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Research Article

# Elaboration and Physico-mechanical Characterization of a Composite Material Based on Waste Paper and a Bio-based Binder Derived from Aloe Barbadensis Miller Juice

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## Abstract

In a context marked by environmental challenges and the need to reduce the carbon footprint of the construction sector, bio-based materials are emerging as a sustainable alternative to conventional materials. This work is part of this approach and aims to develop an eco-friendly composite material based on recycled paper granules and a bio-based binder derived from *Aloe barbadensis* Miller, and to investigate its physical and mechanical properties. To this end, the materials were developed using two paper particle sizes (3 mm and 5 mm), with varying aloe vera juice contents ranging from 65% to 80%. The results obtained show that increasing the aloe vera juice content leads to a decrease in density, from 0.450 kg/m$^3$ to 0.302 kg/m$^3$, as the juice content increases from 65% to 80% for the 3 mm particle size. Similarly, the density decreases from 0.439 kg/m$^3$ to 0.283 kg/m$^3$ for the same juice ratios with the 5 mm particle size. The water absorption rate also decreases with increasing aloe vera juice content, from 286.905% to 200.786% for the 3 mm particle size and from 305.865% to 226.303% for the 5 mm particle size, as the juice content increases from 65% to 80%. The three-point bending strength increases from 1.129 to 1.450 MPa (3 mm particle size) and from 0.815 to 1.007 MPa (5 mm particle size) as the aloe vera juice content increases from 65% to 70%. It then decreases from 1.450 to 0.979 MPa (3 mm particle size) and from 1.007 to 0.700 MPa (5 mm particle size) as the juice content increases from 70% to 80%. Furthermore, the wear resistance increases from 1.554 to 1.876 g/cm$^2$ (5 mm particle size) and from 0.908 to 1.238 g/cm$^2$ (3 mm particle size) as the aloe vera juice content increases, reaching an optimum binder content of approximately 70%. Beyond this value, a decrease in wear resistance is observed due to an excess of binder, with values decreasing from 1.876 to 1.401 MPa (3 mm particle size) and from 1.238 to 0.888 MPa (5 mm particle size). This study shows that the material can be used in construction for lightweight non-load-bearing false ceilings or partition walls.

## Keywords

Bio-based Materials, Bio-based Binders, *Aloe barbadensis* Miller, Valorization, Recycled Paper, Eco-friendly Materials

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# 1. Introduction

The construction sector has long relied on conventional materials whose production is energy-intensive and generates significant amounts of greenhouse gas emissions. It is therefore important to consider using sustainable, eco-friendly materials to reduce the environmental carbon footprint. In response to this issue, the emergence of bio-based materials represents a promising alternative.

Their use offers numerous benefits for the construction sector by contributing to environmental protection through the waste valorization. In this context, the present study aims to develop a composite material from a natural binder and waste materials and to evaluate its main properties. This study therefore aims to develop an eco-friendly construction material based on paper waste and a bio-based binder from *Aloe barbadensis* Miller.

# 2. Materials and Methods

## 2.1. Raw Materials

### 2.1.1. Recycled Papers

The paper used was obtained from end-of-life paper waste collected from the environment after use. The paper was first torn by hand into several pieces and then immersed in water in a basin for 24 hours to facilitate grinding. The soaked paper was then blended to obtain a pulp (Figure 1b). The resulting pulp was dried and then sieved to obtain paper granules (Figure 1c). For the preparation of the materials, two particle-size classes were used: particles passing through the 3 mm sieve and particles passing through the 5 mm sieve but retained on the 3 mm sieve.




***Figure 1****. Method for preparing paper granules (a: paper waste; b: paper waste blended using a mixer; c: paper granules)*

### 2.1.2. Aloe Barbadensis Miller

The *Aloe barbadensis* Miller leaves used in this study were collected from aloe plants at Félix Houphouët-Boigny University. These leaves were processed and prepared to extract the juice, which was then used as a binder for the production of the material (Figure 2).




***Figure 2.*** *Aloe barbadensis Miller (a: leaf; b: juice)*

The binder was extracted by pressing. This process involved cutting 200 g of aloe leaves into small pieces (Figure 2a), then placing them in a blender and adding 30 mL of water to facilitate blending The resulting mixture is poured into a cloth and pressed to extract the juice. The extracted juice is then added to other cut aloe leaves, blended, and filtered again. This process is repeated until the required amount of juice is obtained (Figure 2b).

## 2.2. Material Preparation Method

For the preparation of the material, the juice was added to the paper in granular form, and the mixture was blended for 2 minutes. The mixture was then placed into a mold and compacted using a 3.2 kg mass for 5 minutes. After compaction, the specimens were removed from the mold and then dried. Drying is considered complete when a constant mass is achieved after three to four days. The preparation methodology is summarized in Figure 3.

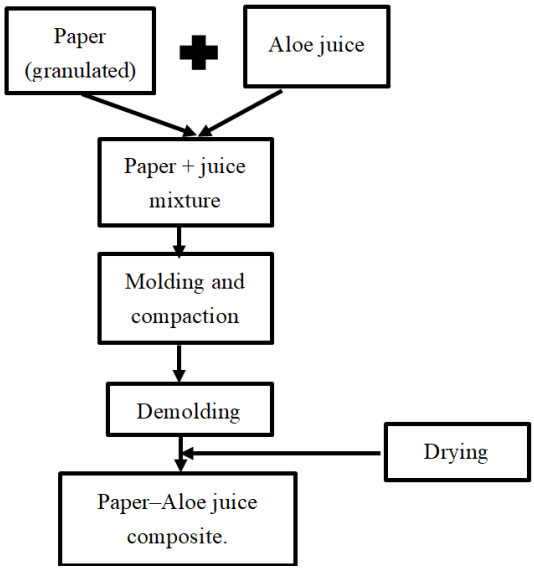



***Figure 3***. *Different stages of material preparation.*

The resulting composites are shown in Figure 4.



***Figure 4***. *Materials obtained.*

## 2.3. Characterization of Composites

### 2.3.1. Physical Characterization

#### (i). Density

As the composites have regular shapes, their length (L), width (l), and thickness (e) are measured.

The volume is determined by multiplying the measured values. Each composite is weighed to obtain its weigth. The density ρ is given by formula (1).

$$\rho = \frac{m}{V} \quad (1)$$

Where m is the weight in kg, V is the volume in $m^3$, and ρ is the density in $kg/m^3$.

#### (ii). Water Absorption by Total Immersion

Absorbed water is responsible for several types of damage, such as mold growth, staining, deterioration of coatings, and cracking in buildings. The procedure for determining water absorption is as follows:

1) The sample is weighed before being immersed in water in a container for twenty-four hours.
2) After twenty-four hours, the samples are weighed again.
3) Total water absorption is calculated using equation (2):

$$W_{abs} = \frac{Ma - Ms}{MS} \times 100 \quad (2)$$

where $W_{abs}$ is the water absorption expressed as a percentage; $M_a$ is the weight of the sample after immersion for 24 hours, in g; and $M_s$ is the dry weight of the sample, in g.

### 2.3.2. Mechanical Characterization

#### (i). Three-point Bending Strength

The bending test was performed on specimens in accordance with ASTM D760-81 (2017) standard [1]. The specimens to be characterized were placed on two simple supports separated by a distance *L*. A third support was positioned on the upper surface at the midpoint between the two supporting points. The bending strength is determined using Equation (3).

$$Rf = \frac{3FL}{2le2} \quad (3)$$

where:

1) F = load measured at failure (N)
2) L = distance between the two support points (mm)
3) b = specimen width (mm)
4) e = specimen thickness (mm)

#### (ii). Wear Strength

This test makes it possible to characterize a material's durability, evaluate the extent of certain types of degradation, and assess the material's ability to resist surface erosion. To measure wear, the device used was developed by Kouakou (2000) [2]. The device (Figure 5) consists of a small carriage mounted on four wheels, with a brush attached underneath. The carriage is mounted on two rails that are joined at both ends. The device is secured to the support by means of metal rods. The carriage is loaded with a 3 kg mass. A handle is used to pull the carriage, which moves along the rails on its wheels. The wear resistance of the sample is characterized by the surface degradation resulting from contact with the brush after 25 wear cycles on the sample surface. Wear is calculated using Equation (4).

$$Wear = \frac{M_{1-M2}}{S} \quad (4)$$

where $M_1$ is the weight in kg before the wear test, $M_2$ is the weight in kg after the wear test, and *S* is the surface area in $m^2$.

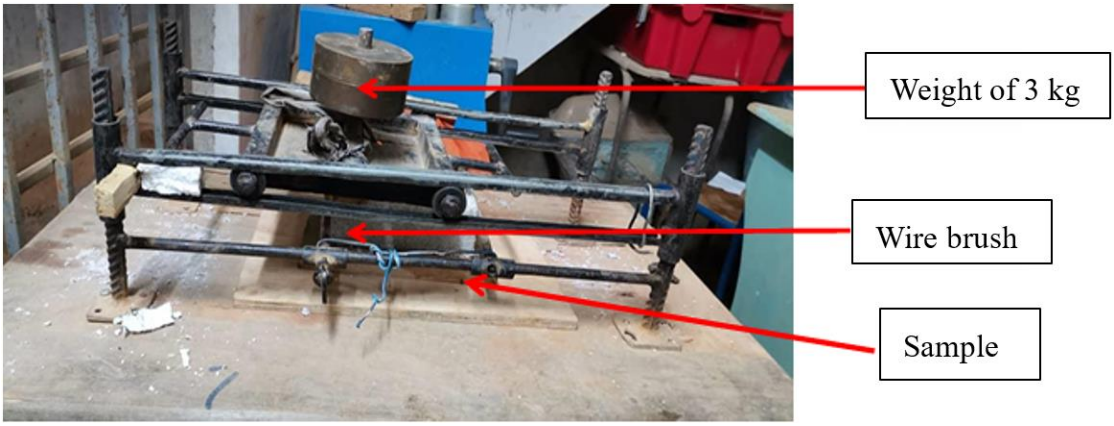



***Figure 5.*** *Wear testing device.*

## 3. Results and Discussion

The results concern samples containing Aloe juice at concentrations ranging from 60% to 80%, as consolidated materials are obtained from a concentration of 60% onwards.

### 3.1. Physical Characterization

#### 3.1.1. Density

Figure 6 shows the variation in density as a function of juice quantity for samples obtained using 3 mm and 5 mm paper granules.

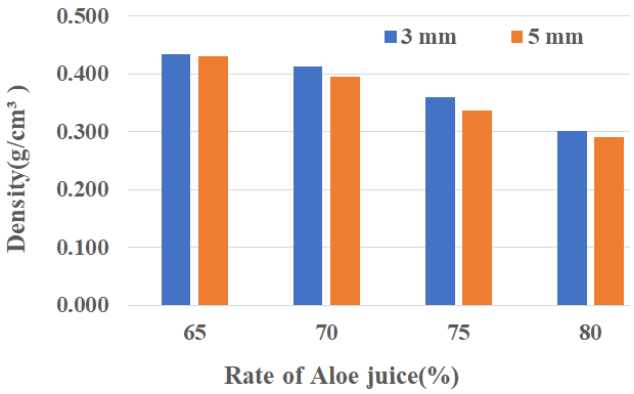



***Figure 6.*** *Density as a function of juice content.*

The density decreases from 0.450 g/m$^3$ to 0.302 g/m$^3$ for Aloe juice contents ranging from 65% to 80% for the 3 mm particle size, while for the 5 mm particle size, it decreases from 0.439 g/m$^3$ to 0.283 g/m$^3$. It can be observed that as the amount of juice increases, the density decreases, regardless of particle size. This may be explained by the fact that the density of the paper granules, 104.9 kg/m$^3$ [3], is higher than that of aloe vera juice. Increasing the amount of aloe vera juice leads to a decrease in the quantity of paper granules. Thus, the reduction in the proportion of paper granules results in a decrease in bulk density. As the proportion of juice increases, the material becomes lighter. These results are consistent with those reported by some authors [4, 5], who showed that the density of a material is strongly influenced by the intrinsic density of its constituents. The incorporation of a higher proportion of a low-density constituent leads to a decrease in the overall density. Samples with a particle size of 3 mm have a higher density than those with a particle size of 5 mm.

This can be explained by the fact that the finer particle size allows for better compaction, thereby reducing the number of pores in the samples, which increases the density. These results are consistent with those reported by some authors [6-8], who demonstrated that particle fineness influences the density of composites.

### 3.1.2. Water Absorption by Total Immersion

Figure 7 shows the variation in water absorption as a function of the different juice contents.

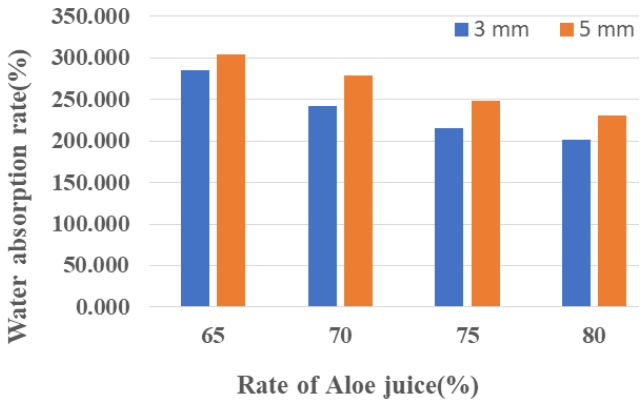



***Figure 7.*** *Water absorption rate as a function of aloe juice content.*

The water absorption rate decreases as the juice content increases, regardless of the particle size of the paper granules. This decrease ranges from 286.905 to 200.786 for the 3 mm particle size and from 305.865 to 226.303 for the 5 mm particle size when the juice content increases from 65% to 80%. The water absorption rate of the coarse particle size (5 mm) is higher than that of the fine particle size (3 mm).

The decrease in the water absorption rate could be explained by the fact that a higher binder content reduces the void spaces between the paper granules, thereby considerably reducing the pathways available for water movement within the composite. At a low juice content, the paper granules are not perfectly bonded together, which means that some of the granules are exposed to water, thereby promoting water absorption due to their hydrophilic nature. The water absorption rate of the coarse paper granules is higher than that of the fine granules due to the presence of pores, which are more prevalent in the coarse granules than in the fine granules [9]. These results align with the work of some authors [10, 11], who demonstrated that increasing the polymer matrix significantly reduces water absorption; the matrix (binder) acts as a barrier that prevents water from reaching the fibers. Similarly, Lee et al. (2006) [12] confirmed in their study that composite absorption increases significantly with a higher proportion of bamboo fibers. Furthermore, some authors [13] demonstrated in their work on the development of a new PVC/reed composite material that the absorption rate increases with the filler content.

These results further confirm our findings. Some authors [14, 15] support this observation by demonstrating in their research that there is a relationship between the proportion of incorporated fibers and the water absorption rate of the material.

## 3.2. Mechanical Characterization

### 3.2.1. Three-point Bending

Figure 8 shows the variation in strength as a function of the amount of aloe juice for particle sizes of 3 mm and 5 mm.

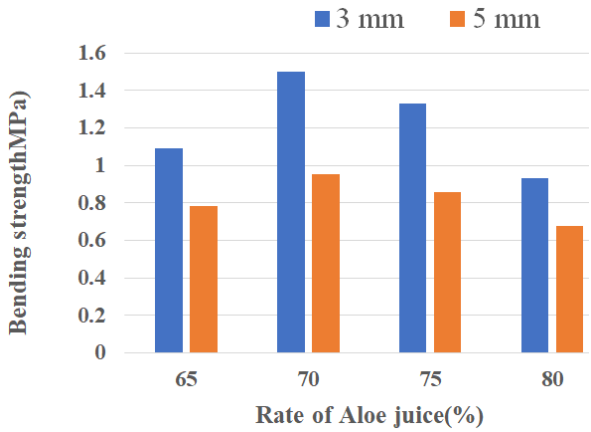



***Figure 8.*** *Variation of bending strength as a function of the amount of aloe juice.*

An increase in resistance is observed, reaching a maximum value of around 70% before dropping. Strengths increase from 1.129 to 1.450 MPa for the fine particle size (3 mm) and from 0.815 to 0.680 MPa for the coarse particle size (5 mm). Beyond 70% juice content, the strength decreases up to 80% aloe juice. Furthermore, the 3 mm particle size exhibits higher strength than the 5 mm size. The increase in strength between

65% and 70% can be explained by the gradual increase in aloe Barbadensis Miller juice, allowing good adhesion between the paper granules and a reduction in areas of weakness between the juice and the paper granules. The decrease observed between 75% and 80% may be attributed to saturation of the mixture with juice. Excess resin compromises the material's rigidity, thereby increasing areas of weakness. This leads to a decrease in strength.

These results are consistent with the findings of some authors [16-19], who observed an increase in bending strength up to a certain threshold, followed by a decrease in the strength of the composites as the matrix content increased.

The higher bending strength of the fine particle size (3 mm) compared with that of the 5 mm particle size can be explained by the fact that materials with finer particles are more densely packed and compacted. This results in a structure that limits crack propagation within the composite when a load is applied. These results are consistent with those reported by some authors [20-22], who showed that finer particles improve flexural strength due to better adhesion.

### 3.2.2. Wear Strength

Figure 9 shows the variation of wear as a function of the Aloe barbadensis Miller juice content for two paper granule sizes (3 mm and 5 mm).

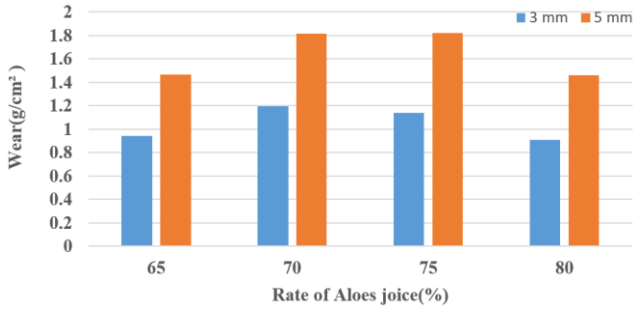



***Figure 9.*** *Variation in wear as a function of the quantity of aloe juice.*

Figure 9 shows that the wear increases from 1.504 to 1.806 g/cm$^2$ for the 5 mm particle size and from 0.965 to 1.198 g/cm$^2$ for the 3 mm particle size when the aloe vera juice content increases from 65% to 70%.

Beyond 70%, the wear gradually decreases regardless of the particle size. For the 5 mm particle size, it decreases to 1.501 g/cm$^2$, while for the 3 mm particle size, it decreases to 0.908 g/cm$^2$.

According some authors [23-25], the coarser the particle size, the lower the wear resistance. Therefore, particle size influences wear strength. The increase in the wear rate between 65% and 70% can be explained by the weak cohesion between the aggregates due to the low juice content, resulting in a poorly consolidated material.

At around 70%, the material reaches a high level of densification and good stress transfer, which leads to an increase in the wear rate.

As the juice content increases, the material becomes more resistant to wear beyond 70% because the cohesion between the particles becomes very strong, resulting in a well-consolidated material. Consequently, during brushing, the mass loss of the samples is very low.

These results are consistent with those of Jolissaint (2015) [26], who showed in his work on flexible bricks for curved walls that increasing the latex content reduces material wear. Similarly, Yomanfo (2018) [27] demonstrated that wear decreases as the latex content in the material increases in his study on the use of Sablatex for carpet manufacturing. The 5 mm particle size exhibits a higher wear rate than the 3 mm particle size. This difference can be explained by the fact that materials obtained with the finer particle size (3 mm) are more compact, stronger, and better consolidated than those obtained with the 5 mm particle size. These results are consistent with those reported by some authors [28-30], who showed that reducing particle size decreases wear in polymer composites. Fine particles disperse more uniformly within the matrix, and their higher specific surface area improves the adhesion between the particles and the matrix.

## 4. Conclusion

This study led to the development of a new material based on paper granules and *Aloe barbadensis Miller* juice. The aim of this study is to valorize paper waste and natural binders in order to reduce the carbon footprint in the construction sector. To this end, variations in paper granule size were carried out to assess their influence on the properties of the materials.

During this study, the binder and paper granules were mixed in varying proportions in order to produce a composite material. The results obtained showed that:

Particle size influences the material properties; the finer the particle size, the better the material properties, particularly in terms of flexural strength.

Density decreases with increasing binder content, from 0.450 kg/m$^3$ to 0.302 kg/m$^3$.

The water absorption rate decreases with increasing binder content, from 286.905 to 200.786.

Bending strength increases from 1.129 to 1.450 MPa for binder contents ranging from 65% to 70%. Beyond 70%, the strength decreases to 0.979 MPa.

The wear rate increases from 1.504 to 1.806 g/cm$^2$ for binder contents ranging from 65% to 70%. Beyond 70%, the wear rate gradually decreases to 1.504 g/cm$^2$ at a resin content of 80%.

According to the NF EN 13964 (2014) standard [31], the material made from paper granules and aloe vera juice can be used for non-load-bearing suspended ceilings or partitions.

## Author Contributions

**Brahiman Traore:** Conceptualization, Methodology, Validation, Writing – original draft

**Obre Sery Paul Jolissaint:** Conceptualization, Methodology

**Souleymane Ouattara:** Conceptualization, Methodology, Validation

**Awa Traore:** Conceptualization, Methodology, Writing – original draft

**Conand Honore Kouakou:** Supervision, Validation

**Edjikeme Emeruwa:** Supervision

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. No financial or personal relationships with other people or organizations have inappropriately influenced this work.

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