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Original Research Manuscript

Application of Mangrove Timber in Reinforcing Concrete

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ABSTRACT

Use of mangrove timber beams for supporting floor slabs in historic buildings in Zanzibar Stone Town is still applied although the available structural data on mangrove timber is inadequate. This concern has called for an investigation on the structural properties of mangrove timber, so that the information obtained could help to establish the structural strength of the existing floor slabs in historic buildings. Hence, mangrove timber specimens were sampled from Zanzibar, and tested in the laboratory for their strengths in tension, compression and shear. The test results showed that mangrove is a hardwood timber of strength class D70, the highest rank of timber classification. Also, concrete beam specimens reinforced with mangrove timber rods, and others reinforced with structural steel were studied. The obtained test results showed that beams reinforced with mangrove timber rods with enlarged ends performed better than those reinforced with uniform mangrove rods. The strength of the beams reinforced with mangrove timber was found to be 50% of the beams reinforced with steel bars, implying that mangrove timber can be used to reinforce concrete beams.

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INTRODUCTION

Concrete is a mixture of predetermined proportions of cement, fine aggregate, coarse aggregates and water, in which the cement and water undergo chemical reactions in hydration to bind the aggregates. In addition to the above, other materials are often incorporated, such as fine powders that can substitute some of the cement, known as additives and small quantities of chemicals, known as admixtures, which can alter and improve some properties of fresh concrete as well as in hardened state. Concrete as it is known today, is the most common construction material worldwide, the properties of which may be determined by design, selection of constituent materials and quality control when casting (Ray, 1995). Basically, to use concrete in places where the applied loads induce tensile or bending stress such as in beams, the tensile capacity of the cross section is improved by adding reinforcement bars within the concrete cross section (Renmokrane et al, 2009). In this regard, the bending capacity as well as the resistance to cracking due to tensile forces is enhanced.

Concrete, timber and steel are three important materials that are used in the construction industry worldwide (Lars and Roger, 2008; Duggal, 2008). Timber as deck/floor material has been extensively used in some areas in Tanzania, especially in Zanzibar. In many other areas of the world structural timber is just used for the external surface of the concrete such as formwork and furniture, and for roofing or ceiling work purposes (Richard, 2010). In Tanzania there is no any experimental research data on structural properties of concrete reinforced with mangrove timber which has been done so far. Hence, there is a need of experimental studies on the suitability and application of mangrove timber in reinforcing concrete.

OBJECTIVES

The main objective of this study was to investigate on the properties of mangrove timber as a reinforcing material in concrete. To achieve this main objective, the specific objectives included the following:

i. To determine the tensile, bending, compressive and shear strengths of mangrove timber.
ii. To determine the ultimate load of resistance of concrete reinforced with mangrove timber.
iii. To identify the failure mode of beam samples reinforced with mangrove timber.
iv. To make comparison between laboratory test results and theory given in BS 8110: (1997) for:
    - Concrete beams reinforced with steel bars and,
    - Concrete beams reinforced with mangrove timber

Mangrove Timber

Mangroves are forests as well as the trees that form them (Figure 1) found along coastlines in the tropics and subtropics, that are able to grow in the salty, very wet soil of the intertidal zones, where they can survive being partly covered by the sea twice a day at high tide. Mangroves trees also need some fresh water, so they grow best in sheltered estuaries, lagoons, bays, and inlets, where fresh and salt water mix. In the right conditions, mangrove forests can extend many kilometers inland, and some species of mangrove tree can grow up to 40 meters tall (Islam and Abdalla, 2015).

Figure 1: Green mangrove trees.

Mangrove Timber in Zanzibar

Zanzibar has about 18,000 hectares of mangrove forest: 6,000 hectares in Unguja Island and 12,000 hectares in Pemba Island. The largest mangrove trees in Unguja Island are found at Chwaka Bay and in Pemba Island at Ngezi-Micheweni. Ten species of mangrove grow in Zanzibar, but red mangrove (*Rhizophoramucronata*), black mangrove (*Bruguieragymnorriza*) and mangrove apple (*Sonneratiaalba*) are the most common (Nell Hamilton, 2011).

SCOPE AND SIGNIFICANCE OF THE STUDY

This study was conducted at Stone Town Zanzibar, because there are many structures with mangrove timber floor beams still existing there. Through this investigation, identification of the capability of mangrove timber as reinforcement material in concrete has been established.

Direct uses of Mangrove in Zanzibar

Mangrove products are used for various purposes, such as fire wood and charcoal for cooking. Houses walls are built using mangrove poles and with lime made using mortar. Mangrove timbers make strong boats, and fishing traps and sea weed farms also use mangrove poles. Mangroves are also used for tanning leather and making dyes.

In Zanzibar, it was used to be a major industry; but now fewer people are involved with, for it is still carried out on a small scale. The fruits of the cannonball mangrove (*Xylocarpusgranatum*) are used as a traditional medicine to treat rashes and stomach pain. Many commercially important fish, shell fish and prawn species depend on mangroves at least during part of their life cycle. Mangrove timber beams were and are still used to support floor slabs in multi-stories buildings especially in historic buildings of Zanzibar Stone Town as shown in Figure 2.

Figure 2: Slab reinforced with mangrove beams.

METHODS, TESTS AND RESULTS

The sampling of specimen was carried out in Stone Town - Zanzibar, Tanzania purposely because of the largest number of buildings whose slab elements are supported by mangrove timber beams as illustrated by Figure 2. Six dried pieces of mangrove trunks were collected for physical tests and for reinforcing concrete beams. Ordinary Portland cement 42.5N, coarse aggregate of size not exceeding 20mm size and sand were collected in Dares Salaam since they are of the same properties as those in Stone Town – Zanzibar.

Preparation of Samples

Sampling and sample preparation was carried out in accordance to ASTM D143-09(2002) Test Methods for Small Clear Specimens of Timber, and ASTM C 78-(2002) Standard test method for flexural strength of concrete

Tensile Strength Test

The tensile strength tests were carried out in accordance to ASTM D 143. (Tensile parallel to grain test). The timber samples had been cut into thin **I**-shaped as can been seen in Figure 3 to ensure that when running the test, failure would occur directly at the central part of the timber samples. The load deformation curve developed during testing is given in graphs in Figure 4 for each specimen. The graphs show that the deformation increases with tensile force and is approximately linear until the point of specimen failure. The ultimate load then occurs at the highest point when the load reaches its maximum value, thereafter drops abruptly signifying that the mangrove timber is a relatively brittle material. The tensile test results revealed that mangrove is a hardwood as its average tensile strength was found to be 83.56N/mm² being higher than the normal structural timber which has an average value of 22 N/mm².

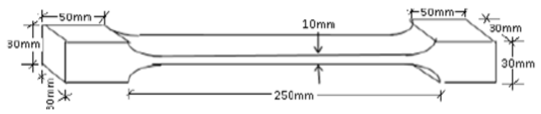


Figure 3: Specimen for tensile strength test.

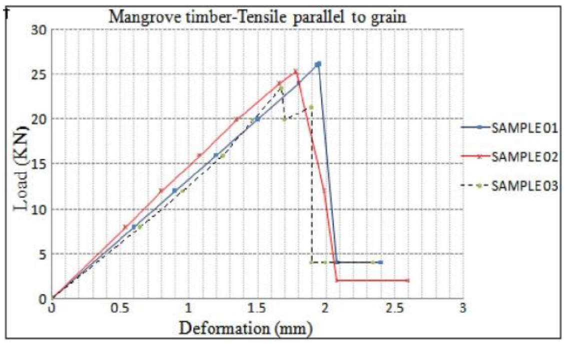


Figure 4: Load deformation curve.

The compressive strength test was carried out in accordance to ASTM D143 (**2002**). The test specimens configuration is shown in Figure 5, while Figure 6 indicates the stress–strain curve for the test results. The results revealed that mangrove is hardwood since its average compressive strength was found to be 49.8N/mm² when tested parallel to the grain and 14.69N/mm² when tested perpendicular to the grain. A summary of the test results for tensile and compressive strengths is given in Figure 6.

Compressive Strength Test

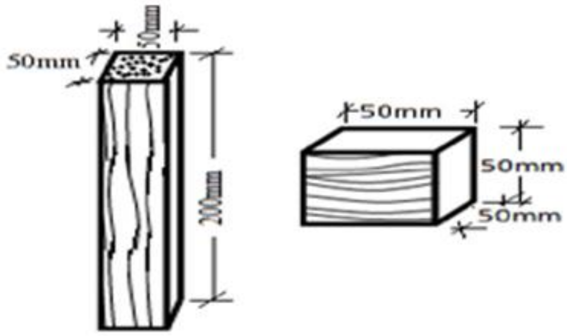


Figure 5: Test specimens for compressive strength.

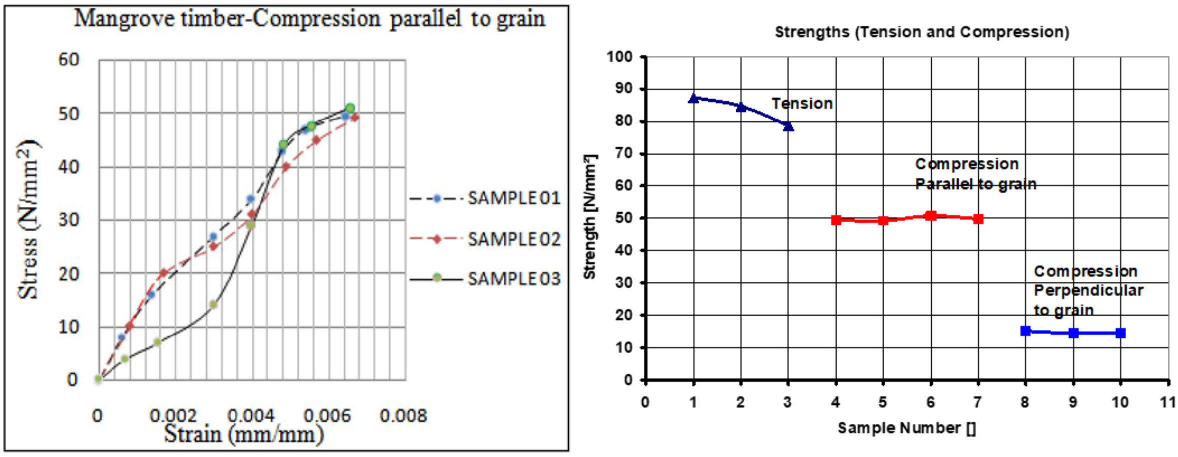


Figure 6: (a) Stress-strain relationship and (b) summary of test results.

Flexural Strength Test

To determine the static bending (flexural) strength of mangrove wood, laboratory tests were carried out according to ASTM D 143-09 (**2002**). Flexural strength test specimen and test setup is shown in Figure 7. Results of flexural strength test are shown in Table 4. The test results revealed that mangrove is hardwood as it posses its average flexural strength of 96.25 N/mm² while its Modulus of elasticity is 4.57 kN/mm².

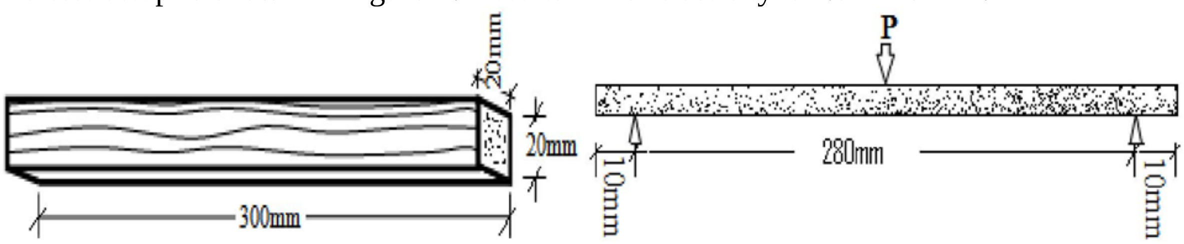


Figure 7: Specimen and flexural strength test set-up.

In Figure 8, shown is typical deflections and the applied force relationship for flexural strength test. Specimens sustained static bending and the initial failure was indicated by a wrinkling of the overstressed compression fibers. The final failure was generally in tension and it was accompanied more or less by snapping as the individual fibers began to break when the maximum load was reached.

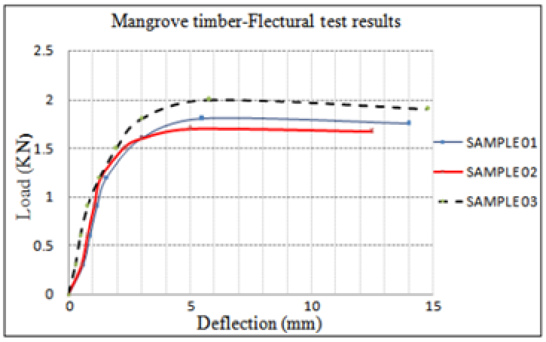


Figure 8: Deflection and the applied force relationship.

Shear Strength Test

Shear strength test was carried out in accordance to EN 408 (2010). The test specimens as well as the test setup are shown in Figure 9. Results for shear strength test vary from 11.20 N/mm² to 14.08N/mm² with an average shear strength of 12.27N/mm² being within the class of hardwood.

The density of mangrove timber, was determined and found to be varying from 1100 kg/m³ to 1190 kg/m³, as plotted in Figure 10.

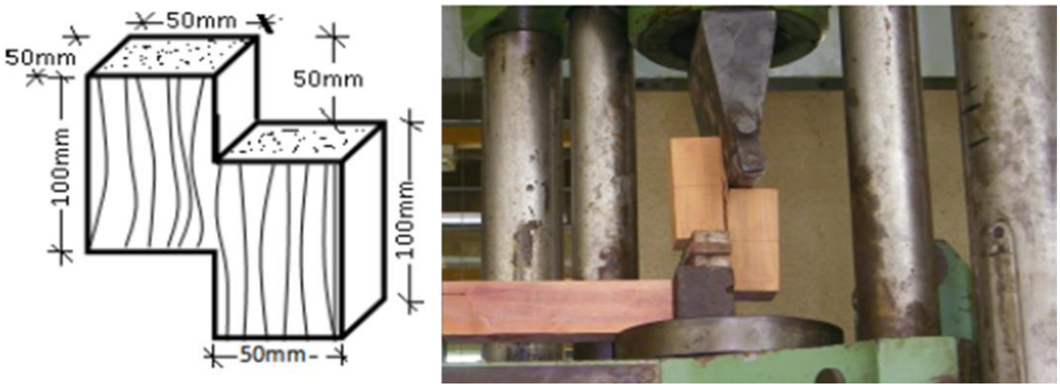


Figure 9: Shear strength test specimen and test setup.

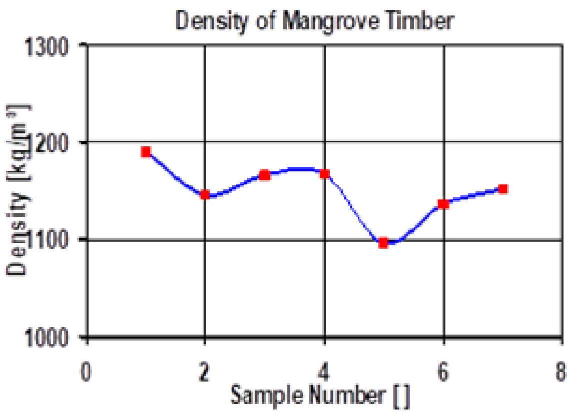


Figure 10: Density of mangrove timber.

Mangrove and Steel Reinforced Concrete Beams

Nine (9) samples of reinforced concrete beams were prepared. The grade of concrete was C25 and only bottom bars were placed. Each beam sample was identified and reinforced as shown in Table 2 and Figure 11.

Table 2: Identification of each reinforced concrete beam

Name of beam and size	Reinforcement material
Control beam (150 x 200 x 1000)	Steel Grade 250
Stone town 1 (150 x 200 x 1000)	Mangrove timber rod (plain uniform)
Stone town 2 (150 x 150 x 1000)	Mangrove timber rod (ends enlarged)

The length of each reinforcement rod was 960mm shorter than the length of beams, in order to prevent the reinforcement rods from appearing in the end surface of beams after removal of formwork. Meanwhile, the amount of reinforcement was different, in which steel was almost 30% of that of timber. This was done to balance the overall strength between steel bars and timber reinforcement rods.

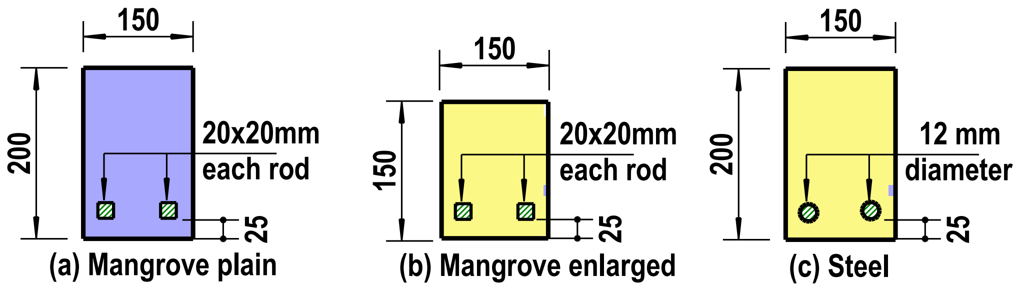


Figure 11: Concrete beams reinforced with mangrove (a and b) and steel (c).

The configuration of uniform size mangrove timber rods was square and the cross section was 20mm x 20mm throughout. The other set of mangrove timber rods shape was square of 20mm x 20mm at its central part, and either end had enlarged cross section of size 30mm x 30mm to enhance anchorage as depicted in Figure 12.

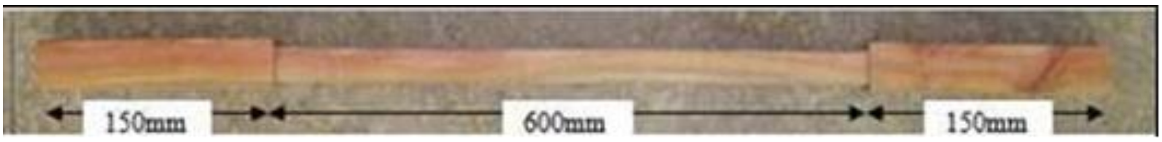


Figure 12: Enlarged end mangrove rod.

Ingredients needed for making concrete were batched by volume, then placed into concrete mixer machine and mixed thoroughly to a uniform mixture. After the fresh concrete was ready, it was sampled for slump test to check its workability. Cube specimens were also prepared for testing the compressive strength of concrete. A vibrating table was used for compacting fresh concrete to make sure that there are no voids in it. After two days, the molds of concrete cubes were opened and the cubes were immersed into a water tank for curing. Beam samples were cured by covering each sample with wet sacks throughout for 28 days. The curing process was essential in order to reduce or eliminate plastic shrinkage cracking, but also ensured an adequate supply of water for hydration and strength development of concrete.

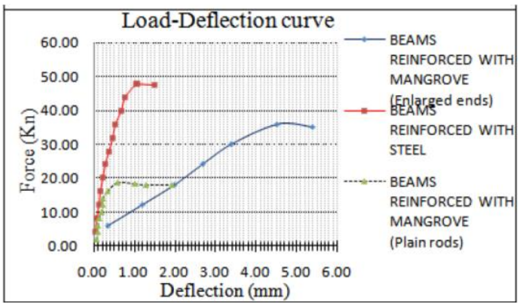
Concrete cube specimens were tested according to BS EN 12390-3:(2009) procedures. The average compressive strength of concrete was found to be 31.1 N/mm² while the design strength was 25N/mm². Therefore, the requirements for compressive strength of concrete for the beam specimens were met.

Flexural Strength Test of Beams

Flexural strength test was carried out in accordance to ASTM-C-78 (**2002**) at 28 days age for beam samples painted in white color on the surfaces. White color surfaces were essential, because it would give a better view of crack occurrence, shape and mode of failure for each beam sample after the test. Figure 13 shows the test results in a graphical form for all three beam sets.

Mode of Failure

The mode of failure of all beams tested is shown in Table 2. It was observed that mode of failure of all beams were slightly different from each other. Mangrove (uniform shape) failed by cracking severely at mid span but carried less load. Figure 14 shows the typical mode of failure of the beam reinforced with enlarged ends mangrove rods.



Figures 13: Load-deflection curves of beams tested in the laboratory.

Figure 14: Failure mode of beam reinforced with enlarged ends mangrove rods.

Theoretical Ultimate Moment of Resistance of Beam Samples.

Estimation of the strength of concrete beams theoretically, was done using equations from BS 8110 Part 1 (1997). The strength of mangrove timber in flexural was taken from the test results as $f_{m,k} = 96.25\ N/mm^2$. With regard to EC-5(2004), the flexural design strength is given by the expression:

$$f_{m,d} = \frac{k_{mod} \cdot f_{m,k}}{\gamma_m} \quad (1)$$

For this case, k_{mod} = 0.70 for class 2 use with moisture content not greater than 20%, and γ_m = 1.1 for timber element joined to hard material like steel or concrete. Therefore

$f_{m,d} = 0.70 \times 96.25/1.1 = 61.25\ N/mm^2$

The beam section was idealized as shown in Figure 15 below.

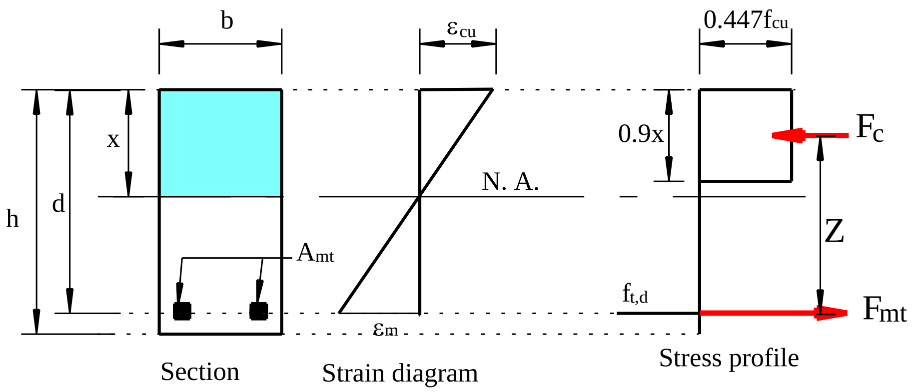


Figure 15: Section, strain and stress profile for a rectangular beam.

The general case being;

$F_c = 0.447\, f_{cu} b(0.9x)$ (2)

$F_{mt} = f_{m,d} A_{mt}$ (3)

For equilibrium, the value of $F_c = F_{mt}$

Therefore

$0.447 f_{cu} b(0.9x) = f_{m,d}.A_{mt}$, and $f_{cu} = 25\ N/mm^2$

Depth of neutral axis:

$$x = \frac{f_{m,d}.A_{mt}}{0.447\, f_{cu}.b}$$

Substituting the values

$A_{mt} = 800$ mm^2, $f_{m,d} = 61.25$ N/mm^2, b = 150 mm, d = 165 mm

x = 29.23 mm

z = d – 0.9x/2 = 151.85 mm

$\Rightarrow M_{Rc} = F_c(z) = F_{mt}(z)$

$M_{Rc} = 0.447\, f_{cu} b\,(0.9x)(z)$

= 6.70 kNm (4)

where M_{Rc} stands for the moment of resistance of a beam section.

Equation 4 gives the moment that can safely be carried by a singly reinforced beam reinforced with mangrove timber. From the test results, the beam with enlarged ends mangrove rods had an ultimate moment of 8.89 kNm while the beam reinforced with mangrove timber rods of uniform shape had an ultimate moment of 5.73 kNm being lower than the theoretical moment. The strengths could be increased if the mangrove rods were three or four of the same size of 20 × 20 mm in each case.

The difference in the strengths for the two beams reinforced with mangrove rods, lays on the fact that there was insufficient bond between timber and concrete. Enlarged end mangrove rods provided anchorage to concrete, and so increased the moment of resistance by 55.15% when compared to beams reinforced with uniform shaped mangrove rods.

DISCUSSION ON THE RESULTS

The test results for tensile strength parallel to grain of mangrove specimens was found to be 83.56N/mm², being almost 33% of mild steel grade 250, but higher than normal local structural timber which has a characteristic strength of 14 N/mm² in average. Results from tests for compressive strength parallel to the grain indicated that it was 49.8 N/mm², while for perpendicular to the grain it was 14.69N/mm². The flexural strength of mangrove timber as obtained from these test results is 96.25 N/mm² while the local structural timber has just 22 N/mm², and E-modulus had an average of 4,57 kN/mm². Finally, the shear strength obtained was 12.27 N/mm² being far higher than the strength of normal local structural timber of 2.0 N/mm². The mangrove timber has been classified as hard wood according to BS EN 338 (2009) Timber Strength Class D70.

Cracking behavior

From experimental results, the beams reinforced with mangrove rods (ends enlarged) showed many cracks than the other beams. The control beams and those reinforced with uniform shaped mangrove rods cracked at the mid span. The cracking loads were 10.4 kN for beam reinforced with uniform shape mangrove rods, followed by 14.0 kN load for concrete beam reinforced with mangrove rods with enlarged ends, and finally the control beams started to crack at a load of 30.0 kN. Beam samples reinforced with mangrove (uniform shape) showed deep cracks in comparison with the control beams and beams reinforced with mangrove rods of enlarged ends.

CONCLUSION AND RECOMMENDATION

The physical tests done on the mangrove timber specimens have revealed that the ultimate strengths were as follows:

a) Tensile strength attained was 83.56N/mm²
b) Bending strength obtained was 96.25N/mm²
c) Compressive strength parallel to grains was 49.8N/mm²
d) Compressive strength perpendicular to grains was 14.69N/mm²
e) Shear strength parallel to grains 12.27N/mm².

Mangrove timber is classified as a hard wood timber of strength class D70 which is the highest rank of timber classification.

With regard to concrete beams reinforced with mangrove timber (one-point load test) it has been noted that:

a) The cracks pattern and mode of failure indicate that Mangrove timber rods with enlarged ends are the best reinforcement configuration as they bear higher loads when compared to mangrove timber rods of uniform shape.

b) The ultimate loads for each type of beam were such that for steel reinforced concrete beam it was 48.0 kN, followed by mangrove timber rods (enlarged ends) with 36.0 kN, and lastly for the reinforced with plain mangrove timber rods was 18.8 kN.

Basing on the test results and conclusions drawn above, it is recommended that

a) Mangrove timber can be used as reinforcing material in concrete beams. As the mangrove rods are embedded in the concrete, they will last longer when compared to the current practice where they support slabs while they just exposed (ref. Figure 2).

b) The Zanzibar Bureau of Standards (ZBS) and Tanzania Bureau of Standards (TBS) should adapt and establish standards or one standard to facilitate proper design of mangrove timber elements since it has high strength.

c) Further research on bond characteristics between timber and concrete has to be done to get a deeper insight as this mangrove timber has sufficient strength suitable for reinforcing concrete. Optimization of the sectional amount of mangrove rods area should be studied too.

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