Flexural Response of Strengthened Masonry Beam with CFRP

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Abstract- **This study aims to develop and demonstrate the effectiveness of engineered cementitious composite (ECC) as bed joint for masonry beams. Engineered cementitious composite (ECC) is a cement based composite with pseudo-strain-hardening behavior and excellent crack control. In this paper, two types of masonry beams were made. The first type is made with ECC as bed joint while the second has cement mortar as bed joint. Masonry beams were made with locally available clay burnt bricks. These beam specimens were tested for four point bending. The experimental results showed that ECC as bed joint is more useful in terms of strength instead of cement mortar. Moreover, masonry beams with ECC as bed joint were externally strengthened with carbon fiber reinforced (CFRP) sheet. The experimental results showed that applying FRP sheets increased the load carrying capacity and ductility.**

Keywords: Cement mortar, Carbon fiber reinforced polymer (CFRP), ECC, Flexural strength, Masonry beam

I. INTRODUCTION

Over the ages, clay-burnt bricks are used extensively as they offer considerable compressive strength, cost effectiveness and ready availability. However, brick is a brittle material and hence failure is sudden with no considerable warnings. Extensive research has been carried out for strengthening the masonry structures. Most of the research investigations have suggested strengthening of undamaged masonry walls in out of plane direction. Agnihotri et al. [1] studied the out of plane behavior of unreinforced masonry (URM) walls with different slenderness ratios and aspect ratios. Authors [1] concluded that out of plane capacity of the URM wall to be inversely proportional to slenderness and aspect ratios. Babaeidarabad et al. [2] have investigate the out of plane behaviour of URM walls strengthened with fabric reinforced cementitious matrix composite. Kyriakides et al. [3] studied the flexural strength of masonry beams retrofitted with ECC layer and brick-mortar interface opening and failure of the ECC layer below the mortar joint.

The use of fiber-reinforced polymer (FRP) for strengthening of structures has attracted great attention due to high tensile strength, non-corrodible characteristics and chemically inert properties. There is few literature available on the use of FRP sheet for external strengthening of masonry beams. Moon et al. [4], Mosallam [5], Singh et al. [6] have studied the flexural response of masonry beams strengthened with FRP strips. The effect of the FRP's type on the failure load and ductility of a masonry beams was investigated. Researchers showed that flexural capacity and ductility of the beams increase with FRP strengthening [4-6]. Galal and Enginsal [7] investigated the flexural behavior of concrete masonry beams strengthened with GFRP rebars and concluded that flexural capacity and stiffness of the strengthened concrete masonry beams significantly improved.

The objective of this paper is to investigate the effect of ECC mortar as a replacement of cement mortar for making of masonry beams. Furthermore, the flexural response of the masonry beams fabricated with ECC as bed joint and externally strengthening with CFRP sheet in different patterns is examined along with prediction of crack and other failure modes.

II. MATERIAL PROPERTIES

A.

Locally available clay burnt bricks in Rajasthan (India) were used in this study. The brick size is 230 × 110 × 75 mm. The compressive strength and water absorption of the bricks are 8.76 MPa and 12.14 %, respectively.

B. Cement Mortar

The mix proportion of cement mortar used as bed joint for casting of masonry beams is 1:3 (cement: sand). Portland pozzolana cement as a binder and local river sand were used to prepare cement mortar. The compressive strength of 70.7 mm cubes of cement mortar is 21.67 MPa after the age of 28 days.

C. Engineer Cementitious Composite (ECC)

Generally, ECC mix consists of cement, micro silica sand, fly-ash, water, super plasticizer, and polymeric fibers to reinforce the mix. Present study used polyester fibers of triangular shape with a trade name Recron 3s CT-2424 supplied by Reliance, India. The fibers length and diameter are 12 mm and 25-35 μm, respectively. The tensile strength, elongation, specific gravity and melting point of Recron fibers are 480 MPa, 30%, 1.31 and 250-265º C, respectively. Portland pozzolana cement (PPC) having specific gravity of 3.15 was used in this investigation. The mix proportion of ECC has been presented in Table 1. Glenium B233 provided by BASF India Ltd. was used as the super plasticizer. The 28 days compressive strength of the 150 mm ECC cube is 55 MPa.

TABLE 1 Mix proportion of ECC

Cement (Kg/m^3)	Silica Sand (Kg/m^3)	Flyash (Kg/m^3)	Water (Kg/m^3)	Super Plasticizer (Kg/m^3)	Recron Fiber (Kg/m^3)
620	620	620	290	8.5	26

D. Fiber Reinforced Polymers (FRP)

The unidirectional CFRP lamina strips were used for flexural and shear strengthening. The strengthening of beams were done by wet layup of one lamina of CFRP sheet (0.4 mm thick) with epoxy resin. The materials properties of CFRP is given in Table 2.

TABLE 2 Materials properties of CFRP laminates

FRP Types	Thicknes s (mm)	Young Modulus (GPa)	Tensile Strength (MPa)	Ultimate Strain (%)
CFRP	2.0	46	690	1.90

III. EXPERIMENTAL DETAILS

E. Test Specimens

A total of 10 masonry beams of 150 x 230 mm cross-section (b × h) and 1300 mm length were cast. In each beam, two layers of clay brick were inserted as shown in Fig. 1. The masonry beams have five brick units in each layer with four mortar joints, each of approximately 20 mm thickness. The thickness of top, bottom and end cover of the beam is maintained as 30 mm. Two types of mortar were used, the first one is cement mortar and second one is ECC. The masonry beams were divided into five series each made of two specimens. Control beam with no strengthening, which used as a bench mark was tested first (series #1-2). Later, beams with flexural strengthening using CFRP sheets externally bonded with epoxy at bottom were tested. The fourth series comprise of beams which were shear strengthened in shear spans on both sides of the beam using U-wrapping of CFRP strips of width 70 mm at the spacing of 100 mm (i.e., 0.43h). No FRP shear strips were provided in constant moment zone.

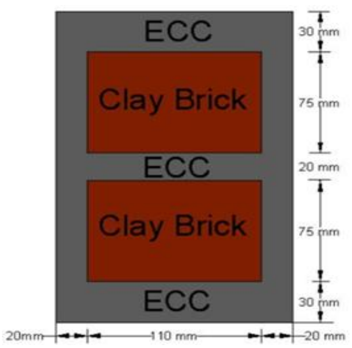

Fig. 1. Cross-section of masonry beam with ECC as bed joint

The fifth series constitutes beams strengthened by U-wrapping of CFRP strips without any spacing. It is continuously wrapped for the whole beam length. The corresponding nomenclature of the specimens are shown in Table 3.

TABLE 3 Designation of specimens

Series No.	Specimen ID	Specimen Details	No of Specimens
1	UMBC	Unstrengthened masonry beams with cement mortar as bed joint	2
2	UMBE	Unstrengthened masonry beams with ECC as bed joint	2
3	CFSMB	Carbon fiber flexural strengthened masonry beams with ECC as bed joint	2
4	CUWMB	Carbon fiber U-wrapping shear strengthened masonry beams with ECC as bed joint	2
5	CCWMB	Carbon fiber continuous U-wrapping shear strengthened masonry beams with ECC as bed joint	2

F. Test Setup

For the flexural response, the beams were loaded under four-point bending test. Load was applied by means of a 200 kN capacity servo hydraulic actuator. Load and deflection of the beams were measured through the control system. The beam was tested of an effective span of 1.10 m with loading span of 100 mm as shown in Fig. 2. All specimens were monotonically loaded at a displacement control rate of 0.05 mm per sec till failure.

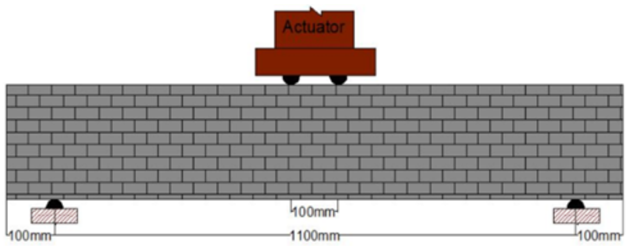

Fig. 2. Test setup of masonry beam under 4 point bending (Series #1-2)

G. Flexural Strengthening

In series #3 (Table 3), the masonry beams were strengthened in the tension zone with one layer of CFRP lamina. The bottom surface of the beam was cleaned for dust before applying epoxy adhesive. The CFRP sheet is glued to the beam with epoxy and the rollers were used for uniform application of epoxy. Epoxy adhesive is allowed to cure for 15 days at room temperature prior to testing. The schematic diagram of series #3 beams is shown in Fig. 3

H. Shear Strengthening

In series #4 (Table 3), the masonry beams were strengthened by U-wrapping of CFRP strips of width 70 mm at the spacing of 100 mm (i.e., 0.43h) in shear spans on both sides of the beam. In series #5, masonry beams were strengthened by complete U-wrapping with CFRP strips without any spacing. The schematic diagram of series #4 and series #5 beams are shown in Fig. 4 and Fig. 5, respectively.

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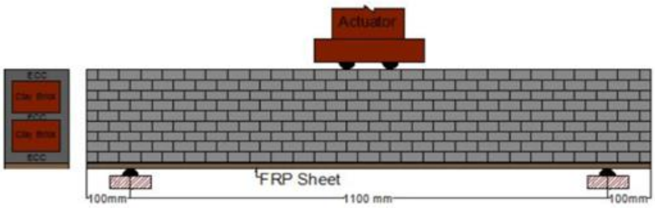

Fig. 3. Schematic diagram of series #3 beam

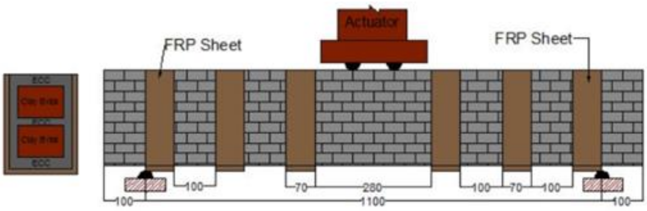

Fig. 4. Schematic diagram of series #4 beam

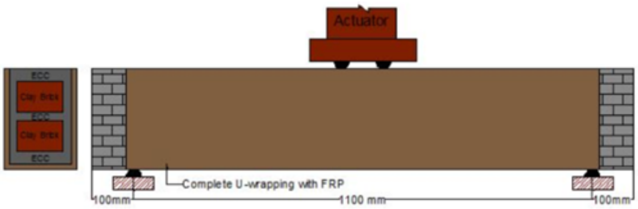

Fig. 5. Schematic diagram of series #5 beam

IV. RESULTS AND DISCUSSION

Test results of the control beams, the beam provided with FRP strips in the tension zone and the FRP strengthened beam in the shear are presented in Table 4. Control beams with cement mortar as bed joint, failed at average load of 3.51 kN and control beams with ECC as bed joint failed at average load of 23.01 kN. It is shown from Table 4 that external strengthening for flexural as well as shear using FRP sheets is very effective for clay burnt brick masonry beam. It is also observed that full wrapping for shear strengthening is more effective than that obtained for strips provided at finite spacing of 100 mm c/c.

TABLE 4 Experimental results of flexural testing

Series No.	Speci-men ID	Average Load (kN)	Average Mid-span Deflection (mm)	% Increase in load	Mode of Failure
1	UMBC	3.51	1.74	-	Flexural
2	UMBE	23.01	12.50	0	Flexural
3	CFSMB	82.18	13.66	257.08	Shear
4	CUWMB	70.12	18.35	204.70	Shear
5	CCWMB	90.16	14.96	291.78	Flexural

I. Failure Mode

As observed from Fig. 6, that the failure of the control masonry beam with cement mortar as bed joint is sudden and occurred due to brittleness of both cement mortar and bricks. It is shown in Fig. 7, the control masonry beams with ECC as bed joint, vertical flexural cracks developed in the constant moment zone followed by flexural shear cracks in shear spans. The normal flexural failure is observed in the control beams and is characterized by yielding of the ECC. Then the cracks widened in the tension zone after the ECC has yielded, and finally the rupture of brick at the mid span of the beam occurred.

It is observed that in the series #3, cracks have originated in the shear zone from the top and propagated towards the end. After this, the FRP has de-bonded in the tension zone of the beam as shown in Fig 8. After having seen this, the beams were strengthened in the shear by U-wrapping as indicated in series #4. In these categories, the cracks have started in the shear zone and hair cracks developed in the flexure. In the series #5, flexural cracks developed inside the FRP wrapping, and at the failure load, FRP sheet ruptured as shown in Fig 9. After the rupture of FRP sheets, beams have suddenly collapsed upon the application of further load. This indicates the effectiveness of FRP fabric sheet affected continuously in changing the mode of failure from shear (Series #4 beams) to flexural failure (Series #5 beams).

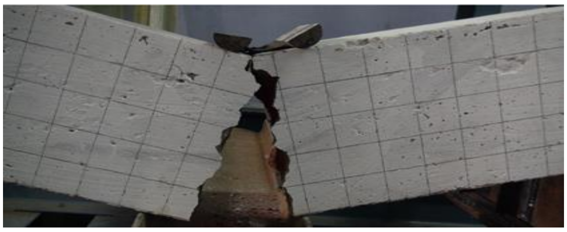

Fig. 6. Flexural-brittle failure of series #1 beam

Fig. 7. Flexural failure of the series #2 beam

Fig. 8. Shear failure of the series #3 beam

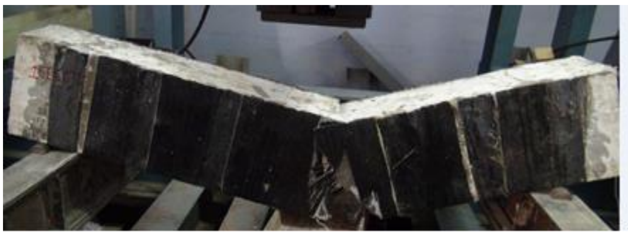

Fig. 9. Rupture of the CFRP sheet in the series #5 beam

J. Load-Displacement Response

Figure 10 depicts the load-deflection relationship for the control masonry beams (Series #1-2). The sudden brittle failure occurred in control masonry beam with cement mortar as bed joint (UMBC). The control masonry beam with ECC as bed joint (UMBE) has shown linear slope up to the cracking load, after the peak loads, the yielding of the ECC occurred. It is clearly shown in Fig. 10, the effect of ECC as bed joint in place of cement mortar has significant effect on the strength of masonry beam. In CFSMB, where one lamina of FRP sheet was provided in flexure, it resulted in the increase of load capacity. After having reached the peak load, there was a sudden drop in load followed by increase in load capacity before ultimate collapse (Fig. 11). This may be attributed to the yielding of ECC in tension and redistribution of the load to the FRP. In the CUWMB (Fig. 11), load has increased with respect to deflection and failure occurred because of the de-bonding of FRP sheet. The masonry beams strengthened by complete U-wrapping (CCWMB) showed a similar behavior as that of the CFSMB except that its post cracking load is higher than that of CFSMB beams as shown in Fig. 11. In this case a sudden drop in the load was observed due to the rupture of the FRP sheet. Amongst all the beams, CCWMB (Series #5) showed an enhanced performance in accordance to the ultimate capacity and deflection. Fig. 12 shows that load-deflection curve of all the beams of various categories used in the study. It is observed that continuous U-wrapping is effective enhancing the flexural strength by changing the mode of failure from shear to flexural. It is possible that FRP strip at large finite spacing could change the mode of failure from shear to flexural.

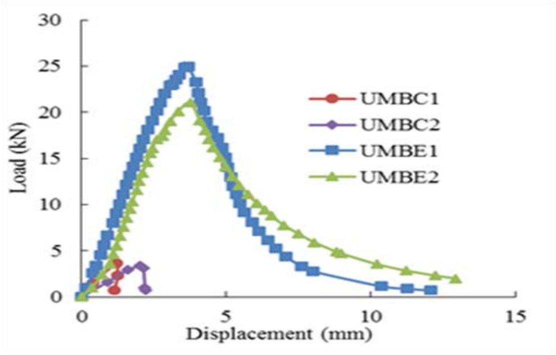

Fig. 10. Load-displacement relationship of control beam (Series #1-2)

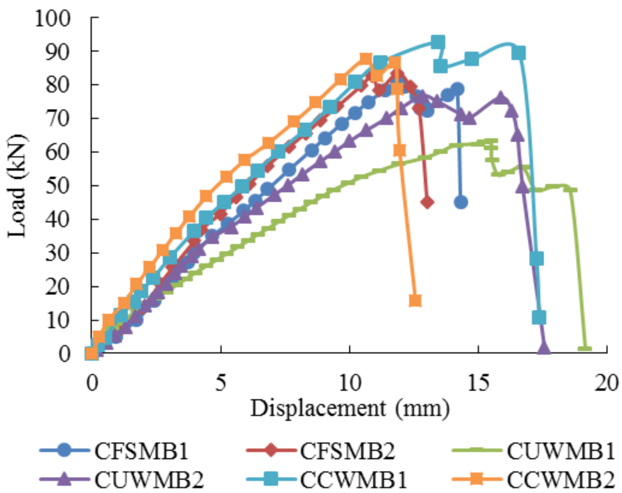

Fig. 11. Load-displacement relationship of strengthened masonry beams (Series #3-5)

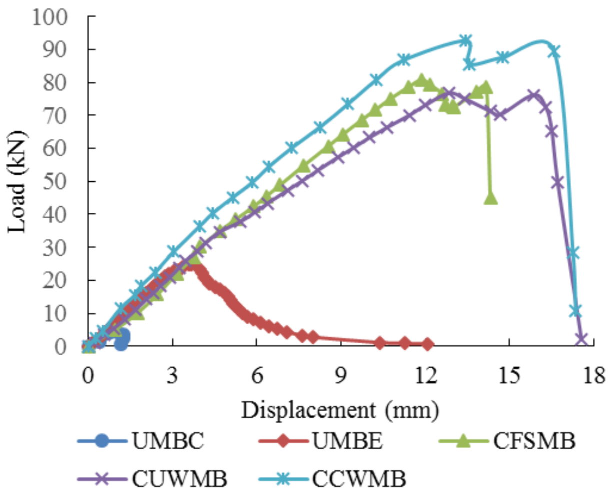

Fig. 12. Comparison of load-displacement response of all beams

V. CONCLUSION

The experimental results of masonry beams using ECC and cement mortar as bed joint with and without external CFRP strengthening show an increase in flexural performance in terms of load capacity and comparison with unstrengthened/control masonry beams. The following conclusions are drawn from this study:

- Load carrying capacity of control masonry beams with ECC as bed joints has increased 6 times of masonry beam with cement mortar as bed joints.
- Masonry beams with ECC as bed joints exhibit ductile performance, signifying that masonry beams covered with ECC and ECC as bed joints could be used as structural beams.
- Masonry beams strengthened with fiber sheets demonstrate a drastic improvement in their load carrying capacity and ductility.
- Load carrying capacity has increased 3 times of the masonry beam with ECC as bed joints strengthened with CFRP sheet.
- The mode of failure changes from undesirable shear failure to the most desirable flexural failure by using continuous CFRP wrapping. The change in failure mode from shear to flexural signifies ductility of masonry beams strengthening for shear.

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