Heliyon 10 (2024) e24628

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

A review on experimental observation on structural performance of bamboo reinforced concrete beam

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ARTICLE INFO

Keywords:
Experimental observation
Structural performance
Bamboo
Reinforced concrete beam

ABSTRACT

Bamboo has many usages. Incorporating bamboo enhances the reinforced concrete beam's (RCB) performance, properties and behaviour as internal reinforcement. A summary of how bamboo influences the RCB properties shall be studied. This review paper discusses the use of bamboo to reinforce RCB and briefly describes the topic. Previous experimental observation results showed that RCB constructed with bamboo significantly improved the flexural, stress-strain, load-deflection, failure mode, crack pattern, tensile, compression, and shear modulus of RCB. Since this bamboo has superior strength, force, mounting and anchoring properties, it can be used as an alternate interior reinforcement, replacing normal steel reinforcing bars in RCB. The structural behaviour and performance of RCB can be enhanced by utilising bamboo in civil and structural engineering, especially in building construction projects.

1. Introduction

Bamboo is abundant, rapidly renewable, ecologically, and has high tensile strength. In the twentieth century, researchers and scientists investigated bamboo to be used as reinforcement in concrete rather than normal steel bars [1]. 4 % of bamboo treated with Sikadur-42 could replace 2 % of conventional steel bars in reinforced concrete beams (RCB) [2]. Both axial compression and bending tests were performed on bamboo reinforced concrete beams (BRCB) and columns [3]. According to the research findings, BRCB had a cracking pattern comparable to regular RCB and columns, which mostly rely on concrete strength to ensure their ductility. According to studies conducted by Leelatanon et al. (2010) [4], using a binder treatment significantly improved the bonding performance between bamboo bars and concrete, increasing bearing capacity and ductility in BRCB and columns. Under a monotonic load of varying eccentricities, Terai and Minami (2021) [5] investigated the mechanical characteristics and influencing variables of bamboo RCB subjected to various treatment procedures and reinforcement ratios.

A technique for creating a bamboo bar composite was proposed by Agarwal et al. (2014) [6]. The composite mitigates the faulty of the original bamboo bar. The bamboo with concrete bonding strength is significantly improved by treatment with epoxy paint and sanding. The studies mentioned earlier demonstrate that bamboo bars may be a suitable alternative to steel bars within a concrete framework and circumstances. Natural bamboo, however, has flaws such as lack of resilience, high water absorption rate, and high tendency to shrink. Moreover, genuine bamboo efficiency varies greatly among areas, species, and anatomical components. The bamboo scrimber was successfully produced using a hot pressing method in an experimental lab [7]. The mechanical features of bamboo scrimber are consistent, strong, long-lasting time, and uneasily to shrink, expand, and crack. The mechanical qualities of both

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https://doi.org/10.1016/j.heliyon.2024.e24628
Received 15 August 2023; Received in revised form 25 November 2023; Accepted 11 January 2024
Available online 19 January 2024

bamboo varieties are similar to lumber. Nevertheless, Javadian et al. (2016) [8] concluded that bamboo performs better than lumbers. The stress-strain, tensile, compression, and shear modulus relationships of bamboo RCB were higher than normal RCB without bamboo reinforcement [9–11]. Furthermore, bamboo bars are also used to reinforce masonry homes in rural and urban areas [12–30].

Most studies on bamboo reinforced concrete beams (BRCB) have solely focused on their flexural and shear responses. The necessity of research on the effect of bamboo-strengthened beams is deeply pressing in the context of reinforcing existing RCB. Bamboo is used to reinforce RCB as internal reinforcement replacing normal steel reinforcing bars. It is evaluated and discussed in this review paper. The data for the increased strengths of newly constructed RC buildings reinforced with bamboo is also stated and discussed in this review article to realise the bamboo material potential. Also, the strengthening of RCB with bamboo by experimental observation will be elaborated in this review paper to investigate the deep study of bamboo technology usage significance in RCB.

2. Bamboo

More than a thousand different kinds of bamboo exist. When bamboo is cut, it will overgrow, and most bamboo species reach maturity in about four to six years. This remarkable bamboo plant is pest and herbicide-resistant and thrives in tropical and temperate climates. Rum village, covering 15 km^2 (27 % of North Tidore district in the United Kingdom), has excellent potential for growing bamboo in the surrounding forest. Evidence suggests that Bambusa Vulgaris bamboo is the largest available bamboo species. This kind of bamboo also fulfils the requirements for a bamboo species in a range of 6–11 m in height, has perforations, and appears in pale yellowish-green colour.

Bamboo bars' processing and treatment phases differ from bamboo strips [31–40]. Bamboo strips for laminated bamboo lumber go through additional bleaching and carbonisation processes with subsequent glueing and pressure [41–50]. In contrast, bamboo bars are prepared at the drying and treatment stages. Dendrocalamus, Bambusa, and Phyllostachys bamboos in Fig. 1 were frequently used as reinforcement materials. The bamboo diameter is directly correlated to its strength [51–55]. It is common knowledge that different bamboo types have different strengths with each other. Sharma et al. (2018) [56] examined the mechanical properties of Phyllostachys Pubescens (Moso) and Dendrocalamus Latiflorus (Ma) bamboos, founding that the modulus of rupture of Moso bamboo was 49 % greater than Ma bamboo, as shown by bending test results. Moreover, the difference in bamboo densities shows that Moso bamboo is 22 % denser than Ma bamboo. Bamboos that are four to five years old with brownish colour are selected to create bamboo bars similar to how laminated bamboo timbers are made. From April to July every year, it is a bamboo breed season. Freshly green bamboo should be avoided to be used because of its high water absorption property and limited strength capacity, causing it to be easily collapsed and fail [57].

The UNESCO association estimates that 800 acres of bamboo can yield enough building materials for a thousand homes [58]. Using lumber may necessitate cutting down trees in a forest, which causes harmful environmental effects, such as air pollution, global warming, ultraviolet radiation and the like. So, bamboo is utilised in many China construction projects, especially in bridge construction projects, replacing regular steel reinforcing bars [58] and is also being used to strengthen roads in India [59]. Bamboo is strong enough to handle and support vehicles that weigh up to 20 tonnes passing on bridges and roads. Figs. 2 and 3(a) and 3(b) show the actual bamboo's form and size, respectively. The bamboo has two different diameters, 0.07 m and 0.085 cm, as depicted in Fig. 3(a)

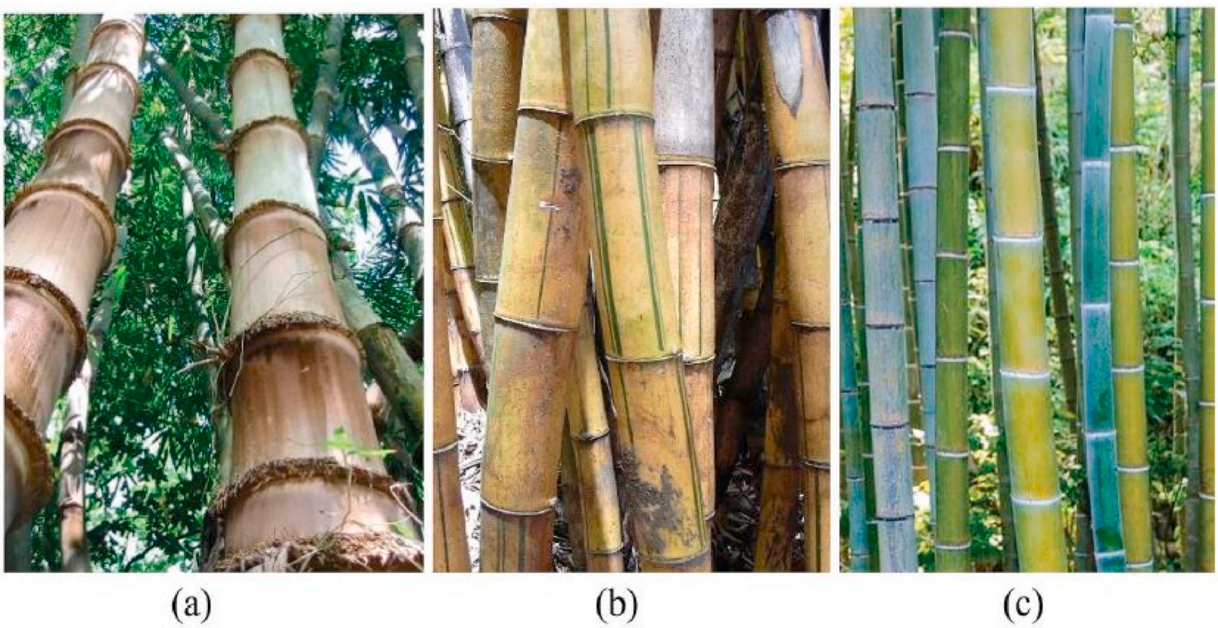

Fig. 1. Bamboo (a) Dendrocalamus (b) Bambusa (c) Phyllostachys.

and (b). The bigger the bamboo diameter, the higher the bamboo strength. The formula to calculate a bamboo volume is $V = \pi r^2 h$. The radius for the bamboo in Fig. 3(a) and (b) are 0.035 m and 0.0425 m. The standard bamboo length is 3 m. So, the bamboo volumes are $V = \pi r^2 h = 3.142 \times 0.035 \times 3 = 0.33\ m^3$ (Fig. 3(a)) and $V = 3.142 \times 0.0425 \times 3 = 0.4\ m^3$ (Fig. 3(b)). Bamboo in Fig. 3(b) has a higher volume than in Fig. 3(a). The bigger the bamboo volume, the higher the bamboo strength. So, the bigger bamboo volume gives high impact strength when used as internal reinforcement in RCB compared to smaller bamboo volumes and regular steel bars.

3. Scanning electron microscope of bamboo

Scanning electron microscope (SEM) images obtained for the microstructure surface of treated bamboo fibres, untreated bamboo fibres, and their biocomposites are shown in Fig. 3. The surface of untreated fibre in Fig. 4(a) is smooth, devoid of cavities, and coated with a layer of residues that compress the fibrils [60]. These residues shield the fibres from the resin and keep it from seeping into the material. The fibril coating material known as cuticle is found to be an aliphatic wax-20 incompatible with most polymers, hindering the reinforcement matrix attachments. The bamboo fibres in Fig. 4(b) have undergone chemical treatment with a 6 % sodium hydroxide (NaOH) solution, revealing a subtle difference as a result of the partial removal of non-cellulosic components such as waxes, pectins, hemicelluloses, lignins, and many more [60]. Increasing fibrils enhances the surface area for interaction and adhesion between the fibres and resins. As Fig. 4(d) delineated, the 11 % NaOH treatment subtly alters the fibre surface [60]. The fibres' surface layer is more heavily leached at this alkali concentration, making them more robust and resulting in stronger adhesion in polymer matrices. The fibre surface layer is lost when the linkage bonds that bind the polymer chains containing lignins and hemicelluloses are broken and fall apart because of their susceptibility to alkali treatment. These SEM findings demonstrate that bamboo fibres treated with 11 % NaOH exhibit enhanced interaction with polymer matrices. Fig. 4(e) depicts biocomposites made from bamboo's natural fibres, which have minimal microfibrillar exposure and minimal interaction with fibre matrices.

4. Experimental observation of bamboo reinforced concrete beam

The results of experimental investigation on the structural performance of bamboo reinforced concrete beam (BRCB) are reviewed in this section.

4.1. Ikponmwosa et al. (2014) [61]

Fig. 5 shows the beam cross-sections used in this research study.

There was no shear failure in any of the beams. The bamboo reinforcement in all beams with a reinforcement number of 3 or 5 in the tension region failed due to flexural tension. Numerous small vertical fractures, starting in the concrete beam tension zone and moving vertically upward on the beam surface towards the compression zone, were diagnostic of these failure kinds. At the collapse point, the tension zone demonstrated one or more evidence of elongated fractures. More than one crack at failure occurred in the beam samples reinforced with four bamboo splints in the tension zone. Regularly, the beam broke down, leading to extensive failure. Flexural compression failure was shown in beams with seven bamboo reinforcements in the stress zone because concrete crushing in compression occurred. The shear plane developed and expanded through a small upper portion in the compression zone region separated from the remaining part of the beam section as well as the load applied inclined due to the development of large vertical

Fig. 2. Bambusa Vulgaris bamboo.

(a) Diameter=0.07 m, Radius=0.035 m, Volume = 0.33 m^3 (b) Diameter=0.085 m, Radius=0.0425 m, Volume=0.4 m^3

Fig. 3. Bamboo size details.

cracks in the tension zone. Moreover, both factors might have contributed to concrete separation in the compression zone, such as bound failure and dissimilar compressive capabilities of aerated concrete and bamboo reinforcement bars in the compression zone. The ultimate moment variability outcomes are depicted in Table 1. It was clear that the experimentally observed beam behaviour and performance increased with curing ages and bamboo splint counts in the stress zone. The higher the number of bamboo reinforcements in the stress area, the higher the resulting moments produced. The flexural performances of the beam specimens were enhanced by increasing the number of bamboo splints in stress zone. The number of bamboo splints in the tensile zone increased the actual and predicted moments. The theoretical moments were more massive than the moments demonstrated in experimental investigation. The low compressive strength of foamed aerated concrete was due to the voids in the concrete matrices contributing to theoretical moment weakness. It was displayed that the presence of voids in the concrete matrices significantly decreased its compressive strength. The impact of water curing might lead to high experimental moment values obtained compared to air curing. The beam strengths were shown to be increased when performing and getting the beam specimens' experimental results in a wet state, especially immersed in water. In water curing, the beams' cracks and fractures hardly produce, spread, and propagate, contributing to the inclining of compressive and flexural strengths. The scatter plot in Fig. 6 illustrates the correlation between theoretical and experimental moments. The linear associations between theoretical and experimental ultimate moments were positive and significantly retained with a 0.923 statistical correlation coefficient.

4.2. *Muhtar et al. (2016) [62]*

Table 2 depicts the beam details utilised in this experimental investigation.

In the pull-out test, the bamboo reinforcement embedded in concrete cylinders with a coating of sikadur 863 and a hose clamp ring illustrated an increase in adhesion stress from 475 % to 522 % compared to normal beam without any bamboo reinforcement with distances of 55 mm and 105 mm between the hose clamps. The beams demonstrate various failure patterns, including concrete bond cone and node failures in bamboo reinforcement. They showed that the placement of hose clamps benefited the beam since the bamboo reinforcement was still attached and not ripped off. Collapse bond-slip failure is shown for specimens lacking hose clamp rings. In a few minor cases, the tensile strengths of bamboo samples were substantially higher than the maximum binding stress acquired between the bamboo reinforcement and concrete, causing the bamboo samples to break down during slippage. Besides that, the needless eccentricity was lacking in alignment introduced by the beams during the test. Compressive and tensile forces acted on the concrete surface. The stress was produced by juxtaposition based on the pull-out test. Then, it multiplied with the beam's shear reinforcement area to get the bamboo reinforcement tensile result. The bamboo reinforced concrete beam failed due to a link breaking between bamboo and concrete. The finding and estimation results from the flexural tests conducted on the bamboo RCB were investigated. The bond stress obtained from the pull-out test was higher than the flexural stress. Fig. 7 demonstrates that the bond strength of the regular bamboo reinforcement (B1 and B2) was less than the water-resistant bamboo reinforcement (B3 and B4) with hose clamped at 105 mm distance. Due to subpar hose clamp installation, beams reinforced with bamboo and hose clamp at 105 mm distance were stiffer than normal beams without bamboo reinforcement.

In most cases, the initial loading stage normally occurred with minimal slippage, followed by a steep increase as well as the load approaching the highest support load. Four beams exhibited excellent bonding performance during early loading phases, causing the load-slip curves to become almost linear. Furthermore, a chemical adhesion reaction governed the binding mechanism between concrete and bamboo reinforcement at the load-slip curves' linear point. The friction force between concrete and bamboo reinforcement occurred once the chemical adhesion link broke down. The bond slips between concrete and bamboo reinforcement was formed as the load became higher, causing to reduce the friction force and contact surface damage. Abrupt beam failure was depicted when the applied load approached the maximum support load. B1 and B2 quickly reached their highest loads at 61 kN and 53 kN at low

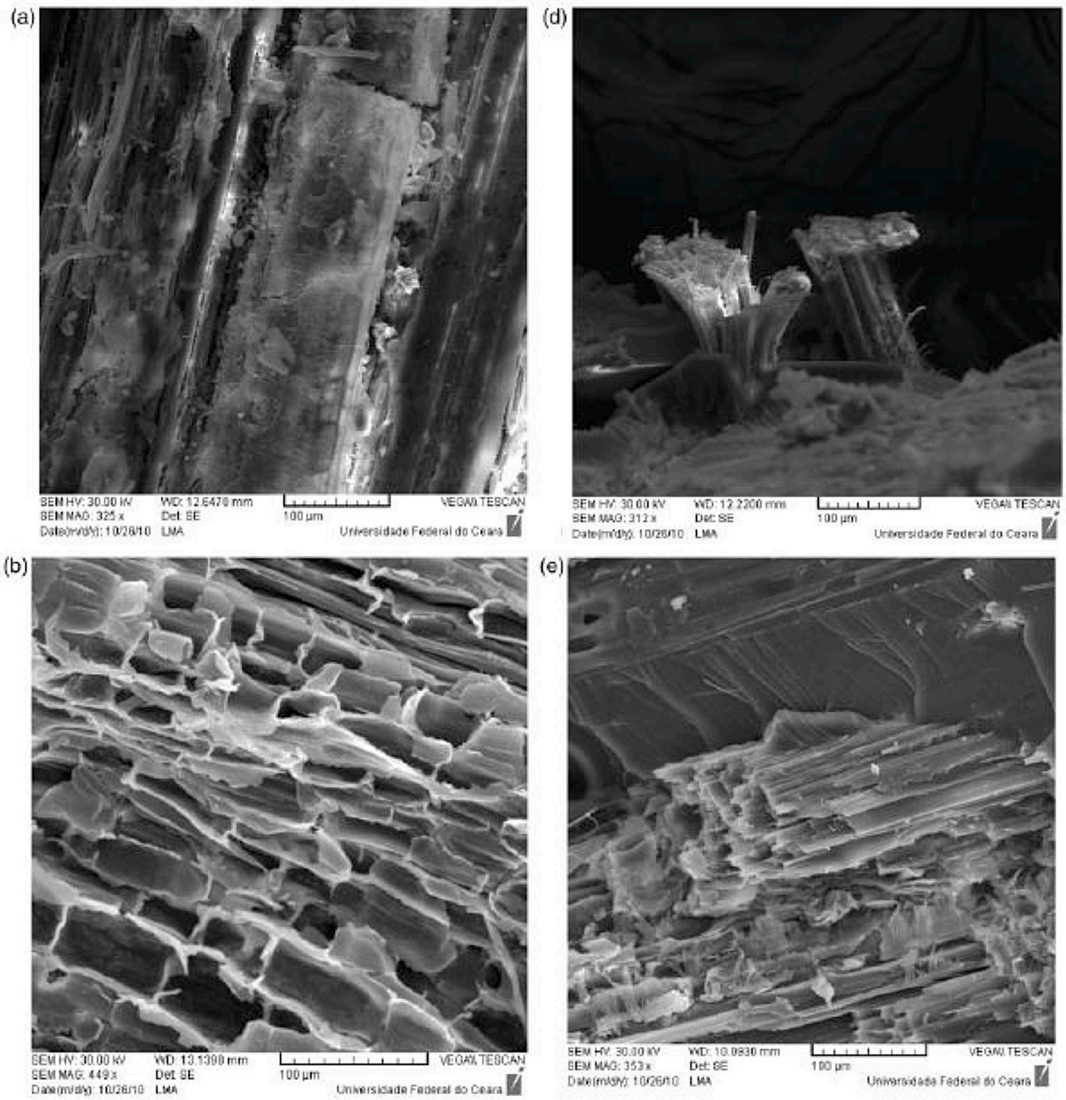

Fig. 4. SEM of bamboo (a) smooth, devoid of cavities, and coated with a layer of residues (b) chemical treatment with 6 % sodium hydroxide (NaOH) solution (d) 11 % NaOH treatment (e) Natural fibres in bamboo [60].

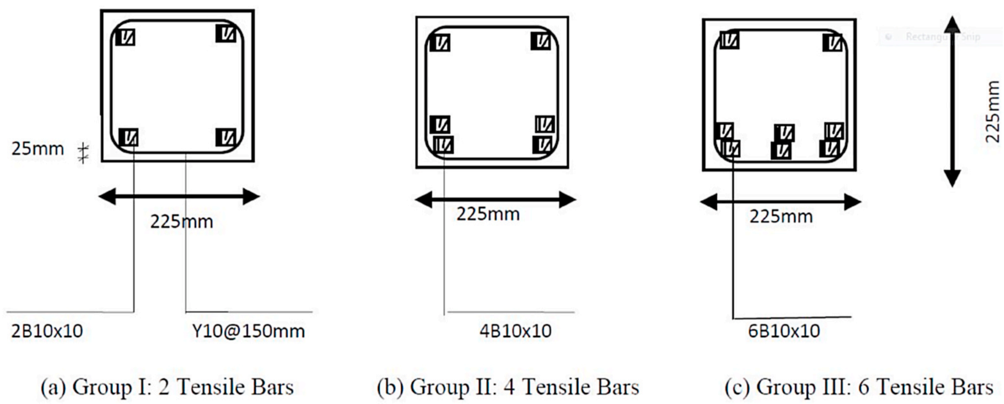

Fig. 5. Three beam cross-section groups [61].

Table 1
Load-moment [61].

	Load-moment (kN-kNm)			
Number of bamboo/Days	**7**	**21**	**28**	**45**
2	3.89–3.28	5.42–4.49	6.1–4	6.01–5.73
4	4.32–3.64	5.58–4.62	6.51–5.34	9.54–7.72
6	4.96–4.19	6.51–5.35	6.67–5.47	9.82–7.94

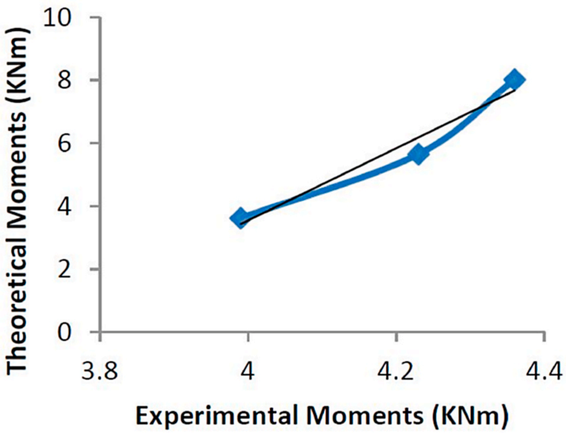

Fig. 6. Theoretical-experimental moments [61].

Table 2
Beam details [62].

Beam	Reinforcement	Stirrup	Hose clamp diameter (mm)
B1	3H12	8H20	10
B2	3H12	8H20	20
B3	3H12	8H20	30
B4	3H12	8H20	40
B5	3H12	8H20	50

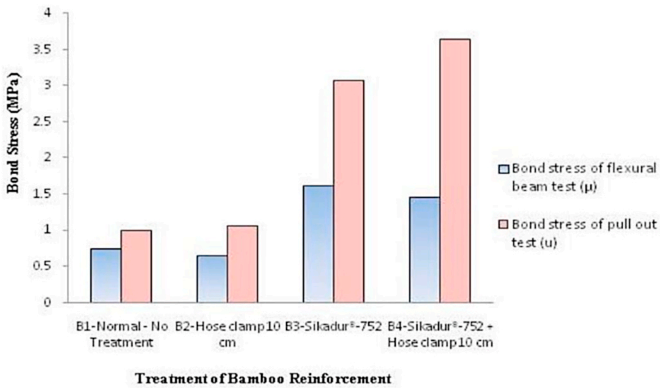

Fig. 7. Bond stress-bamboo reinforcement treatment [62].

slip values. The hygroscopic and slippery surfaces of bamboo characteristics were responsible for being used as alternate reinforcement replacing normal steel reinforcement. B3 and B4 reinforced with bamboo delineated better bond-slip behaviour than B1 and B2. Sikadur or bamboo, including a hose clamp, were utilised to prevent water infiltration. The beams also demonstrate the load-slip curves, which were almost linear up to loads of around 99 kN and 87 kN, indicating good structural bonding behaviour and performance between concrete and bamboo reinforcement. The highest loads of B3 and B4 were more impressive than B1 and B2.

Subsequently, the bond-slip behaviour between concrete and bamboo reinforcement was demonstrated to be highly affected and dependent on the bamboo reinforcement surface condition.

4.3. Chaturvedi (2017) [63]

This study compared the water absorption properties of bituminous and oil-painted bamboo to uncoated bamboo, as shown in Table 3. The bamboo's porous structure easily absorbed water, weakening the bamboo's tensile strength, which ultimately led to the beam's structural collapse. Coating with oil or bituminous paint decreased the water absorption by 37 % and 13 %, respectively, compared to untreated beam specimens without coating with oil or bituminous paint. Oil-based paints, as opposed to bituminous paints, reduce bamboo's ability to absorb water. Oil-painted bamboo showed the greatest resistance to water in the experimental tests performed compared to bituminous paint, which used turpentine as a solvent and performed the worst. It was discovered that the bamboo nodes broke under tensile tension because the fibre components in the bamboo microstructures were brittle and easily failed. The bamboo tensile strength inclined from the starting point due to greater fibre concentration. A beam reinforced with bamboo could support more weights and loads such as dead load, live load, beam self-weight and the like than a conventional steel reinforced beam because the beam reinforcement area was larger, including having small deflection and brittle nature property of bamboo. The large fracture initially started in inner radius spot of the bamboo-reinforced beam, where it was being loaded, propagated, and spread to outer radius spot.

4.4. Lei et al. (2020) [64]

Table 4 displays the beam specimen properties used in this study.

The fracture patterns of GJ specimens that failed under axial compression pressures are shown in Fig. 8. The first sign of the beam damage was a few small fractures towards the top surface at around 65 % of peak load. Multiple vertical fractures occurred and spread downward as the strain grew linearly. Most of the damage to the beam occurred starting from the beam's top surface. The vertical cracks propagated to the beam's centre at the highest load while the concrete at the top of the beam was shattered during destruction, but the steel bars retained their properties. Fig. 9 depicts the failure patterns of ZJA beam samples. When the axial load was between 80 % and 85 % of the maximum load, the beam's higher end would begin to break down, leading to failure. In addition, multiple new cracks formed as the load increased, and the existing cracks became longer. One or two major vertical cracks appeared before the load reached its maximum value. After the load reached its full capacity, it quickly began to drop and the beam crashed within a few seconds, causing the beam to shatter and crushing the concrete around the major cracks. ZJB was a trio of beams with a strong bamboo reinforcement ratio of 1.55 %. The first sign of the vertical crack in the beam was depicted when the axial load was around 75 % of the peak load. The initial fractures spread downward as the strain grew linearly. Simultaneously, additional cracks appeared in a vertical y-direction. When approaching the maximum load applied, the beam developed several vertical cracks that split into multiple divisions. The beam specimen failed when the increasing axial load crushed the concrete surface. Furthermore, the concrete in the compression zone of the beam set was broken early due to the unavailability of bamboo reinforcement. The failure patterns of ZJB beam samples are delineated in Fig. 10. Three beams comprise the ZJC group, and their reinforcing bamboo ratio was 2.67 %. The initial fractures formed on the beam's upper, middle, and lower surfaces simultaneously, as well as the axial stress reached 70 % of the peak load. The initial cracks spread and further cracks formed as the weight increased. The beam specimen was damaged as the concrete surrounding the major fracture crushed and dropped out when reaching the failure load. These beams' primary fractures extended nearly the whole span of the beam before the beams' failure occurred. ZJB beam group exhibited indicators of impending collapse. More ductility, elasticity and endurance could be observed in ZJB and ZJC than in ZJA. Using bamboo reinforcement bars to brace the beams was the main reason for the increasing ductility, elasticity and endurance. Fig. 11 illustrates the failure patterns of ZJC beam samples.

Each beam's axial deformation was calculated by averaging the readings from two displacement metres while the force sensor monitored the axial load obtained. The axial load-displacement curves for the four beam groups could be separated into three phases: elastic, elastic-plastic, and failure. The axial deformations of GJ, ZJB, and ZJC were directly proportional to the axial load imposed in elastic stage. ZJA had plastic qualities in the axial load-axial deformation curve because it had the lowest reinforcement ratio. Apart from that, the concrete strength influenced the beam stiffness. This could be seen in ZJC, which had the most insufficient concrete strength, producing the minimum beam stiffness, while GJ and ZJB had similar elastic stiffness. The beams' curve displayed non-linear behaviour followed by the boosted of axial deformations once the concrete crack formation occurred. All beams reached the elastic-plastic phase at certain points. ZJC had the longest elastic-plastic stage because its reinforcement ratio was the maximum. The highest crack load and axial deformation in ZJC occurred well prior to peak load. On the other hand, the failure stage of axial load-deformation curves initially started after the peak load. Bamboo RCB had a steeper curvature slope than normal RCB. In conclusion, it was demonstrated that the longitudinal bamboo reinforcement bar increased the beam brittleness before breaking down.

Table 3
Moisture content [63].

No.	Coating	Moisture content (%)
1	Uncoated	3.03
2	Bitumen	3.68
3	Oil paint	2.98

Table 4
Beam properties [64].

Specimen	Type	Size (mm)	Number	Reinforcement ratio (%)	Stirrup reinforcement
GJ	Steel	12 x 12	5	1.83	A8-150
ZJA	Bamboo	15 x 15	5	1.75	A8-150
ZJB	Bamboo	20 x 20	5	2.55	A8-150
ZJC	Bamboo	25 x 25	5	3.67	A8-150

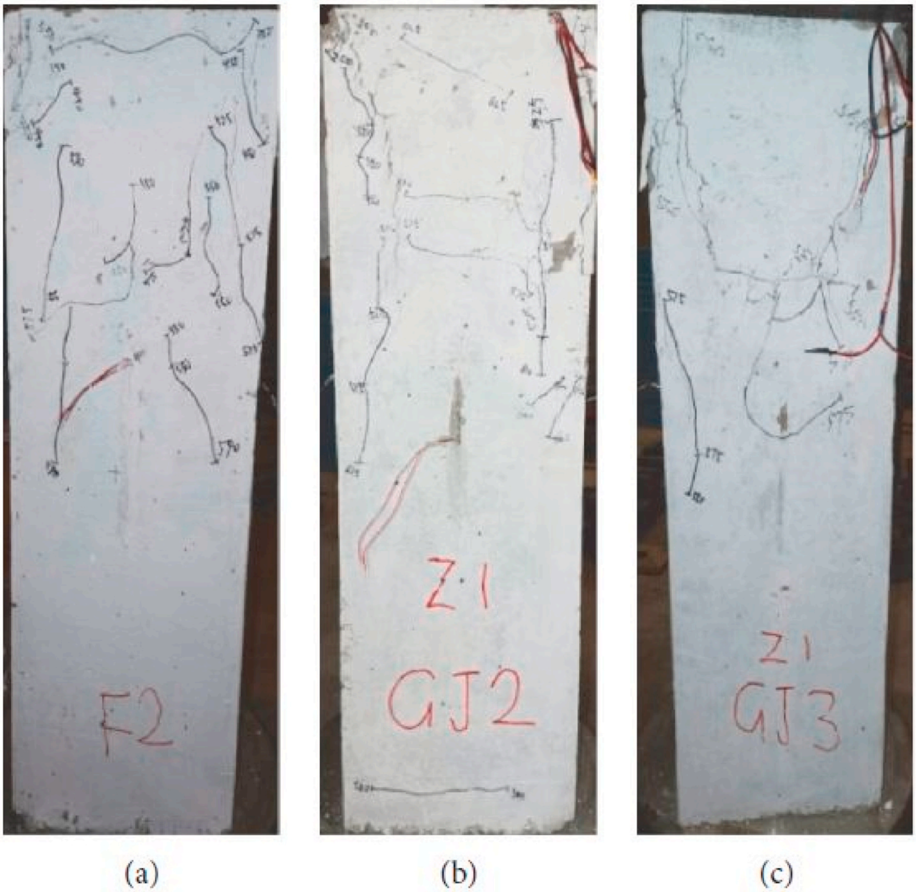

Fig. 8. Crack pattern (a) GJ1 (b) GJ2 and (c) GJ3 [64].

4.5. Mark & Russell (2011) [65]

Table 5 displays the beam specimen details utilised in this experimental study.

The self-weight of the beam was quite low. So, a four-point bending test was subjected to the centre of the simply supported beam to release the maximum uniform bending moment and zero shear forces. Since the biggest flexural stress occurred in this zone area, the cracks began at the soffit of this area. They rapidly propagated towards the beam top surface as the imposed load increased, causing the beam to fail and eventually collapse. As shown in the load-deflection curves in Fig. 10, RCB with longitudinal bamboo reinforcement exhibited the same behaviour as the beams reinforced with longitudinal steel reinforcement. The quantities and types of re-inforcements, either regular steel or bamboo reinforcement, concrete strength, and shear span-effective depth, affected how the RCB responded to the applied load. Subsequently, the proportion of longitudinal tension reinforcement in bamboo was from 4.28 % to 7.94 % of the gross concrete section for all sixteen beams. They were experimentally tested until they failed. The beams' deflections tracked a reasonably precise straight-line variation during the test performed until the first crack appeared on the beams' surface. After the first crack appearance, the deflection curve flattened, perhaps because of local bond slippage and then returned to the almost straight line variation at a shallower slope until the beams ultimately failed. The deflection curve flattened out significantly in the beam members with less longitudinal bamboo reinforcement. Moreover, strain hardening of the tested beams occurred in a small percentage. Prior to collapsing, the beams deflected within a narrow range, demonstrating that the bamboo had limited ductility. Under low load, beams

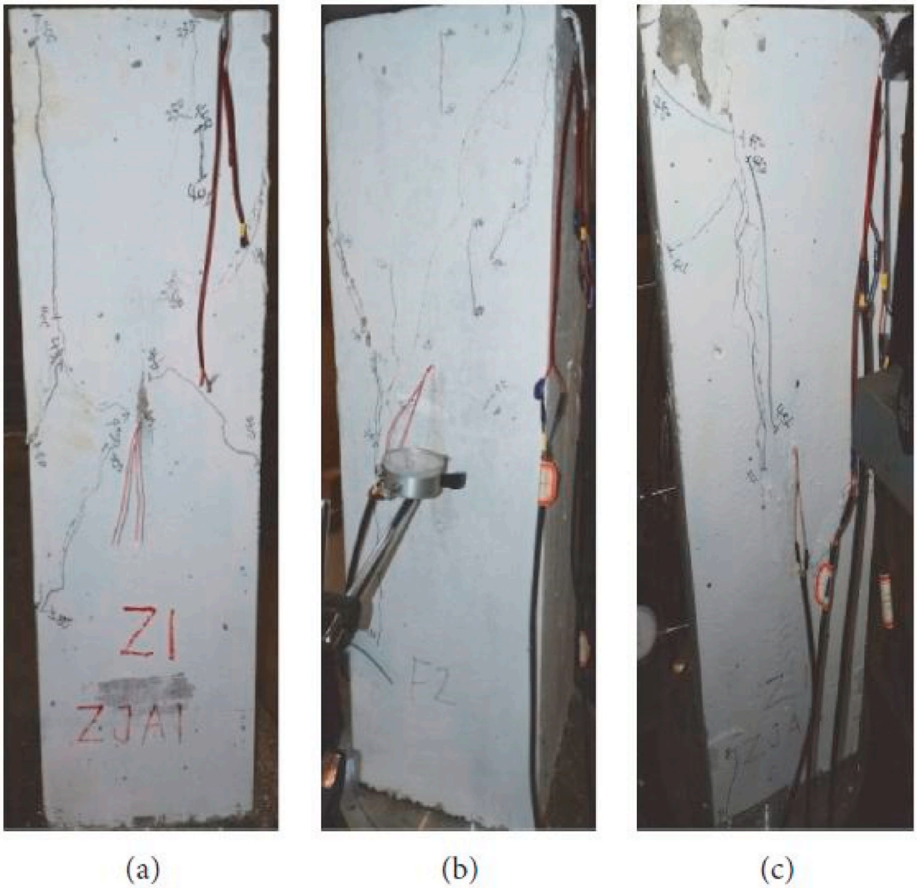

Fig. 9. Failure pattern (a) ZJA1 (b) ZJA2 and (c) ZJA3 [64].

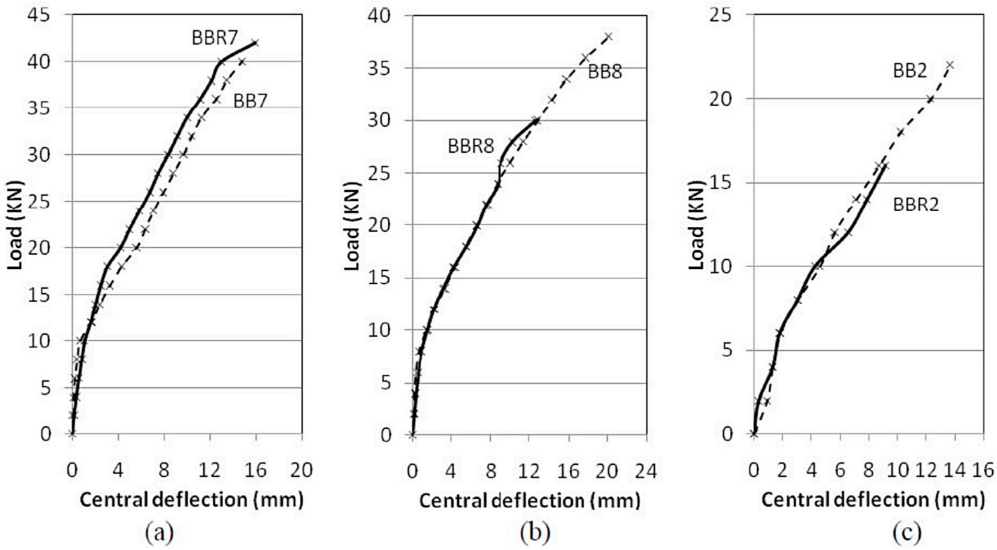

Fig. 10. Load-central deflection [65].

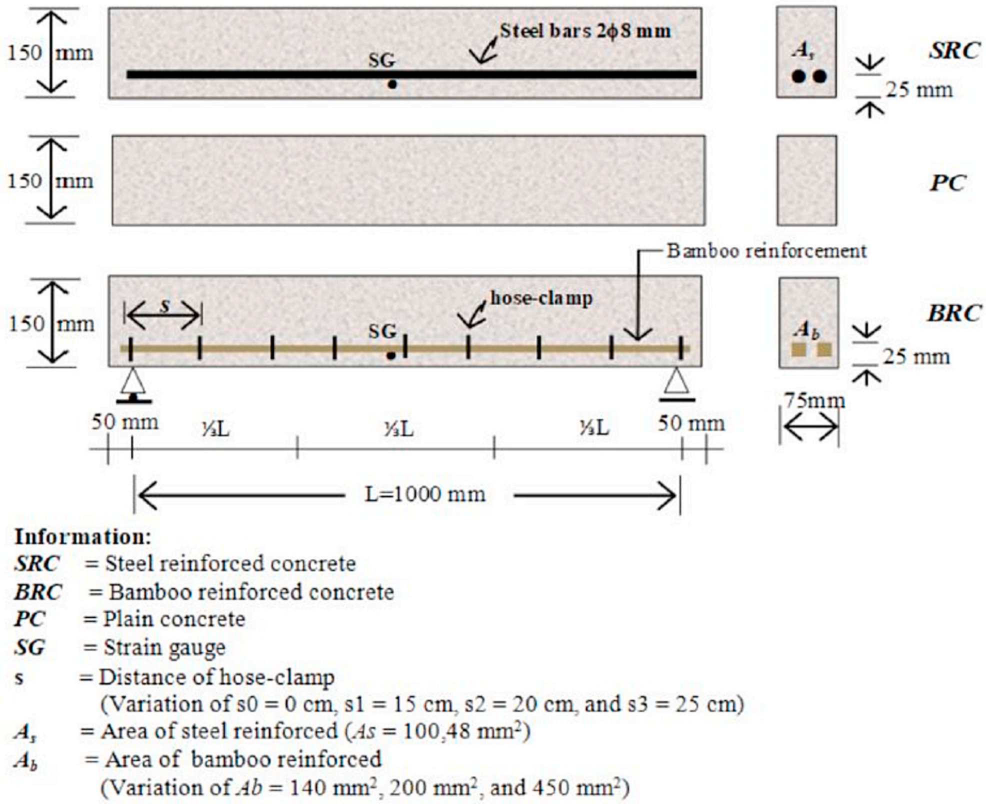

Fig. 11. Beam geometry details [67].

Table 5
Beam specimen details [65].

Beam	Concrete strength (N/mm^2)	Bamboo (%)	Bamboo strength (N/mm^2)
BBR1-BBR4	28	7.05	137.83
BBR5-BBR8	29	7.57	137.83
BB1-BB4	19	8.47	137.83
BB5-BB8	24	5.58	137.83

reinforced with a low percentage of bamboo had higher elasticity and ductility than regular beams without bamboo reinforcement. Fig. 10(a) and (b) display two pairs of beams, BBR7/BB7 and BBR8/BB8, that were identical in size and number of shear stirrups but with different tension bamboo reinforcements and concrete strengths. Despite having great tension bamboo reinforcements and concrete strengths, these two beams, BBR7 and BBR8, did not produce the greatest failure load and displacement. Similar beams with lower tension reinforcement than BBR7 and BBR8 had greater failure loads, as shown in Fig. 10(c). BB5-BB8, with tension reinforcement of 5%–6% of the beam cross-section area with less compressive strength, recorded the highest failure load and displacement values compared to other beam groups. These current findings verified the previous findings that 4%–6% of the beam cross-section area should be reinforced with bamboo to produce the maximum tensile strength.

It was projected that all beams would break down under flexural strain failure rather than shear failure. With insufficient web reinforcement in the beam, the flexural fracture (a-b) propagated towards the loading point when the load (V) increased. The flexural shear fracture (a-b-c) formed under increasing stress. The diagonal tension crack in the beams would terminate at j, followed by the formation of random cracks in the concrete along longitudinal tension reinforcement (g-h) for an av/d ratio between 3 and 7. There was a separation along a-h since this fracture weakened the concrete's attachment along longitudinal tension reinforcement. Hooking longitudinal reinforcement caused the instantaneous collapse. Concrete crushing occurred once the diagonal cracks reached the concrete's compression zone. All beams except BB1 failed in the following failure modes: longitudinal bamboo in tension, concrete crushing, flexural shear, diagonal tension, and shear bond. Concrete cracks in the horizontal tension bamboo bars characterised the failure modes of beams BB5 and BB8. Both beams failed because of diagonal tension. There were no correlations between the stirrup material and the beam failure mechanism. The beam that had the widest crack failed under diagonal stress. In conclusion, all beams failed in brittle shear mode rather than ductile flexure mode in tension reinforcement, even though the material's safety factor of 4.0

for the beam reinforcement had been used in theoretical calculations for bamboo and rattan cane materials.

4.6. Ogunbiyi et al. (2015) [66]

The tensile strengths for high yield steel bars and bamboo are shown in Table 6. The value was between 468 N/mm2 and 803 N/mm2, yielding stress between 380 N/mm2 and 689 N/mm2 and a tensile force between 36 kN and 390 kN. In contrast, the tensile strength of bamboo ranged from 42 N/mm2 to 105 N/mm2, while the yield stress was between 0 and 55 N/mm2, with tensile force between 4 kN and 20 kN. Steel was ductile because it might have been plastically deformed before it broke down. Cracking occurred in the bamboo beam. In other words, no plastic deformation occurred before the beam failure occurred. The acquired breaking elongation was the evidence for this characteristic. The breaking elongation value for mild steel ranged from 31 % to 53 %, whereas for high-yield steel ranged from 19 % to 26 %. The breaking elongation of the brittle failed bamboo beam was 0%–16 %. This research study found that bamboo might be a suitable replacement for steel rebar in RCB. It also emphasised the usefulness of bamboo as a structural element in various building construction projects. Bamboo had been utilised for centuries in engineering and construction projects because of its high strength-to-weight ratio and relative simplicity of usage. Because of its unique properties and qualities, it could also be used to fortify fragile materials. Although bamboo could be used as internal reinforcement in certain circumstances, replacing normal steel reinforcing bars was not easy to use in lightweight construction because there was a change in the beam design calculation and need to be recalculated. Bamboo had high elastic modulus, producing a strong bond with concrete and a tendency for volume change in moisture absorption, which contributed to the success of the beam construction. Bamboo beams could be effectively used as the basis of existing knowledge. Consequently, it was essential to keep in mind that the high modulus of elasticity property of bamboo was a non-limiting factor in many reinforcement applications for structural elements in building construction projects, such as beams, slabs, columns and the like.

4.7. Muhtar, Gunasti et al. (2020) [67]

Fig. 11 shows the three beam geometry details used in this research study.

Fig. 14 displays the load-deflection patterns that resulted from using two different approaches to data processing. The stiffness of bamboo RCB could be calculated from the load-deflection curves. The load-deflection relationship could also be used to predict the beam stiffness using the elasticity modulus values. The load-deflection graph revealed that the BRC was 55 % less rigid than SRC at 50 % ultimate load. The ANN analytic testing results agreed up to 80 % ultimate load in the load-deflection curves. Furthermore, the differences between ANN analytical and actual results were visible in the stiffness of BRC for weights greater than 90 %, as illustrated in Fig. 12. The BRC's initial fracture, located in the elastic area, occurred between 30 % and 50 % of the ultimate load. The ultimate load of BRC was maximised when the hose clamps were installed at a distance of 30 cm and decreased when the distance was declined to 15 cm, indicating that installing hose clamps were too tight that would reduce the elasticity and ductility properties of bamboo reinforcement. The BRC's rigidity and load capability were unimproved by installing the hose clamps with too much tension. The regression analysis findings for six beam specimens in each group, namely BRC-s0, BRC-s1, BRC-s2, BRC-s3 and SRC beams, were utilised to control the load-deflection relationship with the ANN approach. Fig. 13 delineates the regressed usage of ANN analysis findings for each beam group to calculate the BRC's stiffness.

When evaluating the resistance of structural beam parts to bending deformation, beam stiffness was considered the primary parameter. The stress-strain material's fundamental characteristics and behaviour primarily determined the structural beam components' size and stiffness. From the experimental results, the rigidity of SRC was higher than BRC due to the higher modulus of elasticity of bamboo compared to conventional steel reinforcement. In contrast, BRC had excellent elasticity characteristics consistent with the bamboo's stress-strain relationship pattern. This stress-strain relationship pattern demonstrated that bamboo was a suitable material to absorb the force of earthquake imposed on the beam surface. The beam structure's integrity and stiffness were crucial in a beam design. Thus, the low stiffness of BRC needed to be remedied. The graph demonstrates two possible solutions for the BRC's weak stiffness, such as strengthening the bamboo reinforcement and utilising the principle of restricted concrete. For instance, adhesive, increasing concrete surface roughness, installation of hose clamps that acted as hooks and shear connections, and many more could all be used to strengthen the bamboo reinforcement. Improving the concrete strength was one of the essential factors to make the beam stiffer. This study showed that slippage and shear collapse were the primary causes of BRC failure. By adding shear reinforcement to BRC, the fundamental idea of restricted concrete was adhered.

Table 6
Comparative tensile strength of steel and bamboo [66].

Size	Tensile (N/mm^2)	Elongation (N/mm^2)	Tensile (N/mm^2)	Elongation (N/mm^2)	Tensile (N/mm^2)	Elongation (N/mm^2)
10	568.24	20.36	311.50	62.72	42.66	1
12	790.23	37.21	619.19	40.68	42.18	1
16	822.72	46.38	619.82	66.64	79.93	26.18
20	824.51	41.83	483.09	34.79	73.77	23.21
25	803.11	37.22	812.85	30.76	105.71	21.02

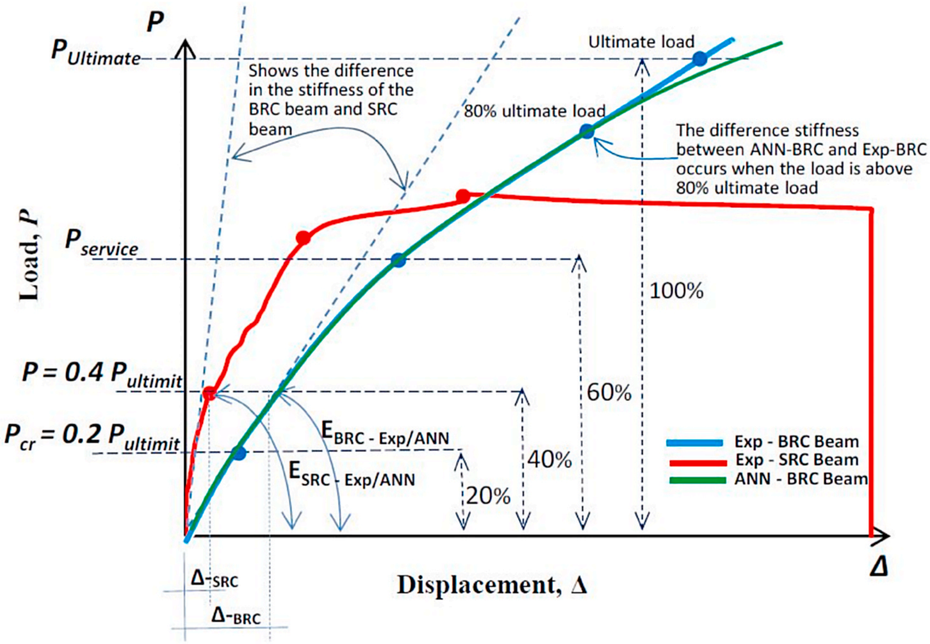

Fig. 12. Load-displacement [67].

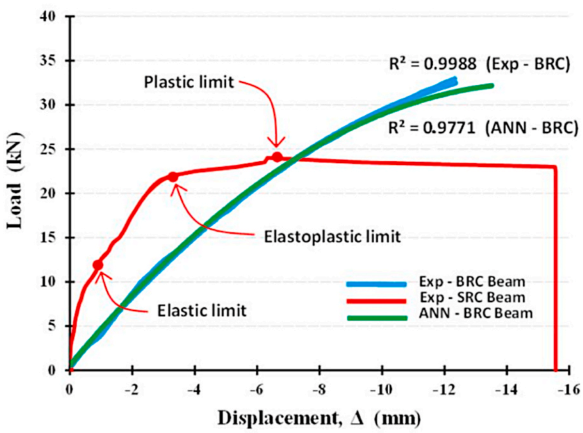

Fig. 13. Load-displacement [67].

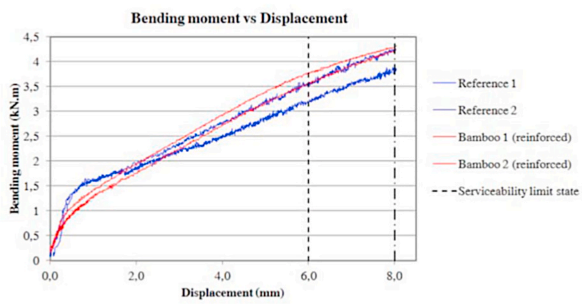

Fig. 14. Bending moment-displacement [68].

4.8. *Tsutsumoto et al. (2019) [68]*

Fig. 14 demonstrate the primary results from the beam bending tests. Before getting the experimental results, it was worth noting that the beam reached the serviceability limit condition in excessive visual displacement with 7 mm deflection at the beam mid-span, corresponding to the deflection/span ratio of 1/350. When the dial indicator showed 8 mm deflection, the beam was withdrawn from the 4-point bending test to prevent further deviation and potential damage to the beam machine test. The acquired findings demonstrated that the beam resistance increased by 40 % due to the additional reinforcement of bamboo splints. The bamboo splint reinforcement could withstand a larger weight to support the beam. The bamboo reinforcement also raised the moment required to bend the beam by 7 mm at the centre and inclined the serviceability limit state by 9 %. The control beam reached its serviceability limit condition earlier than the bamboo RCB. Moreover, a 7 % deflection increase was shown when bamboo splints strengthened the beam. On the other hand, the cracking time taken for the bamboo RCB was 13 % less than the normal beam. Hence, bamboo's influence was unfavourable concerning the cracking onset. Clearly, the beam deflection was the same as the initial crack started to propagate. The extensometer was centrally placed under the beam to measure the strain amounts, low longitudinal reinforcement, loads, and forces. Fig. 15 displays the information gathered from the extensometers attached to the lower surface of the control and bamboo RCB.

The regular beam depicted a typical flow level with more than 8 % deformation for the traction reinforcement in the circumstance corresponding to the final bending moment. Both compressed and crushing concrete areas were diminished due to the concrete's linear behaviour and abrupt elevation of horizontal x and vertical y neutral lines closed to the rupture point. The normal and bamboo beams deformed by 1.36 % and 2 % prior to the beginning of concrete crushing. Nevertheless, the deformation of the bamboo placed on the beam's underside surface practically coincided, indicating that the bamboo was strongly fastened in the beam's internal reinforcement. The lateral bamboo experienced a deformation of 6 %, which made sense as its centre of gravity was situated at the beam mid-span. The regular steel had less deformation than bamboo because the bamboo caused the tensile stress of the beam to incline. There was no clear flow seen when the plastification process began. Concrete crushing, as well as the neutral line fluctuated from its actual position, causing a large deformation to occur in beam 2. The increased strength of the compressed concrete counteracted the tensile stress provided by the bamboo and steel reinforcements, allowing the beam to remain stable until it failed. The beams' cracking pattern is depicted in Fig. 16(a), while the normal and bamboo RCB behaviour is depicted in Fig. 16(b). As forecasted, it could be seen that the beams broke in the middle span right away, where they were subjected to the greatest bending moment. All the tested beams appeared to have similar cracking patterns.

4.9. *Rahman et al. (2022) [69]*

Six beams were cured for 28 days in a water tank before being tested. Table 7 shows the maximum flexural stress and breadth of displacement for a gradually rising load, while Fig. 20 contrasts the bamboo and steel RCB in load capacity results. Based on the findings, bamboo RCB were 8 % lighter than steel RCB. The results demonstrated that the beam weight was not significantly altered when bamboo replaced the steel reinforcement. Furthermore, bamboo was effective in increasing the concrete beam's stress capacity when used as alternative internal reinforcement replacing steel. The load capacity of bamboo RCB inclined more than bamboo RCB, as depicted in Fig. 17. Steel and bamboo RCB had average ultimate loads of 15 kN and 64 kN with 8 and 14 mm displacements. Bamboo had the highest shear capacity, as the displacement showed. Thus, bamboo RCB was 75 % stronger and displaced itself by 47 % compared to steel RCB. The repeated swelling and shrinking that occurred naturally in bamboo was a possible reason for this issue. The two joined materials between concrete and beam reinforcement were slowly separated due to less shrinkage characteristic of bamboo. Therefore, it demonstrates that bamboo was a vital alternative to normal steel reinforcement. According to load test findings in the experimental lab, the bamboo RCB performed at roughly 46 % of its design capacity. Bamboo reinforcement could be used in reinforced concrete structures, particularly for low-cost housing projects, because of its good tensile strength property. The usage of bamboo nodes had also been shown in much previous research to improve the longevity of bamboo. On the other hand, the bamboo nodes could aid in creating a strong, durable, and flexible transverse reinforced concrete wall, preventing it from rupturing under stress

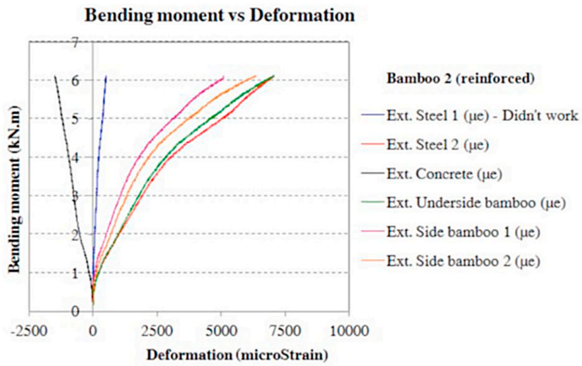

Fig. 15. Bending moment-deformation [68].

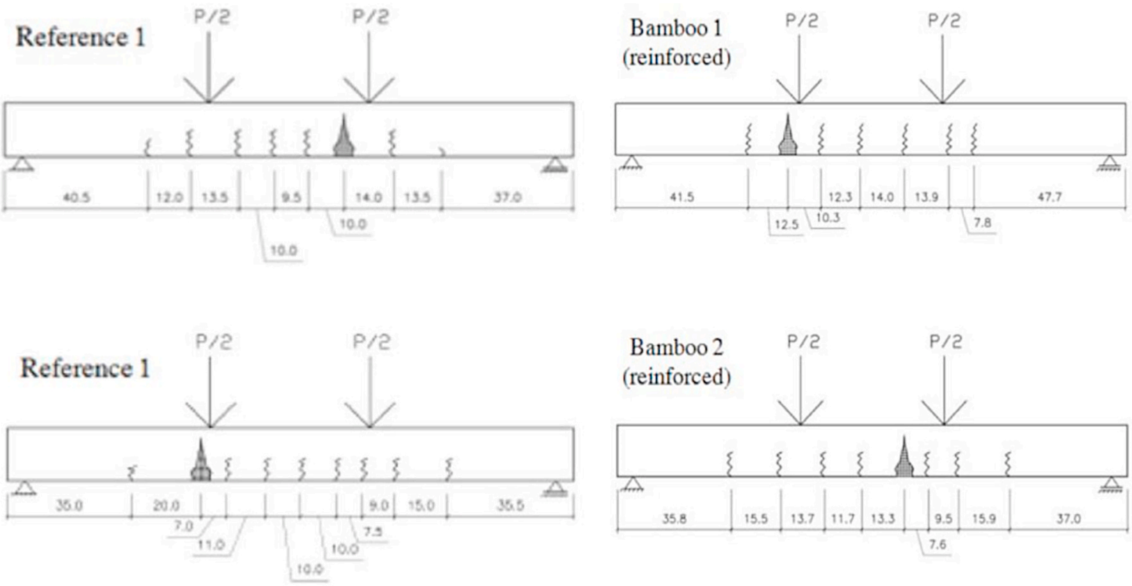

Fig. 16. Crack pattern [68] (a) Reference beams (b) Bamboos 1 and 2.

Table 7
Bamboo RCB properties [71].

Bamboo size (mm)	Spacing (mm)	Bamboo species	Treatment	1st crack load (kN)	Load (kN)	Deflection (mm)
80 x 200 x 1500	–	Malacola	Untreated	–	10.94	2.79
80 x 200 x 1500	–	Malacola	Sikadur 43	–	24.22	3.29
80 x 200 x 1500	–	Malacola	Sikadur 43	–	25.22	3.16
80 x 200 x 1500	–	Dendracola	Sikadur 43	–	32.86	23.51
80 x 200 x 1500	–	Dendracola	Hose clamps + Sikadur 43	9.36	30.86	10.26
150 x 200 x 1200	100	Bambuca	–	37.81	45.11	7.22
150 x 200 x 1200	100	Bambuca	Grooves	45.12	69.45	7.23
170 x 170 x 1400	120	Dendrocola	Alkaline resistant	26.17	53.34	–
170 x 170 x 1300	120	Dendrocola	Alkaline resistant	25.26	50.21	–
120 x 300 x 2500	150	Bambuca	–	27	71	10.46

imposed on the surface.

The tensile strengths of bamboo and steel reinforcements were evaluated. This research utilised three 20 mm bamboo sticks and three 20 mm T10 steel bars for the testing. The average tensile strengths of steel and bamboo sticks were 237 MPa and 483 MPa, which showed that bamboo had higher tensile strength and 48 % stronger than steel bars with the same diameter. The finding results demonstrated that bamboo could replace steel in RCB structures as internal reinforcement. Furthermore, rebar made from bamboo showed sufficient tensile strength that could be used in reinforced concrete building elements, such as columns, floors, roofs, beams, wall panels, slabs, and many more. Subsequently, the tensile strength of bamboo might compete with mild steel in some circumstances. In conclusion, bamboo could be used to replace steel in beam reinforcement because bamboo reinforcement benefited the beam's structural performance and behaviour by inclining the strengths.

4.10. Ghante & Shivananda (2019) [70]

Based on the experimental results, Fig. 18 clearly shows that the beam reinforced with 3 % bamboo could support greater weight than 1.5 % bamboo and plain concrete beams. The flexural failure load of the uncoated bamboo strengthened beam was six times higher than the unreinforced bamboo beam. The improved bamboo reinforced beams could also support greater weight than their unmodified bamboo counterparts. The load-bearing capacity of bamboo-reinforced beams treated with waterproofing was two times bigger than untreated beams. This bigger load-bearing capacity was because the modified bamboo reinforced beams had better and stronger bonding between concrete surrounding and bamboo reinforcement for load transmission. In addition, the beams comprised covered bamboo with coarse aggregate and sand sprinkled on the top of the bamboo reinforcement. It eliminated the bamboo from taking any moisture from the environmental surrounding. Increasing the bamboo reinforcement percentage usage in beams increased their compressive, flexural, and tensile strengths. The tensile strengths of all bamboo splint cycles were shown. The tensile strength decreased as the number of soaking and drying cycles rose. This result demonstrated that additional soaking and drying bamboo splint cycles diminished the bamboo strength. Subsequently, constant and permanent swelling and contracting caused the bamboo splint to

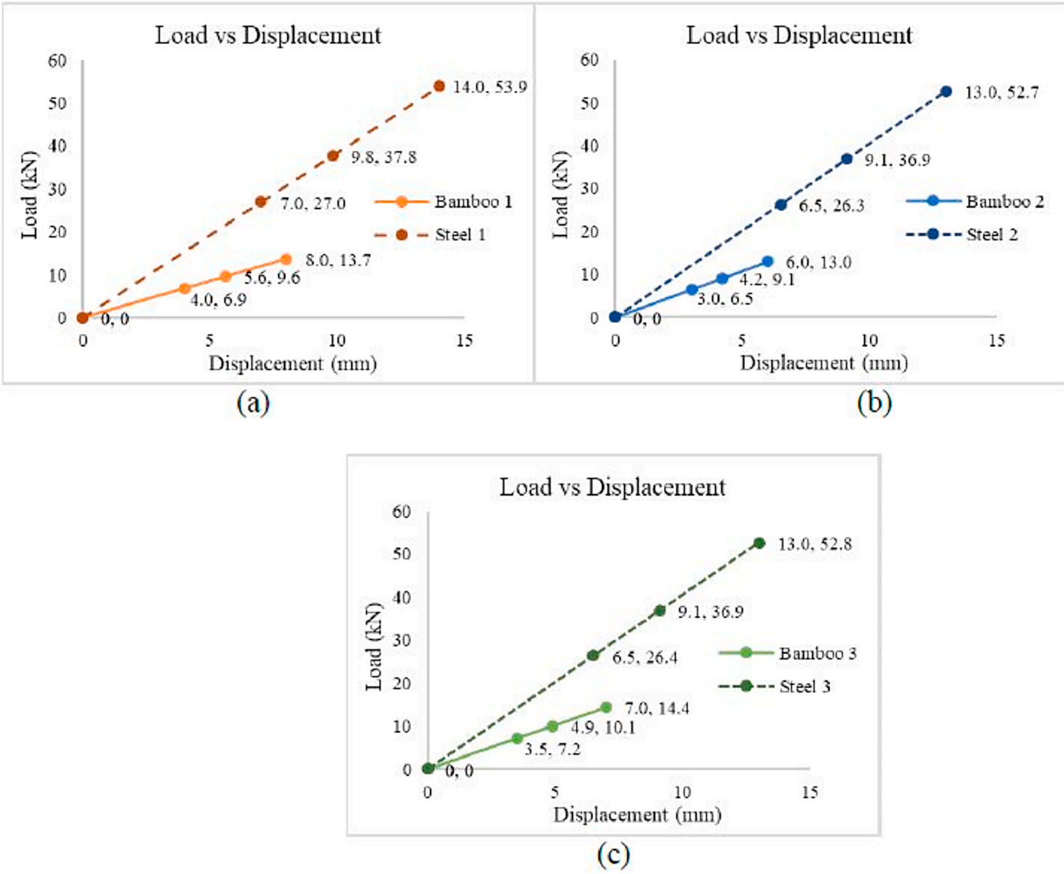

Fig. 17. Comparison of bamboo and steel beams (a) Specimen 1 (b) Specimen 2 (c) Specimen 3 [69].

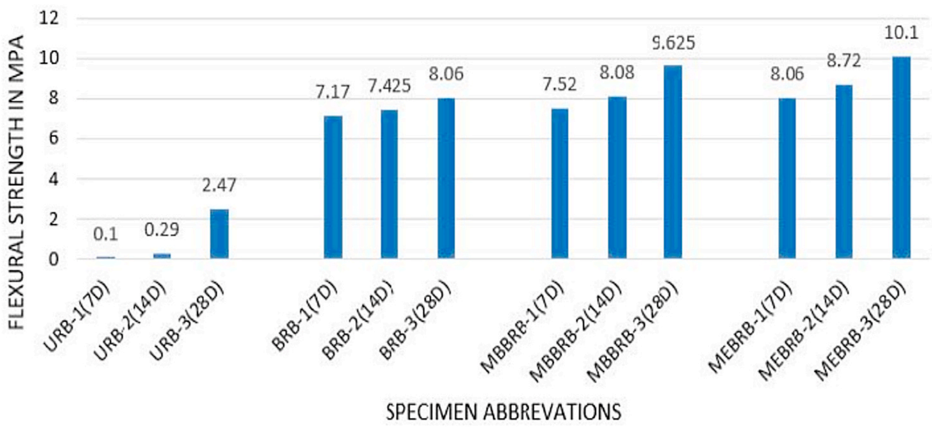

Fig. 18. Flexural strength (7 days) [70].

lose the fibre bond gradually. The tensile strength results of bamboo splints after alternating soaking and drying in magnesium sulphate solution were investigated. Another thing was the beam tensile strength declined as the number of soaking and drying bamboo cycles inclined. This proved that the bamboo's durability continued deteriorating when it was subjected to repeated soaking and drying cycles.

The magnesium sulphate was an acidic solution, with a pH range from 4.5 to 5.5, due to the high affinity of magnesium in hydroxide (OH-) ions. The ratio of hydrogen ions (H+) to hydroxide ions (OH-) increased as hydroxide ions bound with magnesium ions upon including sulphate ions in the solution. The higher acidic solution affected the fibre parenchymas, which was responsible for developing the bamboo fibre strength. The higher the expansion and contraction of the fibre, the higher the tendency of the bamboo splint to lose strength and weaken the whole bamboo splint's strength. The tensile strengths of bamboo splints after soaking in magnesium sulphate solution for all cycles are depicted in Fig. 19. The beam tensile strength decreased as the soaking and drying cycles increased. Repeated washing and drying would reduce the bamboo's resilience. The pH value of potassium chloride was 7. It was a neutral salt solution containing strong acid and alkaline solutions (HCl and KOH). However, some chloride ions that led to lipid breakdown in bamboo fibre parenchymas were left behind because potassium ions had affinities with OH- ions. As a result, the fibre parenchyma, which was responsible for the development of bamboo fibre strength damaged, leading to beam failure as well. As it continued to expand and contract, the bamboo splint lost fibre strength, weakening the whole bamboo splint's reinforcement force and strength.

4.11. Sayed et al. (2022) [71]

Table 7 shows the investigated bamboo RCB summarised in this study.

The adhesion between bamboo bars and the concrete matrices could be improved with efficient water-repellent treatment. Several parameters, like applied coating adhesive characteristic to bamboo and concrete, water-repellent property of coating, and friction behaviour of bamboo-concrete interface, were considered to influence the impermeability of bamboo in this research. Epoxy treatment of bamboo coating with fine sand was one of the most successful methods. The mechanical beam interlock was strengthened by further bamboo surface modification. Table 4 depicts that after the treatment of bamboo reinforcement, the beams' initial fracture load increased well with the ultimate load. The concrete quality and the bamboo types used for the beam reinforcement might be the factor for the increasing beam strengths. Moreover, the flexural behaviour of the beams was drastically enhanced by incorporating lateral reinforcement and altering the beam surfaces. Beam 7 was coated with grooves, glue, and sand. It had first crack and ultimate loads of 43 kN and 66 kN, with a deflection of 7 mm, higher than beam 6, which had the same size and reinforcement ratio but without bamboo treatment. The beams' flexural performance was also improved with a high reinforcement ratio. For instance, beams 2 and 6 had initial fracture and ultimate loads of 9 kN, 35 kN and 22 kN, 43 kN with 13 mm and 7 mm deflections. The values were increased because both beams had high reinforcement ratios. All beams with lateral reinforcement exhibited superior flexural performance and increasing strength values compared to beams without confinement.

The beams failed in various ways depending on bamboo treatment, types of surface modifications and the presence of admixtures. BRC were untreated bamboo beams. Damage occurred in BRC beams along the reinforcement direction caused by bond failure and bamboo sliding. Better cement adhesion was demonstrated in BRC beams with treated bamboo reinforcement, causing the beam's shear cracks in the tensile area to propagate upwards as the failure mode. A similar destruction method was used in bamboo RCB by clamping the hoses together. The big cracks were identical to the beams without bamboo reinforcement. They split into smaller cracks that developed from the lower to the upper surface of the beams. Beams made from grooved and wired bamboo bars had a complete bending destruction failure mechanism similar to SRC beams. Also, bio-beams with and without bamboo reinforcements failed in shear mode. The concrete mixture mixed with fly ash, granite, or GGBS caused the beam to brittlely fail because the concrete mixture mixed with either one of the additive materials did not stick well to bamboo reinforcement. On the other hand, the beams reinforced with bamboo composites failed in three different ways: shear, compression, and reinforcement rupture under bending strain.

There were three distinct phases in the bamboo beams' behaviour: elastic, elastic-plastic, and plastic. Many researchers made an effort to foretell the beams' flexural behaviour. The excellent dependability of the suggested approach created a calculation model for forecasting the local slip in BRC beams through curvature moments and bond stress with 6 % uncertainty. Both FEM and ANN approaches predicted the stiffness and deflection decreased values for BRC beams. 86%–94 % of each study time was spent validating the suggested models. The results analysed concluded that bamboo bars could be used to replace normal steel reinforcement in RCB. However, there were several obligations before using bamboo as beam reinforcement. In order to improve adhesion between reinforcement and concrete matrices, the BRC beams with 3 % reinforcement ratio and bamboo surfaces were modified with grooves in a zigzag manner to provide the best bending bond behaviour. They could withstand more deflection and bending loads imposed over the beams' surface. BRC beams had a greater potential to absorb energy but were less ductile than SRC beams. Most researchers had concluded that this bamboo material should be used to construct lightweight concrete structures for low-rise, high-rise and low-cost buildings where steel usage was limited.

4.12. Richards (2016) [72]

Table 8 delineates the beam sample details utilised in this experimental study.

The fracture appeared in the middle span of the bamboo-treated beams. The flexural crack was one of the crack types formed on the beam surfaces. The cracks initially propagated from the beam support at an angle of 45^{o} until the top of the beam surfaces. The stress level affected the crack size. From the experimental observation, it could be seen that the higher the stress level, the wider the crack size. A record of the cracks propagated along the reinforcement length was also investigated. The bamboo splits implied that they were not securely fastened in concrete as before. The concrete was also spalling to the beam support base due to insufficient binding strength between bamboo reinforcement and concrete. A shear fracture formed on the beam surface, causing it to fail in ductile manner. Fig. 20 depicts the load-deflection of epoxy resin-treated bamboo reinforced beams, while Fig. 21(a), (b), and (c) delineate all the beam failures that were occurred. The modulus of elasticity of the beams was also investigated. The beam also cracked in flexural starting from the beam's one-third central and spread outward. After that, the shear fracture began at one of the beam elements located at the base support and moved upward to the beam element midsection. As the stress level rose, the cracks widened, tending the beams to fail

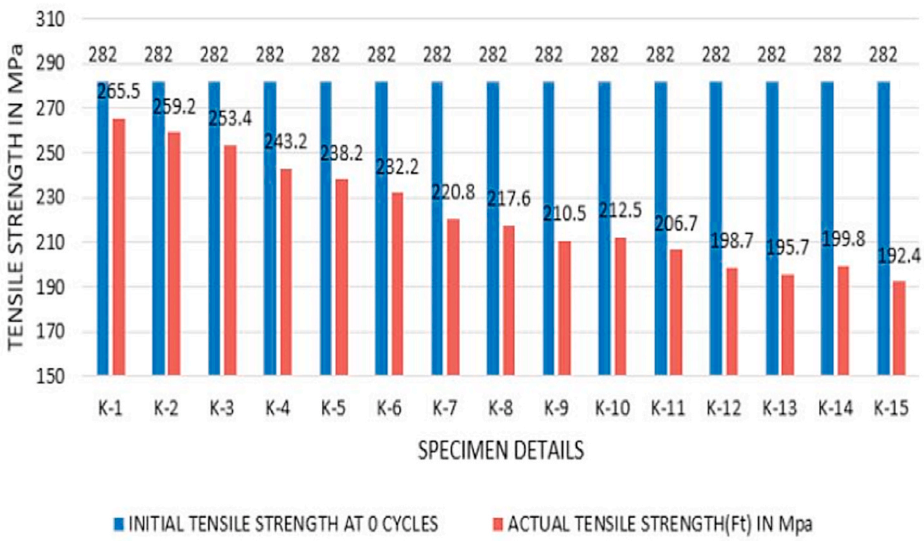

Fig. 19. Tensile strength [70].

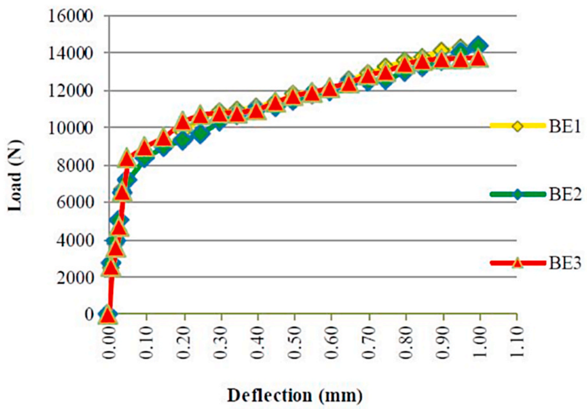

Fig. 20. Load-deflection [72].

Table 8
Details of beam samples [72].

Code	Dimension (l x w x h)	Specimen number	Bamboo surface coating type
P	800 x 150 x 150	4	No coating
BA	800 x 150 x 150	4	Araldite
BE	800 x 150 x 150	4	Epoxy
BC	800 x 150 x 150	4	Coal tar

in shear and flexure failure modes.

The beam cracks in the flexural part starting from the beam's mid-span. The beam element broke down and appeared at its lowest point in the tension zone. Besides that, the beam's flexural fracture grew longer and longer until it stopped at the final load imposed. This flexural fracture demonstrated that the beam could withstand shear force but was vulnerable to flexural force. The concrete was crushed from the bottom to the top surface of the beam, revealing its ductile characteristic. All the beam test result data were collected and presented in Fig. 22, while Fig. 23(a), (b), and (c) depict the beam failure modes. The modulus of elasticity findings showed that 75200 N/mm^2 was the highest value for the beam's flexural element that was strengthened with bamboo and coated with coal tar on its surface.

(a) BE1 (b) BE2 (c) BE3

Fig. 21. Failure modes [72].

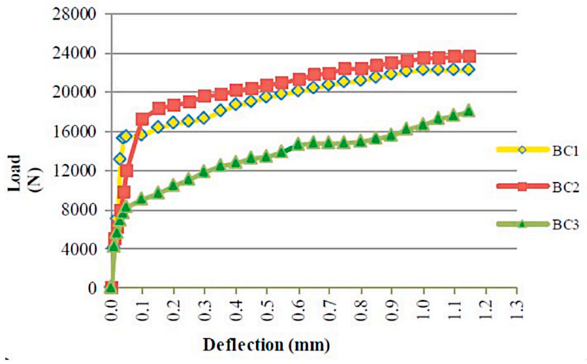

Fig. 22. Load-deflection [72].

(a) BC1 (b) BC2 (c) BC3

Fig. 23. Failure modes [72].

4.13. (Muhtar, 2021) [73]

The failure pattern of shear compression for BRCB indicated the bulk of the crack pattern resulted from the slippage between bamboo reinforcement and concrete. As the crack fractures spread upward through the concrete cover, it revealed the flexural cracks originating from the beam's bottom surface. The crack fractures branched as they approached the bamboo reinforcement. Some of the crack fractures continuing upwards and the remaining cracks propagated 90^{o} perpendicular. The fractures tend to spread laterally in the bamboo reinforcement direction due to minimum bond stress produced at the interface between bamboo reinforcement and concrete. The experimental findings showed that the BRC beam's surface had load shedding despite having shear failure mode. Bamboo reinforcement had greater tensile strength and elastic characteristics than normal steel reinforcement. Cracking and sliding grew gradually and linearly with increasing stress, leading to shear failure in the beam. Although BRC beams were not particularly rigid, they had high elasticity, flexibility and durability. Fig. 24 demonstrates the correlation between bond stress and local slip measured experimentally and calculated using moment-curvature and bond stress. There was a strong correlation between the two charts. The R2 values for experimental finding and moment-curvature and bond stress analysis were 0.936 and 0.994, examined from the coefficient determination perspective in regression analysis. According to moment-curvature connection graphs, the experimental results deviated from the theory was around 7 %, as seen in the bond stress and local slip relation. This relation concluded how the observed data quantity, like fracture patterns and various loads imposed over the mid-span of the upper beam surface, strongly

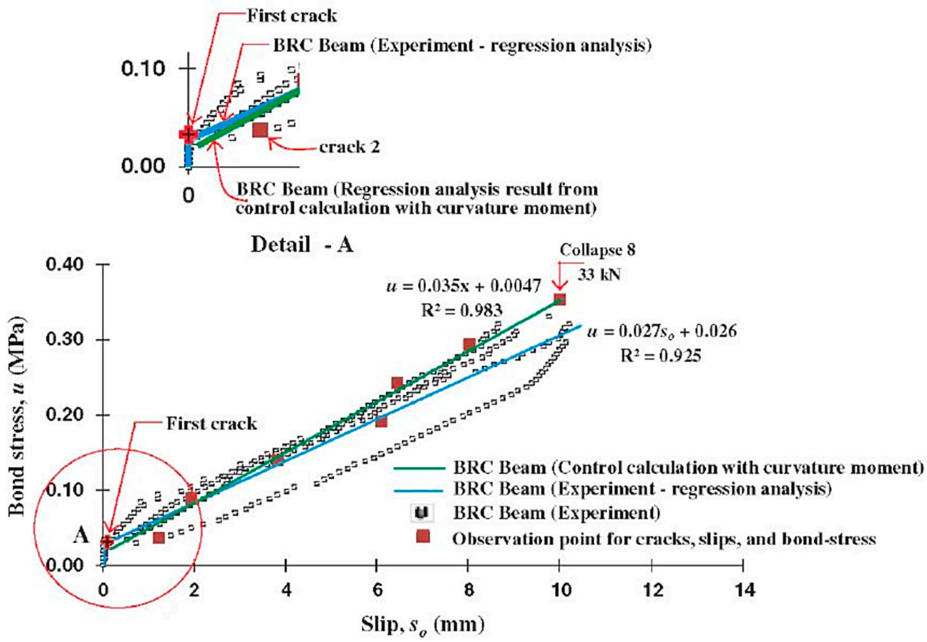

Fig. 24. Bond stress-slip [73].

influenced the estimated precision. The accuracy of the test data was highly affected by several human errors. Human mistake was a common problem, especially while setting up the tools and testing equipments. Thus, to avoid this error, the test equipments must be properly calibrated to improve the precision of the experimental results. However, analytical computation processes were also performed to prove the experimental results confidently.

The ability to extract steel reinforcement from concrete was evaluated. The experimental findings showed 60 % friction bond limit, 70 % bond strength proof, and 80 % bond stress at pre-cracking. Meanwhile, the BRC beams did not exhibit elastic or plastic limitations, as seen in Fig. 24, rendering the concepts of bond strength proof and bond stress at pre-cracking. This concept was in line with the fact that the stress-strain characteristic of bamboo reinforcement did not indicate the melting point, unlike steel reinforcement. The friction bond limit might be linearly extended to the ultimate bond strength state. The value from the initial load to friction bond limit was 30 %, while the value from the friction bond limit to ultimate bond strength was 90 %, which was higher than the initial load to friction bond limit. The friction bond limit, bond strength proof, and bond stress at pre-cracking for SRC beams could also be determined by investigating and examining the connection between bond stress and local slip. On the other hand, a horizontal line between the limit of bond stress at pre-cracking and ultimate bond strength in the relationship between bond stress and slip in the SRC beams. Theoretically, this calculating method could only regulate and validate the models based on experimental data. It could not be utilised for the testing procedures whose objective was to gather the data needed for the model because the input data relied on the experimental data. Data from experimental findings, such as fracture patterns, were still needed to calculate the concrete elongation acquired. This approach was a precise method in determining the concrete elongation compared to concrete measurement using a strain gauge, producing less accurate data. Both ways might anticipate a beam model and assess its structural parts' performance.

5. Review finding

As an alternative to the high cost of reinforcing steel, it has been suggested to use bamboo in reinforced concrete beam (RCB). Typically, monetary issues also need to be considered. While steel reinforcement is considerably more expensive, there has recently been a way to identify more environmentally friendly construction materials in the building construction sector. Bamboo is abundant in many tropical and subtropical regions. The structural and environmental performance of bamboo reinforced concrete beam (BRCB) as an alternative to steel RCB is evaluated in this review. A prototype three and four-bay portal frames are employed to demonstrate the advantages of BRCB and provide a foundation for the life cycle analysis. Standard steel reinforcing bars are typically used in building structures. The bamboo material may replace regular steel reinforcing bars as internal reinforcement. Despite bamboo's extraordinary mechanical properties, it can be summarised and concluded that using bamboo to reinforce concrete and beams is the best idea to address severe problems with durability, strength, stiffness, structural performance, strength and behaviour in RCB.

Moreover, using bamboo in RCB is highly encouraged. Bamboo reinforcement is a viable green replacement compared to steel. It has been demonstrated that BRCB shall be constructed to resist crack propagation and prevent severe failure. Bamboo reinforcement increases the RCB's ductility and post-cracking reserve capacity in the case of overload, which leads to cracking. This cracking behaviour might occur if the link between bamboo and concrete is not strong enough. Some bamboo bond-enhancing surface treatments have been illustrated to be adequate in imparting the necessary bond capacity. However, the essential uncracked design increases the dimensions of RCB members, which has a trickle-down effect that will increase the size of formwork and foundation utilised. Ordinary steel needs to be treated before production. The treatment is generally time-consuming, expensive, hazardous and subjected to severe handling regulations for employee safety. Bamboo is different from steel. It does not need to be treated across its thickness and surface and can be directly used as reinforcement in RCB because of its high strength and strong binding properties. This unconducted bamboo treatment will save time, reduce costs and avoid hazardous and severe handling regulations for employee safety. A large proportion of bamboo breeding can overcome the method used issues in biomass durability when embedded in concrete and RCB. Besides that, bamboo is also effectively helpful in easing RCB preparation, leading to better final product materials than standard steel reinforcing bars. In conclusion, bamboo reinforcement shall be practically used in the building construction sector, especially in RCB production, because it has more advantages such as stronger, cost-saving, higher strength, ductility, stiffness, and load, including better structural behaviour and performance than ordinary steel reinforcement.

6. Organisation and synthesis of the review findings

Concerning global warming and environmental problems, bamboo is an alternative to steel and conventional building materials in RCB production. Steel is one of the most widely used construction materials, contributing to rising construction costs and diminishing renewable resources. Thus, bamboo, an isotropic material, is recommended for reinforcement to replace regular steel bars. From all the experimental findings, it can be synthesised that bamboo grows faster and has two times more strength than steel. Mechanical, chemical, and durability treatments are utilised to extend the bamboo's lifetime. These treatments are undertaken because of their high usage and demand as steel substitution. The parametric analysis justifies, supports, and proves that the use of bamboo in RCB is based on its inherent strength and endurance. Nevertheless, this review article presents the performance and durability of BRCB based on previous relevant laboratory data and experimental findings. Bamboo is practically used in RCB in several countries like China, India, Myanmar, and the like since it is one of the fastest-growing plants compared to other green plants. Subsequently, bamboo can proliferate, generally between two to three months. It also increases the toughness, longevity, and adaptability of RCB when used as reinforcing material. From the many previous experimental findings, it can be concluded that bamboo has a relatively higher modulus of elasticity than steel [74–91]. Therefore, it will be able to reduce the failure of RCB under maximum load and stress applied. In contrast, the BRCB's flexural strength allows for greater load-bearing capacity, ultimate load, and stress-strain properties. In conclusion, it can be organised and synthesised that bamboo is the best reinforcement, cost-effective, and environmentally friendly building construction material.

Over the past few decades, there has been a widespread uptick in environmental and natural resource consciousness. Excessive and inadequate consumption of natural resources are now widely recognised as harmful to ecosystems. There have been significant shifts in recent years towards a more accurate understanding of sustainability as it relates to building development. In the past, many scientists, researchers, and engineers solely focused on technological concerns. Still, as time passed and walked away, several other factors, such as economic and social sustainability, became increasingly important and in high demand. Sustainable advancements in civil engineering, especially in RCB construction and production, can benefit from the usage of bamboo reinforcement. It has been prioritised in many research studies, revealing many potential applications. Subsequently, the previous experimental results showed that the bamboo's culture areas, species, and cross-sectional area produce and contribute to the inclination of the RCB's tensile strength, which may be as high as 300 kN. In addition, the flexural performance of BRCB has been found to improve with longer curing time and bigger bamboo size. Bamboo stirrup usage is also highly recommended because it improves the RCB's flexural and shear capacities. Although the primary objective is to improve the structural performance of the RCB, an additional essential criterion needs to be considered, focusing on the serviceability limit state in order to minimise the RCB's mid-span deflection as well as the RCB's span increases. Since bamboo can replace steel reinforcement, it is recommended and suggested that it is a possible reinforcement for low-cost housing and buildings, which would help conserve and preserve natural resources and reduce environmental pollution.

7. Summary

Herein are outlined the steps involved in order to learn more about how bamboo reinforcement affects the bond strength of RCB. The latest research on bamboo's mechanical properties and its potential use as an alternative reinforcement in RCB are also highlighted. Besides that, bamboo shows the best structural strength improvement as a potential reinforcement replacement in regular RCB, particularly in low-cost building construction sectors. In addition, this review article found that epoxy with sand, coir, galvanised iron, and water-based epoxy with aggregate with a hose clamp produces the best quality reinforcement bond. The manufacturing cost of bamboo bonding treatment can be reduced using epoxy and water-based epoxy coating. Finally, more research is needed to determine and analyse the efficacy and efficiency of chemical treatments as surface treatment when using corrugated or grooved bamboo as alternate reinforcement in RCB replacing normal steel bars. Standard operating procedures (SOP) detailing the proper handling of bamboo reinforcement have not existed until now. Therefore, more study is needed to evaluate the bamboo's potential as an alternate reinforcement in building structural components, especially in RCB construction. Bamboo's significant potential as internal reinforcement instead of steel reinforcement in building construction is shown by the various treatment methods available.

8. Conclusion

(1) The actual and theoretical ultimate moment of resistances of bamboo splint foamed aerated concrete beams rose as the number of bamboo splints in the tensile zone inclined. Adding more bamboo splints in the tensile zone also enhanced the failure loads of the beams.
(2) The bamboo beam's bond-stress reinforcement can be calculated using a direct bond pull-out test. The bond-slip behaviour of bamboo reinforcement in concrete depends on the reinforcement surface state. However, if the hose clamp is not properly installed, it may reduce the ductility of the bamboo RCB despite increasing the beam's stiffness and bond slip. A beam is reinforced with bamboo and covered with water-resistant material and a hose clamp, which reduces the beam cracks' width and breadth before it fails. When the slide mechanism fails, it will cause the beams to crack and eventually fail.
(3) The flexural strength of the oil-painted bamboo reinforced beam is 78 MPa, which is 22 %, 27 % and 20 % higher than control, bituminous paint, and uncoated bamboo beam specimens. Experimentally, the strongest bamboo specimens have bottom, middle, and top nodes of 170 MPa, 160 MPa, and 30 MPa. Due to fibre breaking, the bamboo sample failed at the node. Bamboo's porous structure easily absorbs water. Coating with oil or bituminous paint decreases water absorption by 47 % and 13 %, respectively, compared to untreated specimens. Oil-based paint instead of bituminous paint reduces bamboo's ability to absorb water.

CRediT authorship contribution statement

Solahuddin Bin Azuwa: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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