STUDY ON PALMYRAH AS A REINFORCEMENT MATERIAL

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Abstract: Most developing countries are confronted with acute housing shortage due to their over dependence on expensive, imported building materials. So there is an intense search for innovation of locally available, nature friendly materials.Palmyrah is widely spread all over North East region in Sri Lanka and has found use in many structural applications. This research explores the feasibility of using Palmyrah strips as an alternative for reinforcing steel in short span, lightly loaded slabs and beams.Structure of this research consisted of literature survey, testing mechanical properties of Palmyrah, basic design, construction and testing of Palmyrah reinforced concrete slabs and beams, analysing of results and recommendation.Static bending test, tensile test and compression test were conducted to identify characteristic strength and stiffness properties along with density and moisture content. Water absorption with time was also studied. Slabs and beams with varying reinforcement percentages were constructed and tested.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.It was observed 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. Both beams and slab had flexural failure by fracture of Palmyrah strips and their failure loads increased with increase of Palmyrah reinforcement.Thus it is concluded that Palmyrah strips has potential to be used as reinforcement in lightly loaded slabs and beams.

Keywords: Palmyrah, alternative reinforcement, flexural failure, characteristic strength

1. Introduction

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, its mechanical properties have not been well characterized. The main hurdle for the application of Palmyrah in structural composites 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. Some of these issues have been addressed in this paper as an initiative step to the design process of the Palmyah as a reinforcement bar.

The objective of this paper is to investigate feasibility of using Palmyrah strips as reinforcement in lightly loaded slabs and beams.

2. Literature Review

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.

It is noteworthy to state that previous researches done byGhavami K (1981,1985, 2005) have revealed that the tensile strength of bamboo is relatively high and can reach up to 370MPa.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.Series of research programmehas been conductedby Ghavami K. to access suitability of bamboo reinforced light weight concrete elements for low stress applications.

The results of those investigations show that, for the bamboo reinforced lightweight concrete beam, the ultimate applied load was 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. According to Ghavami K (2005) negrolin-sand wire treatment has improved the bamboo concrete bonding by 90%.

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 foundby Ghavami K (2005) that for steel it is necessary to spend 50 times more energy than for bamboo.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

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 according toKankam C.K., Odum-Ewuakye B. (2006). Also their researches revealed that experimental failure loads were averagely 175% of the theoretically predicted values.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.

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. Dolage D.A.R, Pallewatta T.M, Bandara R.R.G.S (2012) pointed out that physical properties of agri fibresshow no deterioration in concrete medium.

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.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. Methodology

3.1 Characterizing Timber Properties

Seasoned Palmyrah logs were cut and planed according to specified dimensions in BS 373:1957 [8],in a timber workshop in Katubedda. Samples were taken from Point Pedro – Jaffna. Then following mechanical 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.

(b)TensileTestTension parallel to grain is determined by Tensometer. Actual dimensions at minimum cross section were measured to calculate tensile stress. Test samples were 30cm long and 6mm thick.

(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.

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 Reinforcement and Concreting of Slabs and Beams

Palmyrah strips were coated by varnish and dried for 24 hours as a water repellent treatment. Reinforcement details of slabs and beams are given below in table 1 and 2 respectively.

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 later. 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 during the test.

Table 1: Details of Slab

	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*

Table 2: Details of Beams

	Beam dimensions	*Area of bottom reinforcement*	*Area of top reinforcement*	*Reinforcement Percentage*	*Cover*
Beam 1	*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*

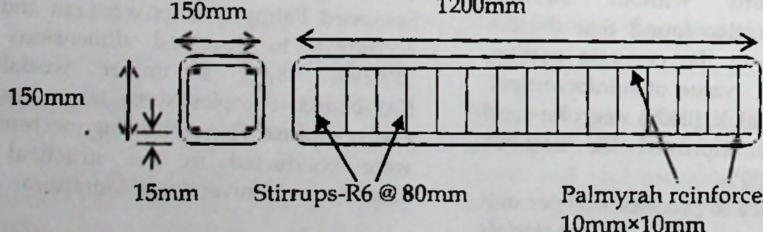
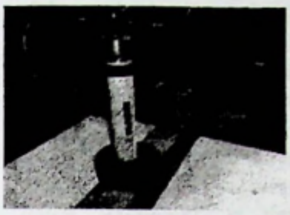


Figure 1: Reinforcement Arrangement of Beams

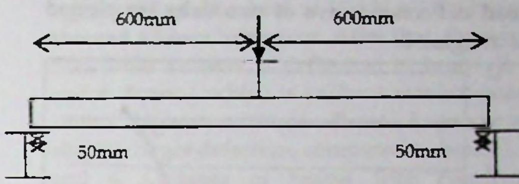
3.3 Testing of Slabs and Beams

The slab was 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 atcentre by means of a hydraulic jack placed on the I beam as shown in figure 2(a) and 2(b). The test procedure included crack monitoring and central deflection measurements.

The beam was 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 3 (a) and 3(b).

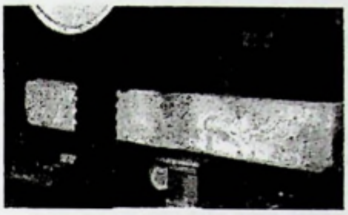


(a)

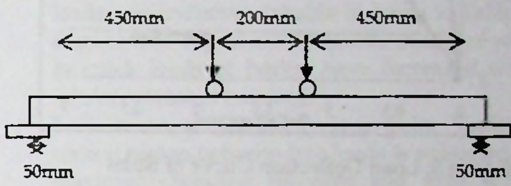


(b)

Figure 2: Centre Line Loading of Test Slabs



(a)



(b)

Figure 3: Two Point Loading of Test Beams

4. Results

Based on the mechanical testsperformed,bending,compression and tensile strengths,modulus of elasticity and density were calculated. Results of those tests are given below in table 3.Cumulative water absorption of treated and untreated Palmyrah strips with time is plotted in figure 4.

Table 3: Mechanical Properties of Palmyrah

	Maximum	Minimum	Average
Bending Strength (N/mm²)	183.21	80.05	144.96
Mean Modulus of Elasticity get from Bending Test (N/mm²)	18485	8788	13214
Tensile Strength Parallel to Grain (N/mm²)	167.5	87.39	122.25
Compressive Strength Parallel to Grain (N/mm²)	90.87	37.13	74.42
Modulus of Elasticity Parallel to Grain (N/mm²)	9985	1248	5494
Moisture Content%	16.23	1.02	13.70
Density(kg/m³)	1136.8	817.9	974.44

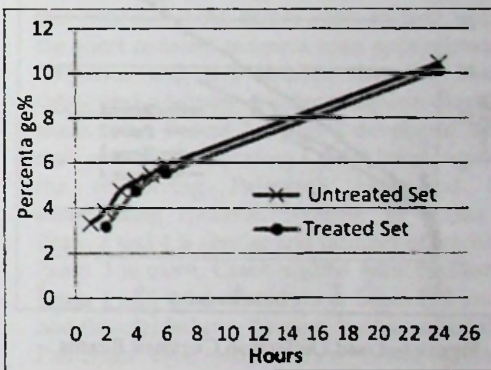


Figure 4: Hourly Water Absorption of Palmyrah

Properties of concrete used for test slabs and beams are given below in table 4. Compressive strength and density of concrete are experimental results while tensile strength and E value of concrete are calculated according to equations given in BS 8110, Part 1, 1985.

Table 4: Properties of Concrete used for Tests

	Slab 1	Slab 2	Beam 1& 2	Beam 3& 4
Cube Strength	21.5	26.14	25.46	24.42
TensileStreng th (N/mm²)	2.08	2.3	2.27	2.22
Density (kg/m³)	2343	2475	2418	2401
E value (N/mm²)	25502	28120	27752	27179

Load deflection curve of two slabs are plotted as in figure 5.

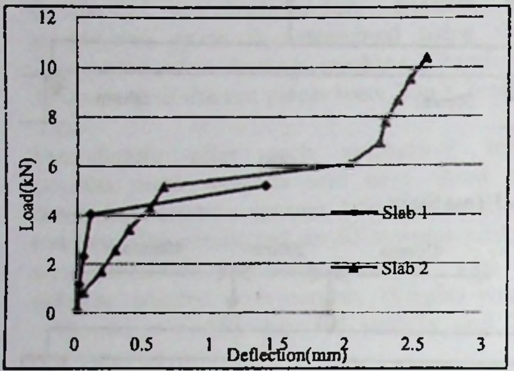


Figure 5: Load Deflection Curve of Slabs

Load deflection curve of beams are shown in figure 6. Experimental failure loads and crack loads of slabs and beams are given in table 5.

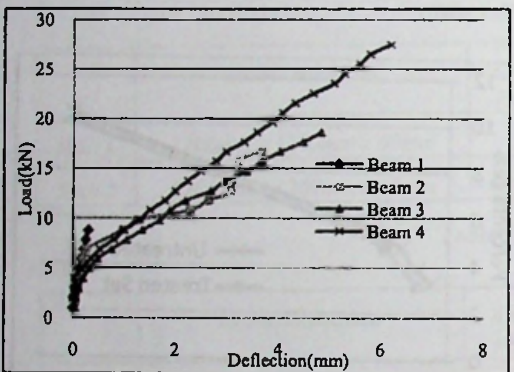


Figure 6: Load Deflection Curve of Beams

Table 5: Results of Slab and Beam Testing

	Crack Load (kN)	Experimental Failure Load (kN)	$\frac{Pcr}{Pe}$
Slab 1		6.64	
Slab 2		16.47	
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 are given in table 6 and table 7respectively. Theoretical moment capacity of unreinforced section Mt_c is derived using equations 1, where b is width and h is depth of the slab or beam. f_{ct} is the tensile strength of concrete.

Theoretical moment capacity of concrete alone $Mt_c = \frac{f_{ct} \times b \times h^2}{6}$ (1)

Theoretical moment capacity (Mt_p) of the slab or beam with Palmyrah reinforcement is calculated on the assumption that section is under reinforced.Strain compatibility is assumed throughout. Only fundamentals such as force and moment equilibrium are used to calculate the moment capacity.Minimum tensile strength of Palmyrah is considered when theoretical moment capacity is calculated. Material safety factors have not been taken into account in all equations for the purpose of comparing theoretical values with experimental values.

Table 6: Experimental and Theoretical Moment Capacity of Slabs

(a)

	Experimental Moment Capacity- Me (kNm)	Theoretical Moment Capacity- Mt (kNm)	
	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

(b)

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

Table 7: Experimental and Theoretical Moment Capacity of Beams

(a)

	Experimental Moment Capacity- Me (kNm)	Theoretical Moment Capacity- Mt (kNm)	
	Me	Based on concrete section alone Mt_c	Including Palmyrah bars in tension Mt_p
Beam1	2	1.3	-
Beam2	5.43	1.27	2.58
Beam3	5.56	1.25	3.79
Beam4	6.75	1.25	5

(b)

	Me/Mtc	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.Discussion

Palmyrah trunk composites of two components, namely heartwood and softwood. Outer perimeter of the cylinder where fibre is concentrated is heartwood whereas sapwood in the core is made mostly out of starch. Only heartwood inherits high strength and stiffness properties. Specimens taken for this experiment consist only heartwood taken closer to the outer skin of matured Palmyrah tree. According to results of mechanical tests, tensile strength of Palmyrah varies between 80-170N/mm^2 and modulus of elasticity ranges between 13-18 kN/mm^2.

Generally initial water absorption of Palmyrah is higher and it 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.

It can be seen in figure 5, 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 5 depicts that the 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 the increase of amount of reinforcement from 0.7% to 1.8% collapse of the slab became remarkably gradual.

It can be seen in figure 6, 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 5 depicts that experimental failure loads as well as crack loads of beams have increased with reinforcement percentage.

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. Number of cracks in Beam 2 and 4 is similar and number of cracks in Beam 3 is more. Crack widths were 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 the loading point. It is evident from table 5, 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 widths 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 6(b) 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 7(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. Recommendations

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.
Snapping of reinforcement is evident at the failure by above experimental results. Therefore more research 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.

References

BS 373:1957 *Method of Testing Small Clear Specimens of Timber.*

Charles K.K, Brigitte Odum E (2000) "Flexural Behaviour of Babadua Reinforced One Way Slabs Subject to Third Point Loading" , *Construction and building materials 15*, pp 27-33.

Dolage D.A.R, Pallewatta T.M, Bandara R.R.G.S (2012) "Tensile Properties and Volumetric Stability of Indigenous Woody Materials under Different Seasoning Techniques", ENGINEER, Volume XXXXV, No 1,pp 9-16.

Ghavami K (2005) "Bamboo as Reinforcement in Structural Concrete Elements", *Journal of Cement and Concrete Composites*, Volume 2,pp. 637-649.

Ghavami K (1995) "Ultimate Load Behaviour of Bamboo-Reinforced Lightweight Concrete Beams", *Journal of Cement and Concrete Composites*, Volume 17,pp. 281-288.

Ghavami K, Hombeeck RV (1981), *Application of bamboo as a construction material: Part I-Mechanical properties and water repellent treatment of bamboo, Part II-Bamboo reinforced concrete beams.* In: Proc of Latin American Symposium on Rational Organization of Building Applied to Low Cost Housing, CIB, Sa˜o Paulo, Brazil , p. 49–66

Kankam C.K., Odum-Ewuakye B. (2006) "Babadua Reinforced Concrete Two-Way Slabs Subjected to Concentrated Loading", *Construction and Building Materials*, Volume 20, pp. 279–285.

Ramasamy H.S, Ahuja B.M, Krishnamoorty S (1983) "Behaviour of Concrete Reinforced with Jute,Coir and Bamboo Fibres", *The International Journal of Cement Composites and Lightweight Concrete*, Volume 5,No1.