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Development of natural polymer reinforced cement/waste paper pulp composites for structural application

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Abstract

This work investigates the influence of white cow hair as reinforcement in Cement/Waste paper pulp matrix for structural applications. Cow hairs as natural polymer, were sourced from an abattoir, and washed properly in clean water and sun dried for 5 days. Paper pulp was prepared by first soaking waste paper in water for 3 days, after which it was grinded in the paper pulp machine to form paper pulp slurry and then sun dried for 5 days. The cow hair after cutting to 10 mm lengths, were thoroughly mixed with the dried paper pulp to develop composite samples of varied weight content using the open mould technique by adding appropriate quantity of cement as binder. The developed composite samples were allowed to cure in air in the laboratory for 27 days before testing. The results of the mechanical properties examined showed that sample S5 containing (80 wt. % paper pulp, 10 wt.% cement and 10 wt.% cow hair) has the best flexural and compressive properties while sample denoted as S4 has the best water absorption property.

Keywords

Waste paper; Paper pulp; Cement; Cow hair; Natural polymer; Composites; Mechanical properties.

Introduction

Pulp and paper industries have been considered the main consumers of natural resources like wood and water, energy in form of electricity and significant contributors of pollutant discharges to the environment. In many parts of the world, local supply of wood cannot support the demand for pulp [1] and this has led to the search for non-wood raw materials in paper making industry.

Since 1970 to present time, the non-wood fiber pulping capacity has increased on a global basis two to three times as fast as the wood pulping capacity. It was also anticipated that during the next decade, the non-wood pulp production will grow annually at an average of 6%, which is three times as fast as the production of pulp on wood basis [2]. Non-wood fiber resources have the potential to complement conventional wood supplies. This is because, they are abundant and have rapid regeneration, and are of comparatively low price [3]. Therefore, non-wood fiber will play important roles in paper making as substitutes or complements to wood. Examples of non-wood fiber resources are wheat-straw, rice-straw, sugarcane straw, bamboo, bagasse, kenaf and palm kernel shell [4]. Non-wood material, particularly wheat straw, was effectively used as the main raw material for papermaking in China due to limited wood resource [5]. By a wide margin, the leading non-wood fiber presently in use is straw, followed by bagasse and bamboo [1].

The use of waste paper as raw material for pulp production has increased during the last several decades, and some paper plants depend almost completely on waste paper. In Japan, waste paper is usually been separated from other household waste [6]. In addition, one of the ways of minimizing environmental nuisance and health risks posed by these wastes is to effectively recycle them.

The cost and environmental hazard on the use of synthetic fibers in reinforcing composites has stimulated extensive research into the design of composite reinforced with natural fibers such as bamboo, sisal, coconut husk, sugar cane, banana leaf and wood fibers [7, 8, 9]. The incorporation of such fibers into cement and other earth-based materials offer significant potential for the development of low-cost construction materials for affordable housing. Oladele and Okoro [10] studied the influence of rattan (*Calamus longipinna*) particulate on paper pulp based composites and observed that the reinforcement material improved the flexural and water absorption properties of the developed composites.

The use of non-wood raw materials provides several interesting advantages; specifically, it allows wood raw materials to be saved for other more decent uses and, hence, deforestation and replanting to be alleviated. It can also significantly reduce wood importation into countries with a shortage of wood raw materials.

The current challenges of the pulp industries are the achievement of affordable quality pulp while preserving the environment by using increasingly smaller amounts of water and energy and gradually fewer raw materials [11]. Works have been done in order to determine the suitability of different binders for paper pulp composite based materials.

Natural rubber can be used as binder for brown- paper-pulp-composite materials since the addition of natural rubber gave better flexural and water-repelling properties [12]. The best composition for optimum flexural properties was 70-30 wt % paper pulp-natural rubber content, while the sample with the best water repellent property was obtained from 60-40 wt % paper pulp-natural rubber content. The work revealed that these materials can be blended together to develop strong and lightweight composite materials for structural applications in low cost buildings [12].

The results of the work by Oladele and Ibukun [13] on the use of white and brown paper for composite development showed that the properties of these two different sources of papers differ from one another and therefore, needed to be considered. White paper pulp gave better mechanical and physical performance than brown paper pulp when bonded with cement. The best mixing proportion was 70-30 wt % of white paper pulp to cement. At this mixing ratio, the best combinations of both mechanical and physical properties were achieved. In this research, cow hair reinforced cementitious/paper pulp composite was developed using white waste papers. The work was carried out to further improve on the mechanical properties of cement bonded paper pulp based composites for structural application. Natural polymer from cow hair was used as reinforcement, therefore, promoting eco-friendly engineering materials.

Materials and methods

The materials used for this study are white waste paper, water, cow hair that serves as the reinforcing phase and cement which acts as binder.

Preparation of the reinforcement

Cow hair fiber was extracted by scraping the hairs from the tails of white Fulani cow known as Zebu breed procured from an abbatoir in Akure, Ondo State and were washed properly to remove impurities followed by sun drying for 5 days. The dried cow hair was cut into 10 mm lengths.

Paper pulp production

White waste papers were sourced from the school environment and were chopped into small pieces using paper cutter before soaking for 3 days with tap water. The soaked papers were poured into paper pulping machine from where it was grinded to form paper pulp slurry.

Figure 1. Dried paper pulp

The pulp obtained was sun dried for 5 days as shown in Figure 1 after which it was pulverised using a grinding machine to obtain fine particle.

Composite production

The composites were developed using the open moulding technique for the various mixes shown in Table 1.

Table 1. Mixing ration for reinforcement, matrix and binder (%)

Samples (S)	Reinforcement (%)	Matrix (%)	Binder (%)
1	2	88	10
2	4	86	10
3	6	84	10

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4	8	82	10
5	10	80	10
6	15	75	10
7	20	70	10
8	25	65	10
9	-	90	10
10	-	100	-

The moulds were properly lined with cellophane to enhance easy removal of the composite from the mould and prevent delamination. The mixture was stirred thoroughly and then poured to fill up the 160 x 55 x 50 mm mould and thereafter, compacted using a compacting machine at a pressure of 20 kN for 5 minutes. The cast composite was removed from the mould and then transferred to a wooden board where it was allow to cure further in air for 27 days before testing.

The masses of the composites as well as the control sample were as shown in Table 2 while the cured samples from the compositions were as shown in Figure 2.

Table 2. Mass of sample constituents (g)

Sample Designation	Reinforcement (g)	Matrix (g)	Binder (g)
S1	0.649	62.29	32.0
S2	1.298	60.87	32.0
S3	1.947	59.46	32.0
S4	2.596	58.04	32.0
S5	3.245	56.62	32.0
S6	4.868	53.09	32.0
S7	6.490	49.55	32.0
S8	8.113	46.01	32.0
S9	0.000	63.70	32.0
S10	0.000	70.78	0.0

Figure 2. Cured samples ready for testing

Mechanical test

Three samples were tested for each representative sample from where the average values for the test samples were obtained and used as the illustrative values.

Flexural test

Three point bend tests were performed in accordance to the standard ASTM D 790 M [14] to measure flexural properties using INSTRON 3382 Floor Model Universal Tester at a crosshead speed of 0.3 mm/mm and at a specific strain rate of 10^{-3}/s.

The samples were of 100 x 30 x 20 mm. Three samples were tested for each weight fraction used and the average values were taken to represent the actual values.

Compressive test

This is the ability of the composite material to withstand loads tending to reduce its size. This was also carried out using the universal testing machine to know the extent at which the composite can endure such type of loads in future engineering applications. Compressive test was carried out in accordance to American Standard Testing and Measurement ASTM C873 [15] and using INSTRON 3382 Floor Model Universal Tester at a fixed crosshead speed of 10 mm/min.

The developed composite samples and the control sample of 100 x 40 mm were used. Three identical samples were tested for each weight fraction from where the average values were used as the representative values.

The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture was used to determine modulus.

Water absorption test

The dried composite samples and the neat sample were immersed in distilled water and the experiment was carried out at room temperature of 24 ± 2°C. The water absorption property of the samples was determined by weighing those samples before immersing them in 700 cm^3 water. This test was done for 7 hours for the various samples. This short time was used to avoid dissolution of the red sand in water if soaked for long time. The samples were examined at an interval of 1 hour by removing, cleaning and then weighing. The weight after a period of 7 hours was taken and the percentage weight gained was used to determine water absorption potential of the materials.

The percentage of water content (W_t) was determined using Eq. [1]:

$$\% W_t = [(W_t - W_o) / W_o] \times 100\% \quad (1)$$

Where: W_t is the weight of sample at time t, and W_o is the initial weight of the sample.

The flowchart for the working algorithm was as shown in Figure 3.

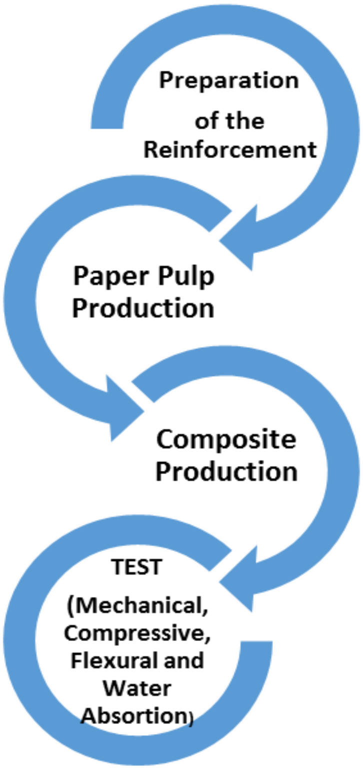

Figure 3. Methodology flowchart

Results and discussion

The mechanical properties and water absorption property results were as presented in Figures 4 to 7 and Figure 8, respectively.

Flexural test

Flexural strength at peak for the developed composite was as shown in Figure 4.

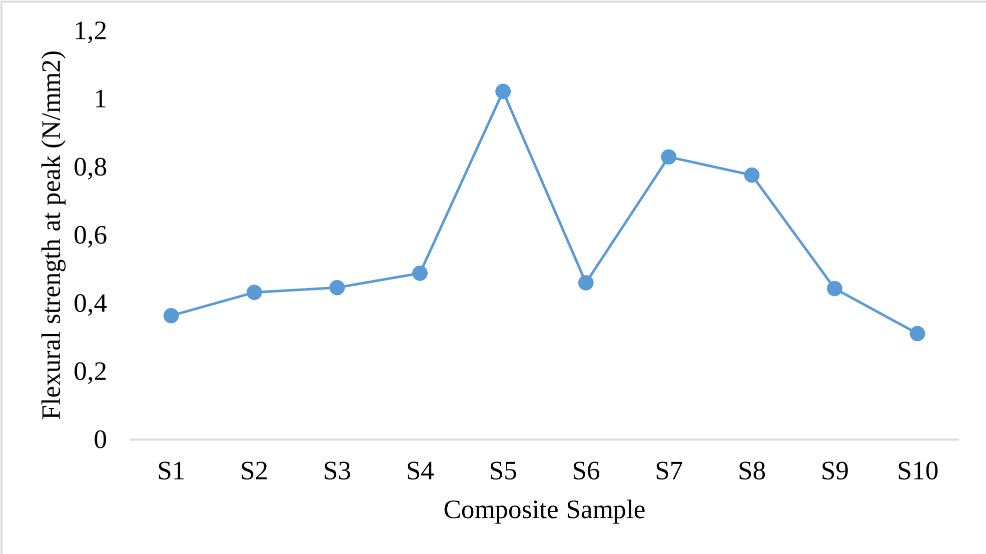

Figure 4. Variation of flexural strength at peak with reinforcement

It was observed that the flexural strength at peak increases as the reinforcement content increase from 2-5% before it begins to decrease. Therefore, optimum strength was attained at 5% reinforcement addition. However, the strengths of the composites from 6-8% reinforcement contents after the optimum strength were still better than those ones that were at the lower content values (2-4%). These showed that the developed composites possess better flexural strength as the reinforcement content increases from 2-8%. From the results, it was also observed that sample denoted as S9 that contain paper pulp and binder possess better strength than some of the reinforced samples with low reinforcement content. But sample denoted as S10 that serves as the control containing paper pulp alone has the least strength. Sample denoted as S5 containing 80 wt. % paper pulp, 10 wt. % cement and 10 wt. % cow hair has the highest flexural strength at peak with a value of 1.02 N/mm^2 compared to other samples.

Compared to samples S9 and S10, it was noticed that the addition of the cow hair fibre as reinforcement has enhanced the flexural strength the developed composites. This was made possible due to the flexibility and good tensile property of the cow hair fibre as a natural polymeric material. However, the addition of cement and cow hair fibre, respectively have aided the enhancement in flexural strength property of recycled paper pulp based composite material. Sample S10 has the least flexural strength with a value of 0.31 N/mm^2.

The result of flexural modulus for the composite samples was as presented in Figure 5.

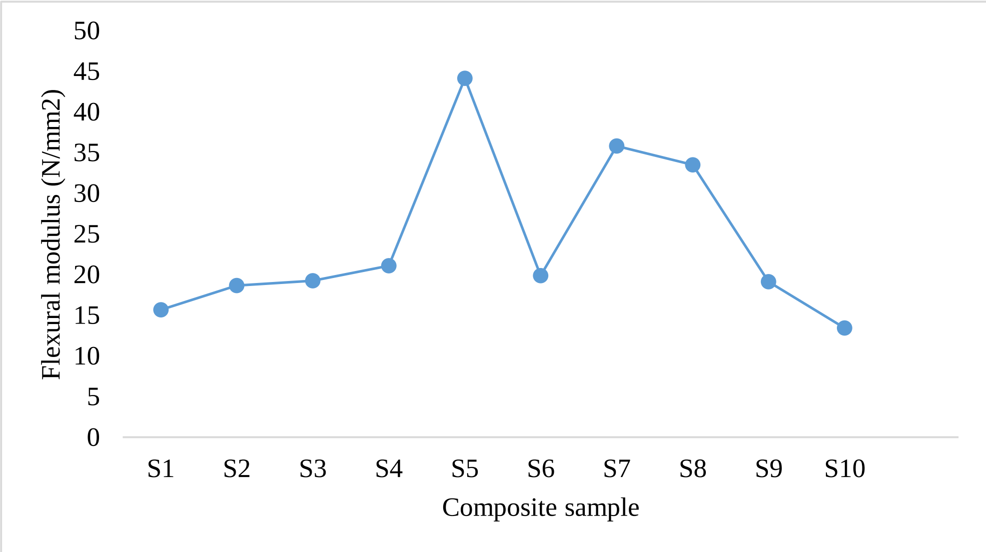

Figure 5. Variation of flexural modulus with reinforcement

Similar trend to Figure 4 was observed from the results. Sample denoted as S5 has the highest flexural modulus with a value of 44.18 N/mm^2 while sample denoted as S10 has 13.44 N/mm^2. Since the two Figures 3 and 4, followed the same trend, whereby, the strength and modulus increases with increase in the percentage of the reinforcement until S5 containing 10 wt. % reinforcement after which it then decreases, these decrease may be due to fibre touching and inadequate bonding strength at the interface. However, sample S10 have the least flexural properties compared to those with binder and reinforcement.

The variation of compressive strength at peak with the composite samples and the control that was denoted as S10 was as shown in Figure 6.

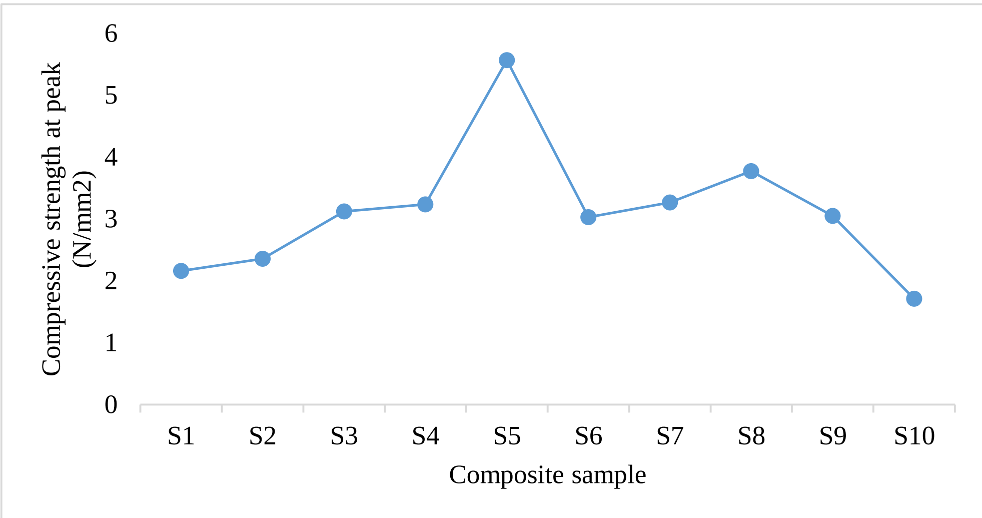

Figure 6. Variation of compressive strength at peak with reinforcement

The result followed similar trend with that of the flexural results from Figures 4-5 which showed that there is agreement in the samples response to the mechanical properties.

From the results, it was observed that sample S5 has the highest compressive strength with a value of 5.57 N/mm^2 followed by sample S8 with a value of 3.78 N/mm^2 while sample S10 has the least value of 1.71 N/mm^2. This enhancement can be attributed to the presence of cement in the composites composition in the expected proportions with optimum at S5.

The result of the variation of compressive modulus with reinforcement was as shown in Figure 7.

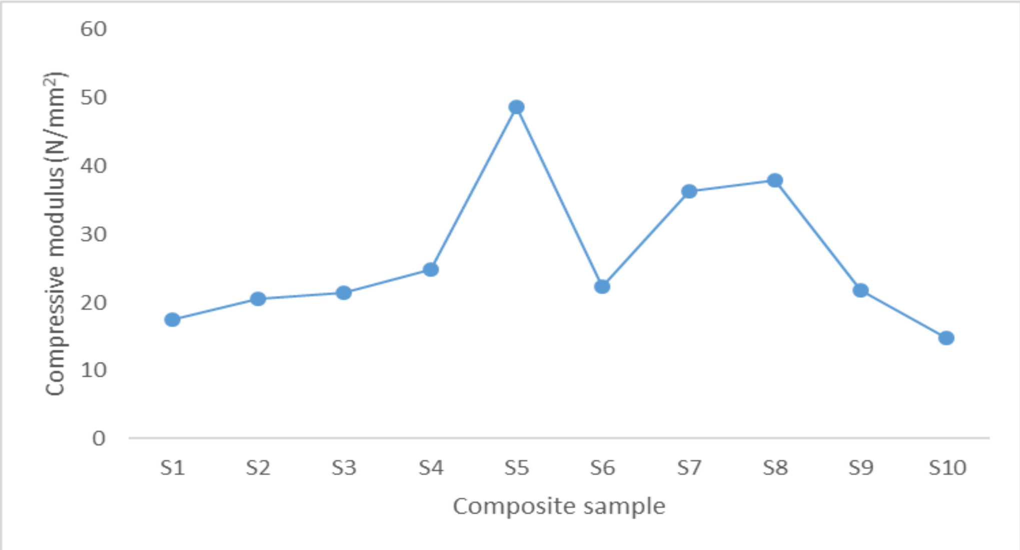

Figure 7. Variation of compressive modulus with reinforcement

It was revealed from the results that sample S5 has the highest compressive modulus with a value of 48.73 N/mm^2 while sample S10 shows the least value of 14.84 N/mm^2. Similar trend was observed for Figures 6 and 7 as the compressive strength at peak and compressive modulus increases with increase in reinforcement until 5 % after which it starts to decrease.

The decrease may be due to excessive amount of cow hair fibres leading to a drastic decrease in the strength of the composite samples. Increase in reinforcement beyond certain level has been discovered to usually led to fibre touching and, hence, weak interfacial adhesion that frequently resulted in weak strength.

Optimum responses observed for sample S5 has shown that this composition is the best for these developed composites.

This test was carried on the samples because the targeted application was in building construction [16]. One of the major areas of application for the composite produced is ceiling. Hence, the need to carry out water absorption test to determine the extent to which the developed composite can absorb water in case of roof leakage.

Rate of water absorption of the composites and the control were as shown in Figure 8.

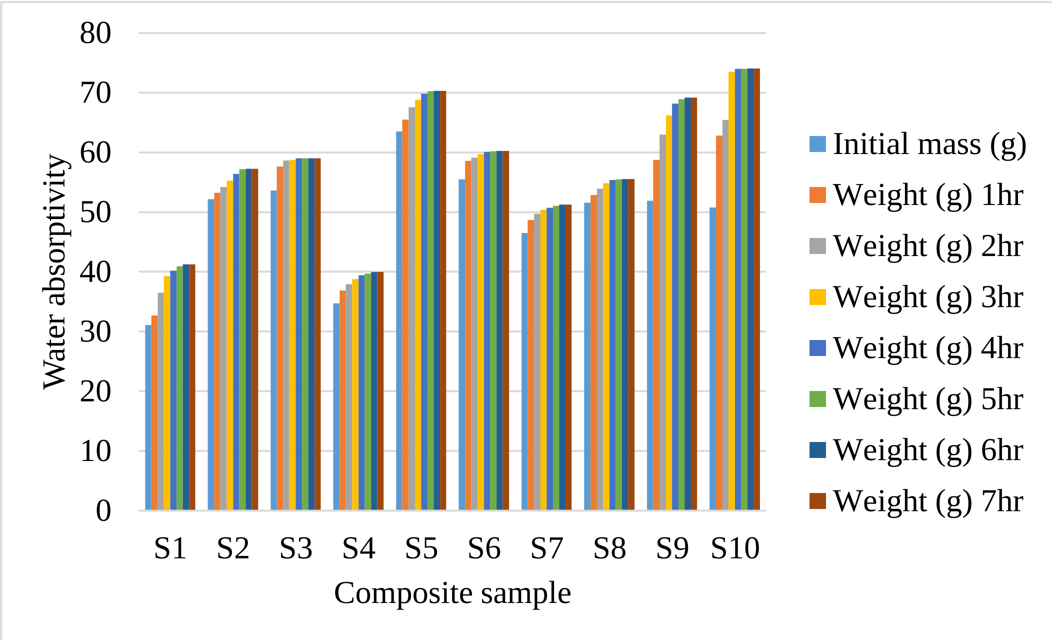

Figure 8. Water absorptivity of the composites

It was observed that most of the developed composites containing reinforcements, S1-S8 possess good water absorption potentials than the samples without reinforcement, S9-S10.

In addition, the rates of water absorptivity for the samples became constant within the time range of 4-6 hours of soaking. This was due to the saturation of the samples and blockage of the pores with water making it difficult for diffusion of the water to continue. All the samples were saturated within the immersion time.

Sample denoted as S4 showed a good level of water absorptivity potential having absorbed the least amount of water during the test period. However, sample denoted as S10 that was without reinforcement and binder was observed to absorb the highest amount of water.

This might be due to the absence of binder in the sample giving the matrix (paper pulp) the ability to accumulate lots of water due to high rate of diffusion compared to the samples with binder and reinforcement.

Conclusions

This work was carried out to promote the use of animal fibres as alternate to vegetable fibres that are commonly used.

From the research, sample denoted as S5, containing 80 wt. % paper pulp, 10 wt. % cement and 10 wt. % cow hair fibres gave the optimum properties in terms of flexural and compressive while sample denoted as S4 gave the best result in terms of water absorption.

Sample denoted as S10 that has no reinforcement and binding materials have the least water absorption, flexural and compressive properties compared to the developed cementitious composites.

The results revealed potential synergy among the constituent with cow hair fibre improving the flexural properties while the cement brought enhancement in the compressive properties compared to the control sample (S10). Also, it was noticed that, the addition of this natural polymer from animal fibre has aided the enhancement of the mechanical and water absorption potentials of the developed composites compared to S9 and S10 that are without reinforcement. The cementitious/paper pulp cow hair reinforced composites do not present health hazard and, hence, are eco-friendly.

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