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STRENGTHENING OF REINFORCED CONCRETE MEMBERS BY USING FRP TECHNIQUES: REVIEW

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Abstract

This review discusses the properties of different materials that are used to strengthen the reinforcement concrete members by using developed and classical materials. Frequently, steel-reinforced material and fiber reinforced polymer (FRP) material are used to increase the strength of concrete members. Also, the Near-surface mounting technique for increasing the strength of concrete members is discussed. At the serviceability, the Near-surface mounting techniques have given an acceptable result for increment in applied load and increased the stiffness of concrete members after cracking.

Keywords: Concrete, shear strength, NSM technique, FRP, and Composite Beam.

1. Introduction

It's known that if the load is increased on structural members, it will necessarily increase the strength of members sections. The design function of structure is changed; the applied load to the structure may be changing too, besides the members require additional reinforcement. Then, the increase in members' strengths necessary when the structure is subjected to deterioration, corrosion, and environmental conditions. Concrete members must be increasing in strength if any of these reasons occurred as follows:

- i- When the live loads are increased, wheel load is increased, and structure subject to vibration due to installations machinery
- ii- Some structural members are subjected to be damaged due to the corrosion of materials or fire and/or vehicle impact.
- iii- Improvement or increasing in structure suitability like deflections, shear, rotation, and cracks.
- iv- change in the structural function of buildings such as remove some of columns, walls or make a gap in the slab.
- v- construction or planning errors due to insufficient dimensions or shortage in steel reinforced.

Steel reinforced is the classic material that is used to increase the strength of concrete members. however, the steel is weak resistance against corrosion and the fact of weight and handling are most likely considered a problem. These are the causes which make the engineering researchers to find alternative materials. One of the alternative materials is Fiber-reinforced polymer (FRP) which has good specifications for instance lightweight, no corrosion, good fatigue, and high strength. It's used to be qualified in the treatment, repair, and strengthening of concrete members. The use of FRP for the first time is in 1990 to increase the resistance of concrete members. Currently FRP technology is widely used.

Upon the Second World War, the researchers develop FRP to be used on/in other sides/application and it's not an innovation. Currently the cost and the quality of FRP are improved respectively and using in various applications [**1**]. Further to that the pultrusion technology is widely utilized and gives the engineering designer and manufacturer more possibilities to fabricate elements with different shapes and forms. The use of beam, wall, column, and slab can be improved. Many researchers investigate the design and analysis of FRP beam, slab and other elements such as Kalyanaraman, Upadyay, and Qiao et **al [1]**

For a decade since 1990 till 2000, concrete and steel are replaced by FRP materials to increase the strength of concrete members, (ACI 2002 and FIB 2001). FRP has many forms in made such as one-directional strips or sheets in one or two directions. Glass (G) and Carbon (C) are the major material of fibers GFRP and CFRP and the epoxy is used to the adhesive in the matrix state. Wet lay-up (fabric and sheet) and prefabricated strip (designated by laminates) are the major material of FRP that are used to increase the strength systems in the market. The light weight, high durability, high tensile resistance, permeability electromagnetic, easy installation and availability in many sizes and geometry of FRB Lead create a significant demand on CFRP or GFRP material to improve the structural strength (FIP 2001) **[2].**

2. FRP has diversity of advantages for instance [3]:

- a) lightweight
- b) Installation is very easy
- c) Durability is very high
- d) Tensile resistance is very high
- e) Deformation capacity is very large
- f) Electromagnetic permeability

g) Availability in many dimensions, geometry and size .
h) Corrosion is very low or Nonexistent.

3. Material (specifications or characteristic)

FRP material (Sheets or tendons) rely on a lot of factors such as what product is required and the country of origin. Therefore, some of FRP tendon's material properties shall be discussed in this review.
The main advantage of FRP tendon is light-weight and the high strength. The weight of the FRP tendon may be made as one-tenth of steel tendons. Both of FRP material and steel material have different characteristics, however the behavior is different when the load is applied. Table 1 illustrates a comparison between the material of steel, AFRP, CFRP, and GFRP. The main aim of Table 1 is to show the information between steel, AFRP, CFRP, and GFRP material for the readers. The characteristics of steel, AFRP, CFRP, and GFRP material are determined to the same manufacturer and these materials could be changed from one manufacturer to another. Thus, study must be conducted the different properties of material for a better use in the projects.

Table 1 FRP and steel tendons Characteristics, Pisani (1997) [4]

Typical properties	Steel	GFRP	AFRP	CFRP
Fiber volume Fraction (%)	-	65	50	65
Density(g/cm3)	7.85	2.15	1.25	1.6
Tensile strength (MPa)	1860	1500	1490	1840
Tensile modulus (GPa)	195	50	62	147
Ultimate elongation (%)	> 3.5	3.0	2.4	1.3
Thermal expansion coefficient, axial direction (10-6 / 0C)	12	5.2	-1.8	0.68
Thermal expansion coefficient, radial direction (10 / 0C)	12	~35	~35	~20
Strength decreases after a 100-year loading (%)	~0	30	35	~0
Relaxation, 200C (%)	3	4	>30	3

Experimentally, the relation between load-displacement of concrete beams and FRP reinforced has the same response for a beam with steel reinforced Mtsuyoshi (1991). CFRP tendons are cultured by using the linear oriented coal tar pitch-based and using the Fiber epoxy to resin (fu=1970 N/mm^2). In compression, GFRP tendons have the lowest tensile strength when it is compared with other FRP reinforcement, (fu=746 N/mm^2 C-Bar), (fu=692 N/mm^2 isopod). They have many advantages such as low cost, non-corrosive, natural magnetically, and high strength. The average compressive strength of concrete cylinder that are used in beams at (30 N/mm^2 to 35 N/mm^2) in the experimental, with the aggregate size has less than 13 mm. Steel reinforcement grade is 400 (fy = 435 N/mm^2) Figure **(1) [5].**

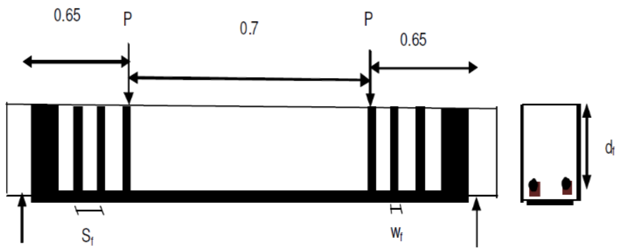


Fig.1 Strengthen by Steel Plate

The strengthening technique depends on the surface of members that need to be strengthened and classified as a technique of externally bonded reinforcement (EBR). It is the most common technique is applied presently. Most research explain that the technique of EBR can't mobilize the tensile resistance of FRP material because of premature deboning (Swamy and Mukhopadhyaya 2001, Nguyen 2001). FRP reinforcement performance can be diminished because of the influence of thaw/ freeze cycles (Balaguer and Toutanji 1998) and significantly decreased while applying low or high temperatures (Pantuso 2000). Likewise, the externally bonded reinforcement (EBR) system is subjected to be damaged due to mechanical malfunctions and vandalism **[2].**

Near-surface mounted (NSM) Strengthening uses a new technique to overcome the disadvantages in the externally bonded reinforcement aforementioned. This technique depends on the bonding between carbon or glass FRP tendons into concrete grooves that are opened in the cover of members need to strengthen ((De Lorenzis 2000). However, the NSM technique is not new that it is used in the Europe in 1940s for a first time to increase the strength of reinforced concrete members. This commands technique Consisting of putting the tendons in grooves located in concrete beam cove. The grooves fill up with cement mortar after putting tendons (Asplund 1949). Currently the steel bars reinforcement can be replaced with FRP tendons and the cement mortar should be replaced with an epoxy adhesive. NSM technique is used in more applications and has several benefits that point out, namely, high strengthening levels, decreases in the mechanical damages, aging effects acts of vandalism and fire when compared with externally bonded reinforcement (EBR) (Warren 1998, Alkhrdaji 1999, Hogue 1999, Tumialan 1999, Warren 2000, Emmons 2001, Carolin and Täljsten 2001, De Lorenzis 2002, Täljsten 2003) **[2].**

4. NSM technique for Reinforcement concrete Structures.

According to the NSM technique, the FRP reinforcement tendons or sheets putting into grooves in the cover of concrete members in the tension region and then bonded the groove by using cementations grout or high-strength epoxy adhesive (Carolin and Täljsten, 2001). In recent years, the NSM technique has attracts extensive type of researches (Nanni and Lorenzis, 2001; Lorenzis, 2002; Nanni and Lorenzis, 2002; Lorenzis, 2004; Lorenzis, 2000, 2004; Novidis, 2007; Lorenzis, 2000; Taljsten, 2003; Rizkalla and El- Hacha, 2004; Teng and Lorenzis, 2007; Al-Mahmoud, 2007; Kreit, 2008). The depth of grooves in the concrete covers is applied to control the Configuration FRP tendons in the Near surface mounted technique (Rizkalla and El-Hacha, 2004). The FRP reinforced bar should be protected against vandalism, impact, wear, and mechanical damage. The near-surface mounted technique can provide a good fire resistance when the fire occurred (Rizkalla and El-Hacha, 2004) and decrease the cost of fire protection measures [21].

(Triantafillou, 1998) presents a fundamental concept of the use of Fiber Reinforced Polymers (FRP) that is to increase the strength of structures, With application examples, figure (2). The past studies and future studies of FRP strengthen and rehabilitation is documented in several journal articles (Taljsten, 1997, Thomas, 1998), conference proceedings (Betti and Meier, 1997; Rahman and Benmokrane, 1998; Keynote), and lectures (Neale and Labossiere, 1997; Maruyama, 1997) and record the test of using NSM reinforced tendon (De Lorenzi, 2000, Blaschko, 2001, Hassan and Rizkalla, 2001 and Nanni, 2001) [6].

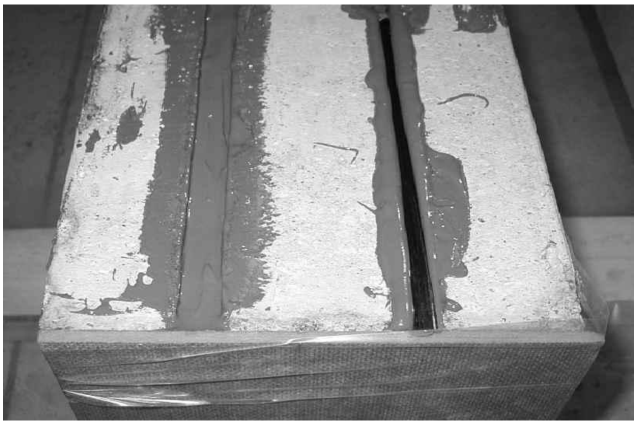


Fig.2 10 mm square rods bonded in slots in the concrete cover

Abdalla [5] examines the crack widths and deflection in the group of simply supported concrete Beams with FRP reinforced bars and groups of concrete slabs with steel reinforced bar and FRP reinforced bars. He evaluates the bending in members under serviceability. The calculation of these studies is compared with the test results. Good conformity is found between experimental and theoretical results. Strains and Deflection of reinforcement concrete beam with FRP tendons are larger than reinforcement concrete beam with steel bars.

Nordin [4] discusses the strengthen in concrete structures that prestressed by CFRP tendons installed in concrete cover. Strengthen concrete structure by using prestressed CFRP tendons have certain to be an active alternative to unstressed CFRP. NSM tendons have a good capability to transmit the stresses from tendons to the concrete once it’s used in prestressed members. No peeling damage during bending despite existence strain losses when releasing the prestressing force.

5. The FRP tendons Near-Surface Mounted

The FRP tendons NSM uses a new technique to increase the strength of concrete members instead of externally bonded FRP sheets [7]. This technique is as NSM - FRP tendons. By making a grooving in the concrete member surface along the direction required to be strengthened, and then the tendons are embedded along. Epoxy paste is put until to half, after that is placed FRP tendons in the groove and carefully pressed until the tendons embedding in epoxy. Then filled the grooved with more Epoxy paste and leveling the surface. Figure (3) shows the section in FRP tendons NSM technique.

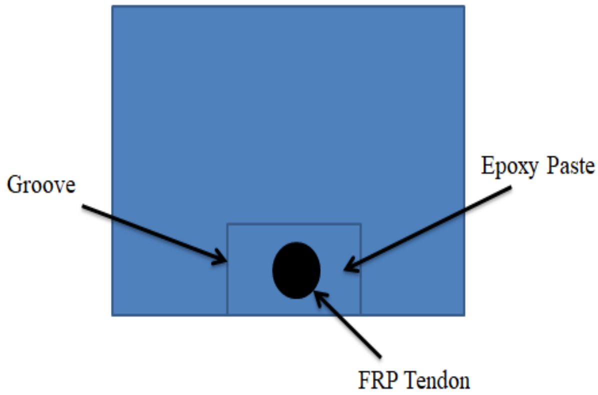


Fig.3 NSM tendons (bars)

In the Europe, the steel tendons are used to increase the strength of reinforced concrete members instead of the FRP tendons technique in the last fifty years ago. Asplund, 1949 is the first reference found that containing the literature of FRP tendons technique. In 1948, the concrete reinforcement bridge in Sweden is checked to deflection at the area of negative bending moment reinforcement during installation, then need to increase the negative bending moment capacity. This is committed by making grooves in the surface and the grooves are filled up with cement mortar, after those putting steel tendons in them because of no experience in the previous. Many tests are conducted on the grooves to obtain a convenient result. design problems and technology are considered in the report (Asplund, 1949).

In the present, the steel reinforces is replaced with FRP tendons and cement mortar is replaced with epoxy paste. FRP resistance to corrosion is a primary advantage of this technique. This characteristic is very important because the position of the tendons is closed and can resist to the environmental impact.
NSM technique is an attractive method of increasing the shear force and bending moment in reinforcement concrete members, walls, and masonry. In certain cases, FRP laminates can be very convenient. They may not require

for creating grooves in the member surface and the low time is needed to make an installation in a comparison with FRP tendons. Feasibility of installation is the other advantage of NSM technique. The NSM technique is more attractive to increase the negative bending moment in beams, decks, and slabs because the reinforcement in these members is subjected to environmental failures and needs to be protective. Bournas [8] points out that the result of experimental for reinforced concrete columns subjects to seismic load. Flexure area is strengthened by FRP, and different types of columns and used NSM technique and then the researcher measures some factories such as glass fiber or carbon fiber reinforced polymer instead of steel reinforcement, amount and configuration of NSM reinforced, kind of bonding agent, and adjustment by a local cover, by comparison, the load-displacement response properties. Good accepted result gets from NSM technique and this gives an applied solution to increase the flexural resistance for reinforced concrete columns under seismic load.

6. The FRP sheets Near-Surface Mounted

In last years, the carbon fiber reinforced polymer sheets NSM technique is also used to increase the capacity of concrete structures. The word "near" is used to distinguish between the externally-bonded FRP tendons technique and the NSM FRP sheets technique, (both techniques on the surface of concrete members). In the NSM CFRP technique, the grooves are created previously on the concrete member's surface. This needs to increase the strength the epoxy-adhesive which is injected in the grooves. The dimensions of CFRP are about 10 mm in width and 1.4 mm thickness, while the groove dimensions are (12– 15 mm), depth and (3- 5 mm) width, Part of researchers utilize FRP tendons instead of FRP sheets, but the grooves have big dimensions [9].

To evaluate the efficiency of NSM technique for beams that ends with fail by pure shear. The comparison is conducted between the response of beams with NSM CFRP and the other conventional stirrups with CFRP sheet. NSM CFRP beams are very effective, faster, and easier to be applicable. Figure (4) depicts the effectiveness for increasing the bearing capacity of loaded beam and increasing the ductility of the beam response figure (4).

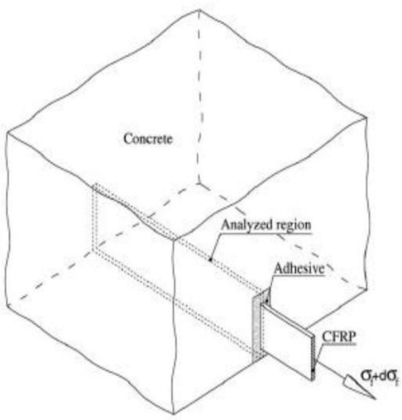


Fig.4 An important region in the Analysis

This technique is utilized to evaluate the concrete beams and concrete columns that fails by bending. Further to that the registered maximum strain value for CFRP is near to ultimate strain for CFRP. This is referred that the NSM CFRP technique is very effective for concrete columns and beams. If the early failure in concrete members is occurred. The response of CFRP should evaluate the concrete bonding members to understand the phenomena of this involvement.

To do so many experimental of bending-pullout is committed, upon the pullout force measurement of the CFRP, and the slip at the loaded and free end. The effect of bond length and the concrete strength for CFRP-concrete bonding response is analyzed. A numerical analysis program is developed to define the correlation between the local bond stress–slip (s-s) and compared with the experimental results.

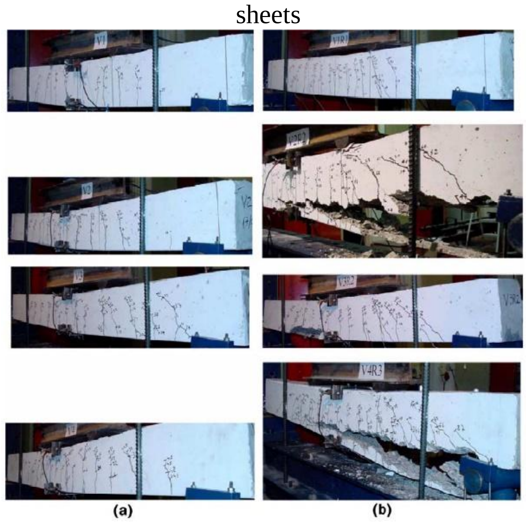
Many approaches are applied to develop the correlation between (s-s) for FRP tendons that depends on the bonding of steel bars-concrete methodology. Focacci et al. proposes a new method in this work and some necessary modifications for the strengthening technique.

During the strength, it's needed to perform some steps as follows:

a. making slots in the concrete member cover, with dimensions (depth and width) based on the product.
b. using an approximate (100-150) bar (high pressurized) to cleaning the slots very carefully, the water must be very free of impurities.
c. when using cement mortar to casting, it is recommended that the slots be wet, but when using an epoxy system, so it is recommended that the slots be very dry.
d. putting the Adhesive material or cement mortar in the slots.

Fortes and Barros [3] discuss the influence of the NSM technique by using carbon fiber reinforced polymer sheets bonded into the flexural zone of concrete beams. The results show the strengthening of using NSM and CFRP, increasing the yielding load from (32 to 47) %, and service load increased by 45%, beams are more stiffness between the cracking loads and yielding loads Figure (5).

Fig.5 influence of using carbon fiber reinforced polymer sheets



Nordin [6] discusses the influence of NSMR on strengthening RC structure. Experimental results expose that the strengthen of RC structures by NSMR is a successful method. Concrete cracking is delayed, and the yield stress of steel is increased. This theory covers the design for bending. However, many works are needed to cover the other kinds of strengthening applications.
Nanni and De Lorenzis [7] recommend that the tensile characteristics of FRP tendons when no data are found, the response of FRM tendons embedded in masonry unit or concrete element using coupon – size piece, studied the structural response of using the FRP tendons in the strengthen of shear in full-size reinforcement concrete beams, and develop a new method to design shear strengthening of beams with NSM tendons. Three types of failure are shown up in the experimental results; pull out of the FRP rod, cracking of the concrete surrounding, and splitting of the epoxy cover. The design method is used to calculate the shear capacity of strengthening concrete beams and gives good response and reasonable result.

Barros and Cruz [9] study the factors that have influences on the relation between local bond stress – slip (Z-S). It enables to bond the carbon fiber reinforced polymer into the near-surface mounted technique. A second-order differential equation is developed to govern the slippage and given data by experimental tests. They are evaluated regard to CFRP anchorage length and the ultimate limit state in this development analysis method. The simulation is revealed the performance of test of pull out bending and adjusted the numerical strategy. Using the (Z-S) relation to simulate the response of concrete – CFRP bond, this relation is a tangential constituent of the material constitutive law.
Khalifa [10] designs the U-anchor system as the new system uses for anchorage and try the system on three full experiments, Figure (6). The experiment consists of a T-Shaped concrete section with Simply supported, four-point loading and steel bar longitudinal reinforcement without stirrups (shear reinforcement). The result reveals that the beams with CFRP strengthen and with U-anchor have shear capacity more than the similar beams. In contrast with no U-anchor and deboning is controlled to failure. While increasing the applied shear CFRP does not deboned.

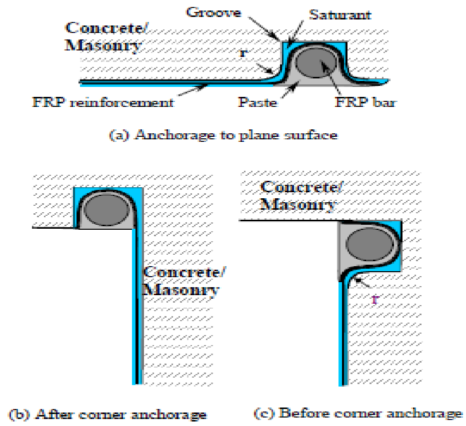


Fig. 6 Different application schemes of the U-anchor

De Lorenzis [11] studies the mechanical bond between concrete and FRP in the NSN technique and investigate the effect of critical factors that act on the performance of the bond. Thirty-six beams are tested and studied the factors such as, groove size, bonded length, type of FRP tendons, (surface pattern and material), and filling up material for all beams with spirally wound, epoxy resin, and CFRP tendons, the failure in the interface between concrete and epoxy. The reason is that the groove has a smooth surface. The bond stresses were decreasing between the concrete and epoxy for asymptotic and ultimate load when groove size and bonded length increased due to the random distribution of stresses along with the bond.
Nanni and De Lorenzis [12] investigate the NSM for FRP tendons to increase the flexural and shear strength for reinforced concrete beams. The study demonstrates that the shear stress is increased when used FRP tendon and NSM technique. In term of T-Beams, the inclined tendons of FRP give shear capacity higher than vertical tendons of FRP, and the change in distance between tendons does not affect shear capacity. Figure (7)

Fig. 7 T-Beams, the inclined tendons of FRP

Nanni and De Lorenzis [13] study the effect of bond between concrete and FRP. The experimental variables are diameter of the tendons, bonded length, surface configuration of the tendons, type of FRP material, and size of the groove. Three types of failure are found in the results; splitting of the epoxy cover, polling out of the FRP tendons, and cracking of the concrete rounding the groove. The deforms tendons have good efficiency and give maximum bond strength because the performance of deforms tendons increase the cover thickness and groove size.

De Lorenzis [14] examines thirty-four beams and the influence between filling material and groove, groove size, bonded length, and surface configuration. Figure (8), The experimental results using calibrated and modeling the bond of NSM reinforcement in 3D- finite element analysis. The epoxy gives mechanical performance instead of cement mortar. CFRP spirally and CFRP ribbed is suitable tendons to NSM technique. The result is conformed when comparing the theoretical and experiment results.

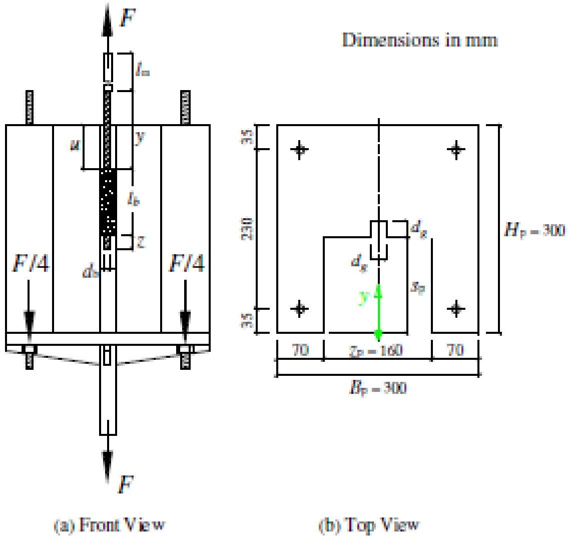


Fig. 8 Test specimen

Taljsten and Nordin [15] examine Fifteen full-size concrete beams and compare the effective test with a theoretical analysis equation. Ten beams strengthen with prestressed CFRP rods, four beams without prestressing, and one beam without strengthened. Prestressed beams and non-prestressed beams with CFRP strengthen is a successful method. The experimental results identify that the fatigue response is improved and increased the yielding load to cracking, and the durability is increased. It is possible to calculate the strain and stress value in the middle point of beams and give a conformed result when comparing them with the test and calculating the shear stress in the bond zone at the end. The work of transfer force between the concrete and rectangular CFRP tendons is very well.

De Lorenzis [16] models the bond test in the transverse and longitudinal plane. The modeling in transverse plane allows to calculate the principal tensile stress behavior of cracking on the cover of NSM tendons and gives the ratio of groove dimension to bar size close to 20, as found in the test. The modeling in longitudinal plane allows to calculate the failure load in bond as a function of the length of the bond and gives the acceptable result with test and anchorage length need in the design. The transverse-longitudinal approach is a good tool to study the bond response and show a useful conclusion in design.

El-Hacha and Rizkalla [17] examine Eight beams under increasing concentrated force that applied in the middle span, all beams are simply supported. FRP reinforcing tendons use to strengthen the beams in flexure and strips with different systems; besides using FRP sheets for the external bond. The experimental result reveals that the use of FRP reinforcing tendons and strips is practical, the stiffness improves significantly, and the flexural capacity is increased in reinforced concrete beams. The FRP strips are provided strength capacity higher than externally bonded FRP sheets for the same material.

Rizkalla and Hassan [18] present both analytical and experimental investigations undertaken to calculate bond properties of NSM CFRP tendons, Figure (9). The proposed method gives a general methodology to calculate the development length of NSM FRP tendons of different types and configurations of fibers. The experimental result indicates that the Rupture of NSM CFRP tendons is not likely to happen regardless of the use of embedment bar length. Bond characteristics, adhesive material, and concrete are used to control the efficiency of CFRP tendon in NSM reinforcement strengthen. The development length of FRP tendons is determined as an accurate by the proposed design chart. The chart is simplified to use, and it gives an excellent correlation with test results. When increasing the groove size and using high concrete strength led to increases the strength of concrete split failure, when using high strength adhesives lead to increasing the cover layer of epoxy and delays the epoxy split failure for FRP tendons.

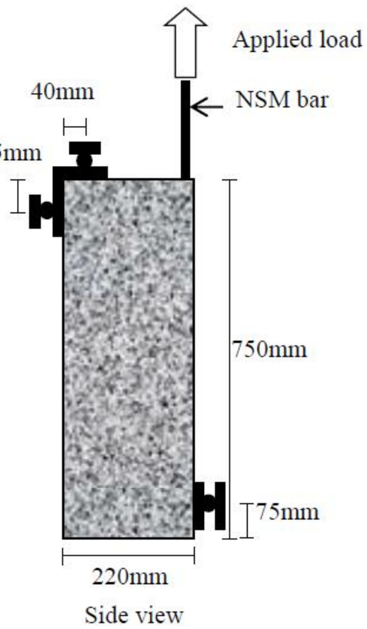


Fig. 9 Specimen loading arrangement

Rizkalla and Hassan [19] study the analysis and investigation undertaken to calculate bond properties of NSM CFRP strips. The model is capable in case of predicting the distribution of interfacial shear stress, mode of concrete beams failure strengthens with CFRP sheet, and ultimate load capacity. A good result is established between predicated and the proposed model. When increasing the ratio of internal reinforcement steel, decrease the compressive strength of concrete and groove width the development length of the CFRP sheet increased. The use of CFRP sheets is effective and feasible for the repair and strengthening of concrete structures. Figure (10).

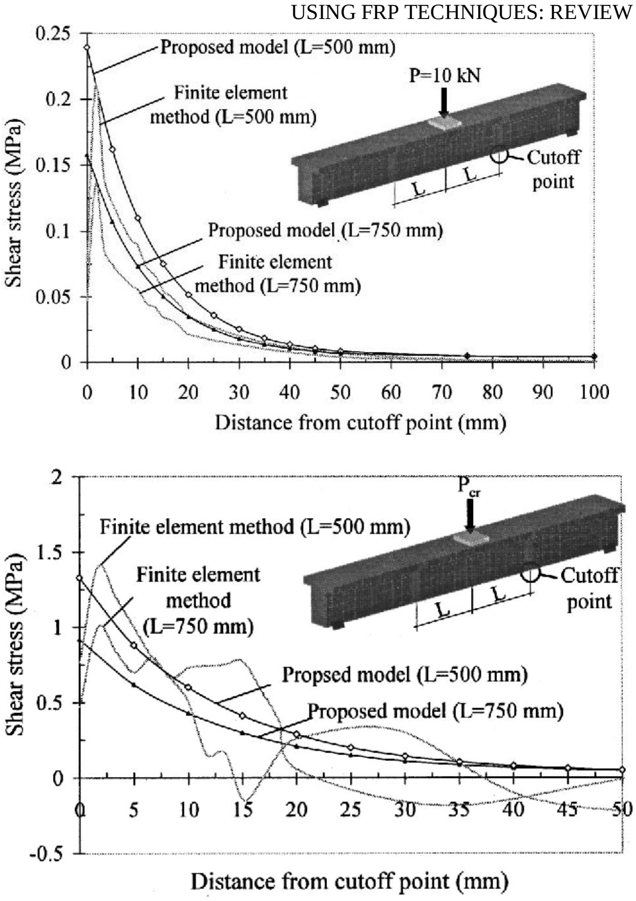


Fig. 10 Results of shear stress and distance from cutoff point.

Noha El. [20] discuss a new technique of shear strengthening for deep beams and reinforced self-consolidating concrete that are compared and suggested with many traditional techniques. Sixteen deep beams of reinforced self-consolidating concrete strengthened by different materials such as glass, carbon, and steel were executed in the experimental program. NSMR and externally bonded layers are used as different techniques. The influences of this technique which is released on using intertwined roving GFRP tendons saturated with epoxy and compared with the other case. The result exposes an increase in the shear strengthening capacity by (36% to 55%) and this increasing depending on GFRP tendons anchorage length. The self-consolidating concrete represents by 2D non-linear isoperimetric finite element, strengthening layers, and reinforcement of the experimental models. The experimental results and analytical results are very close.

7. Conclusion

According to the abovementioned review, the conclusion can be that:

1- Researchers have been actively studying many ways to increase the shear strength of concrete since 1940.

2- There are many materials can used to increase the strength of concrete members such as steel, AFRP, CFRP, and GFRP.

3- In modern development, the steel reinforces is replaced with FRP tendons and cement mortar is replaced with epoxy paste.

4- The pultrusion technology is widely used and gives the engineering designer and manufacturer more possibilities to fabricate elements with different shapes and forms.

5- NSM technique is an attractive method of increasing the shear force and bending moment in reinforcement concrete members, walls, and masonry.

6- NSM technique is used in the Europe for the first time in 1940s to increase the strength of reinforced concrete members.

7- NSM technique is depending on the bonding between carbon or glass FRP tendons into concrete grooves opened in the cover of members need to strengthen.

8- NSM techniques have given an acceptable result for increment in applied load and increased the stiffness of concrete members after cracking.

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