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Comparative Studies of the Effcts of Blocking and Water Repellant Agents on Tensile Strengths of Fanpalm

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ABSTRACT

The effects of blocking and water repellant coatings applied on fanpalm specimens on the tensile strength were examined. Fanpalm specimens (coated and uncoated specimens) were soaked in sodium hydroxide solution for specific periods up to 1 year to expose item to alkaline attack. Two groups of coating agents (blocking and water repellant agents) were applied as treatment agents. The blocking agents were of three types; sodium sulphate, magnesium sulphate and hydroxylamine, while water repellant agents also were of three types sulphur, bitumen and epoxy. Tensile strength tests were carried out on these specimens and results presented. The result revealed that as the duration of soaking in cement slurry of uncoated fanpalm increases, the nominal ultimate tensile strength of the fanpalm decreases from 107 to 17.50 N/mm2 at 366 days in cement slurry. While the specimens coated with water repellant and blocking agents decreased to 40.67 N/mm2 and 18.33 N/mm2 respectively at 366 days. This shows that coating fanpalm with blocking and water repellants will improved the resistant to chemical attack. up to 270 days. Beyond 270 days the coating specimens with water repellant is more effective. The specimens coated with blocking agents are of lower ultimate strength compared with uncoated specimens within 270 to 366 days in alkaline media.

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1. Introduction

Fanpalm is a natural fibre and natural fibres are prospective reinforcement materials but their use until now has been more traditional than technical. They have long served many useful purposes but the application of materials technology for the utilization of natural fibres as reinforcements in concrete has only taken place in comparatively recent years [1]. The use of bamboo, fan palm and some selected woods to replace the conventional steel reinforcements in reinforced concrete beams, columns and slabs have also received attention over the past two decades [2–7]. Mechanical properties of these materials such as stress-strain characteristics, load-deflection characteristics, absorption characteristics and behavior of the composite elements have been investigated. Most of these materials were found to be highly susceptible to dimensional changes and loss of strength with time in water and alkaline media [6,8–10]. This study is focused on fanpalm.Fan palm is a monocotyledon plant [11,12]. The stem consists of three major layers; the bark, the outer core, and the inner core. The bark is greysh coloured, rough and hard. The outer core consists of black and long fibres glued together by lignin [13]. The outer core is a zone of sclerechymatous (thick wall) cells of fibrous and xylem vessels for conducting water [14]. The inner core otherwise called the ground tissue is a zone of parenchymatous (thin wall) cells. It also contains scattered, few fibres and numerous inter cellular air spaces [12,13]. In fibre cells, the lumens are small, cell walls are thick and air spaces are few which result in hardened dense cells. It gives the plant the strength to withstand lateral forces from wind. On the other hand, vessels have large lumen, thin cell walls and numerous air spaces subsequently low density and low strength. The inner ground tissues have numerous intercellular air spaces and thus, low strength and low density [11,12] The physical and mechanical properties of air dried fan palm are summarized in Table 1.

Table 1.
Physical and mechanical properties of fan palm (Borassus aethiopum).

Properties	**Values**
Optimum tensile strength	70 – 131.4 N/mm^2
Compressive strength	40 – 105.2 N/mm^2
Modulus of Elasticity (tension)	19 – 23.5 kN/m^2
Modulus of elasticity (compression)	17.45 – 19.24 kN/m^2
Modulus of rupture	70.59 – 121.4 kN/m^2
Moisture content (air dried)	7.2 – 12.0%
Moisture content (fresh)	150 – 250%
Specific gravity	1.2 – 1.5
Bond stress	1.6 – 2.0 N/mm^2

Source: [11,15]

It was also established that the strength of fan palm reinforced slabs increases with increase in percentage of reinforcements [15]. However, the moment carrying capacities of beams reinforced with fanpalm decreased with time both in water and alkaline environments [16]. These results revealed that fan palm is a prospective good reinforcing material that could be used as partial replacement of steel reinforcements or compete replacements in some concrete members such as: lintels, floor slabs, beams and columns that are not carrying heavy loads, but measures would have to been to taken to preserve its physical and mechanical properties in alkaline and water environments like concrete, sea and off sore environments.

Therefore, the study of tensile strength of fanpalm coated with blocking and water repellants agents ageing in alkaline and water environments is very important to determine the most effective way of preserving the tensile strength of fanpalm in alkaline media. Several investigators have studied the durability of various natural fibres, such as, coir, jute, sisal etc., in various media and exposure conditions [17,18]. The studies were basically on methods to slow down or prevent the decomposition of the fibres in alkaline media. The primary cause of the change in the characteristics of the natural fibres in concrete is due to the chemical decomposition of the lignin and the hemicelluloses. The alkaline pore water in the concrete dissolves the lignin and hemicellulose and thus breaks the link between the individual fibre cells [19]. The decomposition of natural fibers in alkaline environment of concrete can be delayed by impregnating the fiber with water repellent agents (sulphur, epoxy, polymers, bitumen products etc). Water repellant agents will prevent alkaline pore water in concrete from attacking the lignin and hemicelluloses of the natural fibre [20].

2. Methodology

Sliced and seasoned fanpalm logs were procured. The sliced fan palm log was now fixed on the table of the rock well R40 sawing machine with the aid of the G-clamps. The saw of the R40 machine was then lowered down and adjusted to cover the depth of the fan palm logs. The machine was then switched on and the fan palm logs pushed carefully and slowly against the rotating circular saw with the stationary guide. A regular 50 mm x 100 mm rectangular cross sectioned fan palm logs were produced. Each of them was again re-sliced to two to produce a 50 mm x 50 mm sections. The sections were smoothened with the aid of circular smooth grinding machine. The sliced specimen were cut and re-sliced to 10 mm x 25 mm x 310 mm using hack saw and rock well machine respectively. A template of tensile specimen conformed to ASTM C666, (2008) standard made with ply wood was placed on the re-sliced fan palm and the shape carefully marked using permanent marker. Tensile specimens were thereby produced by carefully filing off the fan palm parts that are off the marked lines using the smooth grinding stone machine by positioning the specimens on and off the rolling wheel of the grinder. The finished tensile specimen is shown in Figure 1.

The Alkaline media, which is sodium hydroxide solution (0.1 M NaOH), was prepared by measuring 20 g of granular sodium hydroxide salt in the beaker. The measured 4 liters water was then gradually added to the measured 20 g of sodium hydroxide salt and stirred continuously until all the grains of the sodium hydroxide have disappeared.

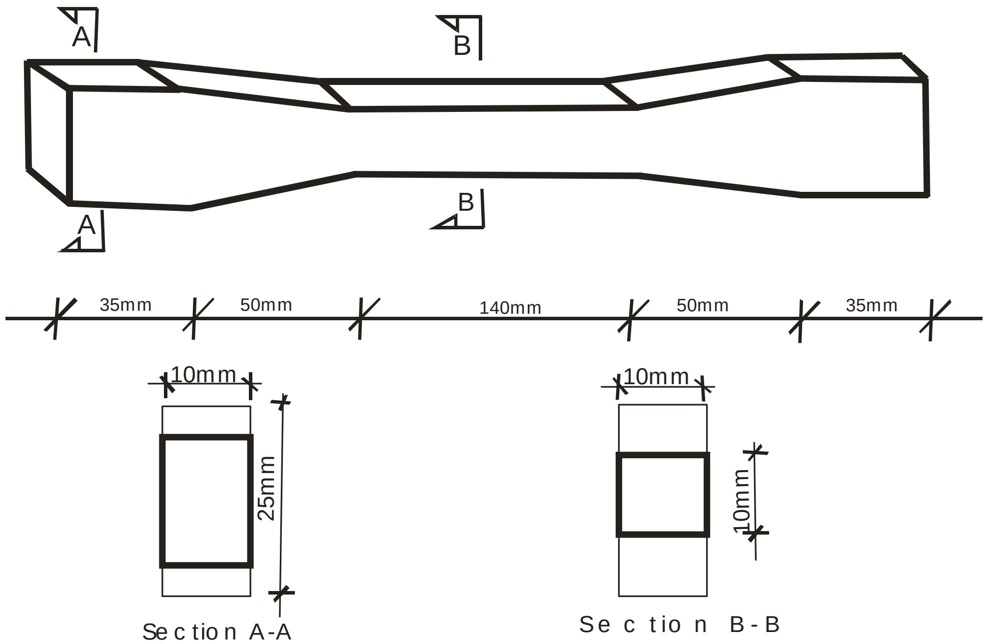

Fig. 1. Fanpalm specimen for tensile strength test.

The coating agents are of two classes, the blocking agents and the water repellent agents. The blocking agents react with fibre components to build up compounds which are difficult to dissolve in alkaline environments but the water repellents filled the pores within the cells of the fibres to make it water proof. Blocking agents include; sodium sulphate, magnesium sulphate, sodium silicates, hydroxylamine, copper compounds and iron compounds. However, sodium sulphate, magnessium sulphate and hydroxylamine were chosen for this research because they are readily available.

The method of preparation of coating agents; magnesium sulphate solution, hydroxylamine solution, sodium sulphate and epoxy solutions are same except that the salt added in each case was different. In each case, 20 g of the salts, measured by Ohuan's weighing balance was added to 50 g of tap water and stirred continuously until the salts completely dissolved. The prepared fanpalm specimens were divided into seven sets. Three sets of the seven sets were coated with blocking agents (sodium sulphate, magnesium sulphate, and hydroxylamine). Another three sets were coated with water repellants (sulphur, epoxy, and bitumen paint). While the seventh set were left uncoated to serve as control. The coated specimens were left to air dried for 24 hours. The tensile strength tests on the specimens were carried out thus; the specimens were held in the grips at the tensile zone of the automatic universal testing machine (Avery Denison Universal Testing Machine, Model 7133 CCJ/DCJ 200KN/400KN/600KN Capacity. The speed was adjusted to the loading rate of 2 kN/mins, the load then applied and the load at failure was read and recorded.

3. Results

Table 2 shows the result of the tensile strength test on fan palm specimens for a period of 365 days under various treatment conditions.

The compares of the tensile stress over a period of one year for all the specimens as presented in Figure 2 to 11. At 7 days, water repellant agent will give better protection to fan palm in alkaline media with epoxy been preferred. However, both water repellant and blocking agents retained higher mean ultimate tensile strength compared to the ultimate tensile strength of uncoated specimens. The uncoated fan palm specimen in alkaline media has the lowest ultimate tensile strength of value 85.0 N/mm^2 at 7 days while uncoated fan palm specimen in water has a value of 88.46 N/mm^2 at 7 days (see Figure 3). This is an indication that alkaline environment affects the tensile stress of fan palm.

Table 2.
Ultimate tensile stress of coated and uncoated fan palm specimen in alkaline and water media.

	Specimen Before Immersion		Tensile Stress (N/mm^2)								
			at begining	7days	14days	28days	56 days	90days	180days	270 days	365days
Uncoated	T_U	T_{U1}	107.5	83.8	80.0	73.0	*32.0	65.0	50.0	50.2	20.0
		T_{U2}	107.4	85.3	70.0	70.0	65.0	70.0	50.0	45.0	15.0
		T_{U3}	107.6	86.0	95.0	70.0	65.0	60.0	60.0	46.0	*5.0
		T_U	**107.50**	**85.00**	**81.67**	**71.67**	**65.00**	**65.00**	**53.33**	**47.07**	**17.50**
Water Repellants	T_{UW}	T_{UW1}	107.4	87.5	88.5	75.6	70.5	63.3	60.0	55.0	20.0
		T_{UW2}	107.5	89.5	84.3	78.4	71.6	65.0	64.0	58.5	20.0
		T_{UW3}	107.4	88.3	88.6	80.0	65.7	65.0	63.0	56.4	15.0
		T_{UW}	**107.43**	**88.46**	**86.13**	**78.00**	**69.27**	**64.43**	**62.33**	**56.63**	**18.33**
	T_E	T_{E1}	107.0	98.4	80.0	80.0	82.5	70.0	67.5	65.0	25.0
		T_{E2}	107.5	98.8	91.4	*25.0	85.0	*40.2	65.3	63.0	45.0
		T_{E3}	107.4	97.0	95.0	81.2	75.0	85.0	60.3	62.0	30.0
		T_E	**107.34**	**98.08**	**88.8**	**80.63**	**80.83**	**77.50**	**64.37**	**63.33**	**33.33**
	T_S	T_{S1}	107.4	92.0	77.5	75.0	67.5	65.5	65.0	63.5	43.0
		T_{S2}	107.5	91.0	85.0	87.5	70.0	68.5	67.0	63.5	30.0
		T_{S3}	107.4	91.1	95.0	80.0	70.0	67.0	67.0	64.0	35.0
		T_S	**107.43**	**91.37**	**85.83**	**80.83**	**69.17**	**67.00**	**66.33**	**63.67**	**36.00**
Blocking Agents	T_B	T_{B1}	107.4	90.5	83.2	78.3	70.2	70.0	67.1	62.5	45.0
		T_{B2}	107.4	91.4	84.5	80.2	69.2	60.0	64.3	63.5	37.0
		T_{B3}	*80.8	93.2	80.6	*40.2	66.0	65.0	57.8	60.1	40.0
		T_B	**107.40**	**91.70**	**82.77**	**79.24**	**68.43**	**68.38**	**63.03**	**62.03**	**40.67**
	T_{Mg}	T_{Mg1}	107.6	90.0	82.5	70.0	66.3	65.0	60.5	60.0	25.0
		T_{Mg2}	107.0	89.8	82.5	72.5	65.0	65.0	63.3	61.0	20.0
		T_{Mg3}	107.3	88.6	70.0	82.5	67.5	65.2	64.7	60.5	10.0
		T_{Mg}	**107.30**	**89.47**	**78.35**	**77.50**	**66.25**	**65.07**	**62.88**	**60.50**	**18.33**
	T_{Na}	T_{Na1}	107.6	90.1	90.0	80.0	67.5	68.5	68.0	62.0	23.0
		T_{Na2}	106.9	90.5	80.5	82.5	71.0	67.5	64.0	60.0	25.0
		T_{Na3}	107.4	90.6	80.5	82.5	65.5	65.0	60.3	60.0	15.0
		T_{Na}	**107.34**	**90.41**	**83.67**	**81.67**	**68.17**	**67.00**	**64.10**	**60.50**	**21.00**
Steel (Control)											

T_H	T_{H1}	107.5	91.0	75.0	70.0	67.5	63.2	60.0	62.0	45.0
	T_{H2}	107.5	92.1	87.5	80.0	67.5	67.5	*54.0	63.0	15.0
	T_{H3}	107.5	91.1	85.0	85.0	*32.5	65.0	63.4	62.5	20.0
	T_H	**107.32**	**91.39**	**83.33**	**78.33**	**67.50**	**65.23**	**61.70**	**62.50**	**26.67**
T_{St}	T_{St1}	410.0	405.0	415.0	415.0	410.0	405.0	406.0	400.0	400.0
	T_{St2}	420.0	410.0	410.0	415.0	490.0	405.0	405.0	379.0	420.0
	T_{St3}	415.0	410.0	410.0	420.0	405.0	407.0	410.0	370.0	350.0
	T_{St}	**415.00**	**408.33**	**411.67**	**416.67**	**401.67**	**405.67**	**405.00**	**383.00**	**390.00**

(*) Denote values not used

T_u = Tensile Stress of Uncoated Fanpalm in Alkaline:
T_E = Tensile Stress of Fanpalm Coated with Epoxy:
T_B = Tensile Stress of Fanpalm Coated with Bitumen:
T_{Na} = Tensile Stress of Fanpalm Coated with Sodium Sulphate
T_{St} = Tensile Stress of Fanpalm Coated with Steel
T_{Uw} = Tensile Stress of Uncoated Fanpalm in Water
T_s = Tensile Stress of Fanpalm Coated with Sulphur
T_{Mg} = Tensile Stress of Fanpalm Coated with Magnesium
N_H = Tensile Stress of Fanpalm Coated with Hydroxylamine

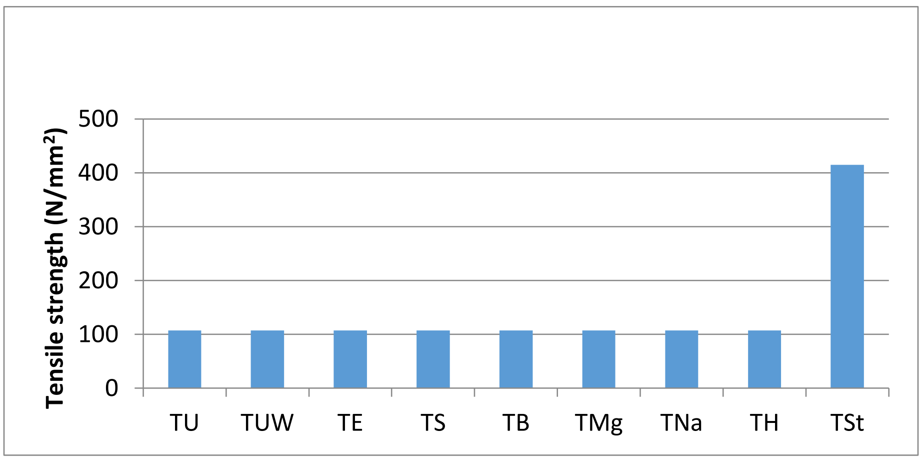

Fig. 2. Tensile stress of coated and uncoated fanpalm at the beginning.

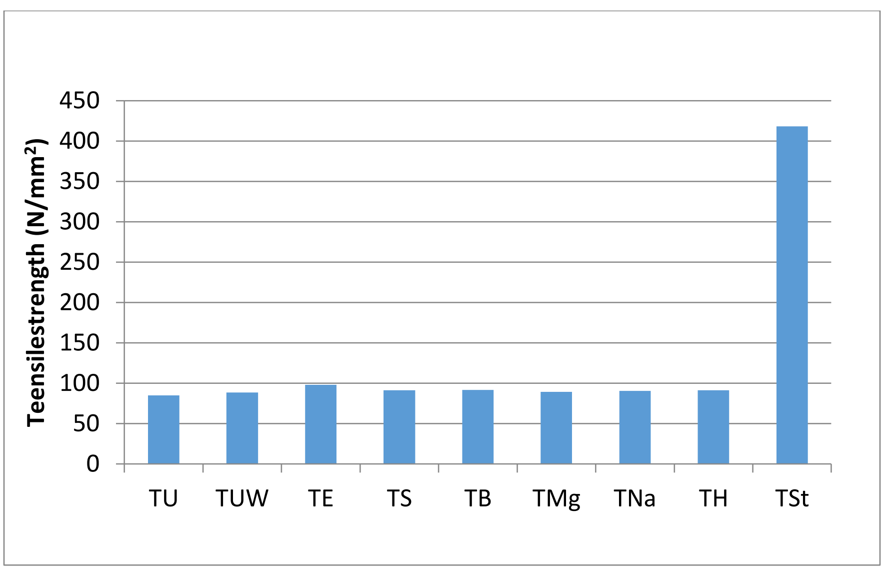

Fig. 3. Tensile stress of coated and uncoated fanpalm at 7 days.

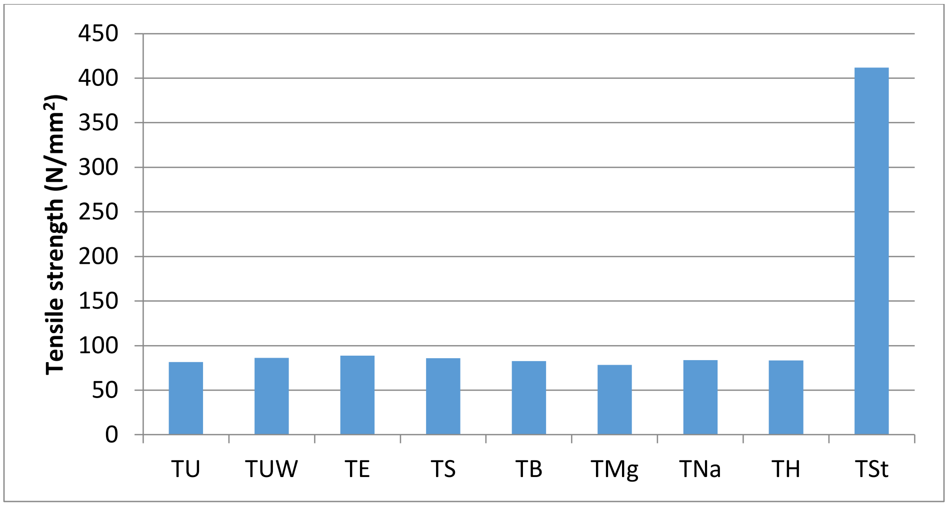

Fig. 4. Tensile stress of coated and uncoated fanpalm at 14 days.

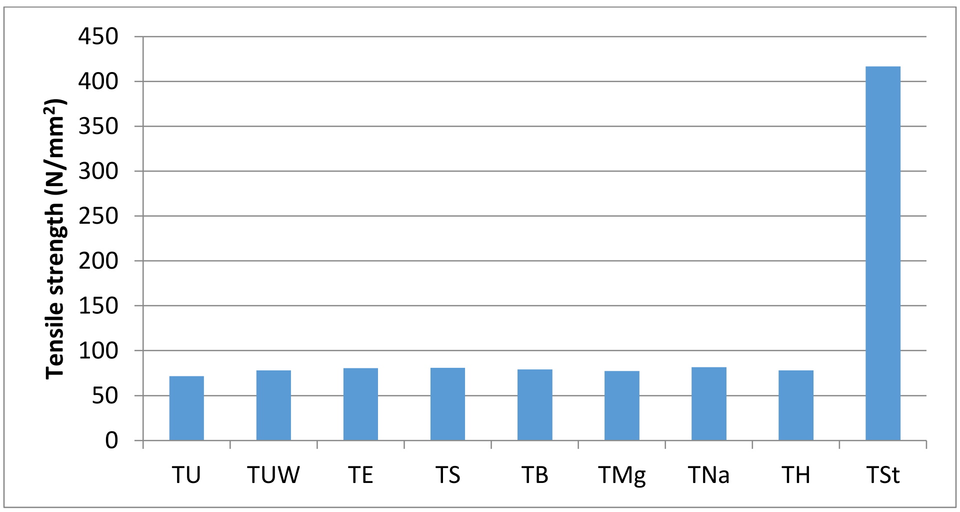

Fig. 5. Tensile stress of coated and uncoated fanpalm at 28 days.

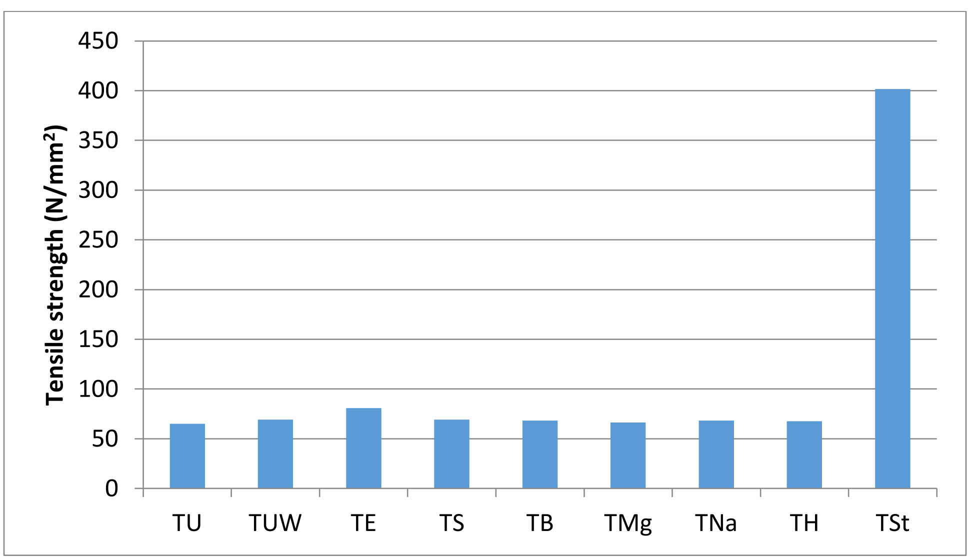

Fig. 6. Tensile stress of coated and uncoated fanpalm at 56 days.

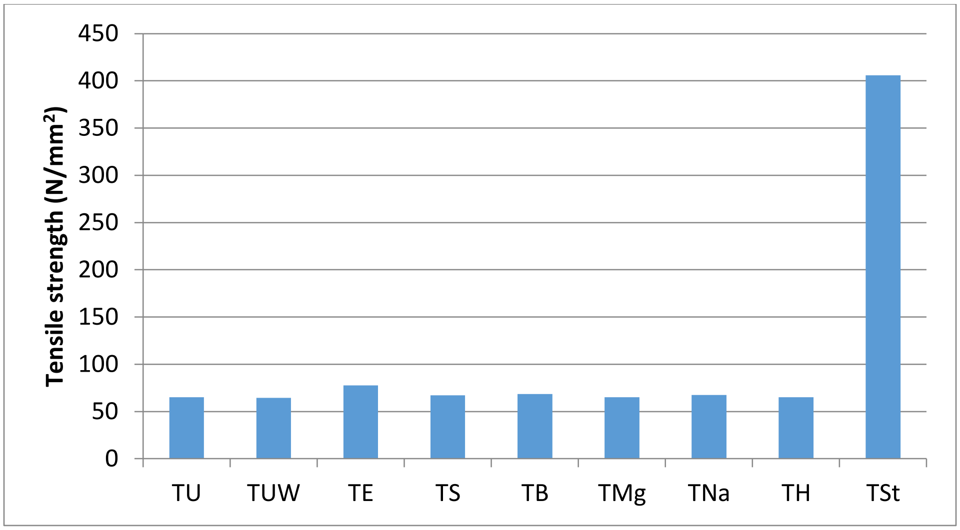

Fig. 7. Tensile stress of coated and uncoated fanpalm at 90 days.

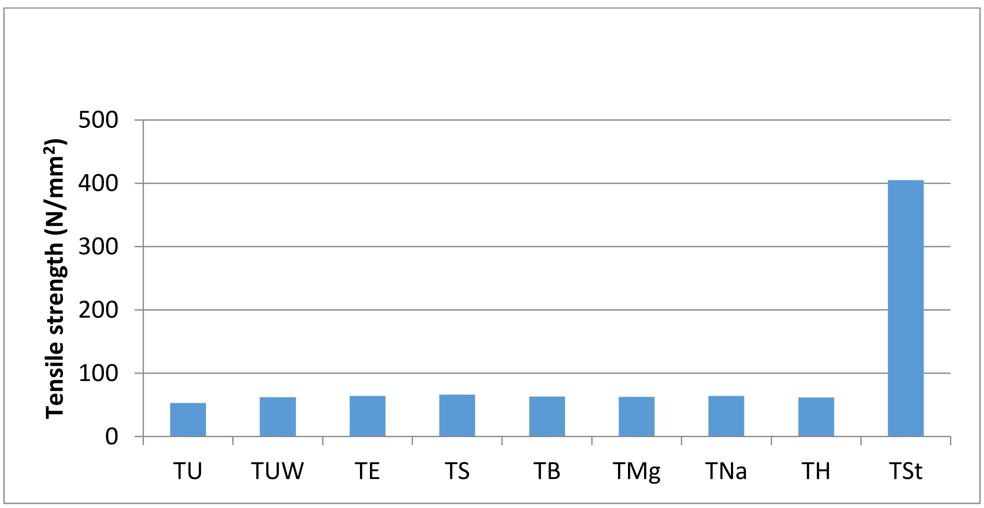

Fig. 8. Tensile stress of coated and uncoated fanpalm at 180 days.

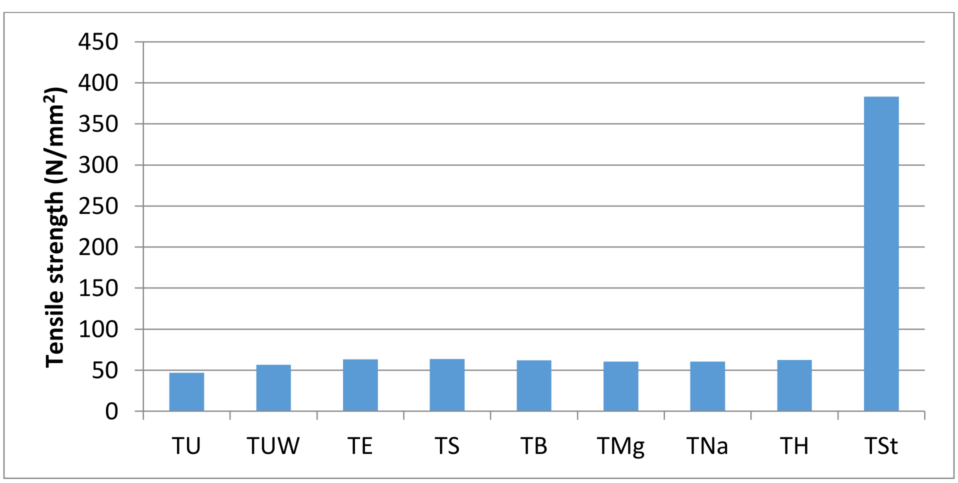

Fig. 9. Tensile stress of coated and uncoated fanpalm at 270 days.

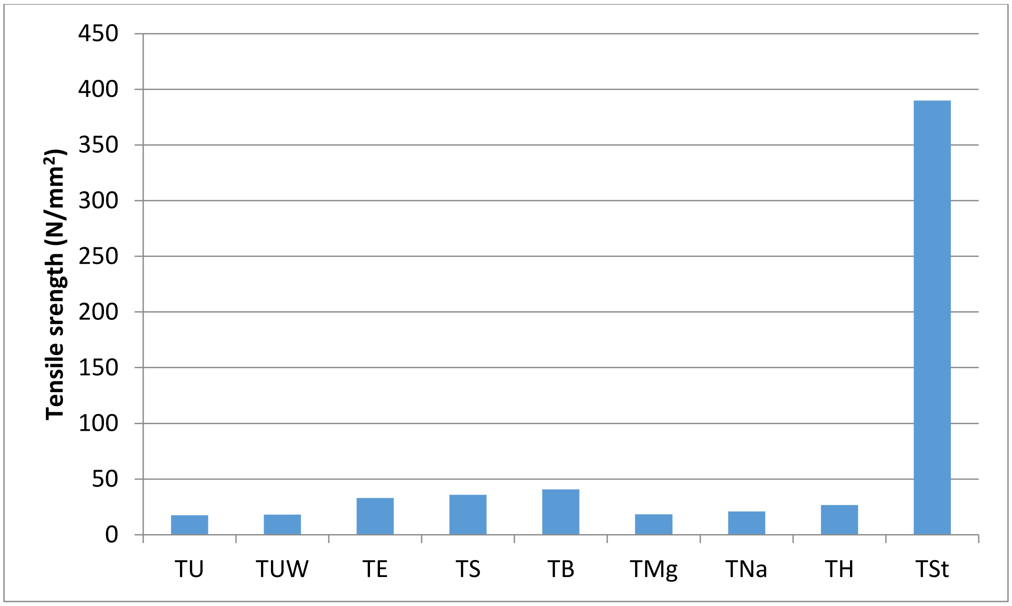

Fig. 10. Tensile stress of coated and uncoated fanpalm at 366 days.

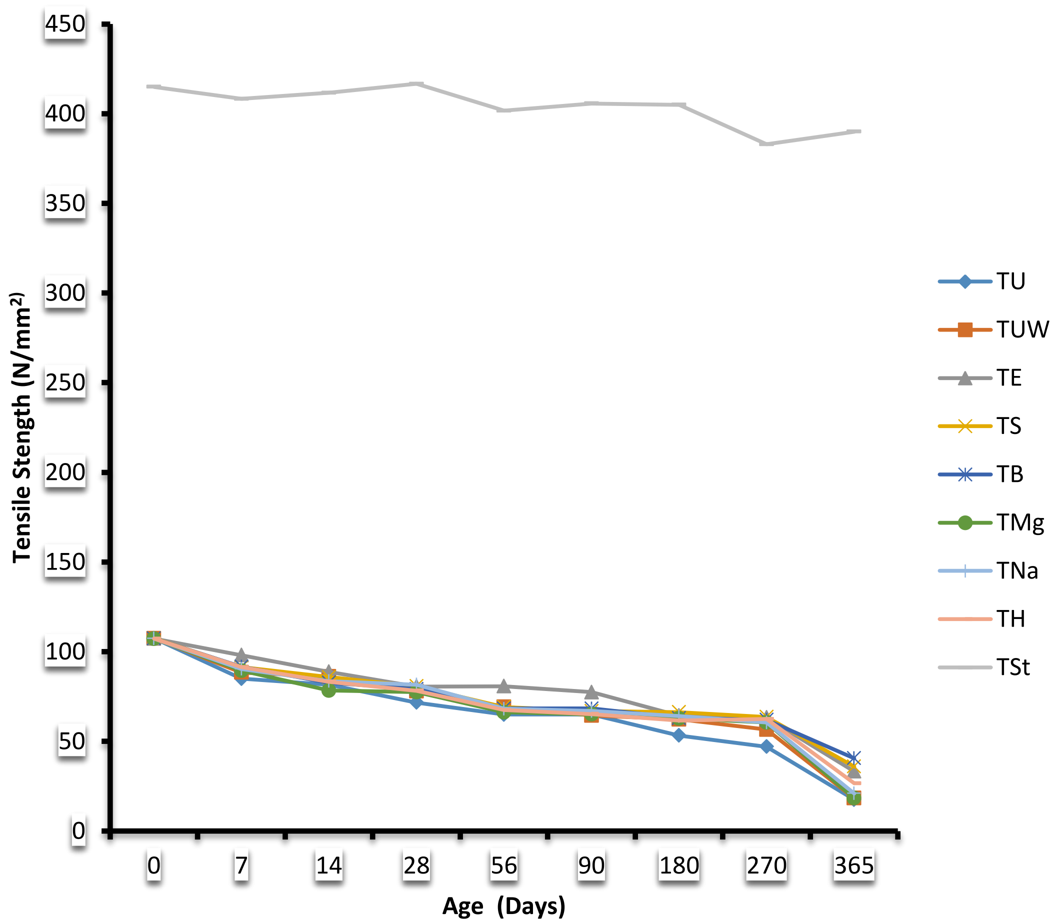

Fig. 11. Tensile stress of coated and uncoated fanpalm in NaOH solution.

At 14 days conditioning in alkaline solution, Figure 4 showed that fanpalm specimens coated with epoxy solution retained the highest ultimate tensile stress of value 88.8 N/mm^2 compared to specimens coated with sulphur and bitumen of the water repellant agents. But out of the specimens coated with blocking agents, specimens coated with sodium sulphate retained the highest ultimate tensile stress with the mean value of 83.67 N/mm^2.

It could be said that water repellant will offer better protection to specimens at this age. It could be noted that uncoated specimens conditioned in water retained higher ultimate tensile stress compared to specimens coated with blocking agents and conditioned in alkaline media. This could be due to the fact that chemical reaction between fan palm specimen and water is slower compared to the reaction between the fan palm compounds and alkaline solution even when it was coated with blocking agents. But as expected, the uncoated fan palm specimens conditioned in alkaline have the average ultimate tensile strength of 81.67 N/mm^2 which is the lowest value at this age. There is a direct attack on the fibres of the fan palm by hydroxyl ions of the alkaline solution. For steel specimens, there was a further decrease in ultimate tensile stress to a value of 411.67 N/mm^2 (see Figure 4 and Figure 11).

The result at 28 days as presented in Figure 5; showed that specimen coated with epoxy still retained an average value of 80.63 N/mm^2 of the ultimate tensile strength which is the highest of the specimens coated with water repellants. While specimen coated with sodium sulphate has an average ultimate tensile strength of value 81.67 N/mm^2 been the highest value of the ultimate tensile stress for fan palm specimens coated with blocking agent. This shows that blocking agents will offer better protection to fan palm than water repellant agents at this stage. Also for the uncoated fan palm, the uncoated fan palm specimen in alkaline media retained the lowest ultimate tensile strength of the mean value 71.67 N/mm^2 compared to uncoated fan palm specimen in water which has an average ultimate tensile strength of 78.0 N/mm^2 at this stage.

At 56 days, there is a further decrease in the ultimate tensile strength for all the fan palm specimens and steel specimens. From Figure 6 and Figure11, it could be observed that of the specimens coated with water repellants, fan palm specimens coated with epoxy still retained the highest mean ultimate tensile stress with mean value of 80.83 N/mm^2.

Out of the fanpalm specimens coated with blocking agents, specimens coated with sodium sulphate retained the highest ultimate tensile stress with the mean value of 68.17 N/mm^2. Also, as expected for the uncoated fan palm specimens, the uncoated specimens conditioned in water have higher value compared to uncoated specimens in alkaline media. This is because uncoated fan palm specimens in alkaline solution are exposed to direct attack of the hydroxyl ions of the alkaline media. There was further decreased in the ultimate tensile stress of steel. The tensile stress decreases to a value of 401.67 N/mm^2.

At 90 days, Figure 7 showed that the specimens coated with epoxy retained the highest tensile stress with the value of 77.5 N/mm^2.

At 180 days, sulphur offers the best water repellant agents to be used as coating agents for fanpalm. Specimens coated with sulphur retained an average tensile stress of 66.33 N/mm^2 compared to its counterpart, epoxy (64.37 N/mm^2) and bitumen (63.03 N/mm^2). For the specimens coated with blocking agents, sodium sulphate offers the best coating agents. Specimens coated with it had an average value of 64.1 N/mm^2 compared with specimens coated with magnesium sulphate of 62.88 N/mm^2 and hydroxylamine of 61.70 N/mm^2. The uncoated fan palm in alkaline media recorded the lowest value of the retained ultimate tensile strength with the value of 53.33 N/mm^2 (see Figure 8). Also there is further decline in the ultimate tensile strength of steel in alkaline media to an average strength of 405.00 N/mm^2 (see Figure 11).

At 270 days, it could be observed from Figure 9 that the retained values of the ultimate tensile strength are close but specimens coated with sulphur retained a slightly higher strength of value 63.67 N/mm^2 when compared to specimens coated with epoxy of value 63.33 N/mm^2 and specimens coated with bitumen a value of 62.03 N/mm^2.

For specimens coated with blocking agents, both specimens coated with sodium sulphate and specimens coated with magnesium sulphate retained the same average ultimate tensile strength value of 60.5 N/mm^2 but specimens coated with hydroxylamine retained the highest mean ultimate tensile stress of value of 62.5 N/mm^2. The ultimate tensile stress of uncoated specimens as presented in Figure 4.2 has a massive decline in strengths. The uncoated specimens in water have ultimate tensile strength 56.63 N/mm^2 and the ultimate tensile stress of uncoated fan palm specimen in alkaline is 47.63 N/mm^2. Also steel recorded further decline in the ultimate tensile strength.

At 365 days, the ultimate tensile strength of the fanpalm specimens coated with water repellant agents (sulphur, epoxy and bitumen), bitumen offered the best coating agent of the three. The specimens coated with bitumen have an average ultimate tensile stress of 40.67 N/mm^2. While specimens coated with epoxy retained an average strength of 33.33 N/mm^2, specimens coated with sulphur retained average strength of 36 N/mm^2 (see Figure 10).

For specimens coated with blocking agent, specimens coated with hydroxylamine retained the highest strength with average ultimate tensile strength retained of 26.67 N/mm^2. The uncoated specimens has the lowest value of retained strength with the uncoated specimen in alkaline media been the lowest with a value of 17.5 N/mm^2.

The steel also slightly decreased in ultimate tensile strength to 390 N/mm^2 (see Figure 11). It could be said though steel has a very high tensile strength compared to the fan palm, both behaved alike in alkaline environment in terms of changes in strength with time.

The steel specimens suffered serious corrosion in alkaline media which lead to massive decrease in effective diameter at 365 days which accounted for its decrease in strength. On the other hand, it was observed that fanpalm does not corrode in the alkaline media but it suffers some degree of softness which could have accounted for its decrease in ultimate tensile strength. The specimens coated with blocking agents are of lower ultimate strength compared with uncoated specimens within 270 to 366 days in alkaline media because the blocking agent might have build up chemical compounds which further attacked the cells of the fanpalm specimens in the media.

The comparison of the ultimate tensile stress under various treatments using anova analysis is presented in Table 3. The results indicated that $f = 228.85$, and $prob > f = 0.0000$ which implies that the ultimate tensile stress is highly significant, that is, the mean stress varies significantly over different treatments for the period of one year.

Table 3.
Anova of tensile stress.

Treatment	Mean	Std. Dev.	Freq.
T_B	73.738887	19.266963	9
T_E	77.134445	21.752901	9
T_H	71.552223	22.658717	9
T_{Mg}	69.516667	24.349902	9
T_{Na}	71.539999	24.111631	9
T_S	74.181112	20.271443	9
T_{St}	404.11223	11.209436	9
T_U	65.971111	25.578467	9
T_{UW}	70.112222	25.011928	9
Total	108.65099	107.20273	81

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	884605.595	8	110575.699	228.85	0.0000
Within groups	34788.3829	72	483.171985		
Total	919393.978	80	11492.4247		

Bartlett's test for equal variances: $chi^2(8)$ = 5.9746 Prob>chi^2 = 0.650

Conclusions

From the results of this research work, the following conclusion can be drawn:

(i) Coating fan palm with water repellant agents (bitumen, epoxy and Sulphur) preserved the strength of fan palm better in alkaline media than the use of the blocking agents (sodium sulphates, magnesium sulphates and hydroxylamine) at the ages above 270 days (see Figure 10).
(ii) Fan palm contains organic compounds, which are active in chemical reactions which affect the durability of structural elements when fan palm is used untreated as reinforcements in concrete elements.
(iii) The rate of decrease of ultimate tensile stress of fan palm specimens in alkaline media was lowered when blocking and water repellants treatment were applied.

References

[1] Audu MT. Durability study of Fanpalm as a Reinforcement Material in Concrete.Unpublished Ph.D Thesis submitted to Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria 2015.

[2] Adetifa. OA. Fanpalm and Bamboo as Reinforcement in Concrete. In Proceedings of the National Seminar on Structural Codes of Practice by Nigeria Society of Engineers, Structural Engineering Division 1088:3–6.

[3] Bystriakova N, Kapos V, Lysenko I, Stapleton CMA. Distribution and conservation status of forest bamboo biodiversity in the Asia-Pacific Region. Biodivers Conserv 2003;12:1833–41.

[4] Michelle. N. Bamboo Boom: Is This Material for You? Scientific American Earth 3.0 Special. http://www.scientificamerican.com/article. Retrieved August, 2009 n.d.

[5] Pakotiprapha B. A study of bamboo pulp and fiber cement paste composites 1976.

[6] Youssef MA. Bamboo as a Substitute for Steel Reinforcement in Structural Concrete. Part I, New Horizon in Construction Materials, Enco publishing Co. Lehigh valley Pennsyvannia, USA 1976:539–54.

[7] Sivaraja M, Kandasamy, Velmani N, Pillai MS. Study on durability of natural fibre concrete composites using mechanical strength and microstructural properties. Bull Mater Sci 2010;33:719–29. doi:10.1007/s12034-011-0149-6.

[8] Fache JO. Mechanical Properties and Physical Characteristics of Fanpalm, BEng. Project Report, Department of Civil Engineering, University of Ilorin, Ilorin Nigeria. 1983 n.d.

[9] Ibi TM. The Behavior of Fanpalm Reinforcement Concrete Beams and Slabs Subjected to Short-term Loading. B Eng Proj Report, Dep Civ Eng Univ Ilorin, Niger 1988:10.

[10] Mojola OO, Omotoyosi AA. Some Strength Properties of Local Bamboo. 1st Natl Conf Theor Appl Mech Univ Lagos, Lagos, Niger 1976:8.

[11] Jimoh AA. Conversion and Properties of Fan palm (Borassus Aethiopum) for Structural Uses 2006.

[12] Dutta AC, Dutta TC. Botany for degree students. Oxford university press London; 1964.

[13] Keay RWJ. Nigerian Trees. Department of Forest Research Institute, Ibadan, Nigeria 1989;4:140–6.

[14] Peng BL, Dhar N, Liu HL, Tam KC. Chemistry and applications of nanocrystalline cellulose and its derivatives: A nanotechnology perspective. Can J Chem Eng 2011;89:1191–206. doi:10.1002/cjce.20554.

[15] Audu. MT. Fanpalm Reinforced Concrete Slab Subjected to Short Term Loading. B.Eng. Project Report, Department of Civil Engineering, University of Ilorin, Nigeria 1989.

[16] Audu MT, Raheem AA. Flexural Strength characteristics of Beams Reinforced with Fan palm under Various Exposure Conditions. Innov Syst Des Eng 2015;6:1–10.

[17] Gram HE, Nimityongskul P. Durability of natural fibres in cement-based roofing sheets. J Ferrocem 1987;17:321–7.

[18] Ramakrishna G, Sundararajan T, Kothandaraman S. Evaluation of durability of natural fibre reinforced cement mortar composite-a new approach. ARPN J Eng Appl Sci 2010;5:44–51.

[19] N.Shafiq, Robles-Aaustriaco L, Nimityongskul P. Durability of Natural Fibres in RHA Mortar. J Ferrocem 1988;18:249–60.

[20] Gram HE, Person H, Nimityongskul P, A. Skarendahl A. FCR-Fibre Concrete Roofing. SKAT, Swiss Centre for Appropriate Technology, St. Gallen, Switzerland 1987:185.