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Near surface mounted strengthening of RC beams using basalt fiber reinforced polymer bars

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HIGHLIGHTS

- Use of BFRP bars for near surface mounted strengthening (NSM) is investigated.
- Characterized the pullout behavior of BFRP bars.
- Influential parameters such as bonded length, groove size and diameter of bar were investigated for pullout behavior.
- Flexural strengthening of RC beams were carried out by using BFRP-NSM method.
- NSM-BFRP strengthening can double the load carrying capability without loosing ductility of RC beams.

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ABSTRACT

Present paper investigates the efficiency of basalt fiber reinforced polymer bars (BFRP) for near surface mounted (NSM) strengthening of RC beams. An experimental program was carried out to determine the pullout behavior of BFRP bars and based on the results, an BFRP-NSM method has been designed. To assess the bond behavior of BFRP to concrete, pullout tests were carried out. The influences of bonded length, groove size and diameter of bar on the bond behavior were analyzed. Based on the results, a ratio of groove size to diameter has been proposed to utilize the maximum potential of BFRP bars in NSM strengthening. Flexural strengthening of RC beams were carried out by using BFRP-NSM method. The diameter of the bar, number of bar and groove size were considered as the influencing parameter. Based on the studies, it is concluded that it is possible to double the load carrying capability without loosing ductility by using this method.

1. Introduction

The use of fiber reinforced polymer (FRP) bars are gaining popularity in the construction sector all over the world. FRP is found to be one of the best retrofit material for many structural components as per the research reported till date. There are many varieties of FRP bars available in the market such as CFRP, GFRP, AFRP and BFRP made of carbon, glass, aramid and basalt fibers respectively. Many promising results are reported in terms of enhancement in load carrying capacity of a retrofitted beam while using CFRP and GFRP bars for near surface mounted strengthening (NSM). In this method FRP rods are fixed into pre-cut grooves on the concrete cover of the elements to be strengthened and studies are reported mainly on the GFRP and CFRP bars [1–10]. However, the experimental database available in literature for NSM of BFRP bars are limited, and the present paper is a contribution towards it.

As FRP bars having certain advantages, the main cause of concern is the bond behavior between FRP bar and concrete that corresponds to stress transfer from concrete into FRP bar. In the NSM technique, there are two bond interfaces: one between the NSM bar and the adhesive, and the other between the adhesive and the concrete. For this technique to perform efficiently, these two interfaces need to be investigated. The proper understanding of stress transfer process between concrete, epoxy and FRP bar is essential in NSM method and henceforth, it is necessary to characterize its bond behavior [11,12]. A comparative evaluation of the pullout behavior of steel and FRP bars were carried out by using direct pullout test [13,14]. Based on the study, it was concluded that the anchorage design for steel rebar is not directly applicable on FRP rebar since the slip of the rebar relative to the concrete surface was greater in the later case. Further, FRP rebars showed lower bond strength values compared to steel rebars. Considering the

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practical advantages of direct pull out specimen while minimizing the problem of eccentricity, a modified direct pull out test can be seen in literature [3,15]. In this test, the variables were type of FRP bar, diameter of bars, groove filling material, bonded length (ranging from 4 to 24 times the nominal bar diameter), groove size (ranging from 1.24 to 2.5 times actual bar diameter) and surface configuration of bars (spirally wounded and ribbed). It is observed that the optimal dimensions of the groove is mainly depended on characteristics of the adhesive, surface treatment of FRP, and concrete tensile strength, surface, aggregates [16]. The failure behavior was also studied during the pullout test and mainly two type of failures such as splitting and pull out was seen [17]. As the bonded length increases the pull out load also increased, but the bond strength decreases due to non-uniform distribution of bond stresses along the bonded length. When pull out failure occurred, it is seen that the groove size does not affects the average bond strength provided that it should be enough to avoid splitting cracks that could accelerate failure.

Present paper mainly reports two aspects on use of BFRP for NSM retrofit. One is the pullout characteristics of BFRP bar. The effect of parameters such as groove size, diameter of bar and bond length was also investigated. To bring up a practical applicability of BFRP using NSM method, experimental investigations have been carried out of RC beams strengthened using BFRP-NSM technique under flexure.

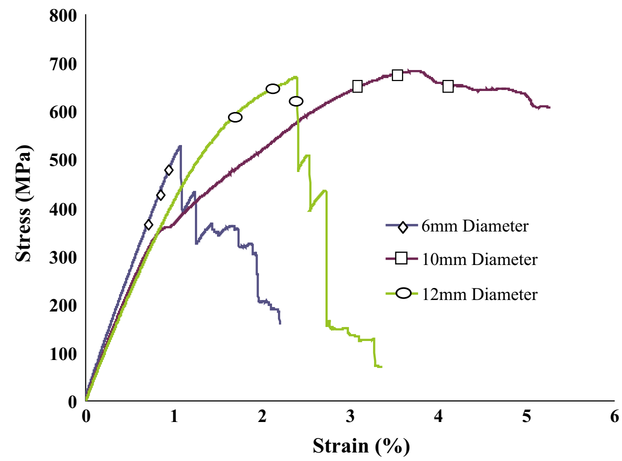

Fig. 1. Tensile behavior of BFRP rods.

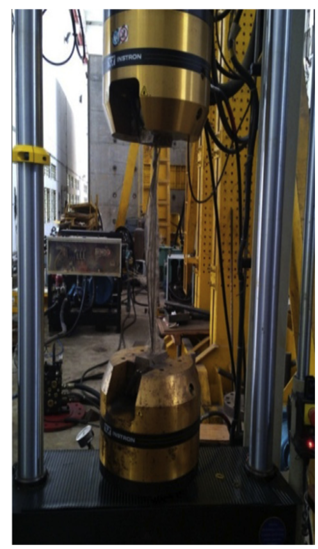

Fig. 2. Typical failure of BFRP rod.

2. Experimental investigations on bond behavior

Direct pull out test of BFRP bar was carried out to determine the bond slip relation and bond strength of BFRP bars. The parameter which are taken into consideration are groove size, bonded length and diameter of FRP bar. In this study the bond length considered are 12, 18 and 24 times the diameter of the bars; size of BFRP bar (6 mm and 10 mm); and groove width (1.5 and 2 times the diameter of the bar).

2.1. Materials used

A C-block configuration [3] was used for conducting the pullout test. Total 15 C-concrete block of M-25 grade is used to cast the concrete block. The mix proportion used is given in Table 1. The adhesive used to embed BFRP bar is Sikadur-330 and the details are given in Table 1. It is a two-component based resin and hardener, solvent-free, moisture-tolerant, high strength and high modulus structural epoxy adhesive.

The BFRP bar used was of 6 mm and 10 mm diameter bars. The uniaxial stress–strain characteristics of BFRP bars of 6 mm, 10 mm and 12 mm diameter is given in Fig. 1 and the failure pattern is shown in Fig. 2. It is observed that the ultimate tensile strength of BFRP rods of 6 mm, 10 mm and 12 mm diameter are 550 MPa, 680 MPa and 690 MPa respectively. The 10 mm BFRP is seemed to have more straining capacity, which is in contrary to what was expected. Hence, it gives an indication that since there are many basalt fibers in BFRP rod, it is essential to perform tensile characterization before any practical use to confirm on the ultimate tensile strength and strain.

2.2. Specimen details and test set-up

In order to prepare a C-shaped concrete mould certain dimension was extruded from the solid cube and a 160 mm × 160 mm × 300 mm C-shaped wooden block was made. Based on the literature one square groove was provided at the center of the block, and a wooden strip of square cross-section of specified dimension was nailed at the center of C-shaped wooden block [3]. The C-shaped wooden block was kept inside the steel mould of size 300 mm × 300 mm × 300 mm. The details of the casting of specimen is shown in Fig. 3. After the completion of curing period for 28 days, C-block was taken out from the tank. The square groove where BFRP bar has to be fixed was cleaned up properly. Each component part A and part B of Sikadur was mixed properly, content of part B to part A 4:1 by weight was poured. First bond length marking was done on the square groove, in order to place BFRP bar at the center of groove thermocol packing was placed at both ends in groove so that bar remain in center. In order to enrich bond between FRP and adhesive BFRP bar sand coating was done. Epoxy was then poured into the groove to cover up to half depth, some mild compaction was given at some intervals so that epoxy gets filled up properly into the square groove.

2.3. Test set-up

The concrete block was placed on steel pedestal at the top of that block two I-section of depth 150 mm was placed and bolted with steel pedestal so that concrete block get fixed and can't get lifted up at the time of testing. In order to protect BFRP

Table 1
Details of materials used.

Grade of Concrete	w/c	Cement	Sand	Coarse Aggregate
Concrete				
M-25	0.5	1	1.8	2.8
Name of adhesive	Compressive strength (MPa)	Tensile strength (MPa)	Modulus of elasticity (MPa)	Mixing ratio (resin:hardner)
Adhesive				
Sikadur-330	82	34	3489	4:1