



Challenge Journal

OF CONCRETE RESEARCH LETTERS

Research Article

Impact of wrap quantity on strength of damaged and undamaged CFRP-reinforced structural members

Serdal Ünal^a , Ahmet Burak Kurt^a , Mehmet Canbaz^{a,*} 

^aDepartment of Civil Engineering, Eskişehir Osmangazi University, 26480 Eskişehir, Türkiye

ABSTRACT

In this study, the effect of carbon fiber reinforced polymer (CFRP) wrapping on the compressive and bending behavior of damaged reinforced concrete structural elements located in high earthquake risk areas was investigated in detail. The main objective was to evaluate the potential of CFRP wraps as an effective strengthening technique for improving the mechanical performance of concrete members that have already sustained damage. During the experimental phase, concrete specimens in the form of 15×15×15 cm cubes and 10×10×50 cm prisms were prepared using CEM IV 32.5 pozzolanic cement, which is commonly used in structural applications due to its durability and environmental benefits. After subjecting these specimens to controlled damage to simulate real-life structural degradation, they were reinforced using single and double layers of CFRP wrapping. The mechanical performances of these wrapped specimens were then assessed through compressive and bending strength tests. The results demonstrated that CFRP wrapping significantly enhanced the compressive strength of the specimens, with double-layer applications showing the greatest improvements. However, the effect on flexural strength was found to be more limited, indicating that although CFRP is 60.83% effective in resisting compressive loads, its contribution to flexural capacity may require additional considerations. Furthermore, double-layer CFRP wrapping not only improved strength but also increased deformation capacity, indicating enhanced ductility and energy absorption. Despite the relatively high cost of CFRP materials, these findings highlight the technique as a practical and efficient solution for the rehabilitation and strengthening of compression load-bearing members, particularly in regions vulnerable to seismic activity.

Citation: Ünal S, Kurt AB, Canbaz M (2025). Impact of wrap quantity on strength of damaged and undamaged CFRP-reinforced structural members. *Challenge Journal of Concrete Research Letters*, 16(3), 133–141.

ARTICLE INFO

Article history:

Received – April 25, 2025

Revision requested – May 21, 2025

Revision received – June 4, 2025

Accepted – June 17, 2025

Keywords:

Carbon fiber reinforced polymer

Composite materials

Reinforced concrete strengthening

Damaged structural elements



This is an open access article distributed under the CC BY licence.

© 2025 by the Authors.

1. Introduction

Earthquakes are natural disasters that can have severe destructive effects on structures, especially in countries located on active fault lines (Bird and Bommer 2004). Most of the loss of life and property from earthquakes is caused by weaknesses in the structural systems of buildings (Wu et al. 2019; Çelik et al. 2024). The primary causes of these weaknesses include the use of substandard materials, inadequate design practices, nonstandard construction practices, and structural wear

and tear over time. Such deficiencies cause serious damage, especially to the main load-bearing elements such as columns and beams, and reduce the overall strength of the structure. Identifying the structural weaknesses of buildings susceptible to earthquake damage is essential to ensure that such structures experience minimal damage—and, most importantly, avoid collapse—during seismic events (Zardari et al. 2024). Therefore, the evaluation of existing buildings and their retrofitting, where necessary, is of great importance for both life safety and economic sustainability. Rather than constructing a new

* Corresponding author. Tel.: +90-222-239-3750 ; E-mail address: mcanbaz@ogu.edu.tr (M. Canbaz)

building, retrofitting existing structures is a less costly and more environmentally friendly solution (Jagarajan et al. 2017; Ma et al. 2012). Structural strengthening is significantly more cost-effective than demolishing and rebuilding existing structures, offering a major economic advantage. Additionally, it minimizes downtime, reducing labor and time losses (Keshmiry et al. 2024). In this context, the need for retrofitting methods that can be applied quickly and increase strength is growing every day.

One of the most effective ways to meet this need is through CFRP wrapping applications (Hegde et al. 2019). Fiber-reinforced polymer (FRP) materials can be manufactured in various geometries and possess a wide range of applications, spanning from industrial uses to construction-related implementations (Eryılmaz Yıldırım et al. 2024). CFRP is a composite material with many advantages such as high tensile strength (usually 2500–5000 MPa), low specific gravity ($\sim 1.6 \text{ g/cm}^3$), corrosion resistance and ease of application (Mitra 2000; Heidarzadeh 2022). CFRP has high tensile strength, low weight, and excellent corrosion resistance due to its carbon fiber content and polymer matrix. It also exhibits high stiffness and dimensional stability under varying environmental conditions (Kim et al. 2023). First used in the aerospace and automotive industries, this material has been widely used in the construction industry in recent years, especially for structural reinforcement. The high modulus of elasticity of CFRP allows it to increase the deformation capacity of reinforced concrete elements (Mousa et al. 2019; Xue et al. 2010). CFRP offers significant advantages over other strengthening materials due to its high strength-to-weight ratio, excellent corrosion resistance, and ease of application. It can also be easily bonded with epoxy-based adhesives, allowing for quick and effective reinforcement of existing structures. It is increasingly being used in structural elements such as columns, beams and shear walls to provide strength against both compressive and tensile loads (Rashid and Bahrami 2023). The high strength-to-weight ratio makes CFRP more advantageous than conventional steel rein-

forcements. Although the cost of CFRP is high, this is offset by its long life and maintenance-free nature (Younis et al. 2018).

This study investigated the effect of CFRP wrapping on severely damaged reinforced concrete members and addressed an important gap in the literature in this area. While many studies in the literature have focused on the strengthening effects of CFRP applications on intact members, this study experimentally evaluated the strengthening of controlled-damage concrete specimens with CFRP. This study addresses the gap in the literature regarding the performance of CFRP wrapping on previously damaged concrete elements, particularly under both compressive and bending loading conditions. The experiments conducted on the strength and deformation behavior of structural elements reveal how effective the application of CFRP wrapping is. As a result of compressive and bending tests performed on 15x15x15 cm cube and 10x10x50 cm prism specimens, it was observed that especially double-layer CFRP wrapping applications provided a significant increase in compressive strength. The effects on bending strength were found to be limited. In this respect, the study contributes to the structural engineering literature and applications by demonstrating that CFRP can be effective, within certain limits, not only in intact but also in partially damaged structural elements.

2. Experimental Study

2.1. Materials

Cement: CEM IV/B 32.5N pozzolanic cement was used as binder in the study. The cement used is the product of Eskisehir Cement Factory (Eskişehir, Türkiye), which is produced according to TS EN 197-1 (2012) standard. The chemical and physical properties of the cement used in the production are given in Table 1.

Water: Municipal water was used in the mixtures. Properties of the mix-water is given in Table 2.

Table 1. Properties of cement.

Chemical content, mg/dm ³									
CaO	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	MgO	Cl-	Na ₂ O	K ₂ O	LOI	SO ₃
40.50	10.60	35.41	2.70	1.81	0.042	0.93	0.96	4.21	2.84
Physical properties									
Specific surface, cm ² /g		Expansion, mm		Initial setting, min.		Final setting, min.		Density, g/cm ³	
4800–5300		1		180–220		230–280		2.85	

Table 2. Properties of water.

Cu, %	Mn, %	Al, %	NH ₄ , %	Fe, %	NO ₃ , %	K, %	Ni, %	As, %	Conductivity, μS/cm	pH	Hardness, Fd ⁰
0.015	0.014	0.05	0.07	0.005	11.3	6.7	5.11	1.21	623	7.4	30.23

Aggregates: Concrete cube specimens were created by using three types of crushed aggregates. Fig. 1 shows an analysis of the particle size of the aggregate mixture. The commercial quartz sand as fine aggregate (specific gravity of 2.65). Further, the densities of the fine aggregates were 2.69, 2.70, and 2.71 g/cm³, for fine aggregate sizes of (0–4 mm), (4–11.2 mm), and (11.2–22.4 mm) respectively.

CFRP: MegaKarbon Wrap K918-K923 brand CFRP was used in the study. The mechanical properties of the

material used are given in Table 3.

Resin: MegaPro Epo Y501 is a two component epoxy based laminating resin specially formulated for MegaKarbon Wrap 300 K918. MegaKarbon Wrap 300 K918 is used to bond the carbon reinforced fiber polymer MegaKarbon Wrap 300 K918 to the surfaces of structural elements in reinforcement applications. The chemical properties of the material used are given in Table 4. The CFRP and resin material used in production is shown in Fig. 2.

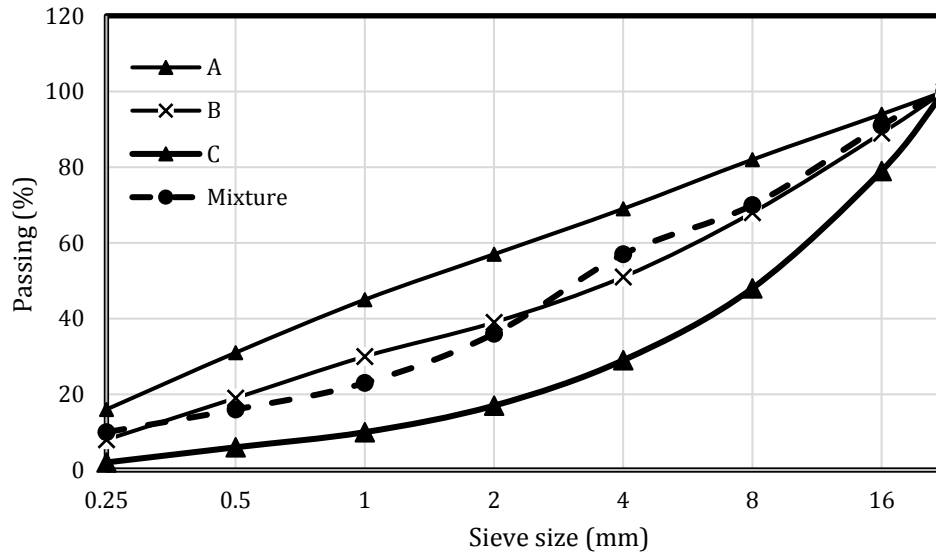


Fig. 1. Granulometry of the aggregate mixture according to EN 12620 (2002).

Table 3. Properties of CFRP.

Width, mm	Tensile strength, MPa	Modulus of elasticity, MPa	Elongation at break, %	Fabric nominal thickness, mm ² /mm
501	4000-5000	>235	~2	0.169

Table 4. Properties of resin.

Specific weight, g/cm ³	Working time, min.	Compressive strength, MPa	Shear strength, MPa	Tensile adhesion strength, MPa
1.08	60	79	>6	52



Fig. 2. CFRP and resin material used in the production of the concrete specimens.

2.2. Method and tests

During the production phase, the concrete was prepared in the mixing ratios given in Table 5. The vibration process was used to evenly distribute the concretes in the mold and to obtain a homogeneous structure. A total of 12 cube (15x15x15 cm) and 12 prism (10x10x50 cm) specimens were produced. The specimens were left outdoors for 3 days for a short setting period, and after set-

ting, the specimens were carefully removed from the molds.

To ensure that the specimens reached their maximum strength, the removed specimens were placed in the specimen curing bath. The specimens were kept in the hardening pool for 28 days, and after full strength development, the specimens were removed from the pool and allowed to dry for 2 days. The specimens were then prepared for testing.

Table 5. Mix ratio of 1 m³ of concrete mixture by weight.

Cement, kg	Water, kg	Aggregate, kg		
		0–4 mm	4–11.2 mm	11.2–22.4 mm
300	180	920	410	570

Half of the concrete specimens produced prior to the wrapping process were damaged to test the performance of the damaged structural elements. After the production stage, the CFRP was cut as follows for single and double wrapping for the cube and prism specimens, with an overlap of 10 cm to wrap the specimens.

- For single wrapping cube specimen: (60+10)×15 cm
- For double wrapping cube specimen: (120+10)×15 cm
- For single wrapping prism specimen: (40+10)×50 cm
- For double wrapping prism specimen: (80+10)×50 cm

To wrap the intact specimens, the necessary wrapping materials were first prepared. Then, the two-part epoxy-based laminating resin (MegaPro Epo Y-501) to be applied to the concrete surface and wrapping material was prepared and the application process started. At this stage, mixing the resin in the correct proportions and applying it properly will improve the performance and structural integrity of the material. To mix the epoxy components, component A and B were combined in a bucket and mixed at a slow speed using a low speed hand mixer.

High speed mixing should be avoided. When mixing the components, the ratio of component A and B was poured into the container so that $1/3=B/A$. The resin used is approved according to TS EN 1504-4 (2006). Unit weight, ultrasonic pulse and compression tests were carried out on 28 day old specimens as hardened concrete tests.

After the production process, tests such as unit weight, ultrasound transmission rate, compressive strength and bending strength were performed to determine the mechanical and physical properties of the specimens before and after wrapping. Unit weight is determined by dividing the weight by the total volume. The ultrasonic pulse velocity is obtained by dividing the sample length by the time it takes for the vibration generated by the transmitting probe to reach the receiving probe in the specimen. Compressive strength is obtained by dividing the compressive force by the specimen area. Fig. 3 shows the bending strength test and some of the damaged specimens while the cube and prism specimens wrapped with CFRP are demonstrated in Fig 4.



Fig. 3. Damaged and undamaged concrete specimens.

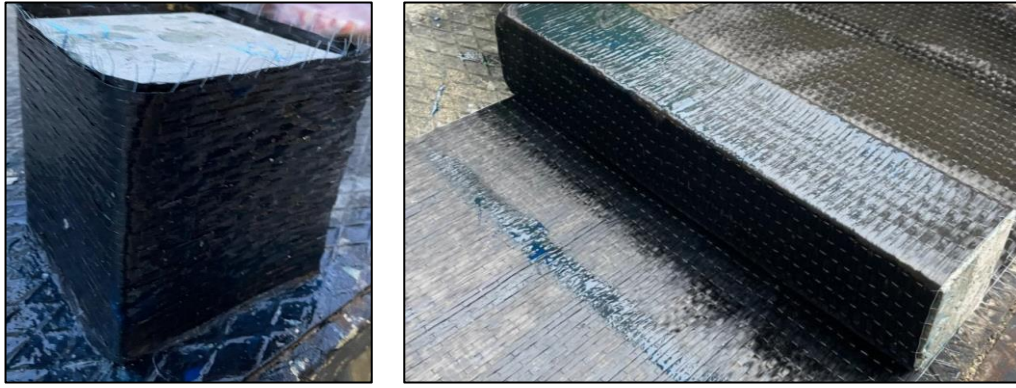


Fig. 4. Cube and prism concrete specimens wrapped with CFRP.

3. Results and Discussion

3.1. Reinforcement test results of low-strength undamaged concrete

The data presented in Fig. 5 shows the results of unit weight and ultrasound transmission velocity tests performed on undamaged concrete specimens with CFRP wraps. In terms of unit weight, while the weight of the unwrapped specimen was 2,198.03 kg/dm³, this value increased by 0.32% to 2,204.99 kg/dm³ with single layer CFRP wrapping and by 0.73% to 2,214.02 kg/dm³ with double layer CFRP. These increases can be explained by the CFRP layers adding additional mass to the outer surface of the concrete. Although the internal density of the structure remains unchanged, the carbon fiber layers applied externally increase the total mass, although at small rates. The ultrasound transmission velocity results

provide more information about the internal structural continuity of the material. In the unwrapped specimen, the transit velocity was 3.24 km/h, whereas this value increased by 2.78% to 3.33 km/h with a single layer of CFRP and by 4.01% to 3.37 km/h with a double layer of CFRP. These increases indicate that the tight wrapping effect of CFRP on the surface of the concrete maintains the continuity in the internal structure, preventing the formation of microcracks and allowing a more uninterrupted passage of ultrasonic waves. Especially in the undamaged specimens, the better adhesion and homogeneous wrapping effect of CFRP resulted in an improvement in wave passage. As a result, the CFRP winding increases the unit weight to a limited extent, but it seems to contribute to the internal structural integrity, especially through increases in the ultrasound transmission rate. This shows that CFRP not only improves the mechanical strength but also the elastic properties and integrity of the material.

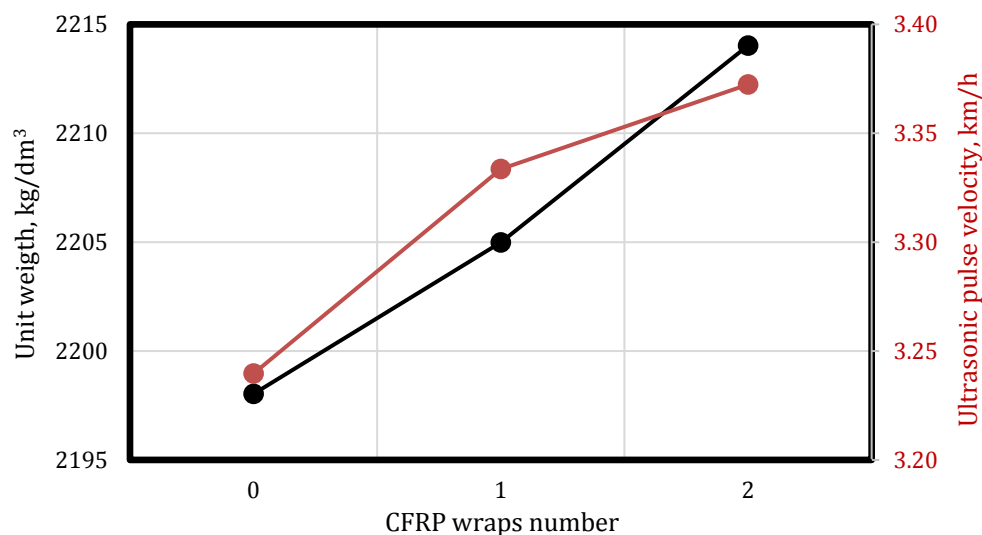


Fig. 5. Unit weight and ultrasound pulse velocities of the undamaged concrete specimens.

The effect of CFRP wrapping on the undamaged specimens is stronger and directly observed in Fig. 6. While the compressive strength of the unwrapped specimens was 10.37 MPa, this value increased by 48.17% to 15.36 MPa with single layer CFRP wrapping. Double layer CFRP wrapping increased the strength by 61.84% to 16.79 MPa. These results show that CFRP wrapping is

much more effective in undamaged structures and that the wrapping can work effectively on the entire surface in the absence of existing micro cracks. Therefore, strengthening with CFRP provides higher performance in undamaged structural elements and the strength increase is more efficient, especially in double layer applications.

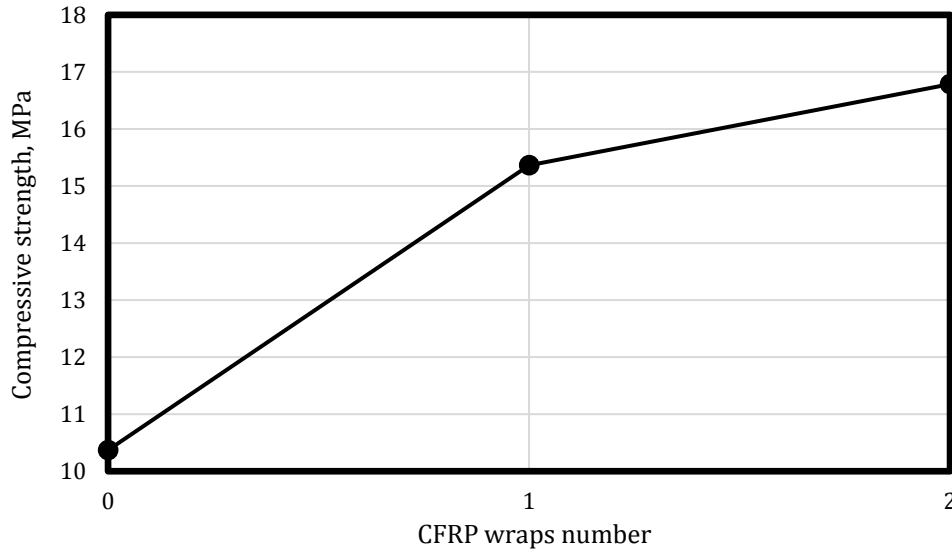


Fig. 6. Compressive strength of the undamaged concrete specimens.

Fig. 7 shows the effect of CFRP wrapping on the bending strength of 15 cm cube-shaped concrete specimens. In the undamaged specimens, the effect of CFRP wrapping is very positive. Single layer CFRP application increased the bending strength by 17.13% to 2.8845 MPa, while double layer wrapping increased this in-

crease by 22.37% to 3.01275 MPa. These increases indicate that the CFRP wrap directly contributes to the load carrying capacity by adhering properly on undamaged surfaces. In conclusion, CFRP wrapping is an effective method to increase bending strength in undamaged specimens.

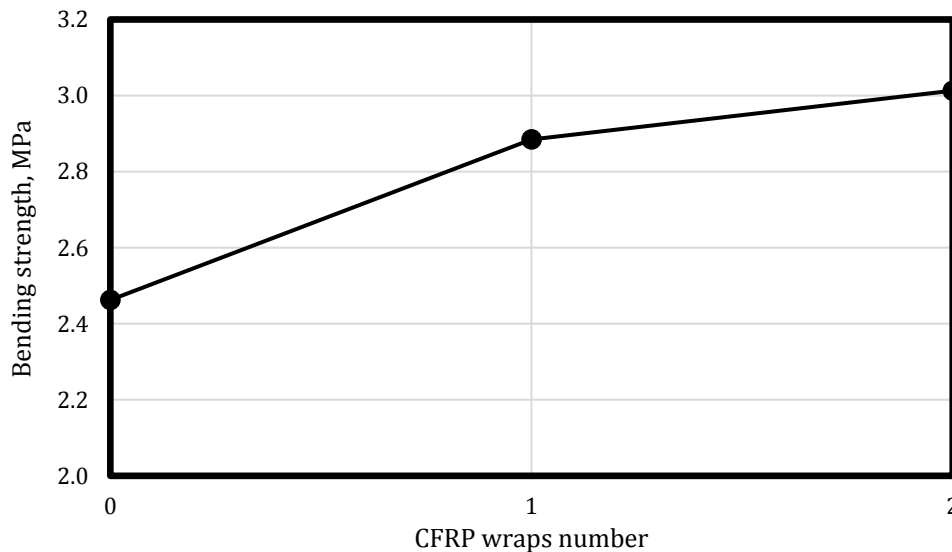


Fig. 7. Bending strength of the undamaged concrete specimens.

3.2. Reinforcement test results of damaged concrete

The results shown in Fig. 8 are from the unit weight and ultrasound transmission velocity tests performed on the damaged concrete specimens after CFRP wrapping. While the unit weight was 2,198.03 kg/dm³ for the specimens without CFRP wraps, this value increased by 0.10% to 2,200.33 kg/dm³ with single layer of CFRP and by 0.23% to 2,203.16 kg/dm³ with double layer of CFRP. These small increases indicate that the CFRP winding provides a slight contribution to the concrete mass and this contribution naturally increases with increasing winding number.

However, this change is due to the effect of the CFRP layer applied on the surface rather than the internal structure of the concrete. Ultrasound transmission rate results provide information about the internal structural integrity of the material. The ultrasound transmission velocity of the specimens without CFRP wraps and with a single layer of CFRP wraps remained the same and was measured as 3.24 km/s. This indicates that the application of a single layer of CFRP has no significant effect on the closure of cracks or the improvement of the continuity of the internal structure. However, with double layer CFRP wrapping, the ultrasonic transmission velocity increased by 2.16%

to 3.31 km/h. This increase indicates that the double layer of CFRP provides a more effective wrapping in the damaged areas, resulting in the closure of cracks, reduction of micro voids and therefore more efficient wave passage. While the application of CFRP has a limited effect on the

unit weight, especially double-ply applications can increase the ultrasonic transmission rate by contributing to the internal structural improvement. This shows that CFRP can partially improve not only superficial but also structural integrity.

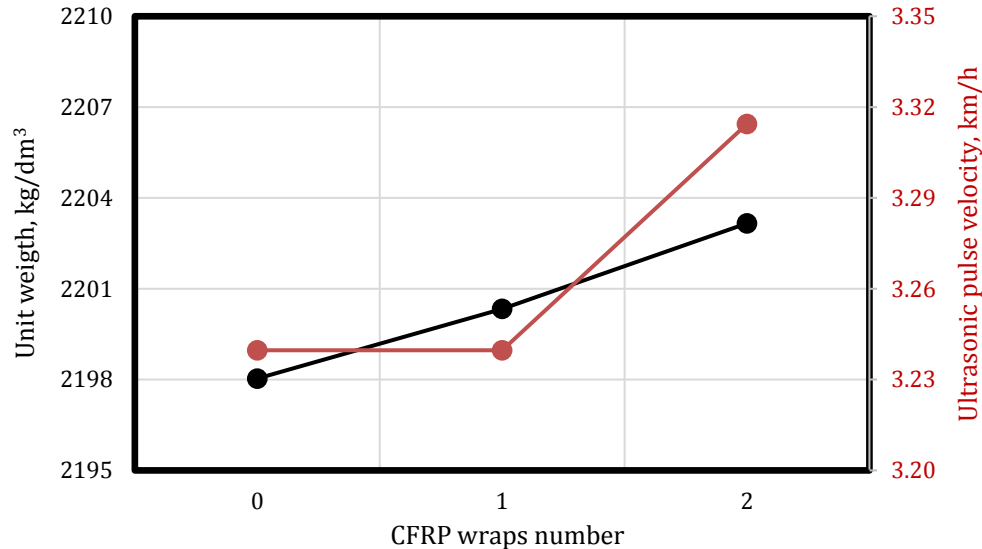


Fig. 8. Unit weight and ultrasound pulse velocities of the damaged concrete specimens.

The effect of CFRP wrapping on damaged concrete specimens is shown in Fig. 9. The compressive strength was measured as 10.37 MPa in the unwrapped condition. When a single layer of CFRP wrapping was applied, the strength increased by 22.99% to 12.76 MPa. The double layer CFRP application provided a more significant increase, increasing the strength by 60.83% to 16.68 MPa.

These increases demonstrate the potential of CFRP to partially strengthen damaged structures. However, it should be noted that the effect of CFRP wrapping may be limited on damaged surfaces and existing cracks may partially reduce the effectiveness of CFRP. Nevertheless, it is seen that this limited effect can be overcome to a great extent with multi-layer wrapping applications.

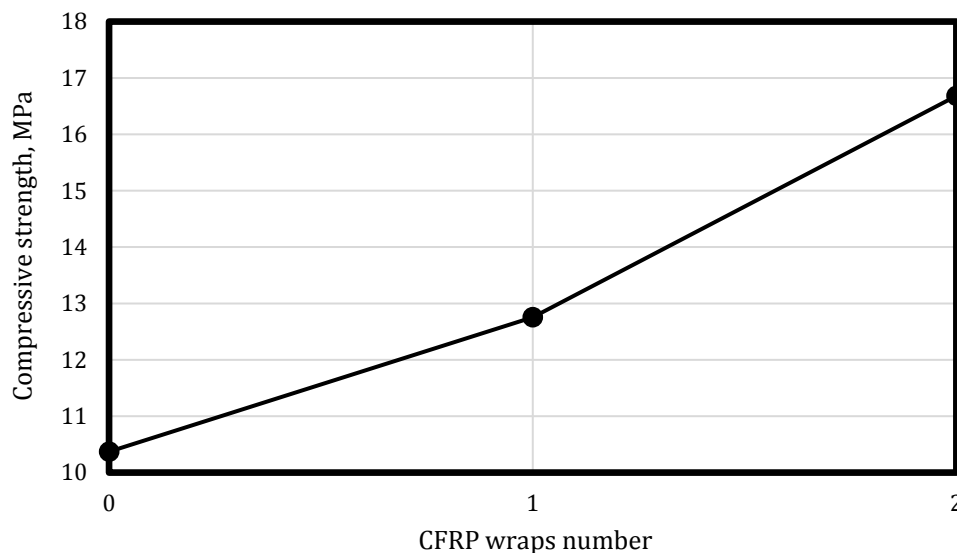


Fig. 9. Compressive strength of the damaged concrete specimens.

The bending test results in Fig. 10 show the effect of CFRP wrapping on the bending strength of 15 cm cube-shaped concrete specimens. The bending strength of both damaged and undamaged specimens without CFRP wrapping was 2.46 MPa. In the damaged specimens, the

strength decreased by 33.41% to 1.64 MPa with a single layer of CFRP wrapping, which can be explained by the inability of CFRP to provide sufficient adherence in the cracked areas and adversely affect the load transfer similar to the literature (Alabdulhady et al. 2022). However,

in the double layer CFRP application, the strength increased again to 2.30 MPa and showed a decrease of only 6.66% compared to the unwrapped condition. This result shows that the double layer of wrapping can restore the bearing capacity to a large extent by creating sufficient wrapping effect in the damaged areas. While CFRP

wrapping is an effective method to increase bending strength in undamaged specimens, positive results can be obtained in damaged specimens only with multi-layer applications. This shows that the effectiveness of CFRP is directly related to the integrity of the specimen surface.

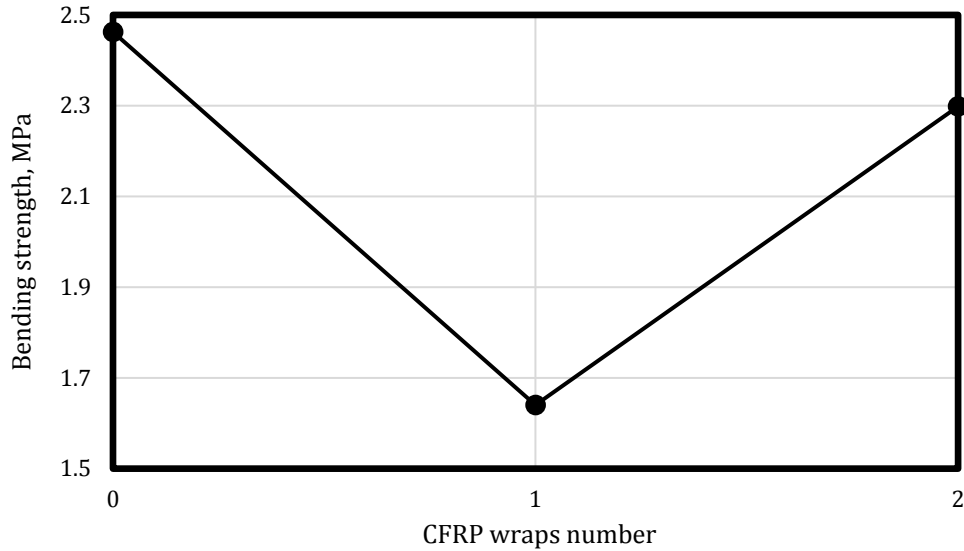


Fig. 10. Bending strength of the damaged concrete specimens.

Fig. 11 shows the fracture mechanisms of the concrete specimens after bending and compressive tests with CFRP wrapping. It was observed that CFRP was effective in maintaining the structural integrity of the prisms in the mid-point loaded bending effect, where

the prisms broke in the middle as expected. In the cube specimens, it was observed that the concrete did not crumble due to the CFRP, where shear stresses at approximately 45 degrees were effective as expected in compression.

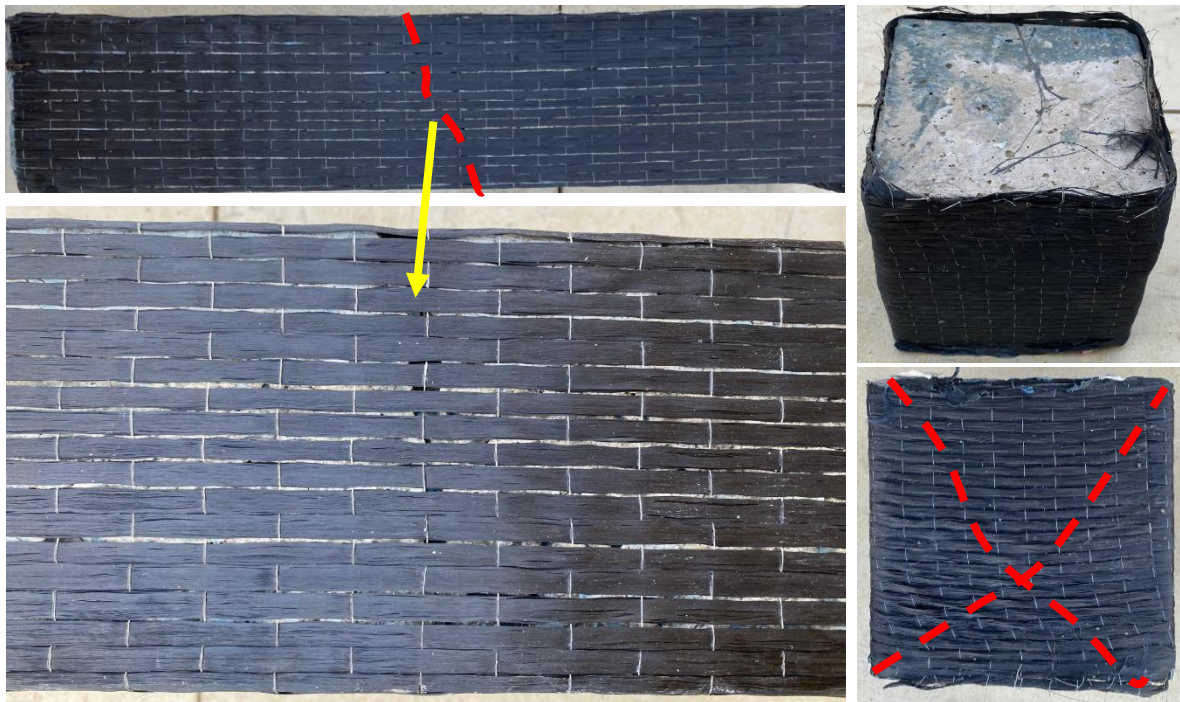


Fig. 11. Fracture mechanism of the concrete specimens.

4. Conclusions

The conclusions of the study are summarized as follows:

- CFRP wrapping applications significantly increase the compressive strength of both damaged and undamaged reinforced concrete elements. Especially double layer wrapping gives much more effective results than single layer wrapping.
- Although the effect on bending strength is not as significant as that on compressive strength, a partial improvement was achieved by CFRP wrapping in undamaged specimens. However, this effect was limited in damaged specimens.
- In damaged specimens, a single layer of CFRP wrapping was insufficient to completely cover the micro cracks, which limited the increase in strength. On the contrary, double layer wrapping more effectively closes the micro cracks and increases the strength.
- Ultrasonic pulse velocity tests show that the double layer of CFRP, in particular, contributes to the internal structural continuity of the concrete and reduces micro voids.
- The unit volume weight increased slightly with the application of CFRP. This increase is directly related to the superficial contribution of CFRP and does not adversely affect the performance of the structure.
- The CFRP wrapping shows higher performance, especially in previously undamaged elements, as it is possible to achieve a more homogeneous and effective adhesion of the wrapping to the concrete surface.

As a result of this study, double layer CFRP wrapping is considered to be a feasible and effective method for reinforcement of damaged and undamaged reinforced concrete members, increasing both strength and strain capacity. Therefore, double layer wraps is recommended for areas where reinforcement is needed.

Acknowledgements

The authors would like to thank KYK (Kütahya Construction Chemicals), Türkiye for material support.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

REFERENCES

- Alabdulhady MY, Ojaimi MF, Chkheiwier AH (2022). The efficiency of CFRP strengthening and repair system on the flexural behavior of RC beams constructed with different concrete compressive strength. *Results in Engineering*, 16, 100763.
- Bird JF, Bommer JJ (2004). Earthquake losses due to ground failure. *Engineering Geology*, 75(2), 147-179.
- Çelik Z, Turan E, Oltulu M, Öner G (2024). Reinforcement of concrete beams using waste carbon-nanoclay-fiberglass laminate pieces. *Challenge Journal of Concrete Research Letters*, 15(1), 1-6.
- EN 12620 (2002). Aggregates for concrete. European Committee for Standardization (CEN), Brussels, Belgium.
- Eryılmaz Yıldırım M, Aybar K, Canbaz M (2024). Size effect on compressive behavior of GFRP bars. *Challenge Journal of Structural Mechanics*, 10(1), 14-20.
- Hegde S, Shenoy BS, Chethan, KN (2019). Review on carbon fiber reinforced polymer (CFRP) and their mechanical performance. *Materials Today: Proceedings*, 19, 658-662.
- Heidarzadeh G (2022). Numerical Modelling of Bond Behaviour of FRP Bar Reinforced Concrete Beam Under High Strain Rate Impact Load. *Ph.D. thesis*, City St George's, University of London, London, UK.
- Jagarajan R, Asmoni MNAM, Mohammed AH, Jaafar MN, Mei JLY, Baba M (2017). Green retrofitting—A review of current status, implementations and challenges. *Renewable and Sustainable Energy Reviews*, 67, 1360-1368.
- Keshmiry A, Hassani S, Dackermann U, Li J (2024). Assessment, repair, and retrofitting of masonry structures: A comprehensive review. *Construction and Building Materials*, 442, 137380.
- Kim, NI, Kwon DY, Burenkhangai D., Lee KM, Bae SY, Chu YS (2023). A study on manufacturing CFRP rebar with a high tensile strength. *Journal of the Korean Ceramic Society*, 60(3), 488-495.
- Ma Z, Cooper P, Daly D, Ledo L (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, 55, 889-902.
- Mitra P (2000). Advanced polymer composites with special reference to carbon fibre reinforced polymer (CFRP). *Proceedings of National Conference on Composites: Science & Technology*, IIT Bombay, 31-48.
- Mousa S, Mohamed HM, Benmokrane B (2019). Strength and deformability aspects of circular concrete members reinforced with hybrid carbon-FRP and glass-FRP under flexure. *Journal of Composites for Construction*, 23(2), 04019005.
- Rashid SP, Bahrami A (2023). Structural performance of infilled steel-concrete composite thin-walled columns combined with FRP and CFRP: A comprehensive review. *Materials*, 16(4), 1564.
- TS EN 197-1 (2012). Cement – Part 1: Composition, specifications and conformity criteria for common cements. Turkish Standards Institution, Ankara, Türkiye.
- TS EN 1504-4 (2006). Products and systems for the protection and repair of concrete structures – Part 4: Structural bonding. Turkish Standards Institution, Ankara, Türkiye.
- Wu J, He X, Li Y, Shi P, Ye T, Li N (2019). How earthquake-induced direct economic losses change with earthquake magnitude, asset value, residential building structural type and physical environment: An elasticity perspective. *Journal of Environmental Management*, 231, 321-328.
- Xue W., Tan Y, Zeng L (2010). Flexural response predictions of reinforced concrete beams strengthened with prestressed CFRP plates. *Composite Structures*, 92(3), 612-622.
- Younis A, Ebead U, Judd S (2018). Life cycle cost analysis of structural concrete using seawater, recycled concrete aggregate, and GFRP reinforcement. *Construction and Building Materials*, 175, 152-160.
- Zardari S, Kutlu İ, Nayebe A (2024). Investigation of structural performances of historical building elements made with local materials using the finite element method. *Challenge Journal of Concrete Research Letters*, 15(3), 101-111.