took 24 hours for hydration. Further, the beams were immersed in water, for a curing period of 28 days.

Fig. 3. Beams retrofitted using cement matrix composite and sisal fiber.

D. Testing of Beams

Testing of the beam was done in a hydraulic jack of 100 kN capacity. The beam was laid up in simply supported condition. Load was applied symmetrically at two points, 30 cm apart each other. Midpoint of the beam was marked and a dial gauge was attached from bottom. The dial gauge was having a least count of 0.01 mm. loading was started from 0 kN and the dial gauge reading was noted for each 5 kN increase in loading. Load at first shear crack was noted. Deflection of the beam was measured up to this load, and the dial gauge was removed. Further loading was done up to the failure of the beam. Load at which the beam fails was noted as the ultimate load in shear.

IV. RESULTS AND DISCUSSIONS

Test data were tabulated and graphs were plotted to compare the properties of control beams and retrofitted beams.

Fig. 4. Testing of the beam under four point loading.

A. Graphs

Two beams were tested in each category and the average values of ultimate load were taken. Deflection of the beams was plotted against the load, up to the load at first shear crack. The beams retrofitted using glass fiber was showing better load carrying capacity than the beams retrofitted using sisal fibers. Epoxy binder is found to be effective compared to Cement matrix composite.

In fig 5, deflection of the beams retrofitted using glass fiber is compared. Retrofitted beams are found to be showing more deflection than control beams. Beams retrofitted using epoxy binder is showing more deflection than the beams retrofitted using cement matrix composite.

In fig 6, deflection of the beams retrofitted using sisal fiber is compared. Retrofitted beams are found to be showing more deflection than control beams. Beams retrofitted using epoxy binder is showing more deflection than the beams retrofitted using cement matrix composite.

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In fig 7, average ultimate load, carried by the beams is compared. Beams retrofitted using glass fiber and epoxy binder is found to be most effective. Beams retrofitted using sisal fiber and cement matrix composite are found to be least effective, still shows an increase in load carrying capacity than control beams. Beams retrofitted using sisal fiber and cement matrix composite is showing more ultimate load than the beams retrofitted using glass fiber and epoxy binder.

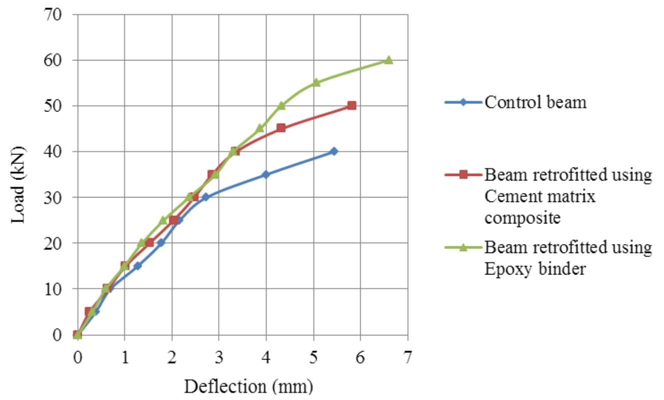

Fig. 5. Load Deflection graphs for beams retrofitted using Glass fiber.

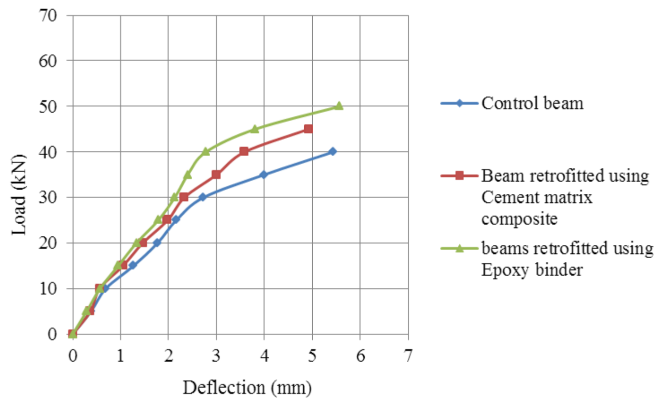

Fig. 6. Load Deflection graphs for beams retrofitted using Sisal fiber.

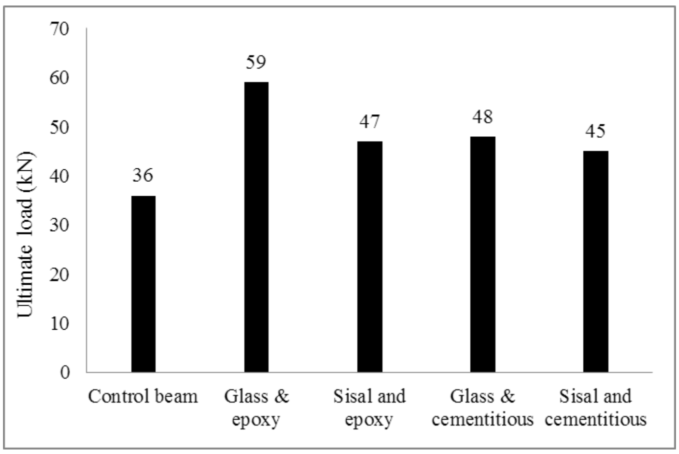

Fig. 7. Comparison of Ultimate load of beams.

B. Conclusion

The following results were obtained by analysing the graphs.

- Beams retrofitted using epoxy binder and glass fiber showed more increase in ultimate load carrying capacity. It showed an increase of 64% than that of control beam. When sisal fiber and epoxy binder was used, the increase was 30%.
- Beams retrofitted with cement matrix composite and glass fiber showed a 33% increase, while the beams retrofitted with cement matrix composite and sisal fiber showed a 25% increase than the control beams.
- In beams retrofitted with epoxy binder, failure occurred by complete stretching and breaking of fiber sheets. Thus the tensile strength of fiber was fully transferred to the beams, which explains the increase in ultimate load carrying capacity.
- In beams retrofitted with cementitious binder, failure occurred either by spalling of composite layer or by cracking of the layer. The fibers at the crack line were fully stretched and broken. So cement matrix was proven to be effective in transferring shear to the fiber.
- Beams retrofitted with cement matrix and glass fiber, showed more percentage of increase in load carrying capacity than the beams retrofitted with sisal fiber and epoxy binders. Thus, cement matrix can effectively replace epoxy binders if fibers with high tensile strength are used.
- In cement matrix, the fibers were dispersed in all possible directions so that cracks through all the directions of propagation were prevented. But in epoxy matrix, fibers were oriented in a single direction and it could not prevent the cracks in the direction parallel to fiber axis.
- Fibers were well concealed inside the cement matrix which makes the beam more aesthetic – it requires no extra plastering after retrofitting.
- Even after the concrete cracked, the fiber was taking further load until it got delaminated or broken. Thus, in retrofitted beams deflection was more, compared to control beams. So retrofitting improves ductility property of the beams also. With more deflection, proper warning is available before failure; which makes the structure safer.

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