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Assessment of Flexural–Shear Behavior of Reinforced Concrete Beams Strengthened with Hybrid CFRP–GFRP U-wrap: Experimental and Numerical Approach

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Abstract:
Because of deterioration, higher stress conditions, or poor initial design, reinforced concrete (RC) beams frequently need to be strengthened. Because of their great strength, portability, and simplicity of usage, fiber-reinforced plastics have emerged as a preferred alternative. A hybrid CFRP–GFRP U-wrap system is a promising method for enhancing structural performance because it combines the flexibility and affordability of glass fibers with the high tensile strength of carbon fibers. This method improves overall durability, controls fracture development, and increases the flexural-shear capacity of beams.
When compared to unstrengthened beams, experimental evaluation of RC beams strengthened using the hybrid U-wrap system reveals a discernible increase in load-carrying capacity, stiffness, and resistance to crack propagation. These conclusions are further supported by numerical analysis, which accurately predicts the observed structural behavior. For practical applications in structural rehabilitation and retrofitting of existing concrete structures, the combination of CFRP and GFRP offers a balanced and effective strengthening solution.

Keywords: Cfrp–Gfrp, Glass Fibers, Flexural-Shear, Retrofitting.

I. INTRODUCTION

Reinforced concrete (RC) beams are widely used as primary load-carrying elements in civil engineering structures. Over time, many of these structures experience deterioration due to environmental effects, material degradation, increased service loads, or design limitations. In such cases, strengthening and retrofitting become necessary to restore or enhance structural performance. Among various strengthening techniques, the use of fiber reinforced polymer (FRP) materials has gained significant attention because of their high strength-to-weight ratio, corrosion resistance, and ease of application. These materials provide an efficient solution for improving the strength and durability of existing concrete members without adding considerable weight.

FRP materials such as Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) have been extensively studied for strengthening RC beams. CFRP offers high tensile strength and stiffness, while GFRP is more economical and provides better flexibility. Combining these two materials in a hybrid system can utilize the advantages of both, leading to improved structural performance. One such effective technique is the U-wrap configuration, which is commonly used to enhance the shear resistance of beams and control crack propagation. This method also helps in improving the overall ductility and load-carrying capacity of the structure.Understanding the flexural–shear behavior of RC beams strengthened with hybrid FRP systems is essential for ensuring safe and efficient design. Both experimental investigations and numerical modeling play an important role in evaluating the performance of such systems. Experimental studies provide real-time behavior and failure patterns, while numerical analysis helps in predicting structural response under different conditions. The combined approach offers a reliable way to assess the effectiveness of hybrid CFRP–GFRP U-wrap systems, making them a promising solution for modern structural strengthening and rehabilitation applications.

II. LITERATURE SURVEY

Wang and Du [1] investigated the shear behavior of concrete beams prestressed with FRP tendons using nonlinear finite element analysis in ANSYS, showing that numerical results closely match experimental observations despite the lower shear strength of FRP materials. Mhaimeed and Abd [2] explored the use of textile carbon yarns and flamingo reinforcing systems as alternatives to steel stirrups, reporting improved shear capacity, ductility, and crack control in RC beams. Similarly, Abed et al. [4] studied GFRP-reinforced concrete beams and found that parameters such as shear span-to-depth ratio and reinforcement ratio significantly influence shear strength and failure modes. Al-Badkubi [3] analyzed voided RC beams using ABAQUS and concluded that solid beams have higher shear capacity, although proper reinforcement orientation can enhance the performance of voided sections.

Further studies focused on numerical modeling and material variations to improve beam performance. El-Kholy et al. [5] developed a finite element model for recycled aggregate concrete deep beams, demonstrating accurate prediction of load–deflection behavior and failure patterns. Sagher and Abed [6] conducted a parametric study on GFRP-RC beams and observed that increasing longitudinal reinforcement enhances shear strength but may increase deflection. Nawaz et al. [7] examined lightweight aggregate concrete beams and reported that they can achieve comparable shear strength to conventional beams under suitable conditions. Yuan and Wang [8] analyzed the effect of fire on RC beams, noting a reduction in flexural and shear capacities after exposure to high temperatures, with numerical results aligning well with experimental data.

In addition, Taware et al. [9] studied the seismic performance of coupling beams in RC shear wall systems and highlighted the role of reinforcement configuration in improving shear resistance and reducing deformation under seismic loading. Alam and Hussein [10] performed a three-dimensional finite element analysis of GFRP-reinforced concrete members and confirmed that numerical models can accurately predict load–deflection response, crack patterns, and ultimate strength. Overall, the reviewed studies indicate that the use of FRP materials and advanced finite element modeling techniques significantly enhances the understanding of shear behavior in RC beams, while also supporting the development of effective strengthening and reinforcement strategies.

III. EXSISTING SYSTEM

Conventional reinforced concrete (RC) beams are typically designed with internal steel reinforcement to resist both flexural and shear forces. Shear resistance is mainly provided by steel stirrups, while longitudinal reinforcement carries bending stresses. Although this traditional system has been widely adopted and proven effective under normal conditions, it often faces limitations when structures are subjected to increased loads, aging, or environmental effects. Over time, factors such as corrosion of steel reinforcement, poor maintenance, and design deficiencies can lead to a reduction in the strength and durability of RC beams.

In many existing structures, shear failure remains a critical concern because it occurs suddenly and without significant warning compared to flexural failure. Conventional strengthening methods, such as increasing the cross-section or adding steel plates, are often difficult to implement due to issues like added weight, labor-intensive processes, and susceptibility to corrosion. Additionally, these methods may not be suitable for structures where space constraints or service interruptions must be minimized.

As a result, the existing system relying solely on traditional steel reinforcement and conventional strengthening techniques may not always provide sufficient performance in modern structural requirements. This has led to the need for more advanced and efficient strengthening solutions that can enhance shear capacity, improve durability, and extend the service life of RC beams without major structural modifications.

IV. PROPOSED SYSTEM

To overcome the limitations of conventional strengthening methods, a hybrid CFRP–GFRP U-wrap system is proposed for enhancing the flexural–shear performance of reinforced concrete (RC) beams. This method involves externally bonding a combination of Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) sheets in a U-shaped configuration around the beam. The hybrid approach is adopted to utilize the high tensile strength and stiffness of CFRP along with the flexibility and cost-effectiveness of GFRP, resulting in a balanced and efficient strengthening technique.

In the proposed system, the FRP sheets are applied to the shear zones of the beam after proper surface preparation to ensure strong bonding. The U-wrap configuration helps in confining the beam and improving its resistance against diagonal shear cracks. This method enhances load-carrying capacity, stiffness, and crack control while also improving ductility. Compared to traditional methods, it is lightweight, non-corrosive, and can be applied without significantly altering the geometry of the structure or causing major disruptions.

To evaluate the effectiveness of the proposed system, both experimental testing and numerical analysis are considered. Beam specimens strengthened with the hybrid U-wrap system are tested under controlled loading conditions to observe their behavior. In addition, finite element modeling is used to simulate and validate the experimental results. The proposed system is expected to provide improved structural performance, making it a reliable and practical solution for strengthening and rehabilitation of existing RC beams.

V. SYSTEM ARCHITECTURE

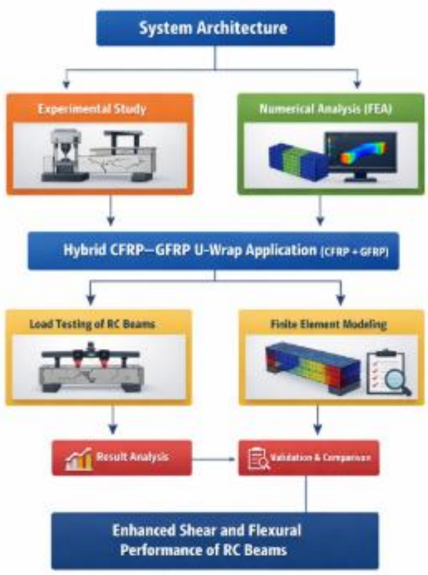

FIG 1. SYSTEM ARCHITECTURE

The system architecture diagram illustrates the overall methodology adopted for enhancing the flexural–shear performance of reinforced concrete (RC) beams using a hybrid CFRP–GFRP U-wrap system. The process begins with two parallel approaches: experimental study and numerical analysis, which are carried out to understand the behavior of RC beams. These approaches are integrated through the application of the hybrid CFRP–GFRP U-wrap strengthening technique. Following this, load testing of RC beams and finite element modeling are performed to evaluate structural response and simulate real-time behavior. The results obtained from both methods are then analyzed and validated through comparison. Finally, the combined outcomes demonstrate improved shear and flexural performance of RC beams, confirming the effectiveness of the proposed strengthening system.

VI. RESULTS AND DISCUSSION

The experimental results indicate that RC beams strengthened with the hybrid CFRP–GFRP U-wrap system exhibit a significant improvement in structural performance compared to conventional beams. The strengthened beams showed higher load-carrying capacity and increased stiffness, along with a noticeable delay in the initiation and propagation of cracks. Diagonal shear cracks were effectively controlled due to the confinement provided by the U-wrap configuration. In addition, the hybrid combination of CFRP and GFRP contributed to better stress distribution, resulting in improved ductility and reduced chances of sudden failure.

The numerical analysis results closely matched the experimental findings, confirming the reliability of the developed finite element model in predicting beam behavior. Load–deflection curves obtained from simulations were in good agreement with test data, and the failure patterns observed in the model were similar to those in the experimental specimens. Minor variations between the two results may be attributed to material assumptions and boundary conditions in the numerical model. Overall, the study demonstrates that the hybrid CFRP–GFRP U-wrap system is an effective and practical technique for enhancing the flexural–shear performance of RC beams, making it suitable for structural strengthening and rehabilitation applications.

VII. CONCLUSION

The study demonstrates that the use of a hybrid CFRP–GFRP U-wrap system significantly enhances the flexural–shear performance of reinforced concrete (RC) beams. The strengthened beams exhibited improved load-carrying capacity, increased stiffness, and better crack control compared to conventional beams. The hybrid combination effectively utilized the high strength of CFRP and the flexibility and cost-efficiency of GFRP, resulting in a balanced and efficient strengthening technique. The U-wrap configuration played a key role in restricting shear crack propagation and improving overall structural behavior.

The comparison between experimental results and numerical analysis showed close agreement, confirming the accuracy and reliability of the finite element model. This validates the use of numerical tools for predicting the behavior of strengthened beams under various loading conditions. Overall, the proposed hybrid strengthening method proves to be a practical, durable, and effective solution for upgrading existing RC structures, making it suitable for real-world structural rehabilitation and retrofitting applications.

REFERENCES:

1. Z. Wang and X. Du, "Nonlinear analysis of the shear behavior of concrete beams pre-stressed with FRP tendons," 2011 Second International Conference on Mechanic Automation and Control Engineering, Inner Mongolia, China, 2011, pp. 6613-6616, doi: 10.1109/MACE.2011.5988561. https://ieeexplore.ieee.org/document/5988561
2. S. Mhaimeed and S. M. Abd, "Shear Capacity of Concrete Beams Reinforced with Textile Carbon Yarns and Flamingo Reinforcing System," 2021 4th International Iraqi Conference on Engineering Technology and Their Applications (IICETA), Najaf, Iraq, 2021, pp. 212-217, doi: 10.1109/IICETA51758.2021.9717950. https://ieeexplore.ieee.org/document/9717950

3. M. R. K. M. Al-Badkubi, "Finite Element Study on Ultimate Shear Capacity of Voided Reinforced Concrete Beams," 2019 2nd International Conference on Engineering Technology and its Applications (IICETA), Al-Najef, Iraq, 2019, pp. 19-24, doi: 10.1109/IICETA47481.2019.9012987. https://ieeexplore.ieee.org/document/9012987
4. F. H. Abed, A. Al-Rahmani and A. H. Al-Rahmani, "Finite element simulations of the shear capacity of GFRP-reinforced concrete short beams," 2013 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), Hammamet, Tunisia, 2013, pp. 1-5, doi: 10.1109/ICMSAO.2013.6552566. https://ieeexplore.ieee.org/document/6552566
5. El-Kholy, S. Elkholy and A. Godat, "Towards Finite Element Modelling of Reinforced Recycled-Coarse Aggregate Concrete Deep Beams," 2022 Advances in Science and Engineering Technology International Conferences (ASET), Dubai, United Arab Emirates, 2022, pp. 1-5, doi: 10.1109/ASET53988.2022.9734846. https://ieeexplore.ieee.org/document/9734846
6. Sagher and F. Abed, "Finite element parametric study of the shear behavior of GFRP-RC short beams," 2017 7th International Conference on Modeling, Simulation, and Applied Optimization (ICMSAO), Sharjah, United Arab Emirates, 2017, pp. 1-5, doi: 10.1109/ICMSAO.2017.7934912. https://ieeexplore.ieee.org/document/7934912
7. W. Nawaz et al., "Shear Behavior of RC Beams Cast with LAVA Lightweight Aggregates," 2019 Advances in Science and Engineering Technology International Conferences (ASET), Dubai, United Arab Emirates, 2019, pp. 1-4, doi: 10.1109/ICASET.2019.8714510. https://ieeexplore.ieee.org/document/8714510
8. L. Yuan and J. Wang, "Experimental study on the mechanical behaviors of reinforced ceramsite concrete beams after fire," 2011 International Conference on Electric Technology and Civil Engineering (ICETCE), Lushan, China, 2011, pp. 5040-5042, doi: 10.1109/ICETCE.2011.5776388. https://ieeexplore.ieee.org/document/5776388
9. A. A. Taware, W. N. Deulkar and S. B. Kharmale, "Evaluation of the Seismic Performance of Coupling Beams for Reinforced Concrete Shear Wall Building," 2024 International Conference on Artificial Intelligence and Quantum Computation-Based Sensor Application (ICAIQSA), Nagpur, India, 2024, pp. 1-9, doi: 10.1109/ICAIQSA64000.2024.10882372. https://ieeexplore.ieee.org/document/10882372
10. M. S. Alam and A. Hussein, "3D-Finite Element Analysis (FEA) of Glass Fiber Reinforced Polymer (GFRP) Reinforced Concrete Members," 2019 8th International Conference on Modeling Simulation and Applied Optimization (ICMSAO), Manama, Bahrain, 2019, pp. 1-4, doi: 10.1109/ICMSAO.2019.8880274. https://ieeexplore.ieee.org/document/8880274