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A Comparative Study of the Physico-Chemical Properties of Cement-Bonded Particle Boards from Semi-Pulped Bagasse and Newsprints

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Abstract: The objectives of this study were to compare the compatibility of semi-digested pulp and fully digested pulp with cement and to further determine how appropriate these two samples are for the production of outdoor particle boards using the hydration test to determine the compatibility through the compatibility factor obtained using the area ratio method. The effects of chemical additives on the compatibilities of the samples with cement and the existence of bond formation were also looked into. Stems of sugar cane were obtained from the Sabo market in Ile-Ife, Osun state, Nigeria while newspaper prints were also gathered from Obafemi Awolowo University, Ile-Ife, Nigeria. The samples were converted to mesh, bleached and then converted to pulp. Different tests comprising proximate analysis, phytochemical screening, compatibility test and hydration experiment. The results of physical tests showed that bagasse is light yellow in colour while the newsprint is yellow solid in colour. Phytochemical screening results indicated that saponins, alkaloids, and tannins were present in high concentration. Infrared analysis indicated the notable presence of hydroxyl, ester and carbonyl groups in the samples. Based on the compatibility values, the addition of additives such as $CaCl_2$ produced higher compatibility values. The study concluded that semi-pulped bagasse and the newsprints are appropriate for the production of the particle boards.

Keywords: Cement, Compatibility Factor, Fully Digested Pulp, Particle Boards, Semi-Digested Pulp

1. Introduction

In Nigeria and some other parts of the world, there have been lignocellulosic wastes in excess discharge. With this development, there is the need not only to properly dispose these wastes but to recycle them by converting them into appreciable and constructive uses. This urge, coupled with the increase in the demand for paper and paper-based products has led to the desire to use this lignocellulosic wastes instead of wood as raw materials in particle board production.

The cellulose fibers in wood, fiber crops, or used paper are separated from one another to create pulp, a lignocellulosic fibrous material [1]. Apart from water, the three primary components of bagasse and other plant materials used to manufacture pulp are cellulose fibers (needed for papermaking), lignin (a three-dimensional polymer that binds the cellulose fibers together), and hemicelluloses (shorter branched carbohydrate polymers) [2]. The aim of pulping is to break down the bulk structure of the fibre source, be it chips, stems or other plant parts, into the constituent fibres. The most popular method of pulping, chemical pulping, accomplishes this without chemically depolymerizing the cellulose fibers, which weakens the fibers, by breaking down the lignin and hemicellulose into small, water-soluble molecules that can be washed away from the fibers [3]. The bulk of pulp produced industrially is converted to paper whose quality depends largely on the method of production. These paper wastes have been put into judicious use in the making of particle boards.

Typically, in the form of discrete particles, lignocellulosic materials are mixed with a synthetic resin or other appropriate binder and glued together under heat and pressure to create particleboard, a panel product [4, 5]. Recently, more focus has been placed on the use of resin as a binder in the production of wood-based panels, such as wheat starch, lignin-based glue, or spruce tannin as a binder for medium density fiberboards. Several different kinds of resins are employed often. The least expensive and most straightforward to use resin is urea formaldehyde. The majority of non-water-resistant boards employ it. Due to its resistance to moisture, melamine formaldehyde resin is much more costly. Moreover, phenol formaldehyde is extremely costly. The lack of moisture resistance, especially when combined with heat, is the main drawback of urea formaldehyde adhesives [6, 7]. These circumstances cause the bond-forming processes to reverse and formaldehyde to be released. The prospect of stricter controls on formaldehyde in homes still exists due to the formaldehyde emission levels from items bonded using formaldehyde-based glue. Also, stricter guidelines for formaldehyde levels at work are expected to be implemented [8].

To create products fit for certain end applications, manufacturing procedures, resin concentrations, board densities, and particle geometries may all be changed. Additives can be used during manufacturing to impart particular performance improvements, such as improved dimensional stability, fire retardancy, and moisture resistance.

2. Materials and Methods

Stems of fairly equal sizes (about 145cm) of sugarcane (*Saccharum officinarum),* were cut from sugar cane located around Sabo, Ile-Ife Osun State Nigeria. Newsprints were gathered from Obafemi Awolowo University campus, Osun state Nigeria.

2.1. Bagasse Processing

The collected sugarcane stems were subjected to series of processes, some of which are described below:

2.1.1. Sample Preparation

The weight of each stem was taken before debarking them. The weight of the debarked stems of sugarcane were also taken and termed as “wet weight”. The sugarcane was then crushed with the aid of an improvised roller to remove the juice. Some of the crushed sugarcane were sundried while others were washed free of sugar before sun-drying them.. Molisch test was conducted to ensure a sugar-free sample. The weight of the dry sugarcane was termed “dry weight”. The dried sample was reduced to particulate forms.

2.1.2. Sample Pretreatment

About 1100g of the dried bagasse sample was heated for 5 mins in a large quantity of water to extract the remaining juice. The resulting solution was tested for sugar continuously until certified free of sugar. It was then sun-dried.

2.1.3. Digestion

An open air digestion method was employed. An 800cm^3 beaker was filled with 100g of the bagasse sample and deionised water to cover the sample after which 30ml of 0.15M NaOH was added. The cooking was done for 20 mins after which the bagasse was observed to have gone soft. The digested bagasse sample was washed thoroughly with deionised water to make them free of NaOH. The washing liquid run-off was continously tested with litmus paper until it became neutral to litmus. This procedure was repeated for other batches of the bagasse samples. This process was what was responsible for the semi-digested nature of the bagasse because it still contained some undigested lignin.

2.1.4. Conversion to Mesh

The semi-digested bagasse shreds were beaten with the aid of a mortar and pestle until a uniform particle sized semi pulp was obtained. A semi pulp was obtained because the digestion was done in an open air instead of a digester (vacuum).

2.1.5. Bleaching

The semi-pulp was subjected to bleaching to remove the unwanted coloured materials present. An appropriate quantity of the semi pulp was transferred into a large beaker and a commercial bleach solution was then added such that the pulp was just excessively soaked. Water was also added to serve as a polar washing medium. The mixture was continuously stirred for about 5mins and left for another 20 mins before being sieved and washed free of the bleach. The bleached semi pulp was then sun dried and stored. This process was repeated for different batches of semi pulp. After drying, the bleached pulp was further reduced to smaller sizes with aid of industrial blenders.

2.2. Fully Digested Pulp

The daily newsprints were used for this purpose. The newsprints were reduced into shreds of small sizes and soaked for about 4 hours before being mechanically converted into pulp.

2.2.1. Conversion to a Pulp

The soaked newsprints were pounded with the aid of mortar and pestle until a uniform particle sized pulp was obtained. They were further washed in de-ionized water to reduce the quantity of printing ink present.

2.2.2. Bleaching

The newsprint pulp was transferred into a large container and an appropriate amount of a commercial bleach with water was then added such that the pulp was just excessively soaked. The mixture was continuously stirred for about 5mins and left for another 20 mins. The resulting pulp was washed free of the bleach with excess water before being sun-dried and stored. On drying, the bleached newsprint pulp was further reduced to smaller sizes and stored in airtight containers.

2.3. Proximate Analysis

The proximate analysis was carried out on the sugar-free bagasse sample particles at Faculty of Agriculture, Department of Animal Science, Obafemi Awolowo University, using the recommended methodologies of Association of Official Analytical Chemists [9] and the underlisted parameters, which were essential for this study were determined: moisture, crude fibre, ash contents, as well as organic matter.

2.4. Phytochemical Screening

The fresh bagasse sample was subjected to phytochemical screening to ascertain the phytochemical substances present in them using the method proposed by Norman [10]. Some of the test include alkaloids, anthraquinones, reducing sugars, glycosides, saponins, tannins and flavonoids.

2.5. Compatibility Test

This was carried out in form of hydration test to determine the level of the compatibility of cement with the lignocellulosic materials. It was also done in the presence of chemical accelerators based on a method developed by the Wood Composite Branch of Forestry Research Institute, Malaysia (FRIM).

The compatibility of cement with fresh bagasse, semi digested pulp and fully digested pulp was determined using the Area-Ratio method which involve the relative area under the curve of the sample-cement mixture and that of neat cement [11]. The equipment used for the test is known as hydration test kit.

2.6. Hydration Experiment

Some hydration experiments were carried out to determine how appropriate the sample was for the production of outdoor particle boards. The experiments include;

2.6.1. Hydration Experiment for Neat Cement

The hydration tests were performed in an hydration set which comprised of the Dewar flask embedded in an insulated system. About 90 cm^3 of de-ionised water was added to 200 g of neat cement in a plastic bag. The resulting mixture was properly agitated until a homogenous paste was formed. A thermometer was immediately inserted before it was sealed with a lid in the insulated experimental hydration set. The temperature changes were recorded at an interval of 30 minutes for 24 hours. The average room temperature was also noted before and after each experiment. This experiment was carried out in triplicate, after which a plot of temperature (°C) against time (hour) was made.

The volume of de-ionised water used for subsequent experiments involving lignocellulosic material was obtained using the expression.

$$\text{Volume of water} = 90 + 15(0.3 - MC/100)$$

$$MC = \text{Moisture Content}$$

It was maintained at approximately 12% [12].

2.6.2. Hydration Experiment Cement-Sample Mixture

Hydration temperature experiment was also carried out on the cement-sample mixture to determine the compatibility of the lignocellulosic sample with cement binder. A sample-cement ratio of 3: 40 was employed. It involved the mixing of about 15 g of sample and 200 g of cement in a plastic bag. They were properly mixed in the dry state before a calculated amount of de-ionised water obtained using the above expression was added. The mixture was then properly mixed with the water until homogeneity was achieved. It was observed that there was a slight rise in temperature during the mixing process. The mixture was quickly placed inside the Dewar flask embedded in the insulated system and thermometer was attached before it was closed with a lid. The sample-cement mixture hydration temperature changes were recorded at an interval of 30 minutes for 24 hours and the average room temperature was also noted before and after the experiment. Three replications of this experiment were carried out. For each of the experiment, a plot of hydration temperatures (°C) against time (hour) was made, and it was compared with the one obtained for neat cement using Area-Ratio method.

The compatibility factor C_A was obtained from the hydration experiment using the expression below,

$$C_A = \left(\frac{Awc}{Anc}\right) \times 100$$

C_A is expressed in percentage (%)

Legend:

$A_{wc:}$ Area under the hydration heating rate curve for sample-cement-water mixture.

$A_{nc:}$ Area under the hydration heating rate curve for neat cement mixture [13].

2.7. Addition of Chemical Additives

To ensure proper mixing with the sample-cement mixture, the appropriate amount of chemical additives were first dissolved in a little amount of de-ionised water before making it up to the calculated required amount of water used in the hydration experiment. This solution was then added to the sample-cement mixture that has been properly mixed.

The chemical additive used for this experiment was Calcium chloride ($CaCl_2$). The amount of additives used in the compatibility experiments was based on the weight of cement used.

The summary of the set of hydration experiments carried out on the samples using the same above described method.

2.8. Preparation of Sample for Infrared Analysis

The bagasse, semi-pulp, and the newsprint pulp and their cured composites obtained from the hydration test experiments were dried, crushed into powdery form and kept in different labelled sample bottles. They were subjected to Infra-red spectrophotometric analysis, using FT-IR system, spectrum BX model, at the Central Science Research Laboratory of the University of Ibadan, Nigeria.

3. Results and Discussion

The results of this study are discussed under the following sub-topics:

3.1. Availability of Sample

The bagasse sample considered to be a waste is readily available because of the consumption and widespread use of sugarcane.

3.2. Physical Properties of the Experimental Samples

The physical properties of the samples showed that the bagasse is a solid and light yellow in colour while the newsprint was obtained as yellow solid. The starting bagasse sample was light yellow but turned brown during digestion before finally giving a whitish colour as a result of bleaching while the starting newsprint which was yellow turned grey as a result of bleaching.

3.3. Proximate Analysis

The proximate analysis showed that the bagasse sample gave values of 10.40, 1.77, 27.42, 7.44, 6.56 for the moisture content, ash content, crude fibre, ether extract and crude protein respectively. It was observed that the percentage composition of the moisture in the sample was approximately 10% (this can be varied depending on the level of dryness) and the crude fibre had the highest value which made the sample to be very suitable for this work [1]. Ash content also known as the mineral content had the lowest value which suggests the presence of low inorganic constituents in the bagasse sample [14].

3.4. Bagasse Wet Analysis

From the result obtained, it is quite evident that a sugarcane stem has a very high juice content which makes it quite heavy. On the removal of the juice it becomes very light. The average weight of the sugarcane stems, wet weight, % wet weight, dry weight, % dry weight were 2416.67, 2133.33, 88.23, 1100 and 15.13 respectively.

3.5. Pulp Yield

A yield of 51.4% was obtained from 1100g of the bagasse sample. This is assumed to be a relatively good result going by the chemical method of pulping employed which usually yields less than 50% of pulp due to the destruction of the cellulose by the NaOH compared to the mechanical where yield as high as 70% are obtained [15].

3.6. Phytochemical Screening

Various phytochemical substances were detected in the hot-water extract of the bagasse samples. Saponins, alkaloids, and tannins were present in high concentration [11] while anthraquinone and flavonoids were absent. The glycosides and reducing sugar were present in low concentration because most of them had been washed off during the pretreatment process.

3.7. Metal Analysis

The metal analysis for the bagasse samples (one with sugar and sugar free sample) showed very high concentrations of potassium for both samples with the values of 43.31 and 53.95 wt% for the bagasse and sugar-free bagasse sample respectively.

3.8. Compatibility Test

The 1% $CaCl_2$ in the semi-pulp gave the best value of 77.08% compared to the 62.55% of bagasse (figure 3) as opposed to the 2% that gave the best result in pulp and the bagasse (figure 2). This suggests that the addition of 2% $CaCl_2$ was counter-productive in the semi-pulp [16]. Cellulose binds better with cement because of the functional groups present as more cellulose are involved in the fully pulped sample as compared to the semi-pulp/bagasse although all gave good values above 60% which made them appropriate for the production of particle boards with better bonding [17].

Table 1. *Compatibility Factor (C_A) for the Pulp, Semi-pulp, and Bagasse-Cement Mixture with Calcium Chloride.*

Sample	Additives	Average C_A (%)	(%$CaCl_2$)
	Pulp	0	76.64
		1	85.01
		2	87.35
	Semi-pulp	0	67.56
		1	77.08
		2	61.72
	Bagasse	0	61.99
		1	62.55
		2	64.49

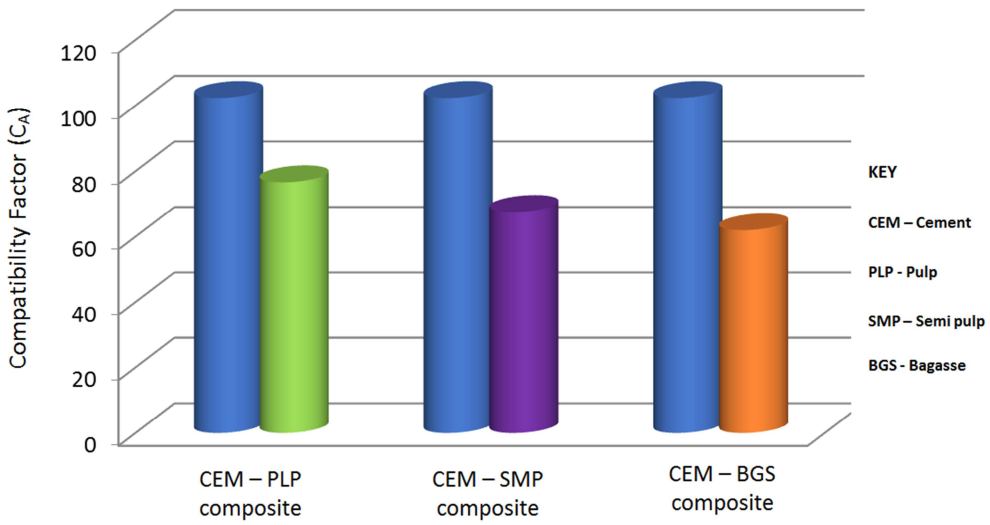

Figure 1. *Compatibility factors of composites without the addition of $CaCl_2$ additive.*

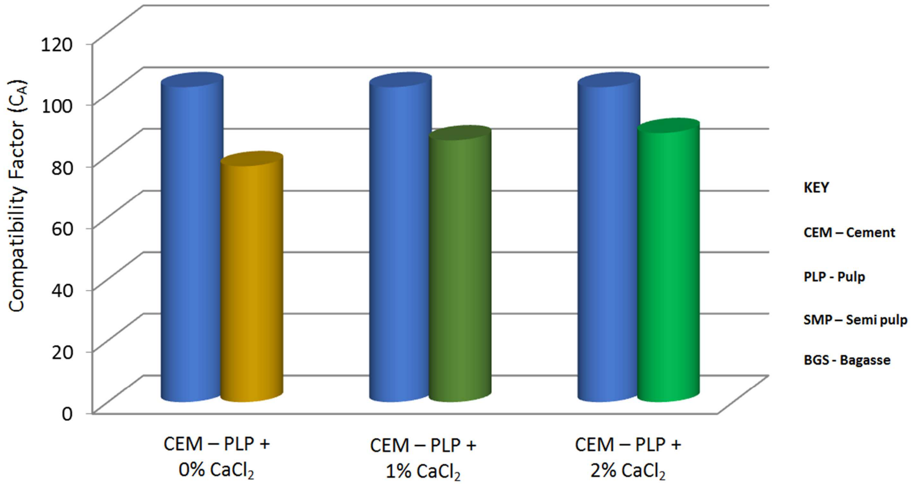

Figure 2. *Compatibility factors of cement-pulp composite with the addition of varying percentage of $CaCl_2$ additive.*

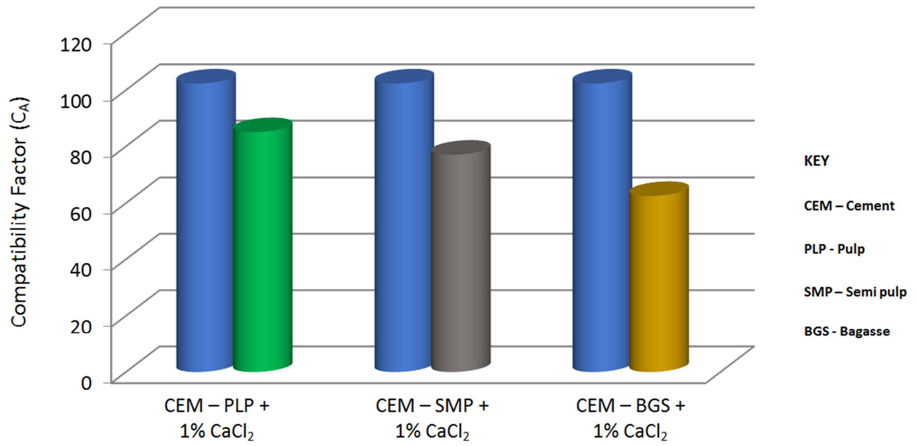

Figure 3. *Compatibility factors of composites with the addition of 1% $CaCl_2$ additive.*

3.9. Infra-Red Analysis

In this study, infrared analysis was used to establish bond formation between the sample particle-cement and chemical additives and to also ascertain that the cured composites from the hydration tests are not the same with our starting materials. The infra-red bands on the bagasse, semi-pulp and the pulp samples were compared with the bands of their respective composites with and without chemical additives.

A lower band shift was observed from 3872.01cm^{-1} for the bagasse to 3868.13cm^{-1}, 3505.49 cm^{-1}, and 3868.13cm^{-1} for the bagasse-cement mixture, bagasse-cement mixture + 1% $CaCl_2$ and bagasse-cement mixture + 2% $CaCl_2$ respectively which indicated bond formation through the hydroxyl group. Similar trend was observed in the carbonyl group where the band moved from 1661.23cm^{-1} for the bagasse to 1646.10cm^{-1}, 1632.38cm^{-1}, and 1654.33cm^{-1} for the bagasse-cement mixture, bagasse-cement mixture + 1% $CaCl_2$ and bagasse-cement mixture + 2% $CaCl_2$, respectively.

Bond formations were also assumed at the C=O and C-O functional groups due to lower shift observed in the semi-pulp and pulp composites with and without the addition of $CaCl_2$. There was a shift to lower band from 1672.33cm^{-1} for the pulp to 1654.33cm^{-1}, 1648.84cm^{-1} and 1648.84cm^{-1}, for the pulp-cement, pulp-cement+ 1% $CaCl_2$, and the cement, pulp-cement + 2% $CaCl_2$ respectively for the C=O functional group. Bonds were also formed through the C-O of esters or ethers due to the lower shift experienced for the bands of the semi-pulp. Generally, it was observed that the bonding in the composites were formed through the hydroxyl (-OH), carbonyl (C-O), esters or ethers (C-O) and amide (N-H).

4. Conclusion

From the results obtained, it can be concluded that both the semi-pulped bagasse and the newsprints are appropriate for the production of the particle boards since all the C_A (compatibility factor) values were greater than 60%. Some of the phytochemicals considered inhibitory in nature were removed during the pretreatment process of bagasse. The addition of additives such as $CaCl_2$ produced better C_A values. Formation of bonds were found to be through hydroxyl (-OH), carbonyl (C=O), and esters or ethers (C-O) functional groups. The newsprints gave the best result therefore will be better in the production of light weight outdoor cement bonded particle boards. More research should be carried out on waste products to determine how appropriate they are for particle board production. The research can also include development of methods to reduce the cost of production and to reduce the use of chemical additives in particle board so as to prevent accidental leaching when using indoors. Other agricultural residues lying fallow around as wastes and pollutants can also be incorporated in this research to reduce their negative effects on the environment. The use of particle boards should be encouraged by setting up production unit which wiall also serve as a means of job creation.

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