ISSN: 1687-1006 p
ISSN: 2682-3640 e

The Egyptian International Journal of Engineering Sciences and Technology

Vol. 31 (2020) 19–34

https://eijest.journals.ekb.eg/

A State-of-the-Art Review: Side Near Surface Mounted (SNSM) Technique for Strengthening of RC Beams

Ramy M. Reda[a*], Zeinab Omar[b], Seleem S. E. Ahmad[b]

[a]Higher Technological Institute, 10th of Ramadan City,44629, Egypt
[b]Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt.

ARTICLE INFO

Keywords:

Side Near Surface Mounted (SNSM)
Flexural Strengthening
RC beam
CFRP
End anchorage

ABSTRACT

Near surface mounted (NSM) technique with fiber reinforced polymer (FRP) worldwide is the most repairing systems for existing concrete structures. The use of NSM strengthening technique to RC members is an alternative method used for applying FRP flexural strengthening. Some limitations of applying the NSM to RC members such as; minimum value of groove to NSM bar diameter and minimum net distance between groove and the beam edge and between two adjacent grooves, which limits the use of NSM technique in RC beams with limited width, therefore many researcher introduce side near surface mounted (SNSM) technique by placing the FRP grooves at the sides of the beam. SNSM technique produced a significant enhancement in the flexural capacity of the RC beams. This paper reviews current research on RC members strengthening with SNSM technique. It focuses on the effect of NSM strengthening bar length, strengthening materials type, strengthening diameter, effect of filling material, effect of end anchorage, effect of the strengthening bars number, strengthening position, effect of spacing between NSM bars, prestress level of FRP, longitudinal reinforcement ratio and effect of pre-cracking of strengthened beams.

1. Introduction

Throughout the world by the time all infrastructure damage as a result of increased the applied loads, corrosion, environmental and ageing [1-3]. Reinforced concrete RC structures such as buildings, bridges, Multi-floor garages, and offshore structures, will demolition or rebuild will lead to bleeding the time and cost. Furthermore, most concrete structures built in the 1950s and 1960s, are unsatisfactory for current specifications [4]. Therefore, strengthening reinforced concrete (RC) structures is required to meet the requirements and extend the service life. Flexurally designed reinforced concrete RC beams can fail due to yielding of the concrete crushing, shear flexure or pull reinforcement. Upgrade the flexural and shear capacities of RC members can be occurs using different solution methods, such as external post-tensioning, steel or concrete jackets, replacement of degraded members or the addition of new extra members however they increase the dead load of repair structures and are time-consuming. So it is necessity to find alternative materials or methods. Strengthening of RC members using fiber reinforced polymers (FRPs) compared to those realized through the techniques that have generally superior performance recently [5]. Because of their high tensile strength, high stiffness, high resistance to insect and fungal growth, high chemical attack resistance, non-corrosive nature, low thermal transmissibility and ease of installation [6-15]. Many researchers were conducted several techniques for repairing and strengthening the RC structures using FRP such as externally bonded (EB) and near surface mounted (NSM) [16-19]. Near surface mounted is a strengthening techniques used epoxy resins as the adhesive in FRP application that has attracted the most international engineering community [20-30], it is based on bonding FRP bars

* Corresponding author. Tel: +2-01018144416.
E-mail address: ramy_mostafa12000@yahoo.com.

or laminates into pre-cut grooves in the concrete cover. Grooves might be for flexure strengthening in tensile surfaces of the RC members or for shear strengthening in the sides of the beams, half of the groove filled with the adhesive and the FRP composites embedding to these grooves then the adhesive filled in the groove and leveled [7, 17, 18]. There are many review papers have been reported in the area of FRP strengthened and repaired structural concrete members However, most of these reviews have involved mainly the EB FRP method and some review for bottom near surface mounted (BNSM) [31, 32]. Applying the bottom near surface mounted to concrete has some limitations [2] such as; the minimum value of the groove dimensions to the bar diameter for smooth and lightly sand-blasted bars must be 1.5 and 2.0 respectively, moreover the minimum net distance between two adjacent grooves equals to two bar diameter and between a groove and the beam edge equals to four bar diameter [33], which limit the use of BNSM technique in beams with limited width and if using more than two FRP bars in strengthening [34]. Therefore, this paper aims to review the side near surface mounted (SNSM) strengthening technique in term of effect of SNSM strengthening bar length, strengthening materials type, effect of strengthening diameter, effect of the filling material, effect of end anchorage, effect of the strengthening bars number, effect of the strengthening position, effect of spacing between NSM bars, prestress level of FRP and longitudinal reinforcement ratio and effect of Pre-cracking of strengthened beams.

2. Effect of NSM strengthening bar length

Sharaky et al. [34] studied experimentally and numerically the behavior of RC beams strengthened with GFRP bars with different length, The GFRP bars with or without end anchorage and end inclination angle, the tested beams consisted of five beams, the beam details are shown in Fig. 1. All beams tested under static four-point loads. The first beam was strengthened with two side NSM GFRP bars of 1800mm in length and without end anchorage. The second beam was strengthened with two GFRP bars of 1800mm in length and bent ends inclined by 90^0 . The third beam was strengthened with two GFRP bars of 1800mm in length and bent ends inclined by 45^0 . The forth beam was strengthened with two GFRP bars of 1400mm in length and bent ends inclined by 90^0 . The fifth beam was strengthened with two GFRP bars of 1400mm in length and bent ends inclined by 45^0 [34].

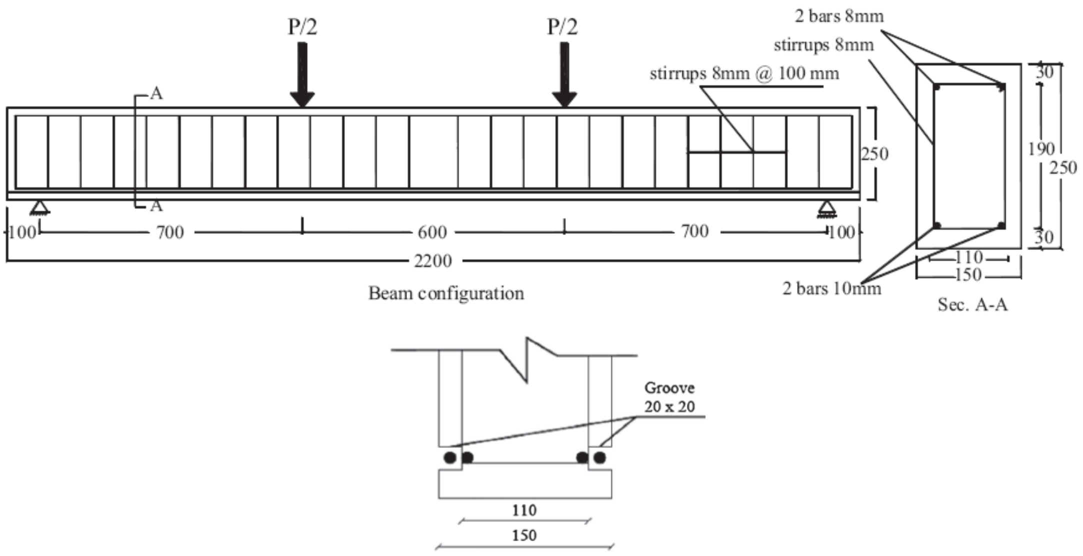


Fig. 1: Beam details and grooves locations (units in mm) [34].

Fig. 2 shows the effect of NSM GFRP bar length and end inclination angles on the behavior of strengthened beams, as shown in figure the load carrying capacity and the stiffness of the strengthened beams decrease with the decrease of the NSM GFRP bar length, the load carrying capacity of beams S2-180/0, S2-180/90, S2-180/45, S2-140/90 and S2-140/45 were 84.91, 81.90, 74.79, 73.36 and 68.80kN respectively with increasing of 175, 169, 154, 151 and 142% if compared with control beam which recorded 48.53kN load carrying capacity. The decreasing of NSM GFRP bars length from 1800mm to 1400mm decrease the load carrying capacity by 10.4 and 8.0% for beams strengthened with end anchorage of 90^0 and 45^0 respectively. Fig. 3 shows the failure modes of the strengthened beams, beam S2-180/0 fails due to concrete cover splitting, the other beams fails due to concrete crushing after debonding of the leg corner of GFRP bar [34].

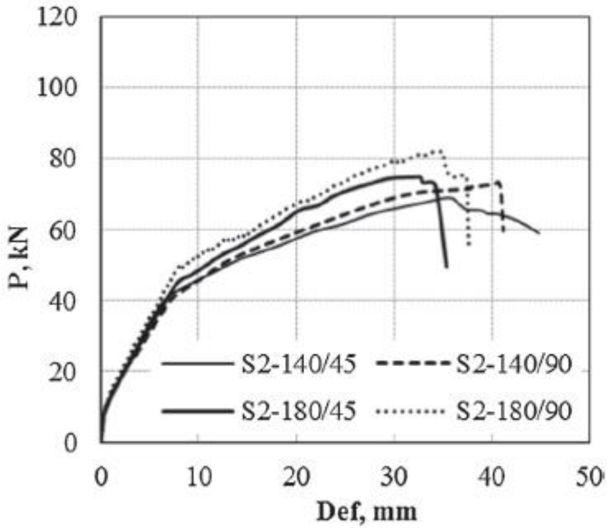


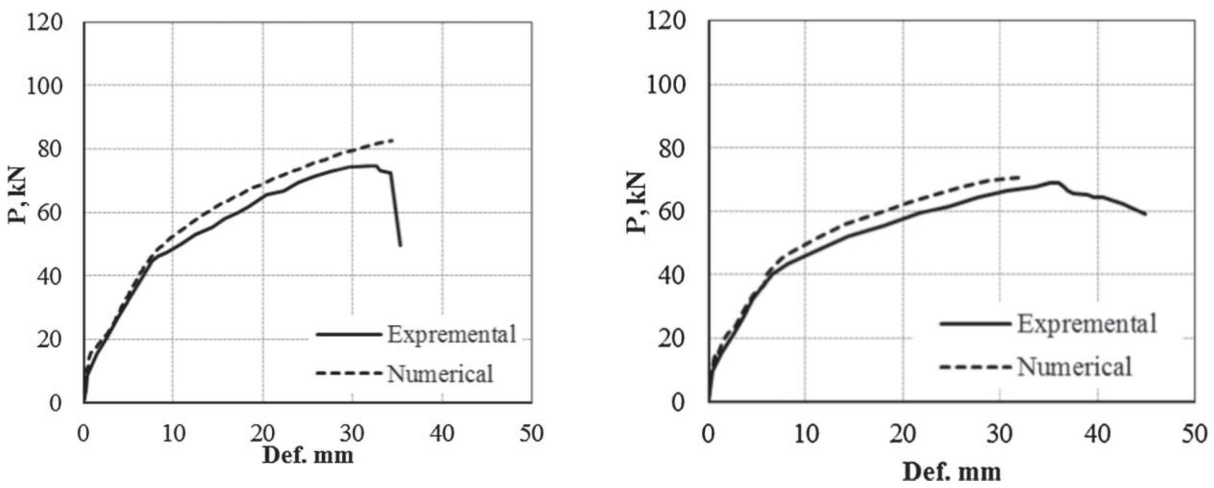
Fig. 2: Effect of bars length and end inclination angle on the strengthened beams [34].

(a)

(b)

Fig. 3: Beam details and grooves locations (units in mm) [34].

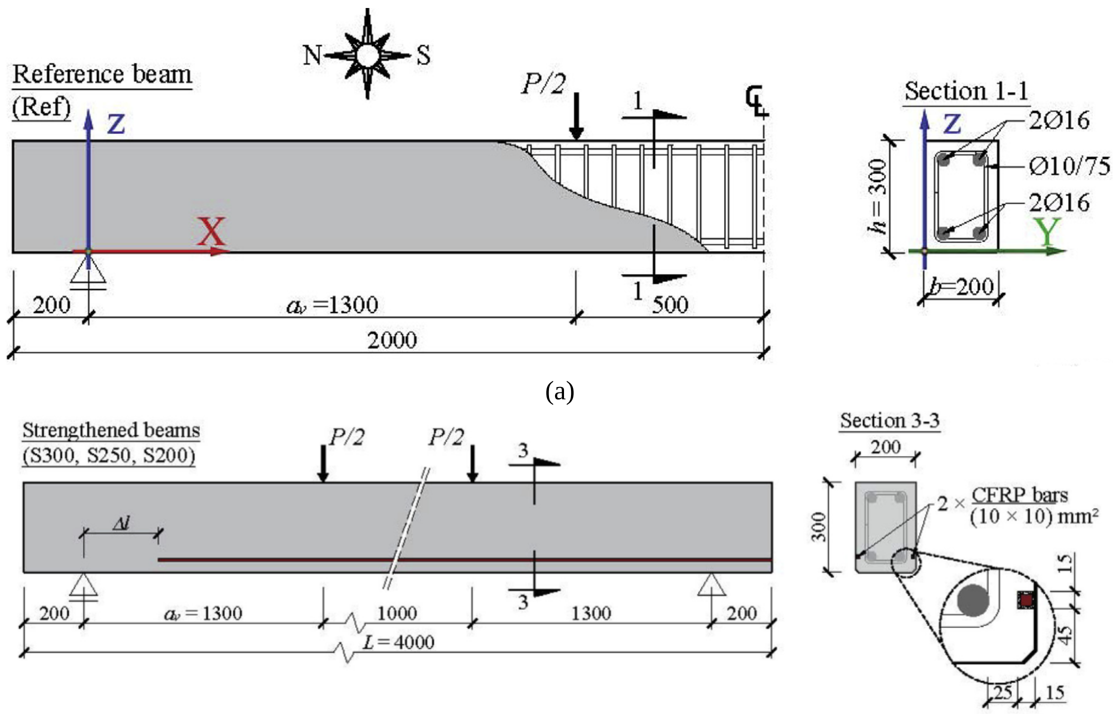
Sharaky et al. [34] simulate the strengthened beams using the FE program (ANSYS) [35], and compared the numerical results with the experimental results as shown in Fig. 4. Figures shows good agreement between the numerical and the experimental results from point of load deflection curves, load strain curves, strain distribution along the NSM bars [34].



(a) (b)

Fig. 4: The comparison between the numerical results with the experimental results; (a) S2-180/45 and (b) S2-140/45 [34].

Sabau et al. [36] studied experimentally and analytically the efficiency of the SNSM technique compared to BNSM with varied NSM CFRP bonded lengths to prevent concrete cover detachment (CCD). Seven RC beams were tested under four-point bending, all beams with a total length of 4000mm and a rectangular cross section of 200×300mm. The first beam was tested as a reference beam; the other six beams were strengthened using different FRP configurations as shown in Fig. 5. Beams S300, S250 and S200 refers to strengthened beams with SNSM technique with values of Δl equal to 300, 250 and 200mm, respectively, Δl is the distance from the beam's support and it is varied only at one end to produce a CCD [36].

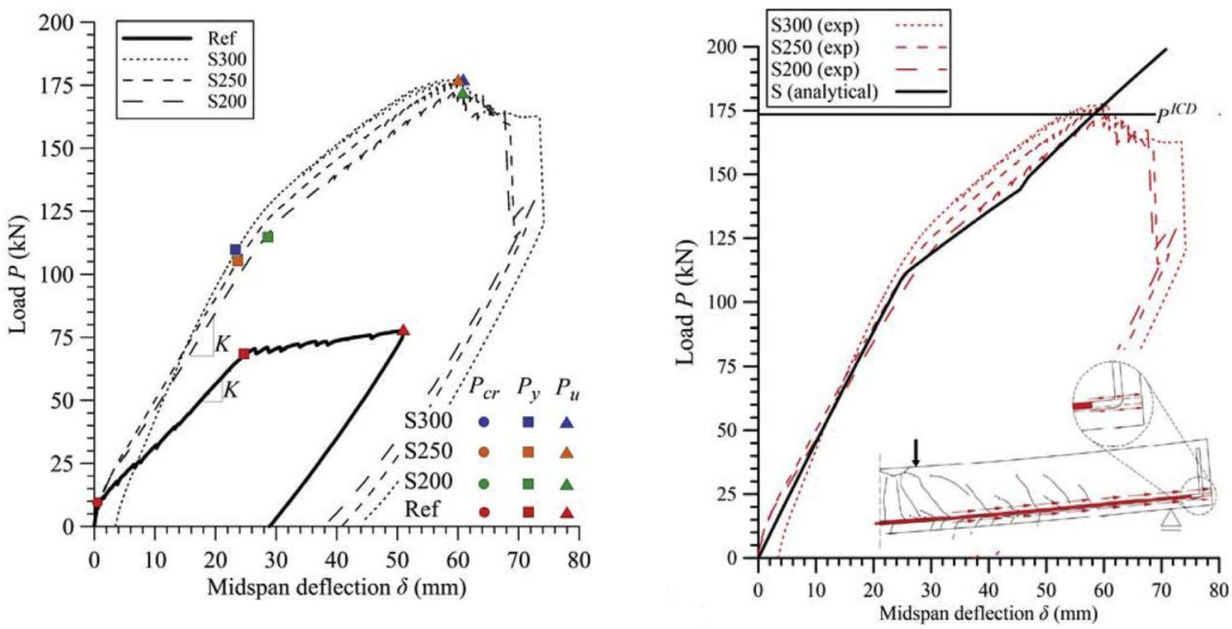


(a)

(b)

Fig. 5: Beams detail (units in mm); (a) Reference beam and (b) SNSM strengthened beam [36].

Load deflection curves of the tested beams and the comparison between the experimental and analytical results were illustrated if Fig. 6. As shown in figure SNSM strengthened beams exhibited a significant increase in the yield and ultimate load compared to the reference beam. The increase in yield load and ultimate load were 98 and 127% respectively. The ultimate load observed form the results were close together this mean that the difference in the anchorage lengths had no effect in ultimate load. Also the results showed good agreement between the experiential and the analytical results [36].



(a) (b)

Fig. 6: Load deflection curves of SNSM beams; (a) Load deflection curves of tested beams and (b) Experimental and analytical comparison for tested beams [36].

Abdallah et al. [37] conduct an experimental program to study the flexural performance of RC beams strengthened with CFRP bars using SNSM technique. The effect of CFRP strengthening length, position of CFRP bars and the type of filling material were studied. The CFRP strengthening length were 210 and 270cm, while the type of filling material used namely epoxy resin with 83 MPa compressive strength and 29.5 MPa tensile strength and mortar with 74.6 MPa compressive strength and 6.2 MPa tensile strength. Six beams of 3000mm total length and a rectangular cross-section of 150mm x 280mm. The longitudinal reinforcement consisted of two steel bars of 12mm diameter in tension and two steel bars of 6mm diameter in compression, steel stirrups of 6mm diameter at every 150mm were used [37].

Beams BC1(270-SR) and BC2(210-SR) were strengthened with CFRP bars placed at the same level of the steel reinforcement using epoxy resin as a filling material and CFRP strengthening length of 270 and 210cm respectively. While beams BC3(270-SM) and BC4(210-SM) were strengthening using the same CFRP strengthening length and CFRP bars position but using mortar as a filling material. Beam BC5(270 UR) was strengthened with CFRP strengthening length embedded in resin and placed above than steel level (20-mm higher than the longitudinal steel bars level) [37].

Fig. 7 shows the load deflection curves of the tested beams. The failure load of beams BC1(270-SR) and BC2(210-SR) were 116 and 106.4kN which represents an increase of 59.3% and 46.2% over the failure load of the control beam respectively, the beams fails due to crushing of brittle compressed concrete and concrete peeling-off in the maximum shear region as shown in Fig. 8. On the other hand, failure load of beams BC3(270-SM) and BC4(210-SM) were 106.0 and 94.1kN with an increase of respectively 45.6% and 29.3% over the failure load of the control beam, the failure mode of the beams were debonding failure between concrete and the filling material, the failure occurred at an earlier stage in beam BC4(210-SM) than in beam BC3(270-SM). We can conclude that; the CFRP bars worked more efficiently as an additional tensile reinforcement. Either increasing the CFRP bars length led to increase the failure load of the strengthened beam and helped to avoid non-conventional failure mode (peeling off) or delayed the debonding failure. Predicted analytical models showed excellent agreement with the experimental results [37].

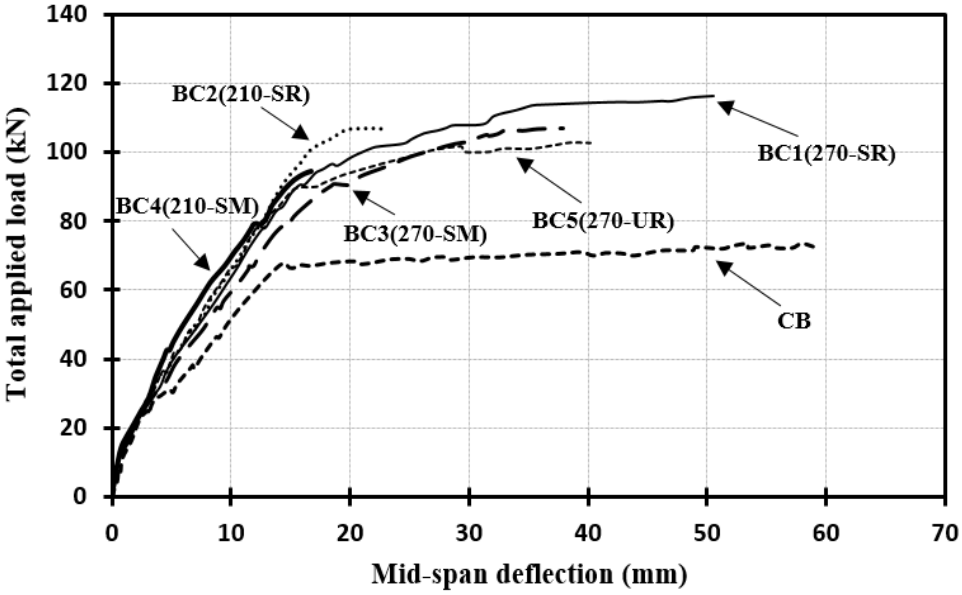


Fig. 7: Load-deflection curves of tested beams [37].

(a) (b)

Fig. 8. Failure mode of beams; (a) BC1(270-SR) and (b) BC2(210-SR) [37].

3. Strengthening materials Type

Hosen et al. [38] Studied experimentally and analytically the behavior of RC beams strengthened with side NSM technique using different FRP bars types such as steel, CFRP and different NSM reinforcement ratio. The tested beams had a dimensions of 250mm x 125mm, a total length of 2300mm and a shear span of 650 mm. The steel reinforcement consisted of two steel bars of 12mm diameter in tension and two steel bars of 10mm diameter in compression and 6mm in diameter for stirrups at every 50mm as shown in Fig. 9. Seven RC beams (control beam and six strengthened beams) were tested under four point bending conditions. Three beams strengthened with SNSM steel bars, the first with SNSM steel bars of 8m, the second with 10mm steel bar diameter and the third with 12mm steel bar diameter. The remaining three with the same SNSM bars diameters but with CFRP bars. Beams SNS8, SNS10 and SNS12 refers to strengthened beams with SNSM technique using NSM steel bars with diameter of 8, 10 and 12mm respectively. On the other hand, beams SNC8, SNC10 and SNC12 refers to strengthened beams with SNSM technique using NSM CFRP bars with diameter of 8, 10 and 12mm respectively [38].

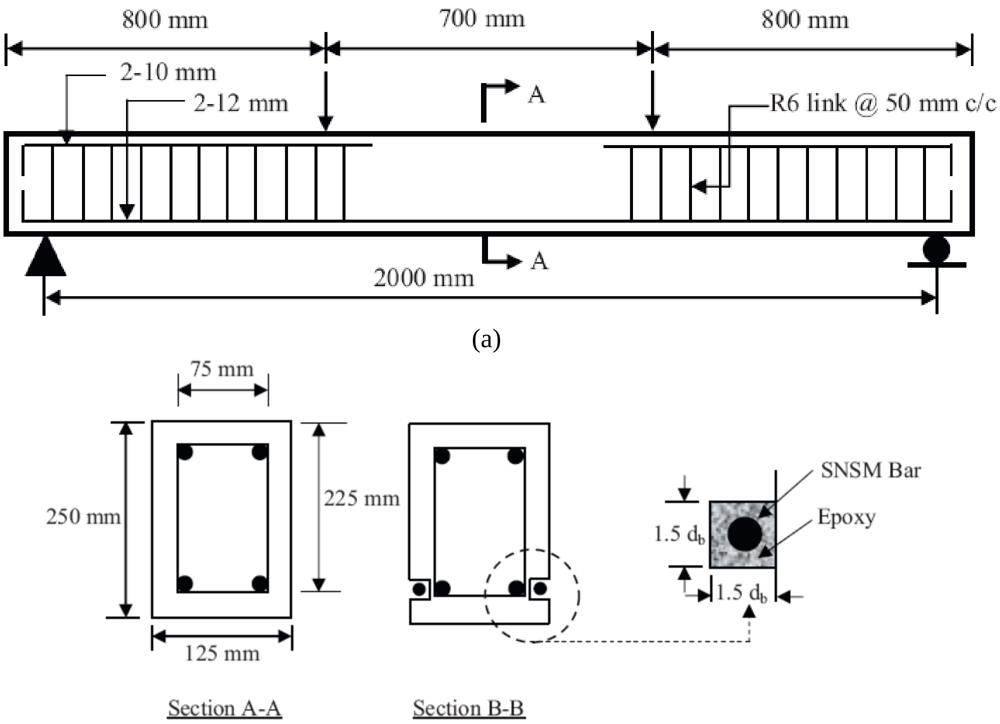


Fig. 9: Control and strengthened beam details; (a) Control beam and (b) Strengthened beam [38].

The load carrying capacities shows that the stiffness of the strengthened beams in the pre-cracking stage significantly influenced compared to control beam, a remarkable increasing in the first crack load by SNSM with steel bars compared with SNSM with CFRP bars. However, the yield and ultimate load of SNSM with CFRP bars higher than SNSM with steel bars as shown in Fig. 10. This is because of the higher tensile strength of the CFRP bars than the steel bars [38].

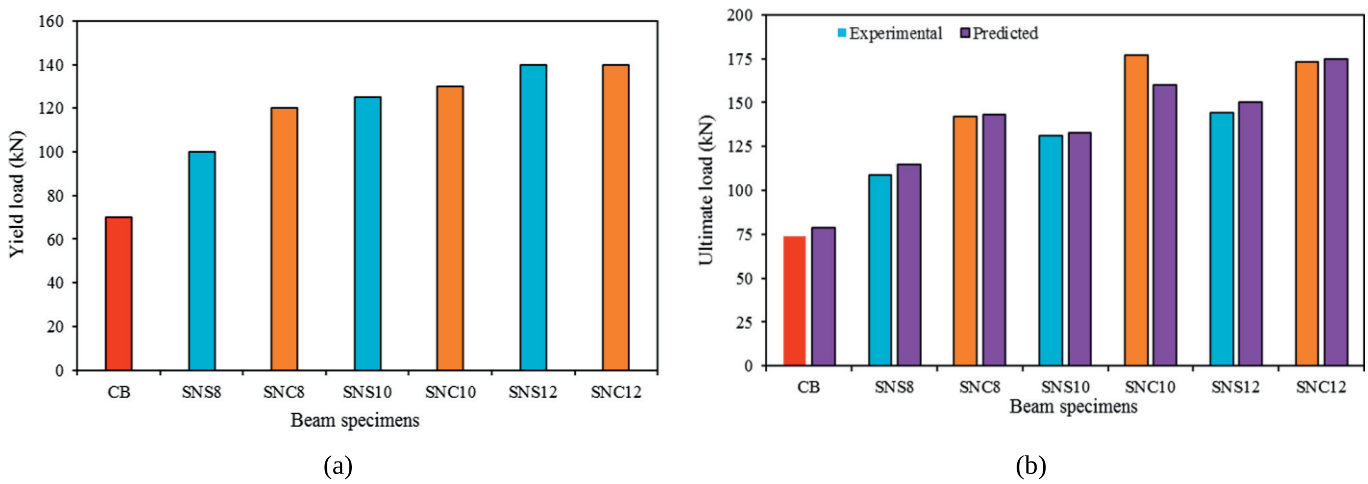


Fig. 10: Load carrying capacity for strengthened beams in different stages; (a) Yield load and (b) Ultimate load [38].

On the other hand, Fig. 11 shows load versus crack widths of the tested beams. The first crack loads of the CB, SNS8, SNS10, SNS12, SNC8, SNC10 and SNC12 were 15.75 kN, 34.70 kN, 35.00 kN, 50.00 kN, 30.00 kN, 30.50 kN and 31.80 kN, respectively. First crack loads for all beams were higher than that for the control beam. Consequently, the SNSM strengthening technique significantly increased the first crack load. The total number of cracks for the same beams were 11, 15, 19, 21, 16, 21 and 23, respectively, and the corresponding average crack spacing of each beam was 180 mm, 109 mm, 102 mm, 96 mm, 106 mm, 100 mm and 94 mm. Therefore, the SNSM strengthened with CFRP bars increased the number of the cracks and decreased the spacing of the cracks more than the

SNSM strengthened with steel bars. Furthermore, the beams strengthened by SNSM with CFRP bars gives higher stiffness than the beams strengthened by SNSM with steel bars, whereas the deflection of the beams strengthened by SNSM with CFRP bars was less than the deflection of the beams strengthened by SNSM with steel bars. The analytical models shows excellent agreement between the experimental results and predicted results [38].

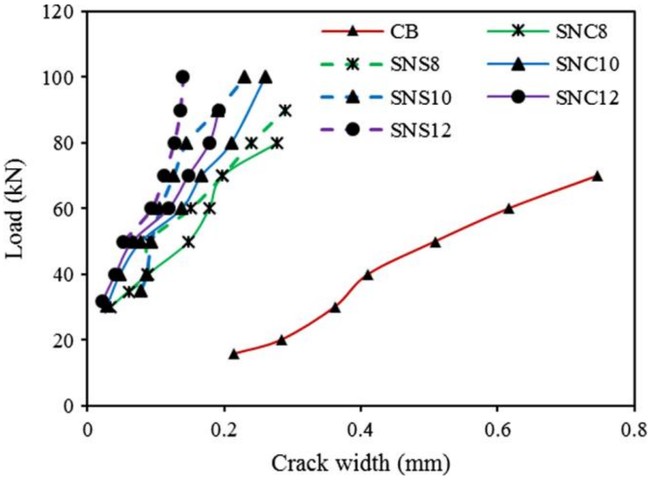
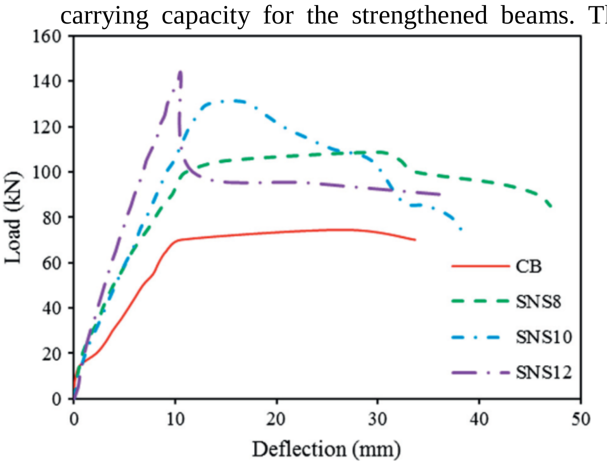


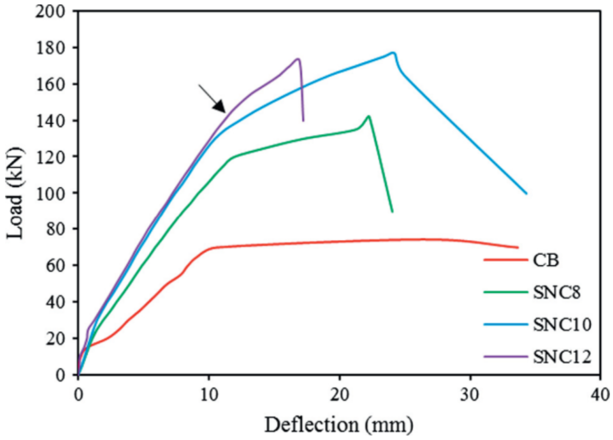
Fig. 11: Load–crack width [38].

4. Effect of Strengthening Diameter

The effect of SNSM strengthening bars diameter was studied by Hosen et al. [38] on the behavior of RC beams as shown in Fig. 12, the figure shows that in case of strengthening with NSM steel bars increasing the NSM bar diameter increase the load carrying capacity for the strengthened beams. The increasing in the load carrying capacity of the strengthened beams with steel bars of diameter 8, 10 and 12mm were 46, 76 and 93% respectively. On the other hand, the increasing in the load carrying capacity of the strengthened beams with CFRP bars of diameter 8, 10 and 12mm were 91, 138 and 133% respectively [38].



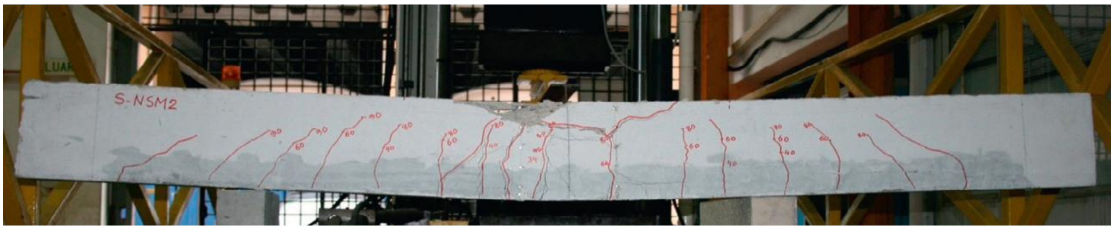
(a)



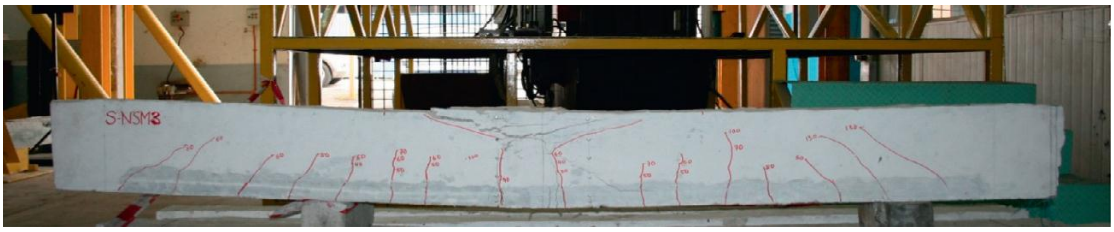
(b)

Fig. 12: Load deflection curve; (a) SNSM-steel beams and (b) SNSM-CFRP beams [38].

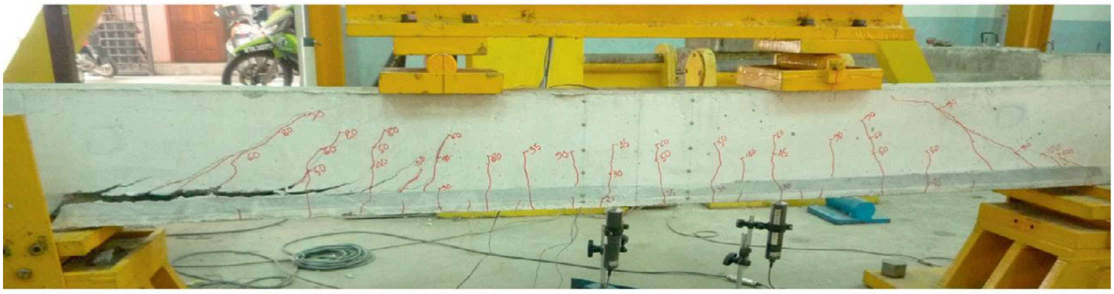
Fig. 13 shows the modes of failure of the tested beams. Beams strengthened with both NSM steel or CFRP bars with diameter 8, 10mm failed in flexure. Vertical cracks were developed when the applied load was increased. Concrete crushing failure occurred after yielding of the tension steel reinforcement and rupture of the SNSM reinforcement as shown in Fig. 13a and Fig. 13b. However, the strengthened beams with NSM bars diameter of 12mm failed through the SNSM bars peeling off, see Fig. 13c. After yielding of the internal main steel reinforcement was yielded then the shear crack initiated at the end of the SNSM bars, the SNSM bars peeled off after the shear stress exceeded the bond strength of adhesive. Excellent agreement between the experimental results and predicted results were concluded [38].



(a)



(b)



(c)

Fig. 13: Failure modes of tested beams; (a) SNS8, (b) SNS10 and (c) SNC12[38].

Shukri et al. [39] studied the behavior of pre-cracked RC beams while strengthening with the SNSM technique using NSM CFRP with three diameters; 8, 10 and 12mm. Seven RC beams were tested, the first was a control beam, the next three beams were non precracked strengthened beams and the remaining three beams were precracked strengthened beams, the beams dimensions and test instrumentation were the same which tested by Hosen et al. [38], see Fig. 9. Beams SNC8, SNC10 and SNC12 refers to non precracked strengthened beams with SNSM technique with NSM CFRP of diameter 8, 10 and 12mm respectively. Beams PSNC8, PSNC10 and PSNC12 refers to precracked strengthened beams with SNSM technique with NSM CFRP of diameter 8, 10 and 12mm respectively. Fig. 14 display the load deflection results of the tested beams [39].

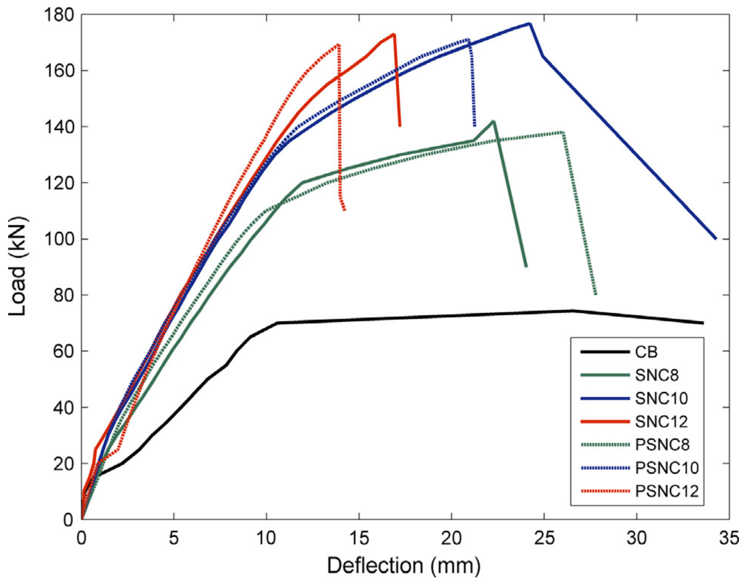


Fig. 14: load-deflection results [39].

From the point of the effect of NSM diameter on the behavior of pre-cracked RC beams, for all strengthened beams; the mid span deflection at failure (□max) gives a significant decrease compared to CB. The decrease in □max proportion to CFRP bar diameters. The beams strengthened with 12 mm CFRP bars showed a most severe reduction in □max which decreased in beam SNC12 and PSNC12 by 49.76% and 58.75% respectively. On the other hand, the pre-yield stiffness (Ke) of all SNSM strengthened beams were increased compared to the control beam, due to the high stiffness of the CFRP bars. The increase in Ke is directly proportional to the diameter of CFRP bars used. SNC8, SNC10 and SNC12 show Ke increase of 67.36%, 86% and 90.06% respectively. While PSNC8, PSNC10 and PSNC12 show Ke increase of 69.17%, 77.59% and 144.15% respectively. Furthermore, the load versus crack width of the tested beams (Fig. 15) clarify that the diameter of CFRP bar used controlling to the reduction of the crack width, for example, beam SNC12, has a much smaller crack width than SNC8 at the same load level, however the difference in crack width caused by the diameter of CFRP bar used more evident compared to the difference in crack width caused by precracking [39].

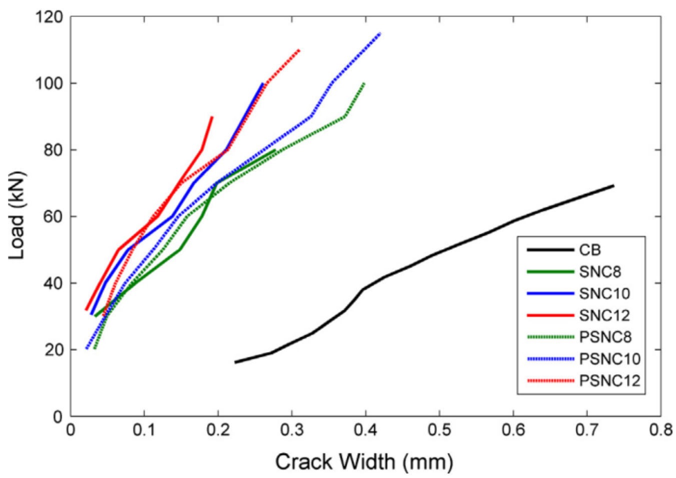
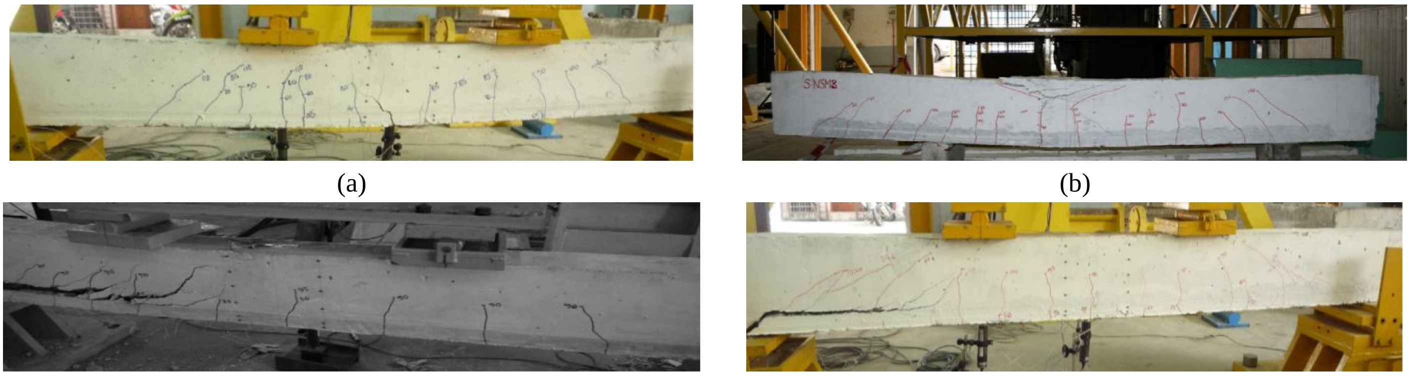


Fig. 15: Crack width of tested beams [39].

The failure modes of the RC beams are shown in Fig. 16. The non precracked and precracked beams strengthened with CFRP bars diameter of 8 and 10mm failed through flexure by means of rupture of the CFRP bars. On the other hand beams SNC12 and PSNC12 failed by concrete cover separation (experienced premature failure). Premature failure resistance is greatly reduced when the diameter of CFRP bar is increased to above 10mm, as seen in Fig. 16 [39].



(a) (b) (c) (d)

Fig. 16: Failure modes of tested beams; (a) PSNC8, (b) SNC10, (c) SNC12 and (d) PSNC12 [39].

5. Effect of the filling material

Abdallah et al. [37] Beams BC3(270-SM) and BC4(210-SM) which strengthened using mortar as a filling material failed due to debonding between the filling material and concrete substrate, whereas no signs of debonding failure were observed in beams BC1(270-SR) and BC2(210-SR) which strengthened using epoxy resin. This indicate that using epoxy resin as a filling material forms better bonding with concrete than using mortar [37].

6. Effect of end anchorage

Sharaky et al. [34] studied the effect of end anchorage on the behavior of RC beams strengthened and used different types of end condition such as straight and with end inclination angle of 45^0 and 90^0 as mentioned above, Fig. 2 shows the effect of the end inclination angle on the behavior of the strengthened beams [34]. The effect of the end anchorage was negative in the case of a comparison between beams strengthened with straight bars and beams strengthened with bent end bars, this may be due to the confinement surrounding the anchorage leg which was surface anchorage unlike the anchorage length in the bottom NSM strengthening technique which was embedded inside the confined portion of the beam. For this the author recommended to use the anchorage inside the beam rather than the anchorage on the beam surface. From Fig. 2 beams strengthened with NSM GFRP bars with end anchorage inclined by 90^0 gives higher load carrying capacity and stiffness than beams strengthened with NSM GFRP bars with end anchorage inclined by 45^0 . The strengthened beams with end inclination angle of 45^0 showed higher ductility compared to CB and strengthened beams with end inclination angle of 90^0 [34].

7. Effect of the strengthening bars/strips number

Ashteyat et al. [40] studied the effect of SNSM strengthening technique on the behavior of control and heat-damaged cantilever beams. L-shape reinforced SCC cantilever were heated at 400 °C and 500 °C for two hours and others left at laboratory temperature as a control beams. The beams were strengthened using single/ double SNSM CFRP strips located at 25 or 60 mm from the beams' top tension then tested under one point static loading at the fee end of the beams, see Fig 17. Increasing SNSM CFRP strips from one strip to two strips increase the load carrying capacity from 147% (compared to control beam) to 181% (compared to control beam) with increase of 34% in the case of the beams that have not been exposed to a high temperature. On the other hand in the beams which heated at 400 °C and 500 °C, increasing the strips number from one strip to two strips increase the load carrying capacity by 73 and 36% respectively. As expected, the use of double SNSM CFRP strips was the most efficient in increasing load capacity.

8. Effect of the strengthening position

Abdallah et al. [37] found that the yield and ultimate load of beam BC5(270-UR) were 83.2 and 102.7kN respectively, beam BC5(270-UR) was yielded before beam BC1(270-SR) which had yield and ultimate load of 90 and 116kN, the failure mode of the two beams were due to concrete crushing. The maximum tensile strain on CFRP bars was 0.0041mm/mm which represents about 32% of ultimate strain of the CFRP (40.6% lower than the maximum measured strain of CFRP bars in beam BC1(270-SR)). So, the slight reduction in the yield and ultimate load of beam BC5(270-UR) compared with beam BC1(270-SR) was due to the additional tensile stress above the steel bars level caused by placing CFRP bars above the steel reinforcement bars, this led to decrease the effective moment arm of the tensile reinforcement (steel and CFRP bars) within the beam cross section and reduce the beam ductility [37].

Ashteyat et al. [40] studied either the effect of the position or location of the SNSM CFRP strips on the behavior of the strengthened beams. The use of SNSM CFRP strips near the tension side of the beam (at 25 mm from the beam tension side) helps averting concrete cover peeling off prior to flexural failure. The benefit of inserting the SNSM CFRP strips at a shallow distance of 25 mm from the tension side with regard to the moment resisting arm for the strips was undermined by the premature concrete cover separation.

9. Effect of spacing between NSM bars, prestress level of FRP and longitudinal reinforcement ratio

Zhu et al. studied experimentally the effect of CFRP spacing, prestress level of CFRP and longitudinal reinforcement ratio on the flexural behavior of RC beams [41], and flexural fatigue behavior of RC beams [42]. Nine RC beams strengthened with SNSM CFRP strips, all details of the tested beams and strengthening were shown in Fig. 18 and Fig. 19. The strengthened beams were loaded to 80% of yield load, then slowly unloaded to initial state and stabled for a period of time before strengthened in order to simulate the actual stress condition of RC beams. The strengthened beams consisted of two series based on the reinforcement ratio; R1 which had a longitudinal tensile steel bars diameter of 20mm and R2 with longitudinal tensile steel bars diameter of 25mm. Beams R1-SB-1, R1-SB-2 and R1-SB-3 refers to beams with reinforcement ratio of 0.56% and spacing of longitudinal CFRP strips equal 50, 100 and 150mm respectively. Beams R2-PSB-1, R2-PSB-2 and R2-PSB-3 refers to beams with reinforcement ratio of 0.88% and prestress level of CFRP equal 0, 15 and 30% respectively. An analytical model based on sectional analysis and the strain compatibility was employed to determine the flexural behavior of the strengthened beams with SNSM CFRP [41].

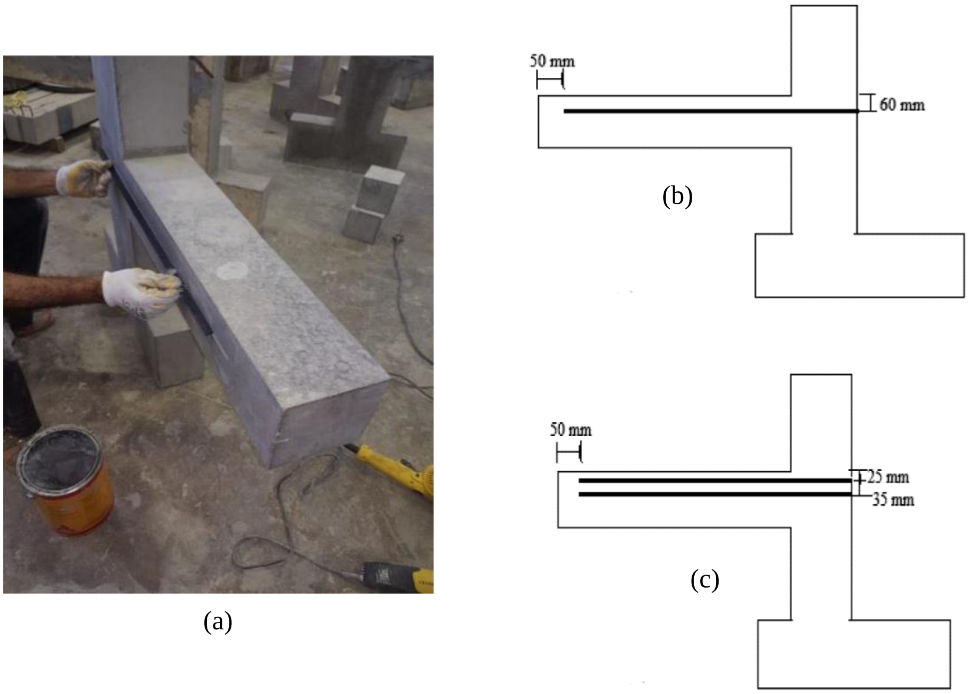


Fig. 17: Strengthening configuration; (a) strengthened beam, (b) strengthened beam using single SNSM strip at distance 60 mm and (c) strengthened beam using double SNSM strips at distance 25 mm [40].

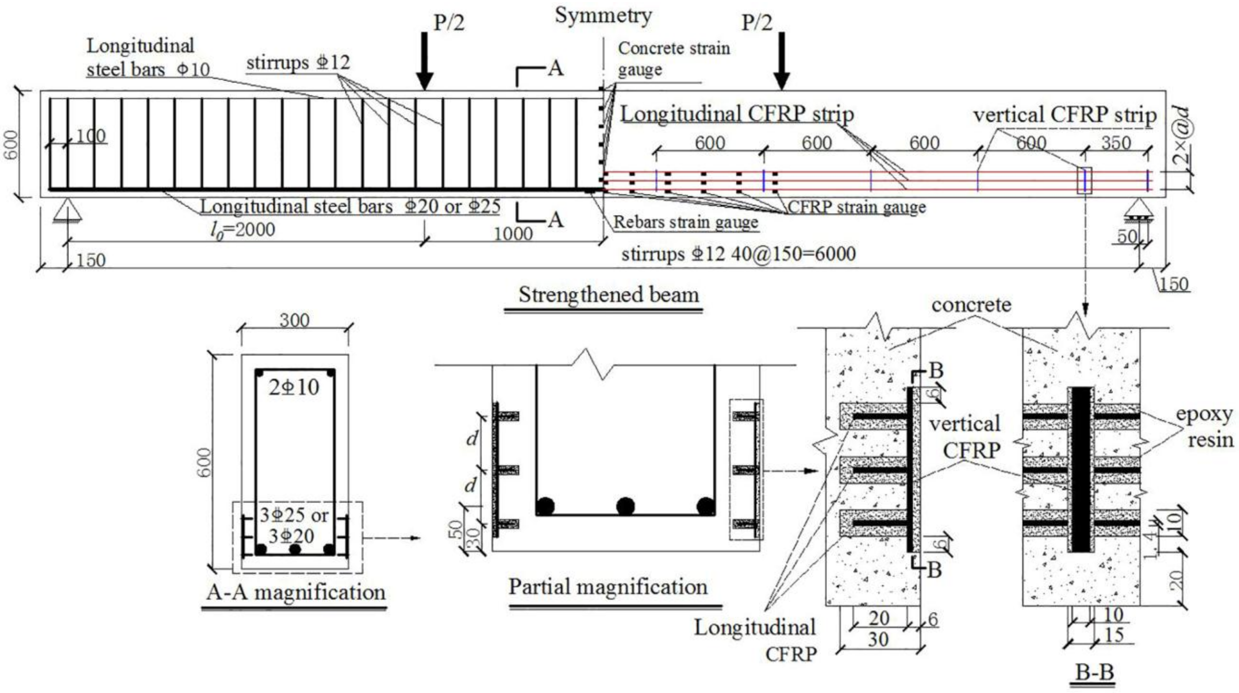
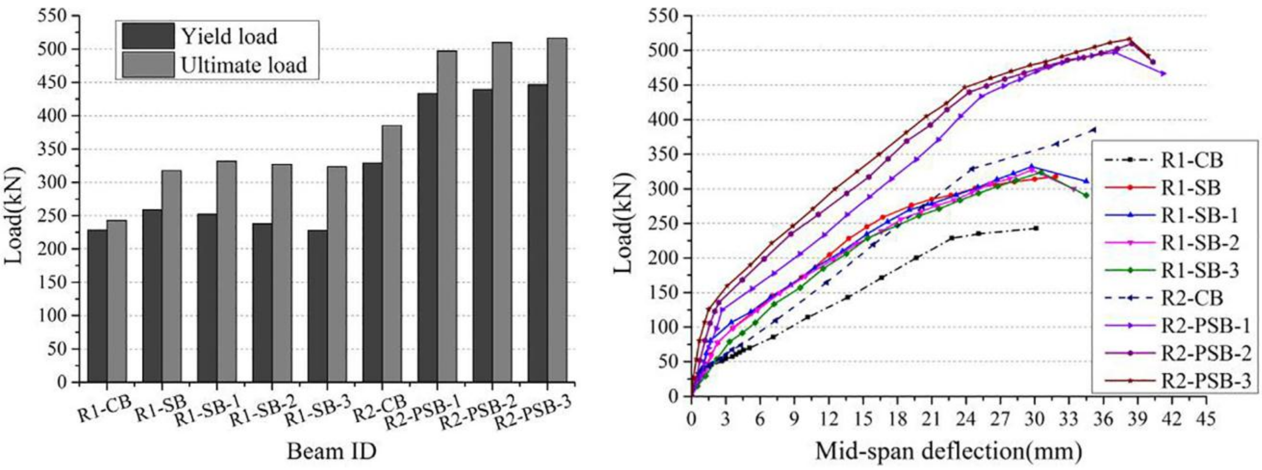


Fig. 18: Strengthened beam details (units in mm) [41].

(a) (b)

Fig. 19: Test setup and strengthening locations; (a) Mounted CFRP and filled epoxy in the groove and (b) Test load [41].

Fig. 20a represent yield and ultimate load and Fig. 20b represent the load-deflection curve of the strengthened beams. Its noted that the ultimate load of all strengthened beams were clearly increased compared to that of un-strengthened beam, the average value of ultimate load were increased by 34.0% and 31.7% for series R1 and R2 respectively. The ultimate load of non-prestressed strengthened beams R1-SB-1, R1-SB-2 and R1-SB-3 were increased by 37%, 35% and 33%. That means the ultimate load of non-prestressed strengthened beams increased with the reduction of longitudinal CFRP spacing. While the ultimate load of prestressed strengthened beam R2-PSB-2 and R2-PSB-3 had increased by 32% and 34% respectively, which mean that the ultimate load of prestressed strengthened beams were enhanced with the increase of longitudinal CFRP prestress level. The ultimate load of strengthened beams R2-PSB-1and R1-SB-1 were respectively by 29% and 31%, which showed that the longitudinal reinforcement ratio had a negative effect on the strengthened beam's bearing capacity for the large size high strength beams [41].



(a) (b)

Fig. 20: Tested beam results; (a) Comparison of yield load and ultimate load and (b) Load versus mid-span deflection [41].

On the other hand the stiffness of prestressed strengthened beams were clearly larger than the non-prestressed strengthened beams compared to the reference beam, the deflection of the non-prestressed and prestressed strengthened beam was increased by 14.6% and 11.75% respectively, which showed an improvement in the stiffness and ductility of the strengthened beam. The use of CFRP strips for all strengthened beams was very effective, especially for prestressed strengthened beams, which indicated that the strengthening using SNSM technique was suitable for large size high strength RC beams. The analytical prediction values of load-deflection were in good agreement with the experimental values [41]. Zhu et al. [42] concluded that the fatigue failure did not occur when they were subjected to a predetermined number of fatigue cycle loading. After 2.5 million fatigue cycle loading, the residual flexural capacity and residual stiffness of un-strengthened beams were lower than those of strengthened beams, which were subjected to 2 million fatigue cycle loading. In addition, the flexural capacity and stiffness of the fatigue test beams were significantly lower than those of the static test beams; the fatigue resistance of strengthened beams with the SNSM prestressed CFRP was superior to that of the strengthened beam with non-prestressed CFRP; the fatigue resistance of the fatigue test beams was better after being strengthened [42].

10. Effect of Pre-cracking of strengthened beams

Shukri et al. [39] studied the behavior of pre-cracked RC beams strengthened with SNSM strengthening technique. As shown in Fig. 14, precracked SNSM strengthened beams increased the beams stiffness by up to 28.4% and reduced ultimate load by up to 3.3% compared to non precracked SNSM strengthened beams. For all strengthened beams the mid span deflection at failure (□max) gives a significant decrease compared to CB. Precracking was found to cause the □max of PSNC10 and PSNC12 to be slightly lower in comparison with SNC10 and SNC12. PSNC8 on the other hand have a slightly higher □max if compared with SNC8. On the other hand, the pre-yield stiffness (Ke) of all SNSM strengthened beams were increased compared to the control beam, due to the high stiffness of the CFRP bars. The pre-cracked beams show higher Ke compared to the equivalent non precracked beams, with the exception of PSNC10 which has a Ke value that is less than that of SNC10. On the other hand load-crack width curve (Fig. 15) clarify that; SNSM strengthening technique reduced the crack width compared to the control beam CB. The figure shows that the crack width of non precracked SNSM strengthened beams is smaller than the equivalent precracked SNSM strengthened beams [39].

Conclusions

This paper reviews currently available research of SNSM strengthening technique of RC members. This review covers basic information on the effect of NSM strengthening bar length, strengthening materials type, strengthening diameter, effect of filling material, effect of end anchorage, strengthening position, effect of spacing between

NSM bars, prestress level of FRP, longitudinal reinforcement ratio and effect of pre-cracking of strengthened beams. From the studies reviewed in this paper the following conclusions can be drawn:

- Side Near Surface Mounted (SNSM) technique can be used as an alternative to the Bottom Near Surface Mounted (BNSM) technique, also it can be used to improve the flexural performance of RC beams, Furthermore, strengthened beams with SNSM technique show higher ductility behavior if compared to the BNSM beams.
- Strengthening using SNSM technique was suitable for large size high strength RC beams
- SNSM CFRP bar length had a considerable enhancement on the ultimate load carrying capacity, failure mode and energy absorption capacity.
- Strengthening with SNSM technique using either steel or CFRP or GFRP bars gives significantly enhancement in the flexural capacity of the RC beams. Strengthened beams by SNSM with CFRP bars showed higher flexural strength and stiffness than that Strengthened by steel bars.
- Increasing the diameter of the strengthening FRP reinforcement increasing the first cracking load, yield load and ultimate load.
- Using epoxy resin as a filling material introduce better bonding with concrete than using mortar and delay the failure due to concrete cover separation
- The position of SNSM strengthening FRP bars placed in the same level of the main steel reinforcement bars make better resisting action to the flexural behavior and ductility than that placed above than the main steel level because it create a new tensile stress level, which consequently caused the cracks to widen further and therefore to expand upwards.
- Increasing SNSM strengthening strips number had a noticeable enhancement in load carrying capacity.
- The stiffness of non-precracked SNSM strengthened RC beams was less than the stiffness of precracked SNSM strengthened RC beams by up to 28.4%.
- The failure modes of the strengthened beams with SNSM strengthening technique were not affected by precracking.

References

[1] Z. Wu, X. Wang, K. Iwashita, "State-of-the-Art of Advanced FRP Applications in Civil Infrastructure in Japan", Composites & Polycon, American Composites Manufacturers Association, Tampa, FL USA, pp. 1-13, 2007.

[2] L.D. Lorenzis, J.G. Teng, "Near-surface Mounted FRP Reinforcement: An Emerging Technique for Strengthening Structures", Composites Part B, Vol. 38, pp. 119-143, 2007.

[3] A. Laraba, A. Merdas, N. Chikh, "Structural Performance of RC Beams Strengthened with NSM-CFRP", Proceedings of the World Congress on Engineering, II, pp. 958-966, 2014.

[4] H.M. Tanarslan, "The effects of NSM CFRP reinforcements for improving the shear capacity of RC beams", Construction and Building Materials, Vol. 25(5), pp. 2663-2673, 2011. doi:10.1016/j.conbuildmat.2010.12.016.

[5] F.A. Fathelbab, M.S. Ramadan, A. Al-Tantawy, "Strengthening of RC bridge slabs using CFRP sheets", Alexandria Engineering Journal, Vol. 53(4), pp. 843-854, 2014. doi:10.1016/j.aej.2014.09.010.

[6] D.A. Bournas, A. Pavese, W. Tizani, "Tensile capacity of FRP anchors in connecting FRP and TRM sheets to concrete", Engineering Structures, Vol. 82, pp. 72-81, 2015. doi:10.1016/j.engstruct.2014.10.031.

[7] U. Berardi, N. Dembsey, "Thermal and Fire Characteristics of FRP Composites for Architectural Applications. Polymers", Vol. 7(11), pp. 2276-2289, 2015. doi:10.3390/polym7111513.

[8] A. Remennikov, M. Goldston, M. Neaz Sheikh, "Impact performance of concrete beams externally bonded with carbon FRP sheets", Mech. Struct. Mater. Adv. Challenges - Proc. 24th Australas. Conf. Mech. Struct. Mater. ACMSM24 2016, 2017, pp. 1695-9.

[9] L. Sorrentino, S. Turchetta, C. Bellini, "In process monitoring of cutting temperature during the drilling of FRP laminate", Composite Structures, Vol. 168, pp. 549-561, 2017. doi:10.1016/j.compstruct.2017.02.079.

[10] J. Huo, Z. Li, L. Zhao, J. Liu and Y. Xiao, "Dynamic Behavior of CFRP-Strengthened Reinforced Concrete Beams without Stirrups under Impact Loading". ACI Structural Journal, Vol. 115, pp. 775-87, 2018. doi:10.14359/51701283.

[11] Y. Ou, D. Zhu, "Tensile behavior of glass fiber reinforced composite at different strain rates and temperatures", Construction and Building Materials, Vol. 96, pp. 648-56, 2015.doi:10.1016/j.conbuildmat.2015.08.044.

[12] J.T. Mottram, "Does performance-based design with FRP components and structures provide any new benefits and challenges", Structural Engineering, Vol. 89, pp. 23-7, 2011.

[13] A. Belarbi, B. Acun, "FRP Systems in Shear Strengthening of Reinforced Concrete", Structures. Procedia Engineering, Vol. 57, pp. 2-8, 2013. doi:10.1016/j.proeng.2013.04.004.

[14] B.H. Osman, E. Wu, B. Ji and S.S. Abdulhameed, "Repair of Pre-cracked Reinforced Concrete (RC) Beams with Openings Strengthened Using FRP Sheets Under Sustained Load. International Journal of Concrete Structures and Materials", Vol. 11(1), pp. 171-183, 2017. doi:10.1007/s40069-016-0182-3.

[15] W. Ferdous, A.D. Almutairi, Y. Huang and Y. Bai, "Short-term flexural behaviour of concrete filled pultruded GFRP cellular and tubular sections with pin-eye connections for modular retaining wall construction", Composite Structures, Vol. 206, pp. 1–10, 2018. doi:10.1016/j.compstruct.2018.08.025.

[16] A. Bilotta, F. Ceroni, E. Nigro and M. Pecce, "Efficiency of GFRP NSM strips and EBR plates for flexural strengthening of RC beams and loading pattern influence", Composites Structures, Vol. 124, pp. 163-175, 2015.

[17] American Concrete Institute ACI 440. (2017), "Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures", MI, USA: Farmington Hills; (ACI 440.2R-17).

[18] S.S. Zhang, T. Yu, G.M. Chen, "Reinforced concrete beams strengthened in flexure with near-surface mounted (NSM) CFRP strips: Current Status and Research needs", Composites Part B, Vol. 131, pp. 30-42, 2017.

[19] S.S. Zhang, "Bond strength model for near-surface mounted (NSM) FRP bonded joints: Effect of concrete edge distance", Composite Structures, Vol. 201, pp. 664-675, 2018.

[20] H. Akbarzadeh, A.A. Maghsoudi, "Experimental and analytical investigation of reinforced high strength concrete continuous beams strengthened with fiber reinforced polymer", Materials and Design, Vol. 31(3), pp. 1130-1147, 2010.

[21] Y. Zhou, M. Gou, F. Zhang, S. Zhang and D. Wang, "Reinforced concrete beams strengthened with carbon fiber reinforced polymer by friction hybrid bond technique: experimental investigation", Materials and Design, Vol. 50, pp. 130-139, 2013.

[22] I.M. Qeshta, P. Shafigh, M.Z. Jumaat, A.I. Abdulla, Z. Ibrahim and U.J. Alengaram, "The use of wire mesh–epoxy composite for enhancing the flexural performance of concrete beams", Materials and Design, Vol. 60, pp. 250-259, 2014.

[23] N. Attari, S. Amziane, M. Chemrouk, "Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheets", Construction and Building Materials, Vol. 37, pp. 746- 757, 2012.

[24] I.A. Sharaky, L. Torres, M. Baena and I. Vilanova, "Effect of different material and construction details on the bond behaviour of NSM FRP bars in concrete", Construction and Building Materials, Vol. 38, pp. 890-902, 2013.

[25] J.S. Cruz, J. Barros, "Modeling of bond between near-surface mounted CFRP laminate strips and concrete", Computers & Structures, Vol. 82 (17), pp. 1513-1521, 2004.

[26] J.A. Barros, D.R. Ferreira, A.S. Fortes and S.J. Dias, "Assessing the effectiveness of embedding CFRP laminates in the near surface for structural strengthening", Construction and Building Materials, Vol. 20(7), pp. 478-491, 2006.

[27] D. Novidis, S.J. Pantazopoulou, E. Tentolouris, "Experimental study of bond of NSM-FRP reinforcement", Construction and Building Materials, Vol. 21 (8), pp. 1760-1770, 2007.

[28] H. EL-Emam, A. El-Sisi, R. Reda, M. Seleem and M. Bneni, "Effect of concrete cover thickness and main reinforcement ratio on flexural behavior of RC beams strengthened by NSM-GFRP bars", Frattura ed Integrità Strutturale, Vol. 52, pp. 197-212, 2020.

[29] R.M. Reda, O. Zeinab, H.E.M. Sallam and S. E. A. Seleem, "Effect of different parameters controlling the flexural behavior of RC beams strengthened with NSM using nonlinear finite element analysis", Frattura ed Integrità Strutturale, Vol. 53, pp. 106-123, 2020.

[30] H. EL-Emam, A. El-Sisi, M. Bneni, M. Seleem and H.E.M. Sallam, "Effects of tensile reinforcing steel ratio and Near-Surface Mounted bar development length on the structural behavior of strengthened RC beams", in press.

[31] N.T.K. Al-Saadi, A. Mohammed, R. Al-Mahaidi and J. Sanjayan, "A state-of-the-art review: Near surface mounted FRP composites for reinforced concrete structures", Construction and Building Materials, Vol. 209, pp. 748-769, 2019.

[32] A. Siddika, M.D.A. Al Mamun, W. Ferdous and R. Alyousef, "Performances, challenges and opportunities in strengthening reinforced concrete structures by using FRPs – A state-of-the-art review", Engineering Failure Analysis, Vol. 111, (2020), 104480.

[33] T.K. Hassan, S.H. Rizkalla, "Bond mechanism of near surface mounted fiber reinforced polymer bars for flexural strengthening of concrete structures", ACI Structural Journal, Vol. 6, pp. 830-839, 2004.

[34] I.A. Sharaky, R.M. Reda, M. Ghanem, M.H. Seleem and H.E.M. Sallam, "Experimental and numerical study of RC beams strengthened with bottom and side NSM GFRP bars having different end conditions", Construction and Building Materials, Vol. 149, pp. 882-903, 2017.

[35] ANSYS – release version 11, "A finite element computer software theory and user manual for nonlinear structural analysis", ANSYS, Inc. Canonsburg, PA, 2007.

[36] C. Sabau, C. Popescu, G. Sas, J.W. Schmidt, T. Blanksvärd and B. Täljsten, "Strengthening of RC beams using bottom and side NSM reinforcement", Composites Part B, Vol. 149, pp. 82-91, 2018.

[37] M. Abdallah, F. Al Mahmoud, R. Boissière and A. Khelil, J. Mercier, "Experimental study on strengthening of RC beams with Side Near Surface Mounted technique-CFRP bars", Composite Structures, Vol. 234, 15 February (2020), 111716.

[38] M.A. Hosen, M.Z. Jumaat and A.B.M. Saiful Islam, "Side Near Surface Mounted (SNSM) technique for flexural enhancement of RC beams", Materials & Design, Vol. 83, pp. 587-597, 2015.

[39] A.A. Shukri, M.A. Hosen, M.A.R. Muhamad and M.Z. Jumaat, "Behaviour of precracked RC beams strengthened using the side-NSM technique", Construction and Building Materials Vol. 123, pp. 617-626, 2016.

[40] A.A. Ashteyat, R. Haddad and Y.T. Obaidat, "Repair of heat-damaged SCC cantilever beams using SNSM CFRP strips", Structures Vol. 24, pp. 151-162, 2020.

[41] Z. Zhu, E. Zhu, "Flexural behavior of large-size RC beams strengthened with side near surface mounted (SNSM) CFRP strips", Composite Structures Vol. 201, pp. 178-192, 2018.

[42] Z. Zhu, E. Zhu, Y. Ni and D. Li, "Flexural fatigue behavior of large-scale beams strengthened with side near surface mounted (SNSM) CFRP strips", Engineering Structures, Vol. 180, pp. 134-147, 2019.