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Comparison between numerical and laboratory methods in the analysis of reinforced concrete beams with fiberglass bars and steel reinforcement

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Abstract

This study aimed to compare numerical and laboratory methods for analyzing the mechanical performance of high-strength reinforced concrete beams. It also aimed to identify the factors that can be used to Improving the mechanical performance of high-strength reinforced concrete beams by incorporating glass fiber reinforced polymers (GFRP). Three beam specimens (B01, B02, and B03) with identical dimensions but different reinforcing materials—steel, hybrid (steel + GFRP), and all-GFRP—were analyzed experimentally and numerically using Abacus and MATLAB. The stiffness, displacement, stress, strain distribution, and energy absorption under flexural loads were determined and evaluated. The results indicated that the B01 beam, reinforced entirely with steel, exhibited the highest initial stiffness and lowest deflection, making it suitable for applications requiring high stiffness. The B02 beam, reinforced with hybrid bars, exhibited increased ductility and higher strain, indicating its suitability for applications requiring deformability. The B03 beam, reinforced solely with glass fibers, achieved a balanced performance between stiffness and ductility. Statistical correlation analysis confirmed a strong agreement between the experimental and numerical data (correlation coefficients > 0.8), confirming the accuracy of the model. Beam B01 proved to be best suited for applications requiring high stiffness, recording the lowest strain value (0.022) and the highest energy efficiency under load (490 and 450), demonstrating its high resistance to deformation. In contrast, beam B02 exhibited a higher

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strain (0.055) and lower energy efficiency (200 and 250), indicating high ductility and reduced efficiency due to the quality of the reinforcement. Beam B03 recorded a medium strain (0.045), reflecting its greater susceptibility to deformation compared to B01, but maintained a higher efficiency than B02. Numerical methods are faster and less expensive, and allow for multiple scenarios to be flexibly analyzed.

Keywords: Concrete beams, stresses, loads, strain, abacus, numerical methods, laboratory methods and DFRP.

مقارنة بين الطرق العددية والمخبرية في تحليل الجسور الخرسانية المسلحة بقضبان الألياف الزجاجية والتسليح الفولاذي

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الخلاصة

هدفت هذه الدراسة لمقارنة الطرق العددية والمخبرية لتحليل الأداء الميكانيكي للجسور الخرسانية المسلحة ذات القوة العالية. كما هدفت لتحديد العوامل التي يمكن استخدامها لتحسين الأداء الميكانيكي للجسور الخرسانية المسلحة ذات القوة العالية من خلال دمج البوليمرات المسلحة بألياف الزجاج. تم تحليل ثلاثة نماذج من الجسور بأبعاد متطابقة ولكن بمواد تسليح مختلفة (الفولاذ، والمختلط (الفولاذ والياف الزجاج) والياف الزجاج) – تجريبيا وعدديا باستخدام برنامجي أباكوس وماتلاب. تم تحديد وتقييم صلابة الجسور والانزياح والاجهاد وامتصاص الطاقة تحت الاحمال الثنائية.

اشارت النتائج الي أن الجسر الأول المسلح بالكامل بالفولاذ أظهر أعلي صلابة أولية وأقل انحراف مما يجعله مناسبا للتطبيقات التي تتطلب صلابة عالية. أما الجسر الثاني المسلح بقضبان مختلطة أظهر زيادة في الليونة واجهاد أعلي مما يشير إلى ملائمته للتطبيقات التي تتطلب قابلية التشكيل. حقق الجسر الثالث المسلح فقط بألياف الزجاج أداء متوازنا بين الصلابة والليونة. أكد تحليل الارتباط الاحصائي توافقا قويا بين البيانات التجريبية والعددية (معاملات الارتباط أكبر من 0.8) مما يؤكد دقة النماذج.

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ثبت أن الجسر الأول هو الأنسب للتطبيقات التي تتطلب صلابة عالية، حيث سجل أقل قيمة اجهاد(0.022) وأعلي كفاءة في استهلاك الطاقة تحت الحمل (490 و450) مما يدل على مقاومته العالية للتشوه.
بالمقابل أظهر الجسر الثاني اجهادا أعلي (0.055) وكفاءة طاقة أقل (200 و250) مما يشير إلى ليونة عالية وكفاءة منخفضة بسبب جودة التسليح. وسجل الجسر الثالث اجهادا متوسطا(0.045) مما يعكس قابليته الأكبر للتشوه مقارنة بالجسر الأول ولكنه حافظ علي كفاءة أعلي من الجسر الثاني.
تعد الطرق العددية أسرع وأقل تكلفة وتتيح تحليلا مرنا لعدة سيناريوهات.
الكلمات الدالة: عوارض خرسانية، اجهادات، احمال، انفعال، جدول حسابات، طرق عددية، طرق مخبرية.

1. Introduction

The design and rehabilitation of structures, whether steel or concrete and their basic comparisons are among the most important focal points, especially in recent years with the advancement of engineering and design sciences [1]. This is especially true in light of the aspirations of all sectors and fields to develop and achieve sustainability in the construction sector in its general and specific concept. There are many diverse factors that affect the rehabilitation and engineering design processes for digital and steel structures. These factors can be divided into environmental, economic and technical factors [2]. Therefore, it was necessary to have visions and strategies that would achieve the engineering, economic, and environmental requirements and standards for engineering designs, as the unsatisfactory performance of any facility could raise major concerns related to security and safety. In light of the fear of building collapse and endangering the safety of individuals, one of the most important steps and pivots for achieving sustainability in the buildings and construction sector was to improve performance using modern design techniques and strategies to develop reinforced concrete structures and beams. Some of these techniques have been developed to improve them, some of which have become effective, others more effective, while some practices remain of limited effectiveness [3]. This is due to some challenges, obstacles, and economic, environmental, and engineering restrictions imposed by

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local and international codes. Despite the multiplicity of improvement techniques and practices, there are many challenges and absolute defects in structures and beams made of concrete and heavy steel, especially when loads increase and the lengths of these beams increase. Therefore, we find that there is a general requirement, which is to modify the structural stiffness and reduce the weights of concrete structures, and traditional methods are no longer possible. They meet most of the needs in this regard. I may have considerations related to security and safety, or considerations related to steel corrosion, or even the occurrence of stresses on the concrete in the beams. Since most structures and facilities, whether in construction projects or even in infrastructure projects such as roads, bridges, and viaducts rely on steel-reinforced concrete, or what is called reinforced concrete, it was necessary to find new methods to develop these structures.[4] .

This study aims to conduct a practical comparison between numerical and experimental methods in analyzing the performance of reinforced concrete beams with fiberglass bars and steel reinforcement through structural modifications. This is achieved through the development of crystalline composite materials, which are characterized by high total tensile strength, high corrosion resistance, light weight, ease of handling, low fatigue stresses, low labor costs, and low energy consumption, qualifying them for use in a wide variety of structures. Among the applications, it can be summarized as an excellent alternative to traditional methods for improving the functionality and performance of reinforced concrete structures, especially steel-reinforced beams [5]. The study also aims to determine the optimal fiber ratios to maximize the mechanical and physical properties of these materials and to determine the relationship between the types of glass, carbon, and polymer fibers, especially in reinforced concrete beams of different lengths and cross-sections. The importance of the study is due to its comprehensiveness and its coverage of the subject from several aspects, including the applied aspect as well as the numerical methods using Abacus simulation programs and comparing them to determine the effect of loads on concrete beams reinforced with fiberglass bars and reinforcing steel accurately and reliably. The study also completely avoided bias in both the data and results, which makes it a useful reference study f The main problem of the

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study is related to the mechanism of evaluating the effect of fibers on the behavior of reinforced concrete beams under different loads and the stresses resulting from these loads, whether they are bending stresses, tensile stresses, compression stresses, or shear stresses, as well as the behavior of these concrete beams when exposed to any emergency loads and the extent of their ability to resist shocks, absorb energy, and limit the spread of cracks [6]. The study also focused on evaluating the effect of adding fibers on the total construction costs and comparing them with traditional methods in developing the performance of reinforced concrete beams. Or researchers and students in the field.

2. Theoretical background and basic concepts

In the field of structural engineering, numerous techniques are available to enhance the performance of steel beams. Other materials, such as fiberglass bars, are also used according to specific requirements and objectives, whether these require improved strength, stiffness, and durability, or improved flexibility, reduced weight, and improved resistance to high loads, environmental factors such as earthquakes, landslides, and increased loads resulting from operating conditions. As shown in Figure 1 illustrates the most important of these techniques.[7].

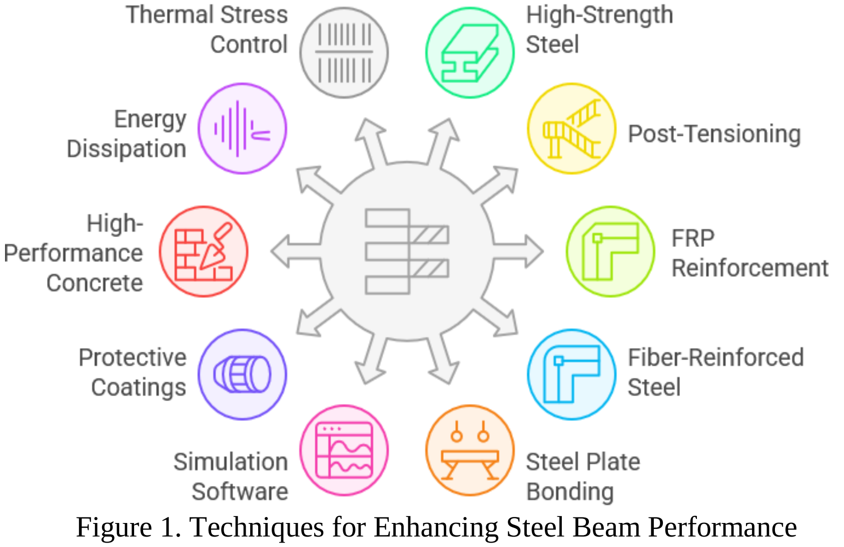

Figure 1. Techniques for Enhancing Steel Beam Performance

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The efficiency of reinforced concrete beams is affected by several factors related to the reinforcing steel, most notably:
•Tensile strength: The higher the strength، the less likely the steel will slide within the concrete.
•Durability of steel: Helps it withstand bending without failure.
•Diameter of steel: Affects the beam's load-bearing capacity.
•Type of steel: Selected based on the loads and environmental conditions.
•Concrete bonding: Strong bonding ensures stress transfer and enhances the beam's performance.[8]

2.1 .Basic concepts

On of this study will present the most important basic concepts related to this study of enhancing the mechanical behavior of high-strength concrete using glass fiber reinforced polymers: a comprehensive study using numerical analysis and experimental verification. Presenting these concepts contributes to the formation of a clear perspective, vision, and a conscious understanding of the stages and steps of the study, both in the theoretical and practical parts. The following are some of the most important basic concepts used during the study:

1) Different types of loads and stresses acting on reinforced concrete beams

a) Static loads: These loads include the weight of the building, equipment, and furniture, and are known as static or dead loads. These loads generate stresses such as bending, shear, and torsion, and are essential in the design of concrete beams [8].

b.) Dynamic loads: They are caused by wind, earthquakes, or vibrations from industrial operations. They change over time and also generate various stresses such as bending and shear.

c) Tensile and compressive stresses: It occurs when concrete is exposed to external forces, such as the weight of the building, temperature changes, or chemical reactions within the concrete, which leads to shrinkage, expansion, or separation between its components[9].as shown in figure2.

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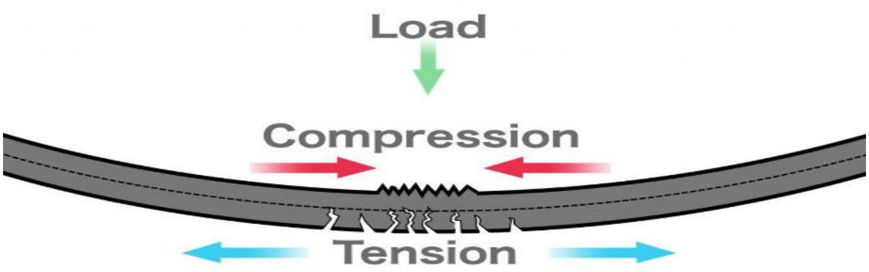
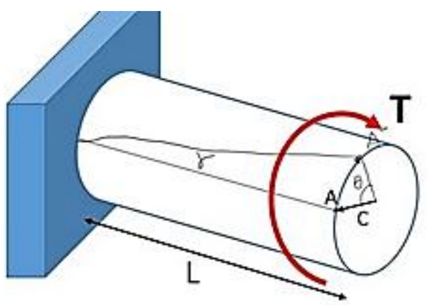


Figure 2. Tensile and compressive stresses

d) Twisting moment: It results from the rotation of forces around a longitudinal axis, leading to oblique cracks in beams. Its resistance depends on the reinforcement ratio, its distribution, the dimensions of the element, and the type of concrete [10]. as shown in figure3.



$$\frac{T}{J} = \frac{\tau}{y} = \frac{\tau_{max}}{c} = \frac{G\emptyset}{L}$$

Figure 3. The bending moment stress.

e) Bending stress: It occurs when a beam is subjected to forces that cause it to bend. It is usually generated by external loads and exhibits a clear distribution of tensile and compressive stresses within the section [11] as shown in figure4.

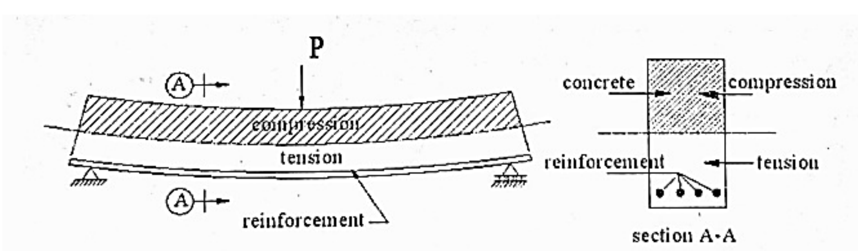


Figure 4. The bending stress (Ft).

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f) Shear stresses: They result from two opposing forces that cause the layers of the material to slide, causing cracks, especially when concrete has a weak resistance to this type of stress. They often occur as a result of inclined or dynamic loads, such as earthquake forces [12].

2) Reinforcing steel

Reinforcing steel is the second essential component in reinforced concrete structures. It gives concrete its strength and durability and increases its ability to withstand various stresses, especially those resulting from tension. In short, it can be said that reinforcing steel is the backbone that gives concrete its strength and load-bearing capacity. The main factors affecting the properties and performance of reinforcing steel in beams are:

•Pull-out strength: Pull-out strength expresses the steel's ability to resist being pulled from the concrete. The higher this strength, the greater the beam's ability to resist cracking and the less likely it is to slip between the steel and concrete.

•Steel ductility: Steel's ductility refers to its ability to bend without breaking or failing. The greater the steel's ductility, the more it can work in harmony with the concrete, enhancing the beam's ability to withstand bending[13] .

•Steel diameter: The diameter of the reinforcing steel bars is one of the factors affecting the performance of reinforced concrete beams. The larger the steel diameter, the greater the beam's ability to withstand the resulting loads and stresses[14] .

•Steel Type: Reinforcing steel types vary based on their mechanical properties. The appropriate steel type is selected based on the type of expected loads and environmental conditions[15] .

•Bonding between steel and concrete: The bonding between steel and concrete is one of the most important factors determining the performance of beams. Proper bonding ensures efficient stress transfer between the concrete and steel, enhancing the strength of the beam[16] .

3) Glass Fiber Reinforced Polymer (GFRP)

Glass fiber is a modern material effective in enhancing the performance of reinforced concrete beams, due to its distinctive mechanical and physical properties. Used in fiber-reinforced polymer (FRP) components, it is characterized by:

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•High tensile strength: It allows it to withstand heavy loads without failure.
•Corrosion resistance: It is unaffected by the surrounding environment، increasing the lifespan of concrete.
•Light weight: It weighs approximately one-quarter the weight of steel، making it easy to use and reducing the need for scaffolding and installation costs.
•Good flexibility: It absorbs energy generated by earthquakes or dynamic loads.
•Fatigue resistance: It can withstand repeated loads without losing its properties.
•Electrical and thermal insulation: It is non-conductive to electricity or heat، making it safe in sensitive environments.
•Glass fiber is available in various shapes and sizes, and its stiffness can be customized according to design requirements, enhancing its effectiveness in reinforcing concrete elements. as shown in figure5.

Figure 5. Fiber Glass Reinforced Polymer (GFRP)

4).Numerical Verification and Analysis

Numerical verification and analysis is a mathematical technique used to solve complex engineering problems using computers. In civil engineering, numerical analysis is used to analyze the behavior of materials and structures under various loads, such as the loading of fiber-reinforced concrete. Verification is the process of comparing the results obtained from numerical analysis with experimental results obtained from laboratory or field tests. The goal of verification is to ensure that the models used in numerical

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analysis are valid and accurately represent the actual behavior of the material[17].

5) Finite element analysis (FEA)

Finite element analysis (FEA) is a powerful and effective tool used in structural analysis. This theory relies on dividing a structure into small parts called "elements" and analyzing each one in detail, allowing for the study of stresses and strains at specific points, whether the loads are constant or variable. To understand this theory, a structure is divided into small elements such as triangles or squares, and the properties of each element are analyzed individually. These properties include bending, strain, tensile and flexural modulus, as well as other physical properties. Equilibrium equations are then applied to each point of the reinforced concrete structure.[18]

6). Factors Affecting the Performance of Reinforced Concrete Beams

The performance of reinforced concrete beams depends on several factors that are interdependent and that measure their ability to withstand various loads and stresses. The most important among these are:

- Concrete Properties: Includes compressive strength, type of mix, additives, and pre-cracks.
- Type and Properties of Reinforcing Steel: Examples of which include tensile strength, elasticity, diameter, bonding with concrete, and type of metal used.
- Reinforcement Details: It is also the spacing of the bars, the number of bars, the fixing length, and the concrete cover of the bars as shown in figure6.
- Type of Loads: Static (e.g., building weight) or dynamic (e.g., wind and earthquakes) directly influences the design approach and the response of the structure.
- Beam Shape and Dimensions: The thickness and depth of the cross-section and span length affect resistance to shear, bending, and torsion.
- Construction and Implementation Methods
    - Accuracy in shop drawings, curing and quality casting, adhesion, and preventing defects such as poor compaction or voids.

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- Humidity, temperature, chemicals, and other atmospheric conditions can weaken concrete and reinforcing steel over time.

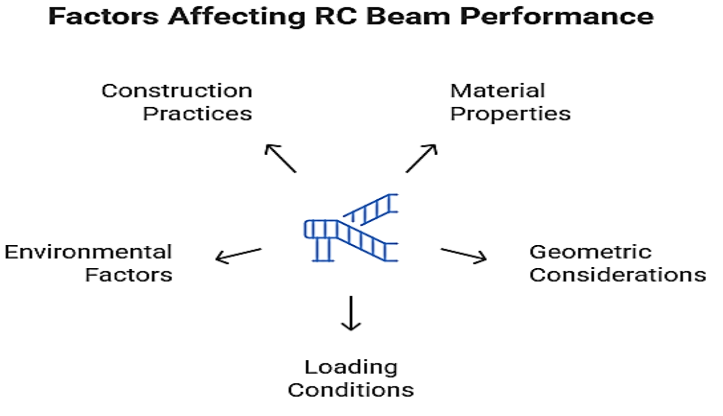

Figure 6. Factors Affecting the Performance of Reinforced Concrete Beams

2.2. Related studies

Various studies have been conducted to investigate the behavior of reinforced concrete beams and evaluate strengthening methods and materials' effects. Numerous studies have explored the behavior of reinforced concrete beams and evaluated the impact of various strengthening techniques and materials. Mahmoud (2012) utilized ANSYS 9 to model both CFRP-reinforced and non-reinforced concrete beams [20]. The study confirmed the accuracy of numerical simulations, particularly when using the Solid46 element, by comparing the results with experimental data and earlier finite element models. Bernardo and Lopez (2013) investigated the ductile and flexural behavior of high-strength hollow-core concrete beams under pure torsion [21]. They introduced the Plastic Torsional Parameter (PTP) to quantify torsional capacity, highlighting its sensitivity to reinforcement ratios and design codes, with the American code yielding superior accuracy. Chen et al. (2015) focused on strengthening rectangular hollow steel beams using externally bonded CFRP sheets. Their findings demonstrated a significant improvement in flexural strength, particularly as crack depth increased, and emphasized the importance of mechanical

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anchoring to prevent premature sheet failure [22]. *Ali, S* et al. (2023) examined the structural effect of embedding PVC pipes in medium-depth concrete beams. They concluded that small-diameter pipes (less than one-third the beam width) had minimal impact, while larger diameters led to a considerable reduction in both stress capacity and stiffness [23]. Al-Khazai and Attia (2019) studied the influence of steel fibers and silica fume on the torsional behavior o Nie, X.f et al (2020) hollow T-beams. Their experimental results revealed substantial improvements, including a 184% increase in cracking torque and a 66% rise in ultimate torsional strength with the addition of 2% steel fibers to the concrete mix [24].

3. Methodology

The methodology used in this study is:A set of methodologies, where the descriptive methodology was used to describe data, variables and results, the quantitative methodology was used to collect and process data, and the analytical methodology was used to analyze and evaluate results, in addition to the comparative methodology by comparing numerical results with laboratory results.

3.1. The applied framework of the study

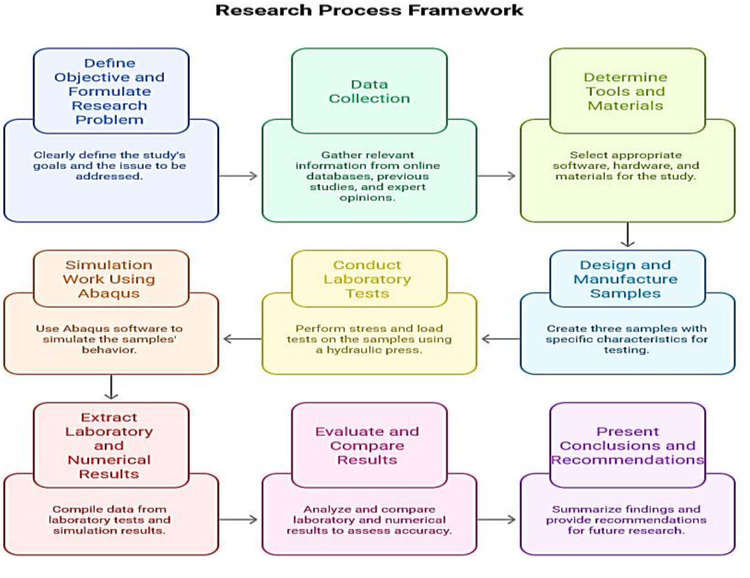

Figure 7. Fiber Glass Reinforced Polymer (GFRP)[2]

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As show in the previous figure (Figure 7) illustrates the applied framework for the study stages and procedures, starting with defining the objective and formulating the research problem, then moving on to collecting data from various sources such as online databases, previous studies, and opinions of experts and consultants. Then, determining the tools and materials used in the study, then designing and manufacturing three samples: B01, BO2, and B03. Then, the stage of conducting laboratory tests on the three samples as an applied method using a hydraulic press for stress and load tests, then conducting simulation work using the Abacus program and finite elements. Extracting the laboratory and numerical results, then evaluating these results and making a comparison between them practically and statistically, then presenting the conclusions and recommendations.

3.2. Materials and Tools

a). Samples: Three reinforced concrete beam samples were designed. The first beam, B01, was fully reinforced with 14 mm diameter steel bars. The second beam, B02, was fully reinforced with 14 mm diameter fiberglass bars. The third beam, B03, was reinforced with fiberglass upper reinforcement and 14 mm diameter steel lower reinforcement. The three beams were 3 meters long, with a cross-sectional area of 20 cm and a width of 15 cm, as shown in Figure 8.

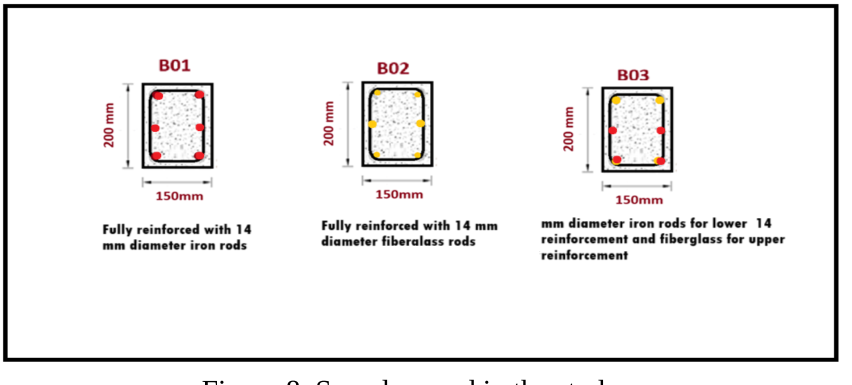

Figure 8. Samples used in the study

b). Data and Software: This includes data related to the properties of the reinforcing bars, whether made of steel or fiberglass; concrete data and properties; environmental data, including temperature and

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humidity; data on the available loads and laboratory capabilities; and simulation programs such as Abacus, statistical analysis programs such as SPSS, and software such as METLAB.

c). Tools and Equipment: This includes laboratory equipment such as hydraulic presses, data recording and monitoring devices, measuring devices, and installation and lifting tools. For simulation, powerful computers were used.

3.3. Procedures

1. Defining the Objective and Formulating the Research Problem

The first stage involved clearly defining the objective of the study, including identifying the specific goals the research seeks to achieve. At the same time, the research problem was formulated, identifying the specific issue or question the study aims to address. This step provided clear direction and focus for the subsequent stages of the research [25].

2. Data Collection

Data collection was a crucial step, as it involved gathering relevant information from various sources. These sources included:

Online databases: Searching and extracting data from relevant online databases to gather existing research and information related to the study topic.

Previous studies: Reviewing and analyzing previous studies to understand the existing body of knowledge, identify gaps, and build on previous research.

Expert opinions: Consulting experts and consultants in the field to gain insights, perspectives, and guidance on the research problem and potential solutions.

3. Determining Tools and Materials

This phase involved identifying and selecting the appropriate tools and materials for conducting the study. This included:

- Choosing software, such as Abacus for simulation, SPSS for statistical analysis, and METLAB for programming.
- Hardware: Identifying and providing the necessary hardware, such as computers, sensors, and testing equipment.
- Identifying the materials used in the manufacture of concrete beams, such as fiberglass and reinforcing steel bars, their specifications, and the concrete.

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4. Specimen Design and Fabrication

The three specimens were designed and manufactured according to the above specifications.

- BO1: Fully reinforced concrete with 14 mm diameter steel bars
- B02: Fully reinforced concrete with 14 mm diameter fiberglass bars
- B03: Upper reinforced concrete with 14 mm diameter fiberglass bars and lower reinforced concrete with 14 mm diameter steel bars

The fabrication process included precise manufacturing techniques to ensure that the specimens met the design specifications and were suitable for subsequent testing. The concrete specimens measured 3 m in size, 20 cm in height, and 15 cm in width.

5. Laboratory Testing

Laboratory tests were conducted on the three samples using a hydraulic press to apply stress and load. This method allowed for the collection of experimental data on the behavior of the samples under controlled conditions. The tests included:

- Fatigue Testing: Applying controlled stresses to the samples and measuring their responses, such as deformation and strain.
- Loading Testing: Applying controlled loads to the samples and measuring the resulting displacement and stress distribution.
- The data collected from these tests provided valuable insights into the mechanical properties and performance of the samples.

6. Simulations Using Abaqus

- In addition to the laboratory tests, simulations were conducted using Abaqus, a finite element analysis program. This involved creating a virtual model of the samples and simulating their behavior under conditions similar to laboratory tests. Through simulation, the simulation model can be validated by comparing its results with laboratory test data.
- Parametric Studies: Performing parameter studies to explore the effect of various parameters on sample behavior.

7. Optimize: Optimize the sample design based on simulation results.

8. Statistical analysis

The study used a set of statistical analyses to evaluate the data and the relationships between variables. The ANOVA test was applied to measure the variance and significance of the data, in addition to

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the unpaired t-test and Fisher's exact test to compare normally distributed data with uncorrelated variables[26].
The correlation coefficient between risk factors, cancer incidence rate, and absorbed radiation were calculated to analyze the statistical relationship between them.
To determine the relationship between stresses, strains, and displacements in the use of iron and fiberglass rods, multiple linear regression was used using the forward stepwise regression model, focusing on variables that achieved statistical significance at $P < 0.05$.
The study also relied on the variance criterion, where the threshold value for the coefficient of variation was set at 1.2%. The higher the coefficient, the more reliable the data. Accordingly, the relationship was analyzed using the following equation:

$$\boldsymbol{Y} = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1\boldsymbol{X}_1 + \boldsymbol{\beta}_2\boldsymbol{X}_2 + \ldots + \boldsymbol{\beta}_n\boldsymbol{X}_n + \boldsymbol{\varepsilon} \quad [5].$$

Where:

- Y: Dependent variable (such as stress or displacement)
- β_0: Constant (Y value at X = 0
- β_1, β_2,...: Regression coefficients
- X_1, X_2,...: Independent variables (such as reinforcement type, load, time)
- ε: Random error
-

4. Results and Discussion

In this section, laboratory and simulation results using Abaqus software are presented. Three simply braced concrete beams were manufactured according to ASTM C39 specifications, and the compressive strength after 28 days was 35 MPa. The mechanical properties of the steel and glass fiber reinforced plastic (G-FRP) reinforcement were determined according to ASTM D7565. The modulus of elasticity of G-FRP ranged from 35 to 55 GPa, compared to 200 GPa for steel, while the ultimate tensile strength ranged from 500 to 1200 MPa, depending on the fiber type and composition.

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4.1. Laboratory results

Table 1: shows stress vs. strain (experimental)

	strain		
stress Mpa	**B01**	**B02**	**B03**
0	**0**	**0**	**0**
3.7	**0.001**	**0.006**	**0.004**
7.2	**0.0015**	**0.007**	**0.005**
11	**0.002**	**0.008**	**0.006**
14.6	**0.003**	**0.01**	**0.008**
16.4	**0.006**	**0.015**	**0.01**
18.2	**0.008**	**0.02**	**0.015**
22	**0.011**	**0.03**	**0.02**
25.5	**0.017**	**0.041**	**0.03**
29	**0.019**	**0.048**	**0.041**
36.4	**0.025**	**0.054**	**0.048**

Table No. 1 shows a comparison between the stress and strain of the three beams. It is clear from the table that the first beam B01, which is fully reinforced with iron, can withstand tensile stress and bending stress better than beam B03 and B02, which are fully reinforced with fiberglass. As for beam B03, it will be less resistant to bending stress and fracture stress, as fiberglass is less hard than iron, which makes it more flexible and durable, but it can withstand less tensile stress and compressive stress [84]. It is also more flexible than beam B02, as the greater the cross-sectional area of the bar, the greater its ability to bend without breaking.

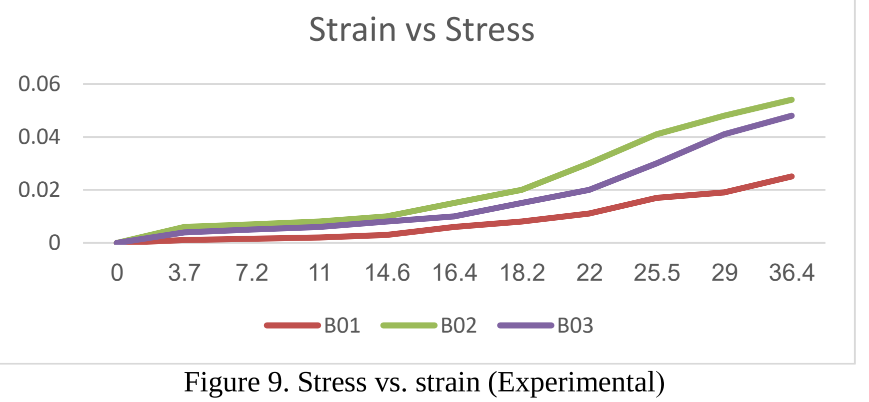

Figure 9. Stress vs. strain (Experimental)

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As shown in Figure 9, the stress-strain curve illustrates the behavior of the three specimens (B01, B02, and B03) under load. Initially, a linear elastic behavior is observed, reflecting a direct relationship between stress and strain, with the slope of the line representing the stiffness (Young's modulus) of the material. After the yield point, the material begins to deform permanently, then enters a hardening phase until it fractures. Specimen B01 exhibited the highest strength and lowest elasticity, followed by B02 with lower strength and higher elasticity, while B03 was the weakest but most elastic. These results demonstrate that increasing the cross-sectional area of the reinforcement enhances the beam's ability to bend before breaking.
.

Table 2: Displacement and deformation

	Deformation		
Displacement (mm)	**B01**	**B02**	**B03**
0	**0**	**0**	**0**
2	**0.01**	**0**	**0.03**
4	**0.03**	**0.1**	**0.08**
6	**0.08**	**0.3**	**0.15**
8	**0.17**	**0.43**	**0.33**
10	**0.25**	**0.54**	**0.48**

Table 2 shows the displacement value (in mm) at different loading points for concrete beams B01, B02 and B03, which differ in the type of reinforcement.

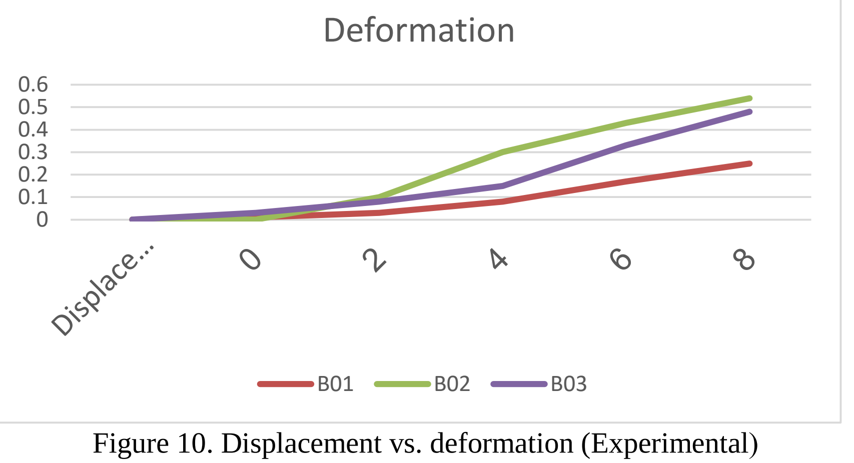

Figure 10. Displacement vs. deformation (Experimental)

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As shown in Figure 10 shows the load-displacement curve for the three concrete beams. Initially, the displacement is zero for all specimens, corresponding to the initial state without load. As the load increases, the displacement gradually increases. Beam B01 exhibited the lowest displacement rate, indicating its high stiffness, while beam B02 recorded the largest displacement rate, indicating its high ductility. Beam B03 achieved intermediate results between B01 and B02. The curve shows that the response of each specimen to load varies depending on the reinforcing material. Some can withstand higher loads before deforming, while others deform early, reflecting the differences in stiffness and ductility between the materials.

1.2. Numerical and simulated results

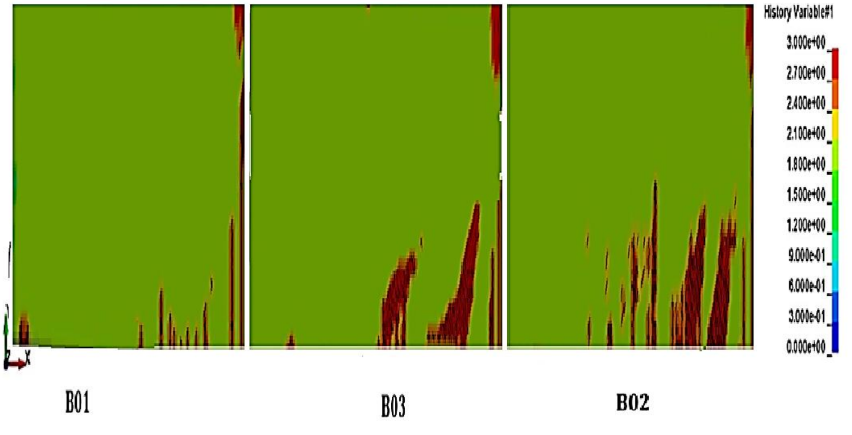

Figure 11. Crack diagram of the beams in the three specimens

As shown in figure 11 shows that the cracks in sample B01 start from the middle but are small, indicating its high hardness. In sample B03, the cracks also appear from the middle and are of medium size, reflecting medium hardness. Sample B02 is the most affected, with the cracks starting from the middle and being larger, indicating a clear decrease in its hardness compared to the other elements.

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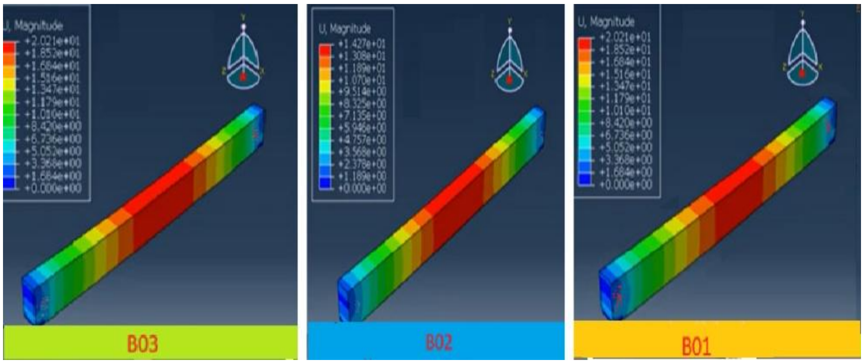

Figure 12. Total stress (B01, B02, B03)

As shown in figure12 shows the stress distribution in the three concrete beams using colors representing stress intensity, with warmer colors indicating areas of high stress. Specimen B01, reinforced entirely with 14 mm diameter steel, showed the highest stress concentration in the center of the beam and near the supports. Specimen B02 and B03, composed of fiberglass, showed the same stress distribution pattern but to a lesser extent, reflecting different structural behavior resulting from the nature and flexibility of the reinforcing material used.

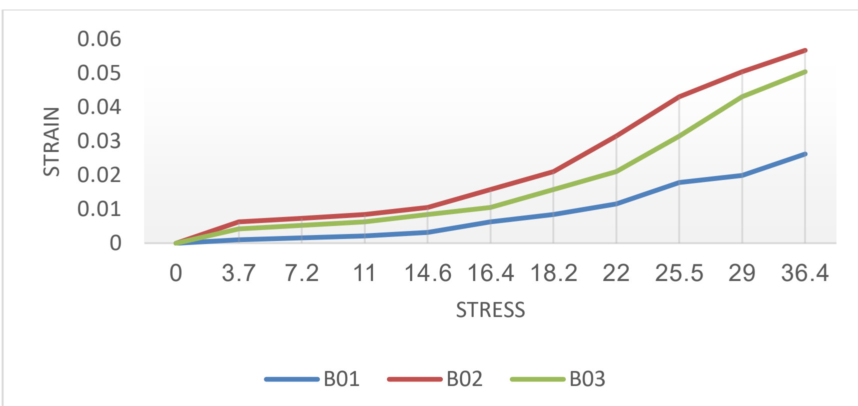

Figure 13. Stress vs. strain (simulation)

As shown in figure13, the stress-strain curve for the three samples, B01, B02, and B03, highlighting the differences in their mechanical behavior under load. Sample B01 exhibited the highest stiffness and lowest elasticity, indicating its high resistance to deformation. B02 represented an intermediate state in terms of stiffness and strain,

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while B03 was the most elastic and the least resistant, making it more susceptible to deformation. This reflects the effect of reinforcement type on concrete properties: the use of steel increases stiffness, while fiberglass provides greater elasticity with lower resistance.

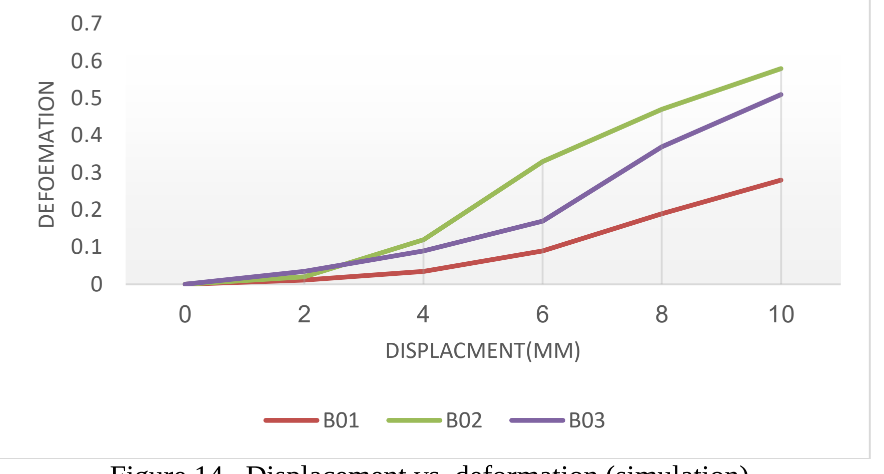

Figure 14. Displacement vs. deformation (simulation)

As shown in Figure 14 the load-displacement curve for the three concrete beams. Initially, the displacement is zero for all specimens, corresponding to the initial state without load. As the load increases, the displacement gradually increases. Beam B01 exhibited the lowest displacement rate, indicating its high stiffness, while beam B02 recorded the largest displacement rate, indicating its high ductility. Beam B03 achieved intermediate results between B01 and B02

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4.3. Comparison between numerical and experimental methods

Table 3: Comparison results between laboratory and simulation results

Property	sample	experimental (laboratory)	Simulation (Abaqus)	Difference (numerical - laboratory)	% difference	f	p-value
Displacement Δm (mm)	B01	4	4.2	0.2	5%	13.2	0.23
	B02	9.2	9.4	0.2	2.10%		
	B03	9	9.2	0.2	2.20%		
strain ε	B01	0.021	0.025	0.004	19%		
	B02	0.054	0.053	-0.001	1.80%		
	B03	0.048	0.045	-0.003	6.20%		
stress N/mm²	B01	490	500	10	2%		
	B02	180	200	20	11%		
	B03	280	300	20	7.10%		

Table 3 shows a close comparison between the results of laboratory tests and numerical simulations using Abaqus for three types of concrete beams (B01, B02, and B03). For displacement (Δm), sample B01 showed the largest relative difference of 5%, while B02 and B03 recorded slight differences of less than 2.2%, indicating good agreement between the experimental and simulated values.
For strain (ε), B01 recorded a 19% larger relative difference, indicating that the simulation predicted a slightly higher strain than the experimental values. The differences for B02 and B03 were very small, not exceeding 6.2%.
For stress (N/mm²), B01 showed the smallest relative difference (2%), followed by B03 (7.1%), while B02 recorded the highest difference (11%), which is acceptable within the limits of model accuracy. Overall, these results reflect high reliability in using Abaqus to simulate the mechanical performance of concrete beams, with minor differences demonstrating the effectiveness of the numerical models in representing experimental reality[27].

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Table 4: Correlation coefficients between numerical and experimental results

	Δm	ε	JI	JR
Δm	**1**			
ε	**0.7788**	**1**		
JI	**0.822**	**0.9974**	**1**	
JR	**0.8214**	**0.9975**	**1**	**1**

Table 4 shows that all correlation coefficients between the laboratory and numerical results exceeded 0.8, indicating a strong, direct relationship between the studied variables. The strongest correlation was recorded between the inertia coefficients (JI and JR) and strain, with values exceeding 0.95, reflecting a high accuracy in the numerical results compared to the laboratory results. The weakest correlation was between strain and displacement, but it remained within the strong range (above 0.8), confirming the validity and reliability of the numerical modeling in simulating the behavior of concrete beams. [28].

5. Conclusions

Through the study on the mechanical behavior of high-strength concrete using glass fiber reinforced polymer (GFRP), a set of key details were communicated:

1) GFRP reinforcement significantly improves the mechanical behavior of concrete beams, enhancing their resistance to bending, shear, and torsional stresses, while improving their ductility.
2) The B01 (steel reinforced) beam showed the highest stiffness and least deformation, and is suitable for load-intensive structural applications.
3) The B02 (hybrid reinforced) beam demonstrated moderate stiffness and high ductility, making it ideal for structures requiring energy absorption and deformation tolerance.
4) The B03 beam (fully GFRP reinforced) offers a compromise between flexibility and strength, demonstrating its potential in medium load applications while maintaining durability.

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5) Numerical simulations using Abacus software were closely correlated with the experimental results, with stiffness and displacement differences not exceeding 0.5%, confirming the validity of the numerical approach[29].
6) Strain and energy absorption were higher in GFRP-reinforced beams, reflecting the ability of this material to dissipate energy during dynamic loading scenarios such as earthquakes.
7) Statistical correlation analysis confirmed a strong agreement between the experimental and numerical data (correlation coefficients > 0.8), confirming the accuracy of the model. Beam B01 proved to be best suited for applications requiring high stiffness, recording the lowest strain value (0.022) and the highest energy efficiency under load (490 and 450), demonstrating its high resistance to deformation. In contrast, beam B02 exhibited a higher strain (0.055) and lower energy efficiency (200 and 250), indicating high ductility and reduced efficiency due to the quality of the reinforcement. Beam B03 recorded a medium strain (0.045), reflecting its greater susceptibility to deformation compared to B01, but maintained a higher efficiency than B02. Numerical methods are faster and less expensive, and allow for multiple scenarios to be flexibly analyzed[30].
8) The light weight, corrosion resistance, and adaptability of GFRP in construction applications underscore its role in sustainable engineering solutions, especially when combined with advanced modeling and optimization techniques.

6. Recommendations

The study arrived at a set of important findings that may assist in enhancing the mechanical strength of high-strength concrete through the application of polymer-reinforced glass fibers. The most important of such findings are:

1) Enlarging the scope of fiber-reinforced concrete research in terms of types of fibers, ratios of mix, form, and manner of distribution of them in concrete, as they are essential to increase strength and durability of beams without compromising their lightness, thus ensuring sustainability in the field of construction.
2) Study of fiber properties (shape, size, and diameter) on the performance of concrete because they have a direct role in increasing stiffness and flexibility.

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3) Study of the types of resins utilized in combination with fibers, e.g., carbon and glass resins, and their suitability with reinforced concrete.
4) Targeting utilization of optimum mixing ratios to ensure maximum performance at least cost using high-end computer technologies to exactly compute the ratios.
5) Deeper studies in numerical analysis techniques and algorithms to identify strengthening mechanisms (chemical and physical), and developing design software to aid engineers in meeting project specifications even during changing conditions or material constraints.
6) Applications of artificial intelligence and machine learning in the design of concrete beams, enabling the calculation of stress and prediction of damage in the future caused by loads or natural disasters.
7) Blending various hybrid approaches to be able to leverage each technology's strength for the purpose of reinforcing beam efficiency, overall structural performance.
8)

Conflict of interest

There is no conflict of interest

References

[1] Malek, A. S., Kobesy, O., Attia, M. M., & Ahmed, O. (2024). Effectiveness of hybrid textile bars in tensile and bond stresses as an alternative to concrete reinforcement. The Journal of The Textile Institute, 1-13.

[2] WAKJIRA, T. G. (2022). APPLICATION OF STEEL REINFORCED COMPOSITES FOR STRENGTHENING OF REINFORCED CONCRETE BEAMS AND COLUMNS: EXPERIMENTAL, ANALYTICAL, NUMERICAL, AND MACHINE LEARNING BASED STUDIES.

[3] X. Li, J. Wang, Y. Bao, and G. Chen, "Cyclic behavior of damaged reinforced concrete columns repaired with high-performance fiber-reinforced cementitious composite," Eng. Struct., vol. 136, pp. 26–35, 2017.

[4] S. Raza, M. K. I. Khan, S. J. Menegon, H.-H. Tsang, and J. L. Wilson, "Strengthening and repair of reinforced concrete

http://www.doi.org/10.62341/istj-vol38-2-an78

columns by jacketing: State-of-the-art review," Sustainability, vol. 11, no. 11, p. 3208, 2019.
[5] S. M. Alcocer and J. O. Jirsa, "Strength of reinforced concrete frame connections rehabilitated by jacketing," ACI Struct. J., vol. 90, no. 3, 1993.
[6] Karataş, M. A., & Gökkaya, H. (2018). A review on machinability of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composite materials. Defence Technology, 14(4), 318-326.
[7] Nuguzhinov, Z. S., Bakirov, Z. B., Vatin, N. I., Bakirov, M. Z., Kurokhtina, I. A., Tokanov, D. T., & Khabidolda, O. (2021). Stress intensity factor of reinforced concrete beams in bending. Buildings, 11(7), 287.
[8] Ghosh, S., & Ghosh, K. (2024). Reinforced Concrete Design. CRC Press.
[9] Fawzy, K., Moustafa, A., & Farouk, M. A. (2024). Innovative reinforcement techniques for optimizing the performance of shallow, wide beams in reinforced concrete structures. Innovative Infrastructure Solutions, 9(10), 395.
[10] Klimov, Y., & Kozak, A. (2025). Theoretical foundations for design of reinforced concrete under plane stress states. Strength of Materials and Theory of Structures, (114), 311-318.
[11] Fayed, S., Ghalla, M., El-Zohairy, A., Mlybari, E. A., Bazuhair, R. W., & Emara, M. (2025). Construction Efficiency in Shear Strengthening of Pre-Cracked Reinforced Concrete Beams Using Steel Mesh Reinforced Strain Hardening Cementitious Composites. Buildings 2025; 15: 945. doi. org/10.3390/buildings15060945.
[12] Klym, A., Blikharskyy, Y., Gunka, V., Poliak, O., Selejdak, J., & Blikharskyy, Z. (2025). An Overview of the Main Types of Damage and the Retrofitting of Reinforced Concrete Bridges. Sustainability (2071-1050), 17(6).
[13] Cairns, J., Du, Y., & Law, D. (2008). Structural performance of corrosion-damaged concrete beams. Magazine of Concrete Research, 60(5), 359-370.
[14] Thanaraj, D. P., Anand, N., Arulraj, P., & Al-Jabri, K. (2020). Investigation on structural and thermal performance of

http://www.doi.org/10.62341/istj-vol38-2-an78

reinforced concrete beams exposed to standard fire. Journal of Building Engineering, 32, 101764.
[15] Omran, G. M., Beygi, M. H., & Dehestani, M. (2020). Numerical analysis of externally prestressed concrete beams and parametric study of factors affecting their flexural performance. International Journal of Advances in Engineering Sciences and Applied Mathematics, 12, 142-157.
[16] Montaser, N. M., Mahdi, I., Mahdi, H. A., & Rashid, I. A. (2018). Factors affecting construction labor productivity for construction of pre-stressed concrete bridges. International Journal of Construction Engineering and Management, 7(6), 193-206.
[17] Hamdy, G. A., & Arafa, D. F. (2021). Experimental investigation of concrete beams reinforced with basalt FRP bars. Fayoum University Journal of Engineering, 4(2), 157-167.
[18] Tawfik, A. B., Rady, M., & Mahfouz, S. Y. (2025). Finite element modeling for the flexural response of notched concrete beams enhanced with steel and carbon fiber reinforced polymer bars under cyclic loading. Mechanics of Advanced Materials and Structures, 1-19.
[19] Adam, M. A., Said, M., Salah, A., & Elsheikh, A. (2023, September). Experimental and analytical study of high performance concrete beams reinforced with Basalt FRP bars. In Structures (Vol. 55, pp. 510-530). Elsevier.
[20] Mahmoud, A. M. (2012). Strengthening of concrete beams having shear zone openings using orthotropic CFRP modeling. Ain Shams Engineering Journal, 3(3), 177-190.
[21] Bernardo, L. F. A., & Lopes, S. M. R. (2013). Plastic analysis and twist capacity of high-strength concrete hollow beams under pure torsion. Engineering Structures, 49, 190-201.
[22] Chen, T., Qi, M., Gu, X. L., & Yu, Q. Q. (2015). Flexural strength of carbon fiber reinforced polymer repaired cracked rectangular hollow section steel beams. International Journal of Polymer Science, 2015(1), 204861.
[23] Ali, S. H., Abid, S. R., Al-Lami, K., Calabrese, A. S., Yosri, A. M., & Al-Ghasham, T. S. (2023). Experimental and Statistical Analysis of Repeated Impact Records of Hybrid Fiber-

http://www.doi.org/10.62341/istj-vol38-2-an78

Reinforced High-Performance Concrete. Buildings, 13(3), 678.

[24] Nie, X. F., Zhang, S. S., Chen, G. M., & Yu, T. (2020). Strengthening of RC beams with rectangular web openings using externally bonded FRP: Numerical simulation. Composite Structures, 248, 112552.

[25] Liu, X. (2025). Analysis of Flexural Load-Bearing Capacity of Damaged Concrete Beams Reinforced with CFRP. Engineering Research Express.

[26] Trung, H. T., Vuong, P. N., & Van, T. T. T. (2025). Comparative Static Analysis in Reinforced Concrete Superstructure Beams: Working Stress vs. Limit State Approaches. Engineering, Technology & Applied Science Research, 15(3), 23938-23943.

[27] Wang, W., Zhang, C., Zhang, Z., Li, L., & Wei, J. (2024, May). Experimental and numerical simulation study on flexural performance of high-strength reinforced concrete beams under static loading. In Structures (Vol. 63, p. 106482). Elsevier.

[28] Hamoda, A., Ghalla, M., Yehia, S. A., Ahmed, M., Abadel, A. A., Baktheer, A., & Shahin, R. I. (2024). Experimental and numerical investigations of the shear performance of reinforced concrete deep beams strengthened with hybrid SHCC-mesh. Case Studies in Construction Materials, 21, e03495.

[29] El-Salakawy, T. S., Gamal, A. A., & Sayed, M. E. (2024). Experimental and numerical evaluation for hybrid reinforced T-beam with different ratios of recycled rubberized concrete. International Journal of Concrete Structures and Materials, 18(1), 30.

[30] Khan, W., Akhtar, S., Rawat, A., & Basu, A. (2024). Experimental and Numerical Study on Flexural Behavior of Concrete Beams Using Notches and Repair Materials. Sustainability, 16(7), 2723.