STUDY ON PALMYRAH AS A MATERIAL FOR CONSTRUCTION

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Abstract

For the pursuit of sustainable development, construction of cost effective houses, with fewer disturbances to nature is a major concern. A permanent rise in the price of building materials which involves heavy capital investments is the reason for the utilization of all kinds of innovative materials. Palmyrah is an important economic resource, which is widely spread all over North East region in Sri Lanka and has found use in many structural applications. This research explores the possibility of using Palmyrah as a material for construction; as an individual structural member as well as reinforcement member in lightly loaded concrete elements. Structure of this research consisted of literature survey, basic design, construction, testing, analysing of results and discussion. There are two main objectives in this study. First objective is identifying mechanical properties of Palmyrah strips for the efficient use of Palmyrah as a structural timber. Static bending test, tensile test and compression test were conducted to identify characteristic values of strength and stiffness properties along with density and moisture content. Ultimately, Palmyrah is graded into a strength class for the benefit of timber suppliers and designers. Second objective is to determine the technical feasibility of using Palmyrah strips as an alternative for reinforcing steel in short span, lightly loaded slabs and beams. Failure loads, crack loads, mode of failure and crack patterns of test slabs and beams were observed. Flexural capacity of concrete slabs and beams reinforced with Palmyrah strips was evaluated. Results of mechanical tests showed variation of properties with maturity, height, cross section and origin. Although heartwood of Palmyrah inherits high bending, tensile and compressive strength, it has to be graded into D40 owing to its low modulus of elasticity. Strength and density of sapwood part is relatively lower due to its high moisture and starch content. It was observed in the experiments conducted that Palmyrah reinforcement enhanced the failure load of the slab by 107% and failure load of beam by 370%. Experimental failure load of slab and beam averaged 140% and 164% of theoretically predicted value respectively. Thus it is concluded that Palmyrah strips have potential to be used as reinforcement in lightly loaded slabs and beams.

Key words: Palmyrah, composite, strength class, non metallic reinforcement, heartwood, sapwood

1.0 Introduction

The current energy crisis provoked by indiscriminate industrial increment and population growth has caused increasing concerns about managing the energy resources available today. The pursuit of sustainable development has become a major issue when trying to meet the challenges in providing proper housing for the ever increasing world population without environmental degradation. The understanding of sustainability in building construction has also undergone changes over the years. First attention was given to the issue of limited resources and how to reduce the impact on the natural environment. Now, emphasis is placed on more technical issues such as materials, building components, construction technologies and energy related design concepts.

Lack of reliable technical information about the local materials makes the consumers mainly depend on industrialised materials for which the information is freely available. It is the reason for, industrialised materials such as ordinary Portland cement (OPC) and steel are still dominating construction industry. In this context, there is an intense ongoing search for non polluting materials and manufacturing processes, which require less energy. Emphasis is placed on innovative, non conventional materials and construction technologies. As a result, extensive researches have been carried out on structural use of indigenous local materials such as bamboo, coconut fibres, sisal, palm and other natural woody plant materials[1,2,3].

Low cost housing construction is a complicated and ever present problem both in developed and developing countries. Recent escalation of steel prices has created controversial problems in Sri Lanka where steel is imported. In addition, after 2004 Indian Ocean Tsunami and thirty years of internal conflict, the demand for low cost construction has been increased drastically. Government's urgent need to rehabilitate people of North East whose lives have been shattered by civil war and Tsunami, has evoked increasing concerns about the necessity for alternative, cost effective materials.

Palmyrah tree flourishes in tropical and subtropical climates in South East Asia. It is a cheap and replenishable agricultural resource which is abundantly available in dry zone of Sri Lanka. It has found use in structural applications such as purlins and rafters for residential dwellings and walls of bunkers. Although there is a great deal of local field experience with Palmyrah, the mechanical properties have not been well characterized and graded. The main hurdle for the application of Palmyrah in structural composites and individual structural member is the lack of sufficient information about the timber, variability in properties from tree to tree and within the tree itself, low bonding between composites and unpredictable durability due to water absorption, insect attack, natural and seasoning defects. These issues have been addressed in this paper as initiative steps to the design process of the timber as a structural member and reinforcement bar.

The objective of this paper is to present a concise summary of mechanical properties such as flexural and tensile strength with stiffness values. Along with that, this investigation has explored the feasibility of using Palmyrah strips as reinforcement in lightly loaded slabs and beams. This paper opens up, with literature review about grading of timber species and timber reinforcement. Then it goes with methodology of experimental process and analysis of their results. It concludes with discussion of results and suitable recommendations.

2.0 Lliterature Review

2.1 Grading of Timber

Strength properties are the key to structural design although other attributes such as appearance may well come into consideration when assessing the overall performance of a component or a structure. Strength grading is described as a set of procedures for assessing the strength properties of a particular piece of timber. The strength grade is arrived at by either visual grading or machine grading. Visual grading is done using the principles set out in BS EN 518: 1995[4] whereas machine grading is done in accordance with the requirements of BS EN 519: 1995[5]. Visual grading will give as an output, the strength related to the visual characteristics and species while machine grading will grade the timber directly to a strength class. The European strength class system is defined in BS EN 338: 1995 [6] and this has been adopted for use in BS 5268[7]. There is a set of classes for softwoods; the 'C' classes ('C' for conifer) and a set for hardwoods; the 'D' classes ('D' for deciduous) [8].

2.2 Timber Reinforcement

For more than half a century, the scarcity and high cost of steel reinforcing bars in many areas of the world have prompted research into the practicability of using natural, non ferrous reinforcing materials such as timber strips and natural fibres.

There has been a growing interest in substituting bamboo and Babadua strips for steel reinforcement in concrete [1, 2, 3,9 and 10]. It is noteworthy to state that previous researches have revealed that the tensile strength of bamboo is relatively high and can reach up to 370MPa[3].This makes bamboo an attractive alternative to steel in tensile loading applications. This is due to the fact that the ratio of tensile strength to specific weight of bamboo is six times greater than that of steel [3].Series of research programme has been conducted to access suitability of bamboo reinforced light weight concrete elements for low stress applications [2].

The results of those investigations show that, for the bamboo reinforced lightweight concrete beam, the ultimate applied load has increased up to 400% as compared with the concrete beams without bamboo reinforcement. It was also found that the 3% bamboo, in relation to the concrete section, is the recommended value of reinforcement. The Negrolin-sand wire treatment has improved the bamboo concrete bonding by 90% [2].

The energy necessary to produce $1m^3$ per unit stress projected in practice for materials commonly used in civil construction, such as steel or concrete, has been compared with that of bamboo. It was found that for steel it is necessary to spend 50 times more energy than for bamboo [1].Since the modulus of elasticity of bamboo is not generally much greater as that of concrete, bamboo does not make a significant contribution to the flexural stiffness of bamboo reinforced concrete sections. Other main shortcoming of bamboo is dimensional variation of bamboo strips within concrete due to moisture and temperature effects, which lead to cracking of concrete during service life [1, 2, 3].

Laboratory tests have been carried out on one way and two way concrete slabs that had been reinforced with Babadua bars. The span to effective depth ratio of the one way slabs, which were subjected to third point line loads ranged between 12.5 and 19.3. Experimental failure loads were found to average 175% of the theoretically predicted values [10].On the average, monotonic and cyclic failure loads of two way slabs were approximately 330% and 270% greater than the theoretical flexural strength respectively, and 148% and 198% greater than the theoretical punching shear strength of unreinforced concrete section [9].

At the same time, there have been extensive researches to investigate feasibility of using natural fibres namely coconut, jute and coir to provide tension in concrete. Their physical properties have shown no deterioration in concrete medium [11].Tensile strength and volumetric stability were investigated on indigenous woody plant materials to be replaced for mild steel reinforcement in reinforced cement mortar composites [12].

The above studies have depicted that the strips or fibres of some ecological materials satisfy fundamental requirements to be used as reinforcing bars in concrete elements. After water treatments, they show no decay in concrete medium. But swelling and shrinkage of timber and low bonding strength between timber and concrete are still critical issues which limit their applications in composites.

3.0 Methodology

This study is carried out in two parts.

1. Identification of physical and mechanical properties of Palmyrah.
2. Investigating feasibility of using Palmyrah strips for reinforcement in lightly loaded concrete slabs and beams.

3.1 Characterizing Timber Properties

Foregoing study under the first part identifies the gaps in the knowledge pertaining to effective use of Palmyrah as a structural member. Under this, Palmyrah strips have undergone grading procedures for timber. Three sets of test pieces from different areas of Sri Lanka were subjected to mechanical tests for the purpose of characterizing mechanical properties. Sample sets A,C1 and C2 are from Point Pedro-Jaffna whereas sample set B was collected from Puttlam. Sample sets A and B contained only heartwood whereas sample sets C1 and C2 also contained softwood.

3.1.2 Mechanical Grading

All test pieces were visually inspected for any strength reducing characteristics before performing mechanical tests. Special attention was given to orientation of fibre and percentage of fibre within the cross section. Seasoned Palmyrah logs were cut and planed according to specified dimensions in BS 373:1957 [13], in a timber workshop in Katubedda. Then following tests were conducted in the structural testing laboratory at University of Moratuwa.

(a). Static Bending Test

Static bending test by central loading method was carried out by universal timber testing machine. Standard dimensions of the test samples were 2cm×2cm×30cm. Distance between point of support of test piece is 28cm. Number of test pieces, subjected to static bending test under sample sets A, B and C were 20,10 and 15 respectively.

(b).Tensile Test

Tension parallel to grain was investigated by conducting a tensile test as shown in figure 1. Actual dimensions at minimum cross section were measured to calculate tensile stress. Load is applied to the 2cm face at the ends of test piece by a special toothed plate grips in Tensometer. Test samples were 30cm long and 6mm thick. Ten samples from sets A and five from B and C were subjected to test.

(c).Compression Test

Resistance to compression parallel to longitudinal grain is determined using the universal timber testing machine. Standard dimensions of the test pieces were 2cm × 2cm × 6cm. Compression tests were conducted on 10, 5 and 5 pieces from sample sets A, B and C respectively.

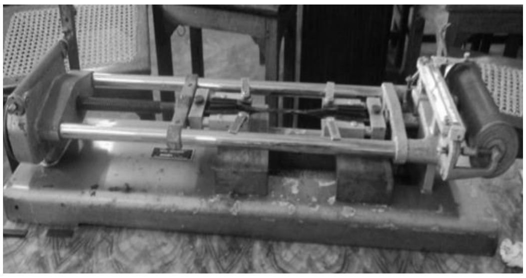
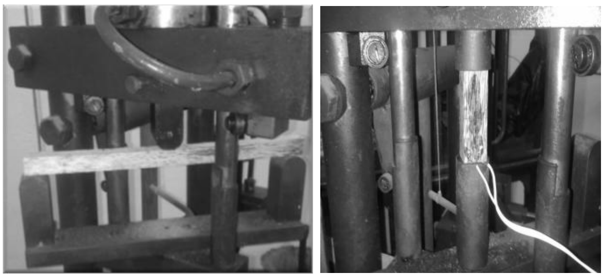


Figure 1: Tensile Test by Tensometer



(a) **(b)**

Figure 2: Static Bending Test and Compression Test by Universal Timber Testing Machine

Immediately after each mechanical test, samples were weighed and oven dried to determine moisture content. Water absorption test was also conducted on 10 samples which were untreated by water repellent and 2 samples, painted with varnish. Weights were measured at hourly intervals initially and 12 hour intervals later.

3.2 Palmyrah Strips for Reinforcement

Second part explores the possibility of using Palmyrah strips for reinforcement in concrete slabs and beams. Palmyrah strips were coated by varnish and dried for 24 hours as a water repellent treatment.

3.2.1 Reinforcement of Lightly Loaded Concrete Slabs

Table 1: Details of Slabs

	Slab dimensions	*Cross section of Palmyrah strips*	*Spacing*	*Reinforcement Percentage*	*Cover*
Slab 1	*1200mm x 1200mm x 60mm*	*10mm×10mm*	*300 mm*	*0.7%*	*15mm*
Slab 2	*1200mm x 1200mm x 60mm*	*10mm×10mm*	*100 mm*	*1.8%*	*15mm*

(a) **(b)**

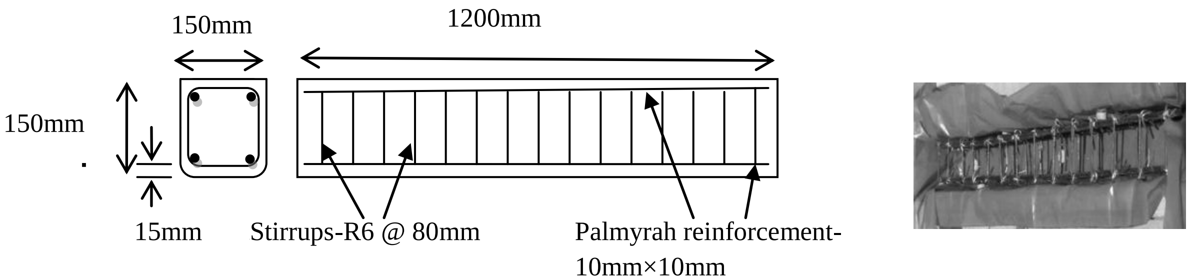
Figure 3: Palmyrah Reinforcement Nets of Slab 1 (a) and Slab 2 (b)

3.2.2 Reinforcement of Lightly Loaded Concrete Beams

Table 2: Details of Beams

	Beam dimensions	*Area of bottom reinforcement*	*Area of top reinforcement*	*Reinforcement Percentage*	*Cover*
Beam 1(with out r/f)	*1200mm x 150mm x 150mm*				
Beam 2	*1200mm x 150mm x 150mm*	*4×10mm×10mm*	*2×10mm×10mm*	*2.67%*	*15mm*
Beam 3	*1200mm x 150mm x 150mm*	*6×10mm×10mm*	*2×10mm×10mm*	*3.5%*	*15mm*
Beam 4	*1200mm x 150mm x 150mm*	*2×20mm×20mm*	*2×10mm×10mm*	*4.4%*	*15mm*

Cement, sand, and coarse aggregate were measured by volume in the proportions of 1:2:4. The water cement ratio of the mix was 0.4. Three cubes were cast from each mixture to measure concrete strength. Slabs and beams were cured by covering the top surface with wet sack and the cubes were demoulded and put into water for curing. The cubes were tested in a universal compression testing machine after 28 days. After 28 days from casting, slabs and beams were coated with white lime. This process is essential, because it will give a better view of crack shape and mode of failure of the slab during the test.

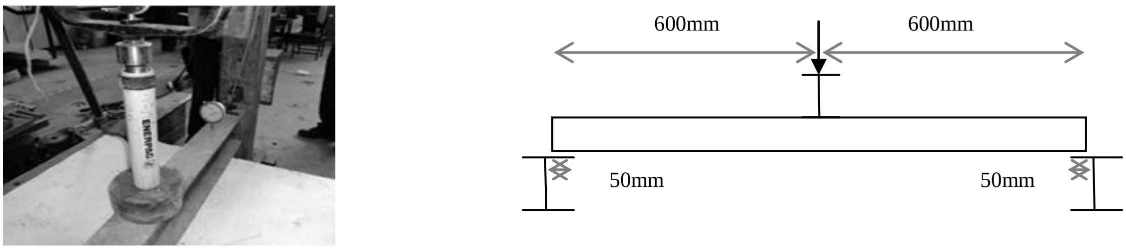


(a) **(b)**

Figure 4: Reinforcement Arrangement of a Typical Beam

3.2.3 Testing of Slabs and Beams

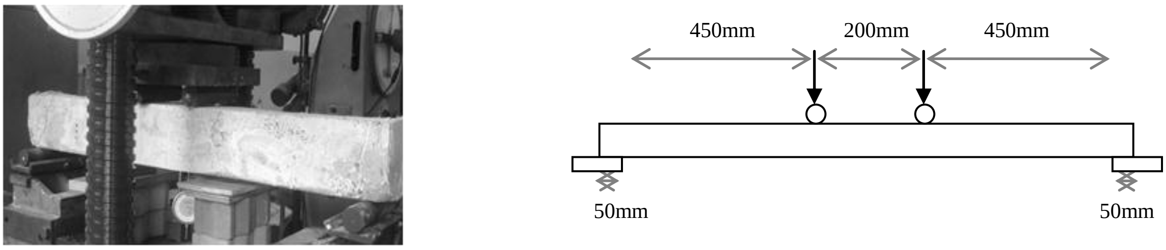
The slab is supported on two I beams with 50mm bearing on either side. A dial gauge was arranged to measure the central deflection of the slab. After the initial dial gauge readings had been taken, line load was applied at the centre by means of a hydraulic jack placed on the I beam as shown in figure 5(a) and 5(b). The test procedure included crack monitoring and central deflection measurements.



(a) **(b)**

Figure 5: Centre Line Loading of Test Slabs

The beam is simply supported with 50mm bearing on either side. A dial gauge was arranged to measure the central deflection of the beam. After the initial dial gauge readings had been taken, two point loading was given as shown in figure 6 (a) and 6(b).



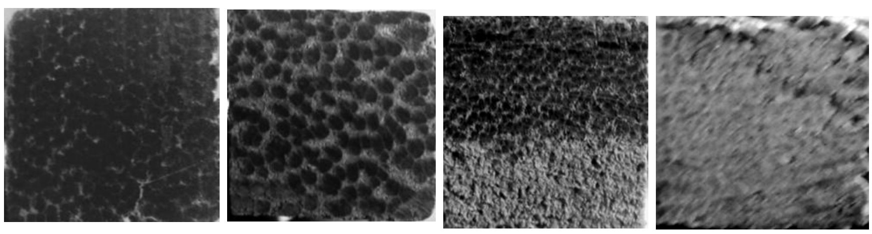
(a) **(b)**

Figure 6: Two Point Loading of Test Beams

4.0 Results

4.1 Characterizing Timber Properties

Majority of fibres are oriented parallel to the longitudinal axis of test pieces in all 3 sets. But some pieces in sample set B showed small deviations. Fibre concentration at cross sections were highest in set A and lowest in set C-1. In set A and C-1 fibres appeared to be small and compressed where as in set B fibres are relatively larger. Samples of set C-2 contains very little or no fibre. Fibre density of random cross sections from each four sample sets are shown below in figure 7.



(a) **(b)** **(c)** **(d)**

Figure 7: Cross Sections of Sample set A(a),B(b),C1(c) and C2(d)

Based on the mechanical tests performed, bending, compression and tensile strengths, modulus of elasticity and density were calculated. Distribution of those values were plotted and statistical analysis was carried out for sub-populations and total population to interpret mean, minimum, maximum and lower fifth percentile values. Results are given in tables 3, 4, 5, 6, 7 and abbreviations to read those tables are given in table 8.

Table 3: Results of Sample Set A

Sample A	Maximum	Minimum	Average	Lower Fifth Percentile Value
$f_{m,k}$ (N/mm^2)	183.21	80.053	144.96	85.07
E_{bt} (N/mm^2)	18484.6	8788.23	13214.0	9246.64
$f_{t,0,k}$ (N/mm^2)	167.5	87.39	122.25	
$f_{c,0,k}$ (N/mm^2)	90.87	37.13	74.42	46.66
E_0 (N/mm^2)	9984.85	1247.8	5494.26	
M/C %	16.23	1.02	13.70	12.22
Density (kg/m^3)	1136.78	817.89	974.44	836.9

Table 4: Results of Sample Set B

Sample B	Maximum	Minimum	Average	Lower Fifth Percentile Value
$f_{m,k}$ (N/mm^2)	167.28	48.92	122.43	60.5
E_{bt} (N/mm^2)	16407.56	9856.22	12927.9	10180
$f_{t,0,k}$ (N/mm^2)	66	42.93	53.1	
$f_{c,0,k}$ (N/mm^2)	86.90	52.81	69.68	52.85
E_0 (N/mm^2)	1559.59	671.92	115.01	
M/C %	15.85	14.1	14.7	14.17
Density (kg/m^3)	1143.38	851.16	999.7	853.2

Table 6: Results of Sample Set C2

Sample C1	Maximum	Minimum	Average	Lower Fifth Percentile Value
$f_{m,k}$ (N/mm^2)	157.68	112.55	140.97	117.68
E_{bt} (N/mm^2)	17672.9	9889.24	13084.8	10422.1
$f_{t,0,k}$ (N/mm^2)	66	42.93	53.1	
$f_{c,0,k}$ (N/mm^2)	53	25.4	39.22	53
M/C %	15	12.52	13.76	12.83
Density (kg/m^3)	969.81	724.32	859.58	764.13

Table 5: Results of Sample Set C1

Sample C2	Maximum	Minimum	Average	Lower Fifth percentile Value
$f_{m,k}$ (N/mm^2)	106.75	46.67	68.58	48.28
M/C %	16.22	14.66	15.48	14.7
Density (kg/m^3)	738.55	539.87	590.29	543.23

Table 7: Results of Total Samples

Sample A+B+C1	Maximum (N/mm^2)	Minimum (N/mm^2)	Average (N/mm^2)	Lower Fifth Percentile Value (N/mm^2)
$f_{m,k}$ (N/mm^2)	183.21	48.92	138.29	80.32
E_{bt} (N/mm^2)	18484.68	8787.24	13118.2	9856.41
$f_{t,0,k}$ (N/mm^2)	167.49	42.93	87.66	43.99
$f_{c,0,k}$ (N/mm^2)	90.86	37.13	72.69	51.84
E_0 (N/mm^2)	9984	265.43	2540.26	445.81
M/C %	15.86	14.31	15.08	12.55
Density (kg/m^3)	997.86	981.54	989.70	815.31

Table 8: Abbreviations of Mechanical Properties

Bending Strength	$f_{m,k}$
Modulus of elasticity parallel to grain(N/mm^2)	E_0
Tensile strength parallel to grain(N/mm^2)	$f_{t,0,k}$
Compressive strength parallel to grain(N/mm^2)	$f_{c,0,k}$
Shear strength	$f_{v,k}$
Tension strength perpendicular to grain(N/mm^2)	$f_{t,90,k}$
Compressive strength perpendicular to grain(N/mm^2)	$f_{c,90,k}$
Mean modulus of elasticity get from bending test (N/mm^2)	E_{bt}

Cumulative water absorption of treated and untreated Palmyrah strips with time is plotted in figure 8.Treated set A is denoted in the figure by set A(T).

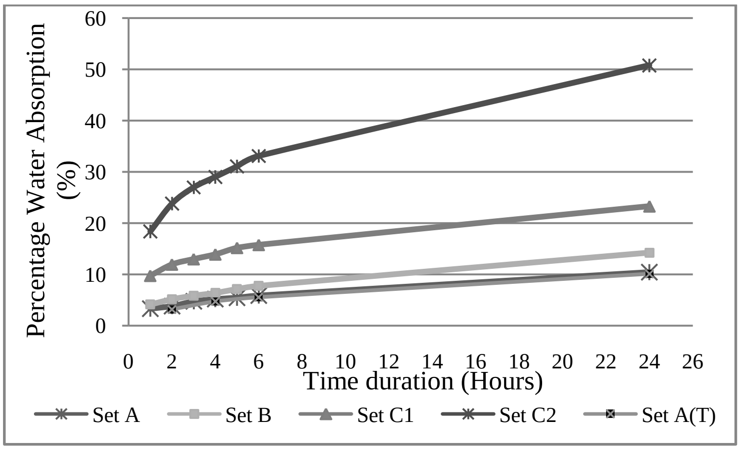


Figure 8: Water Absorption Pattern of Palmyrah Timber

4.2 Palmyrah Strips for Reinforcement in Lightly Loaded Concrete Slabs and Beams

Properties of concrete and reinforcement bars used for slabs and beams are given below in table 9 and 10. Compressive strength and density of concrete are experimental results while tensile strength and E value of concrete are calculated according to equations 3 and 4 respectively. Compressive strength of concrete in flexure is derived from equation 2. Those equations are referred from BS 8110, Part 1.

Compressive strength of concrete in flexure $= 0.67 f_{cu}$ (2)

Tensile strength of concrete $f_{ct} = 0.45\sqrt{f_{cu}}$ (3)

E value of concrete $= 5.5\sqrt{f_{cu}}$ (4)

Table 9: Properties of concrete used for slabs and beams

	Slab 1	*Slab 2*	*Beam 1& 2*	*Beam 3& 4*
Cube Strength (N/mm^2)	*21.5*	*26.14*	*25.46*	*24.42*
Tensile Strength (N/mm^2)	*2.08*	*2.3*	*2.27*	*2.22*
Density (kg/m^3)	*2343*	*2475*	*2418*	*2401*
E value (N/mm^2)	*25502*	*28120*	*27752*	*27179*

Table 10: Properties of Palmyrah reinforcement used for slabs and beams

	Slab1	*Slab 2 and Beam 1,2,3 and 4*
Ultimate tensile strength (N/mm^2)	*Maximum:167.5* *Minimum:87.4* *Average:122.25*	*Maximum:106.2* *Minimum:53.68* *Average:77.34*
Modulus of elasticity (N/mm^2)	*Maximum:18484* *Minimum:8788* *Average:13214*	*Maximum:21097* *Minimum:9758* *Average:15384*

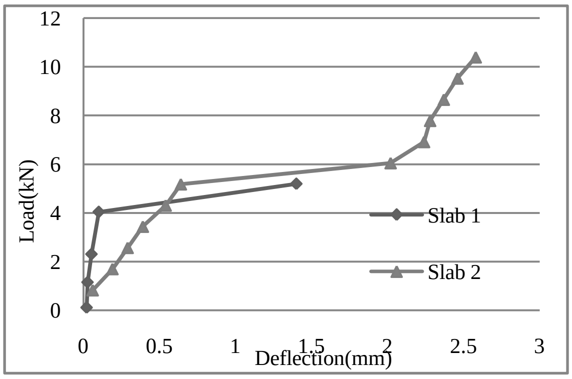


Figure 9: Load Deflection Curve for Slabs

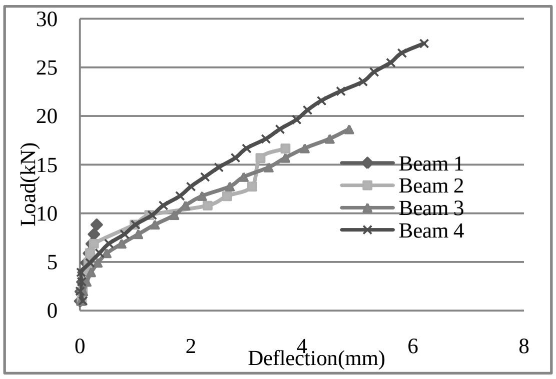


Figure 10: Load Deflection Curve for Beams

Load deflection curves of two slabs are plotted as shown in figure 9 while load deflection curves of beam are plotted in figure 10. Stiffness of the lightly loaded concrete slabs and beams reinforced with Palmyrah can be interpreted from these curves.

Experimental failure loads and crack loads of two slabs are tabulated in table 11 whereas those of beams are tabulated in table 12.

Table 11: Experimental Failure Loads of Slabs

	Experimental Failure Load (kN) Pe
Slab 1	*6.64*
Slab 2	*16.474*

Table 12: Experimental Failure Loads of Beams

	Crack Load (kN) Pcr	*Experimental Failure Load (kN) Pe*	$\frac{Pcr}{Pe}$
Beam 1		*8.83*	
Beam 2	*7.45*	*24.132*	*0.31*
Beam 3	*8.83*	*24.721*	*0.36*
Beam 4	*9.81*	*30.018*	*0.33*

Experimental and theoretical moment capacity of slab and beams with and without Palmyrah reinforcement are given in table 13 and table 14 respectively. Although failure loads were higher, cracks were initiated at lower loads at the middle of the slab and beam bottom. Theoretical moment capacity of unreinforced section Mt_c is derived using equations 5.

Theoretical moment capacity of concrete alone $Mt_c = \dfrac{f_{ct} \times b \times h^2}{6}$ (5)

Where, b is width and h is depth of the slab or beam.

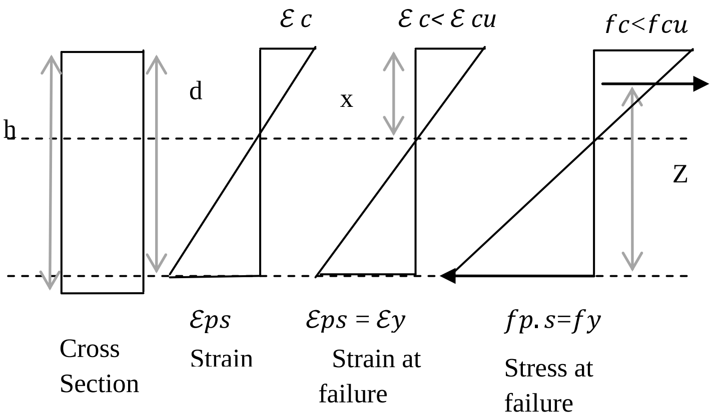


Figure 11: Stress and Strain Distribution of the Slab

Theoretical moment capacity (Mt_p) of the slab or beam with Palmyrah reinforcement is calculated on the assumption that concrete does not contribute to carry tension. Strain compatibility is assumed throughout. Section is assumed to be under reinforced. This assumption can be justified since all slabs and beams had tensile failures. As load is increased, the Palmyrah strain $\mathcal{E}ps$ will reach its breaking point $\mathcal{E}y$, while concrete strain $\mathcal{E}c$ is still below ultimate strain $\mathcal{E}cu$. Failure stress of Palmyrah strips fps is equal to design tensile strength of Palmyrah strips fy. Failure stress of concrete fc is lower than ultimate compressive strength fcu. Neutral axis depth x is found by trial and error process to satisfy force equilibrium. Moment equilibrium is taken to derive theoretical moment capacity. Material safety factors have not been taken into account in all above equations for the purpose of comparing theoretical value with experimental values.

Table 13: Experimental and Theoretical Moment Capacity of Slabs

	Experimental Moment Capacity (kNm) Me	Theoretical Moment Capacity (kNm) Mt	
	Me	Based on concrete section alone Mt_c	Including Palmyrah bars in tension Mt_p
Slab 1	1.826	1.49	1.7
Slab 2	4.53	1.546	2.65

Table 14: Experimental and Theoretical Moment Capacity of Beams

	Experimental Moment Capacity (kNm) Me	Theoretical Moment Capacity (kNm) Mt	
	Me	Based on concrete section alone Mt_c	Including Palmyrah bars in tension Mt_p
Beam 1	2	1.3	-
Beam 2	5.43	1.27	2.58
Beam 3	5.56	1.25	3.79
Beam 4	6.75	1.25	5

Table 15: Comparison between Experimental and Theoretical Moment Capacity

(a)

	$\frac{Me}{Mtc}$	$\frac{Me}{Mtp}$
Slab 1	1.225	1.074
Slab 2	2.93	1.709
Average	2.077	1.4

(b)

	$\frac{Me}{Mtc}$	$\frac{Me}{Mtp}$
Beam 2	4.275	2.1
Beam 3	4.448	1.467
Beam 4	5.4	1.35
Average	4.7	1.639

5.0 Discussion

5.1 Analysis of Mechanical Properties

Characteristic bending strength and density are taken as fifth percentile values of the populations as specified in BS EN 384[14]. Strength class for individual sample sets were determined according to specifications of BS EN 338: 1995. Since densities are higher in all the samples in sample set A, B and C1, it is fair to classify heartwood of Palmyrah as hardwood species although deciduous trees have a different anatomical structure from palm trees. Sample set C2 which is taken from softwood part of the stem, shows low densities and bending strengths near to margin of C40 and D30.This is due to, core of the trunk stores starch and is susceptible to more insect damages. Characteristic bending strengths of sub populations A, B and C1 fall in to D70, D60 and D70 respectively.

Minimum tensile stresses of all sample sets belong to D70 class. Minimum compressive stresses of set A, B and C1 are below the maximum compressive stresses specified under class D70, D70 and D35 respectively. Reason for the low compressive stress in set C1 is that, their cross section is partly made of softwood as shown in figure 4(c). Both E_{min} and E_{mean} values are considered to determine strength class. E_{min} is statistical lower fifth percentile value as defined in BS EN 384. Elastic modulus (E value) of individual populations A, B and C1 falls under D40.As a result, all sample sets are classified into strength class D40. In spite of the origin of the tree, mechanical properties exhibit closer distribution apart from some deviations in bending and tensile stresses. Bending and tensile strengths of test pieces in Puttlam shows relatively lower values than those from Jaffna.

When analyzing total sample population including set A, B and C1, characteristic bending, tensile and compressive strength falls into strength class D70 whereas E values have to be put into strength class D40. This is the same result obtained from analysing individual sample populations. Thus, heartwood part of Palmyrah trunk belongs to strength class D40 while softwood in the core falls in to strength class C40 or below. Palmyrah timber is graded as dry, since range of moisture content is from 12% to 17% which is below 20%.

Although heartwood of Palmyrah has higher strength and density values, its low stiffness value deprive its privilege to be used as a higher grade timber. So grading into strength class may lead to over conservative designs which results in economic losses since lowest parameter decides the class. It is worthwhile to note that, elastic modulus of Palmyrah is lower than that of concrete. It may be a disadvantage when it is to be used as a reinforcing material.

Fibre concentration in cross section and their orientation are dominating factors when determining mechanical properties. Minimum values are outputs of test pieces of which either fibre concentration is very low or fibres are not parallel to longitudinal axis. Degree of maturity of tree is most important factor in deciding its fibre properties. When trees grow older, fibres tends to get compressed which results in high strength and stiffness. Properties also differ along height and cross section. Timber at the bottom part of the trunk, closer to the outer skin displays high fibre concentration and has larger strength and E value. Palmyrah trunk is a composite material, consisting of long and parallel cellulose fibres embedded in a ligneous matrix which contains starch. The fibres are concentrated in regions closer to the outer skin. This is because the trees have been evolved according to the state of stress distribution in its natural environment when stem is subjected to wind forces.

Batch A shows lowest water absorption while batch C2 showed the highest absorption. Generally initial water absorption is higher and timber will get saturated with time. The 24 hour water absorption by Palmyrah is lower than that of bamboo [1]. Also it is evident, that applying varnish has very slightly reduced water absorption. Volumetric stability is an important consideration when timber is used in structures exposed to severe weather conditions. Sri Lanka is a tropical country where long term dry and wet seasons are expectable. Continuous swelling and shrinkage will exert extra stresses at joints and also reduce strength. Volume variation is much more critical when Palmyrah is to be used as reinforcing material embedded in concrete. Reason for the higher water absorption and resultant dimensional variations in batch C, is that they contained more sapwood than batches A and B. So sapwood of Palmyrah cannot be recommended for reinforcing concrete as well as for exposed structures.

5.2 Feasibility of Palmyrah as Reinforcement

It can be seen in figure 9, that the gradients of the load deflection curves of test slabs were relatively large until the appearance of the first crack in the central region of the bottom of the slab. Immediately following this first crack, there was a noticeable flattening of the deflection curve as the line of crack at the bottom is widened. Gradient of the curve has decreased with increase of reinforcement. The sharp increase in the observed deflections of the slabs occurred due to the relatively low value of the modulus of elasticity of Palmyrah.

In a two way slab subjected to centre line loading, maximum bending moment and zero shear prevails at the central point. Table 11 depicts that experimental failure load of slab has increased with reinforcement percentage. Collapse of the slabs occurred through the fracture of Palmyrah bar. Slab 1 failed in almost brittle manner with little warning. But with increase of amount of reinforcement from 0.7% to 1.8% collapse of the slab became remarkably gradual.

It can be seen in figure 10, that up to the appearance of the first tension crack in the central zone all the beams show the same rigidity. Up to the load of 10 kN all the beams showed a linear behaviour. After that, there is a noticeable increase of deflection in beams 2, 3 and 4. Beam 1 which is without reinforcement shows highest stiffness. Beam 3 produced slightly larger defection, compared to beam 1, 2 and 4. Collapse of beams with Palmyrah reinforcement (beam 2, 3 and 4) is gradual while collapse of unreinforced beam is so sudden. Difference between crack and failure loads was indistinguishable in beam 1. Table 12 depicts that experimental failure loads as well as crack loads of beams have increased with reinforcement percentage.

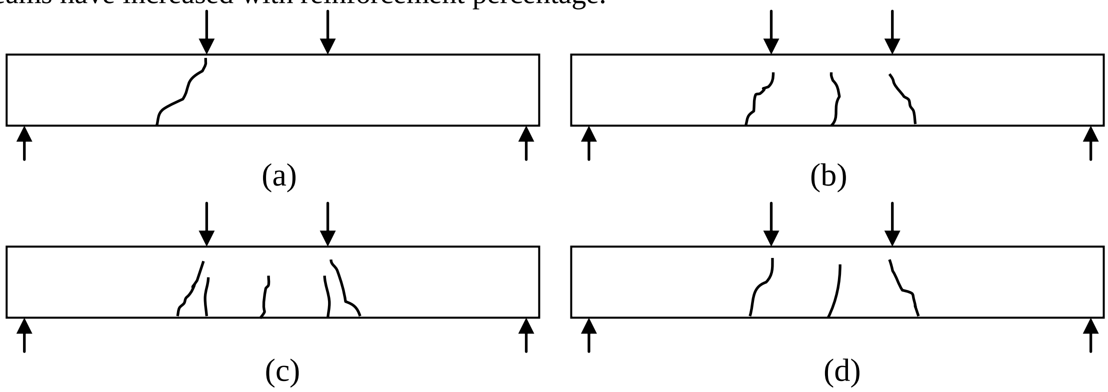


Figure 12: Crack Configuration of Beam 1(a), Beam 2(b), Beam 3(c), Beam 4(d)

In a beam subjected to two point loading, central region between two loads is subjected to maximum bending moment and zero shear while the remaining sections experience maximum shear force and varying bending moment. The largest flexural strains therefore, occur within this middle span and, consequently, cracking initiates at the bottom of this region. All the cracks were formed within the short constant moment span approximately 200 mm, and this implies that the beams developed adequate resistance against diagonal shear. Also, beams 2, 3 and 4 developed more than one crack indicating a good bond between the reinforcing Palmyrah bars and the surrounding concrete. It can be seen from figure 12 that number of cracks in beam 2 and 4 is similar and number of cracks in beam 3 is more. Crack widths are highest in beam 1 and lowest in beam 4. Beam 2, 3 and 4 had flexural failures through fracture of tension Palmyrah bars, while beam 1 had a shear failure at loading point. It is evident from table 12 that crack load of beams averages to one third of failure load.

Cracks were initiated at the bottom of both slabs and beams at lower loads. But calculations show that crack width will not be excessive under service loads. Owing to the low value of the modulus of elasticity and the relatively high tensile strength of Palmyrah, the reinforcement was able to withstand considerable straining before reaching the limit of elasticity. These high strains can lead to substantial cracking in the surrounding concrete near failure. Stiffness of a slab or beam seems to decrease with increase of Palmyrah reinforcement. This may be because elastic modulus of Palmyrah is lower than that of pure concrete.

It is observed from table 15(a) that Palmyrah reinforcement has enhanced the failure load and moment capacity of the slabs averagely by 107% than an unreinforced slab. Experimental failure load and moment capacity of slab is averagely 40% higher than theoretically predicted value with Palmyrah reinforcement.

Table 15(b) shows, moment capacity of beams with Palmyrah reinforcement is averagely 370% higher than theoretically unreinforced beam. Experimental moment capacity of beams averaged 64% higher than theoretically predicted value with Palmyrah reinforcement.

Unlike in steel reinforced concrete which is designed preferably as under reinforced with a limit to the amount of reinforcement to avoid brittle failures, relatively higher percentages of Palmyrah reinforcement can be utilized in concrete members and yet obtain sufficient warning prior to collapse. Since crushing of concrete did not occur until reinforcement percentage of 4.4% from cross section, it can be concluded that there is higher margin for over reinforcement of Palmyrah, compared to steel.

Since the modulus of elasticity of Palmyrah (8-20 kN/mm^2) is generally not much greater than that of concrete, they do not make a significant contribution to the flexural stiffness of Palmyrah reinforced concrete sections. Therefore, in measures aimed at avoiding excessive deflections and cracking under service loads, span/overall slab depth is a more relevant ratio for design considerations than span/effective depth ratio.

6.0 Conclusions

Palmyrah timber can be graded into two strength classes. Flexural strength of Palmyrah ranges from 40-190 N/mm^2 and tensile strength varies from 40-170 N/mm^2. So heartwood with higher strength can be utilized for rafters while those of low strength which also contain softwood can be used for reepers and purlins. Trusses and frames can be designed with D70 strength values while checking deflections with stiffness values relevant for D40. Thus over conservative design is prevented.

Heartwood of Palmyrah has potential to be used as reinforcing material in lightly loaded, short span slabs and beams due to its high strength and low water absorption. Only shortcoming is low modulus of elasticity.

Design calculations showed that Palmyrah reinforced slab is safe to carry distributed live load of 1.5kN/m^2 which is minimum imposed floor load for residential buildings, without excessive deflections and cracks. When material safety factor of 3 is introduced for Palmyrah, and safety factor of 1.5 is used for concrete, safe design can be achieved for slabs and beams of residential buildings.

Snapping of reinforcement is evident at the failure by above experimental results. Therefore more researches should be conducted with varying thickness and reinforcement percentage to get clear idea about crack initiation load and failure load. So that, optimal reinforcement to prevent snapping, maximum reinforcement ratio to prevent over reinforcement, minimum reinforcement ratio and spacing rules to reduce cracks can be found. Since varnish proved not to be adequate to reduce water absorption, better water repellent methods should also be studied and identified. So further research is recommended in the future for the development of simple design code for the application of Palmyrah as a construction material.

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