A Review on NSM-CFRP technique using in Shear Strengthening of RC Deep Beams

Mohanad Hatem*, Abdul Aziz Abdul Samad, Noridah Mohamad, Goh Wan Inn and Saad Abdulqader

Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Malaysia; mohshadhar@gmail.com, azizs@uthm.edu.my, noridah@uthm.edu.my, Wigoh@uthm.edu.my, saad_22660@yahoo.com

Abstract

Near-Surface Mounted (NSM) using Fiber-Reinforced Polymer (FRP) bars has been become an effective technique to improve flexural and shear behavior of existing and or new Reinforced Concrete (RC) elements. This is an innovative and emerging technique and much attention has been given by researchers. Thus, this paper attempts to review past and present studies related to the shear strengthening of RC deep beams using NSM-CFRP bar. The past and present research results were obtained through four major databases namely: ASCE, EBSCO, SCOPUS and Science Direct. The careful concern has been taken to review the literature focusing on NSM-CFRP in shear strengthening. The total final set of 56 articles categorized into three main classes. Class 1 comprises on the review studies on the usage of NSM for shear strengthening. Class 2 includes articles related to the structural behavior of RC members' strength in shear. Class 3 includes articles related to theoretical aspects of the NSM-FRP on shear strength for developing a new approach to calculate shear influences provided by NSM-FRP. In conclusion, this study identifies three basic characteristics of this field: (1) the motivation of using NSM-FRP bars in shear and its applications, (2) open challenges and hindering utilization and (3) the recommendations to improve the acceptance and use of NSM-FRP bars.

Keywords: Application, Concrete Fiber-reinforced Polymer, Deep Beam, Near-surface Mounted, Shear Strengthening

1. Introduction

The durability of the RC structures gradually reduces during the age of structure by time. The resistance of RC concrete members is also reduces because of the corrosion of steel by the environmental factors. Therefore, the strengthening of concrete members becomes very important as the maintenance of structure members took less time and cost as compared to rebuilding them. Although there are many techniques are currently employing to strengthen the RC beams. Recently the usage of FRP attains more attention on account of many attractive properties such as good corrosion resistance, high strength to weight ratio, easy to construct, strengthen RC structures and requires less number of labor as comparing with the other conventional techniques.

The FRP technique has been used successfully since1990's and is being used in RC columns and beams to increase the shear and flexural strength. For the strengthening of RC beams in shear, FRP can be done by using various techniques such as to bond externally on both sides, completely warped with bottom of beams using glass / carbon fiber sheets with U shape warping and

*Author for correspondence



Figure 1. Wrapping schemes for externally bonded FRP¹.

installed by using epoxy adhesive in between the concrete surface and the FRP sheets as shown in Figure 1. Whereas; the second method is the embedded through concrete member as shown in Figure 2 and can be done by drilling holes and embedded the FRP bars using epoxy adhesive through the depth of RC beams for improving the shear or flexural strength of RC beams. FRP technique also improves the resistance of splitting and the effectiveness of bond material or the FRP bar to the environmental. Because of the advantage that has been discussed above; the use of CFPR-NSM has developed recently novel technique to increase the strength of RC members or repair the new / exists member. Figure 3 shows the various groove patterns.

The emergence of Fiber-Reinforced Polymer (FRP) materials has been known as an alternative material for bars reinforcement for concrete members. Generally, FRP can be defined as composites material and as an



Figure 2. Embedded through section technique².



Figure 3. Various pattern of NSM technique³.

alternative to steel reinforcement due to high strength ratio to lightweight, high strength to resist the corrosion in destructive environmental factors. Among other advantages; FRP fibers are high strength to weight ratio, however; the properties of the FRP composite influence mainly by the choice of fiber.

The FRP composites consist of 30% to 70% fibers out of total volume. 50% of its weight ratio, the fiber can carry the load and provide strength, thermal stability, stiffness, and other structural properties to the FRP⁴. Also, FRP composites have high modulus of elasticity, high ultimate strength, the low variation of strength among fibers, high stability of their strength during handing and high uniformity of diameter and surface dimension among other fiber composites. The matrix ensures the position and alignment of the fibers, protection from damage during construction and implication, durability of the composite as well as the protection from the influence of the environment. It is also responsible for the distribution of the loads on the individual fibers⁵.

To sum up; because of high strength and lightweight, the application of FRP composite observed in aircraft, sports equipment, spaceships industry but found more attractive and emerging composite material for the construction industry. Moreover; numerous kinds of fibers: carbon (CFRP), glass (GFRP), aramid (AFRP) or basalt (BFRP) fibers dominating in civil engineering structures.

2. Method

The latest and critical research articles relating to NSMT-CFRP has been reviewed through many venerated and reputed sources including Journals, Technical Reports, Web Blogs and many more. However; the focus has been also taken to highlight the importance of the subjected research. Furthermore; on the basis of reviewed literature; the research gap has been accomplished to best bit the research area. Among the other activities conducted during this research work, the literature was reviewed to discover the challenges and problems in NSM-CFRP research area.

Only English writing journal articles were selected with main focused on the shear strengthening for structural members using NSM with CFRP (bars and laminate). Whereas; the exact query of search is shown in Figure 4. In this research work, the literature has been done through systematic review method analysis has been done through four databases (ASCE, EBSCO, SCOPUS, and SCIENCE DIRECT Databases) from 2008 until 2017. Moreover, this research considered some other important articles from Google scholar to support the concepts of the review work. Likewise; the advanced search options in the search engines were used to exclude book chapters, short communication, correspondences and letters and gain access to up-to-date scientific works relevant to review for this emergent trend of NSM technique and its application in shear strengthening of structural members. A mix key word used in each database classified as ("Deep beam" AND CFRP) ("Deep beam "AND NSM) ("Deep beam "AND "shear strengthening") ("shear strengthening "AND NSM) in advance search engine.

Initially, set a target for mapping the space of research on NSM-CFRP and its applications on shear strengthening into a general and coarse-grained taxonomy of three categories. After the initial removal by scanning of the duplicate articles, remaining articles were filtered by two iterations with title and abstract and by full text reading. The exclusion criteria included: (1) the article is non-English (2) the article is focused on flexural strength of structural members (3) the use of NSM with other type of FRP, AFRP and GFRP bars for strengthening of structural members but very few articles were available on shear strengthening of RC members using NSM-CFRP. Thus, the final sets of articles were classified in detail by using taxonomy. A taxonomy classification suggests various classes and subclasses in three main categories: review, structural behavior, and theoretical studies. All the collected studies from different databases were classified and analyzed to provide intensive overview for the reader in this field.

3. Results and Statistical Information

The scanning of systematic literature review identified 561 total articles. 119 articles from ASCE, 89 articles from EBSCO, 148 Articles from Scopus and 205 articles from Science Direct were discovered. At first scrutiny, exclude the duplicated articles which causing 436 articles left and during second inquiry to remove the non-related articles on the basis of their title and abstract. Finally, obtained a total of 56 published papers excluded after the full scan of keywords related to shear strengthening for structural elements by using NSM with CFRP. All these 56 most relevant to the research topic of this review describing experimental studies, numerical studies and the bond behavior of CFRP bars or laminates within concrete (in case of strengthening of concrete members by CFRP NSM technique). Figure 6 presented review of the main streams on research focusing on NSM and generally show that the four databases for numerous research work.

The results of the deep beam strength with NSM-CFRP highlighted in this review work are divided into five categories as: experimental, numerical, theoretical, bond and review studies. The total number of selected published articles from Scopus was 26 consisting 18 articles for an experimental studies, 3 articles for bond studies, 3 for theoretical studies, 2 on numerical and 1 for review paper. While from Science direct database 15 published articles were selected consisting of 5 articles for experimental studies and bond of FRP studies, 2 for numerical studies, 2 articles for theoretical study and 1 for review study on applications of NSM. And form ASCE database, 8 published articles were selected and comprising of 3 articles for experimental work, 3 for



Figure 4. Flowchart of selected study, with search query and criteria of inclusion.

bond studies and 2 for theoretical studies. In the end, the total number of selected articles published in EBSCO database was 6 articles which comprising of 5 articles for experimental work and 1 for a bond of FRP studies.

3.1 Review

The review studies carried by ⁶ and 7 to describe Near-Surface-Mounted (NSM-FRP) technique concluded that it is the latest, the most promising and efficient for improving both shear and flexural strength. Further concluded that the based on previous experimental research, analytical and numerical studies; the NSM is very effective and proficient technique to increase the strength of concrete elements and Unreinforced Masonry Wall (USM) in shear.

3.2 Experimental Studies

The other category of reviewed work in this research work is the experimental studies regarding the structural behavior. In this category; highlight the experimental work to evaluate the structural behavior. The experimental work done by ⁸ investigated the shear strengthening behavior on a four rectangular RC beams and concluded that NSM-CFRP improved shear strength by 24.4%, 17% and 19.5%



Figure 5. A taxonomy of research literature on shear strengthening by NSM CFRP.

as compared with the control RC beam. Also; showed that shear strength by NSM increased about 17% - 25%, and the average of shear strength gain more than 20%². Similarly study by ¹⁰ investigated the behavior of nine RC beams and found that shear capacity was increased about 16% with externally bonded laminates, and from 22% and 44% range for the beams strengthened with NSM CFRP bars. Likewise, the effectiveness of use NSM-CFRP on shear strengthening by ¹¹ and found that ultimate shear strength increased about 253% max as compared with the control beam. By using both techniques in their research concluded that the failure of beams occurred at shear crack and the average strain obtained through NSM was higher than EBR. Continuous to such discussion, nine

cantilever RC beams investigated by ¹² showed that NSM provide increase in shear strength about 57%-112% and 21% and 88% of maximum strain value.

The ratio of CFRP has a direct impact on the flexural strength and load carrying capacity of the RCC beam. It was concluded that NSM CFRP strips having 0.4% reinforcement ratio for longitudinal steel is 50% higher as compared with various other ratios chosen¹³. Also NSM-CFRP technique is also effective on the lower concrete strength (18.6 MPa), where load carrying capacity improved and similar criteria has been also observed even after the shear crack. But the inclined CFRP laminates provide more effectiveness for shear capacity¹⁴.



Figure 6. Results distribution by data bases.

For the CFRP strips bonding criteria, the externally bonded sheet and internally embedding through section had increased the shear capacity about 30%. Whereas the beams constructed through NSM-CFRP strips and internally embedding by GFRP bars increase the shear capacity to 60%15. Furthermore, the effectiveness of NSM-CFRP on six RC beams and found 25% and 30% shear enhancements for beams strengthened with simple FRP bars, 41%-48% for beams strengthened with anchored FRP and 60% for beams with end anchored bars. The ultimate deflection increased by 40-75% for beams strengthened with anchor bars¹⁶. From the experimental results through investigation by 17 concluded that the NSM provided a shear capacity higher than the EBR due to the load carrying capacity and higher maximum strain values. In their research, the maximum values of shear strength attained 34% and 59% for EBR and NSM respectively. For compressive strength, NSM is very effective method to improve the average compressive strength and found 60 MPa. Whereas inclined laminate

improved the maximum load range about 35%-62% and the maximum strain values were obtained as 0.82%-1.54% corresponding to 50% and 94% of 1.63%¹⁸. Similar results obtained by ¹⁹ showed that the enhancements of shear leading range 3-80% for a different category of strengthening on the basis of investigating sixteen RC strengthened beams behavior.

The study of ²⁰ showed that the NSM technique is more effective than the Externally-Bonded. As NSM-CFRP rod reduce the maximum slip of the tensile of steel bars and no significant in load capacity on NSM CFRP rods in the corroded beam for those who a/d ratio less than 2²¹. NSM technique was used for seven RC beams and resulted that it improved shear strength about 43.6% and 34.6% by pre-grooved cuts. Besides that, results showed that epoxy resin provides better performance than the mortar²². Furthermore, NSM technique can also improve natural frequencies as small value as compared with it before inserting of CFRP²³. Shear capacity and failure displacement of twelve pre-stressed RC beams were improved by 52.0% and 34.4%. But for the beams reinforced in shear stirrups the shear improvement for (900) and (450) and about 50% and 54% respectively²⁴. Additionally, twelve T-cross section RC beams studied by ²⁵ an experimental program was carried out, using three percentages of laminates and, for each one, three inclinations: 90, 60, and 45°. The CFRP-strengthened beams had a steel stirrup reinforcement ratio (p sw and concluded that shear capacity increased as 33% for 60°. The load capacity for 45° is less than the 60° by 28.2%. For the vertical 90° provide 26.5% increment in load capacity. NSM-CFRP technique used on four T-beams by ²⁶ found that NSM-CFRP improved the shear capacity as 15 to 18% as compared with the control beam. Whereas; NSM-CFRP technique used by 27 for fifteen T-cross section beams concluded that in terms of load carrying capacity, NSM is more effective than the EBR. However; the 450 inclination is the most effective for load carrying capacity.

Use of NSM reduce the diagonal cracks due to all level of load and NSM-CFRP increased the shear cracking force of T-beams from 23%-85%²⁸. Similarly, the maximum load and carrying load capacity after shear crack are improved by NSM. But further improvement in shear capacity observed in inclined laminate¹⁵

. Furthermore, NSM increase the average concrete compressive strength of about 60 MPa increase the maximum load capacity about 40% - 53% and maximum strain improvement observed from 74% - 94%³⁰. Such conclusion also found in the research work by 31 and proved that NSM technique is effective to improve the shear strength of RC beams. The various configurations of using NSM-CFRP provided a load capacity after shear crack and in terms of maximum load. But the shear contributions of NSM-CFRP are limited by the compressive strength of concrete in studied forty-nine T-beams. NSM CFRP strips increase the shear strength for retrofitted wall panels from 1.3-2.6 for walls and 1.3-3.7 times for panels³². The study done by $\frac{33}{2}$ proved that NSM greatly enhanced the whole behavior of RC beams due to the load failure and provide an increment up to 31% on average also reduce the maximum deflection as compared with the control beams.

NSM technique is more effective than EB on account of the debonding. Such has been observed that the punching shear strength improved 29% as compared with un-strengthened flat slab and 14% for NSM strengthening. Also, not any debonding failure was recorded with NSM. While no any shear stress improvement observed but the maximum strains about 0.15% to 0.20% were recorded for CFRP³⁴. The study of ³⁵ showed that maximum load enhanced from 66%-81%, the maximum tensile strain in laminates from 12.2% to 16.3%. The ultimate tensile strain of laminates improved 69% but the inclined laminate provide more ductility. The use of NSM-CFRP for bars to shear strengthening of RC deep beams by ³⁶ found increment from 17.3% to 25.5% on shear capacity, the deflection reduction from 6.1% to 16.3% as compared with the control beam. Lastly, the research work done by ³⁷ showed shear strength increased from 21%-83% and the tensile strain about 54%-81% for five T-cross section beams.

3.3 Numerical Studies

For the numerical studies done on NSM-FRP, many authors concluded that it is most effective technique for shear strengthening of the RC beams. In this connection, a three-dimensional mechanical model has been developed by ³⁸ to simulate the contribution of RC beams strengthened by NSM-FRP strips and further for further investigated the influence of the intervening parameters. The result of the parametric studies provides a further understanding of the relative influence of the different parameters on the ultimate behavior of RC beams by using NSM-FRP strips. Furthermore; the finite element analysis has been done to evaluate the behavior of ten RC beams shear strengthened with NSM CFRP laminates³⁹. The study shows that there is large increment in load carrying shear crack with strengthened beams as compared with the reference beam. Additionally, by using NSM technique certain volume of concrete was added CFRP laminates and resulted that incline laminates provide more shear capacity than the vertical laminates and the shear capacity also increased by increasing the percentage of CFRP laminates. Also the numerical model (FE) developed by ⁴⁰ to predict the shear strength contribution for the corroded RC beams strengthened with NSM-CFRP rods. Lastly, a numerical model designed by ⁴¹ to predict fatigue life of the RC concrete beams under NSM-FRP strengthening. The results showed that the most efficient and economically influenced on the fatigue life and fatigue crack behavior were as the bond strength and reinforcement ratios of NSM reinforcement and steel bars. The strain of NSM reinforcements should be limited to avoid the failure due to the fatigue loading.

3.4 Study on Bond

For the bonding studies, analytical model developed by 42 for better prediction of the problems of deboning failure that effects on the behavior of NSM-FRP strips. The study was providing a comparison between analytical and experimental. The comparative results showed the excellent accuracy of the presented model. The bond model generated results can be also used for other applications of the NSM flexural retrofitting used for FRP rods. Furthermore; shear contributions of FRP by applying two different approaches; plastic bond -slip behavior and the numerical model. The numerical model results showed detailed bond-slip modeling of the FRP reinforcement that bonded by NSM. The model used to simplify the assumptions to allow the value of the shear contribution and assumed to near-by the equation accounted to make the design purposes for easy use⁴³.

A study has been carried out bond efficiency of Externally Bonded Plates (EBR) and near surface mounted NSM using eighteen concrete specimens for EBR and twenty four concrete prisms for NSM technique through experimental and theoretical work done by ⁴⁴. The experimental results showed that the specimens failed at the deboning of the epoxy-concrete interface. The detachment of a concrete layer and tensile failure of FRP reinforcement, the maximum efficiency was 106% for the specimen strengthened with carbon strips

of 10*14 mm. Also NSM-FRP strips shear strength contribution procedure for RC beams. The procedure provided numerous simplifications for the relationship of the local bond stress-slip, the average-available-bondlength NSM FRP strip took in considers confined to the concrete prism. The fracture surfaces of concrete assumed to be semi-pyramidal instead of semi-conical⁴⁵. A study on bond was carried out by ⁴⁶ on nine small-scale concrete specimens strengthened with NSM-FRP bars and strips strengthening due to round robin testing (RTT) to investigate the bond behavior. The study concluded that there is no significant in concrete strength on the both mode of failure and load, the differences of bond strength due to the experimental is same as NSM FRP with different setup from 10-25%. The surface strengthened with NSM FRP procedure and the axial stiffness mostly effected on the strength and identified the parameters that influence on nature of bond. Similarly the mechanical model developed by 47 developed fulfilling equilibrium, kinematic compatibility and constitutive laws of both materials, concrete and FRP, and local bond between themselves, takes into consideration the possibility that the NSM strips may fail due to: loss of bond (debonding for shear strength contribution by NSM-FRP strips aimed to developed kinematic compatibility, fulfilling equilibrium, the bond between FRP and concrete and bond between materials constitutive rules. The results found that the shear contribution on RC beams that provided by NSM-FRP strips are externally complex as the strips contribute effectively on shear strength of RC beams. The behavior of NSM FRP strips contributing to the shear defining that the local bond stress-slip relationship yields with NSM-FRP strips peak shear strength contribution variation was negligible on RC beams.

A model has been developed by ⁴⁸ to evaluate mechanical characters suitability of bond between FRP rods and concrete by using three-dimensional modeling. The model found most suitable as it introduced several layers of cohesive elements with adhesive. The experimental and numerical load-slip prediction showed a high level of accuracy in both full and reduce model. The other study by 49 designed for average bond strength, detailing of the groove and the bond coefficient dependent. The study provides more grooving position details and its dimensions as an optimum for many types of FRP reinforcements. Furthermore; the results proposed strain equations for the FRP materials in case of bars or strip. While the bond behavior study by 50 presented experimental results of behavior bond and flexural of strengthened concrete elements by NSM-CFRP laminates under fatigue loading. In their research work, evaluated CFRP laminates bonding with strip having 1.4 mm thickness and 10 mm width embedded through concrete cube of 200 mm into 15×5 mm2 groove dimension. The test results of nine pull out and six slabs specimens showed that the debonding accrued with fatigue loading with maximum fatigue stress about 60% and a slight decrease due to the maximum pullout force as 6%. Finally conclude that the analytical-numerical approach is very effective to study the bond length due to fatigue and for the local-stress bond. Whereas; the numerical study by ⁵¹ investigated the effects of groove spacing on the strength of bond for concrete elements strengthen with NSM FRP strips. Two different FRP strips were embedded into two grooves. Finally FE study based on the 3-D micro-scale model developed by 52 showed that the adjusted grooves FRP strips has positive significantly influence on the bond strength of NSM-FRP strips. The groove height and the concrete strength mainly influenced on the groove spacing. Due to compression between the FE test of this study results and the bond strength model predictions shows verification of the accuracy of NSM bonded joints within two FRP strips.

3.5 Theoretical Studies

A computational procedure has been done by ⁵³ to evaluate the shear strength of the RC beams using FRP strips with NSM techniques. The method was done by some substantial simplifications as assuming the relationship for local bond stress-slip by considering the available average bond length of FRP strips with concrete prism. The study found out the relationship of local bond stressslip as a function of chemical-mechanical properties of content \overline{e} \overline{FRP} . $V_f = \frac{1}{\gamma_{Rd}}$. (2. $N_{f,int}^{L}$. $V_{fi,eff}^{max}$. $sin\beta$)

(1)

Analytical model developed by 54 to investigating the shear strength contribution with NSM FRP by fulfilling equilibrium, kinematic compatibility, and constitutive law bond of the adhered materials and the materials itself. The model used to identify and thoroughly describe some complex phenomena. The results showed that model can be used for finding out the relevant information to apply front-line technique. Furthermore; the study done by 55 to calculate shear strength contribution of NSM-FRP strips with the RC concrete beams. Due to lack of previous literature; the numerical model assumed features of concrete as reducer of the average available bond length resisting and equivalent average resisting of bond length evaluation. For evaluating the maximum effective capacity of the strip, bond length's bond-based constitutive strategy was used by neglecting the post-peak behavior. The results predicted difference in experimental results of the mean and standard deviation as 0.69 and 0.29 respectively.

$$V_{fi,eff}^{max} = V_{fi,eff}(\gamma_{max}) = \frac{\delta_1 \cdot A_2}{2 \cdot L_d \cdot A_3 \cdot \gamma_{max}} \cdot \left[\frac{\pi}{2} - \arcsin\varphi^2 - \varphi \cdot \sqrt{1 - \varphi^2}\right]$$
(2)

A study was done by ⁵⁶ to present two different approaches to predict shear strengthening contribution by NSM-FRP material. The study obtained that both models were excellently accurate by comparing with experimental results and the data collected from literature.

$$Var(V_{pred}) = C_{Ef}^{2}.Var(Ef) + C_{fcm}^{2}.Var(f_{cm}) + C_{\delta}^{2}.Var(\delta)$$
(3)

A new approach for predicting the capacity of shear of RC concrete beams strengthened with FRP-NSM bars used by ⁵⁷ for simplifying modified compression field theory (SMCFT) and considers the features that has relevant to the interaction between FRP and concrete as the deboning

of concrete feature. While the other approach developed by ⁵⁸ for shear capacity prediction of RC concrete beams strengthened with CFRP laminates and rods with NSM technique. The approach was based on the SMCFT with considering the interaction relevant features of concrete and CFRP as a debonding of CFRP. In their research, 100 beams used to obtain results strengthened with various configurations and various CFRP ratios to predictive. The results obtained a 1.09 with a COV of 11% between the analytical approach and the experimental approaches.

$$v = v_c + v_s + v_{fd} = \beta \sqrt{f'_c} + \rho_y f_{yield} Cot\theta + 2. N_{f,int}^{L} V_{fi,eff}^{'max} \frac{sin\theta_f}{b_w d}$$
(4)

A comparative study has been done by ⁵⁹ on different theoretical models and the design cods to understand the use of NSM technique on shear effects in RC beams. The theoretical models developed by_^{8,60,61} helped for leading research work. While the selection codes of design ACI440.1R-06⁶² and CSA-S806⁶³. However; the calculation differences were -38%, -34% and- 68% respectively for studies. While the ACI440.1R-06 difference as +26%. But the CSA-S806 (Association, 2002) gives a difference of -68%. While on the other hand, the experimental work of ⁶⁴ concluded that a lack of inconsistency with the theoretical models calculations and provides difference of +41% for⁶⁰, -73% for⁸ and -4% for ⁶¹. Finally, for the ACI440.1R-06 is -48% and -43% for the CSA-S806 obtained through Cisneros experimental study.

4. Results Distribution

Figure 7 indicates the distributions of the total number of articles reviewed in this research work. All these articles are classified in ten categories as per the year of publication from 2008 to 2017. Only one article having experimental studies published in 2008 and 10 articles were published in 2009 to 2010. The year 2011 has maximum number of publications (11) including maximum number of experimental studies. Furthermore, exactly 13 articles were published in 2012 and 2013. However; only 1 article has been chosen from the year 2014 having scope relating



Figure 7. Results distribution by data bases.

to this research work. In the end 19 articles were published from year 2015 to 2017.

4.1 Distribution by Year of Publications

Figure 8 shows distribution of publication as per the author's country having related studies to NSM-CFRP for improving shear strength of the structural members. 20 countries authors' publications were reviewed in this research work. The total selected articles in this literature review work were 56 articles. The distribution of the articles showed that Portugal is the most interested country by taking 13 different articles for different cases. This was followed by Italy with 10 articles, United States within 8 case studies; where 3 were followed for France and 2 case studies in Canada, Spain, India, Slovakia, and Kuwait. The remaining countries were studied in one

article case study in Australia Brazil, Switzerland, Egypt, Iraq, New Zealand, Belgium, Turkey, Iran, South Korea, and Malaysia.

5. Motivation

The total selected articles that related to using of NSM-CFRP shear strength were classified as the case studies and comparing the use of this technique to improve the shear strength for the structural element as (T crosssection beams, beams, slabs, and walls). The research studies for structure element, 2 articles presented the experimental behavior by the deep beams. While there is no any numerical study for the shear behavior of deep beam strength with NSM-CFRP has been observed. Figure 9 show that the insufficient use of technology within deep beams.



Figure 8. Results distribution by data bases.



Figure 9. Results distribution by data bases.

6. Discussion

Based on the final selected set of articles, the use of NSM-CFRP is a very effective technique to increase shear strength of structural elements. The review showed that the work on deep structural element still limited yet and most of the studies were carried out for the experimental and or numerical studies to test on simply supported beams, T cross beams except for the study of 32 that was carried on masonry wall and as in case study of 34 carried on the slab. However; the remaining studies were focused on bond. All such research articles really support to research gap for the research carried by the authors under the title area of the subject. All the reviewed articles showed that the shear crack has no effects on the shear strength using NSM-CFRP technique as compared with the un-cracked element. In terms of different orientations for the CFRP in case of bars or laminates; the 45° inclined is providing the maximum shear strength as compare with other angles. Finally, by comparing the experimental and numerical studies, numerical studies showed the high level of accuracy in terms of cracks patterns and the curves of load deflection. In the on the basis of reviewed

literature, it is found that NSM-CFRP technique is the most effective technique as compared with externally bonded EB and embedded through-section.

7. Conclusion

This review study aims to contribute such insights by surveying and taxonomizing related to use of NSM-CFRP technique in shear strengthening. A systematic review was carried out through the total collected latest and critical research articles and such were classified roughly into four categories as: reviews on NSM technique and its applications, behavior of structural elements under shear strengthening, studies on the bond between FRP and concrete members and theoretical studies on the shear contribution of NSM-FRP with design procedures. On account of analysis on the all collected articles; the analysis leads to identify the effectiveness of the NSM-FRP technique and its benefit, motivations in field as an emerging field to research and recommendations of use NSM-FRP technique in shear strengthening. The results described with statistical explanations are highlighting the information in collected articles and the existing gaps for

the use of NSM-CFRP technique in shear strengthening for RC members. The selected articles authors described the problems and provided a proper recommendations and advices also helped to find the authentic research gap. On such basis, it is concluded and recommended to extend the implementation of NSM-FRP for RC deep beams, composite structures and masonry walls. Such conclusion encourage to explore further research on shear strengthening of structural elements by using NSM-FRP technique with different devices or embedded sensors in actual situations. Final conclusion is to further research by adopting interdisciplinary approaches with other technological and scientific fields.

8. Recommendations

On the basis of reviewed literature, it is recommended to carry out further studies on the behavior of debonding of near surface mounted NSM-FRP. Also, NSM-FRP technique need to be extend for the other structural elements like composite structures, for better understandings of various parameters like inclinations of installed FRP, effect of spacing and the pre-groove size in structural elements.

9. Acknowledgement

This research has been carried out for further exploring on the NSM-CFRP technique for RC deep beams and in this connection, we; the authors are really thankful to the Faculty of Civil and Environmental Engineering (FKAAS) Univeriti Tun Hussein Onn Malaysia (UTHM), 86400, Batu Pahat, Malaysia.

10. References

- Belarbi A, Acun B. FRP systems in shear strengthening of reinforced concrete structures. Procedia Engineering. 2013; 57:2–8. https://doi.org/10.1016/j.proeng.2013.04.004.
- 2. Morsy AM, El-Ashkar NH, Helmi KM. A comparative study for shear strengthening techniques of reinforced concrete beams using FRP. 4th International Conference on

Proceedings of Concrete Solutions,. Concrete Repair; 2012. https://doi.org/10.1201/b11585-106.

- De Lorenzis L, Teng JG. Near-surface mounted FRP reinforcement: An emerging technique for strengthening structures. Composites Part B: Engineering. 2007; 38(2):119– 43. https://doi.org/10.1016/j.compositesb.2006.08.003.
- 4. Tuakta C. Use of fiber reinforced polymer composite in bridge structures; 2005.
- 5. Teng JG, Chen J-F, Smith ST, Lam L. FRP: Strengthened RC structures. Frontiers of Physics. 2002:266.
- Sabol P, Priganc S. Shear strengthening of concrete members using NSM method. Procedia Engineering. 2013; 65:364–9. https://doi.org/10.1016/j.proeng.2013.09.056.
- Parvin A, Shah TS. Fiber reinforced polymer strengthening of structures by near-surface mounting method. Polymers (Basel). 2016; 8(8):298. https://doi.org/10.3390/ polym8080298. PMid:30974575 PMCid:PMC6432192
- 8. Islam AKMA. Effects of NSM CFRP bars in shear strengthening of concrete members. Structures Congress 2009: Don't Mess with Structural Engineers: Expanding Our Role; 2009. p. 1–14. https://doi.org/10.1061/41031(341)289.
- Islam AKMA. Effective methods of using CFRP bars in shear strengthening of concrete girders. Engineering Structures. 2009; 31(3):709–14. https://doi.org/10.1016/j. engstruct.2008.11.016.
- Rizzo A, De Lorenzis L. Behavior and capacity of RC beams strengthened in shear with NSM FRP reinforcement. Construction and Building Materials. 2009; 23(4):1555–67. https://doi.org/10.1016/j.conbuildmat.2007.08.014.
- 11. Lim DH. Shear behaviour of RC beams strengthened with NSM and EB CFRP strips. Magazine of Concrete Research. 2010; 62(3):211–20. https://doi.org/10.1680/macr.2010.62.3.211.
- Tanarslan HM. The effects of NSM CFRP reinforcements for improving the shear capacity of RC beams. Construction and Building Materials. 2011; 25(5):2663–73. https://doi. org/10.1016/j.conbuildmat.2010.12.016.
- Barros JAO, Costa IG, Ventura-Gouveia A. CFRP flexural and shear strengthening technique for RC beams: experimental and numerical research. Advances in Structural Engineering. 2011; 14(3):551–71. https://doi. org/10.1260/1369-4332.14.3.551.
- 14. Dias S, Barros J. Influence of the concrete properties in the effectiveness of the NSM CFRP laminates for the shear strengthening of RC beams. Advances in FRP Composites in Civil Engineering; 2011. p. 755–8. https:// doi.org/10.1007/978-3-642-17487-2_166.
- 15. Morsy A, El-Ashkar NH, Helmi KM. A comparative study for shear strengthening techniques of reinforced concrete beams using FRP. Fourth International Conference on Concrete Repair with Cooperation by Technical University

Dresden. Germany; 2011. https://doi.org/10.1201/b11585-106.

- Jalali M, Sharbatdar MK, Chen J-F, Alaee FJ. Shear strengthening of RC beams using innovative manually made NSM FRP bars. Construction and Building Materials. 2012; 36:990–1000. https://doi.org/10.1016/j. conbuildmat.2012.06.068.
- Dias SJE, Barros JAO. Experimental behaviour of RC beams shear strengthened with NSM CFRP laminates. Strain. 2012; 48(1):88–100. https://doi.org/10.1111/j.1475-1305.2010.00801.x.
- Dias SJE, Barros JAO. NSM shear strengthening technique with CFRP laminates applied in high-strength concrete beams with or without pre-cracking. Composites Part B: Engineering. 2012; 43(2):290–301. https://doi. org/10.1016/j.compositesb.2011.09.006.
- Singh SB, Reddy AL, Khatri CP. Experimental and parametric investigation of response of NSM CFRP-strengthened RC beams. Journal of Composites for Construction. 2013; 18(1). https://doi.org/10.1061/(ASCE)CC.1943-5614.0000411.
- 20. Kim YJ, Hmidan A, Yazdani S. Variable shear span-depth ratios for reinforced concrete beams strengthened with various carbon fiber-reinforced polymer configurations. ACI Structural Journal. 2015; 112(5):635. https://doi. org/10.14359/51687712.
- Almassri B, Kreit A, Al Mahmoud F, Francois R. Behaviour of corroded shear-critical reinforced concrete beams repaired with NSM CFRP rods. Composite Structures. 2015; 123:204–15. https://doi.org/10.1016/j. compstruct.2014.12.043.
- Al-Mahmoud F, Castel A, Minh TQ, François R. Reinforced concrete beams strengthened with NSM CFRP rods in shear. Advances in Structural Engineering. 2015; 18(10):1563–74. https://doi.org/10.1260/1369-4332.18.10.1563.
- 23. Prado DM, Araujo IDG, Haach VG, Carrazedo R. Assessment of shear damaged and NSM CFRP retrofitted reinforced concrete beams based on modal analysis. Engineering Structures. 2016; 129:54–66. https://doi. org/10.1016/j.engstruct.2016.09.058.
- 24. Kuntal VS, Chellapandian M, Prakash SS. Efficient near surface mounted CFRP shear strengthening of high strength prestressed concrete beams-An experimental study. Composite Structures. 2017; 180:16–28. https://doi. org/10.1016/j.compstruct.2017.07.095.
- Dias SJE, Barros JAO. Shear strengthening of T cross section reinforced concrete beams by near-surface mounted technique. Journal of Composites for Construction. 2008; 12(3):300–11. https://doi.org/10.1061/(ASCE)1090-0268(2008)12:3(300).
- 26. Rahal KN. Near surface mounted shear strengthening of reinforced concrete beams. Spec Publ. 2010; 272:251–68.

- Dias SJE, Barros JAO. Performance of reinforced concrete T beams strengthened in shear with NSM CFRP laminates. Engineering Structures. 2010; 32(2):373–84. https://doi. org/10.1016/j.engstruct.2009.10.001.
- 28. Rahal KN, Rumaih HA. Tests on reinforced concrete beams strengthened in shear using near surface mounted CFRP and steel bars. Engineering Structures. 2011; 33(1):53–62. https://doi.org/10.1016/j.engstruct.2010.09.017.
- Dias SJE, Barros JAO. Shear strengthening of RC T-section beams with low strength concrete using NSM CFRP laminates. Cement and Concrete Composites. 2011; 33(2):334–45. https://doi.org/10.1016/j. cemconcomp.2010.10.002.
- Dias SJE, Barros JAO. Performance of pre-cracked RC beams shear strengthened with NSM CFRP laminates.
 6th International Conference on FRP Composites in Civil Engineering (CICE 2012). International Institute for FRP in Construction (IIFC); 2012.
- 31. Dias SJE, Barros JAO. Shear strengthening of RC beams with NSM CFRP laminates: Experimental research and analytical formulation. Composite Structures. 2013; 99:477–90. https://doi.org/10.1016/j.compstruct.2012.09.026.
- 32. Dizhur D, Griffith M, Ingham J. In-plane shear improvement of unreinforced masonry wall panels using NSM CFRP strips. Journal of Composites for Construction. 2013; 17(6). https://doi.org/10.1061/(ASCE)CC.1943-5614.0000400.
- Mofidi A, Chaallal O, Cheng L, Shao Y. Investigation of near surface-mounted method for shear rehabilitation of reinforced concrete beams using fiber reinforced-polymer composites. Journal of Composites for Construction. 2015; 20(2). https://doi.org/10.1061/(ASCE)CC.1943-5614.0000612.
- 34. Moreno C, Ferreira D, Bennani A, Sarmento A, Noverraz M. Punching shear strengthening of flat slabs: CFRP and shear reinforcement. Concrete-Innovation and Design, Fib Symposium, Copenhagen May; 2015. p. 18–20.
- 35. Barros JAO, Dias SJE, Baghi H, Gouveia AV. New shear strengthening configurations of near-surface-mounted CFRP laminates for RC beams. Journal of Structural Engineering. 2016; 113(6):1275–87. https://doi. org/10.14359/51689029.
- 36. Samad AAA, Hassen DR, Mohamad N, Attiyah AN, Jayaprakash J, Mendis P. Shear rehabilitation of RC deep beams using NSM CFRP Anchor Bars. In: MATEC Web of Conferences. Vol 103. EDP Sciences; 2017. https://doi. org/10.1051/matecconf/201710302010.
- 37. Dias SJE, Barros JAO. NSM shear strengthening technique with CFRP laminates applied in high T cross section RC beams. Composites Part B: Engineering. 2017; 114:256–67. https://doi.org/10.1016/j.compositesb.2017.01.028.

- Bianco V, Barros JAO, Monti G. Parametric studies of the NSM FRP strips shear strength contribution to a RC beam. FRPRCS10-10th International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures. 2011; 1:591–610.
- 39. Barros JAO, Baghi H, Dias SJE, Ventura-Gouveia A. A FEMbased model to predict the behaviour of RC beams shear strengthened according to the NSM technique. Engineering Structures. 2013; 56:1192–206. https://doi.org/10.1016/j. engstruct.2013.06.034.
- 40. Almassri B, Barros JAO, Al Mahmoud F, Francois R. A FEMbased model to study the behaviour of corroded RC beams shear-repaired by NSM CFRP rods technique. Composite Structures. 2015; 131:731–41. https://doi.org/10.1016/j. compstruct.2015.06.030.
- Chen C, Cheng L. Fatigue life-based design of RC beams strengthened with NSM FRP. Engineering Structures. 2017; 140:256–66. https://doi.org/10.1016/j. engstruct.2017.02.065.
- Bianco V, Barros JA, Monti G. Bond model of NSM-FRP strips in the context of the shear strengthening of RC beams. Journal of Structural Engineering. 2009; 135(6):619–31. https://doi.org/10.1061/(ASCE)0733-9445(2009)135:6(619).
- 43. Rizzo A, De Lorenzis L. Modeling of debonding failure for RC beams strengthened in shear with NSM FRP reinforcement. Construction and Building Materials. 2009; 23(4):1568–77. https://doi.org/10.1016/j.conbuildmat.2008.03.009.
- 44. Bilotta A, Ceroni F, Di Ludovico M, Nigro E, Pecce M, Manfredi G. Bond efficiency of EBR and NSM FRP systems for strengthening concrete members. Journal of Composites for Construction. 2011; 15(5):757–72. https:// doi.org/10.1061/(ASCE)CC.1943-5614.0000204.
- 45. Bianco V, Monti G, Barros JAO. NSM FRP strips shear strength contribution to a RC beam: A design procedure. FRPRCS10-10th International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures; 2011.
- 46. Palmieri A, Matthys S, Barros JAO, et al. Bond of NSM FRP strengthened concrete: Round robin test initiative. In: CICE 2012 6th International Conference on FRP Composites in Civil Engineering. International Institute for FRP in Construction (IIFC); 2012:1-8.
- Bianco V, Barros JAO, Monti G. Three dimensional mechanical model to simulate the NSM FRP strips shear strength contribution to a RC beam: Parametric studies. Engineering Structures. 2012; 37:50–62. https://doi. org/10.1016/j.engstruct.2011.12.044.
- 48. Echeverria M, Perera R. Three dimensional nonlinear model of beam tests for bond of near-surface mounted FRP rods

in concrete. Composites Part B: Engineering. 2013; 54:112–24. https://doi.org/10.1016/j.compositesb.2013.05.008.

- 49. Lee D, Cheng L. Bond of NSM systems in concrete strengthening-examining design issues of strength, groove detailing and bond-dependent coefficient. Construction and Building Materials. 2013; 47:1512–22. https://doi.org/10.1016/j.conbuildmat.2013.06.069.
- 50. Fernandes PMG, Silva PM, Sena-Cruz J. Bond and flexural behavior of concrete elements strengthened with NSM CFRP laminate strips under fatigue loading. Engineering Structures. 2015; 84:350–61. https://doi.org/10.1016/j. engstruct.2014.11.039.
- Zhang SS, Yu T. Effect of groove spacing on bond strength of near-surface mounted (NSM) bonded joints with multiple FRP strips. Construction and Building Materials. 2017; 155:103–13. https://doi.org/10.1016/j. conbuildmat.2017.08.064.
- 52. Teng JG, Zhang SS, Dai JG, Chen JF. Three-dimensional meso-scale finite element modeling of bonded joints between a near-surface mounted FRP strip and concrete. Computers & Structures. 2013; 117:105–17. https://doi.org/10.1016/j.compstruc.2012.12.002.
- 53. Bianco V, Monti G, Barros JAO. Theoretical model and computational procedure to evaluate the NSM FRP strips shear strength contribution to a RC beam. Journal of Structural Engineering. 2010; 137(11):1359–72. https://doi. org/10.1061/(ASCE)ST.1943-541X.0000370.
- Bianco V, Barros JAO, Monti G. New approach for modeling the contribution of NSM FRP strips for shear strengthening of RC beams. Journal of Composites for Construction. 2010; 14(1):36–48. https://doi.org/10.1061/(ASCE)CC.1943-5614.0000048.
- 55. Bianco V, Monti G, Barros JAO. Design formula to evaluate the NSM FRP strips shear strength contribution to a RC beam. Composites Part B: Engineering. 2014; 56:960–71. https://doi.org/10.1016/j.compositesb.2013.09.001.
- 56. Perera R, Tarazona D, Ruiz A, Martín A. Application of artificial intelligence techniques to predict the performance of RC beams shear strengthened with NSM FRP rods. Formulation of design equations. Composites Part B: Engineering. 2014; 66:162–73. https://doi.org/10.1016/j. compositesb.2014.05.001.
- 57. Baghi H, Barros JAO. Design approach to determine shear capacity of reinforced concrete beams shear strengthened with NSM systems. Journal of Structural Engineering. 2017; 143(8). https://doi.org/10.1061/(ASCE)ST.1943-541X.0001793.
- Baghi H, Barros JAO. New approach to predict shear capacity of reinforced concrete beams strengthened with NSM technique. Journal of Structural Engineering. 2017; 1(114):137–48. https://doi.org/10.14359/51689433.

- 59. Samad AAA, Mohamad N, Hadipramana J, Amiruddin MRA. Comparative study on theoretical models and design codes for the shear contribution of NSM FRP bars in RC beams. Jurnal Teknologi (Sciences & Engineering). 2016; 78(5):115–19. https://doi.org/10.11113/jt.v78.8263.
- 60. De Lorenzis L, Nanni A, La Tegola A. Strengthening of reinforced concrete structures with near surface mounted FRP rods. International Meeting on Composite Materials, PLAST 2000, Proceedings, Advancing with Composites; 2000. p. 9–11.
- 61. Barros JAO, Dias SJE, Lima JLT. Efficacy of CFRP-based techniques for the flexural and shear strengthening of concrete beams. Cement and Concrete Composites.

2007; 29(3):203-17. https://doi.org/10.1016/j. cemconcomp.2006.09.001.

- 62. 440 ACIC. Guide for the design and construction of structural concrete reinforced with FRP bars: ACI 440.1 R-06. American Concrete Institute; 2006.
- 63. Association CS. CSA-S806-02, Design and construction of building components with fibre-reinforced polymers. Toronto, ON, Canada; 2002.
- 64. Cisneros D, Arteaga A, De Diego A, Alzate A, Perera R. Experimental study on NSM FRP shear retrofitting of RC beams. Proceedings of the Sixth International Conference on FRP Composites in Civil Engineering (CICE-2012); 2012.