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The Use of Cow Hair as an Eco-Friendly Reinforcement Material for Ceiling Tiles

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K E Y W O R D S

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Gypsum

A B S T R A C T

This study explores using cow hair as a sustainable reinforcement in ceiling tiles by analysing its properties and integrating it into cement, kaolin, calcium carbonate, starch, and gypsum matrices. Three formulations were created: Sample A (cow hair cementitious tile), Sample B (Gypsum tiles reinforced with cow hair), and Sample C (gypsum with fillers as the control). All samples underwent water absorption, flexural strength, and friability tests per ASTM standards for interior ceilings.

Results showed all samples absorbed less than 35%, with Sample A performing best at 27.69%. Friability was under 7%, with Sample A again best at 3.97%. Flexural tests indicated that Sample A had the highest strength (2.50 Mpa) and ductility (9 mm), while Sample B had the lowest (1.58Mpa, 4mm), indicating higher stiffness but lower toughness. Sample C showed moderate results.

Regression analysis confirmed elastic load as the main factor influencing deflection (R^2= 99.83%), but limited sample size means further testing is needed.

Overall, cow hair shows promise as reinforcement, especially in moisture-prone indoor environments.

19. INTRODUCTION

The utilization of agricultural residues, such as straw and husks, along with other renewable and sustainable biomass for eco-friendly construction, is increasing significantly. This innovation aims to minimize environmental impact by replacing conventional building materials with greener alternatives, thus promoting sustainability in construction and resource management (Anjum et al., 2021; Desmond *et al.*, 2022). This shift has led researchers to explore natural fibers as sustainable options for reinforcing construction materials. For many years, natural fibers have been valuable in construction, providing strength, durability, and sustainability. Among these, animal hair has gained attention for its ability to enhance the mechanical properties of building materials, such as ceiling tiles (Aravind & Kamaraj, 2023). A key component of these fibers is keratin, a protein found in biological materials like sinews, spider silk, catgut, and human or cow hair (Alli et al., 2021). Notably, hair fibers possess high strength and a significant modulus of elasticity, making them valuable for reinforcement applications (Murillo et al, 2024).

Historically, the use of animal hair in construction dates back centuries. For instance, horsehair was traditionally incorporated into lime plaster to improve tensile strength and reduce cracking (Bansal et al., 2017). This practice took advantage of the natural availability of animal fibers to effectively improve building materials (Murillo et al, 2024).

In the ongoing pursuit of sustainable and cost-effective engineering materials, researchers worldwide have been exploring renewable resources with promising physical and mechanical properties (Ohijeagbon et al., 2021). Historically, asbestos fibers was widely used in civil engineering for producing building components such as ceiling tiles and corrugated roofing sheets due to its desirable mechanical qualities (Murillo et al, 2024). However, with the discovery of its carcinogenic health risks, the demand for safer and more sustainable alternatives has grown significantly (Murillo et al, 2024).

Research by Statnik et al. explored the integration of human hair into elastomer matrix composites, demonstrating that its incorporation improved mechanical strength and flexibility, both essential for durable building materials (Statnik et al, 2023). As a renewable and biodegradable resource often regarded as waste, animal hair presents an eco-friendly solution that minimizes environmental impact. Studies indicate that its inclusion in construction materials enhances tensile strength and flexibility, reducing brittleness and mitigating the risk of cracking in composite structures (Statnik et al, 2023).

Certain animal fibers possess inherent thermal and acoustic insulating properties, contributing to improved energy efficiency and sound management in buildings (Chin, 2020). Ceiling tiles are widely used in building construction, particularly in commercial spaces, due to their aesthetic and functional benefits (Murillo et al, 2024). They contribute to noise reduction, thermal insulation, and fire resistance, making them an essential architectural component. Additionally, research has shown that ceiling tiles and gypsum boards can absorb or diffuse formaldehyde in indoor environments, helping to improve air quality (Danish & Ozbakkaloglu, 2023). However, despite these advantages, conventional ceiling tiles often suffer from certain limitations, including brittleness, susceptibility to cracking, and environmental concerns related to their production and disposal.

One significant drawback is their tendency to become brittle over time, leading to increased fragility and reduced durability (Nugraha et al., 2022). This can result in structural weaknesses, requiring frequent maintenance or replacement. Moreover, the environmental impact of manufacturing conventional ceiling tiles, particularly those made with synthetic binders, poses sustainability challenges.

To address these issues, researchers have explored the use of animal hair as a reinforcement material in ceiling tiles. Animal hair fibers, such as human hair and sheep wool, offer excellent mechanical properties, including high tensile strength and elasticity, which can enhance the durability and flexibility of ceiling tiles (Chen & Patel 2022). By incorporating these fibres, the risk of brittleness and cracking can be minimized, improving the longevity of the material. Furthermore, animal hair naturally exhibits thermal and acoustic insulating properties, contributing to better indoor temperature regulation and noise control (Mohammed et al., 2024).

In the search for sustainable building solutions, researchers have discovered an innovative approach: using cow fur and dog hair fibres as high-performance insulation materials (Mohammed et al., 2024). Cow fur, which is naturally shed and plentiful, provides an eco-friendly option for thermal and acoustic insulation, serving as a renewable resource that reduces waste while improving energy efficiency.

20. MATERIALS AND METHODS

2.1 Research Design

Figure 1.1 Cow hair

The study follows an experimental and comparative research design. Three distinct categories of ceiling tile samples were developed:

a. Cementitious cow hair-based tile model: Composite tiles in which cow hair was used as the sole reinforcement, combined with inorganic fillers (calcium carbonate, kaolin), starch, cement, and water.
b. Modified gypsum ceiling tiles reinforced with cow hair: Hybrid composite tiles in which cow hair is integrated with conventional Plaster of Paris (POP) to enhance reinforcement.
c. Control sample: Standard POP ceiling tiles prepared using traditional methods.

Each sample was tested for strength, heat resistance, sound absorption, durability, and environmental impact. This helps compare cow hair–reinforced composites with traditional materials (Alomaja et al., 2021; Saleh et al., 2023).

2.2 Materials and Sample Preparation

- Cow Hair Collection and Pre-Treatment

Cow hair was collected from farms and abattoirs in Lagos, cleaned with water and detergent, and then treated with NaOH to improve bonding (Oladele et al, 2015; Agbeboh, 2018; Hilal et al., 2025). After rinsing and drying, it was used with locally sourced cement, water, and cellophane sheets. Casting was done using wooden moulds and lab equipment including a tensile machine from WINCOM Company Limited, China.

- Raw Materials for Composite Formation

Figure 2.1 Collected and treated cow hair

Other essential materials include:

a. **Plaster of Paris (POP – 65%):** Used for the control samples and as part of the modified gypsum ceiling tiles reinforced with cow hair composite.
b. **Calcium Carbonate** ($CaCO_3 - 20\%$) **and Kaolin (10%):** Provide filler and improve the composite's stiffness.
c. **Starch (10%) and Cement (25%):** Used as binding agents.
d. **Water (20%):** Acts as a solvent and an activator for the cementitious reactions

Before fabrication, the physical and chemical properties of these materials are verified to ensure consistency and conformity to industry standards.

- Ceiling Tile Fabrication

Cow hair fibres were trimmed to $30 - 40$mm for even mixing and weighed with cement based on the mix design (Rahmanzadeh et al, 2018). Materials were blended manually using a 0.5 water–cement ratio, then poured into wooden moulds ($300 \times 150 \times 6$mm). After vibration to remove air, samples were compressed for four hours, cured by wetting for 24 hours, and then air-cured for 28days at 22 ± 2^0C before testing.

2.2.1 Cementitious Cow Hair-Based Tile Model

In this model, the composite mixture comprises treated cow hair, ($CaCO_3$), Kaolin, starch, cement, and water (Figure 3.2). The fibres are first uniformly distributed in the dry aggregates using mechanical stirring. The binder (cement and starch) is then added, followed by water to achieve a homogeneous mix. The composite is poured into standardized moulds and compacted to minimize voids. After casting, the samples are cured under controlled ambient conditions (typically at 25°C and 60% relative humidity) for 28 days to ensure full strength development (Alomaja et al., 2021).

2.2.2 Modified gypsum ceiling tiles reinforced with cow hair

For the partial replacement samples, treated cow hair is incorporated as an additive into a conventional POP mixture (Figure 3.3). The cow hair is blended with the POP using a mechanical mixer to ensure uniform dispersion. The ratio of cow hair to POP is optimised based on preliminary trials to balance the mechanical and workability properties of the composite.

Figure 2.2 Sample A - Cement based composition

2.2.3 Control sample

Figure 2.3 Sample B – Gypsum tiles reinforced with cow hair composition

Conventional POP ceiling tiles are fabricated using established procedures. These serve as a reference point to evaluate the enhancements provided by cow hair reinforcement (Figure 2.4).

Figure 2.4 Sample C - Gypsum with fillers composition - Control sample

2.3 Performance Evaluation

Mechanical Testing

Mechanical properties were assessed using a Universal Testing Machine (UTM). The following tests is conducted:

i. **Flexural Strength Test:** Using ASTM D790 procedures to measure the material's resistance to bending forces.
ii. Friability Test: Using **ASTM C421** procedures to evaluate the material's tendency to crumble or flake under mechanical stress. Each test is repeated three times for statistical reliability (Agbeboh, 2018).

- Durability Tests

Durability is further assessed through **water Absorption Test** measured by immersing samples in water for fixed intervals and weighed to determine moisture uptake. (Hassanpour & Karbhari, 2024).

2.4 Data Analysis

Collected data from mechanical, thermal, acoustic, and durability tests are statistically analyzed using SPSS software. Methods include:

i. **Analysis of Variance (ANOVA):** To compare performance differences among the three groups (Cementitious cow hair-based tile, modified gypsum ceiling tiles reinforced with cow hair, and control).
ii. **Regression Analysis:** To assess correlations between the percentage of cow hair used and the performance metrics.

2.5 Ethical Considerations and Limitations

Ethical considerations in this study are minimal since the research is laboratory-based. However, responsible sourcing of cow hair, utilizing an agricultural waste product and ensuring eco-friendly disposal of waste materials are prioritized. The study acknowledges limitations such as natural variability in cow hair properties and laboratory conditions that might not perfectly simulate real-world environments (Figure 2.5).

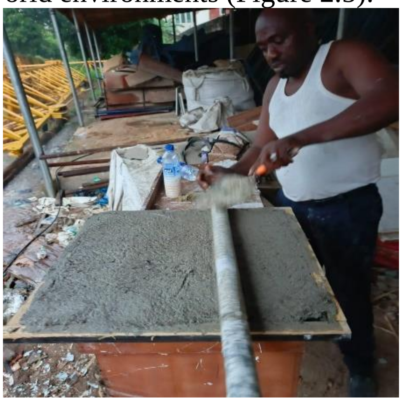

Figure 2.5 Casting and vibration process

2.6 Summary

This methodology chapter outlines the experimental design, sample preparation, fabrication methods, and performance evaluation techniques employed to assess cow hair-reinforced ceiling tiles. By integrating mechanical, thermal, acoustic, durability, and sustainability analyses, the study aims to provide robust evidence on the advantages and potential challenges of adopting cow hair as a sustainable reinforcement material in construction

2. RESULTS AND DISCUSSION

3.1 Flexural Strength Test

Figure 2.6 Ceiling tile fabrication samples

The laboratory test was performed to assess how much stress the materials can withstand before breaking under a bending load. During the test, each sample was subjected to a gradually increasing bending force until failure. The ***elastic load*** refers to the maximum force the material could withstand while still returning to its original shape; this is the point just before permanent deformation begins. The ***plastic load*** represents the force at which the material begins to deform permanently, indicating the onset of structural failure. The ceiling tile samples showed different mechanical performances based on their composition. Sample A, made with cement, kaolin, starch, cow hair, and $CaCO_3$, had the best results, high flexibility and strength with a 9mm deflection and load limits of 60N (elastic) and 75N (plastic). Sample B, modified gypsum ceiling tiles reinforced with cow hair, had the weakest performance with a 4mm deflection and load limits of 38N (elastic) and 44N (plastic). Sample C, composed solely of POP and fillers, exhibited moderate strength and stiffness with a 6mm deflection and load limits of 46N (elastic) and 53N (plastic). These results support earlier findings that natural fibres improve bonding and crack resistance (Ashori and Nourbakhsh, 2010; Oyekan and Kamiyo, 2011; Sathishkumar et al, 2014). Sample A meets the ASTM C208 and BS EN 13964 standards for non-structural ceiling panels, while Sample B provides a lightweight and eco-friendly alternative. Although its mechanical strength is lower, it still meets the basic durability standards for interior ceiling applications.

Table 3.1 Result for flexural strength test

SAMPLES	PRODUCTION COMPOSITION	DEFLECTION (mm)	ELASTIC STATE (N)	PLASTIC STATE (N)	FLEXURAL STRENGTH (MPA)
A Cow hair cementitious tile	Cement (25%) Kaolin(10%) Water (15%) Starch (10%) Cow hair (20%) $CaCO_3$(20%)	9	60	75	2.50
B Gypsum tiles reinforced with cow hair	Plaster of Paris (65%) Cow Hair (15%) Water (20%)	4	38	44	1.58

C Gypsum with fillers Control	Plaster of Paris (65%) Fillers (15%) Water (20%)	6	46	53	1.91

3.2 Water Absorption Test

Water absorption is key to assessing the durability of ceiling tile composites. Excess moisture can weaken materials and cause long-term damage (Shen & Springer, 1976; Khaled, 2015). Based on Table 4.2, the absorption rates were:

Table 3.2 Result for water absorption test

	Sample A	**Sample B**	**Sample C**
Measured Dry Weight (kg)	3.25	2.5	2.63
Measured Wet Weight (kg)	4.15	3.7	3.52
Percentage of Water Absorption Ratio (%)	27.69	28	30

Sample A had the lowest absorption; this is due to dense cement matrix and cow hair reinforcement, which likely reduced porosity and blocked capillary pathways. Sample B showed slightly higher absorption, possibly due to uneven fibre dispersion. Sample C, with no reinforcement, absorbed the most water due to POP's natural porosity.

All samples stayed below the ASTM C208 threshold of 35%, making them suitable for indoor use. These results echo prior studies (Akinyemi & Salami, 2015; Oyenuga et al., 2020), which found that fibre type and matrix density significantly influence water resistance. Overall, cow hair in a cementitious matrix enhances moisture durability and supports long-term structural integrity.
In summary, the incorporation of cow hair, particularly in a cementitious matrix, can reduce water absorption and improve the moisture resistance of ceiling tiles. While the differences between samples may appear small, even slight increases in water uptake can impact long-term performance, especially in terms of strength, stiffness, and dimensional stability.

3.3 Friability

Friability refers to how easily a material breaks or sheds particles under stress, like handling or vibration. For ceiling tiles, high friability can lead to wear and dust, reducing durability. This study measured friability using ASTM C421, the standard method for testing insulation materials.

Table 3.3: Friability Result for the Sample Compositions

Samples	**Initial Weight (g)**	**Finish Weight (g)**	**Difference (g)**	**Friability (%)**
A	126	121	5	3.97
B	102	96	6	5.88
C	110	104	6	5.45

Three ceiling tile samples were tested for friability (tendency to crumble under stress) to assess fire resistance. Sample A (Cementitious cow hair-based tile) showed the lowest friability at 3.97%, which means it had the best resistance to surface wear and material loss. The cow hair fibres probably helped improve the tile's strength by bridging cracks and strengthening internal cohesion, while the cement matrix offered a solid supporting structure. Sample B (Modified gypsum ceiling tiles reinforced with cow hair) had the highest friability at 5.88%, indicating it was more prone to breaking under mechanical stress. Even with cow hair, the lack of cement and other binding agents might have weakened its overall structure, making it more prone to crumbling. Sample C (Control) recorded a friability of 5.45%, just slightly better than Sample B. This shows that while POP alone provides some mechanical stability, without reinforcing fibres like cow hair, its abrasion resistance can be limited. The addition of filler in Sample C may have helped improve its friability performance just a bit. The differences in friability, ranging from 3.97% to 5.88%, highlight that cow hair reinforcement, especially when paired with a cement-based matrix, can really boost the durability of ceiling tiles. Overall, the results indicate that cow hair is quite effective in both cementitious and gypsum systems, helping to improve friability without harming the material's overall strength. Their keratin content chars under heat, which may delay flame spread. Compared to other studies like Okeniyi et al. (2019) on rice husk ash boards with $9 - 10\%$ friability, cow hair composites performed better.

The study concludes that cow hair is a viable, eco-friendly reinforcement for ceiling tiles, offering decent fire resistance and promoting sustainability by repurposing waste materials. Standards like ASTM C423 and ISO 1182 support low weight loss and minimal flaming, aligning with the results here.

3.4 Statistical Analysis (Correlation and Regression Using Minitab)

The regression analysis was conducted (Table 3.4) to examine the relationship between deflection and two predictor variables: elastic load and plastic load. The resulting model yielded a very high coefficient of determination ($R^2 = 99.83\%$), indicating that the two predictors explin 99.83% of the variability in defection. This suggests a strong linear relationship between applied loads and deflection behaviour in the tested ceiling tile samples (Figure 3.1).

Table 3.4: Analysis of Variance conducted on Samples A, B & C

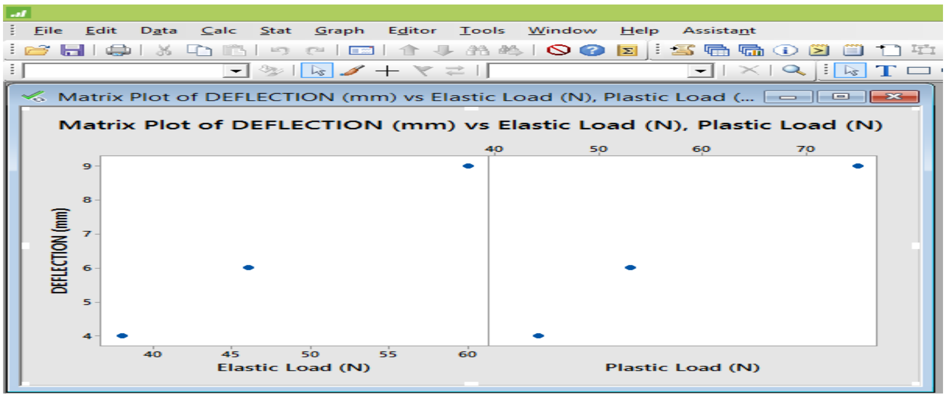

Figure 3.1: Matrix plot of Deflection against Elastic and Plastic Load

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	12.6452	12.6452	588.00	0.026
Elastic Load (N)	1	12.6452	12.6452	588.00	0.026
Error	1	0.0215	0.0215		
Total	2	12.6667			

Model Summary

S	R-sq	R-sq(Adj)	R-sq(Pred)
0.146647	99.83%	99.66%	97.12%

The relationship between deflection and the applied loads was analyzed using multiple linear regression.

The regression equation derived from the analysis is:

$$\text{Deflection (mm)} = -5.4 + 0.34\ (\text{Elastic Load}) - 0.08\ (\text{Plastic Load}) \ldots \quad (1)$$

The regression model shows that the elastic load noticeably increases deflection by about 0.34mm per unit, which aligns with physical expectations. On the other hand, plastic load causes a small reduction in deflection by roughly 0.08mm per unit, but its impact seems a bit weaker. The model's negative constant (-5.4) adjusts the baseline but lacks clear physical meaning due to limited data.

Statistically, the model appears sound $(p = 0.026)$ and highly predictive; it is important to acknowledge a critical limitation: the regression was performed on only three data points (Samples A, B, and C), as indicated by the Degrees of Freedom $(DF = 2)$. This extremely small sample size significantly impacts the reliability and generalizability of the model. **The elastic load** was found to be a statistically significant predictor $(p < 0.05)$, confirming its strong and consistent influence on deflection. **Plastic load,** however, had a borderline $p-$value (0.052), suggesting its effect may be uncertain and potentially influenced by sample variability or structural stiffening.

Overall, the regression model supports the conclusion that elastic load is a key driver of deflection in the tested ceiling tile composites, while the role of plastic load remains less certain. The high R^2 value may reflect overfitting rather than a robust predictive model. To validate the regression and confirm the role of plastic load, a substantially larger dataset is required.

Elastic load is the dominant factor affecting deflection in cow hair-reinforced ceiling tiles. It shows a strong, positive influence with a statistically significant p-value, meaning it reliably predicts bending under service-level stress. Plastic load, on the other hand, has a weaker and slightly negative effect, possibly due to structural stiffening or dataset limitations.

Structurally, elastic load reflects reversible deformation, while plastic load signals permanent change. Since ceiling tiles are typically evaluated under everyday conditions, elastic load is more relevant.

The regression model is statistically sound $(p = 0.026)$ and highly predictive $(R^2 = 99.83\%)$, confirming that both load types together offer a solid framework for understanding deflection, although elastic load clearly leads the way.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The study evaluated cow hair-reinforced ceiling tiles across multiple metrics and found promising results for indoor use:

i. **Water Absorption:** All samples were below the 35% threshold. Sample A had the lowest absorption (27.69%), showing strong moisture resistance due to its dense matrix. POP-based samples absorbed slightly more, with Sample B peaking at 30%.

ii. **Friability:** All samples showed friability below 7%, suitable for indoor fire safety. Sample A had the lowest (3.97%), while Sample B had the highest (5.88%). Cow hair performs effectively in both cementitious and gypsum-based systems, contributing to improved friability without compromising the materials' integrity.

iii. **Flexural Strength:** Sample A showed the strongest performance with a flexural strength of (75N) and the greatest ductility with a 9mm deflection, making it the most mechanically resilient. Sample C had a moderate strength of (53N) and a 6mm deflection, whereas Sample B exhibited the lowest strength at (44N) and a 4mm deflection. This may reflect weaker bonding or less effective reinforcement, possibly due to the gypsum-based matrix. However, reduced deflection alone does not confirm crack resistance, and further testing is needed to assess its toughness and failure behaviour.

iv. **Statistical analysis:** The **elastic load** represents reversible deformation and is more relevant for evaluating ceiling tiles under everyday service conditions. **Plastic load** reflects permanent change and may be influenced by material composition or reinforcement effects. The regression model provides initial insight into the deflection behaviour of cow hair-reinforced ceiling tiles, highlighting elastic load as the dominant factor. However, due to the extremely limited sample size tested, further investigation with a broader dataset is essential to confirm these trends and refine the model's predictive power.

The results of this research work established the potential utilisation of cow hair and cementitious filler materials, such as $CaCO_3$ and Kaolin, in the production of high-strength ceiling tiles.

4.2 Recommendation

Cow hair-reinforced ceiling tiles, especially those made with cement and kaolin, are best suited for low-heat, moisture-prone indoor environments due to their superior water resistance. All tested samples meet ASTM standards for internal ceiling use. Cow hair offers a sustainable reinforcement option without major compromises in fire safety. While POP-only tiles may have slightly better stability, cement-based samples with cow hair deliver stronger mechanical performance.

i Sample A**:** Ideal for high-load areas due to its strength and durability.

ii Sample B: Recommended for lightweight, eco-friendly applications with lower structural demands.

From a design perspective, elastic load is the key driver of deflection**,** making it crucial in structural planning. Plastic load may still play a role, but its influence is less certain and needs further investigation.

NOMENCLATURE

Mpa	Mega Pascal (N/mm^2)
R^2	R-squared (coefficient of determination)
mm	millimetre
N	Newton
kg	Kilogram
%	Percentage
g	gram

Greek Symbols

δ	Delta, deflection (mm)

Subscripts

Avg	Average
max	Maximum
min	Minimum
ref	Reference

Superscripts

*	Corresponding author

Abbreviations

POP	Plaster of Paris
NaOH	Sodium Hydroxide
CaCO3	Calcium Carbonate
UTM	Universal Testing Machine
ANOVA	Analysis of Variance
ASTM	American Society of Testing and Materials
ISO	International Organization for Standardization

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