



Effects of Flame Retardant on the Flammability of Treated and Untreated Bagasse Papers

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Authors' contributions

This work was carried out in collaboration among all authors. Author TUO conceived the research and designed the research work. Author ECN designed all laboratory procedure. Authors FON, ECN and TUO carried out all literatures searches and conducted the laboratory work together with other authors. All authors read and approved the final manuscript.

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ABSTRACT

A comparative study of the proximate analysis, fire characteristics, and mechanical properties of the papers produced from pretreated and untreated bagasse was carried out. The bagasse collected was washed, dried, depithed and ground to pass through a 5 mm sieve using an electric milling machine. A portion was pulped without pretreatment, while others were pretreated (acetylation) before pulping and washing. After which different mass (0,2,4,6,8 and 10 g) of potassium aluminum sulphate, $KAl(SO_4)_2 \cdot 12H_2O$ (alum) as flame retardant was added. The proximate analysis, fire characteristics and mechanical properties were determined. Results show that cellulose content increased with an increase in the concentration of potassium aluminum sulphate, while hemicellulose content increased from 24%-34% for flame retarded paper with 0-10 g concentration of alum. Lignin content also increased from 21.3%-63.2% for flame retarded paper with 0-10 g concentration of alum, respectively. Ash content varied with an increase in the concentration of potassium aluminum sulphate. Results from fire characteristics show that flame propagation and flame duration rate decreased with an increase in the concentration of alum, while ignition time and char formation increased in the concentration of alum. The mechanical properties, tensile strength, modulus and elongation at break were enhanced. Conclusively, pretreatment enhanced the properties of bagasse papers produced.

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1. INTRODUCTION

Bagasse is the fibrous residue that remains after sugarcane stalks are crushed to extract their juice. It is mainly used as a burning raw material in sugar mill furnaces. The low caloric power of bagasse makes this a low-efficiency process. Presently 85% of bagasse production is burnt. Approximately 9% of bagasse is used in alcohol (ethanol) production. Ethanol is not just a good replacement for fossil fuels, but it is also an environmentally friendly fuel. Apart from this, ethanol is a very versatile chemical raw material from which a variety of chemicals can be produced [1].

When appropriate modifications and manufacturing procedures are applied, bagasse displays improved mechanical properties such as tensile strength, flexural strength, flexural modulus, hardness, and impact strength. Bagasse is also found to be easily treated and modified with chemicals besides blending well with other materials to form new types of composite materials. It also satisfies the greening requirements by being biodegradable, recyclable and reusable [2]. The compression and injection molding processes were performed in order to evaluate which is the better mixing method for fibers (sugarcane bagasse, bagasse cellulose and benzylated bagasse) and polymer matrixes [3]. Bagasse consists of approximately 50% cellulose and 25% each of hemicellulose and lignin. Chemically, bagasse contains about 50% α -cellulose, 30% pentosans, and 2.4% ash. Because of its low ash content, bagasse offers numerous advantages in comparison to other crop residues such as rice straw and wheat straw, which have 17.5% and 11.0%, respectively, ash contents, for usage in microbial cultures.

Paper can be defined as a material made of cellulose pulp, derived mainly from wood, rags and certain grasses, processed into flexible sheets or rolls by deposit from an aqueous suspension and used chiefly for writing, printing, drawing, wrapping and covering walls.

Flame retardants are substances added to material or applied to a surface to reduce or delay the combustion of the material to a degree. Examples of fire retardants include aluminum hydroxide, polyethyleneimine (PEI) and polyamines. Flame retardant can be classified

as: durable finishes, semi-durable finishes and non-durable finishes.

In a study performed by Onuegbu and Ekpunobi [4], it was observed that the introduction of little quantity of chlorinated paraffin into a foam drastically reduce the rate of burning of the foam. It was observed that when thermoplastic materials are subjected to heat, both melting and shrinkage have the effect of reducing apparent flammability.

Production of handmade papers from sugar cane bagasse and banana fibers in Oman was done by Khalsa and Priy [5]. It is clear from the study that both bagasse and banana fibers have good properties and can be easily used as raw materials for handmade papers in the lab or home. By adding suitable additives like CaCO_3 and starch, the properties of paper were enhanced.

Moses and Alex [6] carried out the production of particleboards from sugarcane bagasse and *Euphorbia Sap*. The process of board production was established successfully, which is different from the conventional heating and use of synthetic binders. The physical and mechanical properties of the board samples were determined. The bending strength was found to be 0.66N/mm², the tensile strength 0.18N/mm², thickness swelling 9.7% and water absorption 6%. When these properties were compared with the corresponding values given by the Kenya Standard on fibreboard specification (KS 2706-2:2017), the boards were found to be suitable for non-load bearing applications such as insulation and acoustics.

Utilization of sugarcane bagasse and banana midrib mixture as raw materials for paper making using acetosolve method was carried out by Aprianti [7]. From the study, it was discovered that the best ratio of sugarcane bagasse and banana midrib in this study is 12:8 (w/w), which can produce the best yield pulp, cellulose content and kappa number. The best cooking solution concentration in this study is 80% with the ratio of the solution and the raw material is 1:20 (w/v) and 2 (two) hours cooking time can produce the best cellulose content of pulp and kappa number.

The effect of sugarcane bagasse fiber on the strength properties of soil blocks was investigated by Humphrey et al. [8]. The addition of fibres to the soil blocks contributed to a

reduction in the density of the blocks, which could be attributed to the low density of the fibre. This means that when the blocks are used for building houses, the total weight of the structure will be reduced. The fibre reinforced soil blocks were found to have a high water absorption rate, which was due to the fibres pores' effect on the blocks. This implies that high fibre content in the soil blocks may absorb more water in the rainy season, which could affect some engineering properties of the blocks.

The scope of this study is to evaluate the fire characteristics, e.g., ignition time, flame propagation rate, flame duration and char formation of the treated and untreated paper. This study determines the proximate composition of the pretreated and untreated paper and elucidating the mechanical properties such as the tensile strength, modulus and elongation at break of pretreated and untreated paper.

2. MATERIALS AND METHODS

Bagasse was collected from sugarcane dealers in Port Harcourt, Rivers State and potassium aluminum sulphate (alum) $KAl(SO_4)_3 \cdot 12H_2O$ was sourced from Rivers State Water Corporation, Port Harcourt, Rivers State. Chemicals were bought from Ariara market, Aba, Abia State.

2.1 Preparation of Bagasse

The bagasse was washed in copious amount of water to remove sugar. The mixture was drained through a 4mm wire mesh. They were allowed to dry to remove moisture. The bagasse piles (Plate 1) were rotated with one another for even exposure to the sun. After washing and drying, the collected sample was depicted in Plate 2 using a kitchen knife then it was ground to fine powder, the sample was stored in a dried container until it was used.

2.2 Pretreatment of Bagasse

Ground sample was soaked in 10% NaOH solution for one hour at 30°C. It was decanted

and soaked in glacial acetic acids for another one hour at 30°C [9]. Thereafter it was soaked in acetic anhydride containing few drops of concentrated H_2SO_4 for 5 minutes at the sample temperature. The fibers (bagasse) were drained and oven dried.

2.3 Pulp Preparation

Bagasse was packed into the digester cells and soaked in warmed water to soften it. 0.4M sodium hydroxide and 0.1% anthraquinone was added and completed, it was washed several times with water. Washed sample was treated with 2, 4, 6, 8 and 10 g of potassium aluminum sulphate $KAl(SO_4)_3 \cdot 12H_2O$. Starch was added as a binder.

2.3.1 Paper formation

After pulping, the prepared pulp sample was put into shape using mould ready for drying. The preparation was made possible by putting into consideration the type of paper product required. The paper sample was sun-dried to remove moisture from it (Plate 3 a-f).

2.4 Characterization of the Paper Samples

2.4.1 Proximate analysis of test paper

Proximate analysis was carried on the paper using standard methods. The following parameters were characterized: percentage loss, proximate analysis (cellulose content, lignin content, hemicellulose and ash content). Cellulose and hemicellulose content were measured according to Crampton and Maryland [10], lignin was determined according to TAPPI Test Method [11]. The percentage of ash content was calculated using the formula below [12]:

$$\text{Ash content \%} = \frac{\text{weight of crucible and ash} - \text{weight of crucible}}{\text{weight of sample}} \times 100 \text{ --1}$$



Plate 1. Bagasse heap

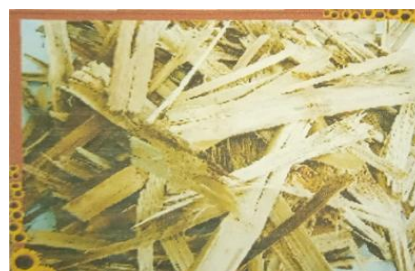


Plate 2. Depithed Bagasse heap

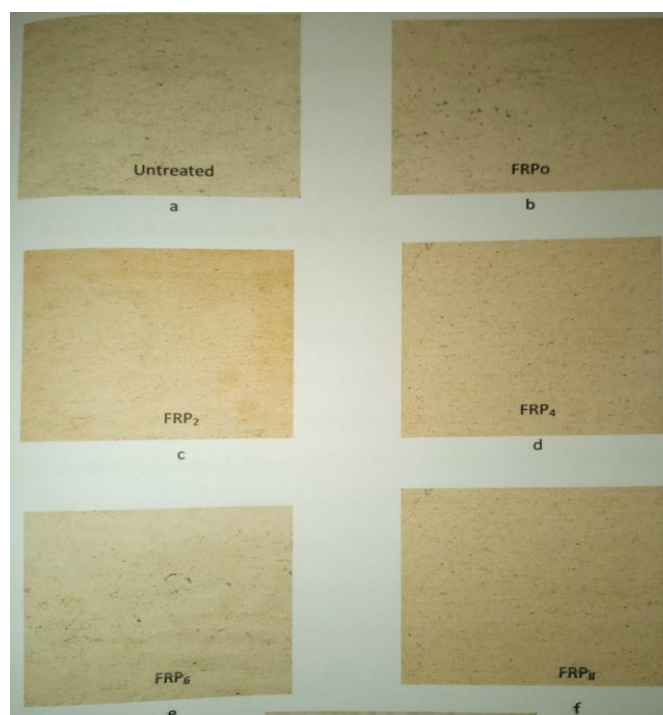


Plate 3. Paper samples produced

2.5 Fire Properties of the Paper

Flame propagation rate, char formation and flame durability test were determined according to the equations described by Eboatu [13]. Tensile properties were carried out using the Instron Universal Testing Machine Model (3369) at crosshead speed of 1mm/min using two test pieces

$$\text{Char formation (\%)} = \frac{\text{weight of sample after burning}}{\text{weight of sample before burning}} \times 100 \quad \text{-- 2}$$

$$\text{Flame propagation rate (cm/s)} = \frac{\text{distance traveled by the flame (cm)}}{\text{Time taken to travel (sec)}} \quad \text{--3}$$

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis

Table 1, shows the results of proximate analysis of percentage cellulose, hemicellulose, lignin and ash content in treated and untreated bagasse paper. The results of the cellulose contents show that the percentage cellulose contents increased with an increase in treatment with sample FRP₀ having the lowest concentration, 6.66% and sample FRP₁₀ having the highest content, 66.6%. The percentage lignin content varied as the samples were pretreated as shown in Table 1, FRP₁₀ has the highest concentration. The ash content decreases with an increase in pretreatment. High ash content is undesirable for

pulping, as it affects normal alkaline consumption.

3.2 Fire Properties

Table 2, shows that as the concentration of potassium aluminum sulphate increases, flame spread decreases. Potassium aluminum sulphate is a very active flame retardant in retarding some polymeric materials such as bagasse. It was observed that samples with 6-10 g of potassium aluminum sulphate are more effective as flame retardant than samples with 0-4 g of potassium aluminum sulphate. From the study it was observed that samples with little or no flame retardant burnt rapidly when compared with samples with flame retardant.

3.3 Effects of Concentration of Potassium Aluminum Sulphate on Ignition Time

Table 3, shows that as the concentration of potassium aluminum sulphate increases, the ignition time of samples increased when compared to untreated. When the samples were treated with 0, 2, 4, 6, 8 and 10 g, of potassium aluminum sulphate, the ignition time (sec) increased from 4, 6, 7, 7, 8 and 9, respectively. This is in addition that an increase in potassium aluminum sulphate concentration increases the ignition time.

3.4 Effects of Concentration of Potassium Aluminum Sulphate on Char Formation

Table 4, shows the effect of potassium aluminum sulphate concentration on char formation. The study shows increased in char formation as concentration increases. Dehydration leads to formation of carbonaceous char that could lead to glowing combustion, untreated sample produced 31.5% char. Pretreated sample without flame retardant produced 43.8% char. Pretreated sample with 2 g of potassium aluminum sulphate produced 48.1% of char. Char formation increases in order from 4 g of potassium

aluminum sulphate to (58.3%), 6 g (59.2%), 8 g (63.0%) and 10 g (63.2%).

3.5 Effects of Concentration of Potassium Aluminum Silicate on Flame Duration

Table 5, shows the effect of alum concentration on flame duration. An increase in concentration decreased the flame duration. As the concentration of alum increased from 0–10 g, the flame duration rate decreased from 60 to 27 secs. The untreated sample has flame duration of 60secs, while pretreated sample without flame retardant has 50secs duration. From the table, flame duration decreases from 60 to 27 secs.

Table 1. Proximate analysis of treated paper samples

Sample	Cellulose content (%)	Hemicellulose content (%)	Lignin content (%)	Ash content (%)
Untreated	6.66	20.0	21.3	1.5
FRP ₀	6.66	24.0	17.1	1.5
FRP ₂	7.53	21.0	14.7	1.0
FRP ₄	26.6	27.0	72.2	1.5
FRP ₆	28.4	29.2	70.5	1.0
FRP ₈	36.7	24.0	74.2	0.5
FRP ₁₀	66.6	34.0	63.2	0.5

Note: FRP_x, x = mass of potassium aluminum sulphate added

Table 2. Effects of Potassium Aluminum Sulphate on flame propagation rate

Sample	Sample length (cm/sec)	Average distance travelled (cm)	Lignin content (%)	Ash content (%)
Untreated	12	8	30	0.27
FRP ₀	12	7.2	30	0.24
FRP ₂	12	6.5	30	0.22
FRP ₄	12	5.2	30	0.17
FRP ₆	12	4.4	30	0.15
FRP ₈	12	4.0	30	0.13
FRP ₁₀	12	3.2	30	0.11

Note: FRP_x, x = mass of potassium aluminum sulphate added

Table 3. Effects of concentration of Potassium Aluminum Sulphate on ignition time

Sample	Sample Length (cm)	Ignition time (sec)
Untreated	12	3
FRP ₀	12	4
FRP ₂	12	6
FRP ₄	12	7
FRP ₆	12	7
FRP ₈	12	8
FRP ₁₀	12	9

Note: FRP_x, x = mass of potassium aluminum sulphate added

Table 4. Effects of Potassium Aluminum Sulphate on char formation

Sample	Sample length (cm/sec)	Weight of Sample	Char after burning	Char formation
Untreated	12	3.8	1.2	31.5
FRP ₀	12	3.2	1.4	43.8
FRP ₂	12	2.7	1.3	48.1
FRP ₄	12	2.4	1.4	53.3
FRP ₆	12	2.5	1.48	59.2
FRP ₈	12	2.3	1.45	63.0
FRP ₁₀	12	3.8	2.4	63.2

Note: FRP_x, x = mass of potassium aluminum sulphate added

Table 5. Effects of concentration of Potassium Aluminum Sulphate on ignition time

Sample Duration	Sample Length (cm)	Flame (sec)
Untreated	12	60
FRP ₀	12	50
FRP ₂	12	45
FRP ₄	12	38
FRP ₆	12	30
FRP ₈	12	28
FRP ₁₀	12	27

Note: FRP_x, x = mass of potassium aluminum sulphate added

Table 6. Mechanical properties of the paper samples

Sample	Tensile Strength (mm)	Modulus (MPa)	Extension Break (mm)
Untreated	0.33	39.32	1.10
FRP ₀	0.27	24.55	0.93
FRP ₂	0.54	42.51	1.15
FRP ₄	0.66	66.19	1.03
FRP ₆	0.86	98.25	1.00
FRP ₈	1.10	103.23	1.18
FRP ₁₀	0.60	52.54	1.27

Note: FRP_x, x = mass of potassium aluminum sulphate added

3.6 Mechanical Properties

The results of the mechanical properties (tensile strength, modulus and elongation at break) are shown in Table 6. From the Table 6, there was a gradual increase from sample FRP₈ – FRP₈ i.e. as fire retardant volume increases from concentration 2 to 8 g, while sample with 10 g/dm³ of fire retardant showed a sharp decrease in tensile strength. Also modulus of the samples decreased initially from untreated sample to pretreated sample without flame retardant and then there was a gradual increase from 2 to 8 g, and a sharp decrease at concentration 10 g/dm³ or FRP₁₀ with 10 g/dm³. Elongation at break showed a slight decrease at FRP₀ follow by a slight gradual increase in FRP₂.

4. CONCLUSION

For paper industries that face a shortage of cellulose fibers, sugarcane bagasse, a fibrous

raw material may be a source for them. The results of the mechanical properties have shown an improvement in the tensile strength, modulus and elongation at the break of the paper. Test results also showed that pretreatment of the sample caused an increase from the Table in the tensile properties of the material, the effect of the fire retardant on the tensile properties of the paper sample could be seen by the increase in value of tensile strength, modulus and elongation at break of the sample as the volume of fire retardant increases. Further study still needs to be carried out to compare papers produced from bagasse's and those produced from other raw materials.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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