

# Study on the Methods of Strengthening Reinforced Concrete Beams with CFRP

Congyang Teng<sup>1</sup>, Zhicheng Zhu<sup>2,\*</sup>

<sup>1</sup> School of Urban Geology and Engineering, Hebei GEO University, Shijiazhuang, China

<sup>2</sup> Department of Civil Engineering and Environmental Management, Glasgow Caledonian University, Glasgow, United Kingdom

\* Corresponding Author Email: ZZHU300@caledonian.ac.uk

**Abstract.** After the long-term use of reinforced concrete structures, there may be structural aging and structural damage, these common engineering problems. As a result, the performance is reduced, so it is necessary to strengthen to meet the corresponding safety requirements. Carbon Fiber Reinforced Polymer (CFRP) has the advantages of lightweight, strong, high tensile strength and tensile degree. Therefore, CFRP is widely used in reinforcement. Based on CFRP reinforcement of reinforced concrete beams, this paper analyzes its reinforcement methods. The paper mainly analyzes the influence of different pasting methods of CFRP on the performance of beams and the influence of material pasting thickness on beams. Through the analysis and research, it can be concluded that CFRP has certain advantages compared with traditional reinforcement materials. Therefore, it can be used to reinforce reinforced concrete beams. This study can provide some reference value for some related projects of reinforced concrete beams reinforced by CFRP.

**Keywords:** CFRP; reinforcement; reinforced concrete beam.

## 1. Introduction

According to the statistics of relevant departments, the total area of existing buildings and structures in China is about 10 billion square meters. Most of them are reinforced concrete structures, and the most in need of reinforcement is concrete structures. During the engineering application, the performance of reinforced concrete structure will be reduced because of structural aging, damage and other problems. If you want to continue to use, then it is necessary to repair the damaged structure and strengthen the way to meet the corresponding safety requirements. The reinforced concrete beam is the main component of the building, and its damage will have a great impact on the building. There are many ways to strengthen the reinforced concrete beam. Some of the traditional reinforcement methods are shown in Table 1 [1-3]. Most of the traditional reinforcement methods are simple in construction and convenient in operation. However, there are different requirements on the material, beam type or reinforcement material, which makes it difficult to determine an exact plan when strengthening different beams.

**Table 1.** Traditional reinforcement methods for reinforced concrete beams

Traditional reinforcement Methods	Advantage	Disadvantage
Increased section reinforcement method	Good reinforcement effect, strong rationality, good adaptability	Long construction period, large work intensity, difficult construction, strictly required of the concrete grade
Steel wire rope epoxy mortar reinforcement method	Convenient construction, obvious construction effect, good corrosion resistance	Higher concrete grade requirements
Centrifugal pump concrete reinforcement method	Simple construction method, low construction cost, small damage to the building structure	Long construction period, poor adhesion
Wire reinforcement method	Obvious improving effect of the bearing capacity, simple construction scheme, small damage to the internal structure	Narrow scope of application, only suitable for round or square columns

Add the fulcrum reinforcement method	Simple operation, obvious reinforcement effect	Affect the use space of the original building
External steel reinforcement method	Simple construction operation, the short construction period, less used of the steel	easy corrosion of the exposed steel
Prestressing method	Simple construction, low material cost, small influence of the building	Protective measures should be taken to prevent rust
Gluing steel reinforcement method	Simple and fast construction process	High requirements for adhesives

The composite materials used in reinforcement are mainly Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer/Plastic (GFRP), and Basalt Fiber Reinforced Polymer/Plastic (BFRP) and so on. Among them, CFRP is the most widely used. CFRP composite is a lightweight, strong material. Compared with various traditional materials, CFRP is more distinctive. Compared with traditional metal materials, carbon fiber composite materials have the advantages of light weight, high strength and high toughness. Compared with plastic products, its strength is ten times that of plastic products. Light weight, high strength is one of the outstanding characteristics of carbon fiber bar composite materials. Carbon fiber composite materials also have good high temperature resistance, low temperature resistance, and high thermal conductivity. The linear expansion coefficient along the fiber axis has a negative temperature effect. That is, with the increase of temperature, the carbon fiber composite has the tendency to shrink, the size is stable, and the fatigue resistance is good. It is also corrosion resistant, anti-aging, long service life. Carbon fiber rod can resist acid, alkali, salt, some organic solvents and other corrosive erosion. It has incomparable advantages over other metals in the field of corrosion prevention, and has better water resistance and aging resistance. Therefore, no matter in the corrosive environment and harsh open air, wet environment operation, its service life can reach more than 15 years. CFRP can usually be used to strengthen reinforced concrete beams, columns, frames and some reinforced concrete structures.

This paper first introduces the concrete methods and advantages of CFRP reinforcement of reinforced concrete beams. Then, the influence of different paste areas and thickness on the performance of beams is analyzed. Some effective suggestions can be put forward for strengthening reinforced concrete beams with CFRP.

## 2. Methods for Strengthening Reinforced Concrete Beams with CFRP

### 2.1. CFRP Plate and CFRP Sheet

When reinforcing reinforced concrete beams with CFRP, the commonly used form of CFRP material is CFRP sheet. The main forms are CFRP plate and CFRP cloth, as shown in Fig. 1. CFRP cloth is made of CFRP fiber woven into a soft cloth-like material, and CFRP plate is a thin plate with a certain thickness. Under the premise of the same width as CFRP cloth, its effective cross-sectional area is 7-11 times that of the cross-sectional area of the sheet. In addition, compared with CFRP cloth, CFRP plate has the characteristics of stable quality performance, convenient construction and so on [4]. The comparison table of mechanical properties of CFRP is shown in Table 2.



(a) CFRP plate



(b) CFRP cloth

**Fig. 1** Schematic diagram of CFRP plate and CFRP cloth [4].

**Table 2.** Comparison of mechanical properties of CFRP [3]

Material name	Model specifications (mm)	Tensile strength (MPa)	Elastic modulus (MPa)	Elongation rate (%)
CFRP plate	1.2×50	2540	1.65×10 <sup>5</sup>	1.73
CFRP cloth	0.167×300	3456	2.5×10 <sup>5</sup>	1.7

He et al. [5] conducted a four-point bending test on 2 concrete control beams and 4 concrete beams reinforced with CFRP plates and proposed an analysis method based on deformation coordination and force balance. The influence of external CFRP plate on the flexural strength of high strength concrete beams is further studied. By bonding CFRP plates to the tensile surface of high-strength reinforced concrete beams, the flexural strength can be improved and the ultimate flexural strength with low reinforcement ratio can be significantly improved [6].

Cao et al. [7] found that external CFRP sheet was effective in improving the crack performance of reinforced concrete beams. When the amount of CFRP and the bond width of CFRP-concrete increase, the crack spacing and crack width of reinforced specimens decrease. The crack development of reinforced concrete beams can be effectively inhibited by applying CFRP sheet with reasonable amount and arrangement.

## 2.2. CFRP Sheet Pasting Method

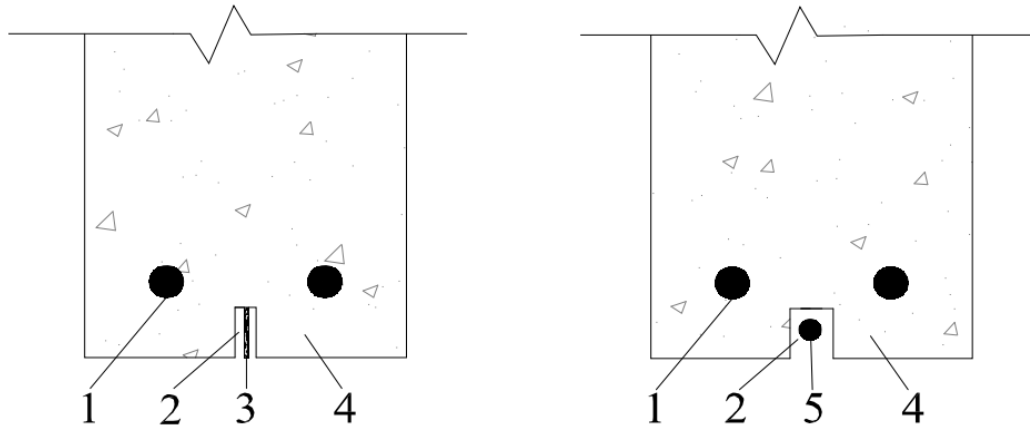
The most common methods of using CFRP for structural strengthening are surface pasting and surface embedding [8].

### 2.2.1. Surface Pasting Method

The application forms of external CFRP strengthening technology can be divided into four types: wet laying system, dry laying system, pre-impregnation system and pretreatment system [9]. Among them, the first two methods are suitable for any structural system and are more convenient to operate. During construction, the surface of the component is coated with resin, and then the multi-way CFRP is directly pasted on the surface of the component. The difference between these two construction techniques is whether the CFRP is dipped into the resin before pasting. The construction method of the pre-impregnation system is to transport the CFRP cloth to the construction site after the pre-impregnation is completed. Its pasting quality is more guaranteed than the wet paving system, and it is suitable for projects with large demand. However, due to pre-impregnation, it is necessary to use heating treatment on the construction site to prevent the resin from hardening and reducing the bonding effect. The pretreatment system is mainly suitable for pasting CFRP plate. Compared with CFRP sheet, the stiffness of CFRP sheet is larger. In order to ensure that the surface of the plate is evenly pasted on the surface of the member, it is necessary to smooth the surface of the plate before construction. After pasting, use the roller to drive out the bubbles inside the rubber layer. However, neither of the latter two methods is suitable for strengthening components with complex sections [10].

### 2.2.2. Surface Embedding Method

The embedded reinforcement method is a new reinforcement method proposed relative to the external reinforcement method, that is, the reinforcement material and bonding agent are added to the pre-treated groove of the structure surface layer, so that it becomes a complete structure. Through these measures, the structural performance can be well improved [11-14]. The section diagram of the reinforced member in the embedded reinforcement method is shown in Fig. 2 [10].

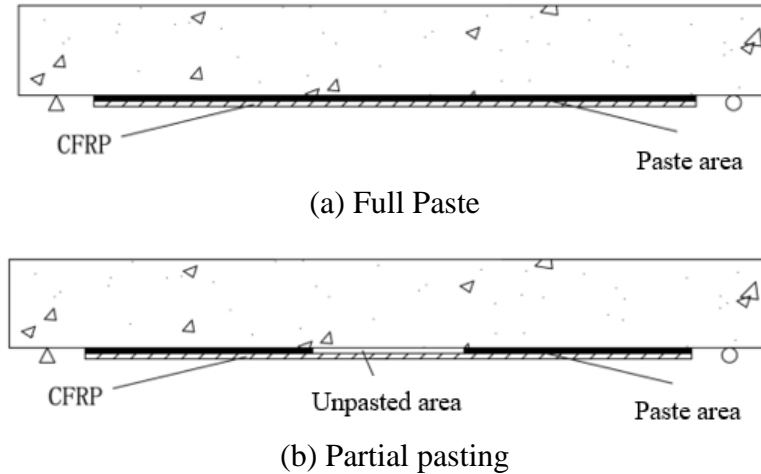


**Fig. 2** Reinforced with embedded CFRP (1-tensile reinforcement; 2-trough; 3-CFRP plate; 4-reinforced beam; 5-FRP bars) [9].

The research showed that in addition to the advantages of the external pasting method, there are unique advantages, that is, the fire performance of the embedded method is far superior to that of the external pasting method. The outer layer of concrete can effectively protect the inner CFRP from most external damage, including fire, impact and friction.

### 3. The Effect of Pasting Method on Beam Performance

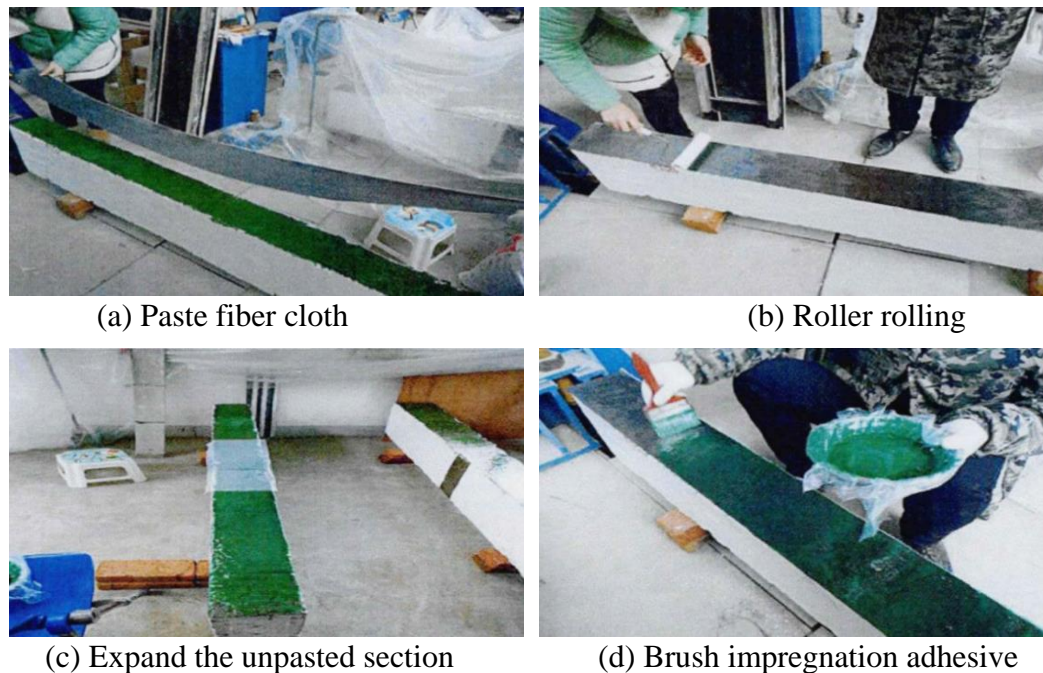
There are different bonding methods for CFRP reinforced concrete beams, such as full paste and half paste, as shown in Fig. 3 (a) and (b), respectively.



**Fig. 3** Schematic diagram of Reinforced concrete beams reinforced by CFRP [15].

#### 3.1. Full Paste

Zhang et al. [1] found that in the experiment on the deflection curve of CFRP arranged at different heights, the deflection and load presented a linear relationship before the structural beam cracking. However, cracks begin to appear on the beam under the action of load. Due to the continuous appearance of cracks, different types of beam routes began to show differences. The deflection curve of the unreinforced beam is significantly slower, while the deflection curve of the reinforced beam is significantly steeper. And the higher the height of CFRP material paste, the steeper the curve trend.



**Fig. 4** Flow chart of reinforcing reinforced concrete beams with CFRP sheet [16].

In the experiment of Zhang et al., the steel bar in the beam and the CFRP material attached on the side shared the tensile stress. In the analysis of the deflection curve, it can be found that the addition of CFRP significantly increases the toughness of the beam. And with the increase of CFRP layout height, the bearing capacity of the beam gradually becomes stronger. However, it can be found that there is almost no change in the bearing capacity when the CFRP reinforcement height exceeds  $1/2$ . It shows that the CFRP arrangement is the most suitable when the height of CFRP is  $1/2$ . Fig. 4 shows the flow chart of pasting reinforced concrete beams with CFRP sheets.

### 3.2. Semi-pasting

Yin [16] proposed what kind of influence the use of semi-pasting by CFRP will have on the reinforcement effect, and whether the difference of unpasted length will affect the reinforcement effect of CFRP on beams. In this regard, a control test was carried out, and the unpasted lengths were controlled to 0, 20, 40, 60, 80 cm to draw a control conclusion. Through the analysis of Yin's research data, this paper concluded that the cracking load reinforcement of beams is the most obvious when all CFRP is pasted. When the unpasted length of CFRP is increasing, the cracking load increases gradually. However, while the unpasted length increases, the yield load and ultimate load increase continuously. It can be seen that when pasting CFRP cloth, the longer the unpasted part, the better the overall strengthening effect of the beam. However, in the actual construction, most of the reinforcement methods used by CFRP to strengthen reinforced concrete beams are glued, but the pasting methods are slightly different. In the study of Yao and Cai [17], the following different pasting modes are used.

(1) A layer of carbon fiber cloth with length  $\times$  width of  $100\text{cm} \times 15\text{cm}$  is partially pasted on the lower side of the concrete in the tension area in the middle span of the beam. The fiber direction is consistent with the beam length direction, and the whole length is pasted to establish Model 1.

(2) The lower side and sides of the beam are pasted with U-shaped strips, and five lengths of  $20\text{cm} \times 75\text{cm}$  of carbon fiber cloth are pasted at intervals. The fiber direction is consistent with the beam length direction. The full-length paste is used to establish Model 2.

(3) A layer of carbon fiber cloth is pasted on the lower side of the concrete in the tension area of the beam span through the length, the width is 15cm, the fiber direction is consistent with the length direction, and the whole length is pasted to establish Model 3.

(4) The middle and lower side of the span is partially pasted with a layer of carbon fiber cloth with a length  $\times$  width of  $80\text{cm} \times 15\text{cm}$ . Each end of the cloth is overlapped with a layer of U-shaped strip

with a length  $\times$  width of 20cm $\times$  75cm. The side of the beam and the bottom are wrapped, and the simulation is considered as one. Model 4 is established.

In summary, the third reinforcement method uses the simplest direct full paste construction method, the first is partial paste, and the second and fourth use different degrees of U-shaped strip reinforcement. From the data studied by Yao and Cai [17], it can be concluded that although the first reinforcement method is simple and convenient. However, because the reinforcement is only in the tension area, the reinforcement effect is not obvious. If the beam produces peel failure, the reinforcement effect will be greatly reduced. The second reinforcement method is also simpler. Considering that U-shaped strip can effectively avoid stripping damage, it will be a good choice in construction. However, the hybrid reinforcement method used in the fourth model is not impressive. All in all, direct paste is a simple and easy to complete and the effect is good. However, the use of U-shaped bar reinforcement is more economical, save materials, reinforcement effect is better.

### 3.3. Influence of Material Paste Thickness on Beam

With the increase of adhesive thickness, the tensile damage of structural beams becomes less and less, and the degree and quantity of cracks at the bottom of beams are improved, which inhibits the expansion of cracks at the bottom of beams. With the increase of the number of adhesive layers, the stiffness of structural beam increases continuously. After the steel bar yield, the upward trend of the curve becomes steeper and steeper with the increase of the paste thickness. The overall energy consumption of the beam increases and the curve declines rapidly after the beam reaches the maximum bearing capacity. The concrete failure rate in the pure bend section of the beam is faster. This indicates that the increase of side adhesion thickness of CFRP material gives full play to the compression performance of concrete [1]. At the same time, with the increase of the number of adhesive layers of CFRP material, the curve coordination gradually tends to be consistent, and the growth rate of bearing capacity is slowing down. It should be noted that the thicker the paste thickness of CFRP material is, the better, and the economy should be considered. In the case of economy, it is not the more side layers, the better. At the same time, the ductility coefficient is greatly reduced, indicating that the increase of the thickness of side bonded CFRP material can restrain the deflection deformation of structural beams.

## 4. Conclusion

Based on the research in this paper, it can be found that CFRP is a very successful scheme to strengthen reinforced concrete beams, which can improve the performance of beams under different conditions. According to the analysis of the height of CFRP, it is most suitable to stick CFRP at 1/2 height of the beam. In consideration of the economic situation, the number of CFRP pasted layers is not the more the better. The reinforced sheet is divided into paste board and paste cloth. The CFRP sheet is pre-impregnated in the factory before being transported to the construction site for pasting. Its adhesive quality is more guaranteed than the wet paving system, and it is suitable for projects with large demand. CFRP plate is mainly suitable for pretreatment system, compared with CFRP cloth, CFRP plate stiffness is larger, but the latter two methods are not suitable for strengthening complex cross-section members.

After these studies, it is found that CFRP can play a very important role in strengthening reinforced concrete beams. However, due to the high cost of CFRP, the appropriate reinforcement method and the appropriate number of paste layers can be appropriately selected under the economic conditions to achieve a better reinforcement effect.

## Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

## References

- [1] Zhang Yaowen, Liu Xujuan, Ma Dongle and Wang Yan-hao. Reinforcement of reinforced concrete beams with CFRP material based on ABAQUS bending resistance study. *Journal of Guangzhou Maritime University*, 2023, 31(1): 77-82.
- [2] Yang Jia and Wang Lianguang. Flexural properties of overloading damaged reinforced concrete beams strengthened with CFRP laminates. *Building Structure*, 2019, 49(24): 107-112.
- [3] National industrial building diagnosis and renovation engineering technology research center. Technical specification of carbon fiber sheet reinforced concrete construction, CECS146. 2022.
- [4] Yang Jia. Study on mechanical properties of damaged prestressed concrete beams reinforced with embedded CFRP slats. Northeastern University, 2022.
- [5] He Shaohua, Fang Zhi, Mosallam Ayman S. Push-out tests for perfobond strip connectors with UHPC grout in the joints of steel-concrete hybrid bridge girders. *Engineering Structures*, 2017, 135: 177-190.
- [6] Qu Enxiang, Zhang Xueyuan, Cheng Siwei et al. The research progress and application of CFRP reinforced concrete beam. *Journal of Building Materials Development Direction*, 2021, 12 (20): 92-93.
- [7] Cao Shuangyin, Lin Xinyan, Jing Denghu et al. Pasted with carbon fiber cloth reinforced concrete beam crack performance test research. *Journal of Building Structures*, 2010, 31(01): 33-40.
- [8] Zhang S S and Yu T. Analytical solution for interaction forces in beams strengthened with near-surface mounted round bars. *Construction and Building Materials*, 2016, 106: 189-197.
- [9] Yu Lin, Wang Fengxia, Jiang Linhua. Study on Durability of reinforced concrete column with carbon fiber sheet. *Cryogenic Building Technology*, 2009, (10): 5-7.
- [10] Liu Zhongliang. Flexural performance of reinforced concrete beams reinforced by CFRP plates with embedded anchors. North China University of Water Conservancy and Hydropower, 2021.
- [11] Spadea G, Swamy R N, Bencardino F. Strength and ductility of RC beams repaired with bonded CFRP laminates. *Journal of Bridge Engineering*, 2001, 6(5): 349-355.
- [12] Huang Peiyan, Deng La, Liu Hanbiao, et al. Experimental study on cracking behavior of reinforced concrete beams reinforced by carbon fiber plates. *Journal of Experimental Mechanics*, 2003, 18(3): 301-307.
- [13] Dias S J E, Barros J A O. Performance of reinforced concrete T beams strengthened in shear with NSM CFRP laminates. *Steel Construction*, 2010, 32(2): 373-384.
- [14] Hamid Y. Omran. Nonlinear 3D finite element modeling of RC Beams strengthened with prestressed Nsm-CFRP strips. *Construction and Building Materials*, 2012, 66(32): 74-85.
- [15] Wang Xingchao. Study on flexural performance of reinforced concrete beams reinforced by CFRP partially pasted, Dalian University of Technology, 2021.
- [16] Yin Junpeng. Study on ductility of reinforced concrete flexural members reinforced by partially pasted CFRP. Anhui University of Science and Technology, 2017.
- [17] Yao Xuan and Cai Bin. Influence of different pasting methods of CFRP on reinforcement of Reinforced concrete beams. *Northern Architecture*, 2017, 2(03): 22-25.