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# Testing of Concrete Beams Reinforced with Wood and Steel Bars Under Flexural Loads

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**Abstract:** Incorporating wood into concrete construction offers significant structural and environmental benefits. Its tensile strength, combined with its workability, aesthetic appeal, and sustainability, makes it a versatile material that complements the compressive properties of concrete. Composite wood-concrete beams are generally lightweight, which reduces construction costs, improves on-site handling, and simplifies installation. This research explores the structural behavior of reinforced concrete beams that incorporate wood as tensile reinforcement alongside conventional steel. The primary objective is to analyze and compare the flexural performance of composite (concrete + steel + wood) beams with that of standard steel-reinforced beams under similar loading conditions. The research investigates the feasibility of using wood as a sustainable, lightweight alternative in low- to medium-load reinforced concrete applications. Previous studies using Musky wood with 10 mm diameter steel bars showed significant performance improvements, increasing load capacity by 117% to 133.5%, and energy absorption by 115% to 269%. In addition, wood-cement composites can enhance flexural strength, improve bonding, and contribute to energy efficiency through reduced thermal conductivity. These benefits highlight the structural and environmental value of incorporating wood into modern concrete construction.

**Keywords:** Wood, Musky Wood, flexural load, RC Beams.

## 1. Introduction

Wood is a widely available natural material known for its versatile properties. It offers excellent thermal insulation, sound absorption, and mechanical strength, making it highly suitable for construction applications. Due to its light weight, wood has long been a preferred material in structural engineering. The study explores how the cross-sectional dimensions of wood influence its load-bearing and moment-resisting capacity, assessing key performance indicators such as ultimate load capacity, deflection behavior, wood's contribution to tensile strength, and energy dissipation under applied loads. The research also aims to validate analytical models that predict the behavior of composite wood-concrete beams and compare them with experimental results. It is worth noting that although wood can absorb some energy and deform slightly under compression, it tends to fracture rather than deform plastically when subjected to excessive force, unlike steel, which has a greater fracture resistance. The strength of wood and steel varies greatly depending on the species, context, and specific properties being compared. Wood has high tensile and cross-grain strength, but its overall strength is lower than that of steel. Wood is also lighter than steel and concrete, making it useful in construction. It also has flexibility, making it resistant to cracking. On the other hand, steel is much stronger than wood in both tensile and compressive strength and can withstand significant loads. It is often used in construction applications. It is heavier than wood but is designed to carry much larger loads over longer distances. Therefore, when combined with steel, we obtain the greater strength and lower weight of composite concrete beams. Simply put, wood supports its own weight more efficiently, reducing the need for additional bracing in some architectural designs. In concrete construction, wood is used to create composite structures. It is readily available, economical, and easy to use. Being a renewable material, wood provides a more sustainable alternative to traditional materials such as steel and concrete. In addition, wooden structures are easy to assemble and disassemble, enhancing flexibility and building efficiency. Wood is also used in permanent composite construction, remaining part of the structural system alongside concrete. The importance of effective shear joints between wood and concrete is emphasized as a key factor in enabling both materials to function as a cohesive composite system. Choosing the right connectors is critical, as it significantly impacts structural performance and overall cost efficiency. Wood-concrete composites, as well as systems incorporating fiber-reinforced polymers (FRP) and concrete, demonstrate the successful integration of diverse materials to improve structural behavior, these integrated structures are increasingly recommended for wider use due to their excellent load-bearing capacity, durability, and superior mechanical performance [1, 2]. In conventional reinforced concrete systems, steel is the main contributor to ductility. However, bamboo fibers are emerging as a sustainable and cost-effective alternative, being approximately three times less expensive than steel reinforcement, Bamboo is also preferred for its strength, light weight, and ease of use [3]. Corrosion of steel reinforcement remains a major cause of deterioration in concrete structures. As an alternative, FRP bars offer promising potential, Due to the superior mechanical and physical properties of FRP, the design of concrete structures with these materials requires different approaches compared to conventional reinforcement. Therefore, it is essential to understand both the advantages and disadvantages of FRP-reinforced systems [4]. From an economic and environmental standpoint, wood is a viable material for producing lightweight, load-bearing, self-compressible, and low-cost building components. Its physical properties also contribute to its partial recyclability. Therefore, the use of wood-concrete composites (WCC) is being encouraged instead of traditional steel reinforcement, especially since WCC systems can be designed to provide improved thermal mass, in line with evolving trends in energy-efficient concrete construction [5]. A similar view is held regarding the suitability of wood for sustainable, lightweight construction, its recyclable nature and structural capabilities make it a suitable alternative to steel, Furthermore, the increasing focus on thermal inertia in concrete structures supports the use of WCC for the manufacture of high-performance panels, In an experimental study, nine beams were subjected to two-point loading. Each specimen was 1800 mm long and had a rectangular cross-section of 200 mm × 250 mm. They found that the maximum applied load was increased by 400% compared to unreinforced concrete beams [6]. Future projections indicate a significant increase in the use of wood in construction, primarily due to its aesthetic appeal, workability, structural strength, and excellent insulating capabilities [7]. In North America and Canada, wood is widely used in residential buildings, especially those less than six storeys, its favorable load-bearing characteristics make it a practical option for structural reinforcement in concrete or as a full replacement for conventional steel [8]. Research indicates that structural performance can be significantly enhanced by combining polymer concrete and fiber-reinforced plastics in high-stress zones, with wood serving as the intermediary material, The study found up to a 185% increase in load capacity under short-term loads [9]. Bamboo is also gaining attention as an effective reinforcement material in concrete due to its sustainability, affordability, and high strength-to-weight ratio. Current trends in construction are increasingly focused on integrating Bamboo components to reduce costs while improving performance. Flexural behavior of Bamboo-reinforced beams has been investigated through various experimental studies [10]. Bamboo exists in over 1,100 to 1,500 known species, and its adaptability makes it useful across numerous applications. In one study involving double-reinforced beams, cracking initiated in the flexural zone and propagated gradually in a triangular pattern. Upon failure, both top and bottom bamboo reinforcements fractured, primarily due to natural knots. The beams failed under an applied load of 15 kN. Additionally, a lack of bond between the bamboo and concrete was observed [11]. To improve the bond between bamboo and concrete, treatment with epoxy resin or tar is recommended. Bamboo exhibits strong tensile capacity, making it suitable for use in reinforced concrete structures, especially in low-cost housing. Its compressive strength typically falls within the range of 47.9 to 69.9 MPa, as global steel production is projected to decline over the next six decades, the demand for sustainable alternatives like bamboo is expected to grow. Due to bamboo's naturally low bond stress, surface treatments are essential to ensure adequate adhesion in structural applications [12, 13]. A total of 26 beam specimens (75 × 150 × 1100 mm) were tested, including 24 bamboo-reinforced concrete (BRC) beams, one steel-reinforced concrete (SRC) beam, and one plain concrete (PC) beam, Bamboo reinforcement was placed in the tension zone, with different reinforcement areas. In some specimens, 8 mm steel bars were used for comparison purposes, The tensile strength of bamboo can reach 370 MPa, making it a cost-effective alternative to conventional steel bars. In addition, bamboo is abundant, rapidly renewable, and environmentally friendly. For structural applications, untreated flexible bamboo is recommended to be reinforced with a safety factor of 1.2[14]. Further refinements of glass fiber reinforced concrete (GFC) systems are still needed as new flooring solutions, Fiberglass reinforced solutions have been explored, including techniques such as bending fiberglass reinforced beams to compensate for the extra weight of concrete and earthquake stresses. This helps ensure that long-span GFC panels meet deflection requirements for an extended period [15]. In wood systems, in most cases, the concrete structure is placed in the compression zone, while the wood is deep in the tension zone. As a result, these structural elements are guaranteed increased stiffness and greater load-bearing capacity, compared with all-concrete GFC panels, the advantages of wood panels include lower loads, the use of two parts, which reduces material and configuration transfer due to their higher load-bearing capacity, and the effectiveness of wood compared to concrete elements [16].

## 2. EXPERIMENTAL STUDY

The research is based on evaluating the structural performance of concrete beams reinforced with a combined material system under flexural loading. The study assesses the effectiveness of incorporating wood as part of the primary reinforcement, comparing its performance to that of beams reinforced solely with steel. Concrete mixtures were prepared using standard components along with Sika Mint® 2004 to enhance workability. The primary steel reinforcement consisted of Ø10 bars. All beams were cast using the same concrete mix and baseline reinforcement, with the addition of laminated wood elements coated in epoxy to improve the bond between the wood and concrete. The test specimens included six concrete beams reinforced with Ø10 steel bars and supplemented with wood sections of varying sizes. Each beam measured 150 x 300 x 1000 mm. Details of reinforcement placement (top and bottom) and wood dimensions are provided in **Table 1**. All specimens were tested to failure under flexural loading. The test setup is illustrated in **Fig.1**, while **Fig.2** presents the beam dimensions and reinforcement layouts.

The bond between wood and concrete is crucial for the performance of composite systems like wood-concrete beams. Since wood and concrete don’t naturally bond well due to wood’s smooth surface and different chemical properties additional treatment is needed [20]. To enhance adhesion, wood surfaces can be grooved or coated with adhesives like epoxy. In this study, the wood was coated with epoxy, sanded, and cured for 24 hours before embedding in concrete **Fig.3-B**. This treatment helps the materials share loads and transfer shear forces effectively, allowing the beam to act as a single unit with improved strength and stiffness. The wood samples, illustrated in **Fig.3-A**. The tested specimens were prepared and cast using the target concrete as shown in **Fig.3-C** and **Fig.3-D** where both types of reinforcement wood and steel were installed using the proposed epoxy and the beams were cast and cured. The strength in compression (Fcu) was assessed using the conventional cubic compression test, yielding an average strength of 40 MPa, consistent with ASTM E519-02 [17]. Before testing the beams, concrete cubes were tested, as shown in **Fig.4-A**. The wood specimens were subjected to compression, indirect tension, and flexural tests, as illustrated in **Fig.4-B, Fig.4-C**, and **Fig.4-D**, respectively, with the results provided in **Table 2**. A 5000 kN capacity hydraulic jack was used to apply the load until failure occurred. Strains and displacements were measured at the center of the beams using two linear variable differential transducers (LVDTs), which have a resolution of 0.01 mm. All LVDTs were connected to a computer-controlled data acquisition system.

During the tests, the crack patterns of the beams were continuously observed and recorded, along with the corresponding displacement readings. Mix proportions for used concrete listed in Table 3.

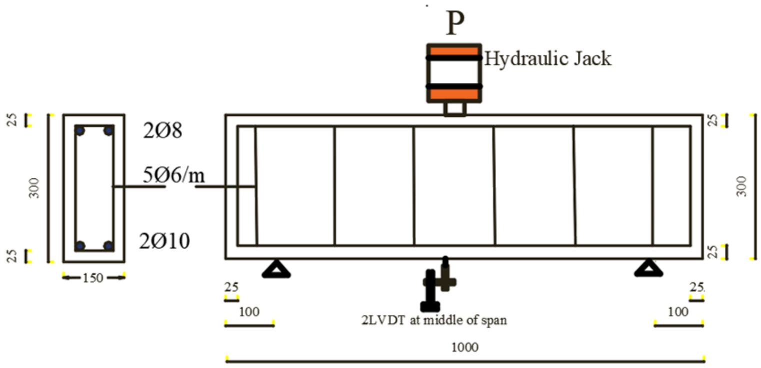


**FIGURE 1.** Test set up for all tested Beams

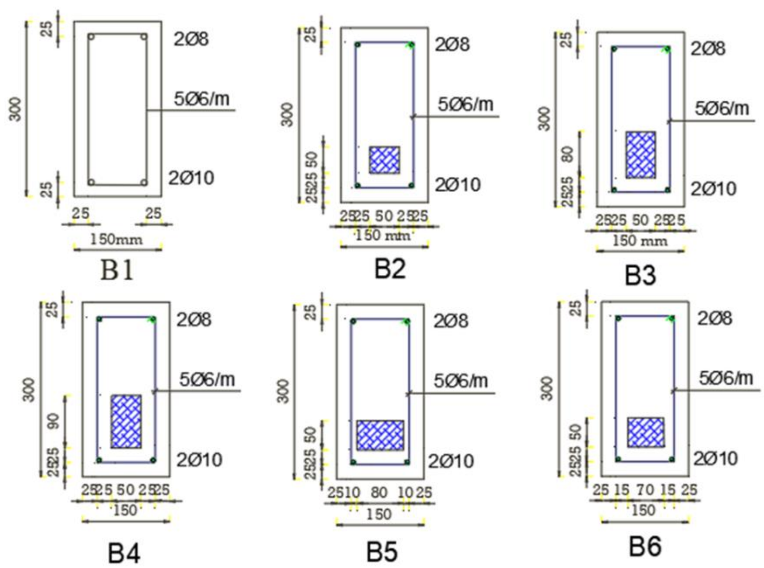


**FIGURE 2.** All Tested Beams Dimension and Reinforcement

**TABLE 1.** The Beams Reinforcement (top, bott) and Wood Dimension

| Beams | Wood Dimension | | | Top Reinforcement | As̀ (mm$^2$) | Bottom Reinforcement | As (mm$^2$) | Awood/ As |
|---|---|---|---|---|---|---|---|---|
| | B (mm) | L (mm) | Area (mm$^2$) | | | | | |
| B1 | - | - | - | 2Ø8 | 100.53 | 2Ø10 | 157.07 | - |
| B2 | 50 | 50 | 2500 | 2Ø8 | 100.53 | 2Ø10 | 157.07 | 15.91 |
| B3 | 50 | 80 | 4000 | 2Ø8 | 100.53 | 2Ø10 | 157.07 | 25.47 |
| B4 | 50 | 90 | 4500 | 2Ø8 | 100.53 | 2Ø10 | 157.07 | 22.28 |
| B5 | 80 | 50 | 4000 | 2Ø8 | 100.53 | 2Ø10 | 157.07 | 28.64 |
| B6 | 70 | 50 | 3500 | 2Ø8 | 100.53 | 2Ø10 | 157.07 | 25.46 |

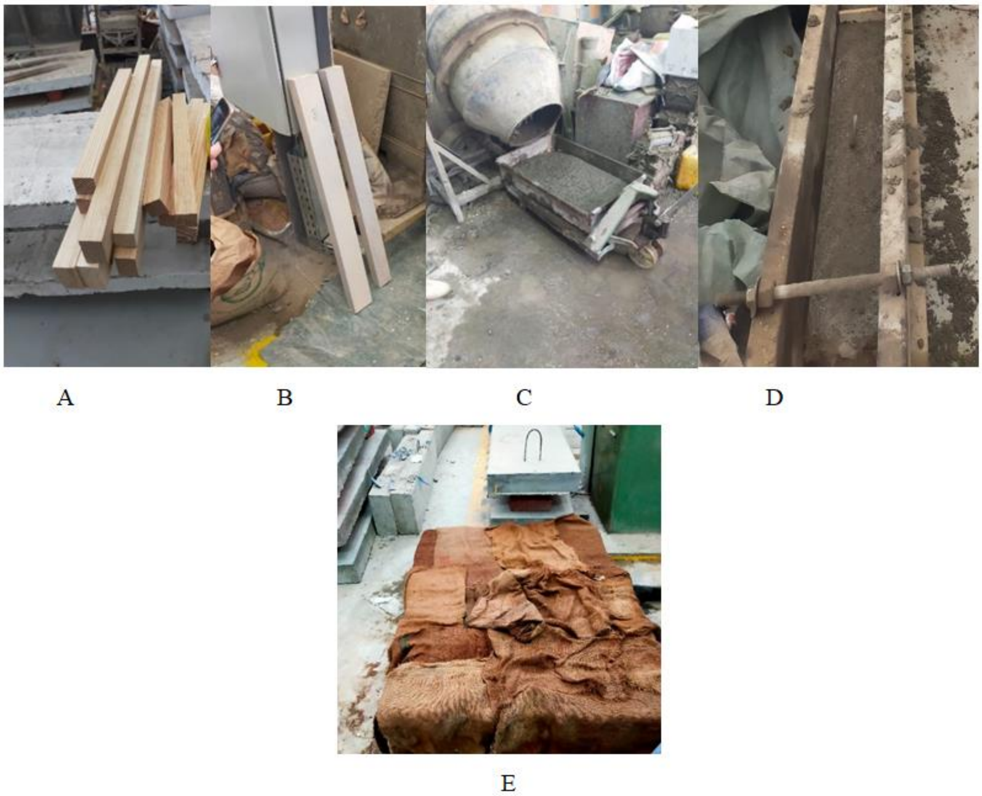


**FIGURE 3.** Sample Preparation

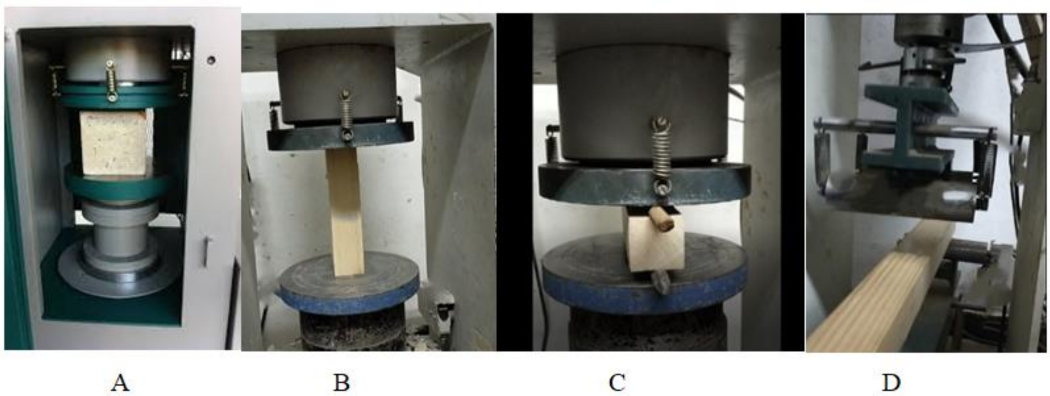


**FIGURE 4.** Wood and Concrete Tests

**TABLE 2.** Mechanical Results of Wood in Compression, Tension and Flexure

| | |
|---|---|
| Average compression strength MPa | 39.2 |
| Average Splitting test MPa | 7.2957 |
| Average flexure test MPa | 3.368 |

**TABLE 3.** Mix proportions for concrete

| Cement content ($Kg/m^3$) | Water content ($Kg/m^3$) | Sand ($Kg/m^3$) | Gravel size 0.5 ($Kg/m^3$) | Sikament R2004 Addition |
|---|---|---|---|---|
| 400 | 200 | 676 | 1014 | 10.0 |

## 3. MODE OF FAILURE:

### 3.1.1 3.1.1 CONTROL BEAM:

The observed mode of failure in the B1 control beam, which had 2Ø10 mm bottom reinforcement, exhibited a pure flexural failure mode. Cracks initiated at the bottom fibers and extended upward to the top fibers, as illustrated in **Fig. 5**. These cracks spread across a broad maximum moment region approximately 480 mm in length and converged toward a single point at the center of the top fibers. The results are provided in **Table 4**, **Fig 6, and Fig 7,** where the failure load, first crack and deflection are shown for all tested beams.

**TABLE 4.** Ultimate Displacement, First Crack and Ultimate Load for all Tested Beams

| Beams | Ultimate displacement (mm) | First crack (kN) | Ultimate load | |
|---|---|---|---|---|
| | | | P max (kN) | increase%= $\frac{p\,\max - p\ control}{p\ control}$ |
| B1 | 6 | 84.33 | 176 | ---- |
| B2 | 6 | 81 | 235 | 33.5 |
| B3 | 4.8 | 93 | 206 | 17 |
| B4 | 6 | 97 | 209 | 18.7 |
| B5 | 5.46 | 65 | 216 | 22.7 |
| B6 | 4.8 | 59 | 207 | 17.6 |

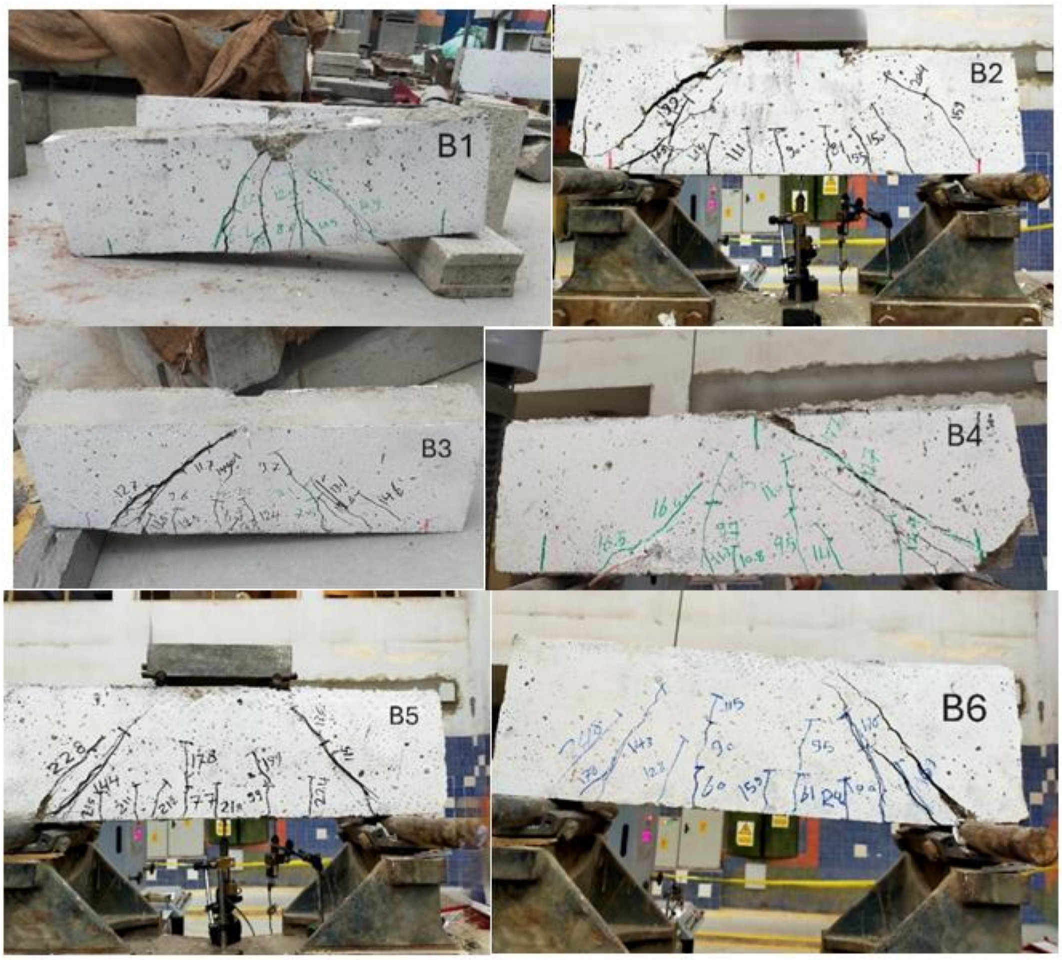


**FIGURE 5.** Failure Mode for All Tested Beams

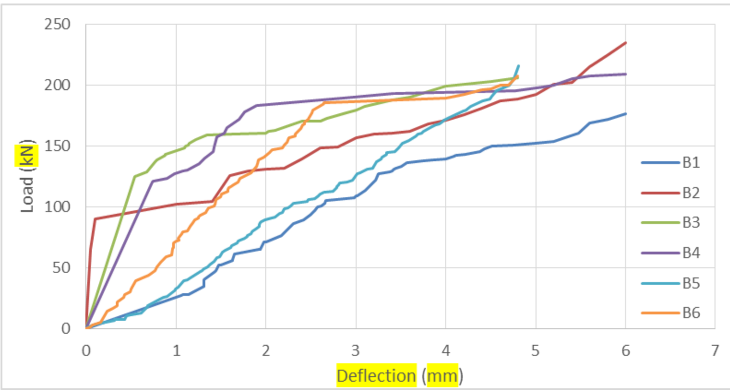


**FIGURE 6.** The Load-Deflection Curves for All Tested Beams

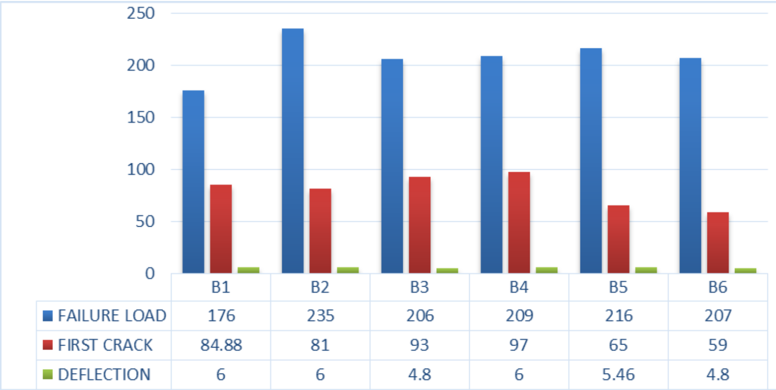


**FIGURE 7.** The Failure Load, First Crack and Deflection for All Tested Beams

### 3.1.2 OVERVIEW OF TESTED COMPOSITE BEAMS:

The failure pattern identified in composite beam B2 reinforced with 2Ø10 mm bars at the bottom and containing a 50×50 mm wood segment exhibited a combination of bending and shear failure. Cracks began near the bottom of the wood fibers and extended upward toward the top. Similarly, composite beam B3, which included 2Ø10 mm bottom reinforcement and a 50×80 mm wood section, also demonstrated a mixed failure mode involving both flexure and shear. In this case, cracks initiated from the lower fibers and converged at a single point near the top fibers. Beam B4, with 2Ø10 mm bottom reinforcement and a 70×50 mm wood section, showed a failure pattern consistent with that of B3, combining bending and shear effects. Cracks originated at the base of the wood fibers and propagated toward a concentrated area at the top. For composite beam B5, which included 2Ø10 mm reinforcement and a 50×90 mm wood section, a similar flexure-shear failure was observed. Cracking began at the bottom fibers and extended to the top. Lastly, beam B6 with 2Ø10 mm reinforcement and an 80×50 mm wood section also displayed a combined failure mode of flexure and shear, with cracks starting at the bottom and moving upward through the wood fibers. All beams demonstrated higher failure loads than the steel-only reinforced beam (B1). However, when comparing beams B3, B4, B5, and B6 to beam B2, it was observed that the increased inertia of the wood section negatively impacted the failure load. In other words, as the inertia grew, the failure load decreased in comparison to B2. This indicates that optimal performance is achieved when the wood section has equal dimensions in width (B) and height (H). Beam B2, with a wood section of 50×50 mm, achieved an ultimate failure load of 235 kN—33.5% higher than that of the steel-only beam B1. When the wood cross-section was increased to 50×80 mm in beam B3, the failure load decreased to 206 kN, exceeding B1 by 17%. Beam B4, with a 70×50 mm wood section, reached 209 kN, a 18.7% increase over B1. Beam B5, using a 50×90 mm section, achieved the highest ultimate failure load in the group at 216 kN, surpassing B1 by 22.7%. Finally, beam B6, with a wood section of 80×50 mm, recorded a failure load of 207 kN, which is 17.6% higher than B1.

## 4. ENERGY DISSIPATION:

Estimating energy dissipation in reinforced concrete beams involves understanding the underlying processes, particularly crack initiation and propagation in a concrete structure. Energy loss due to crack formation can be studied using fracture mechanics concepts. The dissipated energy varies depending on the type of loading applied static, dynamic, or cyclic. Ensuring compliance with standards such as ACI and Eurocode [18] is essential for an accurate assessment. To calculate energy dissipation, a load-deflection curve is plotted based on experimental data. The area under this curve represents the energy dissipated by the material during loading. A larger area indicates greater energy absorption and release, reflecting improved ductility and performance under dynamic or seismic loading conditions. In this study, analysis of the load-displacement responses revealed that the energy dissipation capacity of the beams was significantly influenced by the dimensions of the wood sections, as shown in Table 1. Increasing the wood surface area, compared to the reference beam B1, consistently resulted in greater energy dissipation across the specimens, as detailed in **Table 5**. This improvement is attributed to the increased traction resistance associated with the larger wood contact area. The most significant gains in energy dissipation were recorded in beams B2, B4, and B6, with increases of 269%, 198%, and 184%, respectively, and were particularly pronounced in beam B2. In contrast, beam B5 showed a smaller improvement, of only 85%, likely due to the smaller reinforcing steel surface area.

## 5. DUCTILITY INDEX:

To calculate the flexural ductility of the tested beams, the displacement ductility factor and the flexural ductility coefficient are used. Ductility is the ability of a reinforced concrete member to withstand large inelastic deformations without excessive strength degradation. The displacement ductility factor is defined as the ratio of the displacement (Dmax) at failure load to the yield displacement (Dy). The failure load was considered to be 80% of the maximum (peak) load using an ideal linear curve. According to this technique, the envelope curve and the hyperbolic curve should intersect at a location greater than or equal to 0.4 percentage points and should overlap until the displacement limit is equal. When the bearing capacity is 0.8 peak, the hyperbolic curve displacement is considered to be the displacement along the specimen's envelope curve. The linear curve for each specimen was equal to the average value determined by the push-pull envelope curve, as shown in Figure 8. Figure 9 shows the average ideal linear curve for all specimens. The ideal bilinear curve, where the yield point is determined by the intersection of the elastic and inelastic parts, provides a reliable method for determining the yield displacement. In this research, the bilinear response of specimens was determined using the ASTM E126 procedure [19], following a similar methodology. The parameters used to calculate the ductility index of the tested specimens are detailed in **Table 6.** The experimental results revealed a significant improvement in ductility across all tested beams compared to the reference beam B1. The test results showed that the ductility of the specimens increased significantly compared to the control specimens, except for specimens B3 and B4. Specimen B4 showed the maximum ductility.

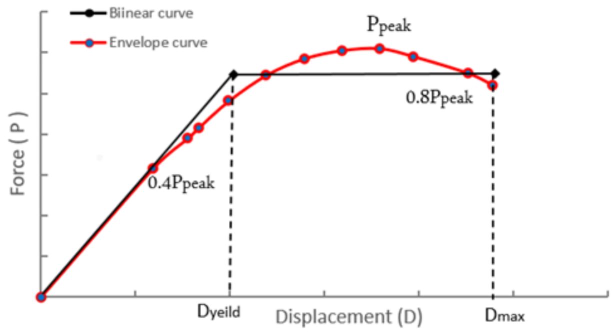

**FIGURE 8.** Bilinear Versus Envelope Load– Displacement Curve

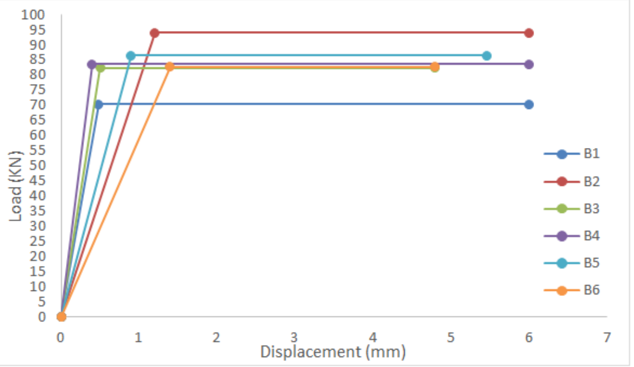

**FIGURE 9.** Average Idealized Bilinear Curves for The Specimens

**TABLE 5.** Total Energy Dissipation for all Tested Beams

| Beams | Total energy dissipation (kN.mm) | Increase % energy dissipation to Control Specimen |
|---|---|---|
| B1 | 605 | - |
| B2 | 1630 | 269.42 |
| B3 | 852 | 140 |
| B4 | 1203.5 | 198 |
| B5 | 517.5 | 85.53 |
| B6 | 701.25 | 115.9 |

**TABLE 6.** Experimental Result for all Tested Beams

| Beam | Max Load (kN) | Relative Displacement (mm) | Cracking Load (kN) | Max. Displacement (mm) | Mode of Failure |
|---|---|---|---|---|---|
| B1 | 176 | 6 | 84.33 | 6 | Bending |
| B2 | 235 | 6 | 81 | 6 | Combined |
| B3 | 206 | 4.8 | 93 | 4.8 | Combined |
| B4 | 209 | 6 | 97 | 6 | Combined |
| B5 | 216 | 5.46 | 65 | 5.46 | Combined |
| B6 | 207 | 4.8 | 59 | 4.8 | Combined |

## 6. ANALYTICAL STUDY FOR ALL SIX BEAMS:

Beams dimensions, As and wood dimensions were located at **Table 2** and shown in **Fig 1** and **Fig 2** Concrete cover= 25 mm at top and bottom, fcu= 40 MPa, fy=500 MPa (common for high-yield steel), Effective depth for steel reinforcement d = h-cover-stirrup dia - $\frac{bar\ dia}{2}$ = 300 – 25 – 6 – 5 = 264 mm (for concrete) and $d_{wood}$ = h – cover - stirrup dia - $\frac{bar\ dia}{2}$ - $\frac{hw}{2}$ (for wood section).

Find depth of compression block (a): Assume tension force = compression force

- Cc = Ts + Tw ⇒ 0.85 * $f_{cu}$ * a * b = As * fy (for beam B1)
- Cc = Ts + Tw ⇒ 0.85 * $f_{cu}$ * a * b = As * fy + Aw * fw (for the combined beams)

Moment capacity:

- Mu = Ts * $(d-\frac{a}{2})$ (for beam B1)
- Mu = Ts * $(d-\frac{a}{2})$ + Tw * $(dw-\frac{a}{2})$ (for the combined beams)

For a simply supported beam with a point load **P** at the center, the maximum bending moment is: $M_{max}=\frac{P*L}{4}$ Rearranged to solve for P = $\frac{4*Mmax}{L}$

Results of the analytical study ($d_{wood}$, Mu and $P_{th}$) and comparison with the experimental results for all tested beams listed in **Table 7.**

**TABLE 7.** Analytical Result and Compered $P_{th}$ with $P_{exp}$ for All Tested Beams

| Beam | $d_{wood}$ (mm) | Mu (N/mm) | $P_{th}$ (kN) | $P_{exp}$ (kN) | $\frac{Pexp - Pth}{Pexp} * 100$ |
|---|---|---|---|---|---|
| B1 | --- | 20.13 | 100 | 176 | 43.18 |
| B2 | 225 | 22.68 | 128.4 | 235 | 45.31 |
| B3 | 210 | 28.32 | 141.6 | 206 | 31.26 |
| B4 | 225 | 27.89 | 139.45 | 209 | 33.2 |
| B5 | 205 | 29 | 145 | 216 | 32.87 |
| B6 | 225 | 28.98 | 144.9 | 207 | 30 |

## 7. CONCLUSIONS AND SUMMARY:

The study analyzed the structural behavior of reinforced concrete beams using combined reinforcement methods involving steel and wood sections of various sizes. The objective was to compare steel-only reinforced beams (Beam B1) with composite beams (Beams B2 to B6) that include wooden reinforcement on the tension side.

- Experimental Findings:

1- Beams B2, B3, and B5 showed significant increases in load-bearing capacity compared to Beam B1 These results highlight the positive influence of wood stiffness and cross-sectional area on structural performance and ductility.

2- Failure modes varied Some beams failed due to flexural stresses Others failed due to shear, indicating the need for additional shear reinforcement (stirrups) to prevent early failure.

3- A clear trend was observed larger wood sections led to higher energy dissipation, enhancing the beam's ability to absorb and resist dynamic or repeated loading.

- Analytical Study Results:

1- Beam B1 (reinforced concrete only) had the lowest moment capacity and ultimate load, as it relied solely on steel in tension.

2- Beams B2 to B6 included wooden sections on the tension side, which:
   - Improved flexural performance
   - Increased moment capacity and maximum point load
   - A direct correlation was found between the size of the wood section and the beam's load-carrying capacity.
   - The best performance was observed in beams with larger wood sections, such as 80×50 mm and 50×90 mm

3- These configurations confirmed the structural benefits of using bonded wood as part of the tensile reinforcement system.

Overall, the combination of wood and steel in the tension zone leads to Increased strength, Improved ductility and better energy dissipation. Composite reinforced concrete-wood beams are shown to be a practical, sustainable, and efficient alternative to conventional reinforced concrete in appropriate structural applications.

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