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Mechanical Strength, Sorption Characteristics, Thermal and Chemical Properties of Chicken Feather Microfibres Reinforced Paper-panels

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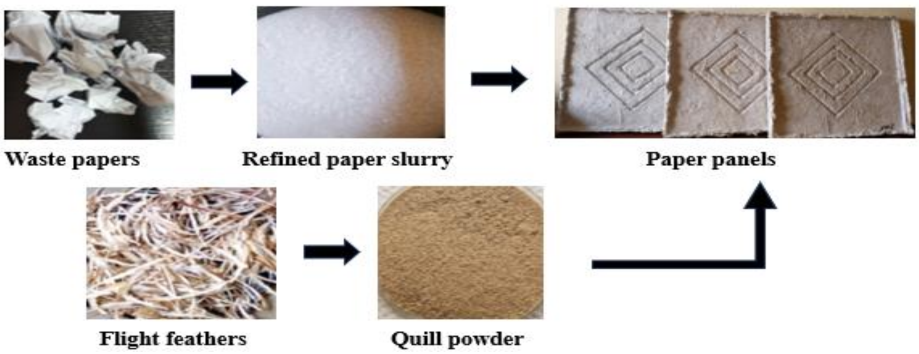
Abstract: Research on sustainable construction materials has focused on incorporating agricultural and industrial waste, such as chicken feathers and waste paper, to reduce environmental impact and enhance material performance, while developing innovative composites. This study explores the production of paper panels from waste print papers and examined the effect of chicken feather microfibres (CFMF) on the physical, mechanical and chemical properties of the panels. Flight chicken feathers were trimmed to obtain the quill and was ground into powder. This was mixed with waste papers which has been reduced into slurry in different ratios (0%, 2.5%, 5%, 7.5% and 10%). The panels were tested for sorption (water absorption and thickness swelling), mechanical (impact strength, moduli of rupture and elasticity), thermal (thermal conductivity and specific heat) as well as chemical (Fourier Transform Infrared Spectroscopy (FTIR)) properties. Sorption tests reveal that the microfibres confer some form of hydrophobicity of the panels. Mechanical tests show moderate impact strength but low modulus of rupture, suggesting its use for non-structural applications. There was a gradual decrease in the thermal conductivity of the wall panels with increasing CFMF. The FTIR result shows no toxic substances in the composition of the panels. The results indicate that the panel is suitable for non-structural interior applications.

Graphical Abstract



1. Introduction

Today, the significant volume of waste that is generated annually on a global scale and its efficient disposal are among the most pressing issues facing humanity. Although there are many different types of waste, biodegradable materials like plant fibres and animal fur receive particular consideration. If not disposed of appropriately, biodegradable wastes that are produced in large quantities, like waste papers and chicken feathers, can also be extremely dangerous. Numerous research teams are modifying new or existing materials with added value using waste materials.

Paper production and waste generation have significantly increased as a result of the global demand for paper across industries like publishing, education, healthcare, and construction. The increasing use of paper emphasises how urgently sustainable waste management solutions are needed. According to Ezeudu *et al*. (2019), Nigeria is expected to generate 5.25 million tonnes of waste paper by 2025. In addition, billions of keratinous wastes are generated form poultry houses yearly (Limeneh *et al*., 2022; Mozhiarasi and Natarajan, 2022). According to Misra *et al*. (2023), chicken feathers are made from free, renewable livestock biowaste and contain roughly 91% keratin, 8% water, and 1% lipids by mass. Because the rachis and fibre are made of hydrophobic keratin, the surface finish of chicken feather fibre exhibits irregularities during composite fabrication. Beta keratin has also been identified as the component of chicken feathers. The main constituent of chicken feathers (CFs) is keratin, with additional trace amounts of water and lipids (Schmidt, 2004). These wastes are processed in compliance with the European Directive's specifications, whose regulations permits only a few uses for CFs such as hydrolysis, composting, and incineration for pet food manufacturing processes. These processes turn CF waste into low-value materials, which leads to the search for different processing techniques and uses that could turn renewable CF waste into a second source of raw materials. In this context, processing the waste from CFs to create a technical material that could be utilised to create composites like wall panels is one possible strategy.

In an attempt to solve what could have been a future garbage crisis, the solution that gets near-universal approval, at least in principle is recycling. Recycling chicken feathers lowers landfill waste, produces high-value products, and lessens carbon emissions. By reducing the amount of waste that needs to be disposed of, reducing deforestation, conserving water, reducing pollution, creating jobs, conserving natural resources like trees, and saving energy, paper recycling programs help to reduce the need for new landfills and incinerators. Natural plant and animal fibres, which carbon neutral and biodegradable have gained the interest of researchers in recent times as reinforcement for composite production (Elidrissi *et al*., 2012; Azzaoui *et al*., 2016; Akartasse *et al.*, 2017; Akartasse *et al.*, 2022). Asides the improved mechanical and bonding as a result of the fibre morphology and chemical structure, some natural fibres also confer flame stalling properties coupled with the fact that they are amenable to modifications due to the presence of stabilised hydrogen bonds from keratin, cellulose and lignin, making them preferable to synthetic fibres such as glass fibres.

Chicken feathers have been reported to have low density (0.8g/cm3 compared to 1.5g/cm3 for cellulose fibres), good resilience and compressibility, sound dampening and warmth retention capabilities, as well as excellent thermal and acoustic properties (Reddy and Yang, 2014; Tesfaye *et al*., 2017 & 2017b). These unique properties of CFs are attributable to morphological structure of the barbs (Qiu *et al*., 2021) make them a good experimental material in production of Wall Panels. Over the past 20 years, a lot of research has been done on the use of CFFs as fibre reinforcement in generic composite materials (Khosa *et al*., 2013; Subramani *et al*., 2014; Tesfaye *et al*., 2018; Kalaikumari *et al*., 2019; Kakonke *et al*., 2020). Research has concentrated on using CFFs as fiber-reinforcement of composite materials made of cement and plastic, specifically in relation to their use as reinforcement in building materials (Huda and Yang, 2008; Acda, 2010b, 2010a; Zhang *et al*., 2018). The use of chicken feathers and papers in the production of composite panels promises a lightweight material suitable for many applications.

While chicken feathers offer unique properties like hydrophobicity, waste paper provides structural support and sustainability, making their combination ideal for composite production (Farhad Ali *et al*., 2017; Taghiyari, 2020; Aradoaei *et al*., 2024). Composites for construction materials have been developed using waste papers (Agyeman Boateng *et al.,* 2024). Amiandamhen and Osadolor (2020) created cement composite panels and waste papers reinforced with kenaf. Sangrutsamee *et al*. (2012) also created a composite made of cement and waste papers that can be used in place of masonry blocks when building structures. It was demonstrated that the blocks met the fundamental specifications for an insulating building material. Kolajo and Odule (2021) produced decorative wall panels from waste papers and chicken feather down fibres, an reported a 15% chicken feather inclusion for optimum sorption properties.

The main objective of this study is to explore hydrophobic properties of chicken feather micro-fibre in paper-panel production, and its effect on strength, thermal and chemical properties of the panels. By combining these two waste materials, the study aims to create a composite material that is not only environmentally sustainable but also exhibits enhanced mechanical and functional properties. Key focus areas include the tensile and compressive strength of the panels, their water absorption and moisture resistance, and the chemical interactions between the keratin in chicken feathers and the cellulose in paper.

2. Materials and methods

2.1 Waste papers

The bleached grade printing waste papers used for this study were obtained from the University of Ibadan campus. These were sorted into grades and cleaned to remove contaminants. The papers were then weighed and reduced into slurry in a consistency of about 15% using an hydropulper. The pulp slurry was refined to ensure proper formation when moulded into panels.

2.2 Chicken feather rachis microfibers

Chicken feathers were collected from chicken processing plants in Ibadan, Western Nigeria. The feathers were cleaned and air-dried for 72 hours according to McDonald and Griffith (2011). The dried feathers were then sorted to remove the flight feathers from the other feather types. This is because the calamus (rachis) is majorly found in the flight feathers. These were trimmed carefully to obtain its rachis. The rachis was milled into fine particle sizes of less than 1.0 mm aperture.

2.3 Wall panel production

The bleached grade waste paper and chicken feather micro fibres (CFMF) (rachis) were combined in several ratios for the wall panel production (**Table 1**). The paper-panel is produced using a 325 by 325 by 20 mm^3 mould designed and fabricated for the purpose (Kolajo *et al*., 2020). The machine is comprised of the mould which holds the composite mix, a counter mould which imprints the design on the moulded product and a screw press assembly that helps in compaction and in draining water from the panel. The formed panel was dried at room temperature (25 ±3 ^{O}C) for 96 hours at about 72% relative humidity. The panels were trimmed to 300 by 300 by 13 mm^3 dimension.

Table 1: Proportions of CFMF to Waste Papers

% Composition	L	M	N	P	Q
Waste papers	100	97.5	95.0	92.5	90
CFMF	0	2.5	5.0	7.5	10.0

2.4 Test Programme

Determination of Physical properties

Water sorption tests were carried out in accordance with modified ASTM D570-98 standards while the density of the panels was obtained using ASTM D792-20 standard. Test samples of 50 x 50 mm^2 were obtained for the determination of water absorption and thickness swelling. Measurements for thickness swelling (TS) were made at the centre of the specimen face using a digital calliper with ±0.01mm accuracy.

Determination of Mechanical properties

Mechanical tests: Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were determined using the Universal Instron 5500R-1132 testing machine in accordance ASTM D1037 standard. An extensometer (Model 3542, Epsilon Technology Corp.) was used to measure the strain, while the Bluehill software (Version 2, Instron) was used to process the data. The Instrumental Falling Weight principle was used to test the impact strength of flat laminate specimens loaded using a variety of specimen fixtures. These were evaluated according to **Eqns. 1 and 2**:

Modulus of Elasticity was determined by:

$$MOE = \frac{\sigma_f}{\epsilon} \quad . \quad . \quad . \quad \textbf{Eqn. 1}$$

Modulus of Rupture was determined by:

$$MOR = \frac{3FL}{2bd^2} \quad . \quad . \quad . \quad \textbf{Eqn. 2}$$

Where: σ_f= stress
F = applied load
ε = strain
L = original length of the material
b = width of the material

Determination of Thermal properties

The paper panels' thermal conductivity was measured using a Hot Disk™ Thermal Constants Analyser with the transient plane source method. Three replicates of circular disc-shaped panels with a diameter of 125 mm and a thickness of 6 mm were analysed. The sample was heated by 1 °C during the experiment by passing a continuous current pulse through the sensor (**Eqn. 3**). The element ΔT's time-dependent temperature increase is revealed by recording the time-dependent resistance variation R(t) over a sensor with known resistance R_0 and temperature coefficient α (**Eqn. 4**).

$$R(t) = R_0[1 + \alpha.\Delta T(\tau). \quad . \quad . \quad . \quad \textbf{Eqn. 3}$$

$$\tau = \frac{t.D}{\sqrt{r}} \quad . \quad . \quad . \quad \textbf{Eqn. 4}$$

Where,

D is the sample's thermal diffusivity, r is the Hot Disk's radius, and τ is the average temperature increase as a function of the time interval t from the beginning of the transient heating.
The sample's specific heat capacity (cp) and thermal conductivity (k) over density (ρ) determine its thermal diffusivity (D).

Fourier Transform Infrared Radioscopy (FTIR) Assay of the paper panel

The composites' functional groups were identified using a Fourier transform infrared (FTIR) machine (PerkinElmer FT-IR system spectrum BX) in compliance with the methodology modified by Fabiyi *et al*. (2009) and Adefisan and Oyelola (2019). The paper panels were ground into powder and about 2 mg of the powder was homogenized with 200 mg of Potassium bromated (KBR) salt. The powdered mixtures were pelletized into thin discs and assayed by the FTIR machine.

3. Results and Discussion

3.1 Water Absorption and Thickness Swelling

Results of sorption behaviours of the composite samples are shown in **Figures 1 and 2**. **Figure 1** shows the results of water sorption tests. There was initial quick water absorption, followed by slow and consistent water uptake. The control sample had the highest water absorption while 10% CFMF 90% WP gave the lowest for all intervals tested. There was however a gradual reduction in water absorption across samples (401.5 to 352.7) with increase in CFMF content. This is explained by the hydrophobic properties of keratin in the rachis microfibers. The rachis in its fine powdery form is believed to have filled all void spaces and reduced the water absorption as well as the thickness swelling of the panels. This finding indeed confirms Kelly (2006) who reported that chicken feather that the rachis consists of hydrophobic properties which supports positive sorption behaviour. Winandy *et al* (2013) in his research of CFMF as an additive in MDF composites stated that less than 10% CFMF seemed to impart a certain amount of water resistance to conductive-mode moisture absorption. The treatment shows that an increase in the proportion of the rachis microfibers will further reduce water absorption in the panels. There is a general decrease in thickness swelling of the panels as the percentage composition of CFM increased. From the results obtained (**Figure 2**), it was established that as percentage of CFMF increases in the composite, its tendency of water absorption and thickness swelling decreased.

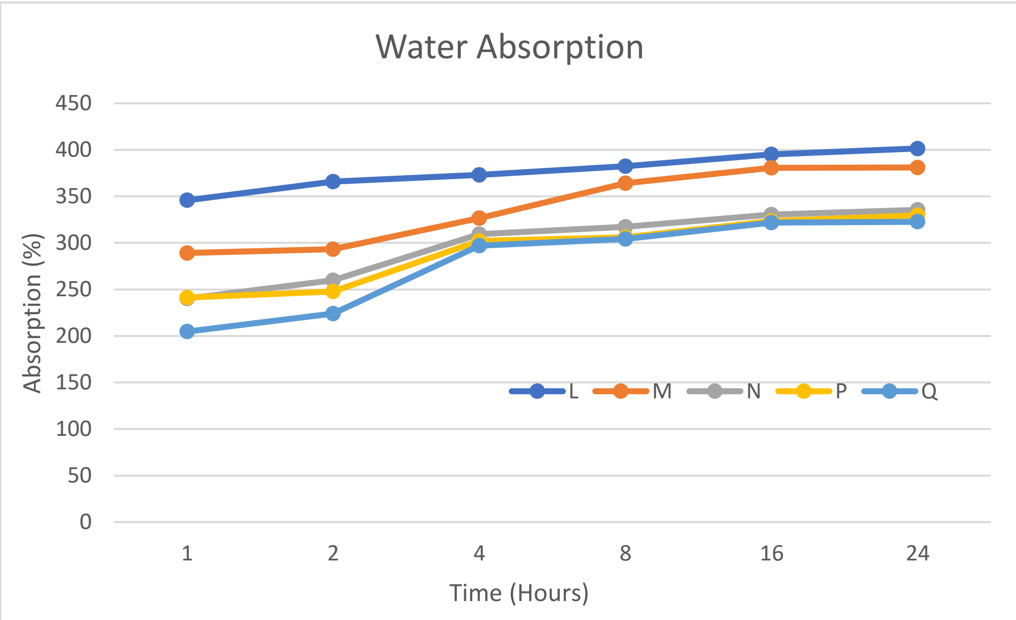


Figure 1: Water absorption rates for the paper panels

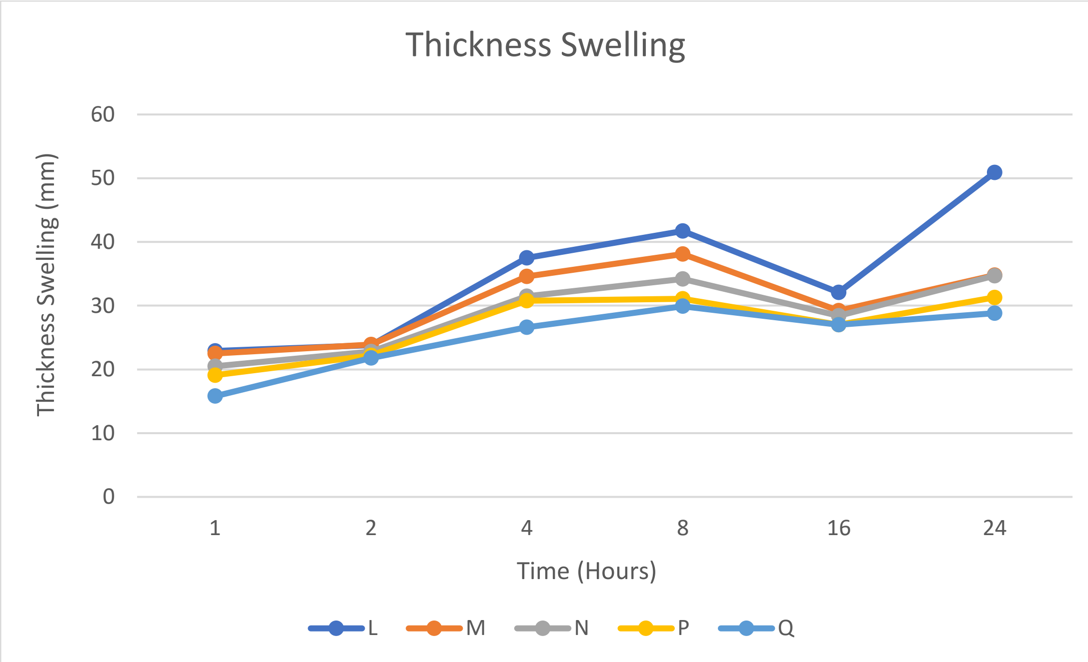


Figure 2: Thickness swelling of the paper panels

3.2 Physical and Flexural Test Results

The result of physical and flexural tests for the wall panels produced are as shown in Table 2.

Table 2: Results of Mechanical Tests

Sample	Density (kg/m^3)	MOE (N/mm^2)	MOR (N/mm^2)	Impact Energy (J)	Impact Strength (J/m)
L	440.00	585.98	2.77	4.32	0.33
M	453.70	692.40	2.56	4.32	0.33
N	474.07	718.72	3.20	6.47	0.49
P	480.00	723.12	4.27	15.11	1.16
Q	481.48	847.88	3.63	21.58	1.66

The densities of the wall panels produced ranged from 440.00kg/m^3 to 481.48kg/m^3, the highest was sample Q, where the lowest was L. The MOE of the wall panel produced ranged from the highest at Q (847.8N/mm^2) to the lowest at L (585.9N/mm^2) while the MOR was between to 2.5N/mm^2 to 4.2N/mm^2. There was a gradual increase in the MOR from sample L to P, but decreased at Q. The general trend shows that increasing the CFMF content improves the strength as well as stiffness of the wall panel. However, according to Cai *et al*., (2021) the Forest Product Laboratory reported that composites with MOR values less than 15.1N/mm^2 and MOE less than 2800 N/mm^2 are not suitable for structural purposes. However, the composite produced may be suitable for non-structural applications.

The impact energy of the panels ranged from between 4.32J (Sample L) to 21.58J (Sample Q). The ability of the panels to withstand impact forces increased as the percentage CFMF increased. This shows that the inclusion of CFMF improves the general strength properties of the panels as the pores were filled with CFMF microfibres, thus increasing the density and consequently, the strength of the paper panels. All the wall panel samples follow variation before they were broken at the same height of 440mm although there are significant variations in the number of drops at which each of the samples broke. It was also established that there was a gradual in the impact strength as the percentage of CFMF increase in the wall panels sample, hence the composite with the highest percentage of CFMF recorded the highest impact strength. The values obtained are lesser to that of gypsum which is 4250J/m (Espinoza-Herrera and Cloutier, 2011).

3.3 Thermal conductivity tests

One important property of wall panels is low thermal conductivity which helps in insulating buildings and reduce the power consumption in heating and air conditioning. The thermal conductivity of the paper panels ranged between 0.10 and 0.13W/mK, with no significant difference in the values as the proportion of CFMF increased in the panels. The values obtained compares well with thermal conductivities of 0.048W/mK for wood (Cetina and Shea, 2018; Bunzel *et al*., 2020), 0.23W/mK for newspapers (Sooriyalakshmi and Helena, 2022) and 0.153W/mK reported for groundnut shell (Raju *et al*., 2012; Prabhakar *et al*., 2015) all of which has been used in the production of composite panels. The low thermal conductivities recorded for the paper panels confirms their excellent insulating properties, making them more suitable for interior panel use, than polystyrene (0.836W/mK) and concrete (2.526W/mK) panels (Alhems *et al*, 2022) respectively.

Table 3: Thermal conductivity results for Chicken feather micro-fibres

Samples	Mass	Temp		Density	Thickness		K	SH
L	53	32	34	126	11.4	14.1	0.131	436.85
M	55	33	34	124	11.4	14.1	0.133	442.79
N	57	33	35	123	11.4	14.1	0.136	448.73
P	58	34	35	126	13.5	12.7	0.133	538.91
Q	47	34	35	126	10.8	10.3	0.108	570.70

SH: Specific heat   K: Thermal conductivity

3.4 FTIR Test results

Table 4 presents the FTIR result of paper panels. The infrared spectrum for 0% to 20%CFMF indicated absorption bands at 3487.00cm^{-1} and 3271.00cm^{-1} corresponding to the O-H stretching vibration which indicates the bondability of the paper with other substances. The Aromatic weak C-H stretching vibration absorption bands are indicated at 1793.76cm^{-1} to 1793.76cm^{-1} which indicates low strength and abrasion properties. The absorption bands for Unsaturated Ketone is indicated between 1639.40cm^{-1} to 1634.74cm^{-1} while absorption bands between 1440.00cm^{-1} and 1406.00cm^{-1} are assigned to Aromatic C-C stretching vibration. The deformation (or bend) of Alkenes and Alkynes occurred at 888.42cm^{-1} to 886.16cm^{-1} and 660.00cm^{-1} to 646.00cm^{-1} respectively.

Table 4: Infrared bands observed in the paper panels

Position (cm^{-1})	Peak Assignment
3487.00-3271.00	O-H stretch
2916.00-2877.00	Hydrocarbon C-H stretch
1793.76-1790.66	Aromatic weak C-H stretch
1639.40-1634.74	Unsaturated Ketone
1440.00-1406.00	Aromatic C-C stretch (in ring)
1153.72-1101.00	C-O stretch
888.42-886.16	= C-H bend in Alkenes
660.00-646.00	≡ C-H bend in Alkynes

Conclusion

The results showed that the inclusion of chicken feather microfibers in waste paper confers some form of hydrophobicity on the resulting paper panels as observed in the sorption experimentation. Also, the improved impact-strength was observed as the proportion of the microfibres in the composite mix increased. The thermal conductivity test also shows that the paper panels have excellent insulating properties which makes them suitable for interior wall cladding applications. Mechanical tests affirmed the panels as suitable for decorative and non-load bearing applications with acceptable resistance to impact forces. Chemical composition of the panels shows no presence of toxic substances and therefore suitable for interior applications. The production of wall paper panels from waste materials have provided a reuse for waste materials and provided a sustainable biodegradable material which is ecofriendly, lightweight and cost effective.

Competing Interests: The authors affirm that this is their own original research and is not under consideration for publication in any other journal or publication outlet. There is therefore no conflict of interest to disclose.
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