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To cite this article: Amjad Ali K Sharba *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1090** 012054

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Retrofitting of RC beams using FRP techniques: a review

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Abstract. In structural and civil engineering, reinforced concrete structures are susceptible to inordinate loadings such as earthquake disasters, terrorist attacks and accidental impacts. This prompts an increasing desire to strengthen as well as enhance the fatigue performance and extend the ability of fatigue life of reinforced concrete structural components especially beams. Since 2003, Iraq has suffered major damage to the structural buildings, so it has become an important issue to study the existing concrete structures. Among the different techniques of rehabilitation of existing structures, fibre reinforced polymer (FRP) as an external bonding has been considered as a popular one. This paper reviews several features of Reinforced concrete (RC) beams strengthened with FRP. Also this paper aims to impart a comprehensive insight on adhesive curing, surface arrangement, and failure modes of RC beams modified with FRP. This effect of FRP for enhancing the techniques of rehabilitation is a three- fold task, to strengthen and retrofit of concrete structures, to extend the fatigue life of the structural element, and eliminates the crack growth rate.

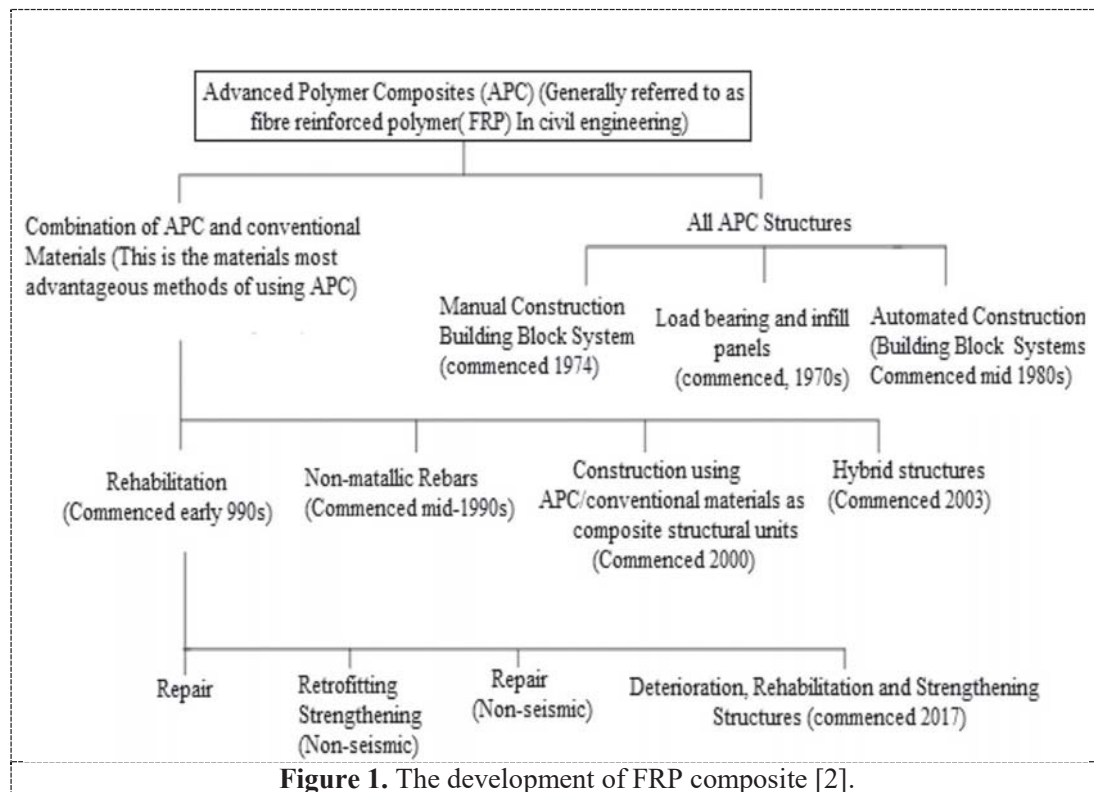
Keywords: Strengthening, Fibre reinforced polymer (FRP), adhesive, failure mode.

1. Introduction

The beginning usage of fiber-reinforced polymer (FRP) was recognized as reinforcement bars in 1975 especially in Russia (figure 1) [1, 2]. Also, FRP is known as a fiber-reinforced plastic, including materials that employ either natural fibers or synthetic to automatically enhance the strength and stiffness of a polymer model [2]. FRPs utilized for the application that related to strengthening and reinforcing element concrete are extremely robust, estimates about 8 times sturdy than the traditional steel rods [3]. Pertinent exploration of the application of FRPs instead of steel rod to subrogate the utilization of bonding the bridge rehabilitation by steel plate and strengthening initiated in Europe since 1980. However, for structural strengthening in America, the FRP composites have been engaged to obtain a great result and for approximately 25 years [4]. Through this period, FRP composite was trusted as a mainstream construction material analogous with the sum of consummated FRP strengthening projects. The performance of FRP for strengthening, retrofitting, and rehabilitation has acquired more prominence among design consultants across conventional



strengthening methods, like setting up of supplemental structural steel frames and elements [5]. FRP is principally acted as interior reinforcement, for example, rebar, or exteriorly-bonded reinforcement to strengthen concrete, masonry structures, steel, and timber [6]. Various methods occupy in the application of strengthening buildings in several manners. The usage of FRP by their outstanding mechanical characteristics for the retrofit of the RC elements is considered as one of them. Characteristics of the FRP strengthening in terms of cost and time have been revealed [7-9]. Nevertheless, vast research studies [9-11] have been executed to examine, especially, the performance of reinforced concrete beams modulate with the plates of FRP. The FRP as a combination of several elements are formed up with a high-quality material that bears high level for tensile strength fibers inserted in an epoxy pattern, they contribute excellent protection to the corrosion, high mechanical strength, low level of weight, an easy, economical and fast way of repair or rehabilitation of columns, slabs or beams [10, 11, 17]. The surface arrangement is so important in order to achieve an effective strengthening interconnection in concrete and FRP. Consequently, the quality and efficiency of the ligation among the concrete and FRP composites play a significant task in conveying the stress among externally bonded FRP plates and concrete structures [18, 19]. When the RC beams are subjected to the load repetitions immoderate fatigue deterioration could occur. FRP owns a special tensile strength property greater from that of iron steel till now weighs just about one quarter [3-5]. The Japanese in 1996 were considered as the first organization that announces the application evidence for using FRP in the field of strengthening of RC elements [20]. Subsequently, FRP has been considered as structural support and has become increasingly more rapidly, officialdoms worldwide were authored the design supervision and guidance [21]. Many of the researches [10, 22] have given attention to fatigue strength and additionally forecasts of the behavior of RC structures in terms of fatigue. This confirms the desire to enhance fatigue appearance and make the life of fatigue more extensive of RC elements employing the technique of making more forceful with FRP. The purpose of this study is to impart an inspection on the supporting of RC structures by utilizing the FRP technique. Besides, this investigation comprises the following states: surface preparation, adhesive curing, fatigue performance, the ligation among concrete and FRP, failure mode. This paper reviews also provide a complete picture of the incorporated utilization of FRP combination materials for rehabilitating, repair, and reinforcing the RC elements in the area of the building industry.



2. Applications of FRP

There is a large assortment of applications in which fibre reinforced polymer can be efficiently applied in structural engineering. FRP composites are employed both repairing and strengthening the existing buildings and for new construction. In general, two major classifications of FRP application can be determined: FRP tendons, and bars used as internal reinforcement as well as FRP sheets, laminates, and wraps as external reinforcement. This part outlines some of the generality common applications of FRPs in civil infrastructure. When the structures become old and the bars have been increased in terms of corrosion in this case, the need for new innovative material in the construction industry to request additional retrofits to extend their durability and life. Engineers throughout the world have utilized Fiber Reinforced Plastic (FRP) to fix their structural problems efficiently and economically. Most of the use of FRP in the field of structural engineering is confined to strengthening and repairing structures. In order to enhance the strength and ductility of an RC structure, The FRP outer shell preserves the concrete core from exposure to cruel environmental conditions and provides confinement to concrete thereby improving the ductility and strength of the concrete elements. Summarizing the main FRP employment options, the exploitation of FRP is categorized in table 1.

Table 1. Application of external and internal FRP reinforcements.

Reference	Internal Reinforcement	Application	Reference	External Reinforcement	Application
Mufti et al.1991 Tezuka. 1994 Keller. 2001	Prestressing tendons	Cable reinforcement, Bridge cable	Shahawy et al. 1996	Laminates and Pre-cured Sheets	Flexural-strengthening of beams and slabs
Benmokrane 1991	Two-dimensional grids	Underground structures	Ilkiet al 2008 Neale 2000 Seible et al,1997 Demers et al 2003	Wrapping Sheets, Jackets.	Seismic retrofit for special structures and columns.
Lopez-Anido,1997 Benmokrane et al,(2000,2006)		Bridge deck Deck and slab systems	Hutchinson et al ,2003 Teng et al,2003	FRP Sheets	Strengthen for shear zone of girders
Cheng, Karbhari,2006 Rizkalla,Tadros,1994		Pre-stressed Grirders	Teng et al., 2007 Fam et al.2003	FRP tubes Outer shells	Precast piles, Fender piles and concrete filled and columns.
Rizkalla et al,1998	One-dimensional ,longitudinal bars	Barrier wall	De Lorenzis Nanni 2002 El-Hacha,2004	Near surface mounted bars and rods	Repair of structural elements of bridge girders
Eddie et al, 2001	Dowels	Highway Pavements	Engindeniz et al, 2005.	FRP sheets	Joint strengthen for RC elements
Rizkalla et al,2006	Shear stirrups	Pre-stressed Grirders	Niroomandi et al, 2010.		

3. Treatment and surface Preparation for Bonding between concrete and FRP

Bonding relies on the characteristics of concrete, adhesive, and composite, it considers so essentially when strengthening FRP with concrete beams to keep away from premature failure. The preparation of surface entails the elimination of concrete paste and extended the pore structures by different techniques like water jetting, sandblasting, grinding, and wiping to improve the bond configuration. Depending on [23], the function performed by the bond between FRP and concrete beams cannot be overemphasized since it transmits the stress among concrete structures and externally bonded FRP plates to create composite action. [11] Execute a single-lap shear evaluation to inspect the impact of bond and force transfer of composite FRP bonded to concrete. Examinations handled on test samples possessing a constant bond length demonstrated that surface arrangement is a prerequisite for reaching a superior bond strength. At the same attitude by using a near end supported single shear pull test, [24] carried out experimental research on the concrete joints that bonded by FRP, they summarized that careful preparation of concrete surfaces performed a useful role in the bond strength. Furthermore, [25] stated that surface preparation of the beam could influence the bond strength as the performance of the sample with a sandblasted surface presented

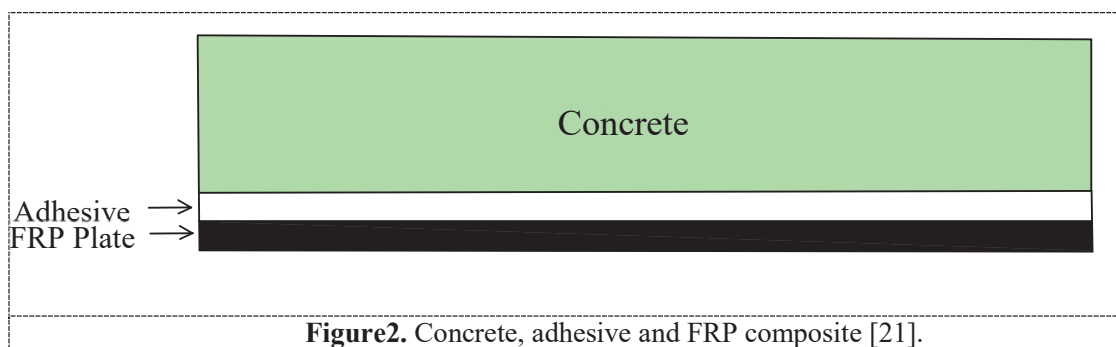
below that of a sample with a roughened surface. As stated by [26], fatigue evaluation of CFRP bonded to concrete to some extent relies on the surface preparation and toughness of the CFRP plate. Furthermore, [27] declared that there is an advantage as the surface is prepared by sandblasting before the action of CFRP employment is to allow the fibre to be around the corners of the concrete specimens by providing a smooth bending to keep away from premature damage during loading. At the same action, [28] the thin layer of paste accrued on concrete specimens has been removed by carried out with water jet and the treatment of surface by utilizing sanding techniques, they executed on failure examinations to investigate the achievement of the two-way techniques. It was stated that the ligation among the concrete and FRP was extremely enhanced by employing the technique of water jet as compared with the other technique as sanding. Furthermore, the failure load becomes about 50% greater as the samples have been treated by water jet. They summarized that by employing the water jet technique it could perform an unsmooth surface to fit in with adhesives. The performance of Reinforced concrete beams that have been retrofit by adhesively bonded FRP subjected to the test of flexural strength that was reviewed by [29]. The whole of the RC beams have 2.3 meters long and considering in service about 4 to 6 months prior to the external supporting by 0.8m CFRP carbon FRP lamina. Before the employment of CFRP, all exteriors of the beam elements were pebble blasted by 180 lattice alumina at the rate pressure of about 270 kpa then consequent elimination of fine particles was executed omitting composite laminas as cleanly and regularly rough to accommodate the adhesives in terms of mechanical interlocking involved by the technique of nylon peel-ply. They summarized that this technique of peel-ply and the whole facade arrangement has the benefit of sufficient adhesion properties for the short term and also as the joints were exposed to ecological senility. Likewise, [30] announced at their investigation that the preparation of the surface within sandblasting improves the immovability of the ligation operation and has an important impact on the sample performance near the utmost loading positions. To define the impact of exterior the harshness of samples concrete in terms of the bond of FRP composites, [31] executed a pull-out test and also shear test on forty samples with various standards of coarseness produced within grinding, brushing, bush-hammering, and sandblasting. Their consequence showed that bush-hammering and sandblasting techniques exhibited nearly all efficient ligation strength with around 30% to 50% improvement more from that of the original strength. Their detecting also showed that the preparation of surface regardless of any application of technology develops along the surface towards uniformity of roughness. [32, 33] examined the influence of grinding the surface of concrete and sandblasting on the breakage energy for the bonding of FRP concrete. After ligation carbon FRP on samples then displaying them to rising axial force till the action of the splitting, the results that obtained from experimental exhibited that higher delamination or fracture energy values and larger roughness of the concrete surface was obtained by grinding escorted by stone wheel characterized via rough iron dust as the contrast with samples that operated by sandblasting. They summarized that the bonding techniques and the preparation of concrete surfaces are considered very important for the correct utilization to obviate precocious failures. In addition, by using the FRP in a large cross-section it could be not reasonable in terms of economic and also resulted in a fragile response of the component and leads to immediate debonding from the concrete facade the strengthening material [34] (table 2).

Table 2: Synopsis of previous research on FRP materials bonding via the concrete surface elements.

Ref.	Marked styles of failure	Major conclusions
[53]	FRP sheets composite debonding concrete crushing shear value at edges plates	-At design supposed to take into account the brittle failure modes. -Demand to develop information about the adhesion performance
[1]	Stripping along with the concrete cover/Shear Debonding	-Failure manner rely upon the ratio of shear span/depth -Needed of the anchorage at the ends particularly at the low ratio of a/d
[55]	FRP debonding, low ρ Crushing of concrete, high ρ	-Incapable to enhance the full FRP strength in the absence of anchorage
[52]	The action of debonding occurred after yielding of reinforced steel	-Need more study about the stress concentrations at the edge of plate. -Choice of bonding tool is so important
[56]	-if transverse wraps are employed along the full length the FRP would rupture. -as plates are sited at the bottom of beams debonding could occur.	-placing wrap along the whole length of CFRP develops the highest load. -ligation laminae on sides and bottom could enhance performance.

4. Adhesive curing

An adhesive is a materiality that applied to the surface as an objective to attach one material to another or as a target to bond two elements together as displayed in Figure2. The application of adhesives among the substrate and compound substance is vital in the process of preparation of surfaces before the application of FRP [21].

**Figure2.** Concrete, adhesive and FRP composite [21].

[35] demonstrated that to emphasize the advancement of composite action of the continuous bond among concrete and FRP has been accomplished by adhesives. As the element is in wet conditions these adhesives should not be applied as it could weaken or have negative effects. At the same line [36] reported that environmental conditions like temperature utmost, contacting directly with rain or dust could accelerate or

retard the resin curing time. They summarized by focusing on the demanded features of the adhesive for the achievement of superior strengthening as;

- It must be easy to deal with it terms of mix, applying, and cure.
- Supposed to be not susceptible to ordinary alteration in the moisture content of the surface that was arranged.
- It has to give a compatible thermal characteristic with both concrete and FRP.
- It must give a low value of creep.

Based on [37] exemplary curing prevents the transference of moisture from the surface of the concrete to the layer of FRP which perhaps changes the action of bonding. by the research of [38], it is most reasonable to authorize adhesive curing in the application of rehabilitation or reconstructed bridges elements by utilizing CFRP to have a full impact prior shutdown it to the traffic since it has held announced by the society of concrete [39], loading while the curing time head for a reduction in the tougher of structural components by ten percent as compared with the condition of entirely cured ones. At the same view, [40] recognized a gradual decrease in the life of fatigue besides developing strain level observed and the reason related to a vibration that experienced from the traffic throughout curing. [41] Reported the usefulness of the curing epoxy adhesives that occurred at temperatures of 93o C as it considers as high temperatures the bond becomes stronger, durable, and tougher when faced with the inappropriate environmental conditions. [42] Revealed that epoxy resin is ticklish to the effective changes of temperature as the operation of curing guide to a slighter glass transition temperature resulting decline in the mechanical characteristics of the resin. Moreover, they emphasized that this negative effect on the mechanical characteristics of the adhesives could affect the bond strengthening among the FRP to concrete. As the temperature exceeded the above value, the effect of resin in terms of mechanical properties will drop, and its change from the solid shape to rubber shape. They recommended in their study [43], that the adhesive that utilized for bonding of FRP to concrete the glass transformation temperature must be preserved at 20oC over the temperature of the surroundings at the ordinary status and ought to be at minimal 45oC. [20] investigated an impaction of the water on the adhesive properties and curing for bonding the CFRP with the concrete, it described the interactivity of water as a resource of groundwater, rain, alkalis with epoxy adhesives affect the degree of curing and also the curing rate. Furthermore, they declared by the way of isothermal differential scanning calorimetric DSC that the water could accelerate the curing rate when it becomes about two percent, degree of curing, and also the curing rate. Furthermore, they declared by the way of isothermal differential scanning calorimetric DSC that the water could accelerate the curing rate when it becomes about two percent, degree of curing, and also the bond strength but superfluity water becomes progressively worse in the durability and the characteristics of epoxy adhesives. Additionally, [44] investigated the impact of polluted resins on the rate of curing and mechanical characteristics of adhesives. Employing near-infrared (NIR) spectrometry to inspect the epoxy adhesives in terms of curing reactions, they found at 60°C there is a raised reaction rate after a few hours and as a consequence, high-level of mechanical properties like flexural strength, utmost tensile strength were realized in epoxy mixture by phenol reagent EP, NT97, as a reason to the appearance of the water as compared to those that gained in the epoxy EA 230.

5. Fatigue Performance of RC Beams

Many researchers give wide attention that conducted by [28, 30] and [10] have all recorded meaningful enhancement in the fatigue resistance and the ability of the RC elements after reinforcing by externally ligation plates of FRP. [45] Stated as under the same loading condition and interval for the beams with strengthening by utilizing laminates of FRP and without strengthening the results shows that the strengthen

beams have a greater fatigue strength of about thrice from that of unstrengthened. In fatigue performance, there was an enormous improvement as also notified in the state that there was a serious weakness that had happened before the modifying of the RC elements [46]. Besides, they remarked for the technique of strengthening by utilizing FRP plates is expected to enhance fatigue proficiency as toughness and strength are developed whereas there is a reduction in the crack propagation build-up in the reinforcement. [47] Study fatigue adequacy of RC beams modulate with CFRP by employed fatigue loading under service. They observed those beams that carrying capacity does not have that influenced in considerable quantities. [48] Studied the RC beams that strengthened by utilizing CFRP of two million cycles that have been failed and the reason could be to the fatigue of beams that become unstrengthened at approximately 500,000 cycles. Moreover, they concluded there was not that meaningfully affect the load-carrying ability of tested specimens when the fatigue has an effect on 2 million cycles. [49] Stated that the RC beams that retrofitted utilizing FRP have been collapse under the employment of higher loads was essentially associated with the failure that occurred at the reinforcing bars whereas affairs of the FRP being considered as minor importance remarked by [10] and [50]. Fatigue examinations on RC beams that retrofitted with CFRP at the low level of temperatures as 29°C to under zero carried out by [51] discovered that failure occurs firstly as a consequence of delaminating the laminates of CFRP and concrete. Nevertheless, [10] stated an inverse remarkable that was vindicated by [44]. Finally, deduced that fatigue examinations at the lower level of temperatures lead to a rise in the toughness of concrete whereas the interface strength among concrete and the FRP is reduced. [52] Examined strengthened CFRP abrasion samples within a concatenation of fatigue performance appraisal. He revealed that there was an increment in the value of fatigue life about around (2.5 to 6) times over the unstrengthened specimens, even so, this quantum has less value of the uncorroded examined samples. Nevertheless, [47] emphasized the reinforcing of the RC beams by utilizing sheets of CFRP pointed to an abundant decrease in bearing strength of the RC beams on the test of the long term that subjected to the humidity condition of 100% and thaw cycles up to 700 cycles. The outcomes observed from the tested of the fatigue proficiency of the RC elements samples reinforced by wraps of FRP exposure to the corrosion exhibited a moderate grade of deterioration as well as ratio decreases at 10 and 20 in the flexural strength and bond failure respectively. They deduced that the attitude of fatigue of the impairment elements reinforced utilizing wraps of the CFRP was developing. The performance of the RC beams that modulate by CFRP wraps beneath service stresses as a reason for fatigue was studied by [53]. Nine samples of RC beams were manufactured and tested under the condition of cyclic loads. Samples of eight beams were modified by utilizing CFRP wraps whereas one specimen was preserved as reference. Specimens were classified as two conditions; the first condition kept in the laboratory whereas the other one was subjected to sustain loading and also the ecological conditioning. As shown in figure 3(a), that the estimated flexural toughness was 6.30 and 7.45 KN/m as belongs to the first and two millionth cycles resembling a reduction of 16% in the samples of the unstrengthened beam. Whereas for the samples that strengthening with CFRP as displayed in figure 3(b), recorded an increase of nearly twice from that of unretrofitted sample. They announced that there was not an adverse effect on all the beams in terms of bond degradation; overmatch the two million fatigue cycles. Despite this, it recognized that there was a notable impairment in the value of flexural stiffness in the modified specimens.

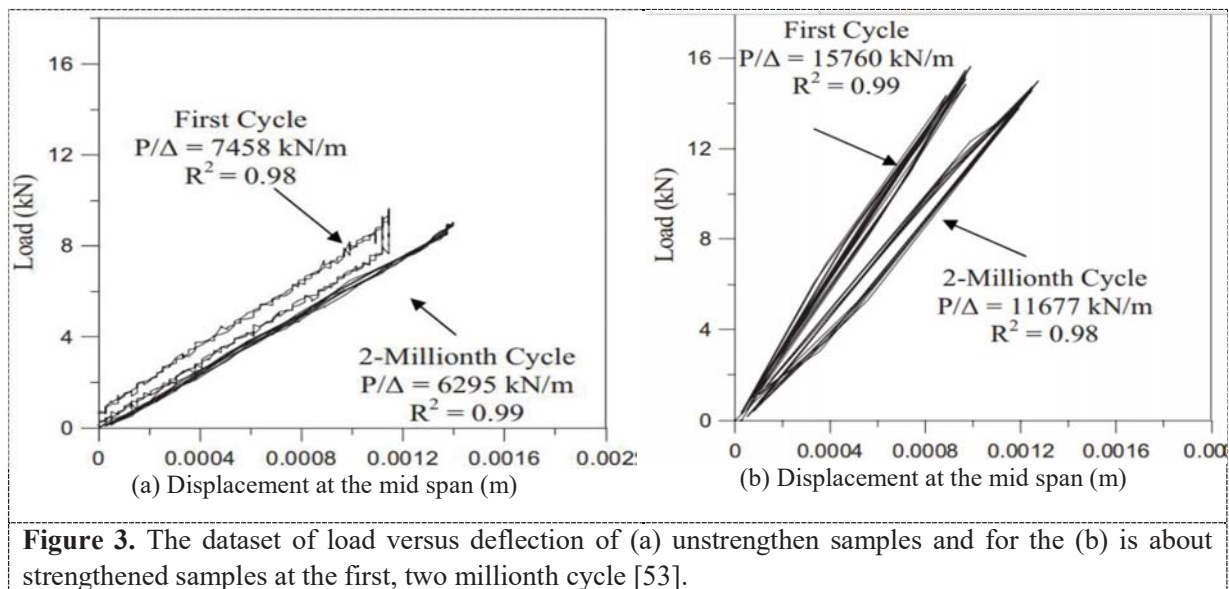


Figure 3. The dataset of load versus deflection of (a) unstrengthen samples and for the (b) is about strengthened samples at the first, two millionth cycle [53].

[10] Studied the RC beams that strengthened utilizing CFRP to assess the performance of the beams that facing fatigue as a substitutional to steel lamination. Five samples of the RC beams that own dimensions of length as a measure of 2300mm, and for the width of 130mm, and for the amount of depth is 230mm, three beams were retrofitted with the bonded lamina, the other two beams were kept as control were examined in fatigue subject to three loading surrogates. The outcomes disclosed that the responsibility of the failure with the RC samples in plated and without plated modes having no various stress scope in the reinforcement is related to the fracturing of reinforcing steel. [54] Focused on the beams that strengthened with wraps of CFRP in terms of fatigue performance at the shear region of the RC beams. Six beams have been examined including CFRP ratio and transverse reinforcing steel carefully tested. The outcomes displayed specimens retrofitted by employing one layer of CFRP could resist five million cycles, some not considering obvious indications of degradation confirming the effectiveness of the technique on exhibiting the structures in terms of fatigue strength whereas the beams that retrofitted by using double layers collapsed in fatigue less than around 5 million cycles. Also, it has been displayed that the fatigue strength of the RC elements enlarged onto comparing the proficiency of specimens includes or not include transverse reinforcing. A study done on the experimental work and analytical on fatigue abilities of the RC elements modulate externally via the layers of CFRP and strips was handled through [55]. It comprises urgent and immobile fatigue examination for various scopes of stress jointly with different arrangements and quantities of CFRP layers on nine samples of RC beams. The results obtained from the Laboratory were utilized to verify the finite element analysis (FEA). There was a reduction in the value of stiffness around (3.56 to 9.54) % for the stress domains of 0.25fy and (0.45-0.9)fy respectively indicating an improvement about 2.7 and 1.6 times in degeneration than that domains for the stress of (0.25-0.35)fy and (0.65-0.90)fy. This investigation summarized the deflection at the mid-span was considerably weakened via domains of stress especially, stress domain of 0.45-0.9fy. Another investigation tested the impact of fatigue loading at different amount of load proportions that have ranged from 0.15 to 0.55 on the interaction among steel sheets and CFRP with the nominal modulus as 240–640 GPa. The unearthing presented that the nominal modulus CFRP wraps have a reduction almost (20 to 30) % in the bond strength [56] (figure 4). The influence on the joint rigidity from

fatigue loading has decreased by about 10% of the rigidity due to the accumulated damage caused by the raising of fatigue loads.

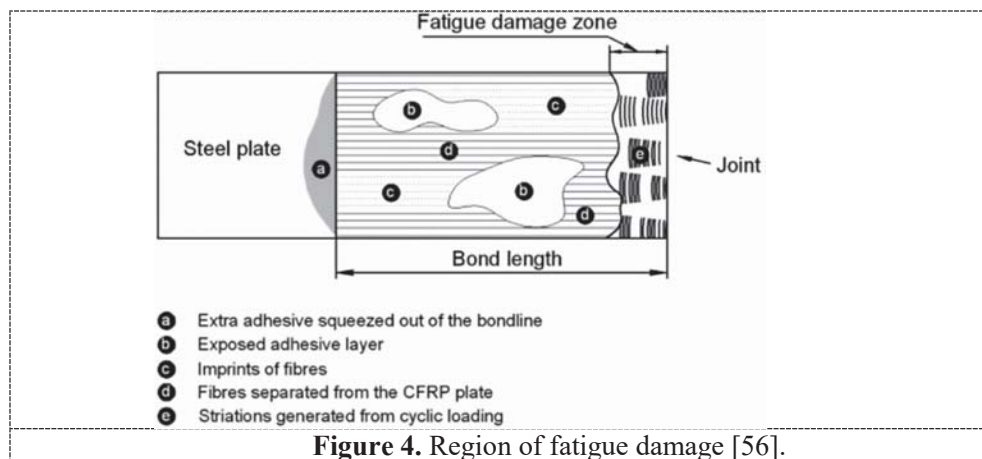


Figure 4. Region of fatigue damage [56].

6. Shear strengthening

Toward shear strengthening, the way of designing for RC elements with external bounded FRP has been obtained in many reports [4, 57]. For strengthening the structure in terms of shear, FRP strips are placed on the outside face of the beam as a U shape in vertical fashioning act as exterior stirrups [58]. For walls shear strengthening, for instance, unreinforced walls, and RC walls can be performed by bending FRPs to one or both sides for the wall at a horizontal, vertical, or the pattern (45°) [59]. [60] announced that by employing twin-layer of (CFRP and GFRP) composite materials to the RC beams improved the ability of strength about 114% as compared with the reference beam, however there was an enhancement around 84% and 72% as compared to the conventional beam as stated by [61] and [40], respectively. Furthermore, the increment in the value of flexural strength of RC beams has been recorded for the three layers of CFRP by 38.86%, for two layers by 46.6%, and one layer by 15.5% as compared to the conventional beam [62]. As a tinny edge, the shear strengthening could be completed with merely one or two layers that have a thickness of 0.5-1 mm and achieved great seismic improvements, especially the response of the plane shear wall [63]. The presence of epoxy resins are durable; so, generally, surface failures occurred in the concrete, as specific, at RC element when there is a weak joint it requires doing shear strengthened [64]. Three major configurations of FRP strengthening, Complete wrapping with side bonding, unwrapping (figure 5) [65]. The applying of wrap along with structural RC components is realized as the common efficient manner for the FRP shear reinforcing attributable to its viability at the appearance of some geometric constraints [45]. Other researchers employed different techniques for shear reinforcing of the RC beams, for instance, ligation steel lamina, using fibre materials, and exterior prestressed [66]. Externally implemented FRP, involving carbon, glass, and aramid fibers, these fibres are been vastly utilized for flexural and shear strengthening of RC beams and columns elements [67]. It is reported that to strengthen the RC beams in the shear zone is recommended to use CFRP as is presented an improvement in the shear strength about (19 to 122) % associated with the trend of the FRP at 45° and CFRP wrap, as comparison with the conventional beam [68]. In general, for the FRP that strengthened beams in terms of shear strength is computed via adding up to the individual components of the shear resistance from the concrete, steel stirrups, and FRP. Reportedly,

the utilize of U-wrap of CFRP for the shear strengthening system in the RC beam is improved the capacity of shear by 50% for applying one layer of CFRP layer and by 92% for using two layers of CFRP [69], depends on the ratio of the shear span related to the depth that restricted to be equal to three or greater than two. For instance, when the ratio is 1.5 for RC beams; CFRP shear strengthening presented no that increment in the value of shear strength. Another research-tested on the bridge deck slabs that reinforced with utilizing CFRP bars with proportions greater than the equivalent reinforcement proportion, the ability of the shear strength has been raised over (81 to 111)% as make a comparison to the traditional slabs [70]. Though the investigation of impaction of the Bucky paper interleaves accumulated from Carbon Nano fibers on the interlaminar toughened properties of the CFRP displayed an improvement of about (31 and 104) % in interlaminar shear strength [71]. [72] remarked when the RC beams were strengthened in the shear zone with a 45^0 fibre direction, the strengthening impact was improved more than 10% in all samples tests. Also recognized that the strengthening of samples with 45^0 CFRP strip does not own the typical diagonal shear cracking manner as noted in samples that strengthened by 90^0 or 0^0 fiber direction, however, it was observed that the beams strengthened with CFRP strips trend at 45^0 the shear cracks advances vertically to the bottom. Another study was done by [73, 74] have been applied double layers of sheets the results displayed a rupture appear along the direction parallel to the fibers of CFRP and the sheets do not delaminate from the concrete. This study also presented that as the beams strengthened with both directions horizontally and vertically way the debonding would not occur. For the samples that have a low sheet depth, the final failure happened in concrete it could be associated with one critical crack, while as a higher sheet depth applied the beams would be failed by concrete crushing and splitting. [75] studied the strengthening of RC beams with FRP strip by applying 90^0 wraps, 45^0 wraps, and U-shape wrap, they deduced that the 45^0 wrap presents high ductility and strength than that of 90^0 wrap. At some condition, the full wrap was employed to recognize the behavior of RC beams and it showed almost similar to the 90^0 wraps in a strip as displayed in figure 6. However, the shear strength could be improved by adding an end anchor.

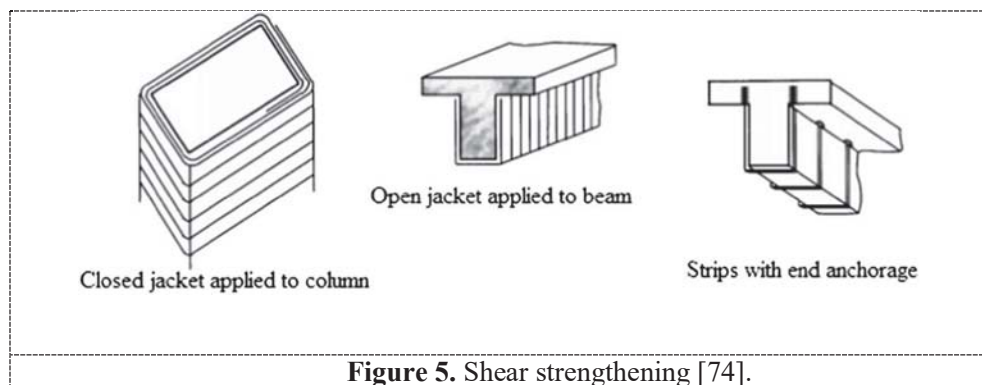
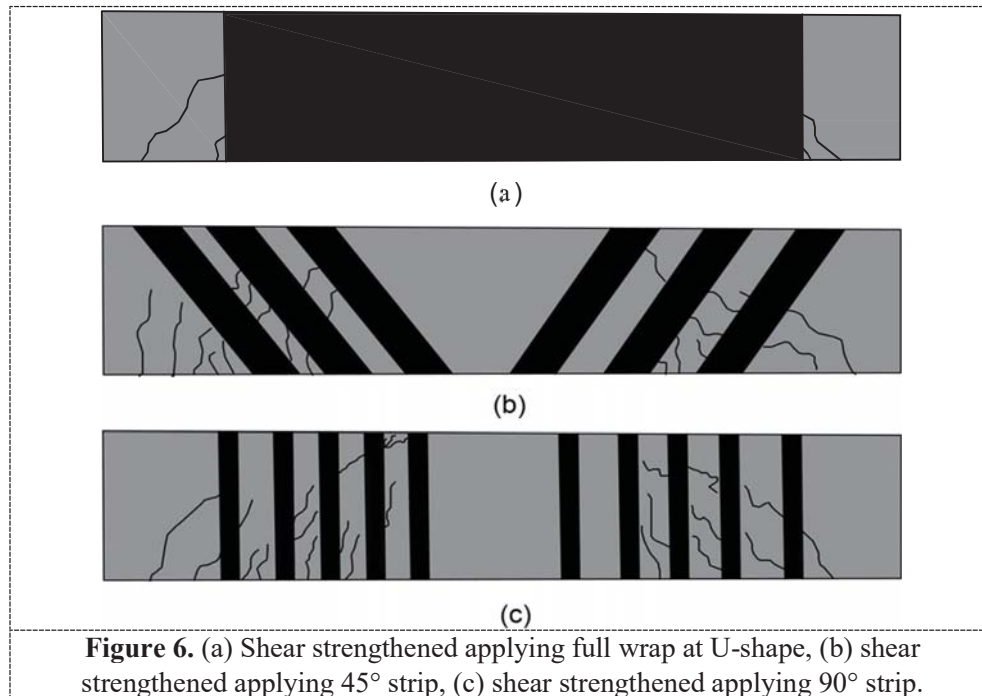


Figure 5. Shear strengthening [74].



7. Conclusion

In this study, this detailed review aims to provide significant knowledge reference for current and pertinent studies on the workable employment of FRP reinforcement, conducted studies, and the strengthening of RC beams by FRP. The research covered the adhesive curing, Shear strengthening, fatigue performance and failure modes of RC beam with FRP, and surface preparation. Based on this study, the subsequent conclusions can be drawn:

1. It is always preferable to use a surface treatment technology that produces a coarser surface since it accommodates more adhesives, improves bond strength, and higher failure load. Moreover, excellent curing restrains moisture transfer inside the FRP and concrete surface and adding 2% water to the adhesives during the process of curing speeds up the curing rate and also the degree of curing while excessive water impedes these characteristics.
2. For the applying of FRP plate there is no requirement for utilize bolts and this could avoids the risk of deterioration the steel reinforcement.
3. Strengthen RC beams by utilizing FRP enhances the retrofitted beams in terms of fatigue performance by stretching the strength and lifetime of the beams. Failure of the beams is mostly affected by the breakage of the reinforcing bars.

4. Shear capability of the CFRP has less effective when the amount of internal steel reinforcement increased. Besides, as the ratio of shear span to depth is large the influence of CFRP would take more space and the possibility of debonding will more occur.
5. The shear capacity can reach the optimum result by utilizing both strengthening schemes, CFRP U-shape wrap, and FRP strip applied at the bottom as well as enhancing the combined impact of shear, flexure, and torsion.
6. FRP is considered as an innovative technology that displays great potential for rehabilitation application, repairing structural elements, and in the construction industry retrofit the RC. Moreover, this technique is considered a very quick application and not demand specialized equipment.

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