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Comprehensive review of near surface mounted technique used in Flexural

KEYWORDS: Near surface mounted reinforcement, Strengthening application, Flexure

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ABSTRACT *Significant research on strengthening reinforced concrete (RC) structure with Near-surface mounted (NSM) fiber-reinforced polymer (FRP) reinforcement has been done in recent years.Strengthening issue solved by use of this NSM FRP reinforcement include the optimization of construction details, models for the bond behaviour between NSM FRP and concrete, reliable design methods for flexural and shear strengthening, and the maximization of the advantages of this technique.This paper provides a comprehensive review of existing research in this area, and outlines directions for further research.*

INTRODUCTION

During the last few years there are so many structures constructed in all over the world. All the structures have varying quality and function, but they are all ageing and deteriorating over time due to corrosion and other distress. Some of these structures need to be upgraded or replaced, because they are in poor condition, not only due to deterioration processes, but also due to errors made during design and execution.There is a great flair in FRP strengthening. However, it is important to have sufficient knowledge on behaviour and applicability of different FRP materials and techniques. FRP reinforcements are available in form of circular or rectangular or strips made by pultrusion, or in the form of fabrics made with fibers in one or at least two different directions used in externally bonding wet lay-up technique. Carbon (C), Glass (G) and aramid (A),Basalt fiber are the main fibers which compose the fibrous phase of these reinforcements, while in most cases in the matrix phase epoxy is used to bind the fibers together. There are severalmethods are available to designers to select for shear and flexural strengthening. Examples include: Reported by (1) Adding external stirrups, (2) Jacketing, (3) Bonding external plates using epoxy or Bolts and (4) Bonding external FRP laminates. After the research of fiber polymer we used newer class of FRP strengthening techniques: near surface mounting reinforcement (NSMR) and externally bonding technique (EBR). FRP materials can be bonded to the exterior of concrete structures using high strength adhesives to provide additional reinforcement to supplement the available internal reinforcing. In addition to external bonding, the FRP reinforcements can be inserted into grooves cut into the structural members in an application called generally near surface mounting (NSM) (Figure1).

The use of NSM reinforcement was developed in Europe for strengthening of RC structures in the early 1950s. In 1948, an RC bridge deck in Sweden needed to be upgraded in its negative moment region due to an excessive settlement of the steel cage during construction. This was accomplished by inserting steel reinforcement bars in grooves made in the concrete surface and filling it with cement mortar. [1]

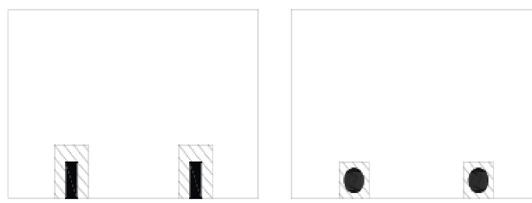

Figure 1: near surface mounted FRP, rectangular shapes and rods

Near surface mounting technique has many advantages vs. externally bonding technique (EBR):NSMR resists end peeling much better than bonded laminates excellent resistance to corrosion,higher percentage of the tensile strength can be mobilized,better anchorage capacity,No preparation work is needed other than grooving.The FRP reinforcement due to the special mounting setupis protected by the surrounding concrete against mechanical influences, therefore, these technique is attractive for strengtheningin the negative moment region. The strengthening has animproved protection against freeze/thaw cycles, elevated temperatures,fire, ultraviolet rays and vandalism. The experimentsshowed also an improved ductility, preferable composite action,and an ultimate load develop more independent from concretesurface tensile strength.[10]The available research indicates that the material properties of the FRP strips and adhesives have a considerable influence on the NSM strengthening effectiveness, but a comprehensive study in this context does not exist. The present work analyzes the possibilities of the NSM technique for flexural strengthening of RC structures and discusses the topics that deserve more research and attention of the FRP community in order to have well sustained strengthening practice, design guidelines that allow the engineers to assume this technique as a valid alternative to other strengthening techniques[3].The existing knowledge on the NSM FRP method is much more limited than that on the externally bonded FRP method, as reflected by the absence of relevant provisions in the existing guidelines on the FRP strengthening of concrete structures issued by (Lausanne-2001)and ACI-440. [5]

The international engineering community has become increasingly aware of the practical advantages of this meth-

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od, which has led to accelerations of research andPractical applications worldwide. Both ACI-440 and fib are currently considering revisions to their documents to include NSM-related provisions. Against this background, this paper provides a critical review of existing research in this area, identifies gaps of knowledge, and outlines directions for further research.[13]

MATERIALS AND SYSTEMS :
GROOVE DIMENTION :
Fiber reinforcements primary function is Carry load along the length of the fiber, provides strength or stiffness in one direction. Near surface mounted method working step are: (1) Cutting the groove using a saw with one or two diamond blades or a grinder with 1.5d as per Research in function of the reinforcement size. (2) cleaning the surface from dust and lose parts using vacuum or compressed air, then the groove is filled halfway with adhesive, afterwards the FRP rod/strip is inserted and lightly pressed to let the adhesive). Flow around the FRP, and (3) the groove is filled with more paste and the surface is levelled shown in figure-2. [2]

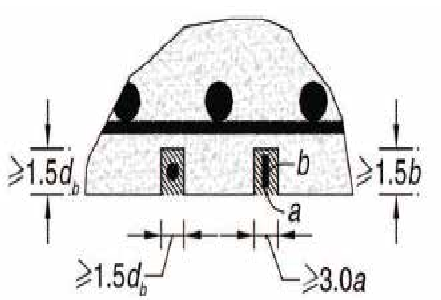

Figure 2: Spacing of the NSM Reinforcement

The minimum dimension of the grooves should be taken at least 1.5 times the diameter of the FRP bar. When a rectangular bar (strip) with large aspect ratio is used, the minimum dimensions must be 3 times the bar width and 1.5 times the bar height (Fig. 2). [8]Optimal dimensions of the groove may depend on characteristics of the adhesive, surface treatment of FRP, and concrete tensile strength, surface, aggregates.

FRP REINFORCEMENTS :
During the study of research paper, carbon FRP (CFRP) NSM reinforcement has been used to strengthen concrete structures.Glass FRP (GFRP) has been used in most applicationsof the NSM method to masonry and timber structures. The present authors are not aware of any study or practical application in which aramid FRP (AFRP) was used. 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. (Figure – 4)

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. [1]The NSM FRP reinforcement may be round, square, rectangular and bars, as wellas strips (Figure - 2 - 3). For brevity, the term "bars" is used herein as a generic term encompassing all cross sectional shapes, while the term "strips" is reserved for thin narrow strips. Different cross-sectional shapes have different advantages, and offer different choices for practical applications.

FRP bars are also manufactured with a variety of surface textures, which strongly affect their bond behaviors NSM reinforcement. Their surface can be smooth, sand-blasted, sand-coated, or roughened with a peel-ply surface treatment. Round bars can also be spirally wound with a fiber tow, or ribbed. [5]

A. GROOVE FILLER :
The groove filler is the medium for the transfer of stresses between the FRP bar and the concrete. 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 have a deformed surface, which produces high circumferential tensile stresses in the cover formed by the groove filler as a result of the bond action. 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. The use of cement paste or mortar in place of epoxy as a groove filler has recently been explored in an attempt to lower the material cost, reduce the hazard to workers, minimize the environmental impact, allow effective bonding to wet substrates, and achieve better resistance to high temperatures and improved thermal compatibility with the concrete substrate.

Results of bond tests and flexural testshave identified some significant limitations of cement mortar as a groove filler. Given these limitations and the very limited data available, future research needs are discussed**. [3]**

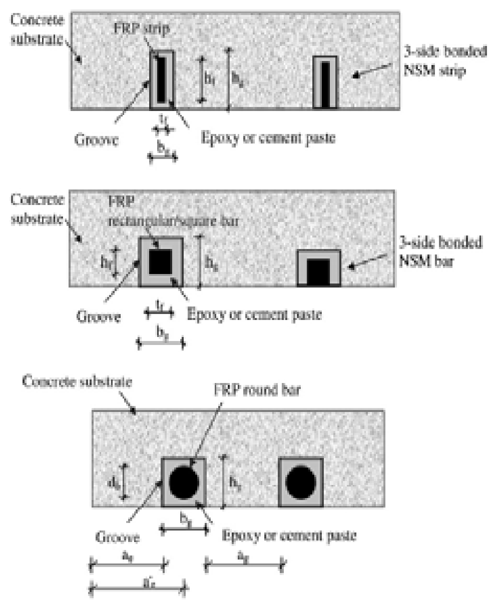

FIGURE 3: Different NSM systems and nomenclature.

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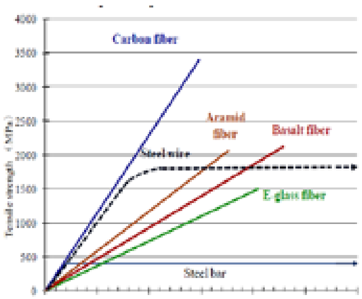

FIGURE 4: Stress-strain relationship of different FRP

GROOVR 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 study of the research review says if longitudinal direction of the FRP coincide with the yielding lines of RC elements (slab/beam), the ultimate load of the slab may not increase too much, the best way of strengthening in flexure or shear can be achieved if the longitudinal directions of the FRP and maximum bending stress were parallel. [1]

FLEXURAL STRENGTHENING :

Flexural strengthening represents the most popular application of FRP reinforcement. The strength design approach with its strength reduction factors as used in ACI 318 (1999) is recommended for RC and PC members using NSM FRP reinforcement. The equations presented in this paper are based on principles of force equilibrium, strain compatibility, constitutive laws of the materials, andreported by ACI Committee 440 (2002).[5]

Table 1: Environmental-reduction factor CE (ACI 440 2002)

Exposure condition	Fiber and resin type	CE
Interior exposure	Carbon/epoxy	0.95
	Glass/epoxy	0.75
	Aramid/epoxy	0.85
Exterior exposure (bridges, piers, and unenclosed parking garages)	Carbon/epoxy	0.85
	Glass/epoxy	0.65
	Aramid/epoxy	0.75
Aggressive environment (chemical plants and waste water treatment plants)	Carbon/epoxy	0.85
	Glass/epoxy	0.50
	Aramid/epoxy	0.70

The existing strength of the structure (Rn) should be sufficient to resist a level of load described by Eqn 1:

(Rn) existing= (1.2D+0.85L)new(1)

FRP properties to be used in all design equations are given as follows (ACI 440 2002 and 2003):[4]

Ffu = FceFfu*

εfu = E εfu*

Where, ffuand εfuare the FRP design tensile strength and ultimate strain considering the environmental reduction factor(CE)as given in Table 1. FRP design modulus of elasticity is the guaranteed value reported by the manufacturer.

Guidance for the calculation of the flexural strengthening effect resulting from longitudinal FRP reinforcement mounted onto the tension face of an RC member is illustrated in Figure 6 for thecase of a rectangular section.Assumptions used in the design are: a) a plane section before loading remains plane after loading; b) the maximum usable compressive strain in the concrete is 0.003, and its tensile strength is neglected; c) FRPReinforcement has a linear-elastic behavior up to failure; and d) perfect bond exists between FRP reinforcement and surrounding concrete.

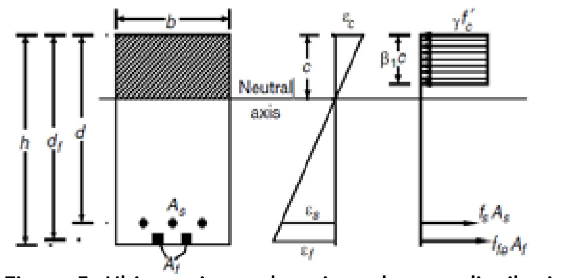

Figure 5: Ultimate internal strain and stress distribution for rectangular sections

The strength reduction factor () given by Eqn 3 should be used (ACI 440 2002):

$$\phi = \begin{cases} 0.90 & for \quad \varepsilon_s \geq 0.005 \\ 0.70 + \dfrac{0.20(\varepsilon_s - \varepsilon_y)}{0.005 - \varepsilon_y} & for \quad \varepsilon_y < \varepsilon_s < 0.005 \\ 0.70 & for \quad \varepsilon_s \leq \varepsilon_y \end{cases} \quad (3)$$

Where εs and εy is the strain in the reinforcing steel at ultimate and yielding, respectively.[5] When failure is controlled by concrete crushing, the Whitney stress block approach (ACI 318 - 1999) can be used without modifications

$$\beta_1 = 2 - \frac{4\left[(\varepsilon_c/\varepsilon_c') - \tan^{-1}(\varepsilon_c/\varepsilon_c')\right]}{(\varepsilon_c/\varepsilon_c')\ln\left(1 + \varepsilon_c^2/\varepsilon_c'^2\right)}$$

$$\gamma = \frac{0.90\ln\left(1 + \varepsilon_c^2/\varepsilon_c'^2\right)}{\beta_1 \varepsilon_c/\varepsilon_c'} \quad (4)$$

.Where,

$$\varepsilon_c' = 1.71\frac{f_c'}{E_c}$$

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and tan-1(εs/εc')is computed in radians. The ultimate effective strain (εfe) that should be

$$\varepsilon_{fe} = K_m \varepsilon_{fu} \quad (6)$$

where κmis a bond dependent coefficient meant to limit the strain in the FRP reinforcement to prevent debonding

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or delamination. [8]

OTHER ISSUE :

As mentioned earlier in the paper, the combined use of NSM FRP reinforcement in conjunction with externally bonded FRP reinforcement has been found to be effective in strengthening beam–column joints. [11]As externally bonded FRP reinforcement alone has met with only limited success in strengthening beam–column joints, this combined approach definitely deserves further work. This combined use to take advantages of both techniques should also be explored in solving other strengthening problems. The use of cement grout to replace epoxy as the groove filler has been explored by a limited amount of work.[1]

CONCLUSION :

Present paper gives an extensive literature review for behaviour and Strengthening of structures with NSM FRP reinforcement that has attracted a considerable attention as a feasible and economic alternative.

The technique can be used to increase both stiffness and flexural strength of concrete elements.

In structural behaviour of flexure and shear strengthened RC beams/slabs, the same amount of NSM reinforcement provides higher load bearing capacity and higher deflection up to failure compared to External bonded FRP laminates method.

The review has shown that the existing work is still limited in both scope and depth and many questions remain to be answered before the technique can be widely accepted by practicing engineers. Based on this review, the more research needs have been outlined for NSM FRP strengthening of concrete structures.

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