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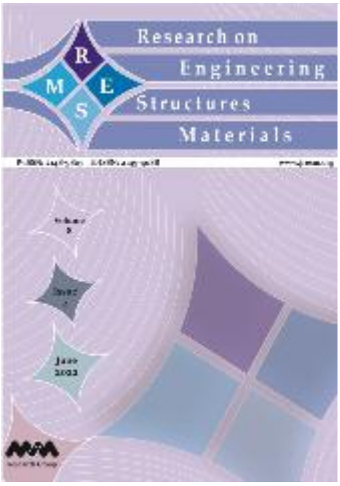

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Reivew Article

Evaluation of energy retention capacity of composite CFRP and GFRP in RC beam strength

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Abstract

Energy dissipation capacity and ductility are two significant parameters to improve structural performance in construction. Although there are many traditional methods of strengthening studies of beams are strengthened with fiber polymers draw attention, especially in recent years. In this study, the strengthening of the beams by the externally bonded reinforcing (EBR) method are investigated. The current studies in the literature are comprehensively reviewed and significant results have been presented. The energy dissipation capacities and ductility values of the important forty CFRP-GFRP beam strengthening studies of the last 10 years have been determined as nearly value based on the load-deflection graphs. The results are given in the table, and the accuracy hypothesis of the mean values of the two groups are statistically made with usage of the T-test. The values were chosen from within the acceptable range to increase the accuracy of the T-test. The average of the selected ultimate load values is very close to each other, CFRPs have also slightly higher load carrying capacity than GFRPs. When it comes to ductility analysis with T-test, it is seen that GFRPs have higher ductility values.

1. Introduction

Beams are significant part of the reinforced concrete structure. Fiber-reinforced polymers Fiber reinforcement polymers (FRP) are significant composite materials for strengthening of RC beams [1]. FRSs are widely used to strengthen reinforced concrete (RC) beams in the last twenty years to provide additional improvement in the mechanical behavior of reinforced structures in terms of strength and rigidity. Since the reinforcement studies using Externally Bonded Reinforcement (EBR) fabrics/laminates in the late 1990s, the method has received considerable attention and development. Composite materials having high strength and elasticity modulus have been developed to strengthen the RC beams externally. According to Razaqpur et al., FRPs are highly efficient in the rehabilitation of RC beams due to their high strength, high elastic modulus, and low density [2]. The use of FRP composite materials in strengthening and repairing RC structures is a received engineering practice. Despite the current code provisions, the design of strengthened of RC beams with FRP composites include several challenges [3]. T.F.El-Shafiey mentioned that the use of delaminates in the strengthening of RC beams have received a significant share in research on the external strengthening of beams [4]. FRP systems for strengthening RC structures have emerged as an alternative to traditional strengthening techniques such as steel plate bonding, section enlargement, and external stretching[2,4]. Fiber selection often controls the properties of composite materials. Carbon, Glass, Aramid, and Basalt materials are the four main types of fibers used in construction. The composite is often referred to as reinforcing fibers, such as, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP).

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There are two main techniques to strengthen of RC beams, which are externally bonded reinforcing (EBR) and near-surface mounted (NSM) techniques. In this study, it has been focused on the EBR techniques that find out their advantages, disadvantages, and application are detailed in the subtitles. Many curves in the literature have been redrawn to better understand the use of the EBR technique in the RC beams. In addition to the application technique used in beam strengthen, the type of fabrics attached is also important. CFRP and GFRP fabrics are widely used in strengthening of RC BEAMs. Hence, mainly focused on the beams that are strengthened with CFRP and GFRP laminates using the EBR technique. Moreover, important findings compiled from studies conducted in the last ten years, which have been added to the tables. The table includes a total of 40 experimental studies reinforced with 20 CFRP and 20 GFRP laminates according to the EBR technique. It is understood from the studies performed that while high strength is generally obtained in the studies with FRP, the energy holding capacity and ductility remain at low levels. This is mostly due to the linear elastic behavior of FRP type materials. In some studies, with additional methods, namely changes in the volumetric ratios of FRPs, the ductility has been increased a little more by increasing the thickness or by methods such as anchoring. The significant consequence of this is the need for external strengthening composites to strength the elastic behavior of the reinforcement.

The maximum strength of CFRPs is higher than GFRPs on average, but GFRPs have higher elongation at break, they also can consume more energy and ductility is slightly higher. As a comparison study, 20 CFRP and 20 GFRP results of articles were analyzed by statistical T-test and the accuracy hypothesis of the mean values was presented mutually. The results show that the standard deviation of the energy and ductility values of GFRPs are normal compared to the means. In addition, when the proximity of the standard deviations between CFRP and GFRP with the mean value is tested with 95% accuracy, it is seen that the value 0 from the results obtained remains in the mean of both groups. These results require the accuracy of the hypothesis.

Hence, many parameters and results of the studies are presented together, and the researchers will have the opportunity to see the results of the studies made with the EBR technique using CFRP and GFRPs. In addition, compiling important studies of the last 10 years and revealing the energy dissipation capacities and ductility according to the load-deflection graphs makes the study unique.

2. Strengthening of RC Beams Using FRP

The composite materials were first used in aerospace applications such as aircraft and spacecraft. Since the 1970s, its usage in other areas has continued to increase. FRP materials are used as reinforcement material for concrete structures as well as reinforcing various structures made of plates, strips, concrete, walls, timber and even steel. The use of FRPs to improve the seismic performance of structures is increasing day by day.

Spadea et al., strengthened the RC beams with EBR- CFRP sheets to observe structural behavior of beams. They tested four beams under displacement controlling. The results show that the adherence between a CFRP plate and the surface of a RC beam that may cause an important deterioration in response of coating beam regardless of an anchor stress and the bond shear between the slab and the concrete substrate [6]. Kotynia et al., conducted an experimental study and numerical analysis of RC beams strengthened in flexure with various externally bonded CFRP configurations. They tested ten rectangular RC specimens with clear span of 4.2 m, as two series to appreciate the influence of using the additional U shaped CFRP system on the intermediate crack stripping of the bottom laminate [7]. In order to take in consideration of the orthotropic behaviour of the CFRP laminates, a numerical analysis was performed in the parametric study, which it was showed that increasing the FRP thickness increases the load carrying capacity when the failure mode is FRP rupture, and increasing the limiting effect increases load carrying capacity when the failure mode occurs as a FRP breakage. A design method was proposed to obtain sufficient load carrying capacity and ductility performance [8].

RC beams should be resistant to various impact and burst loads. Thanks to FRP strengthening techniques can be provided improvements in the strength and flexibility of RC beams [9]. Siddika et al., conducted a review paper for characteristic performance of RC beams reinforced with the FRP that under different loading. Their review study showed that the RC beams can be strengthened with FRP type materials to eliminate damages, provide better strength, flexibility and insulation [9,10].

There are two strengthening techniques of RC beams with FRP materials: externally bonded reinforcing (EBR) laminates near-surface mounted (NSM) bars/strips strengthening techniques [11]. The EBR system is the most strengthening technique in terms of ease of application. It is widely used in strengthen structural elements for shear, flexure, torsion and axial. NSM strengthening technique is used in the feasibility to effectively increase shear load carrying capacity and deformation properties of reinforced structural members. In general, the NSM system consists of placing additional reinforcements inside the concrete cover of the deficient structural element. This technique has outperformed most of the other methods due to the ease of providing a significant increase in the capacity of the structural member [12–15]. Mechanical anchoring systems, grooving methods or without adhesive have been used FRP techniques. In addition, throughout the thickness of the RC element to be reinforced FRP fabrics can be joined by threading or sewing[16–18]. It may be a good idea to round the beam edges before wrapping with FRP to reduce excessive stress on the beam edges and increase compressive strength and also enhance the interaction between FRP and concrete [19–21]. External CFRP sheets are the most common method used to strengthening, rehabilitating or repairing RC members. CFRP increases the bending, shear capacity of the deteriorated members, and extends their useful life [22]. These techniques are schematically illustrated in Fig. 1.

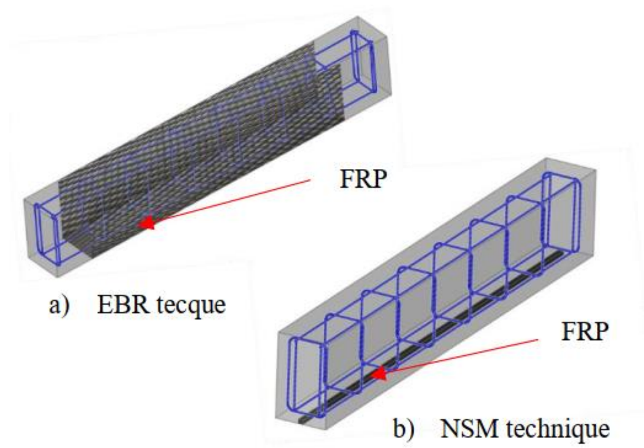


Fig. 1 Illustrated EBR and NSM techniques

There are some techniques such as preparation of the concrete surface for EBR and NSM methods during the strengthening of RC beams, cleaning, epoxy resin adhesive injection and placement of laminates. These preparation steps can be listed as surface preparation, adhesive operation and anchorage provision [16,17,23,24]. Concrete surface preparation can increase the ultimate load by 3-10% [25].

Grooves of special width and thickness are drilled from the concrete surface in NSM technique. Then FRP strips and epoxy resin can be used to fill the concrete. Epoxy resin is applied to fasten FRP boards directly through the specified cavity [26]. Since the NSM technique is applied from the inside, which by opening a channel along the beam, the delamination and environmental adverse effects caused by the EBR technique do not occur. For this reason, the NSM is considered by researchers as a superior technique [9]. In order to remove impurities hidden on the concrete surface, the weak layer is removed in traditional surface preparation and a surface with visible aggregates is obtained. This ensures proper and sufficient adhesion between the concrete surface and the FRP composite [27]. Surface bonding by external bonding is a common method for attaching FRP boards to the surface of concrete beams. Researches have shown that removing a thin concrete surface with water pressure will increase the effect of surface preparation [25]. It was proved that beams softened by water pressure carry more load than those softened by grinding [28].

Epoxy adhesives are an important equipment of the class of structural adhesives, which includes polyurethane, acrylic, cyanoacrylate and other chemistries. These high-performance adhesives are widely used in the construction [29]. Resins are solid and viscous polymers. Applications of epoxy-based materials are wide-ranging, which include coatings, adhesives or clay mineral reinforcements [30]. These polymeric materials, which are properties polyester, epoxy or phenolic forms, provide excellent adhesion strength [26]. There are many types of epoxy resins. Epoxies are known as materials with excellent adhesion and chemical heat resistance properties as well as good and excellent mechanical properties [30]. Manufacturers obtain epoxy resin by mixing certain proportions of epoxy and hardener components in their specifications. This ratio usually ranges from 1:1 to 5:1, unless the epoxy and hardener components are especially specified. Epoxy resins weight approximately 0.5 kg/m2 per unit surface area [26,31]. Epoxy adhesives are better than other common adhesives in terms of heat and chemical resistance. In general, thermosetting epoxy adhesives are more heat and chemical resistant than those hardened at room temperature. Maximum elongation in case of failure occurs in the tensile stress range of 30 MPa to 90 MPa 0.9-4.5% and 1.1 GPa - 6 GPa elastic modulus. The epoxy curing period is generally between 3 days and 14 days and 16 °C - 23 °C temperature [33]. As disadvantages, the strength of epoxy adhesives decreases at temperatures above 177 °C. [31,33–35].

Generally, there are four wrapping methods of FRP sheets to enhancing load carrying capacity of beams. These methods are full wrap on four faces (Fig. 2a), U shape wrap on bottom and two side faces (Fig. 2b), under bound as band (Fig. 2c) and two-side bound on lateral sides method (Fig. 2d). The configurations of FRP shown in Fig. 6 can be continuous sheets, spaced or diagonally bounded. Flexible and U-shaped FRP strips can be used to resist delamination in beams under intense loads. The sheets can be placed in the center line of the point load, covering the beam tensile face [36]. The method of FRP strips on two lateral faces has the disadvantage like decomposition on the faces. The method of FRP strips on two lateral faces has the disadvantage like debonding. In order to prevent or delay separation of FRP sheets used in shear and flexural strengthening, anchoring methods to conventional EBR are used to anchor FRP sheets to the structural member (GM) [13,37,38].

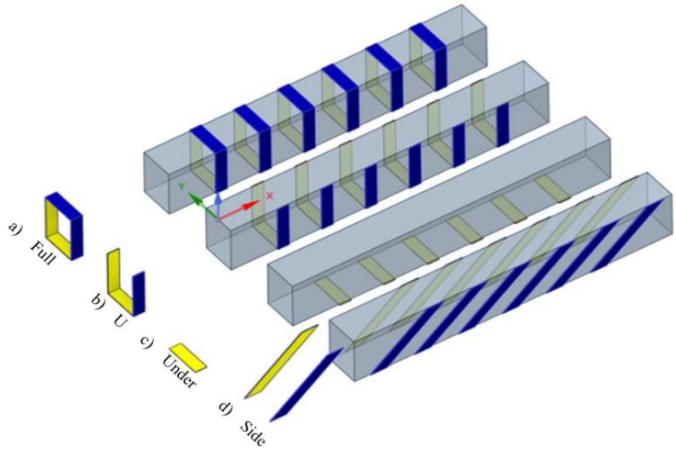


Fig. 2 Wrapping types of FRP on the beams

2.1. Strengthening Beams using EBR Technique

EBR strengthening of damaged beams helps the beams to recover as well as increase shear capacity. Moreover, a CFRP split strip layer increased the total capacity of shear-deficient beams by more than 60%, and an additional layer increased the cutting capacity by another 30% [39]. The quality of the strengthening materials and the technique used play an important role in increasing the load carrying capacity of RC beams. RC beams have many different wrapping techniques. For instance, application of EBR to the external bonding of the beam member along the tension face can effectively increase the flexural strength [9,20,40,41]. In another experimental study, the increase in shear strength of the beam strengthened with U-Wrapped CFRP plates was observed. As a result of the observation, the increase in shear capacity of the fully wrapped WBR1 and WBR2 beams compared to the control samples was observed to be 69.28% and 201.63%, respectively [42]. When the beams with shear deficiency reinforced with GFRP externally and internally, were subjected to the bending test at three points, it was observed that the load bearing capacity increased significantly compared to the control sample. Concrete beams built from individual segments connected to each other by special mechanism referred as segmental beams have a higher ratio of CFRP area and less deflection, in which can maintain the ultimate loading value of 38.4% [43].

There can also be a significant increase in flexural flexibility, energy dissipation and non-elastic performance of the RC beams. The performance of the external GFRP wrapped RC beam makes up for better than the internal wrapped beam [44]. ACI 440.2R for predicting the shear strength of RC beams strengthened with EBR gives conservative estimates of shear capacity due to its inability to capture the variation of β and θ [45]. Recently, EBROG, which is a new method called Externally Bonded Reinforcement on Grooves has been introduced as an alternative to the EBR method to retrofit RC beams. The EBROG method has also been studied by many researchers [37,46,47,56]. Axial and flexural strengthening of RC columns and seismic strengthening of RC beam-column joints are discussed as detail [16,47–49]. The use of the EBROG method in specimens resulted in a significant increase up to the maximum load-carrying capacity compared to the EBR technique in terms of area under the ultimate load capacity, mid-span deviation, and load deviation curve [50]. In most cases, by increasing the number of CFRP layers, seismic parameters such as failure stress, energy absorption and ductility increase. However, in beams with higher strength concrete, the effect of CFRP on mechanical properties and seismic parameters is more pronounced [51]. In another experimental study that reinforced and non-reinforced beams are mutually adjusted, which has been shown that it is possible to obtain economical and higher performance beams by reducing the amount of reinforcement in reinforced beams [52]. The beam that failed by delamination of the CFRP sheets experienced debonding strain of 3341 micro strain which represented 19% of the rupture strain of CFRP sheets. The analytical procedure provided accurate and consistent estimates for the shear capacity of beams tested with CFRP strengthening [53]. An experimental study was conducted on one unreinforced RC box-girder and four RC box-girders strengthened by different CFRP wrapping schemes. In addition, the characteristics of each strengthening scheme are also revealed through comparing the strain distribution pattern of box-girders strengthened with CFRP and that of contrast box-girder.

3. The Strengthening Applications

Reinforcement in RC beams is generally done to increase shear strength, flexural strength, fatigue life, earthquake performance, impact and burst strength [9]. Shear crack and flexural failures widely occur in beams so that shear and flexural strengthening of beams should be considered. Strengthening methods are described in detail below. In the EBR technique, the correct application of the laminates on the desired surface depends on the correct knowledge of the stress surface. It is possible to adhere more than one laminate to the stress side [54,55].

3.1. Shear Strength Performance of RC Beams

sliding and tearing of the molecules of concrete materials of beams. Many studies have been carried out in recent years due to the development of high performance FRP materials to increase the shear performance of the structures [38,56–59]. The FRP composites are effective in the rehabilitation of structures as they stop the propagation of cracks. They increase the hardness and resistance and prolong their lifecycle [60]. The beams are reinforced with steel stirrups to resist shear stresses, also strengthened with longitudinal steel reinforcing bars to withstand flexure stresses. The shear reinforcement of the RC beams adds an external shear reinforcement to support the internal shear reinforcement (stirrups). Test results of beams reinforced using the EBR FRP technique have shown that the high corrosion level of stirrups significantly reduces the shear capacity of both the strengthened and unstrengthen beams [61]. The beam wrapped with three layers of GFRP sheet in the shear spans and anchored with A3 type anchorage system, increases the shear strength by 55.5% with ductile behavior than the non-strengthened beam [62]. As a winding technique, higher strength can be obtained in beams wrapped in a U shape compared to other winding techniques. However, FRP fabrics can be mounted on the surface with techniques such as anchors to increase energy retention capacity and density after bounded with epoxy resin [63]. The failure mode in the strengthened beam can be transformed from shear failure to flexural failure thanks to the CFRP winding. Strengthening of beam with CFRP increased the shear capacity of beams [64]. Shear cracks usually take place at an angle of 45o as shown in Fig. 3 in the compression zone between the applied load and the supports. Shear cracks are closer to the load application area.

It was stated that with the CFRP bars applied using the NSM technique, the shear strength of RC slender beams can be increased between 17% and 25% [65]. In an experimental study conducted by Ibrahim, which was showed that the effectiveness of using both NSM and EB strengthening systems to enhance the shear capacity of RC rectangular deep beams. In the experimental research conducted by comparing the winding system of the CFRP strips with both sides U-shaped and fully wrapped on both sides, the presence of horizontal CFRP strips in the vertical strips increases the shear capacity of the beams ranged between 3-27% for beams with the same properties, while the increase in the ultimate loads ranged between 20-26% and 39.5-46% [66]. In another experimental study strength, stiffness, ductility and crack were compared of specimen before and after retrofit. The experiment showed the ultimate load of beam was enhanced after strengthening, but the ductility and stiffness of the beam were decreased. Shape of cracks also changes between original and wrapped beam [67]. In addition, as the CFRP strip spacing decreases, shear capacity, final deflection and bending stiffness increase. In order to increase the effectiveness of the EBR technique, an increase in the performance of the EBR technique with the help of external reinforcement with a new method called EBROG was observed [68]. The bond strength of the EBROG sample was 42-67% higher than that of the EBR sample [69]. Beams strengthened in shear with externally bonded reinforcement in grooves (EBROG) method the beams shear capacity was increased with and without stirrups by an average value of 40% and 69%, respectively, compared to the corresponding controls. Based on the results of analytical models to estimate shear contribution in traditional methods, the proposed formulations can be used to estimate shear gain due to EBROG laminates [70]

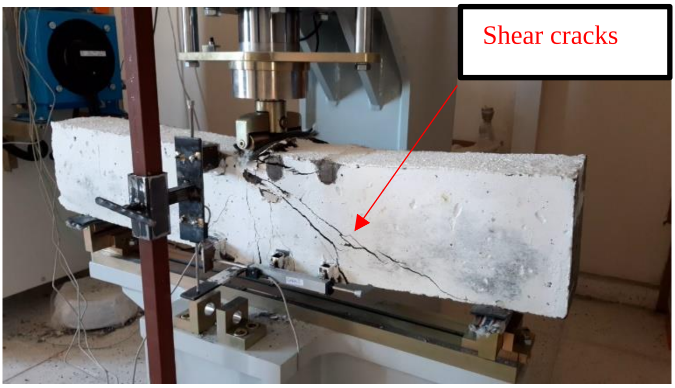


Fig. 3 Shear failures of RC beam

3.2. Flexural Strength Performance of RC Beams

The RC beams commonly undergo flexural fracture in the middle span [71]. Flexural fracture of beam is shown in Fig. 3.4. CFRP laminates with the EBR are an effective technology to increase service life and maximum RC beam loads even when made with low quality concrete [72]. According to some researchers, conventional method for flexural strengthening of RC beams is made by means of EBR, which is adhered to the tension base [73–76]. Thanks to EBROG method longitudinal grooves with a depth of 10 mm resulted in complete elimination of separation and significantly increased load-bearing capacity and also retained 100% capacity of FRP sheets [16]. Moreover, in an experimental study used on the EBR and EBROG methods, in three vertical and inclined configurations demonstrated the effectualness of inclined orientation load carrying capacity of strengthening sheets [77]. According to Daugevicius's estimate deflection method, the deflection of the strengthened RC beam can be calculated, and the deflection can be estimated when the steel yield is reached. In the strengthened the RC beam, maximum bending moment occurs at higher rates due to increasing reinforcement stress, while it occurs at lower values in the non-strengthened beam [78].

Bonding FRP laminates to increase the flexural strength along the tensile face of the RC beams (usually the lower part) is an effective method that has gained interest in recent years [35,79]. Strengthening the RC beams against bending is also an effective method preferred in terms of repair. These preferences increase the confidence in the material and the method used. Singh and Munjal [80] strengthened of tension zone with one layer of the

CFRP lamina for flexural failure. First, they cleaned bottom surface of the beam for dust before applying epoxy adhesive. Then, they strengthened the RC beam by gluing CFRP along the beam by applying epoxy resin uniform to the beam base by means of a roller brush. Similarly, some researchers used steel plates for the flexural strengthening of RC structures with the EBR [81–85]. On the other hand, there are also researchers who argue that the using of steel plates for externally bonded reinforcement is associated with potential corrosion, poor strength, increased dead loads and premature failure of reinforced structural members [86–88]. The application of the adhesive and FRP under the RC beam is shown schematically in Fig. 5.

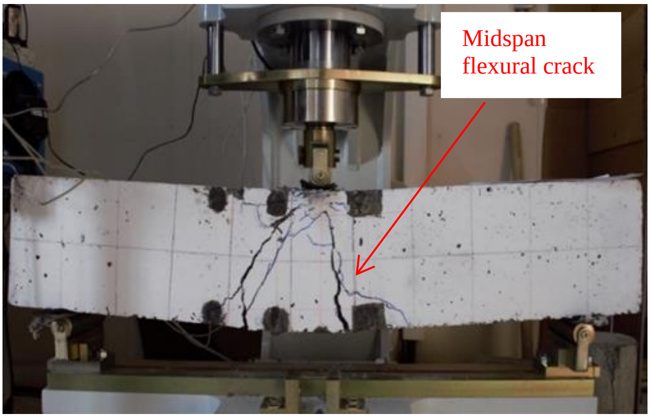


Fig. 4 Flexural failures of RC beam

Bonding FRP laminates to increase the flexural strength along the tensile face of the RC beams (usually the lower part) is an effective method that has gained interest in recent years [35,79]. Strengthening the RC beams against bending is also an effective method preferred in terms of repair. These preferences increase the confidence in the material and the method used. Singh and Munjal [80] strengthened of tension zone with one layer of the CFRP lamina for flexural failure. First, they cleaned bottom surface of the beam for dust before applying epoxy adhesive. Then, they strengthened the RC beam by gluing CFRP along the beam by applying epoxy resin uniform to the beam base by means of a roller brush. Similarly, some researchers used steel plates for the flexural strengthening of RC structures with the EBR [81–85]. On the other hand, there are also researchers who argue that the using of steel plates for externally bonded reinforcement is associated with potential corrosion, poor strength, increased dead loads and premature failure of reinforced structural members [86–88]. The application of the adhesive and FRP under the RC beam is shown schematically in Fig. 5.

It is known that the U-shaped or completely wrapped beams with FRP fibers show very good strength performance, but it is quite complicated to apply in practice completely beams with FRP strips [89]. Flexural strength, stiffness and deflection resistance can be increased in beams by wrapping the FRPs in the form of a U-wrap [35,45]. The thickness of the U-shaped wrapped FRPs can be decisive in determining the strengthening performance of RC beams. For instance, in the flexural tests, which has been observed in several studies that the deflection resistance of RC beams reinforced with two-layer U-wound FRP sheet is reduced by about 39% compared the U-wound FRP strengthened RC beams with a single layer FRP. It can be understood from this that the high ratio of flexural strength weakens the reinforcement [90,91]. The side-externally bonded (S-EBR) strengthening technique with CFRP fabric significantly could enhance the flexural capacity of non-pre-cracked and pre-cracked lightweight RC beams [92]. Anchoring systems are more effective and useful to increase the flexural behavior of beams when use CFRP laminates for flexural strengthening [93,94]. CFRP and GFRP composite fabrics are widely preferred in beam strengthening. Although BFRP fabric is not economical, the RC beam can significantly increase its bending capacity [95].

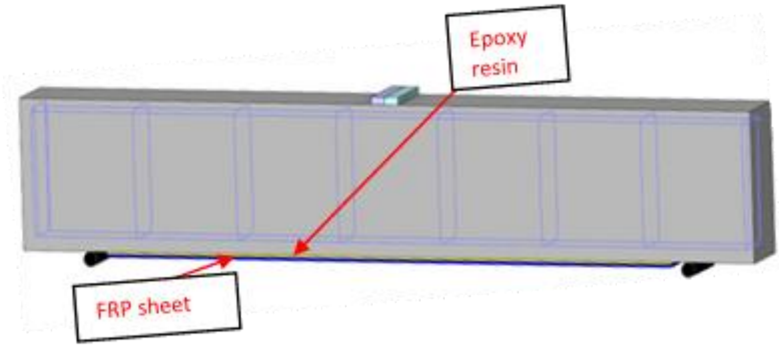
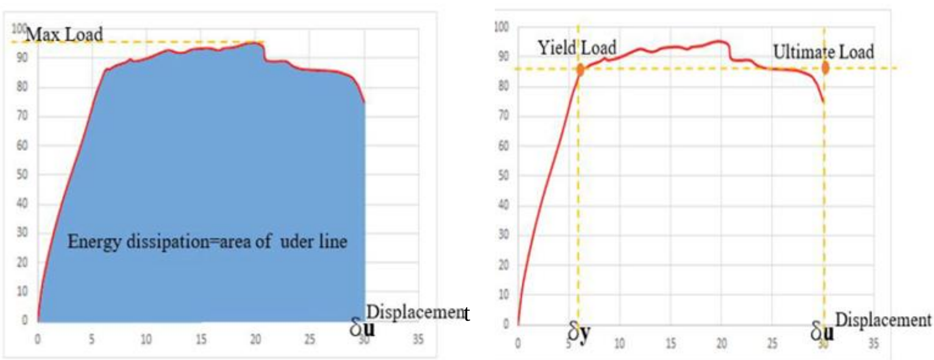


Fig. 5 Activated blind shear ram and shear sequence

3.3. Energy Dissipation and Ductility Performances

The most common composites used in strengthening RC beams using the EBR technique are CFRP and GFRP. Based on this, the studies conducted with both methods in the last 10 years has been examined in detail and the results have been written in Table 4. A total of 40 valuable study data have studied, including 20 from CFRP and 20 from GFRP. As a result of the examined studies, comparisons have been made by giving load-bending graphics of the beams.

With the high strength expected from structural beams, the increase in energy dissipation capacity and the increase of ductility, respectively. As a result of 40 studies examined in Table 1, very little energy retention capacity and ductility values were determined. The energy dissipation capacity is given by the area shown in blue in the load displacement graph in Fig. 6a. Ductility is calculated by dividing the displacement at the ultimate load case by the displacement at the yield point as shown in the graph in Fig. 6b.



(a) Energy dissipation = $\int_0^F F.d\delta$

(b) Ductility=du/dy

Fig. 6 Representation of energy dissipation and ductility

These values, which are not given in the majority, were calculated one by one and added to the Table 1. Thus, a significant compilation and contribution has been achieved in the literature. In addition to these, the energy holding capacities of the reinforced beams and their ductility values are discussed and various assumptions are presented below the Table 1.

Table 1. Mechanical properties of composite

Beam Label	FRP type	Wrapping	Lamina Strength	Lamina Elasticities	Thickness	Lay up	Fc. (MPa)	Beam Length(mm)	Depth of beam(mm)	Width of Beam (mm)	Failure	Strength (kN)	Energy Dissipation (kN)	Ductility (mm/mm)
[89]**(**Gemi et al. 2019**)**														
P2	CFRP	F	-	0	-	±45	30	3200	315	80	B	123	2722	2,17
P3	CFRP	U	-	0	-	±45	30	3200	315	80	B	116.4	5252	3.17
P4	CFRP	U	-	0	-	±45	30	3200	315	80	S	118.9	3124	1.67
P5	CFRP	F	-	0	-	±45	30	3200	315	80	S	132.5	5697	2.08
[96](Arslan et al. 2019)														
CFRP-1-RB	CFRP	F	-	0	-	0/90	0	2500	250	125	B	117.2	6482	4.07
CFRP-1-D75	CFRP	F	-	0	-	0/90	0	2500	250	125	B	117	6073	3.57
CFRP-1-D110	CFRP	F	-	0	-	0/90	0	2500	250	125	S	117.1	1557	1.49
CFRP-1-D160	CFRP	F	-	0	-	0/90	0	2500	250	125	S	68.4	861.6	1.37
CFRP-2-D75	CFRP	F	-	0	-	0/90	0	2500	250	125	B	113	6404	4.39
CFRP-2-D110	CFRP	F	-	0	-	0/90	0	2500	250	125	B	128.5	8785	4.46
CFRP-2-D160	CFRP	F	-	0	-	0/90	0	2500	250	125	S	85.6	1304	1.43
[32] (Hawileh et al. 2014)														
BC	CFRP	B	1548	119.25	0.34	±45	50	1840	240	125	SY	92.44	1216	2.37
[31](Attari et al, 2012)														
PA1	CFRP	U	0	19.2	1.5	±45	39	1500	160	100	S	77.86	8.84	4.05
[40](Shannag et al. 2014)														
B1-J100	CFRP	U	-	-	0.17	0	35	1600	200	100	C	144	678.5	1.06
B1-S100	CFRP	B	-	-	0.17	0	35	1600	200	100	C	132	733.4	1.1
B1-Sh100	CFRP	B	-	-	0.17	0	35	1600	200	100	C	130	987.9	1.35
B2-J100	CFRP	U	-	-	0.17	0	35	1600	200	100	C	112	745.9	1.13
B2-S100	CFRP	B	-	-	0.17	0	35	1600	200	100	C	91	530.3	1.24
B2-Sh100	CFRP	B	-	-	0.17	0	35	1600	200	100	C	83	836.8	1.23
[97](Altin et al. 2010)														
1	CFRP	U	4100	231	0.12	90	25	4000	360	120	S	49.51	677.1	2.23
2	CFRP	U	4100	231	0.12	90	25	4000	360	120	S	82.55	1192	1
3	CFRP	U	4100	231	0.12	90	25	4000	360	120	S	81.99	1042	1
4	CFRP	U	4100	231	0.12	90	25	4000	360	120	S	69.04	823.8	-
5	CFRP	U	4100	231	0.12	90	25	4000	360	120	F	87.68	4508	3.03
6	CFRP	U	4100	231	0.12	90	25	4000	360	120	F	86.31	4081	2.77
7	CFRP	U	4100	231	0.12	90	25	4000	360	120	F	86.63	4032	2.19
8	CFRP	U	4100	231	0.12	90	25	4000	360	120	F	86.36	3318	2.02
9	CFRP	U	4100	231	0.12	90	25	4000	360	120	F	85.21	3805	1.99
10	CFRP	U	4100	231	0.12	90	25	4000	360	120	F	85	4169	1.97
[98]Gamino et al., 2010)														
VTC1	CFRP	U	3500	230	0.13	90	60	1500	360	120	S	220	626.6	2.9
VTC2	CFRP	U	2728	221	0.11	90	59	1500	360	120	BF	305	818.4	3.5
VTC3	CFRP	U	2730	218	0.17	90	60	1500	360	120	D	243	610	2.7
VTC4	CFRP	U	3550	235	0.11	90	57	1500	360	120	BF	275	629.8	1.95
VTC5	CFRP	U	1250	310	1.4	90	55	1500	360	120	S	207	501.2	1.75

Table 1. (Con.) Mechanical properties of composite

Beam Label	FRP type	Wrapping	Lamina Strength	Lamina Elasticities	Thickness	Lay up	Fc. (MPa)	Beam Length(mm)	Depth of beam(mm)	Width of Beam (mm)	Failure	Strength (kN)	Energy Dissipation (kN)	Ductility (mm/mm)
[99](Önal, M. M. 2014)														
KC301	CFRP	F	-	146	0.13	45	20	2200	360	120	S	116	1416	4.8
KC302	CFRP	F	-	146	0.13	45	20	2200	360	120	S	119	1358	5.7
KC303	CFRP	F	-	146	0.13	45	20	2200	360	120	S	117	1376	5.7
[100](Gao. et al. 2016)														
NS	CFRP	B	4286	256	0.11	-	33	2600	300	150	D	118	2022	3.16
PS1	CFRP	B	4286	256	0.11	-	19.8	2600	300	150	R	137	8772	3.77
PS2	CFRP	B	4286	256	0.11	-	15.9	2600	300	150	R	111	4389	3.29
PS3	CFRP	B	4286	256	0.11	-	19.8	2600	300	150	R	119	6791	2.96
PS4	CFRP	B	4286	256	0.11	-	19.8	2600	300	150	R	133	6565	3.53
WPS1	CFRP	B	4286	256	0.11	-	21.9	2600	300	150	R	103	7055	3.02
WPS2	CFRP	B	4286	256	0.11	-	33	2600	300	150	R	110	6971	2.25
SPS1	CFRP	B	4286	256	0.11	-	33	2600	300	150	R	116	5691	2.76
SPS2	CFRP	B	4286	256	0.11	-	33	2600	300	150	R	121	7658	2.77
SPS3	CFRP	B	4286	256	0.11	-	33	2600	300	150	R	115	4973	3
SPS4	CFRP	B	4286	256	0.11	-	24	2600	300	150	R	116	4964	2.36
[101](Moshiri et al. 2020)														
EBR-U	CFRP	U	2800	160	1.4	-	35	3400	500	150	F	30.7	1424	2.46
EBR-U-theoritical	CFRP	U	2800	160	1.4	-	35	3400	500	150	F	30.7	1424	2.46
[39](Karzad et al. 2019)														
RS-0-1L-28	CFRP	U	220	-	0.17	90	36	2700	330	230	SD	58	1798	1
RS-S-1L-30	CFRP	U	220	-	0.17	90	30	2700	330	230	SD	74	2210	1
RS-0-2L-38	CFRP	U	220	-	0.33	90	38	2700	330	230	SD	117.5	3885	2.2
RS-S-2L-38	CFRP	U	220	-	0.33	90	38	2700	330	230	FD	113	5682	1.6
[102](Kim and Shin 2011)														
CC	CFRP	F	2300	270	0.59	90	17.4	2400	250	150	D	78.2	1633.52	3
[103](Antony et al. 2019)														
UCB1L700BL	CFRP	B	4000	230	0.75	-	25	1000	140	120	F+D	42	494.1	2.8
UCB2L700BL	CFRP	B	4000	230	0.75	-	25	1000	140	120	F+D	45.6	436.9	2.5
UCB3L700BL	CFRP	B	4000	230	0.75	-	25	1000	140	120	D	46	363	3.33
UCB2L650BL	CFRP	B	4000	230	0.75	-	25	1000	140	120	D	44	484	3.25
UCB2L600BL	CFRP	B	4000	230	0.75	-	25	1000	140	120	D	42.8	430.9	3.45
[104](Bilotta et al. 2015)														
EBR_c_1.440_	CFRP	B	2052	171	1.44	-	21	2400	160	120	D	36.5	872.5	1.66
EBR_c_1.440_2	CFRP	B	2052	171	1.44	-	21	2400	160	120	D+CS	35.2	842.3	1.66
EBR_d_1.440_1	CFRP	B	2052	171	1.44	-	21	2400	160	120	D+CS	75.1	1810	2.22
EBR_d_1.440_2	CFRP	B	2052	171	1.44	-	21	2400	160	120	D	64.8	1625	2
[105](Triantafyllou et al. 2018)														
RC-COR1S1	CFRP	F	3800	242	1.2		50	2300	300	150	F	191.7	5959.52	2
RC-COR2S1	CFRP	F	3800	242	1.2		50	2300	300	150	F	226.6	7192.32	3.04
RC-COR3S1	CFRP	F	3800	242	1.2		50	2300	300	150	F	245.6	4755,37	4.6
[106](Skuturna and Valivonis. 2016)														
BW1-1	CFRP	U	3800	231		-	35	1500	150	100	R	105	133.5	2.73
BW1-2	CFRP	U	3800	231		-	35	1500	150	100	R	97.8	130	2.6
[68](Mofrad et al. 2019)														
A-EBR-V	CFRP	B	3900	230	0.17	90	42	1400	160	120	S	127.6	503	1
A-EBR-D	CFRP	B	3900	230	0.17	45	42	1400	160	120	S+D	169.3	903	1.4
B-EBRE-V	CFRP	U	3900	230	0.17	90	40.5	1400	160	120	S+D	164.3	592	1.58
B-EBRE-V	CFRP	U	3900	230	0.17	45	40.5	1400	160	120	S+D	153.6	774	1.78
C-EBR-V	CFRP	F	3900	230	0.17	90	42.5	1400	160	120	S+D	192.4	1103	1.4
C-EBR-D	CFRP	F	3900	230	0.17	45	42.5	1400	160	120	S+D	187.9	1280	1.28

Table 1. (Con.) Mechanical properties of composite

Beam Label	FRP type	Wrapping	Lamina Strength	Lamina Elasticities	Thickness	Lay up	Fc. (MPa)	Beam Length(mm)	Depth of beam(mm)	Width of Beam (mm)	Failure	Strength (kN)	Energy Dissipation (kN)	Ductility (mm/mm)
[106](Skuturna and Valivonis. 2016)														
BW1-1	CFRP	U	3800	231		-	35	1500	150	100	R	105	133.5	2.73
BW1-2	CFRP	U	3800	231		-	35	1500	150	100	R	97.8	130	2.6
[68](Mofrad et al. 2019)														
A-EBR-V	CFRP	B	3900	230	0.17	90	42	1400	160	120	S	127.6	503	1
A-EBR-D	CFRP	B	3900	230	0.17	45	42	1400	160	120	S+D	169.3	903	1.4
B-EBRE-V	CFRP	U	3900	230	0.17	90	40.5	1400	160	120	S+D	164.3	592	1.58
B-EBRE-V	CFRP	U	3900	230	0.17	45	40.5	1400	160	120	S+D	153.6	774	1.78
C-EBR-V	CFRP	F	3900	230	0.17	90	42.5	1400	160	120	S+D	192.4	1103	1.4
C-EBR-D	CFRP	F	3900	230	0.17	45	42.5	1400	160	120	S+D	187.9	1280	1.28
[8](Chen et al. 2019)														
EB-1-0	CFRP	B	4131	270.5	0.33	-	30	2400	250	150	D	51.58	1155	2.29
EB-4-0	CFRP	B	4131	270.5	0.33	-	31.7	2400	250	150	D	51.76	759.4	2.11
[107](Firmo et al. 2018)														
BG	CFRP	B	2076	189	1.4	-	37	1500	120	100	F	74	1397.24	1.2
[108](Choobbor et al. 2019)														
B	CFRP	B	3900	230	0.17	-	38.78	840	240	120	R	73.37	1330	3.17
BB	CFRP	B	3900	230	0.17	-	38.78	1840	240	120	R+C	93.07	1098	3.64
[109](Miruthun et al. 2020)														
RCb	GFRP	F	3450	72.4	3	-	25	2000	250	150	D	85.78	486	3.35
RCint	GFRP	F	3450	72.4	5	-	25	2000	250	150	D	64.8	327.1	5.79
RCcro	GFRP	F	3450	72.4	3	-	25	2000	250	150	D	54.2	291.3	2.34
RCinc	GFRP	F	3450	72.4	5	-	25	2000	250	150	D	86.6	810	2.28
[99](Önal M. M. 2014)														
KG301	GFRP	F	4500	146	0.13	45	20	2200	250	150	S	122	1466	3.88
KG302	GFRP	F	4500	146	0.13	45	20	2200	250	150	S	124	1147	2.8
KG303	GFRP	F	4500	146	0.13	45	20	2200	250	150	S	121	1255	4
[110](Ravichandran et al. 2012)														
RCC3	GFRP	B	126.2	7467	3	-	64	3000	250	150	F	66.19	1521	4.17
RCC5	GFRP	B	156	11387	5	-	64	3000	250	150	F	98.1	2417	3.96
RCU3	GFRP	B	446.9	13966	3	-	64	3000	250	150	F	102.8	3786	4.08
RCU5	GFRP	B	451.5	17365	5	-	64	3000	250	150	F	112.6	5087	4.09
[111](Josy and Johny. 2019)														
U1	GFRP	U	-	-	-	-	53	1800	200	120	F	45	177.5	1.71
U2	GFRP	U	-	-	-	-	53	1800	200	120	F	49	209.7	1.35
U3	GFRP	U	-	-	-	-	53	1800	200	120	F	57	271.8	1.75
B1	GFRP	B	-	-	-	-	53	1800	200	120	F	42	123.7	1.29
B2	GFRP	B	-	-	-	-	53	1800	200	120	F	45	276.2	1.19
B3	GFRP	B	-	-	-	-	53	1800	200	120	F	50	237.1	1.83
[112](Meikandaan,y adn Murthy,. 2017)														
F21	GFRP	B	-	-	1.2	-	-	1500	200	100	F+C	70	909.9	3.67
F22	GFRP	B	-	-	1.2	-	-	1500	200	100	F+C	65	1048	3.14
F23	GFRP	B	-	-	1.2	-	-	1500	200	100	F+C	70	769.6	1.8
[113](Ahmed, H. et al. 2019)														
B8-SG-sh-A	GFRP	B	2500	72000	0.17	-	25	1500	350	160	D	11.44	2764	5.4
B8-RG-sh-A	GFRP	B	2500	72000	0.17	-	35	1500	350	160	D	10.74	2685	4.5
[114](Mariappan et al. 2016)														
1.5SF-3UDC	GFRP	-	451.5	17365	3	-	24	3000	250	150	F	100	7585	5.63
1.5SF-5UDC	GFRP	-	147.4	6856	5	-	24	3000	250	150	F	120	9164	6
1.5SF-3WR	GFRP	-	178.1	8994	3	-	24	3000	250	150	F	83	5280	6.67
1.5SF-5WR	GFRP	-	451.5	17365	5	-	24	3000	250	150	F	90	5277	5.2
1.5SF-3CSM	GFRP	-	147.4	6856	3	-	24	3000	250	150	F	70	4190	5.44
1.5SF-5CSM	GFRP	-	178.1	8994	5	-	24	3000	250	150	F	75	5206	4.67

Table 1. (Con.) Mechanical properties of composite

Beam Label	FRP type	Wrapping	Lamina Strength	Lamina Elasticities	Thickness	Lay up	Fc. (MPa)	Beam Length(mm)	Depth of beam(mm)	Width of Beam (mm)	Failure	Strength (kN)	Energy Dissipation (kN)	Ductility (mm/mm)
[115](Shrivastava and Tiwari. 2018)														
SFB1	GFRP	U	-	-	1.2	-	30	1000	150	150	S	53.33	219.2	1.15
SFB2	GFRP	U	-	-	1.2	-	30	1000	150	150	F	53.33	216.2	1.14
FB1	GFRP	B	-	-	1.2	-	30	1000	150	150	S	48.8	226.4	1.09
FB2	GFRP	B	-	-	1.2	-	30	1000	150	150	F	48.8	228.3	1
UB1	GFRP	U	-	-	1.2	-	30	1000	150	150	S	53.33	213.2	1.48
UB2	GFRP	U	-	-	1.2	-	30	1000	150	150	F	53.33	233.7	1.93
[116](Banjara and Ramanjaneyulu. 2017)														
SD2	GFRP	U	200	71000	0.17	45-90	30	1800	200	150	S	77.63	217	0.97
SD3	GFRP	U	200	71000	0.17	45-90	30	1800	200	150	S	66.26	176.1	0.97
SSD3	GFRP	U	200	71000	0.17	45-90	30	1800	200	150	S	95.4	20427	4.83
[117](Nanda et al. 2018)														
CC150GFRP	GFRP	F	2400	70000	-	-	36	1050	150	150	S	69	244.3	1.15
CC300GFRP	GFRP	F	2400	70000	-	-	29	1050	150	150	F	57.3	1167	2.06
[118](Sundarraja and Rajamohan 2009)														
RF2	GFRP	S	3400	7300	1	-	29.11	1000	150	100	F	53	121.8	1
RF2U	GFRP	U	3400	7300	1	-	29.11	1000	150	100	F	55	97.24	1
RF3	GFRP	S	3400	7300	1	-	29.11	1000	150	100	F	50	95.96	1
RF3U	GFRP	U	3400	7300	1	-	29.11	1000	150	100	F	52	76.18	1
RF4	GFRP	S	3400	7300	1	-	29.11	1000	150	100	F	48	115	1
RF4U	GFRP	U	3400	7300	1	-	29.11	1000	150	100	F	55	109.6	1
RF5	GFRP	S	3400	7300	1	-	29.11	1000	150	100	C	49	175.9	1
RF5U	GFRP	U	3400	7300	1	-	29.11	1000	150	100	F+C	50	114.7	1
[119](Panigrahi. et al. 2014)														
SB1	GFRP	S	127.2	209.9	1	45	24.88	1300	150	125	D	172	399.3	1
SB2	GFRP	S	172.8	209.9	1	45	24	1300	150	125	D	220	561.1	1
SB3	GFRP	S	218.4	209.9	1	45	23.32	1300	150	125	D	228	429.3	1
SB4	GFRP	U	264	209.9	1	45	23.13	1300	150	125	D	215	732.3	3.4
SB5	GFRP	U	309.6	209.9	1	45	24.12	1300	150	125	D	200	470.5	1
SB6	GFRP	U	355.2	209.9	1	45	23.68	1300	150	125	D	230	676.9	1.45
SB7	GFRP	U	400.8	209.9	1	45	24.1	1300	150	125	D	232	685.9	2.5
SB8	GFRP	U	446.4	209.9	1	45	24.06	1300	150	125	R	252	1439	1
SB9	GFRP	U	492	209.9	2.5	45	23.08	1300	150	125	R	268	833.7	1.55
[120](Ibrahim Syed et al. 2015)														
S0 L5	GFRP	B	1720	72	5	-	-	3000	250	150	D	88.29	1250	2.25
S1 L5	GFRP	B	1720	72	5	-	-	3000	250	150	D	112.8	2529	2.12
[121](Mohite et al. 2014)														
TB	GFRP	B	1800	70	-	-	20	1500	150	100	F	110	491.5	2.85
SB	GFRP	B	1800	70	-	-	20	1500	150	100	F	110	794.2	4.21
[122](Sivasankar et al. 2018)														
UW-1	GFRP	U	1500	45	-	-	60	1700	250	150	F	114.4	3033	1.18
UW-2	GFRP	U	1500	45	-	-	60	1700	250	150	F	123.1	3598	1.31
BW-1	GFRP	U	1500	45	-	-	60	1700	250	150	F	109.7	3804	1.29
BW-2	GFRP	U	1500	45	-	-	60	1700	250	150	F	114.7	4138	1.71
[123](Kumari and Nayak 2020)														
C-100-FS	GFRP	U	2040	16.07	2	-	27.65	1000	470	100	S	385.7	2022	1.18
C-150-FS	GFRP	U	2040	16.07	2	-	28.2	1000	470	150	S	271.8	2251	1.38
C-200-FS	GFRP	U	2040	16.07	2	-	27.8	1000	470	200	S	187.5	1974	1.37
S-100-FS	GFRP	U	2040	16.07	2	-	27.55	1000	470	100	S	309.2	2960	1.35
S-150-FS	GFRP	U	2040	16.07	2	-	27.65	1000	470	150	S	206.9	1944	1.43
S- 200-FS	GFRP	U	2040	16.07	2	-	27.2	1000	470	200	S	134.9	1463	1.41

Table 1. (Con.) Mechanical properties of composite

Beam Label	FRP type	Wrapping	Lamina Strength	Lamina Elasticities	Thickness	Lay up	Fc. (MPa)	Beam Length(mm)	Depth of beam(mm)	Width of Beam (mm)	Failure	Strength (kN)	Energy Dissipation (kN)	Ductility (mm/mm)
[124](Saribiyik and Caglar 2016)														
G11	GFRP	U	2300	76	0.17	90	17	2000	250	150	F	119	3033	3.25
G21	GFRP	U	2300	76	0.17	90	17	2000	250	150	F	148.1	3598	2.84
G22	GFRP	U	2300	76	0.17	90	17	2000	250	150	F	153.7	3804	3.07
G21-1	GFRP	U	2300	76	0.17	45	17	2000	250	150	F	156.6	4138	3.03
[125](Mini et al. 2014)														
B2	GFRP	B	3450	-	-	-	35.26	700	150	150	F+S R+D	98.4	104.2	1.1
U2	GFRP	B	3450	-	-	-	35.26	700	150	150	F+S R+D	108	223	1
22U2	GFRP	U	3450	-	-	-	35.26	700	150	150	F+S R+D	86.4	127.5	1.1
15U2	GFRP	U	3450	-	-	-	35.26	700	150	150	F+S R+D	75.2	91.12	1
S2	GFRP	D	3450	-	-	-	35.26	700	150	150	F+S R+D	98.4	178.7	1
[31](Attari et al. 2012)														
PA2	GFRP	U	0	19.2	2	45/-45	39	1500	160	100	C	78.95	1601	4.5
[32] (Hawileh et al. 2014)														
BG	GFRP	B	3400	72	0.352	45/-45	50	1840	240	125	C	76,84	1397	2.8

Failure types = **B**: Bending, **S**: Shear, **C**: Cracking, **F**: Flexural, **D**: Debonding, **R**: Rupture, **CS**: Concrete cover Separation, **BF**: break of FRP, **SY**: Steel Yielding Wrapping types = **U**: U shapes, **F**: Full, **B**: Bottom bounded, **S**: Sides bonded.

According to the values in Table 1, the maximum load, energy dissipation capacity and ductility averages have been calculated for each study and listed for CFRP and GFRP respectively in Table 2. Thus, it will be easier to do some statistical analysis. Independent two samples t-test: It is applied to test whether two independent samples are different in terms of a certain variable in different averages. The critical point here is that the condition of being included in groups is completely independent from the variable under study. In other words, the two groups (or two samples) being compared should not be related to each other. Externally reinforcing beams using CFRP and GFRP composites include studies conducted independently in the literature. Therefore, an independent two samples T-test can be applied the for average values obtained such as ultimate load, energy dissipation capacities and ductility values between these two independent groups.

3.4. Outlier Data Control Tests

Before starting the analysis, it is necessary to check whether there is any discrepancy between the values used. The first outlier test has been made among the load values Fig. 7 shows that there is no outlier between the load values used. For example, while performing this check, since the ultimate load values obtained from an original study conducted by Alhamdan and Dirikgil, were greater than 350 kN, the upper levels of the graph gave a warning with red color [126], in which replaced to with study of Kim and Shin [102]. Thus, with the outlier test, all load values were selected within the testable range.

If the P value is greater than 0.05, there is no outlier. According to the data of Grubbs' test all data values come from same normal population as shown in Table 3. Smallest or largest data value is an outlier as shown in Fig. 7.

Although an outlier test has been performed for load values, it is also useful to perform an outlier test in the amount of energy dissipation. Here, in the original strengthening study with CFRP performed by Chellapandian et al. (2019) the average load value of 156.1 kN a very high energy dissipation capacity of 9941.5 kN has been achieved. A high energy dissipation capacity was achieved, but it was omitted from this table as it did not conform to the normal distribution [127]. According to CFRP and GFRP Grubbs' Test values and P values are greater than 0.05, all energy dissipation values are data values come from same normal population as shown in Fig 8. It is useful to mention one more point. When Fig. 9 and Fig. 10. are compared, it can be understood from Fig. 8. that CFRP has higher load values, while GFRP has higher energy dissipation.

Finally, in the outlier test for ductility values, the results were within the normal range. In addition, it can be seen in Fig. 9 that higher ductility results were obtained in strengthening with GFRP compared to CFRP. CFRP and GFRP Grubbs' Test.

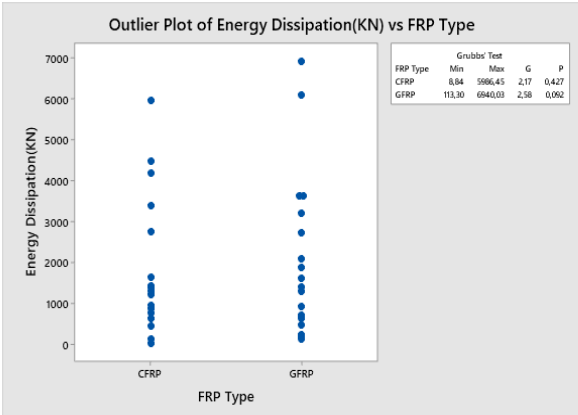


Fig. 8 Outlier test of energy dissipation capacity

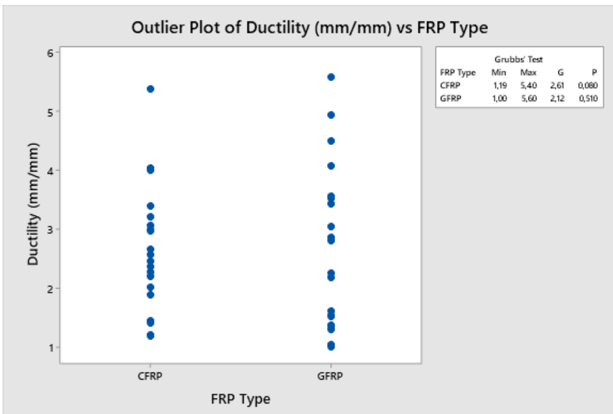


Fig. 9 Outlier test of ductility

3.4. Ultimate Load Carry Capacity

In this section is the comparison of the maximum ultimate strength values between CFRP and CFRP. When the averages of the groups are obtained, it cannot be determined at first sight whether they are different or not. A slight difference between the averages is found statistically significant in some cases, but not found in some cases. Testing differences between two group averages is possible via T-test. Here, it is determined with the help of Minitab statistics program whether the means differ significantly between two groups.

Analysis is carried out with the T- test, which is used to compare the mean values of two different groups with unknown variance.

Table 2. Average result values

No	References		Average		
			Maximum Strength (kN)	Energy (kN)	Ductility (mm/mm)
1	[89] (Gemi et *al.* 2019)	CFRP	122.7	4198.80	2.27
2	[96] (Arslan et *al.* 2019)	CFRP	106.69	4495.23	2.97
3	[32] (Hawileh et al. 2014)	CFRP	92.44	1216	2.37
4	[31] (Attari et *al.* 2012)	CFRP	77.86	8.84	4.05
5	[40] (Shannag et *al.* 2014)	CFRP	115.33	752.13	1.19
6	[97] (Altin et *al.* 2010)	CFRP	89.17	2764.79	2.02
7	[98] (Gamino et *al.* 2010)	CFRP	250	637.2	2.56
8	[99] (Önal, M. M. 2014)	CFRP	117.33	1383.33	5.4
9	[100] (Gao, et *al.* 2016)	CFRP	118.09	5986.45	2.99
10	[101] (Moshiri et *al.* 2020)	CFRP	30.7	1424	2.46
11	[39] (Karzad et al. 2019)	CFRP	90.625	3393.75	1.45
12	[102](Kim and Shin 2011)	CFRP	78,2	1633.52	4
13	[103] (Antony et *al.* 2019)	CFRP	44.08	441.78	3.07
14	[104] (Bilotta et al. 2015)	CFRP	52.9	1287.45	1.89
15	[105] (Triantafyllou et *al.* 2018)	CFRP	221.3	5969.07	3.21
16	[106] (Skuturna and Valivonis 2016)	CFRP	101.4	131.75	2.67
17	[68] (Mofrad et *al.* 2019)	CFRP	165.85	859.17	1.41
18	[8] (Chen et *al.* 2019)	CFRP	51.67	957.2	2.2
19	[107] (Firmo et *al.* 2018)	CFRP	33	1397.24	1.2
20	[108](Choobbor et *al.* 2019)	CFRP	83.22	1214	3.41
21	[109](Miruthun et al. 2020)	GFRP	72.85	478.6	3.44
22	[99](Önal M. M. 2014)	GFRP	122.33	1289.33	3.56
23	[110](Ravichandran et *al.* 2012)	GFRP	94.92	3202.75	4.08
24	[111](Josy and Johny. 2019)	GFRP	48	216	1.52
25	[112](Meikandaan,y adn Murthy,. 2017)	GFRP	68.33	909.17	2.87
26	[113](Ahmed, H. et *al.* 2019)	GFRP	11.09	2724.5	4.95
27	[114](Mariappan et *al.* 2016)	GFRP	89.67	6117	5.60
28	[115](Shrivastava and Tiwari. 2018)	GFRP	51.82	222.83	1.30
29	[116](Banjara and Ramanjaneyulu. 2017)	GFRP	79.76	6940.03	2.26
30	[117](Nanda et al. 2018)	GFRP	63.15	705.65	1.61
31	[118](Sundarraja and Rajamohan 2009)	GFRP	51.5	113.30	1
32	[119](Panigrahi. et *al.* 2014)	GFRP	224.11	692	1.54
33	[120](Ibrahim Syed et *al.* 2015)	GFRP	100.55	1889.5	2.19
34	[121](Mohite et *al.* 2014)	GFRP	110	642.85	3.53
35	[122](Sivasankar et *al.* 2018)	GFRP	115.48	3643.25	1.37
36	[123](Kumari and Nayak 2020)	GFRP	249.33	2102.33	1.35
37	[124](Saribiyik and Caglar 2016)	GFRP	144.35	3643.25	3.05
38	[125](Mini et al. 2014)	GFRP	93.28	144.90	1.04
39	[31](Attari et *al.* 2012)	GFRP	78.95	1601	4.5
40	[32] (Hawileh et al. 2014)	GFRP	76.84	1397	2.8

With the following T-test, it is tested whether the difference is 0 or not for the average maximum load values.

Two- sample T-test CI:CFRP;GFRP

According to the T-test method, μ_1: mean of CFRP, μ_2: mean of GFRP their means and Difference: μ_1 - μ indicates the difference between the two groups

μ_1: mean of CFRP

μ_2: mean of GFRP

Difference: μ_1 - μ_2

Considering the following Descriptive Statistics results, although there are differences between the two groups, the mean significance is found to be 13.

Sample Mean	N	Mean	StDev	SE
CFRP	20	102.1	56.8	13
GFRP	20	97.3	56.3	13

According to the T-test with confidence level 95% accuracy, the hypothesis can be accepted because the value 0 is in the range below. Estimation for difference is shown in below, according to the T-test with 95% confidence level, the difference between CFRP and GFRP is 4.8. In fact, it can be stated that there are differences between (-31.4; 41.1) values. Therefore, since O value is between these two values the efficiency of the average ultimate load values of these two composites is equal to each other.

Difference	95% CI for Difference
4.8	(-31.4; 41.1)

In addition to what is written above, since the P value below is greater than 0.05, the average efficiency between the two groups is acceptable. If the P value was less than 0.05, the difference of two group would be too large and hypothesis would be unacceptable.

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value: 0.27 DF: 37 P-Value: 0.789

CFRP is the undisputed leader in terms of ultimate load strength capacity in beam strengthen with FRP. In the previous outlier test, a data above the normal distribution was changed. Thus, it is understood that from Fig. 10a and b the mean values are in the normal range and close to one another.

3.5. Energy Dissipation Capacity

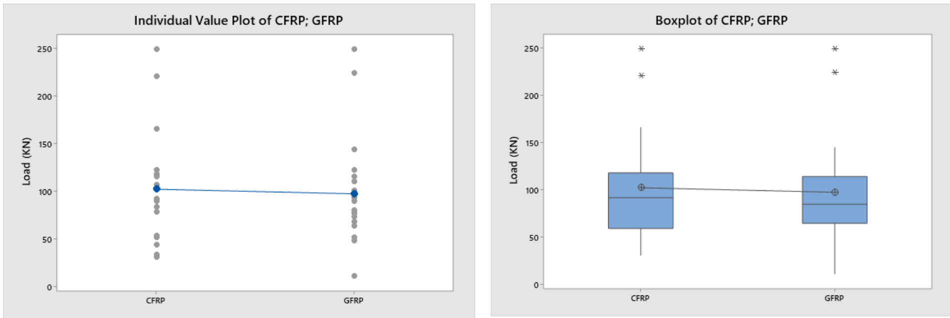
The most important result obtained in this study is the energy dissipation capacity of the strengthened RC beams. Since the study is conducted over CFRP-GFRP comparison, it is checked whether the mean results are within the confidence interval with the statistical T-test. According to the Descriptive Statistics in below, the mean of CFRP and GFRP is so close. However, the SE Mean of GFRP is bigger than Se mean GFRP. Hence, it can be mentioned that GFRPs have more energy dissipation capacity than CFRP.

Sample Mean	N	Mean	StDev	SE
CFRP	20	2008	1834	410
GFRP	20	1934	1943	435

According to the T-test with confidence level 95% accuracy, the hypothesis can be accepted because the value 0 is in the range below.
Estimation for Difference

Difference 95% CI for Difference

74 (-1137; 1284)



(a) Individual value plot (b) Box plot of CFRP and GFRP

Fig. 10 Result of individual and box plot

According to the results, the P value is bigger than 0.05, so it can be, the accuracy hypothesis of the energy holding capacities between CFRP and GFRP can be accepted.

Test

Null hypothesis H_0: μ_1 - μ_2 = 0

Alternative hypothesis H_1: μ_1 - $\mu_2 \neq 0$

T-Value : 0.12 DF: 37 P-Value: 0.902

In Fig. 11 a) and b), it is seen that CFRP-GFRP average energy dissipation capacities are in the confidence interval. In the graph, it is understood that the mean values between CFRP-GFRP are in the confidence level from line them. Moreover, the GFRP energy dissipation capacity is more than CFRP according to average of the mean values. Because individual energy dissipation value plot GFRP has more value above mean of its performed with the values selected in the acceptable range by the T-test showed that the ductility of GFRPs is higher than CFRPs.

3.6. Ductility Capacity

Ductility refers to the flexible behavior of a structure. Ductility also refers to the structure's resistance to collapse from the pour point of the structure to the moment of collapse. If this value is high, it also indicates the energy absorption capacity of the building.

This section reveals the originality of this work. According to statistical results the ductility of the beam strength with GFRP is higher than that of CFRP and it is in the considered range.

Descriptive Statistics

Sample Mean	N	Mean	StDev	SE
CFRP	20	2.64	1.06	0.24
GFRP	20	2.68	1.31	0.31

Estimation for Difference

Difference 95% CI for Difference

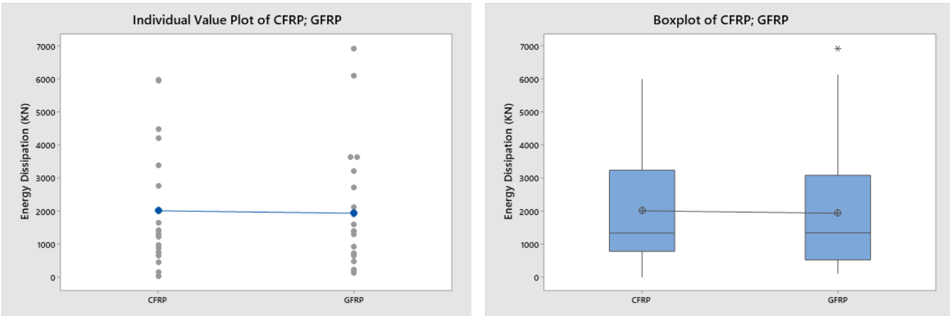
-0,039 (-0.830; 0.751)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

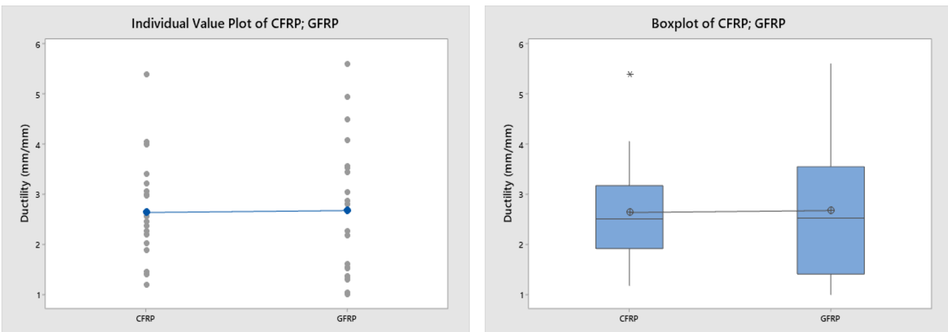
T-Value : -0.10 DF:35 P-Value:0.920



(a) Individual energy dissipation value plot (b) Sum of CFRP-GFRP energy dissipation

Fig. 11 Individual and sum of energy dissipation

It is clear from Fig. 12. that the average ductility value of GFRPs is higher than CFRP. It has been stated before that CFRPs have higher strength. However, the results of the T-test.



(a) Individual ductility value plot (b) Sum of ductility plot of CFRP-GRP

Fig. 12 Individual and sum of ductility

4. Conclusion

As an important structural element, beams are exposed to very different loads. Under these different loads, different damages occur in the beams. All research is an effort to minimize these damages. Composite materials of FRP type are the most preferred reinforcement materials. The aim is to minimize the degree of damage of the concrete to give the structure an elastic behavior and to change from permanent deformation to a recoverable deformation. This study presents the overall design of beams and their strengthening methods with FRP composite materials.

The ultimate strength of RC beams can be doubled thanks to FRP composite materials. EB and NSM methods come to the fore as the basic winding technique. The layers and angles of the fabrics used in the EBR technique significantly affect the shear and flexural beam performance in practice. In addition, it is seen that the strength capacity increases even more when additional anchors are used after the construction.

When the beams are strengthened with the EBR technique, the energy dissipation capacity and ductility of FRP fabrics remain at very low levels. Ductility generally remains around 1. Moreover, in some studies, ductility can be increased a little by methods such as volume increase, layer thickness or anchorage. It can even be increased even more with some hybrid methods.

Comparing the mechanical properties and behavior of CFRP, GFRP, BFRP and AFRP, carbon-reinforced polymers (CFRP) appear to be more advantageous with the 120-580 GPa elastic modulus. Elastic modulus of GFRP is seen at the lowest levels with 35-51 GPa. But in good a EBR strengthening application, it shows more energy dissipation capacity and ductility than CFRP.

Thanks to this study, failure states have been given separately for each study in the table. The combination of failure states obtained from recent studies is an important resource for researchers. Analyzes on the failures can be done in detail in another study. However, here, it is worth noting that delamination and separation failures states are caused by low ductility.

By using the EBR technique, it can be provided great advantages in beam strengthen with CFRP and GFRP composites. However, CFRP, which has very high strength, breaks in overloads and the steel remains alone in the plastic behavior. GFRP has lower strength than CFRP, but it can be preferred for more energy dissipation capacity and ductility in areas that do not require much strength.

In statistics, the T test is used to test the meaningfulness of the difference between two arithmetic means. Based on this, from the T-test analysis performed between CFRP and GFRP, it was proved by graphs that the mean of ultimate load, energy dissipation capacity and ductility were 95% accurate. The mean values obtained in the test were less than 0 and more, so the accuracy hypothesis was accepted. This analysis is also the most original value of this study.

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