EXPERIMENTAL STUDY ON THE FLEXURAL BEHAVIOR OF BRICK – FRP COMPOSITE

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***ABSTRACT**: Strengthening of masonry in flexure by the use of externally bonded Fiber reinforced Polymer (FRP) materials has been investigated in this research study. Two masonry beams of size 2100 x 225 x 225mm were prepared and strengthened by CFRP wrap placed in the form of U – shape. For bonding of FRP materials to masonry surface, locally available epoxy adhesive "CHEMDUR 300" was used in this study. These strengthened masonry beams were tested in two point flexure up to ultimate load carrying capacity. A RC beam was designed considering the ultimate load carrying capacity obtained experimentally with CFRP strengthened masonry beam. The span was taken similar to that of Brick-FRP composite section (or masonry beam). Comparative study between RC beams and strengthened masonry beams was carried out in terms of cost. The cost of FRP strengthened masonry was found to be almost same as cost of construction of equivalent R.C beam. The findings of this experimental study show that in order to bridge the opening in masonry walls, strengthening of brick masonry in flexure using CFRP sheets instead of providing R.C beam could be better option keeping in mind the difficulty of pouring concrete in such situation, overall cost of the RC beam and time required for construction. Future research studies are recommended to be carried out to investigate the durability of FRP-brick composite.*

Keywords: Masonry beam; Strengthening; CFRP sheet; Flexural strength

1. INTRODUCTION

In the developing countries like Pakistan, most of the residential, low rise commercial and educational buildings (up to three storeys) are constructed using brick masonry. In many situations like overloading, change in functionality of the building and alteration in the architectural plans, strengthening of such masonry structures is needed. Different techniques have been used in the past to strengthen the masonry walls subjected to different mode of loadings such as axial compression, in-plane and out of plane bending and shear **[1-4]**.

Fiber reinforced polymer (FRP) materials are being used now- a-days very commonly to strengthen masonry structures. The reason is that FRP materials have low weight and high strength. Moreover, these materials are resistant to external environmental effects, are very flexible and can transform into all kinds of shapes. Many of the FRP materials are composite with two components; one is fiber embedded in a resin matrix, which provides strength and stiffness, while the resin protects the fibers and transfers stresses firstly from fiber to fiber and then finally to the structural element.

In Pakistan, repair and strengthening of masonry structures is being done very frequently after the Earthquake of 2005 in Kashmir. Moreover, due to change in the functionality of the many existing masonry structures, strengthening of masonry walls are done using FRP materials. In such cases masonry load bearing walls are removed to have more space. In order to bridge up the gape after removal of masonry, one way may be to strengthen existing masonry adjacent to concrete slab with FRP materials, which will act as FRP – Brick Composite, instead of providing reinforced concrete beam. The latter option has different problems related to pouring of concrete and cost of construction. In this study, keeping the focus on the former option, flexural capacity of FRP – Brick Composite has been experimentally investigated. The cost of FRP – Brick composite beam is compared with equivalent R.C.C beam designed for same flexure capacity.

2. EXPERIMENTAL PROGRAM

2.1. Preparation of Test Specimens

FRP-Brick composite beams (masonry beams) of practical size having cross section of 225 x 225 mm and span length of 2100 mm were cast in the laboratory as shown in Fig.1. First class bricks available in local market were used for this purpose. Cement-sand mortar with mixed ratio of 1:4 was used to construct these beams. In order to prevent tearing of CFRP wrap, after curing process, all sharp edges were smoothened using grinder as shown in Fig 2. To strengthen the masonry beams in flexure and shear, U - shape CFRP wrap (CFW – 600) was bonded on three sides of beams as shown in Fig.3. For bonding of CFRP wrap with masonry, epoxy adhesive "Chemdur 300" was used. The properties of CFW – 600 are provided in Table 1.

In order to check the quality of materials, tests were performed on bricks and mortar. Compressive strength and water absorption of bricks were found to be 25.3 Mpa and 14.50%, respectively. The compressive strength of mortar was 5.92 Mpa.

Fig.1: Test Specimens (Masonry beams)

Fig.2: Grinding of Masonry beams

Fig.3: Application of CFRP wrap in U-shape

2.2. Test Performed

After curing period of about three days, in order to know about the failure load and failure mode in flexure strengthened masonry beams were tested in flexure (two point loading). Two point flexure loading test setup is shown in Fig 4, where it may be observed that two Linear Variable Displacement Transducers (LVDTs) were employed to record central deflection of the masonry beam. The deflection controlled flexure tests were performed at a loading rate of 2 mm/min using Universal Testing Machine of 100 ton capacity. All data (load and deflection values) were automatically recorded using data acquisition system namely "strain smart" at the rate of 5 points per second. The beams were tested up to ultimate load carrying capacity.

Fig.4: Two point flexure loading test setup

3. RESULTS AND DISCUSSION

3.1 Experimental observations

Recorded data in terms of load and deflection were used to plot average Load-deflection response of masonry beams which is shown in Fig.5, where it is obvious that the maximum load in flexure carried by the masonry beam was 48 kN. Moreover, the behavior of masonry beam up to failure was noticed to be almost linear. Deflection at the time of failure was observed to be 10 mm. As well as the failure mode of masonry beams is concerned, it was due to de-bonding of the CFRP-wrap as shown in Fig.6 which resulted in brittle failure of masonry beams as a whole in contrast to RCC beam where it is always ductile type of failure as shown in Fig.7.

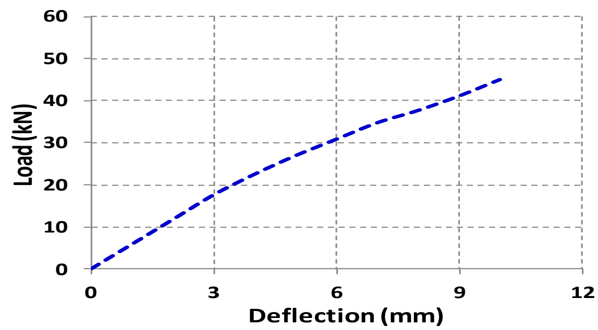

Fig.5: Load-deflection response of masonry beam

Fig.6: Failure mode of masonry beam

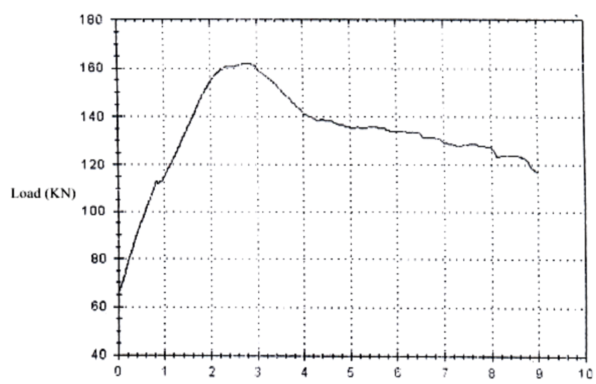

Fig.7: Typical Load-deflection response of RC beam in flexure

Table.1: Technical data of CFW - 600

Materials	Density	Modulus of Elasticity	Laminate Thickness	Tensile Strength	Ultimate Load
	g/cm^3	N/mm^2	Mm	N/mm^2	kN/mm^2
CFW – 600	1.79	220,000	1.2	4900	1000

3.2. Analytical Procedure to calculate Flexural capacity

The position of the neutral axis in the Brick-FRP composite beam is shown in Fig.8 which was determined using equal forces (C = T) concept. Since the masonry itself is very weak in tension, the masonry part below the neutral axis is ignored while calculating the total tensile force.

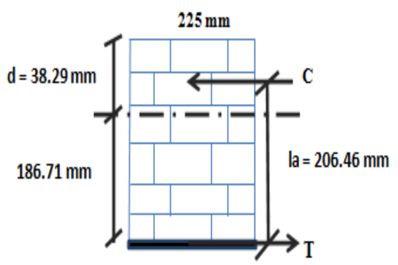

Fig.8: N.A for CFRP strengthened Masonry beam

Data:

Width of beam = 225 mm

Depth of beam = 225 mm

Thickness of FRP = 1.2 mm

ε_{fe} = 0.004 (Strain level for FRP subjected to de- bonding failure) **[5]**

E_{fe} = 220,000 N/mm^2 **[Provided by Vendor]**

f_{fe} = 0.004 x 220,000 = 880 N/mm2

T = 1.2 x 225 x 880 x 0.4/1000 = 95.04 kN

C = 225 x d x 13.79 x 0.8/1000 = 2.4822 x d

By equating forces and ignoring tension carried by the brick masonry below neutral axis, depth of neutral axis is determined:

C = T

2.4822 x d = 95.04

$$d = \frac{95.04}{2.482}$$

d = 38.29 mm

Lever arm = l_a = 206.46 mm

Analytical moment capacity = T x l_a = 19.62 kNm

3.3 Comparison with Experimental Results

For failure load of 48 kN in two point bending obtained experimentally and loading span of 2100 mm, moment capacity was calculated which came out to be 17.5 kN-m. It can be noticed that the experimental moment capacity of masonry beam is close to analytically obtained moment capacity. Based on this observation, it may be concluded that the thickness of CFRP sheet may be decided/calculated to get a certain required moment capacity of masonry beams suing the analytical procedure described above in section 3.2.

3.5 Design of Equivalent R.C.C beam

Based on the ultimate load carrying capacity of masonry beam (48 kN) in two point bending obtained experimentally dully verified analytically, R.C beam was designed for the same span in order to compare the cost of construction of masonry and RC beam for same situation. The design procedure is described below:

Width of beam = 225 mm

f_c' = 21 MPa

f_y = 420 MPa

P_{max} = 48 kN

Depth of the RC Beam:

$$d_{\min} = \sqrt{\frac{M_u}{0.205\times f_c'\times b}}$$

134.4 mm < d (Singly Reinforced Section)

Minimum depth for deflection control = L/16= 133mm

For many practical reasons, minimum depth of the RC beam is generally provided as 225 mm. although the required depth is less but in the present study the depth of the RC beam is taken as 225 mm.

Required Steel Ratio:

$$\rho_{\min} = \frac{1.4}{f_y} = 0.0033 \quad \text{...... ....} \quad \textbf{(2)}$$

$$\rho_{\max} = 0.375x0.85x\beta_1\frac{fc'}{fy} = 0.0135 \text{..........} \quad \textbf{(3)}$$

$$Mu = \phi_b \rho b d^2 fy(1-\frac{1}{1.7}\frac{\rho f_y}{f_c'})$$

d^2 = 18119.36

d = 134.6 mm

$$A_s = \rho bd \quad \text{......................} \quad \textbf{(4)}$$

= (0.0135)(225)(225) = 683.4 mm2

2 - # 19 + 1 - # 13 bars (As = 697 mm2)

Shear Design:

V_u = 24 kN

f_c' = 21 MPa

f_y = 420 MPa

$$\frac{V_u d}{M_u} = 0.31 < 1.0$$

$$\rho_w = \frac{697/2}{225x225} = 0.0069$$

$$V_c = [0.16\lambda\sqrt{fc'} + 17\rho_w \frac{V_u d}{M_u}]b_w d$$

V_c = 38.96 kN $\leq 0.29\lambda\sqrt{fc'}b_w d$ = 67.28 kN

V_c = 38.96 kN

$\phi_v V_c$ = 0.75 x 38.96 = 29.22 kN

$\phi_v V_c / 2$ = 14.61 kN

$V_u > \phi_v V_c / 2$

Therefore, Transverse reinforcement is required

$V_u - \phi_v V_c$ = -5.22 kN (NG)

So, a minimum amount of shear reinforcement is required

Let diameter of bar = # 10 (Av = 142 mm2)

Smax = smaller of d/2 or 600 mm = 112.5 mm

(Select s = 100mm)

So, Shear stirrup = # 10 @ 100 mm c/c

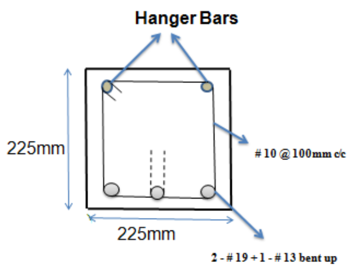

Fig.9: Cross Section of Equivalent R.C.C beam

3.6 Cost Comparison

After designing of RC beam for same loading and span length, detailed cost comparison between RC beam and masonry beam for same application was carried out. While comparing the cost, not only cost of the materials was taken into consideration but also different constructional aspects like form work , labor required and also supports of the adjoining structures were also considered. The comparison in Pakistani rupees is given in Table 2. It can be noticed that for same loadings and span length, masonry beam is more economical.

Table 2: Cost comparison of RC and masonry beams

FRP Strengthened Masonry Beam	**R.C.C beam**
Cost of FRP per ft^2 = 450 Rs.	Cost of Cement Bag = 502 Rs.
Cost of CFRP sheet for one beam = 5906 Rs.	Cost of 1.125 ft^3 Sand = 56 Rs.
Cost of Epoxy for one beam = 7800 Rs.	Cost of 2.25 ft^3 Aggregates = 104
Cost of Jacks to support adjoining slabs (4 days) = 6000 Rs.	Cost of # 19 bars = 460 Rs.
Cost of Labor = 500 Rs.	Cost of # 13 bar = 350 Rs.
Grand Total = 20206 Rs.	Cost of # 10 bar = 796 Rs.
	Cost of Shuttering = 1000 Rs.
	Cost of Labor = 1500 Rs.
	Cost of Jacks to support adjoining slabs (min. 14 days) = 21000 Rs.
	Grand Total = 25768 Rs.

4. CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

Based on the findings of the experimental study reported in the paper, following conclusions are drawn:

- Since brick masonry is weak in tension and strong in compression, presence of CFRP sheet at the bottom provides necessary tensile forces which results in significant enhancement in flexure capacity of masonry beam.
- Bridging of opening in masonry walls made due to change in the function of any masonry building may be done using the concept discussed in this paper instead usual practice of providing RC beam, for which pouring of concrete is some time a difficult task.
- The failure of masonry beam strengthened with CFRP wrap is brittle due to de-bonding or rupture of FRP materials in contrast to RC beam where failure is ductile.
- Analytically determined moment capacity of masonry beam strengthened using CFRP sheet based on the material properties values provided by the vendor showed good agreement with experimental moment capacity.
- Cost of strengthened Masonry beam with FRP and equivalent R.C beam was almost the same.

Since FRP materials are sensitive to fire and should be properly protected with some external surface treatment to decrease the risk of fire. In this regard, it is recommended to carry out some research studies. Another direction of research work in the subject area may be to study the seismic behavior of such composite.

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REFERENCES

1) Łukasz DROBIEC, Radosław JASIŃSKIa, Jan KUBICAa," Strengthening of cracked compressed masonry using different types of reinforcement located in the bed joints", Faculty of Civil Engineering, The Silesian University of Technology, Akademicka 5, 44-100 Gliwice, Poland,2008.

2) Syed Hassan Farooq, "Strengthening of Masonry Wall Panels under in plane loading", Year 2010, *PHD thesis, Department of Civil Engineering, UET Lahore*.

3) Kanvar Bajpai and Dat Duthinh, "Bending Performance of Masonry walls strengthened with near-surface mounted FRP bars", North American Masonry Conference, June (2003), 1052-1063

4) Tim Stratford, Giovanni Pascale, Odine Manfroni and Barbara Bonfiglioli, "Shear strengthening Masonry Panels with sheet Glass fiber Reinforced Polymer", Journal of Composites for Construction © ASCE, V. 8 (2004), 434 – 443.

5) "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures" American Concrete institute" ACI 440.2R – 08, 1 – 80.