Valorization of Jute Powder in Mortars: Homogeneity and Mechanical Performance

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Jute fiber powder (0.25% to 2% of cement weight, with a 0.25% increment) was evaluated for reinforcing cement mortars. The addition of jute powder maintains a constant flow diameter of 180 mm, ensuring good workability and homogeneity. This behavior was attributed to the fine particle size and low dosage of the jute powder, which limited its effect on water demand and rheological behavior of the mortar, despite a slight setting delay proportional to the dosage. The low dosage of the jute powder limited its effect on water demand and rheological behavior of the mortar. The incorporation of fibers enhanced internal heat retention, with the material temperature increasing from 44.5 to 45.8 °C as fiber content increased. Although capillary water absorption slightly increased (up to 6.47%), the mortars maintained good compactness and remained within R1 to R3 classes according to NF EN 998-1 (2016). In the hardened state, jute powder improved tensile strength at an optimal dosage of 0.5%, while a progressive decrease in compressive strength was observed, related to changes in the cementitious microstructure. The dosage of 0.5% appeared to be optimal, offering a good balance between mechanical and thermal performance while preserving workability and durability.

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INTRODUCTION

Rapid urbanization in developing regions represents a major challenge for access to affordable housing. A systematic review, conducted in accordance with the Prisma 2020 guidelines, analyzed 91 studies (2013 to 2024) from Scopus and Google Scholar to identify cost-effective materials and innovative techniques adapted to the context of developing countries (Muhammed 2025). Although housing needs continue to rise rapidly, the elevated cost of building still limits access to affordable homes for much of the population. As a result, the construction industry is facing a difficult dilemma, having to balance conflicting pressures. On the one hand, global urbanization requires an immediate response from the sector to meet the considerable needs of a continuously growing population; on the other hand, concerns related to climate change and the depletion of fossil resources are exerting significant pressure on construction stakeholders. Faced with the immense sustainability challenges confronting cities, it is essential to promote adequate, safe, and affordable housing and to upgrade slums and informal settlements in order to build inclusive, resilient, and sustainable cities (United Nations 2017). In developing regions, low-income households struggle to access housing (Nzau and Trillo 2020) due to weak urban policies and planning, insufficient subsidies, and rapid urban migration (Uddin 2018; Satoto 2023). Research in urban planning, public health, economics, and housing policy indicates that construction costs are the primary obstacle to affordable housing in developing countries (Ahsan 2019). Materials and labor account for 60% to 80% of total housing costs, making cost-effective solutions essential to improve affordability (Montfort *et al.* 2023). The sector must therefore transition toward sustainable and green construction practices to improve its environmental performance (Matthieu 2022).

The thermal and hygric characterization of bio-based materials, particularly those derived from plant resources, offers promising prospects for building envelopes in tropical climates. The main advantages of natural fibers lie in their renewable nature, availability, reasonable cost, and lower environmental impact (Ardanuy 2015). These emerging materials could provide sustainable alternatives by mitigating the adverse effects of certain environmental phenomena on a global scale. These issues, environmental, economic, societal, and social represent a major challenge in humid tropical climates, exacerbated by the increasing energy demand for air conditioning and ventilation systems, which are essential for occupant comfort. Thermal insulation of building envelopes using appropriate bio-based materials derived from vegetation, without prior chemical binders, could contribute to addressing environmental degradation caused by greenhouse gas emissions and improving thermal comfort for occupants (Pierre 2020).

In West African countries, particularly in Benin, jute bags are used to transport agricultural products such as onions, cereals, and others. After use, these jute bags can be collected and then shredded for reuse in construction materials. This research explores the influence of jute powder on the mechanical characteristics of cement mortars, with the objective of promoting plant waste recovery and lowering cement usage without plasticizing admixtures.

EXPERIMENTAL

Jute fibers (1.0 to 4 m length, and 17 to 20 µm diameter) are lignocellulosic materials mainly composed of cellulose and lignin. In this study, uncontaminated used jute bags were obtained at low price from suppliers at Dantokpa market (Benin). The bags were immersed in potable water for 24 h, manually washed without detergent, and air-dried. Following manual defibrillation using a fine pointed tool, the fibers were ground using a Kader mill (10,000 W; 50/60 Hz; 200–240 V). To comply with NF 11-630 (2001) defining powders as particles under 1.0 mm, the material was sieved through a 1 mm mesh. Finally, the obtained powder was rinsed with demineralized water to eliminate remaining impurities and air-dried under controlled conditions to prevent contamination. Addressing the recurring issue of fiber dispersion in the literature, this study proposes converting jute fibers into powder to ensure mixture homogeneity without chemical admixtures. While traditional fiber lengths typically range from 5 to 50 mm, this approach avoids superplasticizers by using a finer jute powder, as suggested by Matthieu (2022). This method enhances the sand–cement–jute matrix uniformity through mechanical processing rather than chemical intervention. The preparation process is illustrated in Fig. 1.

Fig. 1. Fiber extraction stages: 1: Washing the bags with potable water; 2: Air drying; 3: Defibration of jute bags; 4: Grinding the cut jute fibers using a mill; 5: Sieving the jute fibers through a 1 mm sieve; 6: Purifying the fibers using demineralized water; 7: After rinsing, the fibers underwent air-drying in a controlled laboratory environment (23 ± 2 °C, 50 ± 5% RH) until a constant mass was achieved.

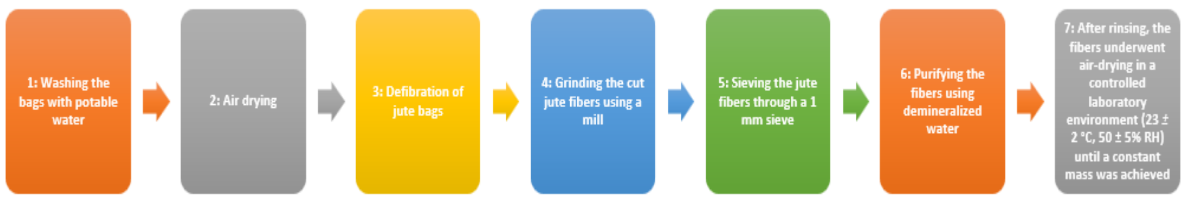

Fig. *2*. Flowchart for the production of jute powder

Jute fibers were incorporated at dosages from 0.25% to 2% (0.25% increments) by weight of cement, based on literature data. Materials included CEM I 52.5 N-PM (2024) Portland cement (NOCIBE, Benin), 0/2 lagoon sand (Cocotomey Zounga, Benin), and tap water (SONEB). The raw materials' physical and mechanical properties. Then, mortar mixtures were prepared and tested in both fresh and hardened states. To ensure reliability, each test was performed in six replicates, with results reported as mean values.

Production of Specimens

Immediately after mixing, the fresh mortar was transferred into standardized prismatic steel molds with dimensions of 40 × 40 × 160 mm, each consisting of three separate compartments, in compliance with EN 196-1 (2016). The molds were filled in with successive layers, and compaction was performed using a standardized mechanical compaction table to ensure proper consolidation and uniformity of the specimens. The experimental program, including tests on both the hardened mortar and its raw constituents, was conducted in accordance with the regulatory framework governing cement-based materials. This includes European standards (EN), their French transpositions (NF), as well as additional ISO standards where relevant.

RESULTS AND DISCUSSION

Material Characterization

The identification and characterization of the constituent materials, including sand, jute fibers, and CEM I 52.5 N (2024) cement, were conducted in compliance with the methodologies specified in Zomahoun *et al.* (2025). The complete physical, mechanical, and chemical characterization of the constituent materials is available in that article. Only the most relevant parameters for the present study are summarized here. The mortars were prepared using a CEM I 52.5 N-PM (2024) cement with a Blaine fineness of 3282 cm²/g and a 28-day compressive strength of 53.3 MPa. The sand was clean and slightly absorbent, with a density of 2.62 Mg/m³, a fineness modulus of 1.97, and a sand equivalent value of 77%. The sand was classified as non-reactive to alkali–silica reaction according to the FD P 18-542 (2023) standard, confirming its non-reactive nature. Potable water complying with applicable standards was used for mixing. The jute powder had a density of 1.46 g/cm³ and was mainly composed of cellulose (45.5%), together with hemicelluloses (23.0%) and a low lignin content (3.9%).

Mortar Characterization

The mortar formulation adopted in this study is consistent with that described by (Zomahoun *et al*. 2025). The mixtures were codified from M0 (control mortar) to M8 (2% jute powder content), with increments of 0.25% fibers for formulations M1 through M8. For the formulation of 1 m^3 of control mortar, the material proportions used consisted of 450 kg of cement, 1350 kg of sand, and 247.5 liters of water, corresponding to a Water/Cement (W/C) ratio of 0.55. Jute powder was incorporated as a partial cement replacement at dosages ranging from 0.25% to 2% by weight of cement. For each replacement level, a specific quantity of cement was substituted with an equivalent mass of jute powder. To ensure the reliability of the test results, the standard deviation as well as the coefficient of variation were calculated for all the experiments. These statistical analyses were used to verify the consistency of the data, and it was found that all coefficients of variation remained below 10%, confirming the good reproducibility of the experimental results.

Setting time

The incorporation of jute fiber powder, at dosages ranging from 0.25% to 2% by mass of cement, generally leads to a slight delay in the setting time compared to the reference mortar. This effect remains negligible at low dosages (0.25%) but becomes more pronounced at higher contents, particularly at 2%. This delay can be attributed to increased interference within the cementitious matrix due to the presence of the fibers.

Table 1. Setting Time of Mortars

Designation	M0	M1	M2	M3	M4	M5	M6	M7	M8
Setting time (min)	222	224	225	230	232	238	240	246	255
Setting duration (min)	74	75	78	80	81	82	85	90	91
Final setting (min)	296	299	303	310	313	320	325	336	346

The integration of plant fibers into cementitious mortar leads to a delay in setting time, as reported by several authors (Chafei 2014; Sedan 2007; Le Hoang 2013; Mathieu 2022). This retardation is attributed to the presence of free sugars leached from the natural fibers. Sedan (2007) linked the setting delay to the degradation of soluble carbohydrates into saccharinic acids, which function as potent retarding agents.

Flow table

Matthieu (2022) observed in his research that the flow table value decreases as the fiber content increases. It should be noted that he used long fibers (0 to 35 mm), which may explain this reduction: long fibers disrupt the packing density of the mix and reduce its fluidity. In the present study, the fibers were used in powder form, allowing for a more uniform distribution within the sand. Consequently, a constant flow table value of 180 mm was observed, regardless of the jute powder incorporation rate. This can be attributed to the fact that the jute powder mixture remained homogeneous, irrespective of the fiber replacement percentage.

Thermal Monitoring of Hydration

Figure 2 demonstrates that mortars incorporating jute fiber powder tended to maintain both external and internal coolness. However, during periods of intense heat, a rise in internal temperature is observed, consistent with the findings reported by Matthieu (2022). While the maximum ambient temperature was recorded at 37.4 °C, the core temperatures of the mortar ranged from 44.5 °C to 45.8 °C for jute fiber powder contents ranging from 0% to 2%.

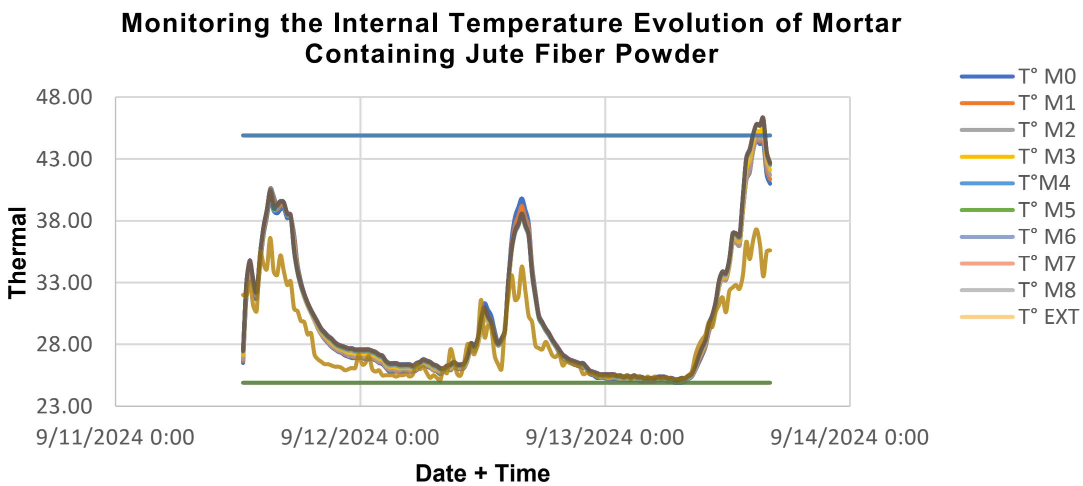

Fig. 3. Thermal monitoring of hydration

Capillary Water Absorption – Mortar

The average results of capillary water absorption tests, carried out on the specimens, are presented in Table 2.

Table 2. Capillary Water Absorption– Mortar

Designation	MO	M1	M2	M3	M4	M5	M6	M7	M8
Capillary Water Absorption (%) in 4 h	0.09	0.15	0.14	0.13	0.14	0.11	0.12	0.15	0.12
Capillary Water Absorption (%) in 24 h	0.10	0.15	0.16	0.13	0.17	0.15	0.14	0.16	0.13

Low water absorption is essential, especially for mortars exposed to rain or used in foundations, as higher absorption increases the risk of moisture infiltration. According to the standard, the limits are c ≤ 0.4, 0.3, and 0.2 $kg/m^2 \cdot min^{0.5}$ for R1, R2, and R3 mortars, respectively. The results indicate that mortars reinforced with short jute fibers and the reference mortar comply with R1 to R3 requirements (NF EN 998-1, 2016). Similar findings were reported by Ramírez *et al.* (2020), who observed higher absorption in fiber-reinforced mortars.

Three-point Flexural Tensile Test

The results indicate that incorporating jute fiber powder into the mortar improved tensile strength at contents of 0.25% and 0.5%, yielding gains of 2.02% and 2.46%, respectively, compared to the reference mortar. However, beyond this threshold, tensile strength gradually declined, with losses ranging from 3.9% to 22.3%. Majumder *et al.* (2023) observed a decrease in flexural strength across all percentages (0.5%, 1%, and 2%) and fiber lengths (5 mm, 10 mm, and 30 mm) tested. Kurpińska *et al.* (2022) demonstrated that the highest flexural strength was achieved with cementitious composites reinforced with ramie fibers. Ramie fibers are characterized by the highest tensile strength among all synthetic and natural fibers tested.

Table 3. Three-point Flexural Tensile Test

Designation	MO	M1	M2	M3	M4	M5	M6	M7	M8
2 days MPa	3.29	3.25	3.20	3.12	2.98	2.83	2.29	2.10	1.98
14 days MPa	3.91	4.00	4.00	3.76	3.60	3.55	2.91	2.86	2.78
28 days MPa	4.88	4.98	5.00	4.67	4.51	4.48	3.97	3.90	3.79

Compression Test

Compressive strength decreased as jute fiber powder content was increased, with a reduction of 4.02% to 45.35% compared to the reference mortar. This means that the jute fiber powder tended to decrease the compressive strength of the mortar. This was attributed mainly to its particle size distribution and morphology, which influence the compactness and cohesion of the cementitious matrix. Majumder *et al.* (2023) also observed a decrease in strength with increasing fiber content and length. Kurpińska *et al.* (2022) showed that dispersed fibers reduce early compressive strength (8.5% to 33%), except for ramie fibers, which increase it by 6.6%.

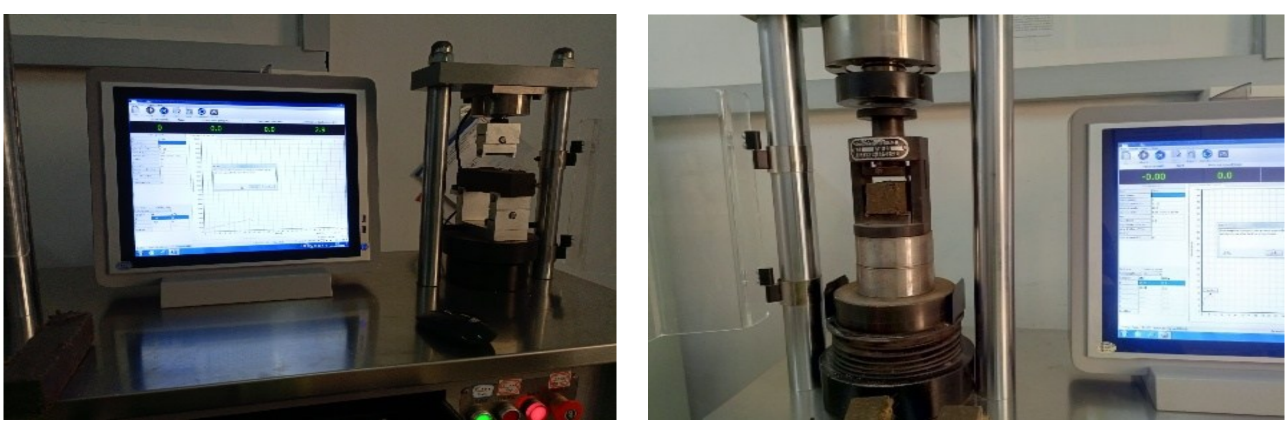

Fig. 3. On the left, the tensile test and on the right, the compressive test

Table 4. Compression Test

Designation	M0	M1	M2	M3	M4	M5	M6	M7	M8
2 days MPa	15.24	14.47	14.68	12.80	12.62	11.97	9.67	8.56	8.36
14 days MPa	28.24	26.97	26.97	26.44	24.96	22.33	21.30	16.97	16.82
28 days MPa	33.14	31.86	31.55	31.38	29.15	28.01	26.58	24.69	22.80

CONCLUSIONS

1. Mechanical Strength: Low jute fiber dosages improved tensile strength, peaking at 0.5%, whereas higher contents had a negative impact. Compressive strength decreased across all incorporation levels.
2. Homogeneity and performance: The incorporation of jute powder improved the homogeneity of the mortar mix and eliminated the need for plasticizing admixtures. All jute-modified mortars, as well as the reference mortar, satisfied the requirements of classes R1, R2, and R3 according to NF EN 998-1 in terms of capillary water absorption. However, the addition of jute fibers (0.25% to 2% by weight of cement) resulted in a slight delay in the setting time compared to the plain mortar.
3. Cost-Effectiveness: The incorporation of jute fibers as a partial replacement of cement reduced cement consumption and allowed the elimination of chemical admixtures, thereby lowering the overall construction costs due to the lower cost of jute compared to cement.

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