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Development of Brown Paper Pulp Filled Natural Rubber Composites for Structural Applications

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Abstract: *To improve the flexural properties of materials for structural applications, composite materials from paper pulp can be bonded with natural rubber. Paper pulp exhibits some bonding potentials which can further be enhanced for some tailored applications by mixing it with another bonding agent. This study describes the influence of natural rubber on the flexural and water absorption properties of paper-pulp-filled natural rubber composites for structural applications. This research was done using pulverised brown paper pulp as the filler and natural rubber was used as the bonding agent. A measured volume of natural rubber was mixed with a known quantity of paper pulp and the mixture was poured into a detachable mould and compacted for about 10 minutes to produce the composite. The developed composites were detached from the mould and allowed to cure in air at room temperature for 27 days. Flexural and water absorption tests were done on the samples. The composite developed from the mixture of 70 wt % brown paper pulp and 30 wt % natural rubber gave the best result for flexural properties, while the sample with 60-40 wt % emerged the best composition for the water absorption property.*

Keywords: *Brown paper pulp; natural rubber; flexural properties; water absorption; structural application*

1. Introduction

Composites are materials that have combinations of two or more materials that result in better properties than those of the individual components used alone. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. They are generally made in two phases: the reinforcement and the matrix. The reinforcing phase provides strength and stiffness while the matrix performs several critical functions, including maintaining the fibres in the proper orientation and spacing and protecting them from abrasion and the environment (Campbell, 2010).

Paper is a wood-based product without which modern civilisation would not have evolved, and would not have been sustained and advanced. Paper pulp can also be used for diverse purposes such as in the preparation of cellulose derivatives like cellulose nitrate, cellulose acetate, regenerated cellulose and many more (Akpabio et al, 2012). Pulps are manufactured from raw materials containing cellulose fibres usually from wood, recycled paper and agricultural residue (Bajpal, 2012). The difference between white paper pulp and brown paper pulp is due to the removal of lignin from the pulp of brown paper which is known as delignification. Lignin provides the mechanical support for stems and leaves and supplies the strength and rigidity of plant walls (Okon and Aniekan, 2012). Generally, paper and pulps have been useful in producing consumer products like books, newspaper print, wall paper, postal products, artwork materials, cardboard, tissue paper and packaging materials amongst others.

Natural rubber is most often produced from the milk-like fluid from latex of certain tropical trees. The latex is a colloid state dispersion (Renner and Pek, 2011). Natural rubber is scientifically unique because of its elasticity which is due to an entropy change resembling that of ideal gas. It differs from energetic elasticity and standard organic, inorganic or metallic solid materials. However, the mixtures of natural rubber latex and paper pulp when prepared by iso-static compression have a high degree of flexural properties. They are polymeric materials displaying excellent physical properties for structural applications. Cellulose, hemicellulose, and lignin are the main constituents of paper that contribute to the tensile, flexural and impact properties of the composites developed from them (Sridah and Prompunjai, 2010).

Waste papers are solid wastes in the environment. Solid waste generation is a growing problem at local, regional and global levels. Solid wastes are those organic and inorganic waste materials, produced by various activities of the society, which have lost their value to the first user. Improper disposal of these solid wastes pollutes all segements of the living environment (air, land and water) (Okoro et al, 2015). To reduce the amount of solid waste in the environment, the use of waste paper in different end use materials is being investigated, as it this case in this research. Recycling of waste paper helps reduce the amount that would otherwise be sent to landfills or incinerators. The use of these waste papers for an engineering application reduces the problem of littering. Paper dumped in landfills currently accounts for 25 % of methane gas released from landfills. Also, municipal landfills account for one third of human related methane emissions of 1.6 million tons of greenhouse gases (Ogunwusi and Ibrahim, 2014).

Furthermore, dry construction methods are needed for saving costs. The use of dry construction methods with appropriate standardised components to reflect the designer's specification would reduce or completely eliminate wastages; and reduce labour requirements, cost and time for construction. The dry construction method is therefore cost-effective and preferred above the conventional method (Adedeji, and Ajayi, 2008). The use of waste paper for the development of structural products, as a dry construction method, will be very cheap, as waste paper which constitute the bulk of the material can also be readily sourced free or at a reduced cost from newspaper companies, offices and schools.

In this work, brown-paper-pulp-filled composites were developed using natural rubber as a binder to produce composite materials that will be used in structural applications like ceiling sheets and partitioning boards. The use of this waste paper will help in reducing waste and burning that was associated with the disposal of waste paper in Nigeria. Processing of this waste paper by grinding with a laboratory milling machine is a better option for the conversion of this material to engineering use. It is safe because there is no environmental pollution that emanates from this operation. Since the papers are readily available and cheap, only the milling process involves the use of energy which therefore makes the production of this product easy and cheap.

2. Experimental

The materials used for this research work include: waste newsprint paper, rubber latex, and ammonia solution and cellophane sheets.

2.1. Preparation of Materials

Natural rubber was tapped from the stems of trees at the Federal College of Agriculture, Akure, and was preserved with ammonia solution. Natural rubber is a thermoplastic material that is highly cross-linked, the property that makes it elastic. It has good frictional property, resistance to abrasion and fatigue. Waste newspaper prints used as brown paper were sourced from newspaper vendors. The papers were later sorted in order to remove contaminants, and afterwards the sorted papers were soaked in water for 2 weeks in order to ensure easy pulverisation in the milling machine. During the grinding process, water was added so as to promote a stress-free milling operation and to form slurry. The pulverised paper was squeezed to remove the water and sun dried for 5 days to obtain fine particulate material.

2.2. Development of Composites

The composites were developed by forming homogeneous pastes from the mixture of natural rubber and brown paper slurry in predetermined proportions as shown in Table 1.

Table 1. Mixing proportions of brown paper pulp with natural rubber

Compositions\Samples	Control	A	B	C	D	E	F	G	H
Paper in slurry (%)	100	95	90	85	80	75	70	65	60
Natural rubber (%)	-	05	10	15	20	25	30	35	40

Paper slurry was formed by blending 1 kg of the sun dried particulate paper with 2 litters of water followed by mixing in a bucket to form the slurry. The composition of the mixture was 500 g of the brown paper slurry and 200 g of the natural rubber. This was chosen after preliminary investigation into how best to blend these two materials.

Each representative samples were produced by pouring the homogenous pastes into the flexural mould and compressed with a cold compression moulding machine at ambient temperature for about 10 minutes until they are compacted. The samples were de-moulded after compaction and allowed to dry further at room temperature in the laboratory for 27 days as shown in Figure 1. This curing time was in agreement with the conventional curing time for cementiteous based composites (Oladele and Afolabi, 2015).

2.3. Property Tests

The dried composite samples were made to undergo both flexural and water absorption tests. These tests are very important based on the environmental challenges they are to be subjected to in service. This material is for use as structural material, namely portioning boards, which are likely to experience flexural or bending challenges when sudden load hits them. Also, water can come in contact with the boards, therefore, this test is also essential.

Figure 1. Samples of compacted brown paper samples mixed with natural rubber

2.3.1. Flexural Test

The flexural test was carried out by a Testometric Universal Testing Machine in accordance with ASTM D790. To carry out the test, the grip for the test was fixed on the machine and the test piece, with dimensions of 150 x 50 x 3 mm, was hooked on the grip and the test commenced. As the specimen was stretched the computer generated the required data and graphs. The Flexural Test was performed at the speed of 100 mm/min.

2.3.2. Water Absorptive Test

Since this material is likely to come in contact with water as a building material, it was necessary to carry out water absorptivity test to determine the extent to which the formed composites can absorb water.

In determining the water absorption property of the composite materials, each of the composites was weighed (g) in air with the aid of an electronic weighing balance and then immersed in 700 cm^3 of water. This test was done for 6 hours for the various samples of paper composite boards. Every hour the composite samples were removed, cleaned, and then weighed again. The water absorption capacity was found out according to the procedure described in the ASTM D 570 standard. The data collected was used to determine the % water absorption using:

$$\%\, Water\ Absorption = \frac{Final\ Weight - Initial\ Weight}{Initial\ Weight} \times 100 \quad (1)$$

3. Results and Discussion

3.1. Flexural Test Results

Figure 2 shows the bending strength at peak results for the samples. An evaluation of the influence of natural rubber on the developed paper pulp composites revealed that the addition of natural rubber increased the bending strength property of most of the samples produced as compared to the control sample.

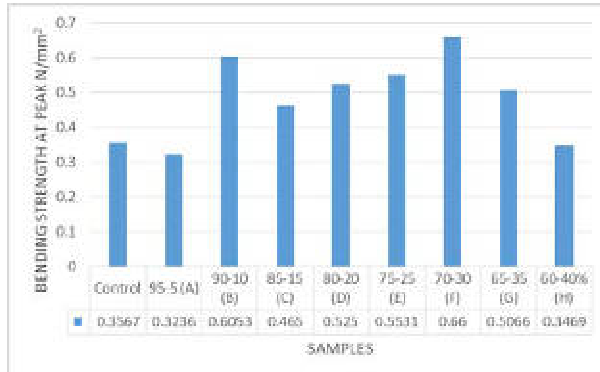

Figure 2. Variation of bending strength at peak with samples

According to the results, the bending strength at peak can only be enhanced within a given range of the proportions of the paper pulp and the natural rubber which can be taken to be from 90/10 to 65/35. The addition of natural rubber below 10 wt% shows that the material is not enough to bring about the desired improvement. This is because there is not enough material to aid proper wetting and bonding while the addition in excess of 35 wt% was too much and give higher ductility. With the exception of samples B within this range of optimum performance, the responses of the materials show a progressive increase in the bending strength at peak from sample C- F before experiencing a decrease in G. However, sample F, with composition 70-30 %, exhibited the best bending strength at peak performance with a value of 0.66 N/mm^{2,} closely followed by sample B with composition 90-10 % having a bending strength at peak value of 0.61 N/mm^2. These showed that the best performances based on the likely sources of enhancement were seen to arise from the two extremes.

The response of the developed materials to bending modulus was presented in Figure 3. All the developed composites except sample G possess better bending modulus than the control. The two samples with the best bending strength at peak happened to be the ones with the best bending modulus. However, a contrary trend to the bending strength at peak was observed between them—there is a progressive decrease in the bending modulus from sample C-E. From the results, it was observed that natural rubber indeed enhanced the bending modulus property of most of the composite samples when compared to the performance of the control sample. The consistency of sample F with composition 70-30 % was obvious as it exhibited the best performance in this category with a value of 34.37

N/mm^2 followed by sample B, composition; 90-10 % with a value of 26.31 N/mm^2. This further confirms the importance of adding natural rubber to brown paper pulp in the development of paper-based composites for structural applications.

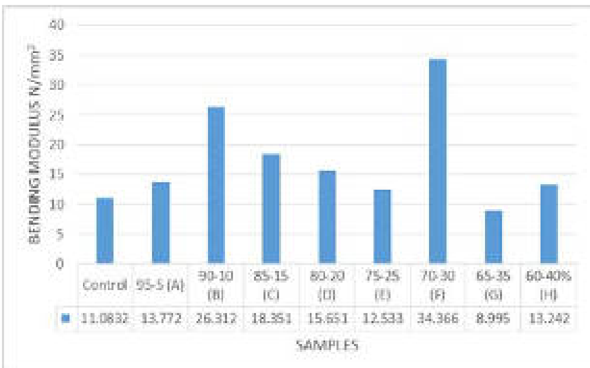

Figure 3: Variation of bending modulus with samples.

The results of the flexural properties tests show that sample F is the best brown paper composite produced. This is as a result of its flexural properties—good strength and stiffness. With these results, it is obvious that the addition of natural rubber to brown paper pulp with 70 % paper and 30 % natural rubber composition is a potential means for the development of low cost and environmentally friendly structural material. The results on the bending properties have shown that bending strength at peak increases within the range that produce the best results while the bending modulus was observed to decrease within the same range. These responses show that the two properties were inversely proportional.

3.2 Water Absorptivity of the Composite samples and the control

The results of the water absorption properties were as shown in Figure 4. It was observed from the plot that, as the natural rubber content increases, the water absorption tendency for the developed composites decreases. The control sample as well as samples A, D, F and H, possess % increase without attaining saturation within the 6 hours. However, samples B, C, E and G attain saturation state at 4, 3, 4 and 4 hours, respectively. The rate of water absorption was high for samples A-F, while that of samples G-H was low.

This suggests that as the natural rubber content increases, the rate of diffusion of water molecule within the pores of the paper-pulp-based composites reduces, thereby giving rise to a considerably low amount of water being absorbed by samples G with composition 65-35 % and sample H with a composition of 60-40 %. This test was essential, since paper tends to dissolve in water and contamination with water in service cannot be ruled out.

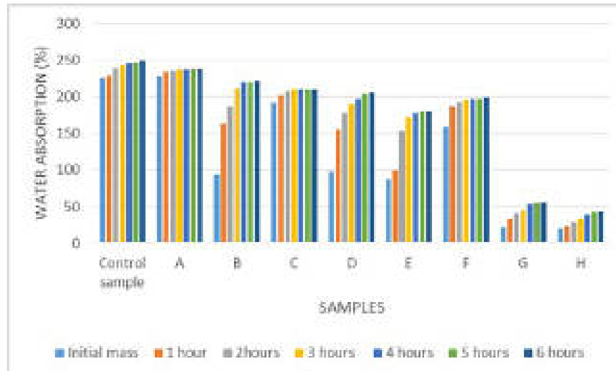

Figure 4. Percentage water absorption test on the samples for 6 hours

4. Conclusions

The results of the research into the influence of natural rubber on the flexural and water absorption properties of brown-paper-based composites have revealed the possibility of binding paper pulps made from brown paper with natural rubber to produce composite materials for structural applications. These materials are readily available and can be sourced locally at affordable rates. Also, they are environmentally friendly and can be easily processed. From the results, the following can also be deduced:

- 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.
- 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 light weight composite materials for structural applications in low cost buildings.

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