Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 41 Issue: 05-2022
DOI 10.17605/OSF.IO/BNMX7

STRUCTURAL PERFORMANCE OF CONCRETE COLUMNS REINFORCED WITH BORASSUS AETHIOPUM MART TIMBER

OUBEDOULAYE KONE[1], DAVID OTIENO KOTENG[2], MOHAMMED MATALLAH[3] and CHARLES KARIMI KABUBO[4]

[1] Department of Civil Engineering, Pan African University, Institute for Basic Science, Technology and Innovation, Jomo Kenyatta University of Agriculture and Technology Nairobi, Kenya.

[2] School of Civil and Resource Engineering, Technical University of Kenya, Nairobi, Kenya

[3] Department of Civil Engineering, University of Tlemcen, Algeria

[4] Sustainable Materials Research and Technology Centre, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

ABSTRACT

Concrete is a widely used construction material all over the world. It is invariably reinforced with steel to mitigate its low strength in tension. Steel is derived from natural deposits of hematite and magnetite, and the extraction from ore uses subsidiary raw materials, primarily coal and limestone, and a large amount of energy. This results in continuous depletion of non-renewable natural resources, degradation of the landscape, and pollution of the environment due to the emission of greenhouse gases during extraction. If the use of steel in concrete can be reduced through the use of organic reinforcing strips derived from plants that can be planted and harvested, therefore renewable, this would not only result in sustainable use of resources but would also reduce environmental pollution and degradation of the landscape. This study investigates the possibility of using brasses aethiopum mart timber strips as reinforcement in concrete columns. The results obtained show good potential for their use as reinforcement in columns. Substantial reduction in the cost of construction can also be expected.

Index Terms - Sustainability, Energy, Brasses Aethiopum Mart Timber, Compressive Strength, Cost Reduction, Steel, Reinforced Concrete Column.

1. INTRODUCTION

Concrete is a construction material that is widely used across the world. In 2019, it was estimated that the world per capita consumption of cement stood at 580kg, which translated to a per capita concrete consumption of around 1.49 m^3[1]. In the same year, Africa had a per capita cement consumption of 200 kg or a per capita concrete consumption of 0.51 m^3[2–4]. Concrete is invariably reinforced with steel bars to mitigate its low strengthin tension. Steel is extracted from non-renewable, naturally occurring hematite and magnetite deposits in an energy-intensive industrial process that uses supplementary natural materials such as coal and limestone[5]. Many countries of the world do not have economic deposits of the requisite raw materialsfor steel production. Theyhave to rely onimportation which adds to the carbon profile of steel, or recycle scrap metal in an equal energy-intensive process[6]. If less steel can be used in concrete structures, the adverse effects of the use of steel would be mitigated.

On the other hand, organic-based concrete reinforcing strips, if found suitable, are renewable inputs that can be cultivated across the world. The energy used in producing steel and greenhouse gases emitted in the industrial processes would be reduced, resulting in a greener environment

Research on the partial replacement of contemporary non-renewable building materials by renewable natural materials and compliance with international protocols will reduce the harmful consequences of industrial production and reduce construction costs [7–9]. Several studieshave been carried out to evaluate the feasibility of employing plant reinforcements to replace steel in reinforced concrete members. Among the plants researched are bamboo, landolphiabuchananii, palm, and even borassus aethiopum mart and natural fibres derived from the trees[10–13].

Borassus aethiopum mart, commonly known as African palm or borassus, is a smooth, bottle-shaped palm that may reach a height of 25 m when mature. It is mainly found in Africa, in areas with a high-water table, such as forested savannah grasslands[14–18].Parts of borassus tree are used for food, handcrafts and medicine[19–24].In the field of construction, this wood gives a relatively long lifespan and is used as a beam, rafter, lintel, and post/column [25–27].

Research into the use of borassus aethiopum mart as reinforcement in reinforced concrete structures is focused on identifying the mechanical properties of this woodsuch as compressive strength, tensile strength, bending strength, adhesion strength, shear strength, hardness [11], [12], [28–30]. Other investigations have focused on determining the fire resistance of the same wood[31].

This study used borassus aethiopum mart timber (BAMT) strips as longitudinal reinforcement in a slender column loaded in compression. Comparison is made on its efficacy as concrete reinforcement material with a similar column reinforced with steel bars. Comparison with a column reinforced with steel bars is made when the column is reinforced with an equal area of BAMT and when the column is reinforced with an equivalent area of BAMT. The results showed 11% and 3% load capacity loss, respectively.

2. MATERIALS AND METHODS

The materials and procedures used in the present work are described in this section.

2.1 Materials

The brasses aethiopum mart wood used in this study was from Kenya's coast, specifically from Mivumoni in Msambweni sub-county in Kwale County. When it was taken down, the tree was around 40 years old.

The materials that were used in carrying out the concrete mix were river sand of 5 mm maximum particle size, crushed aggregates of 5 – 20 mm particle size,Portland cement, CEMI 42.5N, and potable water.High yield reinforcing ribbed steel bars of 12 mm diameter and characteristic strength of 500 MPa were used as longitudinal reinforcement in the control column. Ribbed bars of diameter 6 mm were used in all columns as confining stirrups at a spacing of 180 mm. The borassus reinforcing strips were of 10.6 mm square cross-section and compressive strength of 60 MPa[32].

2.2 Method

This study was devoted to conducting the compression test to determine the crushing load of the test columns. The columns were designed to be slender with a cross-section of 150 mm x 150 mm and a height of 1,500 mm. Six columns with borassus longitudinal reinforcement and steel transverse reinforcement were used in this study. In the first three specimens (BAMT1), 4No. BAM strips were used, giving a cross-section area approximately equal to that of steel in the control specimens. In the next three specimens (BAMT2), 8No. BAMT strips were used, giving the cross-section area required by design when BAMT is the reinforcing material.

Another three columns were made with 12 mm diameter longitudinal steel bars to act as control. The reinforcement to the columns were arranged as shown in Fig.1 and as given in Table 1.

The columns were designed using Euro code 2. The BAMT reinforcing strips were sawn into square cross-sections of 10.6 mm x 10.6 mm at the timber workshop. Confining stirrups of 6 mm diameter were then placed at 180 mm intervals and tied with binding wires. The cover to reinforcement was 20 mm.

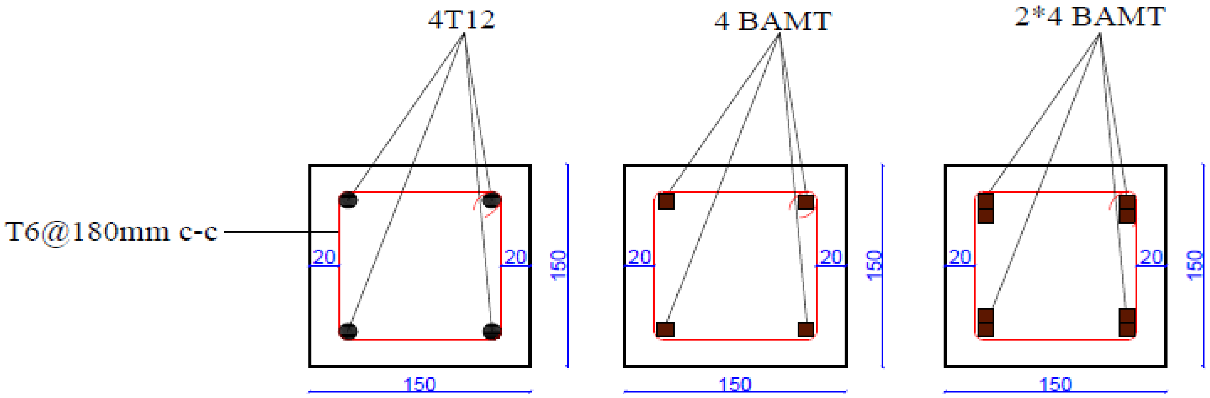


Fig. 1. Cross-section area of columns

TABLE 1. Properties of specimens

Specimen Group	**Longitudinal Reinforcement**				**Stirrup**
	Type	**Size (mm)**	**Number**	**Reinforcement ratio (%)**	
Control	Steel	T12	4	2.01	T6@180 mm
Sample 1	BAMT	10.6*10.6	4	2.01	T6 @ 180 mm
Sample 2	BAMT	10.6*10.6	8	4.02	T6 @ 180 mm

2.3 Reinforcement Preparation and Strain Gages Fixing

Sensors (strain gages) were installed to monitor the deformation of the reinforcement and the concrete. The surfaces of the reinforcement and column were ground smooth to provide appropriate areas for installing the electrical resistance strain gages. The strain gages were then protected from moisture by applying a bandage of fabric socked in liquid wax. The placement of the strain gauges to the reinforcement is shown in Fig. 2.

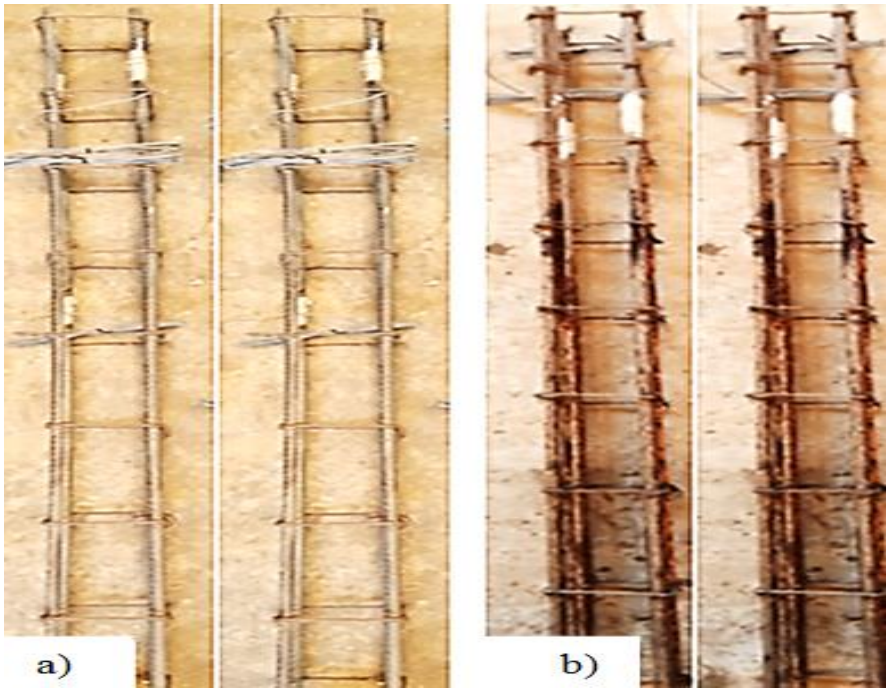


Fig. 2. Fixed strain gages on reinforcement: a) Steel; b) BAMT.

2.4 Concrete Preparation and Casting

Class 30 concrete was designed using the DOE approach and was used for this test. The concrete was thoroughly mixed using a mechanical mixer to produce a homogenous composition. The concrete workability was tested by the slump test, and the slump obtained averaged 40 mm. The concrete was then poured into the column formworks and compacted using a poker vibrator, and the surface was levelled smooth using a steel trowel. The formwork was removed the next day, and the columns were covered with moistened cloth for 28 days. 150 x 150 x 150 mm cubes were also made and cured in water until the time of the test at 7, 14, and 28 days to confirm the design strength. The columns and cubes are shown in Fig. 3.

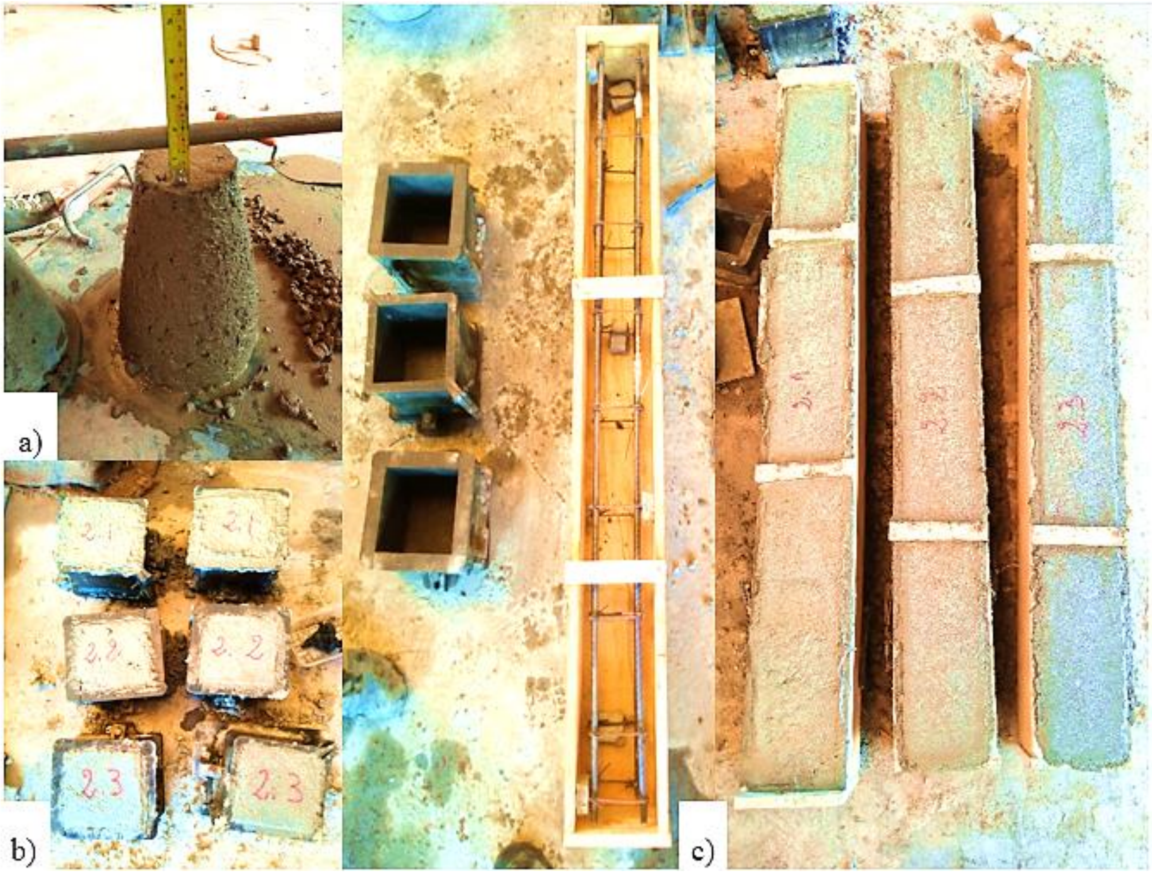
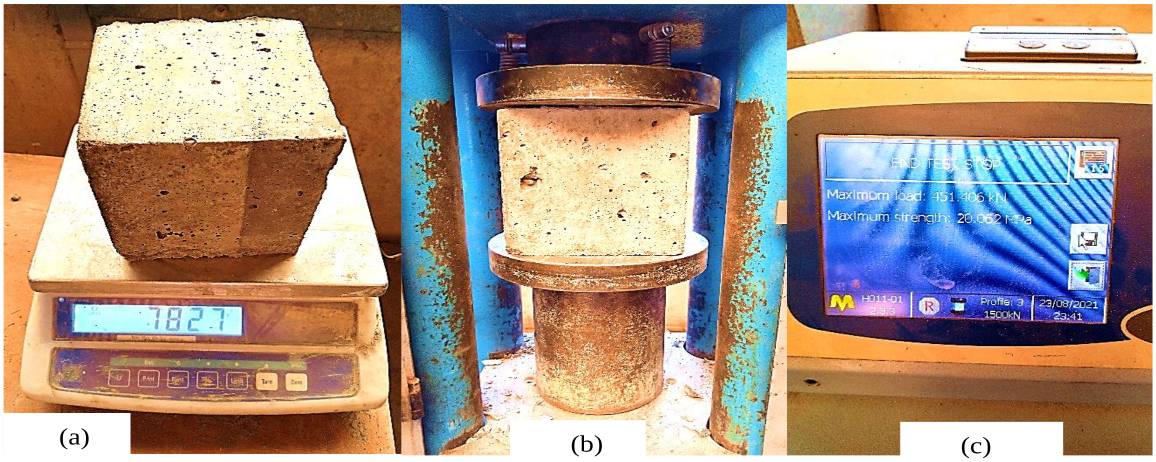


Fig. 3. Casting of columns and test cubes: (a) determination of slump. (b). casting of test cubes. (c). casting of columns.

2.5 Compressive Test of Concrete Cubes

This test aimed to verify whether the target strength of the concrete was achieved. The cubes were removed from water on the day of the test and were wiped with a soft cloth, then air-dried for 1 hour. The cubes were weighed then were placed centrally between the platens of a compression testing machine with a load capacity of 1,500 kN.The load was applied at the rate of 0.5 kN per second until failure. The maximum compressive strength was read from the machine. Three cubes were tested to an average strength for each record. Fig. 4 illustrates the compression test on the cubes.



END TEST STOP

Maximum load: 451.406 kN

Maximum strength: 20.062 MPa

Fig. 4. Compression test for cubes (a). weighing the cube. (b). applying compression load. (c). results read from a display screen.

2.6 Column Compression Test

For the compression test, the column was placed between two rigid beams in a steel frame as shown in Fig. 5. Load was applied from the top using a hydraulic jack with a capacity of 500 kN and was measured using a load cell connected to a data logger.The strain in the concrete and the reinforcement were measured using the strain gages which were connected to the data logger. Axial deformation of the columns was measured using two linear variable differential transformers (LVDT), both of which were connected to the data logger. The strain in the concrete and the reinforcement was measured by the strain gauges which were also connected to the data logger. In this way, it was possible to monitor the changes in all the variables at one point in the data logger.

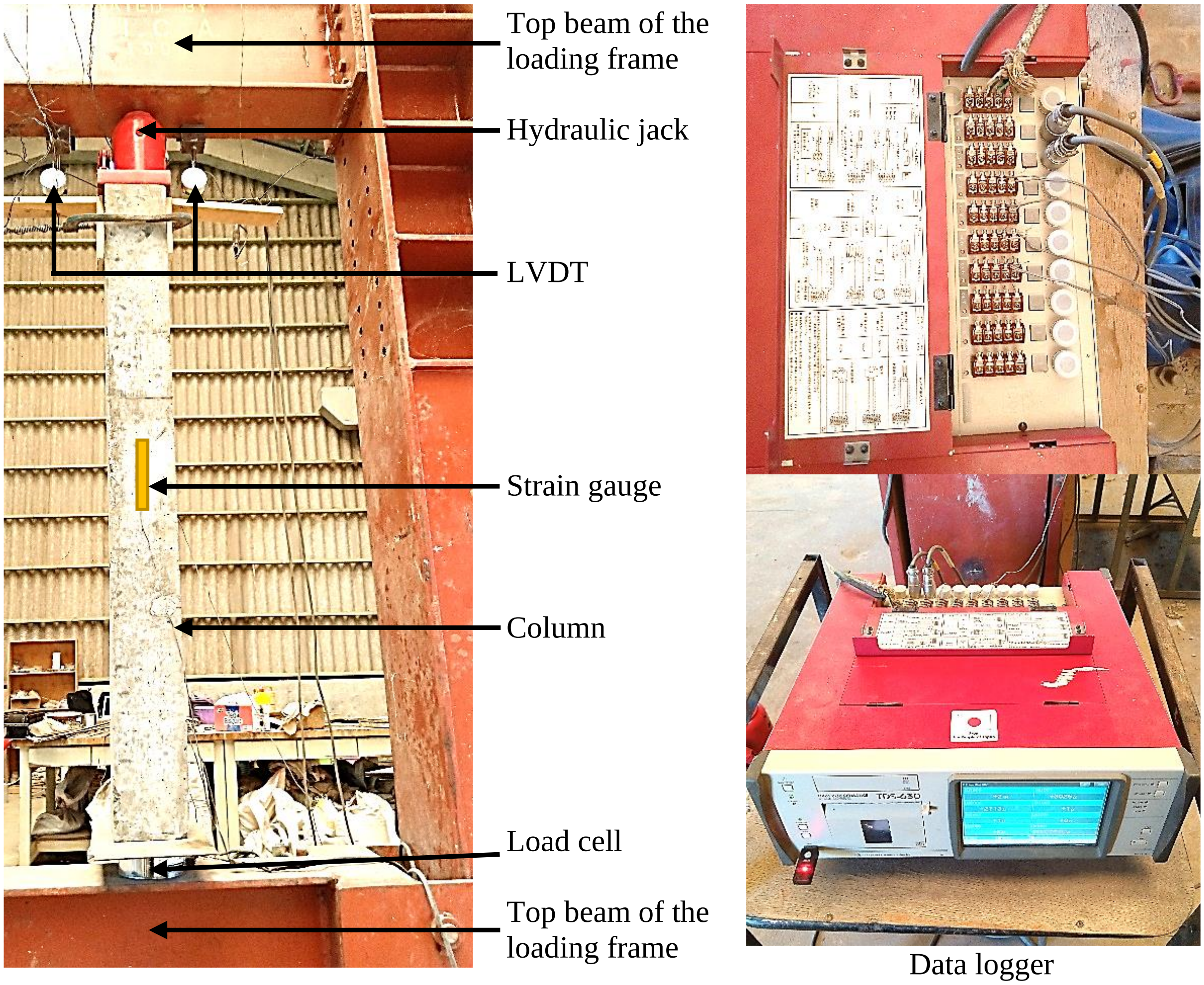


Fig. 5. Column experimental set-up

3. RESULTS AND DISCUSSIONS

The maximum loads, displacements, stresses, and deformations measured in this study are the averages of three samples from each set of specimens.

3.1 Cube Compressive Test

Table 2 shows the concrete compressive strength for the three sets of tests. The difference in the strength of concrete between the control and the test samples is 2.5 % which is not significant.

TABLE 2. Concrete compressive strength of the columns.

Serial No.	**Description**	**Concrete strength (MPa)**		
		7 days	14 days	28 days
1.	Control column	28	34	40
2.	BAMT1	30	37	39
3.	BAMT2	26	32	39

3.2 Column Failure Patterns

The failure crack patterns of the control specimens were as shown in Figure 6. At approximately 65 % of the failure load,many fine cracks appeared at the bottom of the columns. The cracks progressed upwards with increasing load. At failure load, the cracks extended to the centre of the column. Crushing of the concrete occurred at the bottom of the column. These failure patterns are shown in Fig. 6.

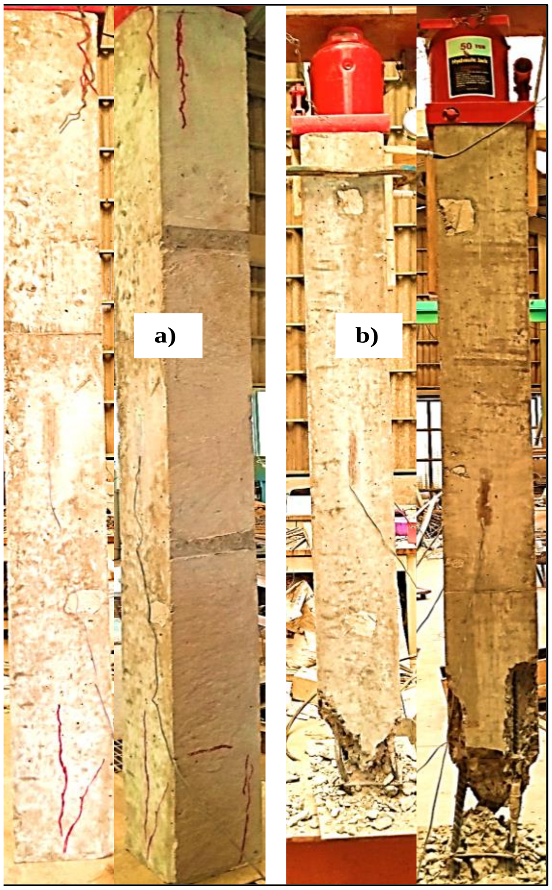


Fig. 6. Failure mode of the control specimen: a) Crack pattern; b) Failure

For specimens reinforced with BAMT, cracks formed at the bottom of the columns at approximately 60 % of the failure load. The cracks increased with the increasing load but did not extend upwards. The concrete cover at the bottom of the columns spalled off with the increasing load. At failure, the reinforcing strips broke, and the column fell down. This was in contrast tothe control in which the steel was deformed but still kept the column upright. The failure mode is shown in Fig. 7.

Fig. 7. Failure mode of the BAMT specimens: a) Crack pattern; b) Failure

3.3 Colum Load-Bearing Capacity

Fig.8 shows the relative strength of the three specimens. It is seen that the BAMT1 supported 11 % less load than the control for an approximately equal area of reinforcement. On the other hand, BAMT2, which had double the area of reinforcement of the control,supported,approximates 3 % less load than the control and approximately 8 % more load than BAMT1.

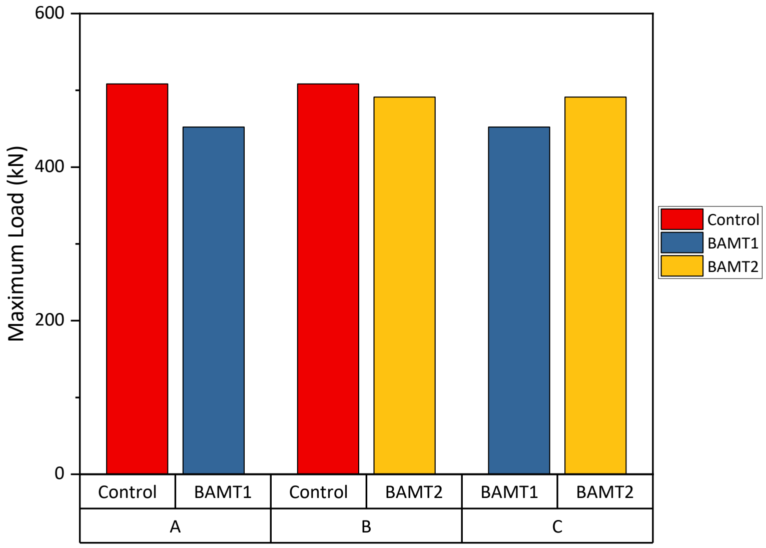


Fig. 8. Maximum load-Reinforcement ratio

3.4 Axial deformation of columns

Fig.9gives the specimens' load-displacement curves. The average axial load and axial displacement of each of the three specimen types are shown. The axial displacement of each kind of specimen is the average value measured by the two LVDTs, and the axial load is recorded by the load cell. The axial load-axial displacement curves for the three groups are separated into three zones, namely the elastic, elastoplastic, and fracture zones.

The elastic zone represents the rectilinear part of these three curves. This line is longer for the control sample, while it is approximately the same for the other two samples. This difference can be explained by the fact that steel is more elastic than Borassus wood, with a modulus of elasticity of 210,000 MPa compared to that of Borassus of 3,387 MPa. [32].

The curves exhibit non-linear behaviour in the elastoplastic zone. This starts at a stress of approximately 75 % of the failure load in steel and at approximately 20 % of the failure load for borassus. This could possibly be due to the less elasticity of wood compared to steel.

The load-displacement curves enter the failure phase after the maximum load is reached. In this zone, the loads progressively diminish until the column breaks down.

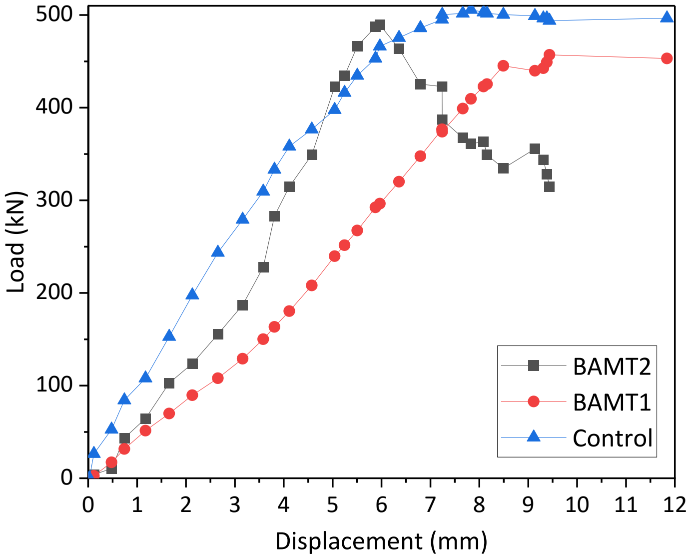


Fig. 9. Axial deformation of columns.

3.5 Strain-Stress

The stress-strain curves of the control specimens are shown in Fig.10. Upton 60 % of the ultimate stress, the strain in concrete and steel are the same and show a linear increase with increasing stress. With increasing load, the steel takes more strain than concrete. This implies a good bond between steel and concrete. The sample enters the elastoplastic phase after the concrete column cracks. The increase in the strain of both concrete and steel exceeds the increase in stress. On the other hand, the strain in steel increases more than in concrete, implying a reduced bond between the two materials. This non-linear behaviour is caused by the formation of cracks that transfer more load to the steel. The strain differential between the concrete and the steel increases with increasing load until the column collapses.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 41 Issue: 05-2022
DOI 10.17605/OSF.IO/BNMX7

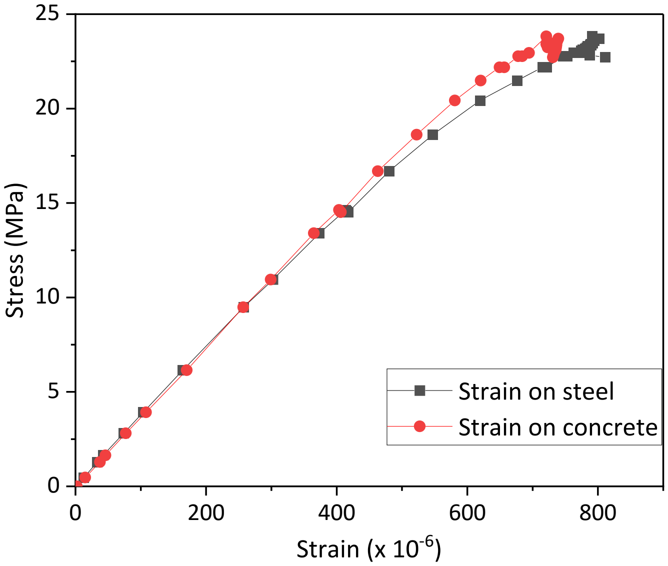


Fig. 10. Stress-strain curve for control

In Fig. 11, it is observed that in the case of BAMT samples, the strain in the reinforcement is higher than that in concrete from the onset but is more pronounced in BAMT1 than in BAMT2. In both cases, the difference in the strain in reinforcement and concrete increases with increasing load. This would imply slippage in the bond between concrete and the BAMT. It is also observed that at failure, the load is transferred to the borassus after the concrete has been crushed.

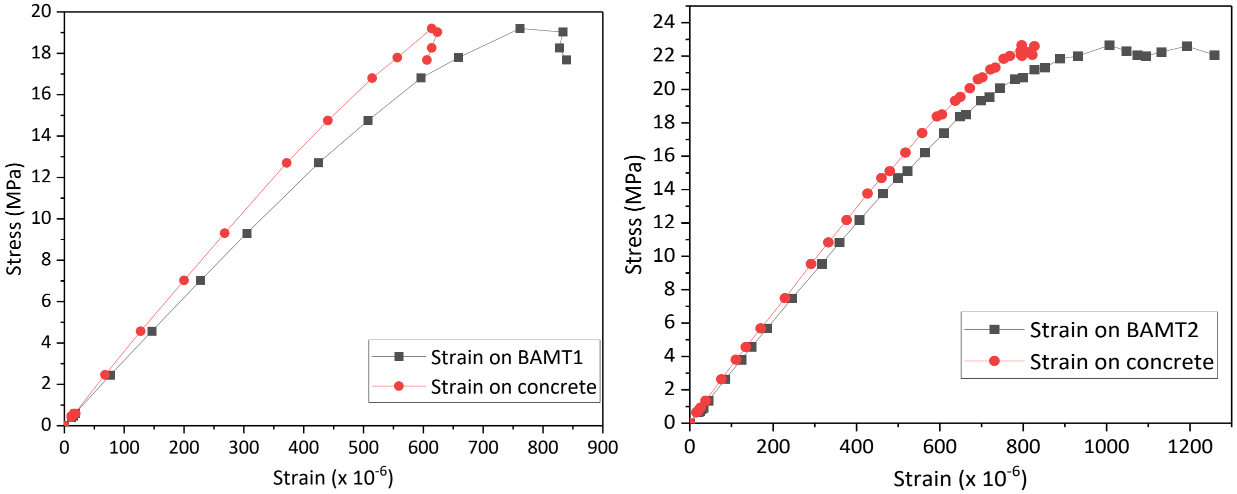


Fig. 11. Stress-strain curves for borassus

4. 4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

The following conclusions are derived from this study.

BAMT can be used as reinforcement in concrete columns.

With the same area of reinforcement, BAMT reinforced column loses only 11 % of the strength compared to the control. This reduction in strength is reduced when the area of borassus reinforcement is increased.

The axial deformation of the column reduces with increased area of BAM reinforcement.

The strain in BAMT is more significant than that in concrete under load, and the difference in strain between borassus and concrete increases with increasing load. This contrasts with the control when both steel and concrete are initially at the same strain until cracking starts.

At failure, BAMT reinforcement undergoes more plastic deformation than concrete, and this increases with an increase in the area of reinforcement.

4.2 Recommendation

BAMT has shown good potential for use as reinforcement in concrete columns. However, long term performance under adverse conditions of use warrants investigation.

Acknowledgements

The authors gratefully thank and appreciate the financial and administrative assistance provided by the Pan African University of Basic Sciences, Technology, and Innovation (PAUSTI); and the Jomo Kenyatta University of Agriculture and Technology (JKUAT) for the usage of the Wood Workshop and Structural Laboratories.

REFERENCES

[1] IBEF, “August 2019,” *Aust. J. Crop Sci.*, no. 13(08):2019, 2019, doi: 10.21475/ajcs.19.13.08.

[2] SchmidtW., HiryaN. N. M., BjegovićD., H. UzoegboC., KumaranS. G., "Cement technology in sub-Saharan Africa-Practical and scientific experiences,"*Am. Ceram. Soc. Bull.*, vol. 91, no. 5, pp. 52–56, 2012.

[3] JacksonR. B., FriedlingsteinP., AndrewR. M., CanadellJ. G., Le QuéréC., PetersG. P., "Persistent fossil fuel growth threatens the Paris Agreement and planetary health,"*Environ. Res. Lett.*, vol. 14, no. 12, 2019, doi: 10.1088/1748-9326/ab57b3.

[4] IsakssonR., BabatundeO., "Opportunities for improved sustainability in house building: The case of Dar es Salaam,"*African J. Sci. Technol. Innov. Dev.*, vol. 11, no. 4, pp. 457–463, 2019, doi: 10.1080/20421338.2017.1409456.

[5] Commission européenne, *study on the EU's list of Critical Raw Materials (2020), Factsheets on Non-critical Raw Materials*. 2020.

[6] BalogunS., EsezoborD., AdeosunS., SekunowoO., "Challenges of Producing Quality Construction Steel Bars in West Africa:Case Study of Nigeria Steel Industry,"*J. Miner. Mater. Charact. Eng.*, vol. 08, no. 04, pp. 283–292, 2009, doi: 10.4236/jmmce.2009.84025.

[7] ZhangB., WangZ., YinJ., SuL., "CO 2 emission reduction within Chinese iron & steel industry: Practices, determinants and performance,"*J. Clean. Prod.*, vol. 33, pp. 167–178, 2012, doi: 10.1016/j.jclepro.2012.04.012.

[8] Mendiara T.., "Negative CO2 emissions through the use of biofuels in chemical looping technology: A review,"*Appl. Energy*, vol. 232, no. September 2018, pp. 657–684, 2018, doi: 10.1016/j.apenergy.2018.09.201.

[9] Ozturk I., Acaravci A., "CO2 emissions, energy consumption and economic growth in Turkey,"*Renew. Sustain. Energy Rev.*, vol. 14, no. 9, pp. 3220–3225, 2010, doi: 10.1016/j.rser.2010.07.005.

[10] Ghavami K., "Bamboo as reinforcement in structural concrete elements,"*Cem. Concr. Compos.*, vol. 27, no. 6, pp. 637–649, 2005, doi: 10.1016/j.cemconcomp.2004.06.002.

[11] GBAGUIDI AISSE V., "Etude-De-La-Possibilite-Dutilisation-Du-R-Nier-Comme-Armature-V-G-Tale-Dans-Les-L-Ments-De-Structure-Des-Ouvrages-En-B-Ton-Arm-Cas-Des-Pouters(1).Pdf," vol. 7. pp. 1–7, 2009.

[12] GBAGUIDI-AISSE G., AKOWE SARE M., Sohounhloue J., MICHOZOUNNOU R.,. FOUDJET A. E., "Mechanical Characterization of the Lapping Zone of Palm Wood Mechanical Characterization of the Lapping Zone," no. August, 2018.

[13] Ketter M. K., Nyomboi T., Abuodha S. O., "Investigation of Landolphia buchananii stem material properties as a concrete reinforcement material Keywords :," 2015.

[14] WickensG. E., BurkillH. M., "The Useful Plants of West Tropical Africa,"*Kew Bull.*, vol. 41, no. 2, p. 471, 1986, doi: 10.2307/4102963.

[15] BellouardP., "Le rônier en A.O.F.," *Bois et Forêts des Tropiques*, vol. 14. pp. 117–126, 1950.

[16] RuffoC. K., BirnieA., TenganäsB., *Edible Wild Plants of Tanzania*, no. 27. 2002.

[17] GuinkoS., OuédraogoA., "Usages et enjeux de conservation du rônier (Borassus L .) à l ' Est et à l ' Ouest du Burkin a Faso," *Homme, plantes Environ. au Sahel Occident.*, no. 19, pp. 1–6, 2005.

[18] MichonL., AdeotiK., KoffiK., EwedjeE.-E., StaufferF. W., "Borassus Mart ., a Purpose Palm in Togo and,"*Palms*, vol. 62, no. 2, p. 57, 2018.

[19] AliA., AlhadjiD., TchiegangC., SaïdouC., "Physico-chemical properties of palmyra palm (Borassus aethiopum Mart .) fruits from Northern Cameroon," vol. 4, no. March, pp. 115–119, 2010.

[20] B. Sambou, A. Goudiaby, F. Ervik, and M. Cire, "Palm wine harvesting by the Bassari threatens Borassus aethiopum populations in north-western,"*Biodivers. Conserv.*, vol. 11, pp. 1149–1161, 2002.

[21] ZongoO., TapsobaF., CisseH., TraoreY., SavadogoA., "Modes of Use of the Palm Borassus aethiopum Mart. by the Rural Populations of Eastern and Central-Eastern Regions from Burkina Faso,"*Int. J. Curr. Microbiol. Appl. Sci.*, vol. 7, no. 12, pp. 62–74, 2018, doi: 10.20546/ijcmas.2018.712.009.

[22] GbessoF., Adjatin A., Dansi A. A., "Aphrodisiac Properties of Hypocotyls Extracts of Borassus aethiopum Mart (Arecaceae) Collected in Central of Benin Republic,"*Int. J. Curr. Microbiol. Appl. Sci.*, vol. 5, no. 3, pp. 802–814, 2016.

[23] Gruca M., Yu W., Amoateng P., NielsenM. A., PoulsenT. B., BalslevH., "Ethnomedicinal survey and in vitro anti-plasmodial activity of the palm Borassus aethiopum Mart,"*J. Ethnopharmacol.*, vol. 175, pp. 356–369, 2015, doi: 10.1016/j.jep.2015.09.010.

[24] Sarkodie J.,Squire S., "Borassus aethiopum, A Potential Medicinal Source of Antioxidants, Anti-

Inflammatory and Antimicrobial Agents,"*Herb. Med. Open Access*, vol. 1, no. 1, pp. 1–7, 2015, doi: 10.21767/2472-0151.10003.

[25] Gibigaye M., “Etude ethnobotanique et usages mécaniques du rônier (Borassus aethiopum mart) au Bénin,” *Ann. des Sci. Agron.*, vol. 13, no. 2, pp. 69–86, 2010.

[26] GiffardP.-L., “Le Palmier Ronier #Borassus aethiopum# Mart.,” *Bois et Forêts des Tropiques*, no. 116. pp. 3–13, 1967.

[27] Siaw D. E. K. A., "The stock and socio-economic uses of Borassus Aethiopum in Abrimasu Forest Reserve of Mampong Forest District,"*J. Energy Nat. Resour. Manag.*, vol. 1, no. 3, pp. 148–155, 2018, doi: 10.26796/jenrm.v1i2.32.

[28] SohounhloueA. Y. J., GBAGUIDI AISSEG. L., SolbesB., GalimardP., "Borassus aethiopum mart of Benin used as reinforcement in concrete: Adhesion characterization,"*Struct. Mech. Eng. Constr. Build.*, no. 6, pp. 74–80, 2017, doi: 10.22363/1815-5235-2017-6-74-80.

[29] Ngargueudedjim K.E., DorokoH., Bassa B., NtamackG. E., Charif D'ouazzane S., "Determination of thermal and physical properties of palmyra wood (Borassus aethiopum Mart.) from Malfana in Chad,"*Int. J. Adv. Res. Eng. Technol.*, vol. 6, no. 12, pp. 49–58, 2015, [Online]. Available: http://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=6&IType=12.

[30] Samah O. D., B. K. Amey, A. Vianou, E. Sanya, Atcholi E. K., “Caractérisation du Rônier (Borassus Aethiopum) ‘Cocker,’” *Технические Науки*, vol. 3, no. 23, pp. 140–146, 2013.

[31] Samah O. D., "Determination of mechanical characteristics and reaction to fire of RNIER (Borassus aethiopum Mart.) of Togo,"*African J. Environ. Sci. Technol.*, vol. 9, no. 2, pp. 80–85, 2015, doi: 10.5897/ajest2014.1767.

[32] Kone O., Koteng D.O., Matallah M., Kabubo C. K., "Mechanical Characteristics of Kenyan Borassus Aethiopum Mart timber as Reinforcement for Concrete,"*SSRG Int. J. Civ. Eng.*, vol. 8, no. 11, pp. 7–12, 2021, doi: 10.14445/23488352/IJCE-V8I11P102.