International Journal of the Physical Sciences Vol. 6(15), pp. 3567-3575, 4 August, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS10.376
ISSN 1992 - 1950

Review

Review on bonding techniques of CFRP in strengthening concrete structures

M. Z. Jumaat, M. M. Rahman* and M. A. Rahman

Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

Accepted 10 May, 2011

Selecting appropriate bonding technique is crucial for strengthening and repairing concrete structures as different bonding techniques have different performances. A state-of–the-art review of different bonding techniques that is epoxy bonding technique, prestressed strengthening technique, unbonded anchored technique/mechanically fastened technique using CFRP is dealt and the corresponding advantages and disadvantages are highlighted in this review. Existing unbonded anchored techniques/mechanically fastened techniques are critically reviewed and compared to the other conventional strengthening techniques which will help in selecting the appropriate bonding technique for strengthening and repairing concrete structures. Future recommendations in this field are also indicated in this paper.

Key words: Epoxy bonding, unbonded anchored technique, mechanically fastened technique.

INTRODUCTION

Concrete structures can become deficient during their service life and require strengthening and repairing. This need may arise as a result of design or construction errors, functional changes, design code updates, damage accumulated over time or caused by accidental overloading, fires, or earthquakes. Since replacement of deficient structures requires huge investments, strengthening has become the suitable way for improving their load carrying capacity and prolonging their service life. While complete replacement of a deficient/deteriorated structure is a desirable option, strengthening/repair is often the more economical one. Nowadays, fiber reinforced polymer (FRP) systems are used in several applications to strengthen existing RC structures instead of the traditional systems using steel. FRPs may be attached on a beam or a slab tension surface to provide additional flexural strength, on the sides of a beam to provide additional shear strength, or wrapped around columns to provide confinement and additional ductility.

In addition, concrete and masonry walls may be strengthened to resist seismic and wind loads, concrete pipes may be wrapped with FRP sheets to resist higher internal pressures and tanks may be strengthened to withstand higher pressures. In an FRP-strengthened structure, the FRP materials are attached to an existing concrete member mainly to improve the load carrying capacity. Thus, the area of the provided reinforcement is increased. The attached materials act compositely with the original member, producing a section that has an improved strength. There are many methods for strengthening, such as: section enlargement, steel plate bonding, external post tensioning method, epoxy bonded (EB) system, unbounded anchored system and near-surface mounted (NSM) system. General methods for strengthening are summarized in Table 1.

The basic concept of strengthening is to improve the strength and stiffness of concrete members by adding reinforcement to the concrete surface. Conventionally, steel reinforcement has been widely used as a strengthening material. For example, section enlargement using steel reinforced concrete, steel plate bonding, and external steel post-tensioning technique have been widely applied as shown in Table 1. Recently, strengthening by utilizing fibre-reinforced-polymer (FRP) material has been investigated and applied because of its many advantages compared to the conventional steel reinforcement.

*Corresponding author. E-mail: mukhlesrhd@yahoo.com.

Table 1. Methods for strengthening.

Methods	Description
(a) Section enlargement	"Bonded" reinforced concrete is added to an existing structural member in the form of an overlay or a jacket.
(b) Steel plate bonding	Steel plates are glued to the concrete surface by epoxy adhesive to create a composite system and improve flexural strength.
(c) External post tensioning system	Active external forces are applied to the structural member using post-tensioned (stressed) cables to improve flexural strength.
(d) Epoxy bonded (EB) system	FRP composites are bonded to the concrete surface by using epoxy adhesive to improve the flexural strength. FRP material could be in the form of sheets or plates.
(e) Near-surface mounted (NSM) system	FRP bars or plates are inserted into a groove on the concrete surface and bonded to the concrete using epoxy adhesive
(f) Unbounded /mechanically fastened system	This method uses a powder-actuated fastener gun to install mechanical fasteners and fender washers through holes in the FRP predrilled into the concrete substrate, "nailing" the FRP in place

EPOXY BONDING SYSTEM

FRP sheets or plates are bonded to the concrete surface using epoxy adhesive systems. Two general methods for this type of strengthening with FRP are: the externally bonded system and the near-surface-mounted (NSM) system. The basic concept of these two systems is to improve flexural strength and stiffness by adding FRP material to the concrete surface. To improve the bond strength between the concrete and the FRP, the concrete surface is usually treated by sandblasting. For the NSM system, FRP bars or plates are inserted into a groove that is made in the concrete surface with a concrete saw. The groove is then filled with epoxy adhesive to bond the FRP to the concrete. The externally bonded system has been more generally applied due to its simple installation procedure. Design guidelines and specifications have also been established well for this system (ACI 440.2R 2008; ISIS Design Manual No. 4 2008). In particular, their practical implementations for strengthening by epoxy bonding are numerous (Costa and Barros, 2010; Kothandaraman and Vasudevan, 2010; Ombres, 2010; Rasheed et al., 2010; Badawi and Soudki, 2009; Baghiee et al., 2009; Capozucca, 2009; Mohamed et al., 2009; Mukherjee and Rai, 2009; Tan et al., 2009; Wang and Hsu, 2009).

On the other hand, the NSM system is a relatively new technique with fewer applications performed so far. The NSM system has shown an improvement of flexural capacity with a good bond property (Lorenzis et al., 2001; Barros et al., 2008; Rasheed et al., 2010; Jung et al., 2005; El-Hacha et al., 2004a). A comparison study between the two systems showed that NSM system exhibited better load carrying capacity due to higher bond strength at the FRP-concrete interface (El-Hacha and Rizkalla, 2004; Hassan and Rizkalla, 2002). The NSM FRP composites are also protected from external mechanical damage, since they are placed within a groove in the concrete cover and are completely covered by the epoxy adhesive.

Bond characteristics in Epoxy Bonded and NSM method

The bond strength between the concrete and the FRP is extremely important to provide the composite behaviour. This bond property can be represented by the bond stress-slip relationship, which is derived from various bond tests: 1) concrete pull-out test (single or double shear test), 2) axial tension test, 3) cantilever beam test, 4) notched beam test, and 5) hinged beam test (Nanni et al., 1995). Based on these bond tests, various bond stress-slip relationships have been proposed (Dai et al., 2005; Nakaba et al., 2001). They showed that maximum bond strength is affected mainly by concrete strength,

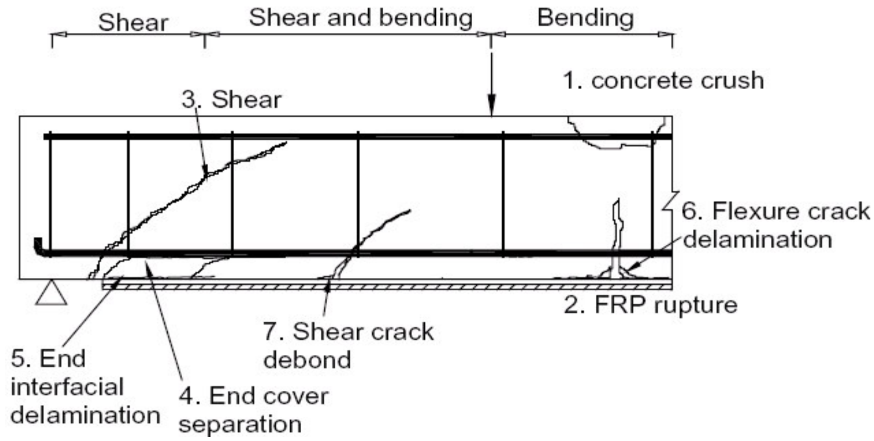


Figure 1. Failure modes of EB strengthened beams (Pham and Al-Mahaidi, 2004).

Table 2. Description of failure modes for externally bonded systems (Choi, 2008).

Failure modes		Description
Case I: Full composite action	1. Concrete crushing 2. FRP rupture	If premature failures are prevented, the ultimate flexural capacity of the beam is reached when either the FRP composite fails by tensile rupture or the concrete crushes in compression. This is similar to the classical flexural failure modes of RC beams except for the brittle failure of FRP rupture.
Case II: Premature failure	1. End cover separation	1) Failure of the concrete cover is initiated by the formation of a crack at or near the plate end due to high interfacial shear and normal stresses caused by the abrupt termination of the plate.
	2. End interfacial delamination	2) This debonding failure is initiated by high interfacial shear and normal stresses near the end of the plate that exceed the strength of the weakest element (concrete or epoxy).
	3. Flexural crack induced debonding	3) Flexural crack induced debonding happens when the concentrated bond stress at the crack location exceeds the shear strength in the weakest layer.
	4. Shear crack induced debonding	4) Shear crack induced debonding occurs in the zone where both shear and bending moment are significant. It is caused by the combination of two mechanisms. The first one is similar to that of flexural crack induced debonding. The second is by the vertical movement of the inclined crack.

thickness and stiffness of the FRP, surface preparation, strength and stiffness of the adhesive, and the bonded length (Lorenzis et al., 2001; Chen and Teng, 2001). The maximum bond strength is generally known to be between 4 and 8 MPa depending on the main influencing factors (Dai et al., 2005). On the other hand, for the NSM system, (Lorenzis et al., 2004; Lorenzis and Nanni, 2002) performed simple pullout tests for NSM bars with different variables.This research showed that the NSM groove size, type of FRP, type of epoxy, and concrete strength were the main factors affecting the maximum bond strength of the NSM system.

Failure modes of Epoxy Bonded and NSM method

The epoxy bonded (EB) system presents more failure modes in comparison to conventional reinforced concrete (RC) beams. Failure modes are classified into two types. The first type of failure includes the common failure modes such as concrete crushing and FRP rupture based on complete composite action. The second type of failure is a premature failure without reaching full composite action at failure. The failure modes of FRP strengthened structures with the epoxy bonded system are summarized in Figure 1 and Table 2. For the NSM system, premature debonding failure, such as splitting failure or pull-out failure, has been observed, but general failure modes have not been widely reported due to the lack of experimental data.FRP strengthened beams often fail prematurely without reaching the full capacity of the FRP or the concrete due to the limit of the bond strength between the FRP and the concrete. This type of failure occurs suddenly without warning. Many studies have been performed to explain each premature debonding failure mode; however, the exact mechanism for the premature bond failures has not yet been established due to numerous influencing factors affecting the bond strength at the FRP-concrete interface.

Mechanical anchors for Epoxy Bonded system

Various anchor systems such as bolts, mechanical anchors, or U-shaped sheets have been investigated as end anchors for the epoxy bonded system. Eshwar et al. (2008) developed two different types of FRP based anchor system, namely, a near surface mounted (NSM) end anchor and a spike anchor. They found that each of these systems was highly effective in increasing the capacity of the strengthened member by delaying debonding failure. Researchers studied the use of end anchorage techniques, such as U-straps, L-shape jackets, and steel clamps for preventing premature failure of RC structures with CFRP anchors for epoxy bonded RC structure (Ceroni, 2010; Jumaat and Alam, 2010; Jumaat et al., 2010; Wang and Hsu, 2009; Aram et al., 2008; Ceroni et al., 2008; Xiong et al., 2007; Pham and Al-Mahaidi, 2006).

PRESTRESSED FRP STRENGTHENING SYSTEM

FRP composites are being investigated as an alternative material for prestressing due to their high tensile strength, low relaxation losses and high corrosion resistance compared to conventional steel tendons. Numerous research and demonstration projects utilizing FRP prestressed tendons have been performed and full scale FRP prestressed concrete bridges have been constructed around the world (ACI 440.4R 2004). In contrast, limited research is reported on the use of prestressed FRP system for repairing and strengthening purposes. The main advantage of this system is the recovery of the serviceability of structures, such as crack closure and deflection reduction. On the other hand, the disadvantages of prestressed FRP strengthening system are complicated installation procedure and low deformability compared to prestressed steel tendons. Wight et al. (2001), and El-Hacha et al. (2003) investigated prestressed FRP sheets and they concluded that prestressed CFRP sheets could remarkably improve the serviceability, as well as the ultimate strength of the beam. One of the challenges of prestressed externally bonded systems is the development of a proper anchor system at the ends of the FRP because the shear stress (bond stress) and normal stress (peeling stress) become extremely high at the end of the FRP due to prestressing. As a result, various anchor systems have been developed and investigated. Their research showed that an improvement of the ultimate flexure response was achieved in prestressed strengthened beams with anchors compared to beams with no anchors.

On the other hand, prestressed NSM system utilizing carbon FRP (CFRP) bars or plates has been recently investigated. Nordin and Taljsten (2004, 2006) applied a prestressed NSM system to RC beams and found that the ultimate load carrying capacity and the serviceability were greatly improved and that the force transfer from the FRP to the structure was working well without an external anchor unlike externally bonded prestressing system. Jung et al. (2007) tested prestressed NSM beams using both the CFRP bar and plate with the prestressing force of 20% of the ultimate CFRP strength and also compared the test results with the non-prestressed beams. They concluded that the cracking load and the stiffness of the beam were greatly improved compared to the non-prestressed beams and could prevent the premature debonding failure. Gaafar and El-Hacha (2007) tested prestressed NSM beams with various prestressing levels. They found that the serviceability and the ultimate load carrying capacity were improved as the level of the prestressing force was increased while deformability was decreased when increasing the prestressing force. They concluded that the optimum prestressing limits was between 35 and 45% based on the test results. Badawi (2007) investigated the monotonic and fatigue performance of prestressed NSM strengthened beams. He found that the prestressed strengthened beams showed an improved performance of static and fatigue resistance compared to unstrengthened beams.

Application of prestressed FRP strengthening systems

In contrast to the steel, FRP materials have very low transverse load carrying capacity. Therefore, application of a prestressed FRP system requires development of an appropriate anchor system. General prestressed FRP strengthening systems developed so far are summarized in Table 3.

Mechanically fastened FRP strengthening system

A new strengthening technique has recently been introduced based on mechanically fastening (MF) FRP plates to the concrete, without any bonding, by means of closely spaced powder actuated fasteners.This technique

Table 3. Various prestressed FRP strengthening systems (Choi, 2008).

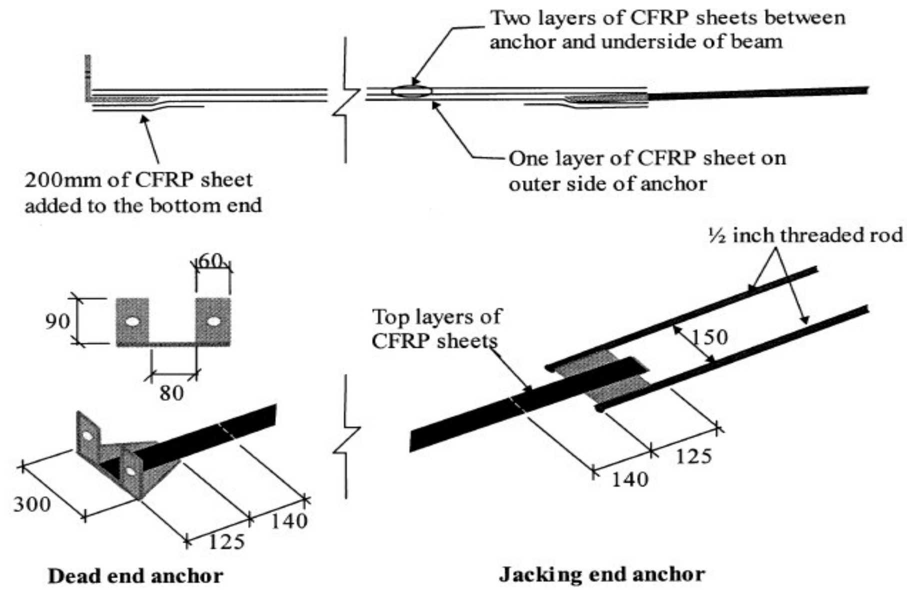
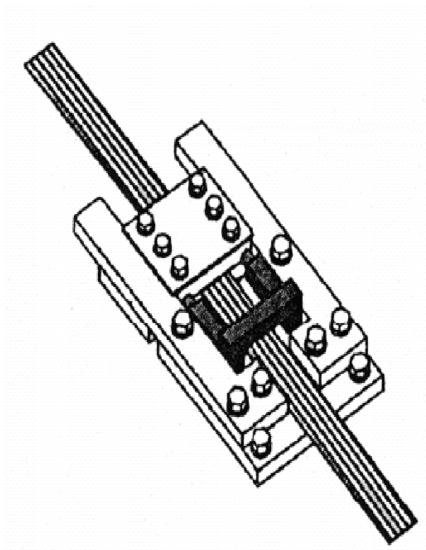
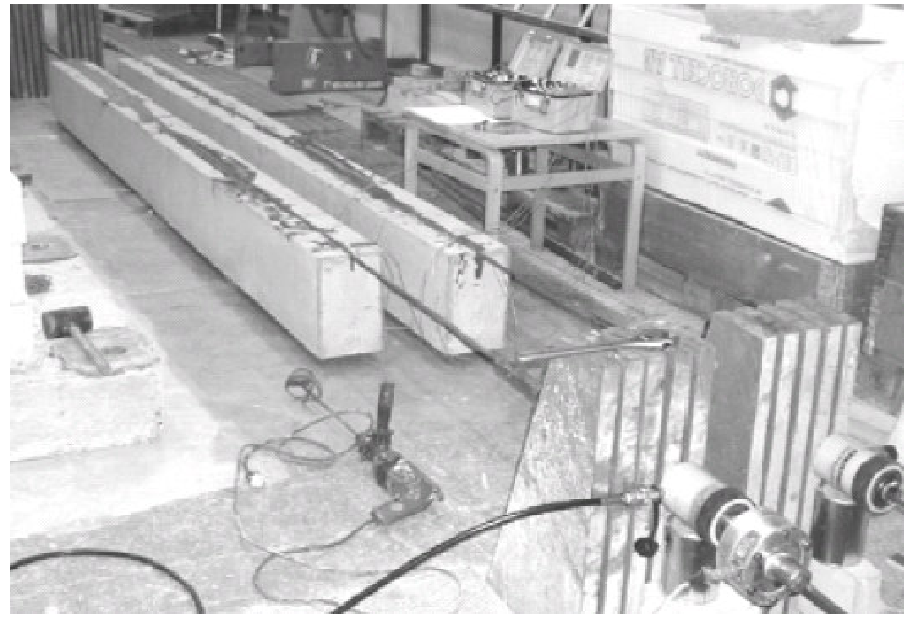
System	Description	Examples
FRP sheet (EB)	Strengthening using prestressed FRP sheets has been developed and investigated (Wight et al., 2001; El-Hacha et al., 2003; El-Hacha et al., 2004b). Various anchor systems for prestressing FRP sheets such as: round bar anchor, elliptical anchor and flat plate anchor were developed. The figure shows an example of flat plate anchor for prestressing FRP sheets developed by (El-Hacha et al., 2003).	
FRP plate (EB)	Initial intensive research and development project with regard to the strengthening with prestressed FRP plates were performed in the beginning of the 1990's. Various anchor systems for prestressed FRP plate have been developed and applied in the real structures (Millar et al., 2004). The figure shows one of the anchors for the prestressed EB plate system.	

Table 3. Contd.

FRP bar (NSM)	Strengthening with prestressed FRP bars can be applied effectively by the use of NSM bars. Shown is the prestressing setup for prestressed NSM bars developed by (Nordin and Taljsten, 2004).	
FRP bar (external Tendon)	Strengthening with prestressed FRP bars can be applied by the use of external tendons. Shown is the prestressing set-up for prestressed FRP bars developed at Waterloo (El Refai., 2007)	

utilizes off-the-shelf tools to attach pultruded FRP strips to the concrete. This technique has many advantages as its rapid installation using simple hand tools, no special labour skills are needed and no surface preparation is required. With this system, it is also possible to use the strengthened structure immediately after the installation of the FRP strengthening strips. Furthermore, this system provides an anchorage mechanism since it consists of using mechanical fasteners (Bank, 2004). With this technique, the attached FRP strips must have a high bearing strength as well as high longitudinal strength. The fasteners are embedded into the concrete using a powder actuated fastening gun. Adequate embedment of the fasteners is required in order to secure the FRP strip to the concrete surface (Lamanna et al., 2004).

The fasteners can be shot directly into the concrete surface or can be driven in shallow pre-drilled holes in the concrete. The latter is recommended to reduce initial surface cracking and concrete spoiling during the fastener driving and to increase the tensile and shear capacity of the embedded fastener. Some notable disadvantages of this method have been observed, including scale effects, greater initial cracking induced by the impact of fasteners in higher-strength concrete and less-effective stress transfer between the FRP and the concrete because of discrete attachment points. However, failure modes in these specimens are more ductile than failures associated with the externally epoxy bonded method. In cases where speed and ease of installation are major concerns, mechanically anchored FRP method is a viable option (Borowicz, 2002).

Previous works on mechanically fastened FRP strengthening system

A few research investigations have examined the feasibility of using the mechanically fastened technique for the external strengthening of RC structures. In one of these investigations, small-sized beams strengthened with MF FRPs were tested and the results were compared with the results from beams strengthened with conventional bonded FRPs and to the results from a control beam (Lamanna et al., 2001). The gained strength for the mechanically fastened technique was up to 70% of that from the conventionally bonded technique. The mechanically fastened technique was extremely rapid and the failure modes of the strengthened beams were more ductile than those strengthened by the bonded method. Initial cracks developed in the concrete due to the shooting of the fastener. Nevertheless, results from preliminary studies indicate that significant strength increase is possible through the use of mechanically anchored unbonded FRP strengthening system in specimens tested under monotonic conditions (Borowicz, 2002).Later on; Lamanna et al. (2004) tested 15 RC beams. Two beams were unstrengthened, twelve were strengthened with mechanically fastened FRP strips and one was strengthened with a bonded FRP strip. The effects of three different strip moduli, different fastener lengths and layouts, and predrilling holes were examined. It was concluded that, by using the mechanically fastened method, it was possible to achieve a failure mode similar to that of a conventional reinforced concrete beam. Predrilling holes reduced the amount of visible initial cracking and concrete spalling and allowed greater penetration of the fasteners, resulting in a better overall strengthening and ductility.

More recently, Galati et al. (2007) studied the effect of anchoring systems on the performance of FRP strengthening systems. Five RC beams were strengthened with pre-cured FRP laminates using chemical and mechanical anchoring devices. The results showed that the use of anchors increases the ultimate capacity of the strengthened beam and the mechanically fastened FRP system is a valid alternative to the bonded FRP systems. In addition, the use of the mechanically fastened system results in a pseudo-ductile mode of failure. At last, Lee et al. (2007) studied the short-term effects of simultaneous environmental exposure and sustained load on RC beams strengthened with mechanically fastened FRP strips. Different types of fasteners and anchors were used in this investigation. The tested beams were subjected to two different conditions: 1) outdoor weather and 2) high temperature effects. A total of 60 freeze/thaw cycles were obtained from the outdoor hourly temperature data. The applied sustained moment at mid-span was about 27% of the concrete crushing moment of the mechanically fastened FRP-strengthened beam. It was found that no degradation under the different environmental conditions with and without sustained load occurred during a six-month trial period.

In addition to the aforementioned laboratory investigations, several case studies have been conducted to address the analysis, design, installation and testing for five old deficient bridges (Lee et al., 2007). In all situations, the mechanically fastened FRP system proved to be a feasible solution for the strengthening of the major damaged areas of the bridges. From the earlier discussion, it is clear that mechanically fastening (MF) system is an emerging technique for strengthening RC structures. It has many advantages over other conventional strengthening techniques, but this technique is still in its infancy. So, further research in this field is necessary to understand the uniqueness of this technique.

CONCLUSION

This paper reviewed the research works on different bonding techniques using CFRP. It is addressed an important practical issue which points into selecting appropriate bonding technique in different conditions of

RC structures. Existing unbonded anchored techniques / mechanically fastened techniques are critically reviewed and compared to the conventional strengthening techniques which will help in selecting the appropriate bonding technique for strengthening and repairing concrete structures.

FUTURE NEEDS

There is still a need for further experimental work on reinforced concrete structures strengthened with the mechanically fastened method to uncover its unique benefits and to fully understand the structural behaviour of mechanically fastened FRP-strengthened members. The following are some recommendations for future work:

1. A broader parametric study should be performed. Parameters such as effect of the number of fastener rows, spacing between fasteners, and different fastener arrangements could be of particular interest.
2. Practical design guidelines need to be developed for designing reinforced concrete structures strengthened with the mechanically fastened system.
3. Fatigue testing on full-scale specimens strengthened with the mechanically fastened system need to be conducted.
4. Issues such as the long-term durability, degradation of the FRP strips at the fastener locations, and environmental effects need to be studied in greater depth.
5. It is strongly recommended for the modelling of FRP-strengthened structures to incorporate an appropriate interface model between the concrete and FRP, to accurately simulate the interfacial behaviour and to obtain reliable predictions of the response of FRP-strengthened structures.
6. For determining the general failure mode of NSM method more research work is necessary.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the grant provided by the University of Malaya to fund the research work.

REFERENCES

ACI 440.2R-08 (2008). Guide for the Design and Construction of Externally Bonded FRP System for Strengthening Concrete Structures. ACI Committee 440, American Concrete Institute, Farmington Hills, MI, 45 pp.
ACI 440.4R-04 (2004). Prestressing Concrete Structures with FRP Tendons. ACI Committee 440, American Concrete Institute, Farmington Hills, MI, 35 pp.
Aram MR, Czaderski C, Motavalli M (2008). Debonding failure modes of flexural FRP-strengthened RC beams. Compos. Part B: Eng., 39: 826-841.
Badawi M (2007). Monotonic and Fatigue Flexural Behaviour of RC Beams Strengthened with Prestressed NSM CFRP Rods. PhD thesis, University of Waterloo, Waterloo, Ontario, Canada.
Badawi M, Soudki K (2009). Flexural strengthening of RC beams with prestressed NSM CFRP rods – Experimental and analytical investigation. Constr. Build. Mater., 23: 3292-3300.
Baghiee N, Esfahani RM, Moslem K (2009). Studies on damage and FRP strengthening of reinforced concrete beams by vibration monitoring. Eng. Struct., 31: 875-893.
Bank LC (2004). Mechanically fastened FRP (MF-FRP) - A viable alternative for strengthening RC members. FRP Composites in Civil Engineering- Seracino, Ed.,Adelaide, AUSTRALIA, University of Adelaide.
Barros JAO, Varma RK, Sena-Cruz JM, Azevedo AFM (2008). Near surface mounted CFRP strips for the flexural strengthening of RC columns: Exp. Eng. Struc., 30: 3412-3425.
Borowicz DT (2002). Rapid strengthening of concrete beams with powder-actuated fastening syst. and fiber reinforced polymer (FRP) composite material. MS thesis, Department of Civil Engineering, University of Wisconsin-Madison, Madison, Wise. USA.
Capozucca R (2009). Static and dynamic response of damaged RC beams strengthened with NSM CFRP rods. Compos. Struct., 91: 237-248.
Ceroni F (2010).Experimental performances of RC beams strengthened with FRP material. Constr. Build. Mater., 24: 1547-1559.
Ceroni F, Pecce M, Matthys S, Taerwe L (2008). Debonding strength and anchorage devices for reinforced concrete elements strengthened with FRP sheets. Compos. Part B: Eng., 39: 429-41
Chen JF, Teng JG (2001). Anchorage Length Models for FRP and Steel Plates Bonded to Concrete. J. Struct. Eng., 127: 784-791.
Choi HT (2008). Flexural Behaviour of Partially Bonded CFRP Strengthened Concrete T-Beams. PhD thesis, University of Waterloo, Civil and Environmental Engineering, Waterloo, Ontario, Canada.
Costa IG, Barros JAO (2010). Flexural and shear strengthening of RC beams with composite material - The influence of cutting steel stirrups to install CFRP strips. Cem. Concr. Compos. In Press, Corrected Proof.
Dai J, Ueda T, Sato Y (2005). Devel. of the Nonlinear Bond Stress-Slip Model of Fiber Reinforced Plastics Sheet-Concrete Interfaces with a Simple Method. J. Compos. Constr., 9: 52-62.
El-Hacha R, Filho DS, Melo GS, Rizkalla SH (2004a). Effective of Near Surface Mounted FRP Reinforcement for Flexural Strengthening of Reinforced Concrete Beams. Proceedings of International Conference on Advanced Composite Materials in Bridges and Structures, ACMBS-IV, Calgary, Ontario, Canada.
El-Hacha R, Green MF, Wight RG (2003). Innovative System for Prestressing FRP Sheets. ACI Struct. J., 100: 239-252.
El-Hacha R, Green MF, Wight RG (2004b). Flexural Behaviour of Concrete Beams Strengthened with Prestressed Carbon Fibre Reinforced Polymer Sheets Subjected to Sustained Loading and Low Temperature. C. J. Civil Eng., 31: 239-252.
El-Hacha R, Rizkalla SH (2004).Near-Surface-Mounted Fiber-Reinforced Polymer Reinforcements for Flexural Strengthening of Concrete Structures. ACI. Struct. J., 101: 717-726.
El Refai A (2007). Monotonic and fatigue flexural performance of RC beams strengthened with externally post-tensioned CFRP tendons. PhD thesis, University of Waterloo, Waterloo, Ontario, Canada.
Eshwar N, Nanni A, Ibell TJ (2008). Performance of Two Anchor Syst. of Externally Bonded Fiber-Reinforced Polymer Laminates. ACI Mater. J., 105: 72-80.
Gaafar MA, El-Hacha R (2007). Prestressing concrete beams using NSM FRP technique. Proceedings of International Symposium on Fiber-Reinforced Polymer Reinforcement in Concrete Structures. FRPRCS-8, Partas, Greece, pp. 8-11.
Galati D, Rizzo A, Micelli F (2007). Comparison of reinforced concrete beams strengthened with FRP pre-cured laminate system and tested under flexural loading. In Proceedings of the Eighth International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures, FRPRCS-8, Thanasis C. Triantafillou, Ed., Patras, GREECE, 10 p.
Hassan T, Rizkalla SH (2002). Flexural Strengthening of Prestressed Bridge Slabs with FRP System. PCI J., 47: 76-93.
ISIS Canada Network of Excellence (2008). FRP Rehabilitation of Reinforced Concrete Structures. Design Manual, No. 4, ISIS Canada Corporation, Winnipeg, Manitoba, Canada.

Jumaat MZ, Alam MA (2010). Experimental and numerical analysis of end anchored steel plate and CFRP laminate flexurally strengthened R. C. beams. Int. J. Phys. Sci., 5: 132-144.
Jumaat MZ, Rahman MM, Alam MA (2010). Flexural strengthening of RC continuous T beam using CFRP laminate: A review. Int. J. Phys. Sci., 5(6): 619-625.
Jung WT, Park HY, Park JS, Kang JY, Yoo YJ (2005). Experimental Investigation on Flexural Behavior of RC Beams Strengthened by NSM CFRP Reinforcement." Proceedings of International Symposium on Fiber-Reinforced (FRP) Polymer Reinforcement for Concrete Structures. ACI Symp. Publication, SP-230-46, pp. 795-806.
Jung WT, Park JS, Park YH (2007). A study on the Flexural Behavior of Reinforced Concrete Beams Strengthened with NSM Prestressed CFRP Reinforcement. Proceedings of International Symposium on Fiber-Reinforced Polymer Reinforcement in Concrete Structures. FRPRCS-8, Partas, Greece, pp. 8-10.
Kothandaraman S, Vasudevan G (2010). Flexural retrofitting of RC beams using external bars at soffit level - An experimental study. Constr. Build. Mater. In Press, Corrected Proof.
Lamanna AJ, Bank LC, Scott DW (2004).Flexural strengthening of RC beams by mechanically attaching fiber-reinforced polymer strips. J. Compos. Constr., 8(3): 203-210.
Lamanna AJ, Bank LC, Scott DW (2001). Flexural strengthening of RC beams using fasteners and fiber-reinforced polymer strips. ACI Struct. J., 98(3): 368-376.
Lee JH, Lopez MM, Bakis CE (2007).Flexure behaviour of reinforced concrete beams strengthened with mechanically fastened FRP strip. In Proceedings of the Eighth International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures. FRPRCS-8, Thanasis C. Triantafillou, Ed*.,* Patras, GREECE, 9 p.
Lorenzis L., Nanni A (2002). Bond between Near-Surface Mounted Fiber-Reinforced Polymer Rods and Concrete in Structural Strengthening. ACI Struct. J., 99(2): 123-132.
Lorenzis L, Lundgren K, Rizzo A (2004). Anchorage Length of Near-Surface Mounted Fiber-Reinforced Polymer Bars for Concrete Strengthening - Experimental Investigation and Numerical Modeling. ACI Struct. J., 101(2): 269-278.
Lorenzis L, Miller B, Nanni A (2001). Bond of Fiber-Reinforced Polymer Laminates to Concrete. ACI Mater. J., 98(3): 256-264.
Millar D, Scott P, Clenin R (2004). Bridge Strengthening with Prestressed CFRP Plate System. Proceedings of the Second International Conference on FRP Composites in Civil Engineering, Adelaide, Australia, pp. 463-469.
Mohamed BB, Abdelouahed T, Samir B (2009). Approximate analysis of adhesive stresses in the adhesive layer of plated RC beams. Comput. Mater. Sci., 46: 15-20.
Mukherjee A, Rai GL (2009). Performance of reinforced concrete beams externally prestressed with fiber composites. Constr. Build. Mater., 23: 822-828.
Nakaba K, Kanakuto T, Furuta T, Yoshizawa H (2001). Bond Behavior between Fiberreinforced Polymer Laminates and Concrete. ACI Struct. J., 98(3): 359-367.
Nanni A, Bakis CE, Boothby TE (1995).Test method for FRP-concrete systems subjected to mechanical loads: Stage of the art review. J. Rein. Plast. Compos., 14(6): 524-558.
Nordin H, Taljsten B (2004). Prestressed Near Surface Mounted Reinforcement (NSMR) for Strengthening Concrete Beams. Proceedings of the Second International Conference on FRP Composites in Civil Engineering, Adelaide, Australia, pp. 447-454.
Nordin H, Taljsten B (2006). Concrete beams strengthened with prestressed near surface mounted CFRP. J. Compos. Constr., 10(1): 60-68.
Ombres L (2010). Prediction of intermediate crack debonding failure in FRP-strengthened reinforced concrete beams. Compos. Struct., 92: 322-329.
Pham H, Al-Mahaidi R (2006). Prediction models for debonding failure loads of carbon fiber reinforced polymer retrofitted reinforced concrete beams. J. Compos. Constr., 10: 48-59.
Pham H, Al-Mahaidi R (2004). Assessment of Available Prediction Models for the Strength of FRP Retrofitted RC Beams. Compos. Struct., 66(1-4): 601-610.
Rasheed HA, Harrison RR, Peterman RJ, Alkhrdaji T (2010). Ductile strengthening using externally bonded and near surface mounted composite systems. Compos. Struct., 92: 2379-2390.
Tan KH, Saha MK, Liew YS (2009). FRP-strengthened RC beams under sustained loads and weathering. Cem. Concr. Compos., 31: 290-300.
Wang YC, Hsu K (2009). Design recommendations for the strengthening of reinforced concrete beams with externally bonded composite plates. Compos. Struct., 88: 323-332.
Wight RG, Green MF, Erki MA (2001). Prestressed FRP Sheets for Poststrengthening Reinforced Concrete Beams, J. Compos. Constr., 5(4): 214-220.
Xiong GJ, Jiang X, Liu JW, Chen L (2007). A way for preventing tension delamination of concrete cover in midspan of FRP strengthened beams. Constr. Build. Mater., 21: 402-408.