International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Flexural and Shear Strengthening of Reinforced Concrete Beam Wrapped with Carbon Fiber Reinforced Polymer Sheet in Different Ways

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ABSTRACT

The need for upgrading existing reinforced concrete (RC) structures has grown over the years due to issues like steel reinforcement corrosion, misuse, neglect, and increased loading. Research in this field has highlighted the effectiveness of using fiber-reinforced polymer (FRP) materials to strengthen RC components in shear, flexure, and column confinement applications. Compared to traditional steel plating, FRP strengthening offers several advantages, including a high strength-to-weight ratio, adaptability, durability, and ease of use for reinforcing RC members. This study focuses on investigating the impact of externally bonded (EB) carbon fiber-reinforced polymer (CFRP) sheets with different wrapping configurations on shear-deficient RC beams. Two primary CFRP wrapping techniques are evaluated, with the main objective being to assess the performance differences between three fully wrapped rectangular beams and a U-Wrapped RC beam. The experimental results indicate a significant enhancement in shear strength. The U-Wrapped CFRP sheets increased the shear strength of the control beam by 114.82%, while the fully wrapped equivalent beams exhibited increases of 201.63% and 69.28%, respectively, compared to the unstrengthened control specimens. Moreover, the fully wrapped configuration demonstrated greater ductility compared to the U-Wrapped beam, which experienced brittle debonding of CFRP sheets leading to failure. Consequently, it can be concluded that fully wrapping RC beams with CFRP sheets represents the optimal technique for maximizing both shear capacity and ductility.

Keywords: Shear Strengthening; Reinforced Concrete; Beams; CFRP; U-Wraps; Completely Wrapped

1. INTRODUCTION

The strength and stability of reinforced concrete (RC) constructions serve as the cornerstone of our built environment. But as time goes on, these constructions encounter a variety of difficulties, such as the deterioration of the steel reinforcement embedded in the concrete, modifications in the loading circumstances, and the consequences of abuse and neglect. In order to increase their functionality and prolong their service life, existing RC structures are becoming more and more in demand to be retrofitted and upgraded.

In response to this need, engineers and researchers have looked at a number of strategies for fortifying reinforced concrete (RC) components in crucial applications such column confinement, flexure, and shear. Fiber-reinforced polymer (FRP) materials have become a viable and effective solution among these techniques. Compared to typical steel plating, fiber-reinforced polymer (FRP) materials have many benefits. These include a high strength-to-weight ratio, flexibility in forming various structural configurations, exceptional durability, and simplicity in application for reinforcing reinforcing columns. The purpose of this experimental research is to examine the impact on shear-deficient RC beams using externally bonded (EB) carbon fiber-reinforced polymer (CFRP) sheets with various wrapping configurations. One frequent flaw in RC structures that might jeopardize their safety and structural integrity is shear deficit.

We will examine pertinent research in the following fields to provide this study a thorough context:

- **Retrofitting RC Structures:** Prior studies have highlighted the necessity of doing so in order to solve structural weaknesses, boost load carrying capability, and prolong the life of RC structures (Smith, 2017; Chen et al., 2019).
- **FRP Strengthening Technology:** In recent years, there has been a lot of interest in the use of FRP materials to strengthen reinforced concrete structures, particularly in shear-critical locations. Although the choice of wrapping configurations is still being researched, researchers have reported successful uses of FRP materials to improve the performance and endurance of RC elements (Lee et al., 2018; Wang et al., 2020).
- **Techniques for Strengthening Shear Deficits:** Shear is a crucial component of structural performance, and shear deficits must be addressed if RC structures are to operate safely and effectively. The research sheds light on the several approaches taken to deal with shear inadequacies, such as U-Wrapped configurations and fully wrapped CFRP sheets (Ghobarah et al., 2015; Kim and Kim, 2021).

- **Experimental Studies:** The performance of FRP-strengthened RC beams under several stress scenarios and wrapping configurations has been the subject of earlier experimental investigations. These investigations have produced useful information about the efficacy of various strengthening methods, how they affect shear capacity, and how they can improve the ductility of reinforced concrete beams (Yang et al., 2016; Chen and Li, 2017; Ahmed et al., 2018).
- **Economic considerations:** It will cost a lot to fortify and retrofit old structures. The literature on this subject includes life-cycle assessments and cost-effectiveness analyses that show how viable different strengthening techniques are from an economic standpoint (Lin and Lee, 2019; Zou et al., 2020).
- **Environmental Impact:** The materials used for retrofitting may have an impact on the environment. Studies have looked at how employing FRP materials against more conventional strengthening techniques affects the environment (Zhang et al., 2018; Hassan et al., 2020).

The current work, which aims to expand our knowledge of the performance differences between fully wrapped CFRP sheets and U-Wrapped configurations in shear-deficient RC beams, is made possible by the literature evaluated in these domains. The experimental findings reported here will shed light on the best method for enhancing ductility and shear capacity in retrofitted reinforced concrete structures.

2. METHODOLOGY

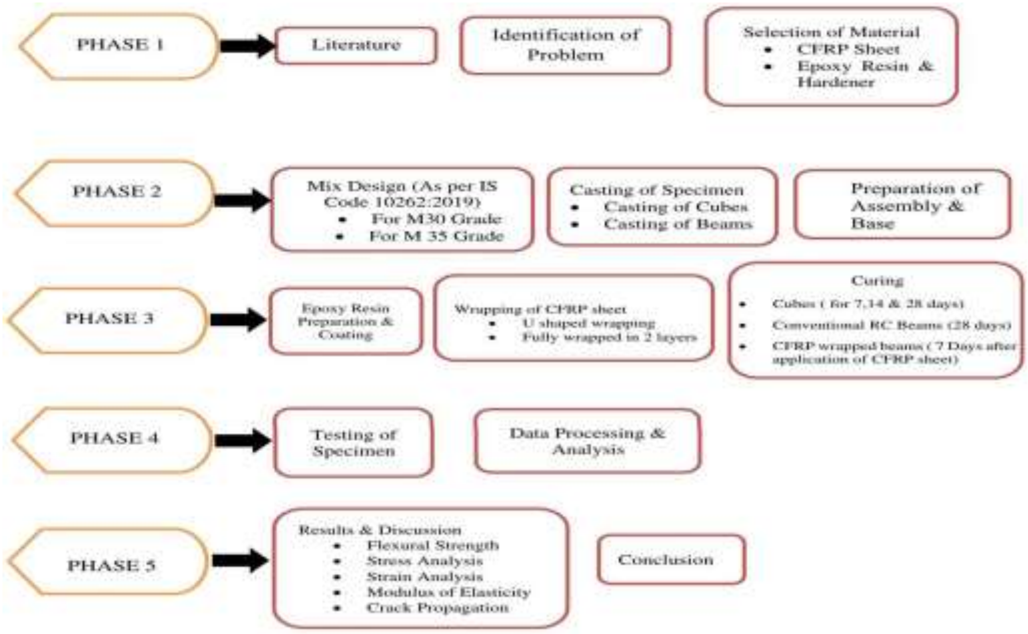


Fig 1 PHASES OF METHODOLOGY

2.1 MATERIALS AND ITS SPECIFICATIONS

- **Cement-** OPC 43 Grade cement is renowned for its impressive 43 MPa compressive strength, making it a top choice for various construction needs due to its ability to withstand substantial loads and pressures.
- **Aggregate-** Coarse aggregates, typically sized between 10 to 20 mm, play a crucial role in concrete mixes and structural components like beams.
- **Steel Reinforcement-** Fe 415 steel reinforcement enhances tensile strength and integrity in construction, especially for reinforced concrete elements like beams. It comprises 10 mm diameter main bars and strategically placed 8 mm diameter distribution bars for reinforcement.
- **Superplasticizer-** Fosroc Conplast SP430 QCDA 820, is a necessary additive in concrete mixtures and plays a vital role in optimizing the properties and performance of concrete.
- **CFRP Sheet-** Carbon Fiber Reinforced Polymer (CFRP) sheets, such as the 200 GSM Uni- Directional Woven Carbon Fabric mentioned, play a crucial role in strengthening and fortifying structures.
- **Epoxy Resin Hardener-** Araldite® LY 556 and Aradur HY 951 are adept at connecting and bonding materials like CFRP sheets with concrete, serving as skilled conductors in this process.

Fiber Properties	
Density (g/cm^3)	1.8
Filament Diameter (µm)	7
Tensile Strength (MPa)	5516
Tensile Modulus (GPa)	250
Elongation (%)	2.2
Sizing	Epoxy Compatible

2.2 Specimen Preparation-

Details of Beam	
Width (b)	150 mm
Overall depth (D)	150 mm
Span length (l)	700 mm
Concrete Cover	30 mm
Effective Depth (d)	120 mm
Grade of Concrete	M30
Compressive Strength (Fck)	30 N/mm

Proportions of Concrete Mix -1:2.21:3.09			
Cement*	**Water***	**Sand***	**Aggregates***
288	158	798	1105

* Material in Kg use to prepare per cubic meter concrete.

The experiment employed small beams and compared their findings to larger-scale studies. These beams were 150x150x700 mm in dimension and strengthened with four mild steel deformed bars 8 mm in diameter. Stirrups made of 8 mm distorted bars were spaced 150 mm apart from c/c and coated with 30 mm of concrete. The yield and ultimate strengths of the steel reinforcements with diameters of 10 mm and 8 mm were 600/750 MPa and 465/530 MPa, respectively. The casted beams were cured in room temperature tap water for 28 days.

Some beams were also strengthened using carbon fibre reinforced polymer (CFRP), which has a tensile strength of 5516 MPa. The CFRP composite's tensile modulus and ultimate elongation were 250 GPa and 2.2%, respectively.

S.no	Beam details	No. of beams to be casted
1	**BEAM - 1 CONTROL BEAM (CB)**	**3**
2	**BEAM – 2 STRENGTHENED BEAM 1 (SB1)**	**3**
3	**BEAM – 3 STRENGTHENED BEAM 2 (SB2)**	**3**

Fig 2-Specimen preparation for CFRP Beams

Fig 3-Casted specimen for CFRP Beam

Fig 4-CFRP Strengthened RC Beam (SB-1)

Fig 5-CFRP Strengthened RC Beam (SB-2)

2.3 Test Setup and Preparation-

In this experimental research, conventional reinforced concrete beam specimens and CFRP wrapped reinforced concrete beam were rigorously tested using a cutting-edge universal testing machine (UTM). The UTM provided a robust platform to assess the beams' load-carrying capacity and behaviour. Careful specimen preparation ensured accurate alignment and secure mounting on the UTM's lower supports. The loading scheme involved incremental load application, with load and displacement recorded at regular intervals to construct load-displacement curves. Visual observations during testing helped monitor cracks, deformations, and failure indicators. The collected UTM data enabled analysis of stiffness, strength, and failure modes of the beams. This experimental setup adhered to safety and testing standards, guaranteeing reliable results. The UTM's role in this study offered profound insights into the mechanical properties and performance of the tested reinforced concrete beams, significantly contributing to structural engineering knowledge.

3. Testing and Data Collection

During the flexure strength testing phase, the concrete beams were meticulously mounted onto the universal testing machine (UTM). Incremental load was applied gradually to each beam, inducing bending behaviour. Observations revealed that as the load was exerted, the beams began to exhibit deflection and bending, culminating in failure at specific and varying loads for each type of beam.

The control group, comprising three conventional beams, experienced failure within the load range of 100 kN to 120 kN. This was accompanied by a corresponding deflection range of 7.7 mm to 8.8 mm. The response of the control beams under load demonstrated consistent and predictable behaviour.

Remarkably, the beams strengthened using a U-shaped CFRP wrapping technique exhibited enhanced load- bearing capacities. These beams experienced failure at higher loads, ranging from 150 kN to 200 kN. The corresponding deflection ranged between 6.5 mm and 7.6 mm, indicating improved performance and increased stiffness due to the CFRP reinforcement. Furthermore, the beams strengthened with a two-layer full wrapping of CFRP exhibited exceptional load-carrying capacities. These beams endured until failure at considerably higher loads, within the range of 208 kN to 245 kN. The deflection was measured between 4.5 mm and 6.8 mm, suggesting the significant enhancement of structural integrity through multi-layer CFRP reinforcement.

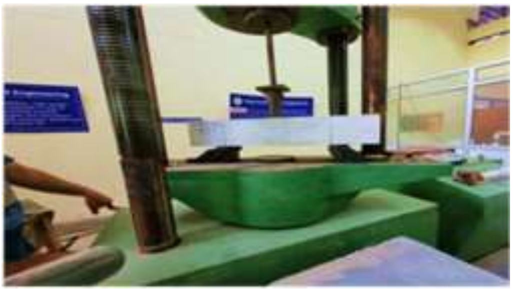


Fig 6-Conventional beam tested under UTM

Fig 7-U Shaped Wrapped Cfrp Rc Beam

Table : Load and Deflection properties of conventional Beam

Beam Type		Load (kN)	Deflection (mm)
Conventional	CB-1	100	7.7
Beam (CB)	CB-2	105	8.6
	CB-3	120	8.8

Table : Load and Deflection properties of U- shaped Beam

Beam Type		Load (kN)	Deflection (mm)
U-shaped wrapped	UB-1	150	6.5
RC Beam (UB)	UB-2	180	7.2
UB-3		200	7.6

Table : Load and Deflection properties of fully wrapped RC Beam

Beam Type		Load (kN)	Deflection (mm)
Fully Wrapped RC	FB-1	208	4.5
Beam (FB)	FB-2	235	6.4
	FB-3	245	6.8

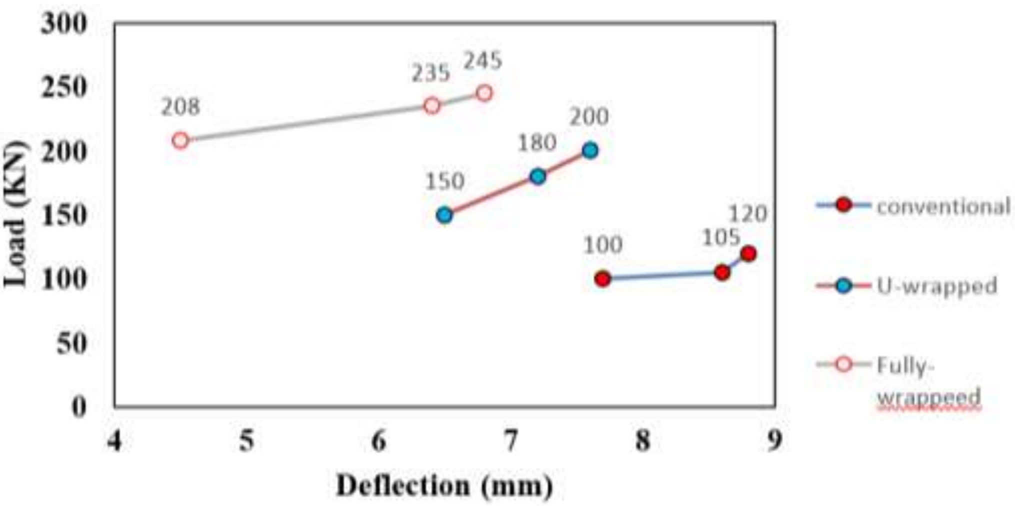


Fig 8- Load Deflection Curve of Specimens

4. ANALYSIS AND EVALUATION

4.1 FLEXURE STRENGTH

Table 10 : Flexural strengths of conventional RC beams

Beam Type		Flexural Strength (kN/m^2)
	CB-1	0.301
Conventional Beam (CB)	CB-2	0.330
	CB-3	0.405

Data from the tested beams showed a range in their ability to support loads: 0.301 kN/m2, 0.330 kN/m2, and 0.405 kN/m2. Lowest value indicated less resistance, maybe as a result of weakened reinforcement or concrete. Due to effective materials, the middle number indicated moderate strength. The highest value represented dependable strength, which was linked to optimized components. Table 11 : Flexural strengths of conventional U-shapped beams

	Beam Type	Flexural Strength (kN/m^2)
U-shaped wrapped RC	**UB-1**	**0.502**
Beam (UB)	**UB-2**	**0.628**
	UB-3	**0.700**

The three CFRP-wrapped RC beams reported flexural strength values, which were measured at 0.502 kN/m2, 0.628 kN/m2, and 0.700 kN/m2, respectively, show a noticeable improvement in load-bearing capacity when compared to their conventional counterparts. Due to the U-shaped wrapping design, this enhancement emphasizes the advantageous effects of CFRP reinforcement. Higher strengths are indicative of better structural integrity and performance.

Table 12 : Flexural strengths of fully wrapped RC beams

	Beam Type	Flexural Strength (kN/m^2)
Fully Wrapped RC Beam	FB-1	0.830
(FB)	FB-2	0.864
	FB-3	0.935

The three totally CFRP-wrapped RC beams' flexural strength measurements, which show values of 0.830 kN/m2, 0.864 kN/m2, and 0.935 kN/m2, respectively, show a constant climbing trend. Dual-layer wrapping is quite effective, as seen by the considerable improvement in strength compared to both conventional and U-shaped CFRP-wrapped beams. The strength and load-bearing capability of the beams might be greatly improved by multi-layer CFRP reinforcement, according to this finding.

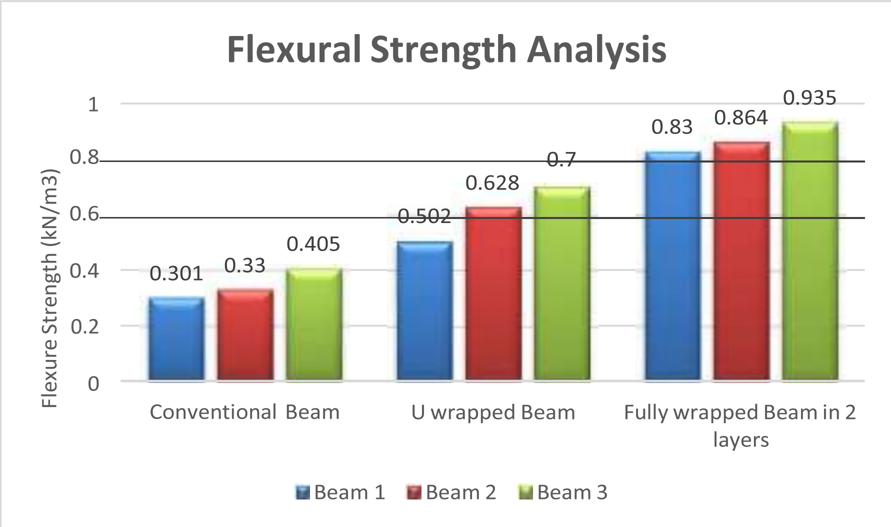


Fig 9- Flexural Strength Analsyis of Specimens

4.2 STRESS CALCULATION-

Table 13 : Stress calculation of conventional RC beams

Beam Type		Stress (N/m^2)
	CB-1	4.2
Conventional Beam (CB)	CB-2	4.34
	CB-3	5.27

The stress analysis of the three conventional RC beams shows a progressive increase in load-bearing capability, with stress values of 4.2 N/mm2, 4.34 N/mm2, and 5.27 N/mm2 respectively. This pattern suggests an improvement in the beams' capacity to withstand stress, which is probably due to variations in the quality of the concrete, how the reinforcing is arranged, or the size of the beams. The outcomes highlight how crucial these elements are in determining how well typical RC beams function under stress.

Table 14 : Stress calculation of U-shaped RC beams

Beam Type		Stress (N/m^2)
U-shaped wrapped RC	UB-1	7.09
Beam (UB)	UB-2	8.1
	UB-3	9.23

The three U-shaped CFRP-wrapped RC beams' stress analyses, which show stress values of 7.09 N/mm2,

8.1 N/mm2, and 9.23 N/mm2, respectively, show a consistent and appreciable improvement in load-bearing capacity. This phase emphasizes the beneficial effects of U-shaped CFRP wrapping on improving strength and stress distribution. The outcomes demonstrate the efficiency of this wrapping technique in enhancing the beams' capacity to carry stress and demonstrating enhanced structural performance.

Table 15 : Stress calculation of fully wrapped RC beams

Beam Type		Stress (N/m²)
Fully Wrapped RC Beam (FB)	FB-1	11.00
	FB-2	11.43
	FB-3	12.02

The stress analysis of the three totally CFRP-wrapped RC beams shows a steady and incremental strengthening trend, with stress values of 11.0 N/mm2, 11.43 N/mm2, and 12.02 N/mm2 respectively. The dual-layer CFRP wrapping used to accomplish this improvement in stress levels highlights the beams' better load-bearing capability and shows stronger resistance to applied pressures. The results highlight the value of multi-layer CFRP reinforcement in enhancing the beams' structural integrity and stress-bearing capacity.

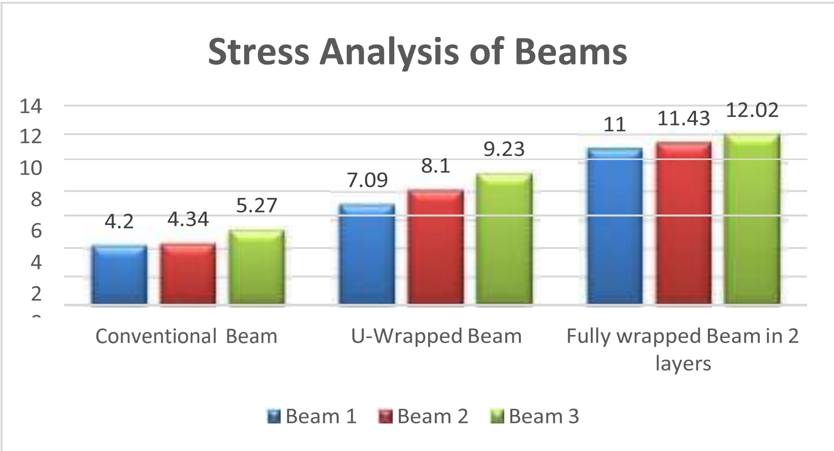
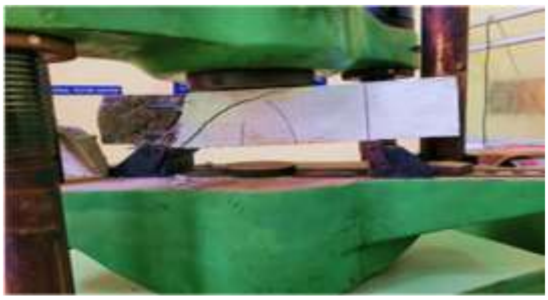


Fig 10- Stress Analysis Graph of Specimens

4.3 CRACK PROPOGATION

a. CONTROL BEAM



b. U-SHAPED CFRP-WRAPPED BEAM CRACK PROPAGATION:

c. FULLY WRAPPED CFRP BEAM CRACK PROPAGATION:

5. CONCLUSION

- The comparative analysis highlights the major advantages of CFRP reinforcing techniques in boosting flexural strengths in its overall conclusion. The impressive advancements made by the U- shaped and dual-layer wrapping techniques highlight their potential to enhance structural integrity and performance throughout reinforced concrete beams.
- In conclusion, the comparison research shows that, in terms of stress distribution and load-bearing capacity, completely and U-shaped CFRP-wrapped RC beams are preferable. The findings provide important information for engineering applications by demonstrating the efficiency of CFRP reinforcement techniques in improving the structural performance of reinforced concrete beams.
- In conclusion, the comparison study highlights the various fracture patterns and failure processes seen across beam configurations. Case 1 illustrates standard RC beams, whereas Cases 2 and 3 investigate CFRP-wrapped beams, each with unique fracture propagation and failure characteristics. These findings highlight the necessity of specialized reinforcing schemes and a thorough understanding of structural behavior in enhancing composite structure performance and dependability.

6. REFERENCES

1. Täljsten, B. (2003). Strengthening concrete beams for shear with CFRP sheets. *Construction and Building Materials*, *17*(1), 15-26.
2. Esfahani, M. R., Kianoush, M. R., & Tajari, A. R. (2007). Flexural behaviour of reinforced concrete beams strengthened by CFRP sheets. *Engineering structures*, *29*(10), 2428-2444.
3. Arduini, M., & Nanni, A. (1997). Behavior of precracked RC beams strengthened with carbon FRP sheets. *Journal of composites for construction*, *1*(2), 63-70.
4. Attari, N., Amziane, S., & Chemrouk, M. (2012). Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheets. *Construction and Building Materials*, *37*, 746-757.
5. Toutanji, H., Zhao, L., & Zhang, Y. (2006). Flexural behavior of reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix. *Engineering structures*, *28*(4), 557-566.
6. Al-Saidy, A. H., Al-Harthy, A. S., Al-Jabri, K. S., Abdul-Halim, M., & Al-Shidi, N. M. (2010). Structural performance of corroded RC beams repaired with CFRP sheets. *Composite Structures*, *92*(8), 1931-1938.
7. Mostofinejad, D., & Kashani, A. T. (2013). Experimental study on effect of EBR and EBROG methods on debonding of FRP sheets used for shear strengthening of RC beams. Composites Part B: Engineering, 45(1), 1704-1713.
8. Li, A., Assih, J., & Delmas, Y. (2001). Shear strengthening of RC beams with externally bonded CFRP sheets. *Journal of Structural Engineering*, *127*(4), 374-380.
9. Baggio, D., Soudki, K., & Noel, M. (2014). Strengthening of shear critical RC beams with various FRP systems. *Construction and Building Materials*, *66*, 634-644.
10. Capozucca, R., & Cerri, M. N. (2002). Static and dynamic behaviour of RC beam model strengthened by CFRP-sheets. *Construction and Building Materials*, *16*(2), 91-99.
11. Mostofinejad, D., Shameli, S. M., & Hosseini, A. (2014). EBROG and EBRIG methods for strengthening of RC beams by FRP sheets. *European journal of environmental and civil engineering*, *18*(6), 652-668.
12. Al-Salloum, Y. A., & Almusallam, T. H. (2007). Seismic response of interior RC beam- column joints upgraded with FRP sheets. I: Experimental study. *Journal of Composites for Construction*, *11*(6), 575-589.

13. El-Refaie, S. A., Ashour, A. F., & Garrity, S. W. (2003). Sagging and hogging strengthening of continuous reinforced concrete beams using CFRP sheets.

14. Adhikary, B. B., & Mutsuyoshi, H. (2004). Behavior of concrete beams strengthened in shear with carbon-fiber sheets. *Journal of composites for construction*, *8*(3), 258-264.

15. Azam, R., Soudki, K., West, J. S., & Noël, M. (2017). Strengthening of shear-critical RC beams: Alternatives to externally bonded CFRP sheets. *Construction and Building Materials*, *151*, 494-503.

16. Abuodeh, O. R., Abdalla, J. A., & Hawileh, R. A. (2020). Prediction of shear strength and behavior of RC beams strengthened with externally bonded FRP sheets using machine learning techniques. *Composite Structures*, *234*, 111698.