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Development of rattan (*Calamus longipinna*) particulate reinforced paper pulp based composites for structural application using waste papers

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Abstract

Many organic waste materials such as paper and polyethylene bags pose environmental nuisance. The cost of building materials is high and beyond the reach of many people in developing countries. In this paper, efforts have been made to convert rattan, waste papers and starch into the production of ceiling and partitioning boards. Paper pulp was produced by chopping waste papers into smaller piece and soaked in boiled water after which it was stirred thoroughly to form paper pulp. Rattan particulate was also produced by hammering, chopping, pounding and milling of rattan canes. The rattan particles were sieved and a particle size of 437 μ was used, varying mass of paper from 300-400 g and particulate rattan (treated and untreated) of 2-8 g were mixed and bonded with starch slurry for the various samples produced. The mixtures were thoroughly mixed and poured into 150×50×30mm detachable mould and compacted for 5 minutes using a laboratory compaction machine. The composite were allowed cure at room temperature for 21days, after which flexural and water absorptivity tests were carried out on the samples. It was found that the composite samples ST_4 and S_5 happen to be the best in terms of flexural strength properties while the addition of rattan particulate fibre aid water repellent potential for the developed composites. This composite can be recommended for production into boards of varying thickness, length, and breadth for varying range of partitioning and ceiling applications.

Keywords

Rattan particulate; Waste paper; Paper pulp; Composite; Flexural strength; Starch slurry

Introduction

The renowned Christian Awake magazine, in 1990, stated that in USA, over 400,000 tons of wastes were disposed of every day, running into millions of dollars. In Nigeria, a western African nation especially, urban areas like Lagos, Kano, Ibadan etcetera, all kinds of organic wastes such as polythene bags, paper, agricultural wastes, among others are norm [1]. The amount of solid waste per capita generated in developing countries has risen to about 20 tons per year [2]. Some of these wastes are burnt in open air, producing substances that pose health hazards. One of the ways of minimizing environmental nuisance and health risks pose by these wastes is to effectively recycle them. Rice husks, maize cub, waste paper, starch and cement were used to produce ceiling boards. Ceiling boards are required in houses to reduce sound and heat and they give additional aesthetics.

Asbestos ceiling boards have brittle properties, pose health risks to humans and are relatively costly. Therefore, there is a compelling need to produce alternative products that are cheap, using local organic materials that could pose little or no health hazards.

Flexural strength measures the ability of material to resist bending under load condition. Water absorption is the ratio of mass of water absorbed over the dry mass of material [3].

A composite material is defined as a combination of two or more materials that results in better properties than when the individual components are used alone. A composite is designed to display a combination of the best properties of each of the component materials. Properties of composite are strongly dependent on the properties of their constituent materials, their distributions, and the interaction among them [4]. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the fibres via the interface [5]. Natural fibres are potential reinforcing materials and they are utilized in the past for more traditional than technical applications. Due to the relatively high cost of synthetic fibres such as, glass, plastic, carbon and Kevlar that are being used in fibre reinforced composites, and the health hazards of asbestos fibres, it has become necessary to explore natural fibres [6]. Paper has been utilized in everyday life for more than 20 decades.

They are known to possess surface roughness, porous structure, and optical opaqueness. They also have poor dimensional stability and bad water resistance which is due to the hydrophilic nature of the cellulose they are made of [7]. Regular paper is made of cellulose ju diameter in the range of 20–50 mm. The large surface roughness, porous structure, and optical opaqueness of regular paper are intrinsic barriers to hosting electronic devices on the surface of this material. Ways to overcome these problems include smoothing the roughness by super-calendering, coating a layer on the surface [8-10].

Natural fibres are produced from renewable resources, are biodegradable and relatively inexpensive compared to the traditionally used synthetic fibres.

The mechanical properties of waste paper pulp can be enhanced by reinforcing it with natural fibre. However, research had shown that the tensile strength of paper composites can be greatly improved by refining and fibre orientation. The fibre orientation of the paper also leads to a coinciding anisotropy in the composite properties [11].

In this work, rattan particulate reinforced paper pulp based composite was developed using starch slurry as binder. Dried pulverised paper pulp was used as the matrix, while rattan particulate was used as the reinforcement. The matrix and reinforcement were bonded using starch slurry to produce composite materials that will be used in structural applications such as ceiling sheets and partitioning boards. The aim of this work was to utilized waste papers that are readily available and constitute environmental pollution to develop rattan particulate reinforced paper pulp composites for structural applications.

Materials and method

Materials for this research work includes Waste newsprint paper, Starch slurry, Rattan canes, Water, Ammonia solution, Potassium hydroxide solution, Gas cooker, Pot, Plastic buckets with cover, Pestle and mortar, 150 x 50 x 35mm detachable metal mould, Compacting machine, Electronic measuring balance, Testometric universal machine, sieve shaker, Milling machine, Measuring cylinder, Paper cutter, Sieve, Hacksaw, Hammer and die, Stirring rod.

Production of paper pulp

The waste papers were chopped into smaller piece using paper cutter, the chopped paper was soaked in boiled water for 3days in a plastic bucket to form pulp. It was stirred thoroughly to form paper pulp slurry. The pulp was sieved and sun dried for 5days as shown in Figure1. Various weight of the dried pulp was weighed using electronic weighing balance into some plastic bowls. The varying mass are: 400, 380, 360, 340, 320, 300g.

Having measured the paper pulp, it was soaked with 1200cm3 of water for 15 minutes to wet the texture of the pulp .The wet pulp was pulverised to a slurry form using a milling machine.

Figure 1. *Wet (left) and dry samples (right) of paper pulp*

Production of rattan particulates

The rattan canes were hammered into sheet by using a metallic hammer and die. The canes sheets were later chopped into smaller particle as shown in Figure 2. The chopped canes were reduced to shredded form by the used of mortar and pestle. Half (50 %) of the shredded canes were treated with potassium hydroxide (KOH) solution to increase the adhesive nature of the canes as well as removing impurities from the canes. This was also done to preserve and to reduce the rate of contamination of the particles when it is incorporated in to the matrix. The rattan was sun dried to remove the moisture content. The rattan particles were pulverised for further size reduction using a milling machine. The milled particles of the cane were made to undergo sieve analysis to separate the particles into various particle sizes. However the particle size that was used for this work is 437microms. The milled particles were weighed into various weights which includes; 2, 4, 6, and 8 g. This was done for both the treated and untreated particles.

Figure 2. *Rattan canes in whole form (left) and in shredded form (right)*

Chemical treatment

Chemical treatments of natural fibres participate in the enhancement of the fibres properties as well as the mechanical properties of the subsequent composites from them compared to the untreated fibre ones [12]. In this work, rattan fibres were treated with potassium hydroxide by dissolving two molar of potassium hydroxide (112g) in 2000cm3 of water, which is stirred thoroughly with a stirring rod to form a potassium hydroxide solution. The fibres were then soaked in the solution and then transferred into the water bath where it is left for 4hours at a temperature of 500C. After this process is carried out, the fibres were removed from the water bath and later washed and allowed to dry in air. The chemical treatment given to natural fibres prevent the degradation of the fibres since they possessed high level of water absorption [13].

Production of starch slurry

Starch based composite materials are potential materials for eco-friendly packaging applications because of their biodegradability and cost-effectiveness [14]. In this work, Four kilogram of local starch was sourced from the market. The sourced starch was dissolve in 300cm3 of water at room temperature in a vessel. Three litres of water was heated to it boiling point using a gas cooker and then maintain at that temperature for 3 minutes. The boiled water was poured into the vessel containing the solution of starch in water; the boiled water was poured into the vessel slowly and stirred at a faster rate so as to ensure the production of lumps free starch slurry. The starch slurry is allowed to cool in air for 15 minutes before it is transferred into a 5 litre jerry can for preservation.

Mixing and compaction of the composite components

The wet slurry of milled paper pulp were mixed with the pulverised rattan particles and these was done at some predetermine ratio of the component. However the starch slurry was used as binder for various samples of the composite.

The entire mixture was thoroughly mixed and then poured to fill up the 150 x 50 x 30 mm mould and compacted under a pressure using the laboratory made compacting machine and the pressure was maintained at 20 KN for 5minutes. Before casting, the top of the compacting mould was covered with cellophane to enhance easy removal of the composite from the mould and prevent delamination. Having done this process, the mould was disassembled and the cast composite was removed and then transferred to a wooden board where it is allowed to cure in air in the laboratory as shown in Figure 3. The composite were prepared for flexural and water absorptivity tests.

Figure 3. *Samples prepared for flexural test*

Variation of components

In the production of this paper pulp based composite, the following parameters were varied.

Rattan particulate mass was varied from 2-8 g.

The paper pulp mass was varied from 300-400 g.

The starch slurry mass varied from 0-100 g.

The variation of the components of the composite in % mass is as shown in Tables 1 and 2.

Table 1. Variation of components with paper pulp and starch slurry

Designation of samples	Paper pulp (g)	Starch slurry (g)
A	400	0
S_1	380	20
S_2	360	40
S_3	340	60
S_4	320	80
S_5	300	100

In this work, the composite of designation "A" denotes that it composition is made up of paper pulp only. Designation "S" denotes that the composition is made up of paper pulp and starch slurry.

Table 2. Variation of components with paper pulp, starch slurry and rattan particulate fibres (Treated and Untreated)

Designation of samples		Paper pulp	Starch slurry	Rattan particulate
Treated	Untreated			
A	A	400	0	0
ST_1	SU_1	300	98	2
ST_2	SU_2	300	96	4
ST_3	SU_3	300	94	6
ST_4	SU_4	300	92	8

It is expected that the proportion of the reinforcement should either be one third or one fourth of the matrix but in this work, we discovered that large volume of the rattan particles does not form a uniform phase with the matrix phase. So the volume of the reinforcement was drastically reduced so as to form a uniform phase as well as to strengthen the matrix phase.

The mass of the starch slurry was measured by relating its density to the fixed mass of the desired binder in order to obtain the required volume of the binder needed. The density of the starch was 1.5g/cm3.

Properties test

The dried sample was made to undergo both flexural and water absorption tests as follows:

Flexural test

The flexural test was carried out using Instron Universal Tensile Testing Machine that works on a three point flexural technique. The test speed was 50.00mm/min over a span of 100.00mm.

Water absorptivity test

Since this material is likely to come in contact with water as a ceiling sheet, so it will be necessary to carry out water absorptivity test to determine the extent to which the formed composite can absorb water in case of roof leakage.

In determining the water absorption property of the composite samples, each of the composite were weighed in air and then immersed in 700cm3. This test was done for 7 hours for the various samples of the composite. The composite were weighed in air when dried with the aid of an electronic weighing balance and then soaked into water. The weight after 7 hours was taken once they are removed and cleansed. The percentage weight gained was used to determine the water absorptivity.

Results and discussion

Flexural test

The major mechanical test carried out on the developed composites is the flexural test. This was done because the material in serve will be exposed to bending load or stress in most cases when suspended in the house as a ceiling sheet. The results were as shown and discussed below.

Figure 4 shows the bending strength at peak results for the samples. From the results, it was observed that sample ST4 with composition (300: 92: 8) g has the highest bending strength at peak with a value of 1.97N/mm2. This was followed by sample S5 with composition (300: 100) g and value 1.73N/mm2. Sample A which has paper pulp alone was with a value of 0.70 N/mm2. With these results, it is obvious that the addition of treated rattan particulate fibre in addition to starch slurry and paper pulp is the best for the development of good and strong paper board ceiling sheet for structural application.

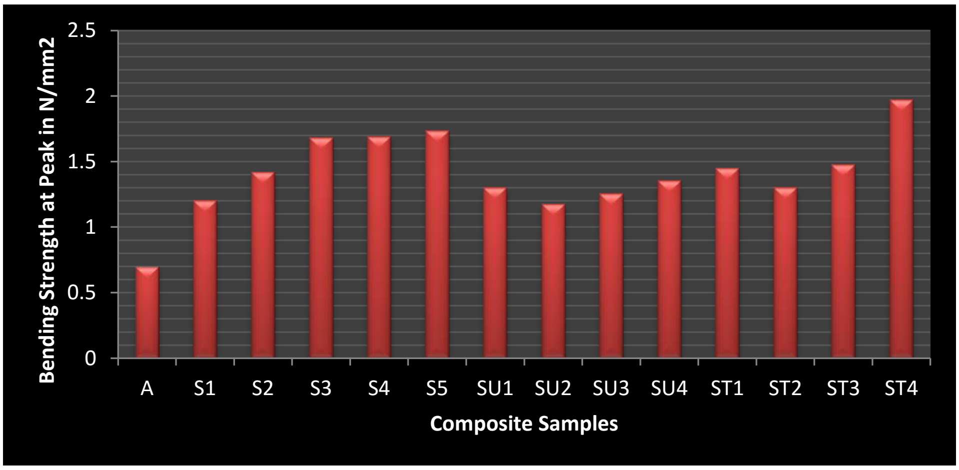

Figure 4. *Variation of bending strength at peak with samples*

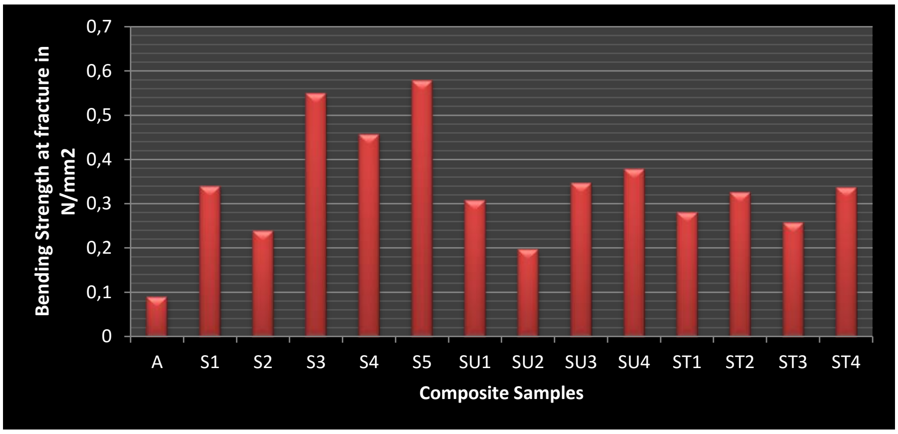

Figure 5. *Variation of bending strength at fracture with the samples*

Figure 5 shows the bending strength at fracture results for the composite samples. From the results, it was observed that sample S5 with composition (300: 100) g has a value asof 0.58 N/mm^2 followed by sample S3 with composition (340: 60) g which has a bending strength at fracture of 0.55 N/mm^2. Sample A which has paper pulp alone was with a value of 0.09 N/mm^2. The delay in fracture was observed in these (S5 and S3) samples compared to the rattan particulate fibre reinforced samples as well as the 100 % paper pulp samples because they are more ductile than others due to the presence of more starch slurry that serves as binder. The results show that the fracture strength increases as the starch content increases for the three different categories of compositions considered.

Figure 6 shows the bending modulus results for the composite samples. Similar trend as for the bending strength at peak was observed. From the results, it was observed that sample ST4 with composition (300: 92: 8) g has the highest bending modulus with a value of 56.21 N/mm^2. This was closely followed by sample S5 with composition (300: 100) g and value 51.58 N/mm^2.

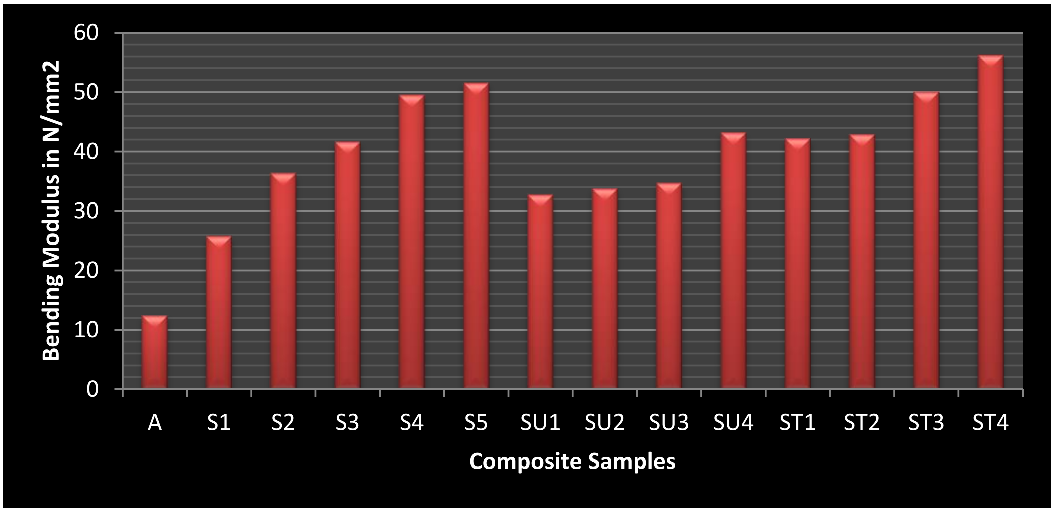

Figure 6. *Graph of the bending modulus of the composite samples*

Compared to these two samples, sample A which has paper pulp alone has the least bending modulus of 12.45 N/mm^2. This show further that, the addition of treated rattan particulate fibre in addition to starch slurry and paper pulp is the best for the development of good and strong paper board ceiling sheet for structural application. Since the chemical treatment of natural fibres will reduce the rate of degradation of the fibres in the matrix materials thereby enhancing the mechanical properties of the produced composite [15].

It was observed from the Figures that the bending strength at peak, bending modulus and bending strength at fracture follow similar trend where these properties tend to increases the rattan particulate fibre as well as starch slurry tends to increase. It was also discovered that composite samples with treated rattan fibres possess higher bending strength at peak, modulus, and fracture than those with untreated rattan fibres; this was due to the enhancement of the strength of adhesion between the treated rattan fibre, paper pulp matrix and the starch as a result of the alkali treatment of the rattan fibre.

Percentage water absorptivity test of the composite samples

It was observed from Figure 7 during the comparative study of the percentage water absorptivity of the samples that, the rate of water absorption increases with increase in the amount of starch slurry while it decreases as the amount of rattan particulate added increases in both treated and untreated conditions.

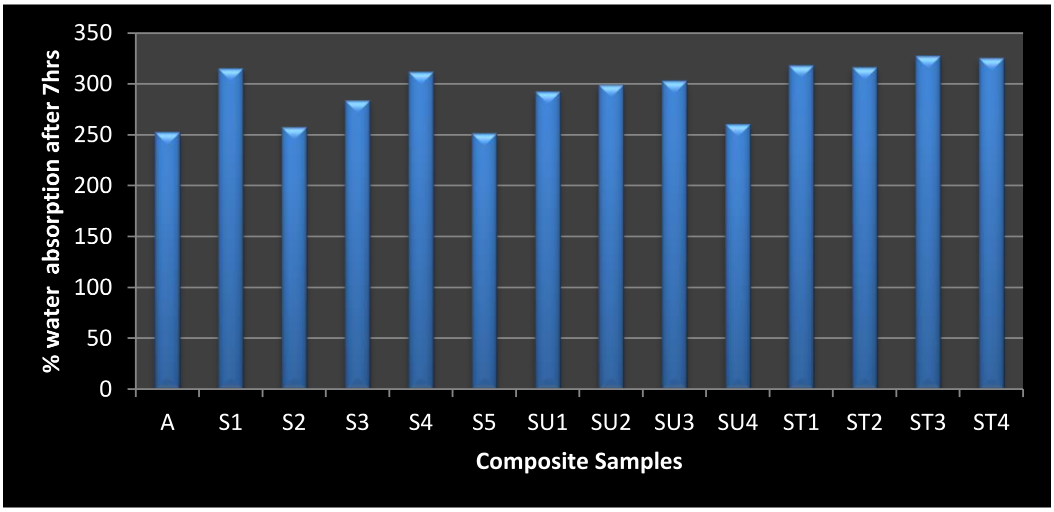

Figure 7. *Graph of percentage water absorption test on the samples after 7 hours*

This shows that the addition of the rattan can help stabilize the water absorption tendency of the developed composites. Considering the three major components of the developed composite, the untreated samples gave the best set of results followed by the starch slurry addition only. The rattan was a very strong and tough material commonly used as furniture material. However, the treated samples absorbed more water than the untreated and starch slurry addition only samples respectively. The result shows that S2 with composition (360: 40) possess the best water absorption property after 7th hours of soaking in water by absorbing the least amount of water.

Conclusions

Investigations carried out on the use of treated and untreated particulate rattan fibres as reinforcement in paper pulp matrix revealed that the reinforcement material improved the flexural and water absorption properties of the developed composites. While treatment of the rattan particulate enhanced the bending strength at peak and modulus of the paper pulp based composite, the untreated rattan particulate enhanced water repellent capability. The use of starch slurry as binding material also improves the bending strength at fracture. These shows that the combination of these selected environmentally friendly materials are promising materials for structural applications.

References

1. Berge H., *Asbestos Fundamentals, Origin and Properties*; 1963, McGraw-Hill, London.
2. Callister W. D., *Materials science, An Introduction: Fifth Edition*, John Wiley and Sons Inc. New York, 2001, pp. 162,163,180-185, 511-517.
3. Jackson N., *Civil Engineering Materials*, Macmillan Ltd. London, 1984, pp. 386-387
4. Jorgenson S. E., Johnson, I., *Principle of Environmental Science and Engineering*, 1989, Bombay.
5. Kakani S. L., Kakani A., *Material Science.1st edition*, New Age International (P) Limited, Publishers 4835/24, Ansari Road, Daryaganj, New Delhi 2:3, 2004, pp. 22 & 83.
6. Oladele I.O., Daramola O.O., Fasooto S., *Effect of Chemical Treatment on the Mechanical Properties of Sisal Fibre Reinforced Polyester Composites*, Leonardo Electronic Journal of Practices and Technologies, 2014, p. 1-12.
7. Zhiqiang F., Hongli Z., Colin P., Liangbing H., *Development application and commercialization of transparent paper*, Translational Materials Research, 2014, 1, 015004.
8. Ihalainen P., Määttänen A. J., Järnström D., Tobjörk R., Peltonen J., *Influence of Surface Properties of Coated Papers on Printed Electronics*, Ind. Eng. Chem. Res., 2012, 51, p. 6025-6036.
9. Kim D. H., Kim Y. S., Wu J., Liu Z., Song J., Kim H. S., Haung Y. Y., Hwang K. C., Roger J. A., *Ultrathin Silicon Circuits with Strain-Isolation Layers and Mesh Layouts for High Performance Electronics on Fabric, Vinyl, Leather and Paper*, Advanced Materials, 2009, 21, p.3703-3707.
10. Trnovec B., Stanel M., Hahn U., Hubler A. C., Kempa H., Sangl R., Forster M., *Coated Paper for Printed Electronics*, Professional Papermaking 2009, 1, p.48-51.

11. Kröling H., Fleckenstein J., Nubbo N., Endres A., Miletzky F., Schabel S., *Non-Woven and Paper Based Epoxy Composites*, Science and Technology Das Papier, 2014, http://www.ptspaper.com/fileadmin/PTS/PTSPAPER/01_Ueber_uns/Dokumente/Veroeffentlichungen/2014_Non-woven_ipw_5_6_2014.pdf.
12. Oladele I. O., Omotoyinbo J. A., Adewuyi B. O., Kavishe F. P. L., *The Effects of Production Processes on the Mechanical Properties of Sisal Fibre Reinforced Polypropylene Composites*, Philippine Journal of Science, 2013, 142(2), p. 189-198.
13. Oladele I. O., Faola A. E., Adewuyi B. O., Oluwabunmi K. E., *Effect of Chemical Treatment on Water Absorption Capability of Polyester Composite Reinforced with Particulate Agro-Fibres*, Chemistry and Materials Research, 2013, 3, p. 13.
14. Shujie Y., Yanjun T., Junming W., Fangong K., Junhua Z., *Surface Treatment of Cellulosic Paper with Starch-Based Composites Reinforced with Nanocrystalline Cellulose*, Journal of Industrial and Engineering Chemistry Research, 2014, 53(36), p. 13980-13988.
15. Susheel K., Kath B. S., Kaur I., *Pre-treatments of natural fibres and their application as reinforcing materials in polymer composites*, Polymer Engineering Science as a Technical Report, 2009.