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Feasibility of Using Palmyrah and Bamboo Strips as Reinforcement in Lintels

H. Y. V. Dias[1], M. A. S. S. Munasinghe[2] and K. Baskaran[3]

[1, 2, 3]University of Moratuwa, Katubedda, Sri Lanka

yomaldiaz@gmail.com, TP: +94716837096

Abstract: Timber species such as Palmyrah, Bamboo and Babadua have been identified to have potential to replace reinforcing steel in concrete elements. This research was conducted to assess the feasibility of using Palmyrah and Bamboo strips as reinforcing material in lintels. The low ductility of such timber specimens, as observed during the experiments, governed this selection of a lightly loaded low risk structural element for the study. Tensile strength, water absorption and desorption characteristics, associated dimensional variations, anchorage bond strength and flexural strength of Palmyrah and Bamboo strips coated with different water repellents were evaluated using a series of laboratory experiments. Having identified double varnish coated water repellent technique to give the highest anchorage bond strength and lowest water absorption, four lintels were cast keeping two as unreinforced control specimens and two reinforced with Palmyrah and Bamboo strips. While both reinforced beams exhibited under-reinforced behaviour, one with Bamboo reinforcement achieved an incremental moment capacity of 250% and the beam with Palmyrah reinforcement achieved that of 168% compared to their respective unreinforced beams. Hence, it was concluded that both Palmyrah and Bamboo shows potential to be used as reinforcement for lintels.

Key Words: Timber Reinforcement, Bamboo, Palmyrah, Lintel

1. Introduction

Construction industry is one which consumes significant amounts of non-renewable resources. With growing concerns on developing sustainable and cost effective solutions, much focus has been given during the last two to three decades to identify renewable materials, which can successfully replace conventional construction materials.

Steel is one such conventional construction material that is imported to Sri Lanka. Its uses within the country range from low cost rural housing schemes to high rise buildings in the heart of Colombo. The reason for steel to be considered the “go to” solution in structural and even non-structural applications could be the availability of a comprehensive and accurate knowledge base of its properties and the convenient availability of the material throughout the country [1]. Ghavami (2005) [2] specifically identified this lack of knowledge and research on locally available materials in developing countries as a key factor leading to the eventual use of industrialized materials for every application.

There have been a number of studies conducted in the past to determine the engineering properties of some natural fibres. Research conducted on Bamboo, Babadua, Raffia, Palm, Jute Wood have established a comprehensive knowledge base with respect to their mechanical properties [3-7].

In the Sri Lankan context, some research has been conducted to identify the mechanical properties of Bamboo and Palmyrah species found at various regions within the island, and to assess the performance of Palmyrah reinforced concrete beams and slab panels.

The present study was conducted to assess the feasibility of using Bamboo and Palmyrah strips as reinforcement in lintels. The choice of this structural element depended on the mechanical properties of timber species tested. Both Bamboo and Palmyrah specimens exhibited low ductility compared to steel during testing stages [1, 2, 8, 9]. It was decided to adopt a lightly loaded common concrete element with low structural significance for the study due to this reason.

2.Review of Literature

2.1 Bamboo as a reinforcing material

Tests on mechanical properties of bamboo have been conducted by various researchers in the past. Table 1 summarizes the findings by past researchers with respect to strength and stiffness properties of Bamboo.

Table 1 - Mechanical Properties of Bamboo

		Ghavami [3]	Harish et al. [8]	Pratima et al. [9]
Ultimate Tensile Strength (N/mm^2)		< 370	115-128	139-164
Modulus of Elasticity (GPa)			9.5-19	5.1
Ultimate Compressive Strength (N/mm^2)			108	
Pull Out Strength (N/mm^2)	Treated	0.73 - 2.75	0.9-1.3	
	Non Treated	0.52	0.95-1.07	
Shear Strength (N/mm^2)			29	

The ultimate tensile strength of Bamboo is comparable with that of Mild steel. Thus, the strength to weight ratio of Bamboo could be six times higher than that of Steel [3].

The modulus of elasticity established from previous researches for both Bamboo and Palmyrah species are comparatively low. They are in fact lower than that of concrete, and does not make a considerable contribution to the flexural stiffness of the reinforced beam [2]. In general, modulus of elasticity of Bamboo is considered to be approximately 1/15 of that of Steel [10].

Another issue associated with using timber in engineering applications is the damage due to insect attack. Bamboo with moisture content less than 15% is less likely to be susceptible to such attacks [3]. The service life of Bamboo in contact with ground can be as low as 1 year [10].

Testing of Bamboo reinforced beams have shown that prime cause of failure is the tensile failure of concrete and Bamboo. Even the over reinforced test specimens have not developed compression failure due to the impossibility of creating perfect bonding between concrete and Bamboo [3].

Absorption, desorption of moisture and associated dimensional variations are also major shortcomings that prohibit the use of Bamboo bars as reinforcement in concrete in their raw form. Stresses induced in the hardened concrete due to volumetric changes in timber reinforcement may introduce cracks, impairing the durability of the element [4, 5].

With effective treatment techniques, Bamboo-concrete bonding has found to increase by more than 100%. A reinforcement percentage of 3% has found to increase the ultimate load capacity of Bamboo reinforced beams by 400% compared to their unreinforced control specimen [3].

Bamboo reaches its full growth in a few months and maximum mechanical resistance is developed in a few years. It is also the fastest growing woody plant on the planet belonging to the grass family [11].

The colour of Bamboo is an indication of the maturity of the plant and could be used as a basis when identifying suitable specimens for engineering applications. Brown coloured trunk is an indication that the tree is at least three years old.

The properties of Bamboo vary depending on the nature of growth, climate conditions and soil moisture conditions. Therefore, although there exists a considerable amount of reliable information from past researches, it is required to establish reliable strength parameters pertaining to local conditions as past research may not be representative of local Bamboo species.

2.2 Palmyrah as a reinforcing material

Palmyrah growth in Sri Lanka is predominant in the dry zone, quite notably in the northern region. Generic uses of Palmyrah in building construction range from roofing elements such as rafters and purlins to earth retaining walls in bunkers.

Table 2 - Mechanical Properties of Palmyrah

	Baskaran et al. [1]
Tensile Strength parallel to grain (N/mm^2)	40-170
Modulus of Elasticity (GPa)	8-20
Compressive Strength parallel to grain (N/mm^2)	72-90
Flexural Strength (N/mm^2)	40-190

Baskaran et al. [1, 2] conducted experiments on Palmyrah samples from Jaffna and Puttlam from which the basic engineering properties shown in table 2 were established. The authors adopted the guidelines set out in BS EN 338: 1995 [12] in classifying the strength class of the specimen. Although the characteristic strength values conformed to the minimum strength limits of G70, hardwood of Palmyrah was categorized as G40, as the Elastic modulus of the tested specimens only achieved the limiting values of G40 class. The authors further stated that the tested specimens, despite originating from different regions in the island, exhibited similar mechanical properties.

3. Methodology

3.1 Tensile Strength Testing

Simple tensile strength tests were performed to evaluate the tensile strengths of Bamboo and Palmyrah strips. Three Palmyrah strips with approximately 12mm x 12mm cross sectional dimensions were tested using the Amsler machine.

Fifteen Bamboo specimens extracted from top, middle and bottom parts of the tree were tested using the tensometer. A fractured Bamboo specimen is shown below in figure 1.

Figure 1: A failed Bamboo specimen under tensile strength testing

3.2 Water Absorption and Desorption Testing

3.2.1 Palmyrah

Two series of tests were conducted on both softwood and hardwood samples of Palmyrah, coated with a variety of water repellent agents. Single and double coats of sanding sealer, varnish, black oil, bitumen, water paint and oil paint were utilized under this scheme.

Initially, the weights and the dimensional measurements of Series 1 Palmyrah samples were recorded. These samples were then put in the oven. Weights and dimensional measurements of these samples were recorded every 15 minutes. The oven dried Palmyrah samples were then immersed in water and similar readings were taken with time under absorption testing.

Series 2 contained a different set of treated and untreated Palmyrah samples. Here, the absorption test was conducted prior to the desorption test.

3.2.2 Bamboo

Water absorption tests were conducted on 63 treated and untreated Bamboo samples extracted from top, middle and bottom parts of the trunk. The test specimens were submerged in water for a total duration of 96 hours and weight measurements were taken within the test duration.

A separate set of 15 untreated Bamboo samples were used for desorption testing where the samples were oven dried for 24 hours and weight measurements were taken.

3.3 Pull Out Test

These pull out tests were carried out considering the guidelines established in BS EN 12504-3, (2005) [13]. Three varnish double coated Palmyrah specimens with approximately 12 mm x 12 mm cross sectional dimensions were tested using the Amsler testing machine, after 28 days from their casting date. Anchorage lengths of 50 mm, 100 mm and 150 mm were provided for the three specimens to assess the variation of pull out force with anchorage length. Figure 2 below shows the Pull out test setup and a failed sample split in to two to see the anchorage slip.

a b

Figure 2: (a) Pull out test setup, (b) Failed test specimen

Seven Bamboo specimens with different water repellent treatments and nodal arrangements were tested with each having 200 mm anchorage.

3.4 Bond Strength under Flexure

In order to investigate the behaviour of bond strength between the two types of timber reinforcing bars and concrete, the guidelines stated in BS EN 12269-1 (2000) were adopted. For each type of reinforcement, four beams were cast with the following properties.

i. Plain unreinforced concrete beam
ii. Beam reinforced with an untreated reinforcing bar, having an anchorage length of 600 mm
iii. Beam reinforced with a treated reinforcing bar, having an anchorage length of 400 mm
iv. Beam reinforced with a treated reinforcing bar, having an anchorage length of 600 mm

The tensile reinforcement area was 144 mm^2 and 300 mm^2 for Palmyrah and Bamboo reinforced beam specimens respectively. The Bamboo reinforced beam was of 1400mm x 150mm x 100mm dimensions whereas the Palmyrah reinforced beam had dimensions of 2000mm x 200mm x 150mm. Water repellent technique used for all 8 beams was varnish double coating. Palmyrah reinforced beams were cast with grade 35 concrete and tested 7 days after casting. The ones reinforced with Bamboo were cast with grade 25 concrete and tested 38 days after casting.

Two point loading system, as indicated in figure 3, was used when testing the beam specimens. Under this loading scheme, the portion of the beam between the two loading points is under pure flexure. This is desirable as the test is required to investigate the bond behaviour under flexure. Central deflection, crack initiation load and failure load were recorded.

Figure 3: Testing for bond strength under flexure of a Bamboo reinforced specimen

3.5 Testing of Lintels

Theoretical flexural moment capacity of an unreinforced concrete section assuming a triangular stress distribution can be derived as;

$$M_t = \frac{f_{ct} b h_m{}^2}{6} \qquad (1)$$

Where;

hm is the height of the section at mid span

The tensile strength of concrete, fct was found using equation 2, as per the guidelines of BS 8110; Part 1, (1985).

$$f_{ct} = 0.45\sqrt{f_{cu}} \qquad (2)$$

Flexural capacity of an under reinforced section was evaluated using equation 3.

$$M_t = A_s f_t \left[d - \frac{k_2 A_s f_t}{k_1 f_{cu} b}\right] \qquad (3)$$

Where;

A_s is the provided reinforcement area

f_t is the tensile strength of reinforcement material

d is the effective depth of section

k_1 is the factor to account for maximum compression strength at flexure

k_2 is the depth factor

k_1 is taken as 0.67 and k2 is taken as 0.45 as per the guidelines of BS 8110; part 1, (1985) [14].

Experimental moment capacity under flexure at mid span, M_t is derived as;

$$M_t = \frac{wl^2}{8} + \frac{Pl_w}{4} + \frac{Rl_e}{2} \qquad (4)$$

Where;

w is the self-weight of the beam

P is the load at failure

l is the total length of the beam

l_e is the distance between supports

l_w is the distance between loading points

R is the support reaction

A design was carried out considering a typical lintel opening using the guidelines provided in BS 5977-1 (1981) and BS 8110-1 (1985). The Palmyrah reinforcement was of 400 mm^2 cross sectional area where as Bamboo reinforcement was made up of two bars with each having 150 mm^2 cross sectional area.

Concrete beams reinforced with varnish double coated Palmyrah and Bamboo bars were cast using grade 35 concrete. For each reinforced beam, an unreinforced control beam specimen was cast from the same concrete. All the beams had 1400 mm x 150 mm x 100 mm dimensions. Testing was done 7 days after casting.

Two point loading system was used in testing and central deflection, initial cracking load and ultimate failure load were recorded.

4. Experimental Results

4.1 Tensile strength

Tensile strength testing yielded much cohesive results for Palmyrah samples with an average tensile strength parallel to grain of 86.5 N/mm^2 and a maximum of 103.0 N/mm^2.

However, Bamboo exhibited a much wider distribution of tensile strength values among its 15 tested samples with a minimum of 29.9 N/mm^2 and a maximum of 226.2 N/mm^2, resulting in an average of 109.7 N/mm^2 and a standard deviation of 54.0 N/mm^2. The samples extracted from the bottom of the trunk showed relatively cohesive tensile strength values, also greater than those exhibited by the samples from middle and top portions of the trunk.

4.2 Water absorption and desorption

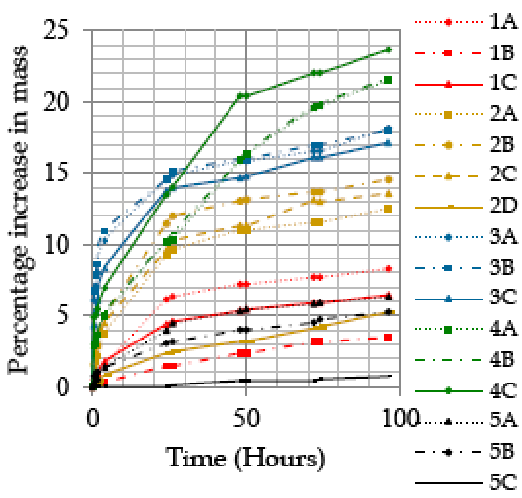

Figure 4: Water absorption characteristics of Palmyrah specimens – Series 1

Table 3: Specimen groups for Figure 4

Group	Treatment Type
1	1st coat varnish, 2nd coat sand sealer
2	Solignum coated
3	Untreated hardwood
4	Untreated softwood
5	1st coat sand sealer, 2nd coat varnish

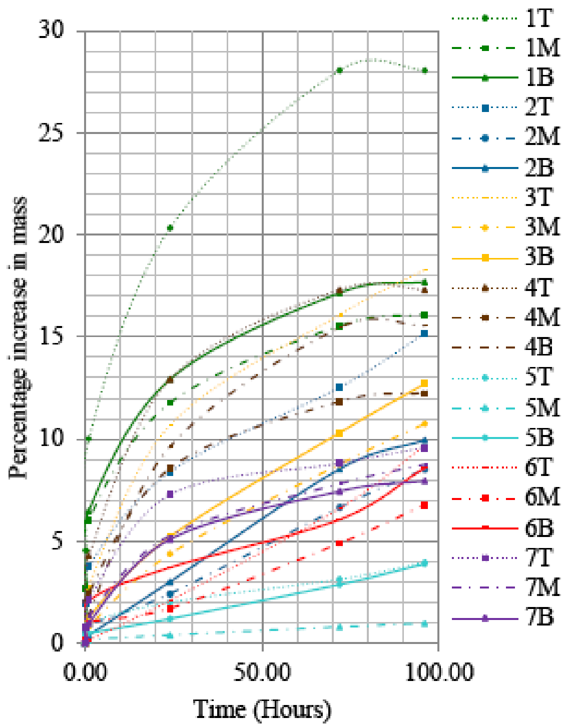

Figure 5: Water absorption characteristics of Bamboo specimens

Table 4: Specimen groups for Figure 5

Group	Treatment Type
1	Untreated specimen
2	Sand sealer single coat
3	Varnish single coat
4	Black oil single coat
5	Sand sealer double coat
6	Varnish double coat
7	Black oil double coating

The potential for swelling was evaluated for these different water repellent techniques by measuring the mass of the test specimen with time and the results were plotted as in Figures 4, 5 and 7. The results indicate that for both Palmyrah and Bamboo species, untreated specimens exhibit the greatest water absorption amounts. Combined sand sealer and varnish coating appears to be the most effective water repellent technique among the tested, with the potential to limit water absorption to 8% by mass at 100 hour exposure for both timber species.

The volumetric changes were calculated using the measured changes in the cross sectional dimensions and lengths of the samples and plotted as shown in figures 6 and 8.

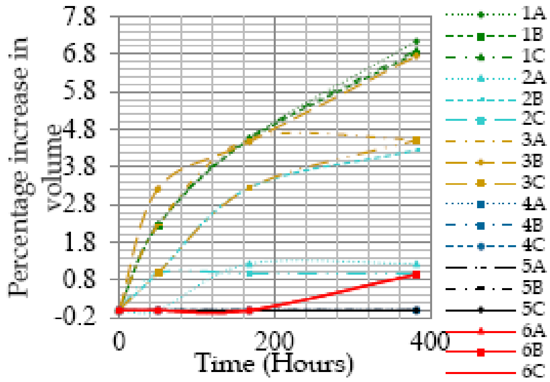

Figure 6: Swelling potential of treated Palmyrah specimens – Series 2

The percentage increase in volume of varnish and bitumen coated specimens was less than 1% after being submerged in water for 400 hours.

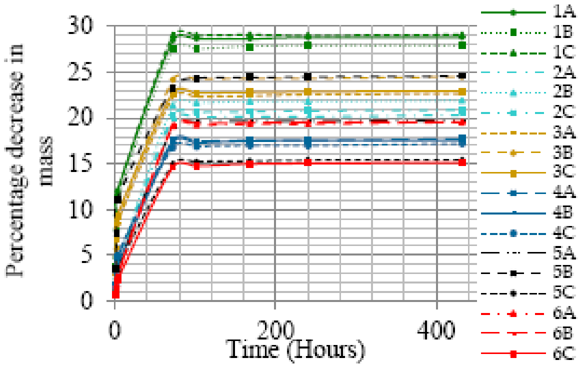

Figure 7: Water desorption characteristics of Palmyrah specimens – Series 2

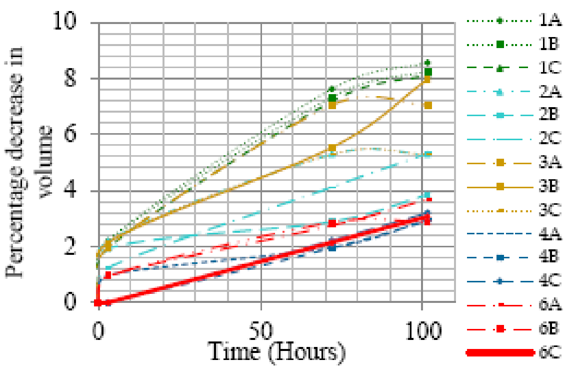

Figure 8: Shrinking potential of treated Plamyrah specimens – Series 2

Table 5 - Specimen groups for Figures 6, 7 and 8

Group	Treatment Type
1	Untreated specimen
2	Solignum coated
3	Water paint and oil paint
4	Sand sealer coated
5	Varnish coated
6	Bitumen coated

Percentage reduction of mass during desorption testing was less than 20% for both bitumen and sand sealer coated specimens. Corresponding reductions in volume were under 6%.

4.3 Anchorage Strength

Pull out tests conducted on varnish double coated Palmyrah strips with 12mm x 12 mm cross sectional dimensions yielded the results shown in table 6. The reduction in pull out load, with the reduction of anchorage length however, as expressed in table 6, is very low.

Table 6 - Anchorage strength of Palmyrah strips

Specimen	Anchorage length (mm)	Pull out load (kN)
A	150	5.9
B	100	5.4
C	50	4.7

Results of the anchorage strength tests conducted on Bamboo strips are tabulated in table 7.

Table 7 - Anchorage strength of Bamboo strips

Specimen	Anchorage length (mm)	Pull out load (kN)
A	200	8.4
B (with node)	200	14.6
C	200	8.4
D (with node)	200	16.1
E	200	7.7
F (with node)	200	12.7
G (Corrugated)	200	11.9

The Bamboo specimens with nodes exhibit pull out loads greater by 65% - 90% compared to the ones without nodes.

4.4 Bond Strength under Flexure

Flexural strength test specimens failed exhibiting under reinforced behaviour. Crack initiation for all beams occurred at mid span. However, Bamboo reinforced beams developed a noticeable crack spanning from one of the loading points at the top to the bottom of the beam, which lead to the ultimate failure. Further investigations revealed that such cracks occurred across spans containing nodes in the Bamboo reinforcement bar. The resulting stress concentration at such locations could have caused such failure patterns. The addition of both types of timber bars, as tensile reinforcement, has increased the failure load as well as provided ductility to the beams.

4.5 Testing of Lintels

A longitudinal crack was visible along the centre of the bottom surface of the Palmyrah reinforced beam at failure. This undesired drawback was eliminated in the Bamboo reinforced beams by providing two reinforcing bars with smaller cross sectional areas rather than one bar with larger cross sectional area. In addition to the flexural crack at mid span, Bamboo reinforced beam exhibited a diagonal crack similar to the one experienced under testing for anchorage strength under flexure. This crack, as shown in figure 9, spanned from one of the loading points to the bottom surface of the beam diagonally. Further investigation by removal of concrete around the crack revealed the existence of nodes in both Bamboo strips. Local stress concentration due to these nodes could have caused this crack.

Figure 9: Additional crack across the beam in Bamboo reinforced specimens

The initial crack in all the tested beams occurred at approximately 5 kN. The Palmyrah reinforced beam failed at an ultimate load of 12.8 kN with an enhancement of 156% from its unreinforced counterpart. For the Bamboo reinforced beam, with an ultimate failure load of 20 kN, this enhancement amounted to 300%.

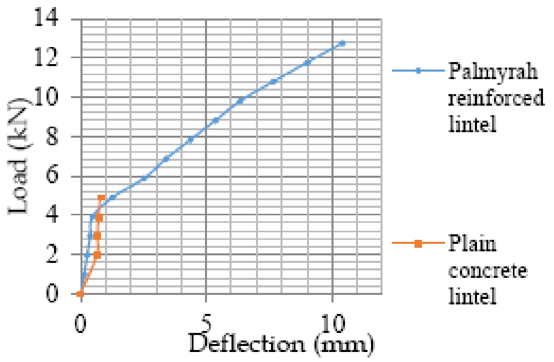

Figure 10: Load vs. Deflection curve for Palmyrah reinforced lintel

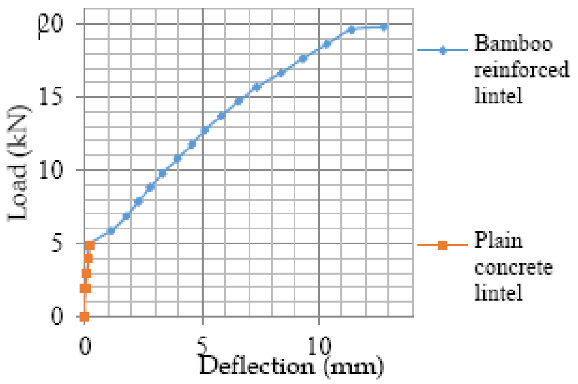

Figure 11: Load vs. Deflection curve for Bamboo reinforced lintel

In Figure 10 and Figure 11, the gradients of the curves for the two lintels in each figure are very similar within the elastic region. Hence, both types of timber reinforcement considered here have negligible effect on the stiffness enhancement of the lintels. The load causing initial crack is approximately the same for both reinforced and unreinforced lintels. However, the addition of the timber strips have provided significant ductility to both reinforced lintels compared to their unreinforced counterparts.

Theoretical and experimental moment capacities of Palmyrah reinforced lintel and its control specimen were evaluated and the values are given in table 8. Here, the compressive strength and the tensile strength of concrete were evaluated to be 36.4 N/mm^2 and 2.5 N/mm^2 respectively. Uniaxial compressive strength test and splitting tensile strength test were used to derive these values.

Table 8: Theoretical and experimental moment capacities of Palmyrah reinforced lintel

Specimen	M_t (kNm)	M_e (kNm)	$(M_e-M_t)/M_t$ x100%
Unreinforced lintel	1.12	1.44	28.6
Bamboo reinforced lintel	3.03	5.02	65.7

The experimental moment capacity of the Palmyrah reinforced concrete beam differs only by - 1.2% compared to its theoretical moment capacity.

Testing for Bamboo reinforced lintel yielded the moment capacities presented in table 9. Here, the average compressive and tensile strengths of concrete were 43.2 N/mm^2 and 3.0 N/mm^2 respectively. These too were also derived using the uniaxial compressive strength test and splitting tensile strength test.

Table 9: Theoretical and experimental moment capacities of Bamboo reinforced lintel

Specimen	Mt (kNm)	Me (kNm)	(Me-Mt)/Mt x100%
Unreinforced lintel	1.12	1.44	28.6
Bamboo reinforced lintel	3.03	5.02	65.7

The experimental flexural capacity is greater by 65.7% in comparison to the theoretical moment capacity of the Bamboo reinforced concrete lintel.

5. Conclusions and Recommendations

The following conclusions were made from the results of the experimental study.

i. Both Palmyrah and Bamboo reinforcement increase the flexural capacity of lightly loaded lintels

ii. Although the introduction of these reinforcing timber strips had negligible effect on the initial cracking load, the ultimate failure occurred with the failure of tensile reinforcement, exhibiting under reinforced behaviour

iii. Varnish and bitumen coating have the potential to limit water absorption to 8% by mass and limiting dimensional variations to negligible proportions

From the experimental results, it can be concluded that both Palmyrah and Bamboo exhibit strong potential to be used as reinforcement in lightly loaded concrete lintels with minor structural importance. However, it should be noted that the tests conducted under this study primarily address the short term behaviour of tested elements. Long term behaviour and properties are of significant importance, as the practical applications of these would at least have a design life time of 50 years, as in the case of residential houses.

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