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Experimental Investigations on the Thermal and Chemical Properties of Chicken Feather Fibres and Sawdust Reinforced Composite Board with Epoxy Resin

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ABSTRACT

Waste materials from animals and plants are environmentally friendly alternatives to synthetic materials such as green composite reinforcement. Conventional construction materials such as asbestos, PVC, and synthetic boards contain chemical elements that are toxic to humans when exposed to heat. These materials easily decompose under high temperatures, releasing the poisonous substance into the environment This study investigates the thermochemical potential of chicken feather fibre (CFF) and sawdust (SD) composite board as an eco-friendly material for low-cost ceiling and particle board applications. The thermal stability and chemical properties of the CFF/SD composite board were characterised through thermogravimetric analysis (TGA) and energy dispersive X-ray analysis (EDX). The TGA results show that CFF/SD composite samples S213, S222, and S231 exhibit optimal stability with 0.9, 9.3, and 1.9% weight loss when exposed to heat at the temperature regions of 0 - $300^{o}C$, 300 – $500^{o}C$ and 500 - $848^{o}C$ respectively. The chemical composition of CFF/SD composite indicates the presence of essential elements which make the composite non-hazardous. The experimental results demonstrate that composite boards produced from waste CFF/SD materials are promising alternatives for low-cost, eco-friendly ceiling and particle boards for indoor applications.

Keywords: non-hazardous, thermal stability, ceiling boards, particle boards, sustainable construction, eco-friendly materials, green composite reinforcement.

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1. INTRODUCTION

Green composites are biomaterials that are completely biodegradable and environmentally friendly, and research efforts have been performed to produce them [1]. These materials are made of lignocellulosic bio-fibre that comes from natural sources and biodegradable polymers. Green composites have gained a lot of attention in the manufacturing and educational sectors because of their appealing qualities, which include low density, high specific strength, recyclability, affordability, and being eco-friendly. Numerous studies and research articles have been published to shed light on the different features of green composites. Zini and Scandola [2] discussed how utilizing green composites has positive effects on the environment. [3] and [4] documented the use of green composites in consumer goods. The available biopolymers and natural fibres to build green composites and their qualities were reported [4, 11, 12]. [7] and [8] provided a thorough analysis of the characteristics, modifications, characterization, processing methods, and applications of green composites. In the United States, about 2109 kg of chicken feathers are produced each year [9]. Chicken feathers are disposed of as waste products and they are usually buried; however, there are other, more advantageous uses for this waste. The protein known as hydrophobic keratin, which has a diameter less than that of wood fibre but a strength comparable to nylon, makes up chicken feather fibre (CFF). Furthermore, CFF has a high aspect ratio and is eco-friendly, renewable, and durable. The positive attributes described contribute to the appealing benefit of employing CFF as polymer reinforcement. This work also aims to use sawdust, one of the main industrial wastes from the harvesting and processing of wood, as a filler alongside chicken feathers. The uncontrolled disposal of sawdust is causing harm to the environment, although it can be used to produce heat energy. However, during combustion, harmful substances such as ash, nitrogen oxides, carbon monoxide, sulfur oxides, and volatile organic compounds are released into the atmosphere, which can adversely affect the human respiratory system [10].

Nowadays, contamination from waste disposal has put further strain on the environment, which is already delicate [11]. Several researchers are investigating different approaches for getting rid of all sorts of industrial and agricultural waste to reduce their impact on the environment. Sawdust is one waste material that can be recycled to create new, environmentally acceptable products [12]. Sawdust and natural fibres are used for natural fibre-reinforced composite boards, intended to replace traditional materials such as asbestos, metals, and wood [15, 16]. [15] developed a composite ceiling board made of agro-waste that is utilized in homes to add aesthetics and minimize heat and noise. Extensive research has been conducted on the mechanical properties of green composites [16].

Understanding the thermal characteristics of green composites is essential to determining their potential to withstand heat in various environmental settings. When producing green composites for a given application, their melting and glass transition temperatures are crucial variables to consider to avoid early failure.

2. EXPERIMENTAL

2.1. Materials

A wide range of materials were considered the basic and additional materials for this research based on their specific functions. The main materials used in this study are chicken feather fibres (CFF) and sawdust particles (SD). This forms the base material referred to throughout the study as the CFF/SD composite ceiling board. Sawdusts are known for absorption and bonding capabilities, while chicken feathers have inherent strength and tenacity. Additional materials used were mono-ammonium phosphate ($NH_4H_2PO_4$) and sand (SiO_2), a chemical compound that retards fire [17, 18] thereby boosting safety concerns. Sand also inhibits fire caused by materials and supports the rigidity of a component or structure. Calcium carbonate ($CaCO_3$) acts as a filler to improve the material's properties and adds more reinforcement [19]. Moreover, fillers made of copper (Cu) are added to the composite material to provide conductivity and maybe improve particular electromagnetic properties, based on the proposed use of the material.

Chemicals such as adhesives and catalysts were used in addition to the basic materials to improve the bonding properties and functions of the developed composite. Epoxy adhesive, a thermosetting resin was chosen to add to the ultimate durability and strength of the composite material. During the production, methyl ethyl ketone (MEK) serves as a solvent to help dissolve and distribute different materials. The study explores new directions in the production of composite materials by combining the materials and additives specified in Table 1, utilising both natural and synthetic ingredients to obtain desired performance characteristics.

Table 1. Composite materials.

S/N	Materials	Functions
1	Chicken feather fibres (CFF)	Base material
2	Sawdust particles (SD)	Base material
3	Sand (SiO_2)	Fire retardant
4	Mono-ammonium Phosphate ($NH_4H_2PO_4$)	Fire retardant
5	Epoxy	Binder
6	Epoxy hardener	Binder
7	Methyl Ethyl Ketone (MEK)	Catalyst
8	$CaCO_3$	Filler

2.2. Composite Preparation

The procedure employed in this study to prepare the materials was similar to that of [20], which comprised a systematic series of steps for transforming the raw chicken feathers into fine fibres suitable for CFF/SD composite. Sawdust was obtained from woodwork shops and upon collection, large wood fragments and debris were removed from the sawdust to prevent interference during the grinding process. The sawdust was ground into smaller particles and sieved through a 250 µm mesh for uniform distribution. Finally, the refined sawdust was sun-dried for a full day to eliminate moisture.

According to the experimental design of [21], the chicken feather fibres and sawdust (SD) were combined in predetermined ratios of 15, 20 or 25% CFF, 9, 12 or 15% SD along with additives such as $CaCO_3$, sand (SiO_2), mono-ammonium phosphate, to enhance thermal properties of the composite. The epoxy adhesive was poured into the mixture and stirred thoroughly for complete adhesion of the materials in the matrix and methyl ethyl ketone (MEK) was added to accelerate the curing process. The mixture was poured into a mould, and a pressure of 2.5 N/mm^2 was uniformly applied. After it was allowed to set for 24 hours, the composite boards were cured in an oven at different temperatures of 100–200°C and for durations of 60–180 minutes. After curing, the CFF/SD ceiling boards were cooled, trimmed and labelled based on their composition and curing parameters.

2.3. Design Method

The samples were subjected to thermogravimetry analysis (TGA) and energy dispersive X-ray (EDX) test to determine their responses when exposed to heat and the chemical contents respectively. On the samples, coded sample numbers are noted in the order of material, curing time and curing temperature, and the low, medium, and high are designated as 1, 2 and 3 respectively. The different levels (low, medium, and high) for the process variables are material (35, 45 and 55%wt), curing time (60, 120, and 180mins), and curing temperature (100, 150, and 200ºC). Using the coded levels to achieve the optimal outcomes for the desired properties, altering the time, temperature and material composition at the levels while assessing the responses was done systematically using the Box Benkehn 3^3 experimental design.

3. RESULTS

3.1. Thermogravimetric Analysis

The samples were analysed according to the ASTM E2105-00 test standards [22]. It evaluates the mass of the material based on temperature under controlled conditions. The TGA decomposition process releases the absorbed moisture, eliminates the resins and chemicals, and finally decomposes the samples [23]. The three significant regions of weight loss of the samples subjected to thermogravimetric analysis (TGA) were analysed with the detailed values shown in Table 1. A typical thermograph for the samples displays the decline in the curve gradient between 0°C and 900°C. The thermographic curves represent the weight loss trend of the samples as they are subjected to increasing temperatures. The slopes in the curves indicate the changes in the composition weight of the samples over the temperature range, thereby describing the sample thermal behaviour.

Figure 1 describes the initial weight loss attributed to the loss of water in the samples, which occurs between 0°C and 300°C. At this phase, sample S213, developed with 45%wt of CFF/SD concentration, cured for 60 minutes at 200°C demonstrates optimal thermal stability. The sample loses 0.9% of its weight due to the loss of absorbed water.

Figure 2 describes the major weight loss observed between 300 to 500°C. The loss is connected to the simultaneous degradation and volatilization of epoxy and fibres of the composite materials. Sample S222, developed with 45%wt of CFF/SD for 120 minutes at 150°C was observed to exhibit the optimal stability during this phase, with a minimal weight loss of 9.3%. Meanwhile, with the highest weight loss of 81.7%, sample S123, developed with 35%wt CFF/SD for 120 minutes at 200°C shows to be the least stable when subjected to the same heat. It suggests that samples with low material concentration contain the highest chemical amount leading to increased degradation.

The major degradation of the material was followed by the final weight loss determined between 500 to 848°C as shown in Figure 3. It was observed that the S231 composite sample produced with 45%wt of CFF/SD for 180 minutes at 100°C has minimal degradation with 1.9% weight loss of the material. The results imply that the developed composite with 45%wt of CFF/SD shows better thermal stability when exposed to heat at these ranges. It also indicates that the composite has improved fire-resistant properties, which qualifies it for use in situations where thermal stability and fire resistance are essential.

Table 2. Thermogravimetric analysis of developed composite and control samples.

Samples	Temperature °C										
	20	50	100	200	300	400	500	600	700	800	848
S112	100.0	99.8	99.6	98.7	96.3	66.6	24.1	19.6	18.0	16.5	16.0
S312	100.0	100.0	98.8	96.9	83.3	49.3	13.3	11.1	8.1	6.1	4.9
S132	100.0	99.8	99.1	95.5	90.5	61.9	22.0	5.8	4.8	3.9	3.5
S332	100.0	98.5	94.3	94.9	64.5	15.9	4.7	6.1	5.5	3.3	1.6
S121	100.0	99.0	97.4	96.6	90.9	59.1	22.6	10.8	8.7	4.1	2.0
S321	100.0	100.0	99.6	97.3	90.0	14.4	11.6	10.6	10.1	9.5	9.1
S123	100.0	100.0	100.0	97.6	95.7	61.9	14.1	9.9	8.6	7.1	6.6
S323	100.0	99.8	98.7	96.4	93.3	57.2	22.5	21.7	20.4	19.5	18.6
S211	100.0	99.8	98.6	95.7	93.7	56.8	12.1	9.1	7.6	6.4	5.7
S231	100.0	100.0	99.7	98.3	97.6	46.8	17.7	17.2	16.7	16.1	15.8
S213	100.0	100.0	100.0	100.0	99.1	66.1	27.0	18.7	18.2	17.4	16.9
S233	100.0	99.8	98.8	95.0	90.0	29.2	10.1	6.1	4.9	4.3	3.8
S222	100.0	100.0	100.0	99.9	96.5	91.6	87.2	54.1	22.2	18.3	17.5

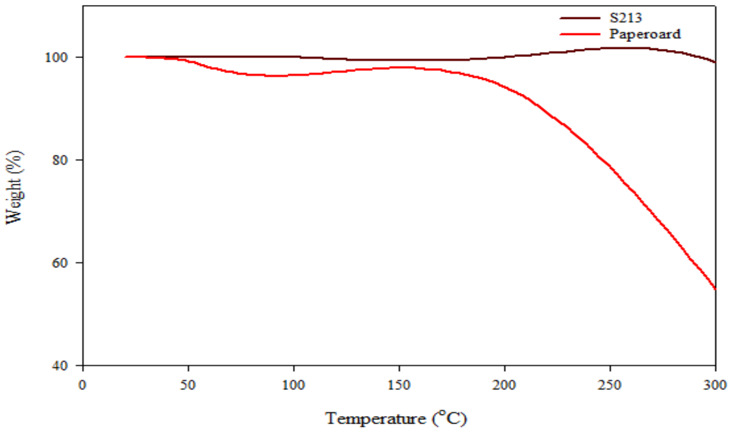

Figure 1. Thermograph of the optimal and minimal sample at the first decomposing stage.

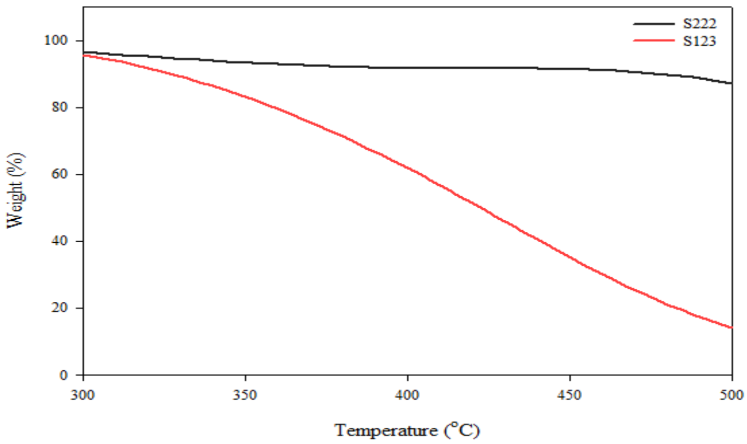

Figure 2. Thermograph of the optimal and minimal sample at the second decomposing stage.

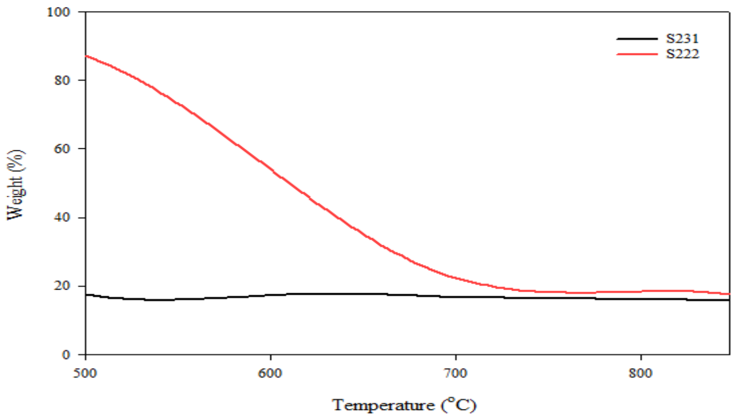

Figure 3. Thermograph of the optimal and minimal sample at the third decomposing stage.

3.2. Energy Dispersive X-ray (EDX)

The EDX analysis reveals the presence of various chemical elements in the optimally developed composite (S113), asbestos, PVC, and paperboard. The X-ray spectrum of the elements displayed during the analysis describes the energy (peak) of emitted X-rays of specific elements and their detected counts at each energy level. These emitted X-rays during the analysis were used to generate a spectrum, displaying the peaks of the corresponding elements. The abundance of the elements in the samples represents the height of the peak. It suggests that the higher the peak element, the more abundant it is in the sample.

Figure 4 shows the energy spectrum of the developed optimal sample S113. The spectrum indicates that carbon exhibits the highest peak among the elements detected, attributed to including calcium carbonate ($CaCO_3$) in the sample during production. The presence of $CaCO_3$ which is widely used in industries, indicates a mineralogical component in the sample. The figure also displays the concentration of copper (Cu), in the form of copper (II) oxide (CuO) as high, an essential element critical for numerous biological processes, which is considered to be safe for the environment [24] Other detected elements like Calcium (Ca) and iron (Fe) are essential elements according to [24] and have relatively lower hazard levels when absorbed by the body.

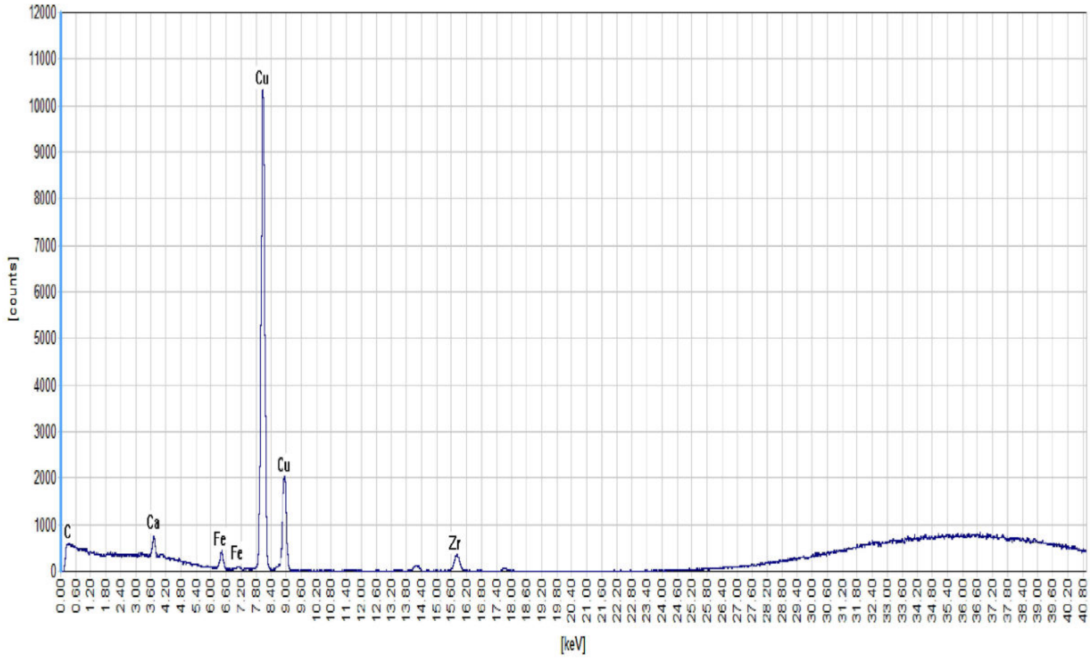

Figure 4. Energy spectrum of the CFF/SD composite sample.

4. CONCLUSIONS

This study investigated the possibility of the use of sawdust (SD) and chicken feather fibre (CFF) composite boards as environmentally friendly substitutes for traditional synthetic materials in construction interior applications. The TGA and EDX analysis of the samples shows that the CFF/SD composite is a suitable environmentally friendly solution due to its excellent thermal stability and non-toxic chemical composition. The minimal weight loss of the composite when subjected to different temperatures shows that the CFF/SD composite has a good heat resistance quality, and the absence of harmful chemical components confirmed its safety for indoor use. These results indicate that waste materials like CFF and SD can be efficiently recycled into low-cost, eco-friendly particle and ceiling boards, supporting sustainable building methods and lowering dependency on dangerous synthetic materials.

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