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State-of-the-Art Review of Strengthening of RC Beam in Shear by Near Surface Mounting Technique

Keyur P. Kanani[1] Prof. Mazhar A. Dhankot[2]
[1]P.G. Student [2]Associate Professor
[1,2]Department of Civil Engineering
[1,2]Marwadi Education Foundation and Group of Institutes, Rajkot, Gujarat

Abstract— Strengthening of RC members like slabs, columns and slabs have been done using Fiber-reinforced polymer (FRP) materials since last three decades. A lot of research is undergoing to ensure durability strength and long life to the deteriorated or distressed RC structural members. Use of FRP laminates and bars made from Glass, Carbon, Aramid fibers have proven its worth. A recently developed natural fiber derived from Basalt rock which is widely used as fire proof material owing its thermal properties is fabricated in form of bars and strips and have been used in strengthening of RC members. Glass, Carbon and Basalt fiber laminates have been used to strengthen RC members like beam in flexure and shear through external bonding. However, the delaminating of these laminates depends largely upon its surface preparation. This has resulted in development of near surface mounting (NSM) techniques which involves avoids the delaminating. Glass fiber bars and strips have been largely used to strengthen RC beams using NSM technique in flexure and shear. Some studies have also been conducted for investigating flexural strengthening of RC beams in flexure using this technique. The paper presented here describes a detailed review of those works and it is observed from the review that investigation still needs to be conducted in area of shear strengthening of distressed RC members by using basalt bars and strips through NSM technique.

Key words: Near Surface Mounted, Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), Basalt Fiber Reinforced Polymer (BFRP), Flexural strengthening, Shear Strengthening

I. INTRODUCTION

Recently, fiber-reinforced polymer (FRP) reinforcements have been used extensively as an alternative reinforcement material to steel for new construction as well as for strengthening and repair of existing structures. Strengthening of Reinforced concrete (RC) elements mostly use two methods EBR (Externally Bonded Reinforcements) method and NSM (Near Surface Mounted) method. Steel bars have resulted in several disadvantages including difficulty in handling at site and possibility of corrosion at the adhesive-steel interface. Therefore, the strengthening of concrete structure by bonding FRP bars to concrete surfaces using polymer adhesives is becoming an effective way of improving performance of structures.

A. *Use of FRP's:*

Strengthening of concrete structures must be considered when the existing structure deteriorates or any alteration to the structure has to be made due to which the structure may fail to serve its purpose. In some cases it can also be difficult to reach the areas that need to be strengthened. When strengthening is going to be undertaken all failure modes must be evaluated. The strengthening should be designed with consideration to minimize the maintenance and repair needs.

Use of FRP in strengthening process is increasing day-by-day due to its numerous advantages, i.e. corrosion resistance, lightweight, ease of installation, less maintenance, ideal for external application.

B. *History of FRP's:*

Bakelite was the first fibre-reinforced polymer. Dr. Baekeland had originally set out to find a replacement for shellac (made from the excretion of lac beetles). Chemists had begun to recognize that many natural resins and fibers were polymers, and Baekeland investigated the reactions of phenol and formaldehyde. He first produced soluble phenol-formaldehyde shellac called "Novolak" that never became a market success, and then turned to developing a binder for asbestos which, at that time, was moulded with rubber. By controlling the pressure and temperature applied to phenol and formaldehyde, he found in 1905 he could produce his dreamed-of hard mouldable material (the world's first synthetic plastic): Bakelite. He announced his invention at a meeting of the American Chemical Society on February 5, 1909.

The development of fibre-reinforced plastic for commercial use was being extensively researched in the 1930s. In the UK, considerable research was undertaken by pioneers such as Norman de Bruyne. It was particularly of interest to the aviation industry.

II. VARIOUS STRENGTHENING TECHNIQUES

The most common used flexural strengthening techniques with FRP composites are:

- Externally bonded reinforcement (EBR) using FRP Bars.
- Near surface mounting (NSM) method using FRP Bars.

A. *Externally Bonded Reinforcement (EBR):*

EBR FRP sheet and strip are the most commonly used techniques for flexure and shear strengthening of concrete beams and slab as shown in Figure 1. However EBR FRP reinforcements have debonding problem between concrete surface and the reinforcements [2]

Figure 1(a) shows four sides of RC beam wrapped using CFRP sheet. Four Sides of RC beam are wrapped using GFRP sheet is given in Figure 1(b), Figure1.(c) shows three side of beam are wrapped using U shape FRP continuously along the length. FRP lays of U shape are wrapped at some interval is presented in Figure1.(d) .Figure 1(e) shows FRP sheet is wrapped at 90º with respect to longitudinal axis of beam. FRP sheet is wrapped at 45° with respect to longitudinal axis of beam is given in Figure1 (f).

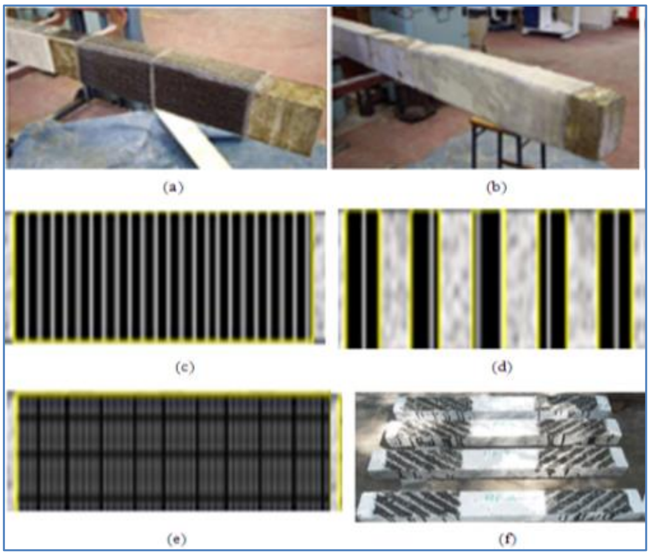

Fig. 1: FRP wrapping of RC elements

Bridge girders and long span slabs are strengthened using EBR method as shown in Figure 2(a) and Figure 2(b) respectively [3].

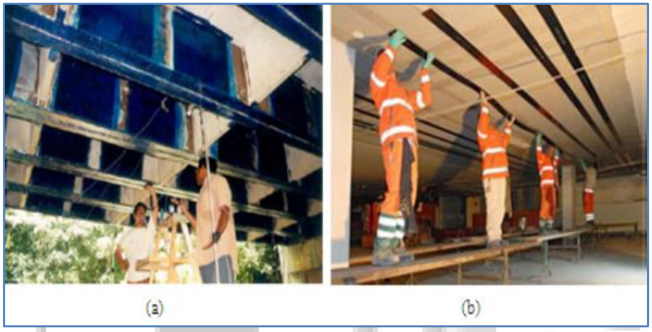

Fig. 2: Field applications of FRP using EBR method

B. *Near Surface Mounted (NSM) Reinforcement:*

NSM is one of the most recent and very promising strengthening techniques for the RC structures. NSM is based on the use of circular rectangular bars and strips of carbon and glass and Basalt fiber reinforced polymer (GFRP or CFRP or BFRP) materials installed in RC elements for strengthening. [4]

Several options are available to designers for selecting appropriate strengthening methods for RC elements in flexure and shear. The flexural strengthening options include increasing the amount of longitudinal reinforcement by attaching metal plates or FRP laminates to the surface on the flexural tension face. Such arrangement provides additional conventional reinforcement, by embedding NSM strips or FRP rods near the Flexural tension side of the beam. Examples of shear strengthening options include adding external stirrups, bonding external plates

Via epoxy or bolts, bonding external FRP laminates, and adding new stirrups followed by increasing the cross section size. One recently proposed technique uses NSM FRP strips, and NSM conventional rebar to increase the area of transverse reinforcement.

Grooves in beam were prepared FRP reinforcement was installed, in it and grooves were filled using epoxy is shown in figure 3 (a) and figure 3 (b) respectively.

Fig. 3: Strengthen using NSM Technique.

NSM method was employed for strengthening of bridge slab and girder using FRP bars as presented in Figure 4(a) and Figure 4(b). Strengthening of RC slabs using NSM FRP bars is given in Figure 4(c) and (d) respectively.

Fig. 4: RC elements strengthened using NSM FRP

For strengthening of brick masonry walls also NSM FRP reinforcement is found very useful. Horizontal grooves in brick wall were prepared as shown in Figure 5(a). FRP reinforcements were installed in that groove as shown in Figure 5(b). Finally, the grooves are filled by injecting the filling material as shown Figure 5(c).

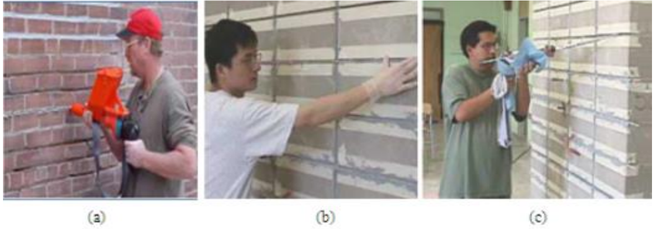

Fig. 5: Masonry wall is strengthened in horizontal direction using NSM FRP

Masonry wall is also strengthened by installing FRP reinforcements vertically as shown in Figure 6(a) and Figure 6(b) respectively. The grooves were filled by injecting filling material as shown Figure 6(c).

Fig. 6: Masonry wall is strengthened in vertical direction using NSM FRP reinforcement

III. COMPARED TO EXTERNALLY BONDED FRP REINFORCEMENT, THE NSM SYSTEM HAS A NUMBER OF ADVANTAGES AS FOLLOWS.[5]

1) NSM bars are protected by the concrete cover and so are less exposed to accidental impact and mechanical damage, _re etc. This aspect makes this technology particularly suitable for the strengthening of negative moment regions of beams/slabs.
2) The amount of site installation work is reduced, as no surface preparation is required apart from the grooving.
3) NSM bars are more easily anchored into adjacent members to prevent debonding failures. This feature is particularly attractive in the flexural strengthening of beams and columns in rigidly-jointed frames, where the maximum moments typically occur at the ends of the member.
4) NSM reinforcement is less prone to debonding from the concrete substrate.
5) The aesthetics of the strengthened structure is virtually unchanged.

IV. REVIEW OF LITERATURE

Various techniques are available for strengthening of RC elements. Use of Fiber Reinforced Polymer Composites is the latest alternative for strengthening of RC elements. FRP reinforcements have higher tensile strength compared to the steel rods. Use of FRP composites is not limited to new construction, but they are also used to enhance the structures deficient in flexural and shear.

Methods for strengthening existing reinforced concrete structures have been extensively studied over the past half a century. After the introduction of advanced composite materials in construction over the past 20 years, strengthening techniques have involved from surface bonded FRP laminates to near-surface mounted FRP bars. The purpose of these studies has been the understanding of the behavior of the strengthened members under increased applied loads and their modes of failure. Through a proper understanding of the failure mechanisms of these members, the feasibility and effectiveness of each strengthening technique can be established. Although the NSM Technique is a relatively recent development, it has become one of the most promising techniques for strengthening RC and masonry structures due to the many advantages it offers relative to other externally bonded FRP systems.

De Lorenzis et al. (2000)[6] investigated the strengthening of RC structures with NSM FRP rods. Each of the four full-scale specimens were 4575 mm long with the following T -beam cross sectional dimensions: height of 405 mm, flange thickness of 100 mm, web width of 150 mm and flange width of380 mm. The specimens consisted of an unstrengthened control beam and three strengthened beams using NSM CFRP rods. Two beams were strengthened with sandblasted CFRP rods each fitted with two #3 (3/8") or two #4 (4/8" or 112") rods while the fial beam was fitted with two #4 deformed GFRP rods. All the grooves were square in cross section with side-length of 19 mm and 25 mm for the #3 and #4 rods, respectively. They found that the specimens strengthened with two NSM CFRP #3 and #4 rods each increased the load carrying capacity by 30% and 44.3%, respectively, relative to the corresponding unstrengthened or control specimen. Both CFRP beams failed due to the debonding of the NSM reinforcement, thus since bond was the controlling failure mechanism, increasing the amount of NSM reinforcement did not produce a proportional gain in capacity.

De Lorenzis and Nanni (2001)[7] investigated shear strengthening of RC beams with NSM CFRP rods. Each of the 8 full scale T-shaped beams were 3000 mm long with the following cross sectional dimensions: height of 405 mm, flange thickness of 100 mm, web width of 150 mm and flange width of 380 mm. The specimens consisted of six beams with no internal steel shear reinforcement and the remaining two with internal steel stirrups at a spacing that did not satisfy the ACI 318 Code (1995) requirements. The beams were designed with equal flexural reinforcement and allowed to fail in shear despite the NSM shear strengthening. The following parameters were examined during the experiment: spacing of the NSM FRP bars (178 mm and 127 mm), inclination of the NSM FRP shear resisting bars (vertical and 45°), anchorage of the NSM bars in the flange using epoxy filled drilled holes, and the presence of internal steel stirrups. Each NSM CFRP reinforcing bar was 9.5 mm in diameter and was inserted within a 19 mm wide by 19 mm deep vertical groove extending along the full height of the beam web. In the absence of internal steel shear reinforcement, they found as high as 106% increase in the beams capacity compared to the control beam without shear reinforcement. In the beams with internal shear reinforcement, the NSM technique increased the capacity 35% relative to the companion beam with stirrups but without NSM FRP bars. Generally, in the NSM reinforced beams the governing failure mode was the splitting of the epoxy cover, but when the specimens involved anchorage of the NSM bars in the flange or 'closely' spaced 45° NSM reinforcement, the failure mechanism changed to the splitting of the concrete cover along the longitudinal reinforcement. Finally, they reported that NSM shear reinforcement, unlike internal steel shear reinforcement, are not able to restrain the longitudinal steel reinforcement subjected to dowel forces thus it does not enhance the dowel forces, contribution to the overall shear strength of the beam.

Hassan and Rizkalla (2003)[8] investigated the bond in concrete structures strengthened with NSM CFRP strips. Each of the nine simply supported specimens were 2500 mm long with the following T -beam cross sectional dimensions: height of 300 mm, flange thickness of 50 mm, web width of 150 mm and flange width of 250 mm. The specimens consisted of one unstrengthened control beam and eight beams strengthened with NSM CFRP strips. The 1.2 mm wide by 25 mm high CFRP strips were inserted inside a single 5 mm wide by 25 mm deep groove along the mid-width of the bottom face of the beam. The test parameter was the embedment length of the NSM CFRP reinforcing strip (150, 250, 500, 750, 850, 950, 1050 and 1200 mm). They found that ultimate load carrying capacity increased by as much as 53% and the groove dimensions used were capable of preventing epoxy cover failure. The beam with 850 mm embedment exhibited the same bending capacity as the specimens with 950, 1050 and 1200 mm embedment, indicating the critical embedment length to be 850 mm. Localized debonding failure was observed at bar cut-off locations due to concentrated shear stresses and within the region of maximum moment due to wide flexural cracks. Through their analytical model produced after the laboratory tests, they found that the development length of strips increased when the internal steel reinforcement ratio increased. Additionally, the development length was found to decrease with increases of either concrete compressive strength and/or groove width.

Teng et al. (2003)[9] conducted an experimental study on the debonding failures of RC beams strengthened with NSM CFRP strips. A total of five specimens were constructed, each being 3200 mm long with cross sectional dimensions of 150 mm wide by 300 mm high. The specimens consisted of one unstrengthened control beam and four beams strengthened with one NSM strip. The 5 mm wide by 16 mm high strips were inserted into an 8 mm wide by 22 mm deep groove along the mid-width of the beam bottom face. The test parameter was the length of embedment of the NSM CFRP reinforcement (500, 1200, 1800 and 2900 mm). They found for the specimens of 1200 and 1800 mm embedment, the governing failure mechanism was the debonding of the concrete cover, while for the specimen with 2900 mm embedment the governing failure mode was concrete crushing. After analyzing the FRP strain and bond stress distribution, they reported debonding propagation from the bar cutoff section to the section of maximum moment for the beams with 500, 1200, 1800 mm embedment. Conversely, in the beam with 2900 mm embedment, the debonding propagated from the maximum moment region to the cutoff region as a secondary mechanism after the governing mechanism, concrete crushing had occurred. Prior to the flexural tests, they conducted tensile pull tests using various NSM bar embedment lengths and noted that the bond stress distribution developed in pull tests could not be used to predict flexural bond stresses. The reasons are the presence of flexural and flexural-shear cracks which alter the distribution, the curvature of the beam and the generated dowel forces due to bond cracks.

Barros and Fortes (2004)[2] examined the flexural strengthening of RC beams with NSM CFRP reinforcing strips. A total of eight specimens were constructed each 1500 mm long with nominal cross sectional dimensions of 100 mm wide by 175 mm high. The test specimens consisted of four beams strengthened with NSM CFRP strips and the remaining four being unstrengthened and serving as control specimens. The 2 mm wide by 10 mm high strips were inserted into a 4 mm wide by 12 mm deep groove along the mid-width of the bottom face of the beam when a single strip was used, along 1/3 points when two strips were used and along 1/4 points when three strips were used. The test parameters were the amounts of steel and NSM CFRP reinforcement. It was the objective of the investigation to double the flexural strength of each control specimen by adding a particular amount of NSM reinforcement. It was observed that three of the four strengthened beams failed due to the debonding of the concrete cover. Portions of the detached layer extended above the level of the primary tensile reinforcement. The average increase in the ultimate load was 91% compared to the corresponding control specimen, and the CFRP reinforcements reached 62 to 91% of its ultimate strain. The authors suggest that their observed force-strain relationships consisted of three quasilinear segments: the first segment ranged from zero load to the cracking load, the second from the cracking load to the yielding load of the conventional reinforcement, and the third from the yielding load to the load corresponding to the initiation of slippage at the FRP-concrete interface. In the first segment all materials behaved linearly, along the second segment the concrete had cracked, internal steel reinforcement was behaving linearly while there was minimal slipping of the CFRP reinforcement, and along the final segment the steel had yielded and the slipping of the CFRP increased until failure was reached.

Barros et al.(2004)[10] conducted tests using NSM CFRP strengthening techniques. The tests consisted of three test series involving three types of RC elements. The first series involved eight 1000 mm tall RC columns designed to fail in flexure with cross sectional dimensions of 200 mm by 200 mm. The tensile faces of the column were strengthened with three 10 mm deep by 2 mm wide CFRP strips inserted within 15 mm deep by 5 mm wide grooves spaced evenly at 114 points across the width of the strengthened face. Four control columns were initially tested under eight load cycles varying between +/-2.5 mm and +/-20.0 mm axial displacement, in increments of +/-2.5 mm at a displacement rate of 150 µm/s. Subsequently these columns were strengthened with NSM bars and re-tested to failure. The performance of these strengthened columns was compared to that of another four similarly strengthened columns which did not involve pre-testing. They found that strain values of the CFRP strips approached their rupture strains, yielding an average increase of 92% and 34% in the columns load carrying capacity for the columns constructed with 4 No. 10 and 4 No. 12 internal steel reinforcements, respectively.

The second series of testing involved the construction of eight 1500 mm long RC Beams designed to fail in flexure with nominal cross sectional dimensions of 175 mm high by 100 mm wide. The eight specimens consisted of four strengthened beams and the remaining four being the companion unstrengthened control specimens. The tensile face of each beam specimen was strengthened with one, two or three 10 mm deep by 2 mm wide CFRP strips inserted within the 12 mm deep by 4 mm wide grooves spaced evenly at 112, 113 or 114 points of the bottom face of each beam, depending on the number of strips used. The objective of this test program was to double the load carrying capacity of the beam specimens by varying the amount of steel and the amount of CFRP used. They observed that the average increase of ultimate strength and average increase of cracking load was 91% and 51%, respectively. They also found that the NSM strengthening on average increased the load corresponding to the maximum serviceable deflection by 32% and the load corresponding to the onset of internal steel yielding by 39%.

The third sense involved the construction of five 900 mm long RC beams designed to fail in shear with cross sectional dimensions of 150 mm wide by 150 mm high. The five beams consisted of a single control beam, a beam with steel stirrups, a beam using an externally bonded CFRP sheet and the remaining two beams were strengthened with NSM CFRP strips. The two beams strengthened with NSM CFRP strips used the same strips and groove dimensions as in the second series; however, they differed by the orientation of the installed NSM reinforcement along the beam (vertical or 45°) versus the horizontal. The objective of this test program was to double the load carrying capacity of the beam specimens by varying the amount of steel and the amount of CFRP used. They observed that the ultimate strength of the strengthened beams increased ranging from 50 to 77% with respect to the unstrengthened control beam. Additionally, the strengthened beams illustrated larger deflections at their associated ultimate loads than the control beam ranging from 118% to 294%, indicating a high level of deformability at failure amongst the strengthened beams.

EI-Hacha and Rizkalla (2004)[11] conducted an experimental study on flexural strengthening by NSM FRP bars and externally bonded FRP strips. Each of the 8 T-beam specimens was 2700 mm long with the following cross sectional dimensions: height of300 mm, flange thickness of 50 mm, web width of 150 mm and flange width of 300 mm. The specimens consisted of one control specimen, three beams strengthened with NSM CFRP bars, one beam strengthened with NSM GFRP strip and the remaining three specimens externally strengthened with either CFRP or GFRP strips. Among the four beams involving NSM FRP, groove dimensions and number of bars installed along the beam were varied. Additionally, to compare the effectiveness of the NSM strengthening system, they constructed externally bonded specimens with an equal amount of FRP reinforcement as in the NSM FRP strengthened beams. They found that the use of NSM FRP reinforcement increased the flexural stiffness and ultimate load carrying capacity of the specimens. The strengthened beams behaved similar to the unstrengthened control specimen prior to cracking, but after cracking their stiffness increased, deflections were limited and crack widths were reduced. The beams strengthened with the NSM system were able to achieve higher ultimate load compared to the beams strengthened with the externally bonded FRP strips. The increase in strength between the two systems for type I and type 2 configurations were 79% and 25%, respectively, illustrating the significance of concrete-FRP bond area for developing the reinforcement stresses.

Kang et al. (2005)[12] conducted an experimental and analytical study on the flexural behavior of RC beams strengthened with NSM CFRP laminates. They constructed 5 prismatic test specimens that were 3000 mm long and having a cross section of 300 mm high by 200 mm wide. The five beams consisted of one control beam and four specimens strengthened with NSM CFRP strips. The test parameters included the varying of the groove depth (15 and 25 mm) and groove spacing (60 and 120 mm). Based on their results, the authors derived an analytical model which produced results similar to the recorded data. Upon variation of the groove depth they found that there is a critical groove depth after which no additional capacity could be gained. Additionally, the analytical results revealed a critical edge distance of at least 40 mm for the NSM reinforcing bars.

Jung et al. (2005)[13] examined the flexural behavior of RC beams strengthened by NSM CFRP reinforcement. Each of the 8 rectangular RC beams were 3000 mm long and having a 300 mm deep by 200 mm wide cross section. The specimens consisted of an unstrengthened control specimen, two beams strengthened with externally bonded CFRP sheets or strips and the remaining five strengthened with the NSM bars or strips. Of the five NSM beams, two beams used mechanical interlocking grooves which involved cutting grooves perpendicular to the longitudinal NSM CFRP bar or strip. The following parameters were examined during the tests: type of CFRP reinforcement (externally bonded versus NSM), shape of the NSM reinforcement (strip and round bar) and the application of the mechanical interlocking grooves. They found prior to cracking all the strengthened specimens exhibited behavior similar to the unstrengthened control beam, however, after cracking the strengthened beams behaved stiffer than the control. The externally bonded and NSM reinforced beams exhibited ultimate load increases ranging 30 - 47% and 39 - 65%, respectively, compared to the control specimen. The governing failure mechanism for the NSM reinforcement was the debonding of the bars from the concrete cover, thus with the application of the mechanical interlocking epoxy-filled grooves, they were able to increase the beam capacity by 15% compared to the conventionally placed NSM specimens.

Soliman et al. (2008)[14] conducted an experimental and analytical investigation of RC beams strengthened in bending with NSM CFRP bars. Each of the10 RC specimens were 2600 mm long with a rectangular cross section of the following dimensions: height of 300 mm and width of 200 rnm. The specimens were tested using two internal steel reinforcement ratios 0.80% (series A) and 0.40% (series B) while varying the bonded length of the bar. Four bond lengths were tested for series A and B specimens consisting of 12, 24, 48 and 60 times the diameter of the NSM CFRP bar, while the remaining two beams were used as control specimens. The strengthened beams were reinforced with a single 9.5 mm diameter CFRP bar inserted within a 19 rnm wide by 19 mm deep groove running along the length of the beam where the unbonded length was centered at the beam mid-span. They observed that all the strengthened beams failed due to the separation of the concrete cover initiated at the CFRP cut-off points near the beam supports. Beams in series A all showed increases in ultimate load carrying capacity with the exception of the one with the smallest bonded length of 12 times the bar diameter, where only the yielding load was increased by 16% compared to the companion control specimen. They found that increases in flexural strength among series A beams were greatest up to the bonded length of 48 times the bar diameter. Series B beams exhibited increases in strength, compared to their associated control beam, of22%, 32%, 71 % and 75% when the bonded lengths was increased from 12 to 60 times the bar diameter as stated earlier. All strengthened beams behaved similarly to the unstrengthened control beams following the debonding of the NSM CFRP bar.

Capozucca[15] investigated behavior of damaged beams. Beams were damaged by developing cracks using mechanism. Beams were of size 150x250x3500 mm. CFRP bars are used to strengthen the RC beams. After strengthening the RC beams experimentally, static and dynamic tests were done and results were compared with theoretical results. The strengthening of damaged RC beams using NSM CFRP rods improved the load deflection response. The flexural stiffness of strengthened beams increased and a high ultimate load caring capacity was recorded. Experimental results by static tests are close to theoretical data obtained for strengthened RC beam sections.

Kishi et. al.[16] investigated flexural load-carrying capacity of the existing RC members reinforced with near surface mounted fiber reinforced polymer rods and debonding behavior of those FRP rods. Aramid FRP rods were used for strengthening RC beams and compared their results with AFRP sheet on the tension-side surface were also tested in which axial stiffness between two reinforcing materials was kept similar for both cases. Due to similar axial stiffness of NSM AFRP rods with that of AFRP sheet, flexural reinforcing effects of the NSM AFRP rods was found similar with those of bonding FRP sheet. RC beams reinforced in flexure with NSM AFRP rods being debonded due to a peeling action of critical diagonal crack, where the cracks were developed in the lower concrete.

Anwarul[17] evaluated behavior of four concrete beams with regular steel reinforcement in flexure. The control beam had typical shear steel and the other three beams were strengthened in shear using CFRP bars. Strains were recorded during loading to failure of the beams. CFRP bars were installed at different spacing. The concrete beams in shear using NSM CFRP bars exhibited, an increase of shear strength by 17% to 25%. Strains in the NSM CFRP bars until beam failure were observed of almost one-third of ultimate strain.

Barros et. al[18] evaluated performance of five beams: without any shear reinforcement, reinforced with steel stirrups, strengthened with strips of wet lay-up CFRP sheets, applied according to externally bonded reinforcement technique, and two beams were strengthened with NSM laminates of CFRP, one of them with laminates positioned at 90° angle and the other with laminates positioned at 45° angle in relation to the beam axis. The NSM shear strengthening technique was the most effective of the CFRP systems in terms of the beam load carrying capacity, as well as deformation capacity at beam failure. Increase in load caring capacity of the beams strengthened by EBR and NSM techniques was observed by 54% and 83%, respectively. The increments were 77% and 307%, respectively, indicated that efficacy of NSM technique was more pronounced in terms of deformability index.

Rizzo,[19] conducted comparison between NSM and EBR methods and also performance of RC beams strengthened at different angles in particular for NSM method. Beams were of sizes 200x210x2000 mm. Results shows that shear strength increased by 16% in the beams strengthened with externally bonded U-shape wrapping, and ranged between 22% and 44% for the beams strengthened with NSM reinforcement. The use of NSM reinforcement was more efficient in terms of exploitation of the FRP tensile strength due to early debonding of the externally bonded laminate. Higher load carrying capacity was observed for beam strengthened at 90° angel compared to beam strengthened by 45° angel.

Barros et. al[20] assessed that effectiveness of the NSM shear strengthening technique with CFRP laminates applied in high-strength concrete beams reinforced with a certain percentage of existing steel stirrups, and with or without pre-cracks, influence of the percentage and inclination of the laminates and the percentage of existing steel stirrups. From the got results it can be reasoned that the NSM shear strengthening technique with CFRP laminates is exceedingly viable in RC beams of an average compressive strength around 60 MPa. Adequacy with CFRP laminates increase with the concrete grade. The embraced NSM shear strengthening setups, predominantly those with overlays at 45°and 60°, have altogether increased the behavior of RC beams, since they gave a huge increment as far as ultimate load and ultimate deflection. In any case the percentage of CFRP, the inclined laminates were more efficient than vertical laminates and the load carrying limit has expanded with the rate of CFRP. At the point when contrasted and past results got in lower grade of concrete. Because of the generally high grade utilized, the resistance to the concrete fracture propagation during the debonding process of the laminates crossing the basic inclining crack has activated essentially the tensile limit of the CFRP laminates. In fact, the most extreme strain recorded in the overlays up to the maximum load has extended somewhere around 0.82% and 1.54%. These qualities compare to half and 94% of the CFRP extreme strain (1.63%), respectively. The highest values of the maximum strain were recorded in the beam with the lower percentage of inclined laminates. A vital part of the viability of the NSM technique, regarding the analyzed beam, is the limit of this technique to prepare the yield stress of the stirrups before the Maximum load of the strengthened has been achieved.

Sabola[21] concluded that NSM method is an compelling technique of shear strengthening of the concrete elements in Experimentally, Analytically, Numerically. Significant reserves in the shear resistance of strengthened elements given by actual formulations suggest a need to improve the design rules for efficient design of strengthening concrete structures.

V. CONCLUSION

Based on the previous studies and the above literature review the following conclusions can be made:

1) Change in behavior of beams when strengthened in flexure using different diameter and numbers of bars.
2) Performance of beams strengthened in shear by changing spacing of FRP bars.
3) Performance of beams strengthened by changing angle at 45°, 60°, 90°.
4) Guidelines of preparing size of groove and its relationship in terms of bar diameter.
5) Percentage of load to be applied to make the beams damaged sufficiently.
6) Selection of cross-section dimensions and span of RC beams.
7) Design of RC beam based on codal provisions
8) Information about properties and understanding of behavior of RC beams strengthened using FRP reinforcement.
9) Test setup, interpretation of test outcomes.

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