A REVIEW ON STRENGHTENING TECHNIQUES USING NSM AND EB FRP COMPOSITES

Hanu Chandran[1], Dr.Subha K[2]

[1]P.G Scholar, Dept. of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India
[2] Professor, Dept. of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India

---***---

Abstract - *Near-surface mounted (NSM) and Externally Bonded (EB) fibre-reinforced polymer (FRP) reinforcement are the most promising strengthening techniques for reinforced concrete (RC) structures. Research on this topic started only a few years ago but has by now has great attention. The main Issues raised by the use of such FRP reinforcements include the optimized methods of construction, models for the bond behaviour between FRP and concrete, flexural and shear strengthening methods which are reliable , and proper utilisation of benefits of these techniques.*

Key Words: **Near Surface Mounted, External bonded, FRP , Strengthening, FEA ,Bond behavior, FRP bars, FRP Laminates**

1.INTRODUCTION

Fibre reinforced plastic (FRP) reinforcement plays a very important role in the retrofitting and rehabilitation of reinforced concrete (RC) structural elements as an external and near surface reinforcements. Recent developments in these fields have a wide range of application. Several investigators carried out experimental or theoretical investigations on concrete beams and columns retrofitted with carbon/glass fibre reinforced polymer (CFRP, GFRP, and HYBRID) composites in order to study their characteristics. Many practical applications worldwide now confirm that the technique of bonding FRP laminates or plates to external surfaces and usage of internal bars is a technically sound and practically efficient method of strengthening and upgrading of reinforced concrete load-bearing members that are structurally inadequate, damaged or deteriorated. Of all the materials used as reinforcement, carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP) composite materials have found special favour with engineers and applicators because of their many advantages. After that over a period of time some researchers started doing their work on Hybrid FRP (combined layer of CFRP and GFRP fibres).

NSM-FRP is an appealing method to strengthen existing and new structures due to its advantages over EBR systems, mainly from the improved efficiency achieved from better strain distribution resulting in higher utilization of available strain and its higher resistance to many environmental factors due to being embedded into the concrete cover. Although temperature susceptibility is still slightly high for NSM-FRP, it is considerably reduced by changing the grout filler type. This is a newly emergent research topic area and is still under preliminary investigation. Drawbacks of using NSM-FRP, such as lack of protection against vandalism and concrete fracture around NSM laminate grooves can be addressed by using a relatively new method called hybrid composite plates (HCPs). These plates consists of strain hardening cementitious composite (SHCC) and FRP sheets, which provide protection against damage and improving transfer of stresses between FRP and concrete.

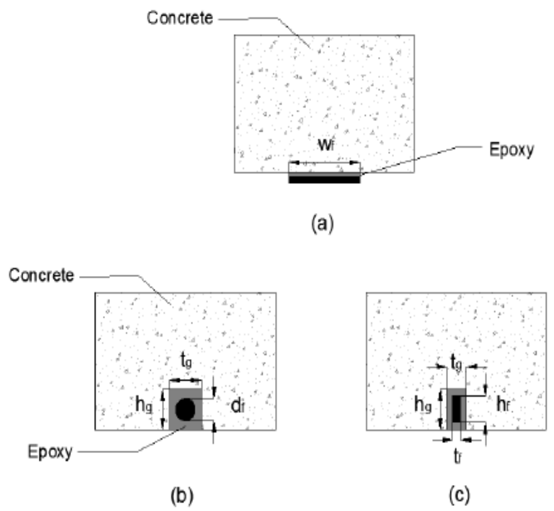

Fig -1: FRP strengthening methods (a) EBR FRP plate or sheet (b) NSM FRP rod or bar (c) NSM FRP laminate or strip.

2. MATERIALS AND SYSTEMS

2.1 Fibre reinforced polymer composite and systems

FRP composites are comprised of a matrix and reinforcing fibres. Reinforcing fibres are responsible for carrying most of the load applied to the composite, while the matrix provides protection to the fibres from surrounding environment, transfers stresses between fibres, and keeps reinforcing fibres in place

2.1.1 Reinforcing fibers

Various types of fibres are commercially available and each type suites a couple of applications. However, there are mainly three types of fibres which are commonly employed in civil infrastructure: carbon, glass, and aramid. The comparison tensile properties of these common fibres are listed in fig-2.

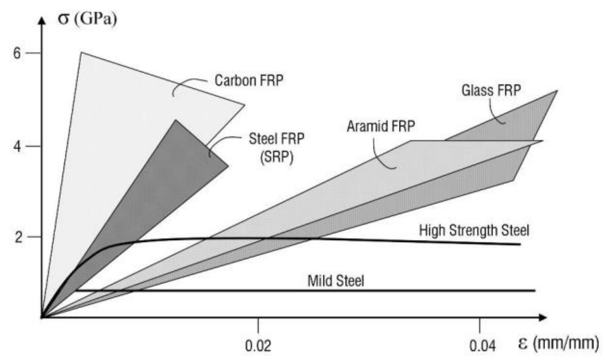

Fig -2: Strength characteristics of different fibres

Mainly, Carbon fibres are used in civil applications. They are manufactured to have a wide range of tensile properties. They have tensile modulus-weight ratios, high tensile strength-weight ratios, negative coefficient of thermal expansion (CTE), and outstanding resistance to fatigue. However, they have some disadvantages such as their high cost, low strain-to failure, weak resistance to impact, and high electrical conductivity .Glass fibres are commonly available in two types: E-glass and S-glass. Glass fibres are characterized by their low cost, high tensile strength, and superior insulating properties. However, they have some disadvantages. They have low tensile modulus and high density in comparison with the aramid and carbon fibres, high abrasion sensitivity and low resistance to fatigue.

2.1.2 Matrix

Matrix materials can be polymeric, metallic, and ceramic. Polymeric matrix includes two major classes: thermosetting and thermoplastic. Molecules of thermoplastic matrices have weak cross-links, so temperature variation can create different configurations for thermoplastics, and thus such matrices has not been used in civil infrastructure applications. Thermoplastic matrices are commonly utilized with short fibres

2.1.3 FRP Reinforcement

In recent studies, carbon FRP (CFRP) NSM reinforcement has been used to strengthen concrete structures. Glass FRP (GFRP) has been used in most applications of the NSM method to masonry and timber structures. The tensile strength and elastic modulus of CFRP are much higher than those of GFRP, so for the same tensile capacity, a CFRP bar has a smaller cross-sectional area than a GFRP bar and requires a smaller groove. This in turn leads to easier installation, with less risks of interfering with the internal steel reinforcement, and with savings in the groove-filling material. FRP bars can be manufactured in a virtually endless variety of shapes. Hence, the NSM FRP reinforcement may be round, square, rectangular and oval bars, as well as strips (Fig-3).

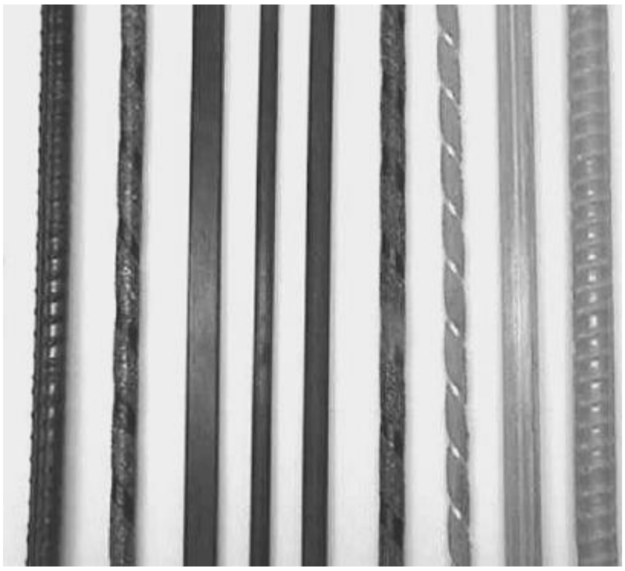

Fig- 3. Different FRP bars

2.1.4 Groove filler

The groove filler is the medium for the transfer of stresses between the concrete and the FRP bar. In terms of structural behaviour, its most relevant mechanical properties are the tensile and shear strengths. The tensile strength is especially important when the embedded bars that have a deformed surface, which produces high circumferential tensile stresses in the cover formed by the groove filler (simply referred to as ''the cover'' or ''the epoxy cover'' hereafter) as a result of the bond action. In addition, the shear strength is important when the bond capacity of the NSM reinforcement is controlled by cohesive shear failure of the groove filler. The effect of the modulus of elasticity of the groove filler has never been experimentally investigated.

The most common and best performing groove filler is a two-component epoxy. Low-viscosity epoxy can be selected for strengthening in negative moment regions as the epoxy can be ''poured'' into the grooves. For other cases, a high-viscosity epoxy is needed to avoid dripping or flowing-away. The addition of sand to epoxy can increase the volume, control the viscosity, lower the coefficient of thermal expansion, and raise the glass transition temperature. A drawback of this addition seems to be reduced adhesion at the bar–epoxy interface for a smooth bar surface.

2.1.5 Groove dimensions

Fig-4 shows several configurations of NSM FRP reinforcement, where d_b is the nominal diameter of a round bar, and t_f and h_f are the thickness/width and the height of an FRP strip or rectangular bar respectively. The groove width b_g, the groove depth h_g, the net distance between two adjacent grooves a_g, and the net distance between a groove and the beam edge ae are all relevant construction parameters, which can influence the bond performance and hence the structural behaviour.

For round bars, De Lorenzis , based on results of bond tests with square grooves ($b_g = h_g$) and defining

$$k = b_g/d_b,$$

proposed a minimum value of 1.5 for k for smooth or lightly sand-blasted bars and a minimum value of 2.0 for k for deformed bars. Parretti and Nanni suggested that both b_g and h_g should be no less than $1.5d_b$. For NSM strips, Blaschko suggested that the depth and width of the cut groove should be about 3 mm larger than the height and thickness of the corresponding FRP strip respectively, so to obtain an adhesive layer thickness of about 1–2 mm. Also for NSM strips, Parretti and Nanni recommended that the minimum width of a groove be no less than $3t_f$ and the minimum depth be no less than $1.5h_f$.

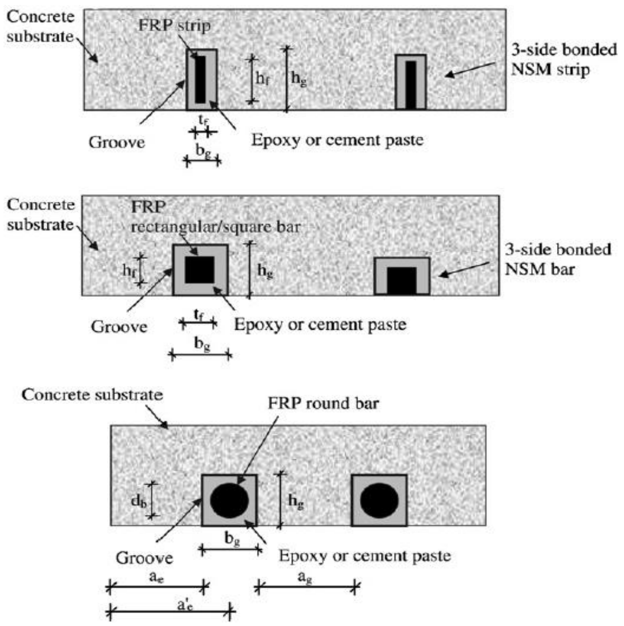

Fig- 4. Configurations of NSM FRP reinforcement

2.1.6 Groove position

If a single NSM bar is to be provided to the tension side of an RC member, it should naturally be centrally located over the beam width. When two or more NSM bars need to be provided, then the distance between two adjacent NSM bars and the distance between the edge of the member and the adjacent bar become important design parameters. The effect of these parameters is discussed in the section on bond behaviour.

2.1.7 Adhesively Bonded FRP Plates

Pultruded FRP plates (also called laminates or strips), having high tensile strength, are glued to the soffit of concrete members to increase the flexural capacity. The plate is glued to the tensile face of the member in such a way that ensures the fibres are aligned with the member's longitudinal axis.

3. FLEXURAL STRENGTHENING BY NSM

Some existing studies were conducted on beams strengthened with NSM bars of limited embedment lengths. Although such tests were intended to study bond failure mechanisms, they are not ''pure'' bond tests as the bond performance is affected by flexural cracking. Moreover, the NSM FRP bars in such tests generally extend into the shear spans, where part of the interfacial shear stress is directly dependent on the transverse shear force in the beam.

Hassan and Rizkalla conducted flexural tests on RC beams with NSM CFRP round ribbed bars and strips of varying embedment length. Failure of beams with NSM round ribbed bars occurred by splitting of the concrete cover followed by the complete debonding of the bars in all cases

Teng et al. conducted flexural tests on RC beams with NSM strips of varying embedment length. As the embedment length increased, the failure mode changed from concrete cover separation starting from the cut-off section, to concrete crushing followed by secondary cover separation close to the maximum moment region .

All existing test results of strengthened beams, slabs, and columns indicate that the NSM reinforcement improved the ultimate load and the load at the yielding of steel reinforcement, as well as the post-cracking stiffness. Some test programs included identical beams strengthened with equivalent amounts of FRP provided as either externally bonded or NSM reinforcement. In all cases, the NSM reinforcement performed more efficiently, as debonding of the NSM reinforcement occurred at a higher strain or did not occur

3.1 Failure modes of flexurally-strengthened beams

Failure modes of flexurally-strengthened beams The possible failure modes of beams flexurally-strengthened with NSM FRP reinforcement are of two types: those of conventional RC beams, including concrete crushing or FRP rupture generally after the yielding of internal steel bars, for which the composite action between the original beam and the NSM FRP is practically maintained up to failure, and ''premature'' debonding failure modes which involve the loss of this composite action.

The likeliness of a debonding failure depends on several parameters, among which the internal steel reinforcement

ratio, the FRP reinforcement ratio, the cross-sectional shape and the surface configuration of the NSM reinforcement, and the tensile strengths of both the epoxy and the concrete. Some researchers extended the NSM FRP reinforcement over the beam supports to simulate anchorage in adjacent members. Despite this anchorage,
debonding failures can still occur.

Blaschko reported the results of two beam tests: the first one failed by concrete cover separation starting From the cut-off section but the second beam, which was provided with a steel U-jacket bonded to the cut-off section, failed by the rupture of the FRP strips.

3.1.1 Bar–epoxy interfacial debonding

This mode involves interfacial debonding between a bar and the epoxy and has been observed for sand-blasted Round bars. This mode correlates well with the failure mode observed in bond tests on the same type of bars. However, unlike in a bond specimen, the epoxy cover in the beam was intersected by flexural cracks which facilitated the initiation of longitudinal splitting cracks and hence accelerated interfacial debonding.

3.1.2 Concrete cover separation

The formation of bond cracks on the soffit of the beam has been observed in tests ,and these bond cracks are inclined at approximately 45 degree to the beam axis. Upon reaching the edges of the beam soffit, these cracks may propagate upwards on the beam sides maintaining a 45_ inclination within the cover thickness, and then propagate horizontally at the level of the steel tension bars. Debonding may next occur in different forms, depending on the subsequent evolution of the crack pattern.

4. FLEXURAL STRENGTHENING BY EB

Externally bonded reinforcement (EBR) consisting of fiber reinforced polymer (FRP) composites has been successfully deployed worldwide for strengthening existing concrete structures. It is generally more economical and convenient than other repair systems Numerous experimental and field applications have shown that EBR FRP can efficiently increase the flexural strength of a concrete member . One of the drawbacks of the EBR FRP method is the man power needed to attach continuous laminate along the entire length of the member. The difficulty is more evident when the concrete member is too long or inaccessible. Construction of scaffolding along the length of a member can be time consuming and costly . Although splicing FRP laminates is an option, it is not commonly used in practice. Much of the research investigating lap-splicing FRP plates/sheets has focused on steel substrate.

Yang and Nanni 2002 investigated the lap-splice length and fatigue performance of lap-spliced CFRP laminates through double lap-shear steel coupon tests. It was found that 38.1 mm (1.5 in.) lap-splice length is sufficient to provide continuity for the lap-splice system, under static loads. Fatigue tests were performed on 101.6 mm (4 in.) lap-spliced specimens. The study reported that the provided lap-splice length can resist more than 2.0 million load cycles with no effects on residual strength, providing that the maximum applied stress does not exceed 40% of the ultimate static strength.

Dawood and Rizkalla 2006 conducted an experimental study on steel beams and doublelap shear steel specimens to investigate the effectiveness of lap-spliced CFRP laminates, using different splice configurations. The study indicated that controlling failure mode is debonding of the splice from the primary laminates due to high shear stresses at splice ends. The study also showed that implementing reverse taper at the splice ends results in reduction of the end shear stresses, and could increase the structure load capacity.

Dawood et al 2007 extended the above study to include the effects of various taper configurations, the effects of increasing splice length, and the effects of using mechanical anchorage near the splice ends. The study reported that using reverse taper at both (1) the butt-joint of primary laminates, and at (2) at splice ends results in increasing the splice capacity to twice as the splice without reverse taper. While increasing the splice length or providing additional mechanical anchorage have minimum influence.

5.CONCLUSIONS

Strengthening of structures with NSM FRP reinforcement is a technique that has attracted a considerable attention as a feasible and economic alternative to the technique of strengthening structures with externally bonded FRP reinforcement. The former technique offers some significant advantages over the latter, including the more efficient use of the FRP material due to a reduced risk of debonding failure and the better protection of the FRP material from external sources of damage. Research on the strengthening of structures.

REFERENCES

[1] De Lorenzis L, Nanni," A. Shear strengthening of reinforced concrete beams with nearsurface mounted fiber-reinforced polymer rods". ACI Struct 2001

[2] De Lorenzis L, Rizzo A, La Tegola A. "A modified pull-out test for bond of nearsurface mounted FRP rods in concrete". Composites 2002.

[3] De Lorenzis L, Nanni A. "Bond between near-surface mounted fiber reinforced polymer rods and concrete in structural strengthening". ACI Struct J 2002.

[4] De Lorenzis L, Lundgren K, Rizzo A. "Anchorage length of near surface mounted fibre reinforced polymer bars

for concrete strengthening experimental investigation and numerical modelling". ACI Struct J 2004.

[5] De Lorenzis L. "Anchorage length of near-surface mounted fiber reinforced polymer bars for concrete strengthening – analytical modelling". ACI Struct J 2004.

[6] Novidis D, Pantazopoulou SJ, Tentolouris E. "Experimental study of bond of NSM-FRP reinforcement. Construct Build Materials". ACI Struct J 2004

[7] De Lorenzis L, Nanni A, La Tegola A."Flexural and shear strengthening of reinforced concrete structures with near surface mounted FRP rods". In:Proceedings ACMBS III, Ottawa; 2000.

[8] De Lorenzis L. "Strengthening of RC structures with near surface mounted FRP rods". PhD thesis, Department of Innovation Engineering, vol. 3, University of Lecce, Italy;

[9] Taljsten B, Carolin A, Nordin H. "Concrete structures strengthened with near surface mounted reinforcement of CFRP". J Adv Struct Eng 2003;6(3)

[10] El-Hacha R, Rizkalla S. "Near-surface-mounted fiber-reinforced polymer reinforcements for flexural strengthening of concrete. J" ACI Struct 2004.

[11] Mostofinejad D, Moshiri N. "Compressive strength of CFRP composites used for strengthening for RC columns: comparative evaluation of EBR and grooving method." ASCE J Compos Constr 2015

[12] Maaddawy T, Sayed M, Magid BA. "Effect of cross sectional shape and loading condition on performance of reinforced concrete members confined with carbon fiber reinforced polymers". Mater Des 2013;.

[13] Hadi MNS, Zhao H. "Experimental study of high strength concrete columns confined with different types of mesh under eccentric and concentric loading". ASCE J Mater 2013;

[14] Herwig A, Motavalli M. "Axial behavior of square Reinforced Concrete columns strengthened with lightweight concrete elements and unbonded GFRP wrapping". ASCE J Compos Construction 2016;16:747–52.

[15] Yung-Chih Wang and K. Hsu. (2008, Jan.). "Design of FRP-wrapped reinforced concrete columns for enhancing axial load carrying capacity". Composite Structures [Online]. 82(1), pp. 132-139.

[16] Marc Quiertant and Jean-Luc Clement. (2008, Jan.). "Behavior of RC columns strengthened with different CFRP systems under eccentric loading". Construction and Building Materials [Online]. 25(2), pp. 452-460

[17] Tamer El Maaddawy, Mohamed El Sayed and Beckry Abdel-Magid. (2010, May.). "The effects of cross-sectional shape and loading condition on performance of reinforced concrete members confined with Carbon Fiber-Reinforced Polymers".

[18] Tamer El Maaddawy, "Strengthening of Eccentrically Loaded Reinforced Concrete Columns with Fiber-Reinforced Polymer Wrapping System: Experimental Investigation and Analytical Modeling," J. Compos. Constr., vol. 13, no. 1, pp. 13-24, Feb. 2009.

[19] Bernát Csuka and László P. Kollár. (2012, Feb.). "Analysis of FRP confined columns under eccentric loading "

[20] Joaquim A.O. Barros, Rajendra K. Varma, José M. Sena-Cruz and Alvaro F.M. Azevedo. (2008, Dec.)."Near surface mounted CFRP strips for the flexural strengthening of RC columns: Experimental and numerical research "

[21] Tamer El-Maaddawy and Amr S. El-Dieb, J., "Near-Surface-Mounted Composite System for Repair and Strengthening of Reinforced Concrete Columns Subjected to Axial Load and Biaxial Bending,"

[22] Antonio Nanni. (2003, Sep.-Oct.). "North American design guidelines for concrete reinforcement and strengthening using FRP: principles, applications and unresolved issues"

[23] L.C. Hollaway. (2010, Dec.). "A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties"

[24] Kambiz Narmashiri and Mohd Zamin Jumaat. (2011, Jan.)." Reinforced steel I-beams: A comparison between 2D and 3D simulation"

[25] H. Toutanji, L. Zhao and Y. Zhang. (2006, Mar.)." Flexural behavior of reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix"

[26] Tan, Kiang Hwee, "Strength Enhancement of Rectangular Reinforced Concrete Columns using Fiber-Reinforced Polymer,"

[27] Masia, Mark J., Trevor N. Gale, and Nigel G. Shrive, "Size Effects in Axially Loaded Square-Section Concrete Prisms Strengthened using Carbon Fibre Reinforced Polymer Wrapping,"

[28] Mandal, Siddhwartha, Andrew Hoskin, and Amir Fam, "Influence of Concrete Strength on Confinement Effectiveness of Fiber-Reinforced Polymer Circular Jackets,"

[29] Raj, Rasheed. L. S, and Al-Azawi, T. K. (2013). "Experimental Analysis of Reinforced Concrete Slabs Strengthened with Steel Plates"