13TH CANADIAN MASONRY SYMPOSIUM
HALIFAX, CANADA
JUNE 4TH – JUNE 7TH 2017

FLEXURAL RESPONSE OF REINFORCED MASONRY BEAMS WITH CEMENT MORTAR AS BED JOINT

Munjal, Pankaj[1] and Singh, S. B.[2]

ABSTRACT

The flexural response of reinforced masonry beams with FRP rebars are investigated experimentally. Masonry beams are made in different ways with cement mortar as a bed joint. Masonry beams of 150 x 230 mm cross-section and 1300 mm length were cast using locally available burnt clay bricks and cement mortar of proportions 1:3 (cement: sand) as bed joint. In each beam, two layers of burnt clay bricks were inserted having 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 with cement mortar. These masonry beams were reinforced with two types (pultruded and hand-layup) of carbon fiber reinforced polymer (CFRP) bars of 8 mm diameter. These masonry beams were tested for four-point bending and loaded monotonically up to failure. Flexural capacity, deformation, and crack patterns of tested control masonry beams and CFRP reinforced masonry beams are compared and discussed. This paper demonstrates various failure patterns developed during the four-point bending. The experimental results show that CFRP reinforcement increases the load carrying capacity and deformation capacity. Moreover, effectiveness of types of CFRP rebars (pultruded and hand-layup) on the flexural strength of masonry beams are discussed based on experimental results.

KEYWORDS: *carbon fiber reinforced polymer (CFRP), cement mortar, flexural strength, hand-layup, masonry beam, pultruded*

INTRODUCTION

The Fiber reinforced polymer (FRP) rebar is a new construction material, gradually gaining acceptance from civil engineers. In the last decade, there has been a rapid increased in using FRP bars for Civil Engineering constructions due to enhanced properties and cost-effectiveness. Most of the FRP bars are used in bridges, electrical isolations, tunnels, marine structures. There is ample literature available on the use of FRP bars as a reinforcement in the concrete structures. Theriault

[1]Research Scholar, Department of Civil Engineering, BITS Pilani, Pilani, Rajasthan, India, pankaj710munjal@gmail.com
[2]Professor, Department of Civil Engineering, BITS Pilani, Pilani, Rajasthan, India, sbsinghbits@gmail.com

and Benmokrane [1], Saadatmanesh and Ehsani [2], Nanni [3], Shapira and Bank [4], Yost et al. [5], and Saikia et al. [6] have studied on utilizations of FRP rebars in the reinforced concrete (RC) beams and indicated that it could be a promising material as an alternative to the conventional steel reinforcement in concrete structures. Theriault and Benmokrane [1] studied the strength, deflection and cracking behavior of the concrete beams reinforced with FRP reinforcements. Authors [1] reported that the residual crack width decreases as the FRP reinforcement ratio increases. Saadatmanesh and Ehsani [2] investigated the flexural behavior of concrete beams reinforced with Glass Fiber Reinforced Polymer (GFRP) rebars and observed that debonding of GFRP bars occurred at the time of failure. Yost et al. [5] investigated the shear strength of concrete members reinforced with GFRP bars and observed that the characteristics of shear failure for GFRP-reinforced beams are similar to that of steel-reinforced concrete beams. Authors [5] reported that the shear strength is significantly lower for GFRP-reinforced beams compared to steel-reinforced beams. Saikia et al. [6] studied the flexural behaviour of concrete beams reinforced with GFRP rebars using four-point flexural test. Authors [6] observed that the failure of the GFRP reinforced concrete beams was mainly due to slippage of rebars in the concrete matrix. Kassem et al. [7] investigated the flexural and serviceability performance of 24 simply supported beams reinforced with carbon, glass, and aramid FRP bars. Authors [7] found that the FRP-reinforced beams failed by concrete crushing because the actual reinforcement ratio was greater than the balanced reinforcement ratio.

On the other hand, numerous experimental studies have been conducted on applications of FRP bars for strengthening of masonry walls with near surface mounted (NSM) technique. Tumialan et al. [8], Turco et al. [9], Mahmood and Ingham [10] carried out the experimental studies on out of plane (i.e., flexural strengthening) and in plane (i.e., shear strengthening) of masonry walls with near surface mounted (NSM) FRP bars. Tumialan et al. [8] concluded that flexural capacity of masonry walls strengthened with NSM FRP rebars has increased by 4 to 14 times of that of unstrengthened/ or control specimens. Singh and Munjal [11] have conducted the experimental study on masonry beams reinforced with FRP bars using the NSM technique and concluded that the NSM strengthening technique is very effective for enhancing the flexural strength of masonry beams.

There is dearth in literature on applications of FRP rebars as an internal reinforcement for reinforced masonry beams. Galal and Enginsal [12] investigated the flexural behavior of masonry beams that are internally reinforced using GFRP rebars. Authors [12] concluded that flexural capacity and stiffness of the reinforced masonry beams significantly improved as the internal GFRP reinforcement ratio has increased. Singh and Munjal [13] studied the flexural performance of reinforced masonry beams with ECC as a bed joint that are internally reinforced using pultruded CFRP rebars. Authors [13] concluded that load carrying capacity has increased by 2.5 times of that of unreinforced masonry beams using three numbers of CFRP bars.

However, most of these past studies indicate that there are limited studies on masonry beams which are internally reinforced with CFRP bars. The aim of the present paper is to determine the flexural performance of masonry beams which are internally reinforced with two types (pultruded and hand lay-up) of CFRP rebars. Furthermore, the flexural response of these masonry beams is examined along with the prediction of cracks and other failure modes.

MATERIAL PROPERTIES

Masonry

The burnt clay bricks of size 230 × 110 × 75 mm, locally available in Rajasthan (India) were used in this study. The average compressive strength of burnt clay bricks and masonry prisms are 8.76 MPa and 3.90 MPa, respectively. The masonry prisms were cast with five clay bricks stack bonded using cement mortar with cement/sand ratio of (1:3). Portland pozzolana cement was used throughout the experiments. The water absorption of burnt clay bricks were observed to be 12.14%. The tests to measure the compressive strength and water absorption were performed according to IS 1905:1987 [14] and IS 3495:1992 [15], respectively.

Cement Mortar

The mortar mix ratio of 1:3 (cement: sand) was used to construct the masonry beams. Portland pozzolana cement as a binder and local river sand were used to prepare cement mortar. The material properties of the Portland pozzolana cement and local river sand used are same as described by Singh et al. [16]. The compressive strength of 70.7 mm cubes of cement mortar is 22.15 MPa after the age of 28-days and test was performed as per IS 2250:1981[17].

Carbon Fiber Reinforced Polymer (CFRP) Bars

In this study, two types of FRP bars are used. The first type is manufactured by Pultrusion process and supplied by ZOLTEK, India (Manufacturers Company). Type 2 is fabricated locally by hand lay-up process using mechanically developed specialized twisting equipment. In this equipment, hooks are connected to the handle at the ends of the equipment, and carbon fiber rovings are tensioned between the hooks. Carbon fiber impregnated with epoxy adhesive. After tensioning the fiber between two ends, hooks are rotated for outward twisting. This way the carbon fiber also get entangled with each other and then get stretched outward causing excess resin to drip out. This also helps in maintaining uniform bar diameter without sagging. After the proper number of rotations, the hooks and handles are fixed, and the entire set is left to cure. The FRP bar is cut from the ends after 72 hours. The typical length and diameter of the CFRP rebar is 1.5 m and 8 mm, respectively. The tensile strength and Young's modulus were determined as per standard ASTM D7205/D7205M [18]. The materials properties of FRPs bars are presented in Table 1.

EXPERIMENTAL DETAILS

Specimen preparation

A total of twelve masonry beams of size 150 × 230 mm cross-section (b × h) and 1300 mm length were cast. In each beam, two layers of clay burnt-bricks were inserted as shown in Figure 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 and bottom cover of the beam is maintained as 30 mm with mortar. The specimens were divided into three series; each series contain two specimens. In the first series, two specimens were not reinforced to act as a bench mark.

Series #2 consisted of two specimens which are reinforced with three numbers of pultruded CFRP bars of diameter 8 mm. The schematic diagram of reinforced masonry beams with CFRP bars is shown in Figure 2.

Series #3 comprises of two specimens which are reinforced with three numbers of hand lay-up CFRP bars. The diameter of CFRP bars are 8 mm. The corresponding nomenclatures of the specimens are presented in Table 2.

Table 1: Material properties of CFRP bars

Properties	Pultruded CFRP bars	Hand Lay-up CFRP bars
Diameter of bar (mm)	8	8
Tensile strength (MPa)	2217	1671
Modulus of Elasticity (GPa)	55	48
Rupture strain (%)	4.49	3.68

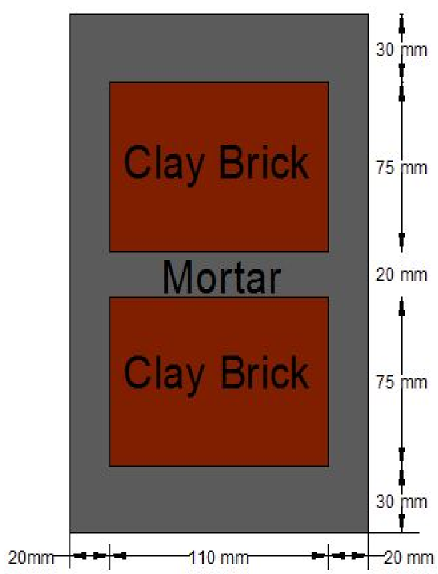

Figure 1: Cross-section of control masonry beam

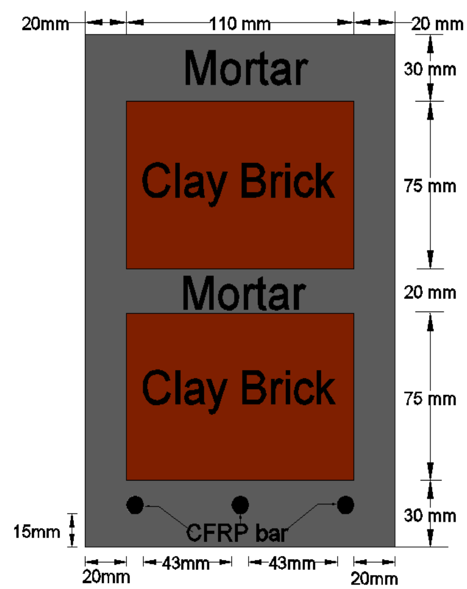

Figure 2: Cross-section of reinforced masonry beam

Table 2: Designation of specimens

Series No.	Specimen ID	Specimen Details	No of Specimens
1	CMB	Control masonry beams	2
2	RMBPC	Reinforced masonry beams with Pultruded CFRP bars	2
3	RMBHC	Reinforced masonry beams with hand lay-up CFRP bars	2

Test method

Masonry beams were tested under four-point loading applied with 200 kN capacity servo hydraulic actuator under displacement control mode with a rate of 0.05 mm per sec till failure. Load and deflection of the beams were measured through the control system. The beams were tested for an effective span of 1.10 m with loading span of 100 mm as shown in Figure 3.

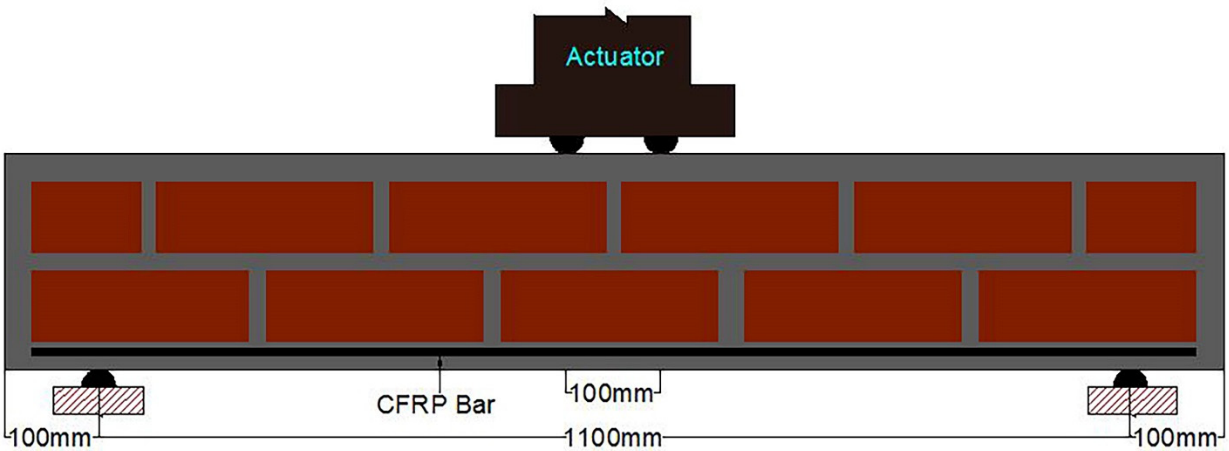

Figure 3: Test set up of reinforced masonry beam

RESULT AND DISCUSSION

The experimental test results of the unreinforced and reinforced masonry beams are presented in Table 3. Responses and failure patterns of the masonry beams are described in the following sections.

Table 3: Experimental results of tested masonry beams

Series No.	Specimen ID	Average Failure Load (kN)	Average Mid-Span Deflection (mm)	P_{RB}/ P_{CB}*	δ_{RB}/ δ_{CB}**	Mode of Failure
1	CMB	3.58	1.38	-	-	Flexural
2	RMBPC	48.70	20.34	13.60	14.74	Flexural
3	RMBHC	42.78	12.48	11.95	9.05	Flexural

* P_{RB} = Load carrying capacity of reinforced masonry beam
* P_{CB} = Load carrying capacity of control masonry beam
**δ_{RB} = Mid-span deflection of reinforced masonry beam
**δ_{CB} = Mid-span displacement of control masonry wall

Series #1

In the unreinforced/ or control masonry beams the flexural cracks started at the tension face and propagated towards the compression face leading to sudden failure as shown in Figure 4. The control specimens failed suddenly due to brittleness of both bricks and cement mortar. The beam (CMB) failed at ultimate average load of 3.58 kN and corresponding mid-span deflection of approximately 1.38 mm was observed. The load-deflection response of the control specimens is linear up to the peak load then sudden collapse was occurred as shown in Figure 5.

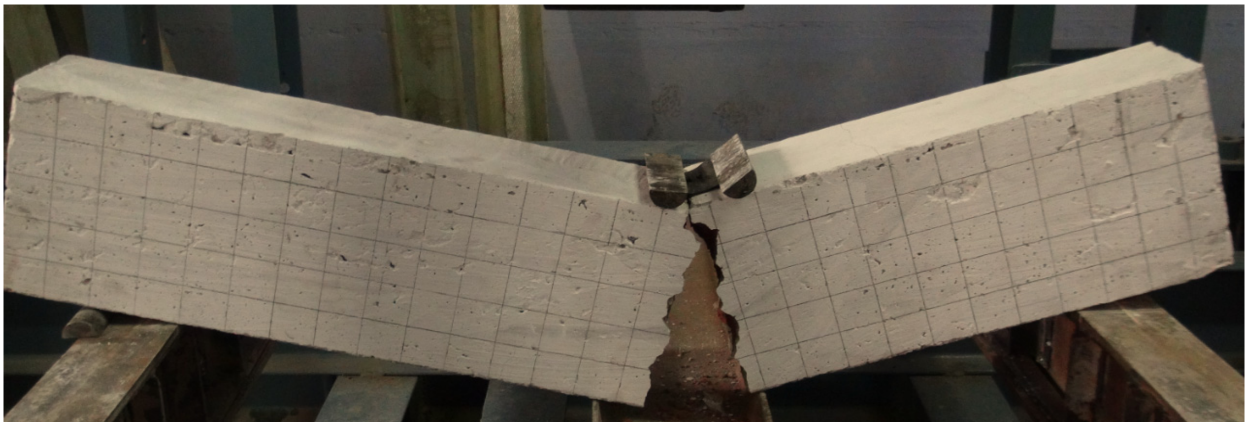

Figure 4: Failure mode of control masonry beam (CMB)

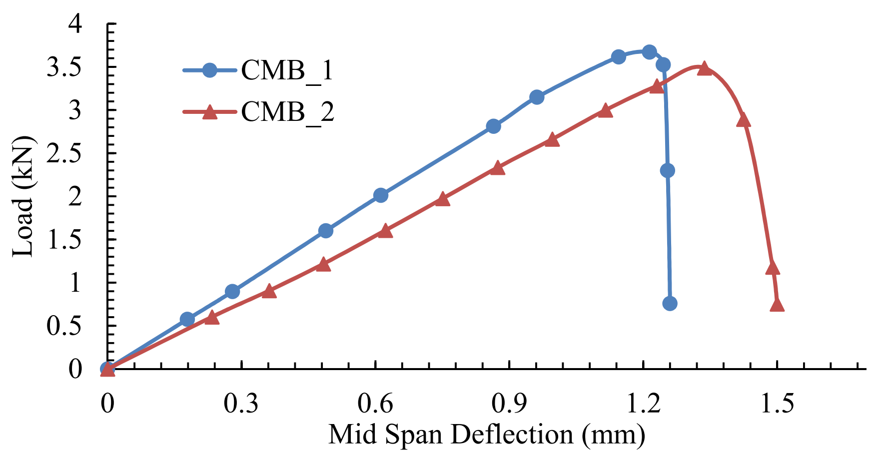

Figure 5: Load-deflection response of Series #1 beam (CMB)

Series #2

In the reinforced masonry beam with pultruded CFRP bars (RMBPC), first crack appeared in the vertical direction close to the left side of loading point, as shown in Figure 6. As the load was increased, the cracks widened in the tension zone and propagated towards the compression face. The load deflection response of Series #2 specimens is shown in Figure 7. In the reinforced masonry beam with pultruded CFRP bars (RMBPC), large deflection was observed after the peak load due to slippage of CFRP bars, as show in Figure 7. The slippage occurred in the reinforced masonry beam due to smooth surface of CFRP bars.

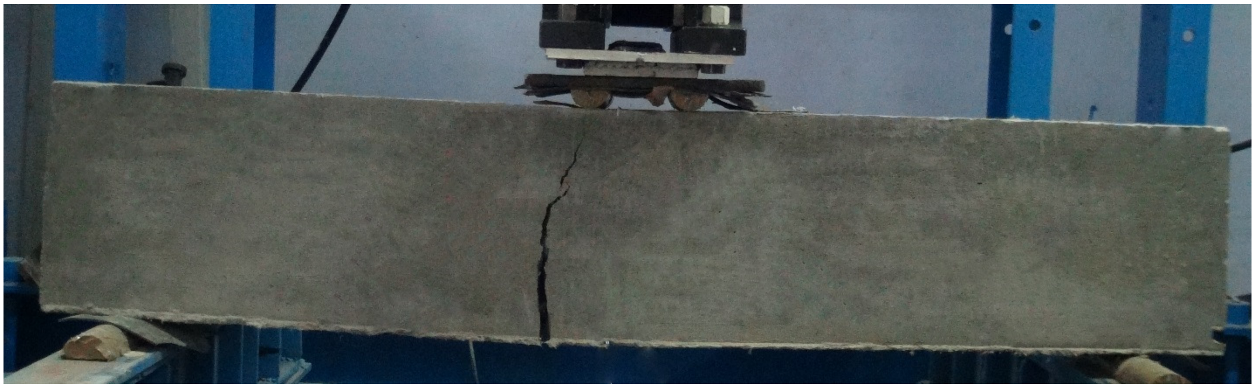

Figure 6: Failure mode of reinforced masonry beam with pultruded CFRP bars (Series #2)

Series #3

In the reinforced masonry beams with hand lay-up CFRP bar, vertical flexural cracks developed in the mid span zone. The normal flexural failure was observed in the series #3 beam. The failure pattern of the reinforced masonry beams (RMBHC) is shown in Figure 8. The load-deflection response of the Series # 3 specimens is shown in Figure 7. The response of the specimens (RMBHC) is linear up to peak load where a sudden drop in load occurred. Then, the specimen featured a gradual increase in load and deflection, possibly because of the progressive failure of CFRP bars, followed by another load decay. Finally, the rapid drop in the load response was observed as shown in Figure 7.

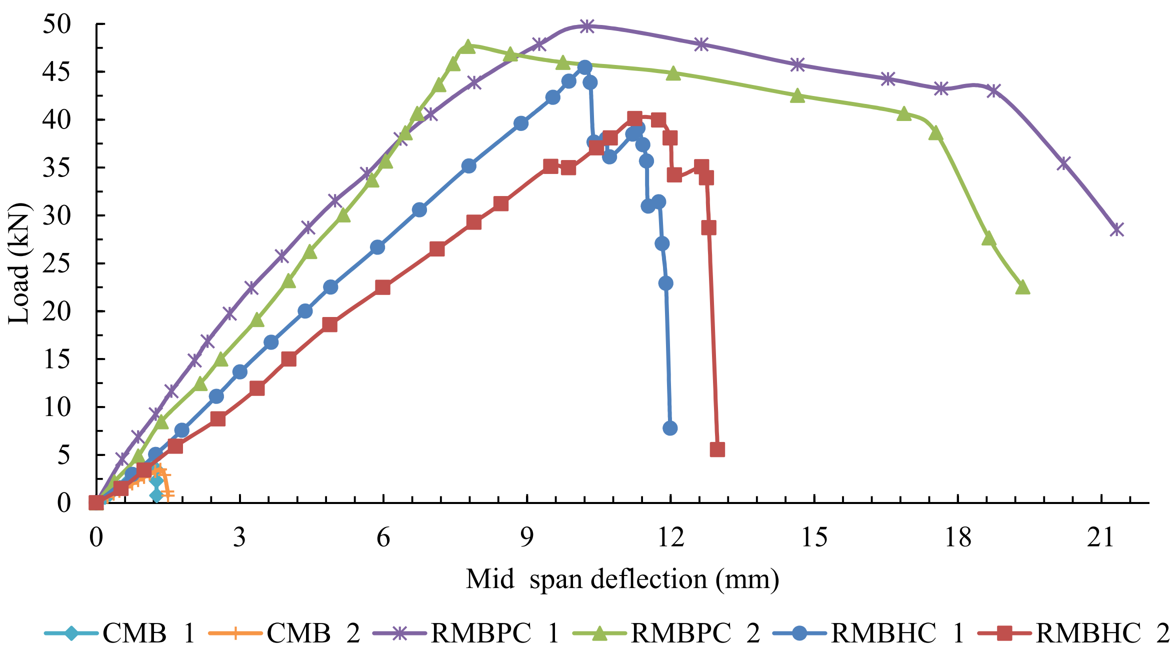

Figure 7: Load-deflection response of all the specimens (Series #1-3)

Figure 8: Failure mode of reinforced masonry beam with hand layup CFRP bars (Series #3)

CONCLUSION

The experimental results of reinforced masonry beams with CFRP bars show an increase in flexural performance in terms of load carrying capacity and ductility in comparison with unreinforced/ or control masonry beams. The following conclusions are drawn from this study:

- Reinforced masonry beams with three CFRP bars in the tension zone demonstrated a drastic improvement in their load carrying capacity and deformability.
- Load carrying capacity of hand layup CFRP bars has increased by 12 times that of unreinforced masonry beams.
- Slippage of pultruded CFRP bars was observed in the reinforced masonry beams due to smooth surfaces, it could be avoided by providing sand coating on the CFRP bars before use.
- Further study is needed to check the effect of bond of FRP bars and flexural response of masonry beams.

ACKNOWLEDGEMENTS

This project is a part of Department of Science and Technology (DST), Govt. of India sponsored research project (No. SR/S3/MERC/0051/2012). The financial support of DST is highly appreciated.

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