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Research Article

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Special Issue

A Themed Issue in Honour of Professor Clement Uche Atuanya on His retirement.

This themed issue pays tribute to Professor Clement Uche Atuanya in recognition of his illustrious career in Metallurgical and Materials Engineering as he retires from Nnamdi Azikiwe University, Awka. We celebrate his enduring legacy of dedication to advancing knowledge and his impact on academia and beyond through this collection of writings.

Edited by
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Investigating the thermal properties of *Hyparrhenia Rufa* (giant thatch grass)

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Abstract

Hypearrhenia rufa also called giant thatching grass, is a traditional roofing material made from dry vegetation and has been used for centuries across various cultures and geographical regions. Despite its widespread historical use, there is a notable gap in scientific understanding regarding its thermal properties. This study aims to investigate the thermal properties of *Hypearrhenia rufa*, including its insulation capabilities, thermal conductivity, and resistance to heat transfer. The study involves collecting and preparing samples of giant thatch grass for experimental testing, analyzing the data to determine the factors influencing its thermal performance, and drawing conclusions regarding its suitability for modern insulation. The thermal properties of this plant species were evaluated using differential scanning calorimetry analysis. The results showed that *Hypearrhenia rufa* has a very low thermal conductivity of 0.0462 W/m.k and thermally stable, making it suitable for use in various industrial and agricultural applications. This property is highly desirable in an insulation material as it helps to regulate temperature and reduce energy costs. Also, the plant exhibits high thermal resistance of 5.411 K/W. Furthermore, the thermal behavior of the plant was found to be influenced by its chemical composition, particularly its cellulose and lignin content. The findings of this study provided valuable insights into the potential use of *Hyparrhenia Rufa* as an insulating material in various industries. With its abundance in many African countries, this grass has the potential to be a sustainable and cost-effective solution for insulation purposes. The insights from this research can contribute to the development of more environmentally friendly and efficient insulation materials.

Keywords: Thermal conductivity, Insulator, Thermal resistance, Differential scanning calorimetry

1. Introduction

Hyparrhenia rufa is a species of grass known by the common name giant thatching grass. It is native to Africa and it is widespread in the world as a cultivated forage and fodder for livestock (*Ley de Coss et al., 2021*). It is drought tolerant and withstands dry seasons of several months (*Northern Territory Government, 2013*). A tall, perennial grass, growing between 2 and 3 m tall; and the culms are generally straight and unbranched with diameter ranges between 1.0 and 4.0 mm, averaging at 2.4 mm (± 0.77 mm) (*Strohbach and Walters, 2015*). It is aggressive and has self-seeding ability demonstrated by its capacity to compete with native savanna grasses (*Northern Territory Government, 2013*). Native to Africa, it is widely distributed across the continent, thriving in a variety of habitats ranging from grasslands and savannas. Its widespread use throughout history is attributed to its availability, affordability, and insulating properties.

Giant thatch grass, renowned for its ability to provide natural insulation, keeping interiors cool in hot climates and warm in cold climates. Additionally, giant thatch grass is often favoured for its rustic aesthetic appeal, making it a popular choice for traditional and eco-conscious architectural designs. Despite its historical prevalence, there remains a significant gap in scientific understanding regarding the thermal properties of *hyparrhenia rufa*. While anecdotal evidence and historical records attest to its insulating capabilities, there is a lack of systematic research quantifying its thermal performance *(Ahmad and Ahmad, 2018)*. This knowledge gap presents a barrier to leveraging *hyparrhenia rufa* effectively in contemporary construction practices, particularly in the context of energy efficiency and sustainable building design.

Insulation keeps the home cooler in hot weather and warmer in cold weather. This lessen the burden of heating and cooling appliances that is required to keep the house comfortable; thereby, reduces cost of energy. There are five types of insulators: thermal insulators, acoustic insulators, waterproofing insulators, radiation insulators, and electrical insulators (*Salih, 2021*). Thermal insulators are those materials that prevent or reduce various forms of heat transfer (conduction, convection and radiation) (*Imhade et al., 2022*). Acoustic isolators prevent the permeability of sound and absorb it or try to disperse it (*Salih, 2021*). Waterproofing insulators prevent rain, groundwater and surface water from producing moisture which can damage the elements of construction and release undesired smells with the breeding of insects and mice. Radiation energy is released in the form of electromagnetic waves such as light, UV, infrared, x-ray and gamma, or as small particles such as alpha and beta. Radiation insulators protect humans and facilities from the harmful effects of such radiation emissions. Any substance contains a number of atoms. These atoms have some electrons in the outer orbit called "free electrons". It is such easy to expel the free electrons from the external orbit and make it move to another atom. The flow of electrons from an atom to another is called electrical current. Electrical insulators do not allow flow of electric current through them.

Thermal conductivity is the property of a material to conduct heat. Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. The thermal conductivity of a material varies with the temperature. The reciprocal of thermal conductivity called thermal resistivity. There are a number of ways to measure thermal conductivity of a material using the conductivity meter aperture. The unit of thermal conductivity is (W/m.K). The presence of water or humid air in the insulator reduces the thermal insulation value of the material and it may destruct the material rapidly. The effect of moisture is measured by moisture absorption and permeability.

Glass wool is one of the most common thermal insulators as well as polyurethane, cork, polymers and many other materials. Most thermal insulators are expensive and some are not environmental friendly. The combination of natural fiber composites have shown good thermal insulation property (*Pisello and Rosso, 2015*; *Muthukumar et al., 2019*). *Hyparrhenia Rufa* is not only readily available at little or no cost but it is a natural grass which do not contribute to environmental degradation. This study aims to investigate the thermal properties of *Hypearrhenia rufa,* and its suitability as thermal insulator. Understanding the thermal properties of giant thatch grass is essential for several reasons. Primarily, it enables engineers to design buildings and appliances with optimal thermal performance, balancing comfort and energy efficiency. Moreover, it informs building codes and regulations, ensuring that thatch roofing systems meet modern standards for insulation and fire safety. Furthermore, it contributes to the broader discourse on sustainable insulation materials, highlighting the potential of natural, renewable resources in mitigating environmental impacts *(Kymäläinen et al., 2008).* Ultimately, it is hoped that this research will contribute to the advancement of sustainable building practices and the preservation of cultural heritage associated with thatch roofing. *(Ziegler and Altstädt, 2020).*

2.0 Material and methods

2.1 Sample Collection and Preparation

A systematic approach was employed to collect giant thatching grass samples from its natural habitat as shown in plate 1. Sampling site was selected to ensure a representative variety of grass specimens. Samples was collected during the appropriate season to account for any seasonal variations in grass composition.

Upon collection, the grass samples was carefully cleaned to remove any dirt, debris, or contaminants. Following cleaning, the samples was air-dried to remove excess moisture while avoiding exposure to high temperatures that could alter the grass's natural properties (see plate 2). Once dried, the samples was cut into standardized dimensions to ensure consistency across all experimental specimens.

Plate 1: Giant thatching grass

Plate 2: Samples prepared for testing

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2.2 Thermal Conductivity Measurement

The differential scanning calorimetry analysis of the giant thatch grass was carried out using TA Instruments DSC 2920 with controller thermal analyst 2000, at 10°C/min constant heating rate following the ASTM E1269-18 (2018) standard procedure. This was aimed at determining the thermal conductivity.

2.3 Optical Microscopic Analysis

Microscopic analysis was conducted to examine the cellular structure and fiber morphology of African thatching grass. Thin sections of the grass samples was prepared and observed under an electron microscope. Images were captured at varying magnifications of 50, 100 and 200 to visualize the arrangement of cells, distribution of lignin, and orientation of fibers within the grass tissue. This structural characteristics were correlated with the thermal conductivity and moisture absorption properties of the grass samples.

2.4 Moisture Content Analysis

A petri-dish was washed and dried in the oven. Approximately 2 g of the sample was weighed on electronic weighing balance and carefully drop into the petri-dish. The weight of the petri-dish and sample was noted before drying. The petri-dish and sample were put in the oven and heated at 105°C for 2 hours, the result was noted and it was heated for another 1 hour until a steady result is obtained and the weight was noted. The drying procedure was continued until a constant weight was obtained.

$$\%\, Moisture\ content = \frac{W_1 - W_2}{weight\ of\ sample} \times 100 \tag{1}$$

Where W_1= initial weight of petri-dish and sample and W_2 = weight of petri-dish and sample after drying.

2.5 Elemental Characterization

The elemental compositions of both wet and dry samples were determined. Heavy metal analysis was conducted using Agilent FS240AA Atomic Absorption Spectrometer according to the method of APHA 1995 (American Public Health Association). Atomic absorption spectrometer's working principle is based on the sample being aspirated into the flame and atomized when the AAS's light beam is directed through the flame into the monochromator, and onto the detector that measures the amount of light absorbed by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiation interferences.

3.0 Results and Discussions

Thermal conductivity measurement for Hyparrhenia rufa was conducted using a Differential Scanning Calorimeter (DSC). Sample was prepared as per the standardized dimensions and conditioned to a consistent moisture content. The determined thermal properties are presented in table 1.

Table 1: Result of thermal conductivity measurement

Sample ID	Thermal Conductivity	Thermal Resistance
Hyparrhenia rufa	0.0462 W/m.k	5.411 K/W

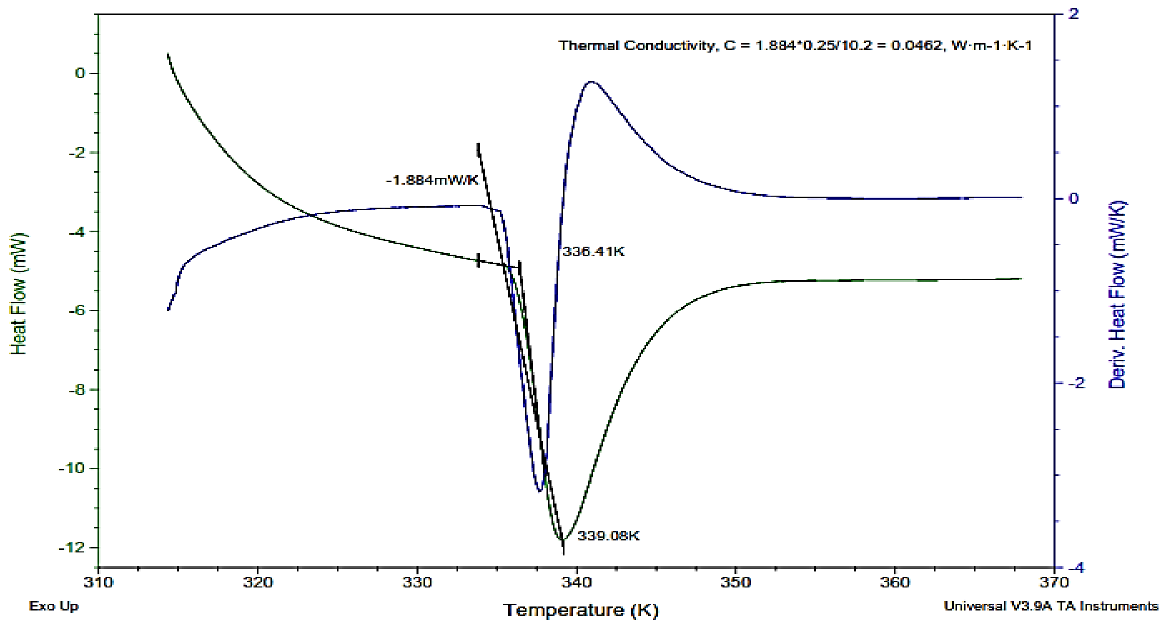

Figure 1: Differential scanning calorimetry analysis of giant thatching grass

The differential scanning calorimetry plot of the sample of giant thatching grass is shown in figure 1. The green curve represented the differential scanning calorimetry plot while its derivative is represented with the blue curve. The sample was heated from ambient temperature of 300.15 K to 370 K. The initial mass of the test sample was 7.20 mg. The thermal conductivity, *C* was evaluated from the slope of differential scanning calorimetry curve at thermal conductance of 1.884 mW/K as:

$$C = Thermal\ conductance \times slope \qquad (2)$$

The result indicate that giant thatch grass has low thermal conductivity, making it a suitable material for thermal insulation. The value of thermal conductivity of giant thatch grass is within the range of thermal conductivities of widely used insulating materials in engineering application as can be seen from table 2. In fact, its thermal conductivity indicated that it is a very good insulator. The thermal resistance of the sample was extrapolated from thermal conductivity result using equation 3.

$$R = \frac{L}{K} \qquad (3)$$

Where L = thickness of the sample = 0.25 mm and K = thermal conductivity = 0.0462 W/mK
The thermal resistance of giant thatch grass is 5.411 K/W. The result indicate that giant thatch grass has a high thermal resistance and as such is a very good insulator. The sample will not allow conductive heat mode to pass through it easily.

Table 2: Comparison of the thermal conductivity of giant thatching grass and other insulators

Material	Thermal Conductivity (W/m.k)
Polystyrene Foam	0.033 - 0.037
Fiberglass	0.035 - 0.045
Hemp Fibers	0.040 - 0.045
Flax Fibers	0.038 - 0.042
Asbestos	0.12
Asphalt	0.69
Acrylic	0.2
Rubber	0.35
Wool	0.05

Wood	0.15
Cork	0.05
Cotton	0.04
Perlite	0.05
Hyparrhenia rufa (giant thatch grass)	0.0462

Table 3: Moisture content analysis for dry and wet samples

Sample	Wt of dish	Wt of sample	Wt of dish + sample before drying	Wt of dish +sample after drying	% moisture
Wet	2.004	30.594	32.598	31.278	65.868
Dry	1.009	33.938	34.947	34.851	9.514

Table 3 presented the moisture contents of both wet and dried samples of giant thatch grass. The moisture contents of both wet and dried samples of giant thatch grass were evaluated using equation 1 as 65.87 % and 9.51 % respectively. This indicates that when giant thatch grass is wet, it absorbs some moisture. Its moisture absorption rate is moderate when dry and similar or even better to other natural fibers, suggesting it maintains reasonable thermal efficiency even in humid conditions.

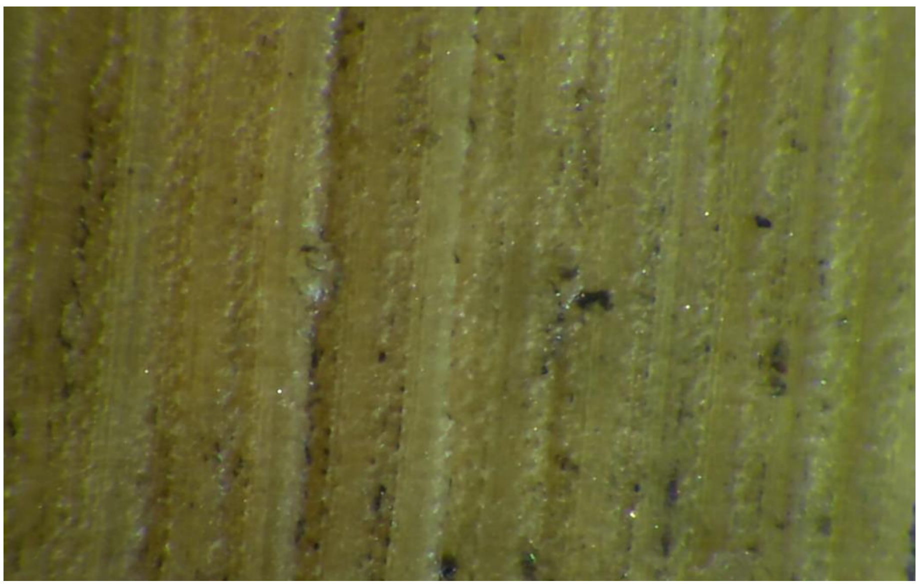

Figure 2: Micrograph of giant thatch grass @ 200 magnification

Microscopic analysis was performed using an electron microscope to examine the fiber structure of giant thatch grass. The micrograph of giant thatch grass with a magnification of times two hundred is shown in figure 2. The images revealed a dense network of interwoven fibers, high cellulose content with visible lignin and small air pockets within the fiber matrix. The dense and interwoven structure, along with the presence of air pockets, contributes to the low thermal conductivity of giant thatch grass. The high cellulose and lignin content enhance the material's structural integrity, which is crucial for maintaining its insulating properties over time.

Elemental characterization was done on the wet and dry samples to determine their elemental composition. The results are summarized in the table 4.

Table 4: Results for elemental characterization of giant thatching grass

Parameters ppm	Wet	Dry
Aluminum	0.186	0.989
Potassium	8.299	7.899
Calcium	4.893	6.078
Mercury	0.022	0.003
Cadmium	0.014	0.010
Zinc	3.267	4.167

Iron	5.567	3.378
Sulphur	6.978	8.277
Phosphorus	13.899	18.267
Manganese	2.899	5.899
Carbon %	4.898	8.922
Silicon	3.289	6.089
Sodium	8.337	5.988
Magnesium	1.677	3.788

Phosphorus is the most prominent in both samples with 13.899 ppm and 18.267 ppm for wet and dried samples respectively. Though phosphorous is very reactive, its half-filled electrons in 2p orbital are very stability making it to have free electrons. Phosphorus is a nonmetal, solid at room temperature, and a poor conductor of heat and electricity. Also, sulphur with 6.978 ppm and 8.277 ppm for wet and dried samples respectively is a nonmetal and poor conductors of heat and electricity. The valence electrons of carbon are tightly bonded; hence, carbon is a good thermal insulator. Silicon has a low thermal conductivity. This means it transfers heat at a much slower rate than some other materials, leading to excellent heat resistance. When calcium exists in the form of calcium silicate, it serves as a good thermal insulator that could be used for various industrial purposes. Thus most of elements that made up *Hyparrhenia rufa* contributed to its thermal insulating property.

4.0. Conclusion

This research aimed to investigate the thermal properties of *Hyparrhenia rufa* and assess its suitability as an insulation material. The key findings from the study are as follows:

- *Hyparrhenia rufa* exhibited an average thermal conductivity of 0.0462 W/m·K, indicating its effectiveness in reducing heat transfer and making it a viable insulation material.
- *Hyparrhenia rufa's* thermal properties are comparable to other natural fibers like hemp, wood, cork, and flax, and it competes well with synthetic insulators such as polystyrene foam, especially considering its environmental friendliness.
- The material demonstrated a moderate moisture absorption rate of 65.86 and 9.514%. While this result showed an increase in thermal conductivity under wet condition, it remains within acceptable limits for insulation materials.
- Microscopic analysis revealed a dense network of interwoven fibers and a high cellulose content, contributing to the material's low thermal conductivity and structural integrity.
- Elemental analysis showed that *Hyparrhenia rufa* is primarily composed of phosphorous, sulphur, carbon and trace elements such as silicon, potassium, and calcium. These components support its insulating properties and thermal stability.

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