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Sustainable Composite Materials: Exploring Peanut Shells for Improved Mechanical Properties in Bio-Ceramics

Mohamed Leulmi, Rachid Nasri,
Department of Mechanical Engineering LR-MAI-ENIT, Faculty of Technology, National School of Engineers of Tunis ENIT, University of Tunis El Manar, B.P. 37. 1002 Le Belvédère Tunis. Tunisia.

Fairouz Chouit
Department of Technology, Faculty of Technology , 20 Aout 1955 University, P.O. 26, road El-Hadaiek, Skikda, 21000, Algeria.

Abstract
This research study focuses on the recycling of materials and reduction of emissions, specifically in the context of incorporating peanut shells into mortar as reinforcement for composite materials. The main objective is to determine the optimal manufacturing parameters and evaluate the performance of these materials. A variety of experimental techniques were employed to assess the physical and mechanical properties of the composite materials. Samples of mortar containing different proportions of peanut shells were prepared and subjected to tests measuring flexural strength, compression, absorption, and density. The findings indicate that the addition of fine peanut shell powder significantly enhances the flexural strength of the mortar. However, it is important to exercise caution as excessive amounts of peanut shell powder can have a detrimental effect on this strength. Similarly, the incorporation of relatively coarse powder improves flexural strength, although extreme amounts may lead to unfavorable outcomes. Generally, fine powder exhibits superior performance compared to coarse powder, with the exception of a 2% dosage rate. In summary, the utilization of peanut shells as reinforcement in composite materials offers advantages in terms of flexural strength, provided that the optimal dosage is carefully determined. This research aligns with the objective of preserving the environment by exploring sustainable alternatives. The findings contribute to sustainable practices by promoting material recycling and reducing emissions. Further optimization of these composite materials has the potential to facilitate their widespread application across various industries, thereby advancing environmental sustainability.

Keywords **: Unconventional Reinforcement, Composite aterials, Peanut shells, Mortar.**

I. INTRODUCTION

To address the universal demand for environmental protection and resource management, it is important to create new laws and adapt new concepts. Waste valorization and recycling have proven to be effective approaches in light of the economic and ecological constraints of recent years. Waste is a problem that is inherent to both biology and industry. Recycling and waste valorization are now acknowledged as future-oriented solutions to bridge the gap between production and consumption while protecting the environment. Recycling has two positive ecological consequences: the reduction of waste volume and the preservation of natural resources [1, 7].

Bio-composite materials reinforced with plant fibers present a compelling alternative in the construction field due to their durability and ecological impact [2, 3]. The use of unconventional reinforcements, such as plant fibers, helps reduce reliance on traditional materials and valorizes agricultural waste [2-5, 18-28]. Peanut shells, abundant and inexpensive, offer various environmental benefits when recycled into composite materials [6-7, 18, 19]. These materials have been the focus of numerous studies.

For example, V.A. Ajayi et al. [7] explored the valorization of agro-wastes, including melon seed shells, groundnut shells, and groundnut peels, through various biotechnological routes to generate distinct products. Echeverría-Maggi et al. [19] examined the production of durable panels using banana fibers and peanut shells, investigating their physical and mechanical characteristics with different binders. They found the panels had comparable strength to conventional non-structural panels and good thermal insulation. Ekpenyong et al. [18] studied the use of groundnut shell particles in construction materials, varying the proportion of untreated and treated groundnut shells and analyzing their properties, yielding promising results for this type of composite material

The primary objective of this study is to investigate the utilization of peanut shells as unconventional reinforcement in composite materials, focusing on their application in mortars. Mortars are crucial in construction, and incorporating plant-based reinforcements [7-9], such as fine and slightly coarse peanut shell powder, has the potential to enhance their mechanical properties. Various experimental techniques are employed to characterize the composite materials reinforced with peanut shells to achieve this objective. The performance of the reinforced mortars is assessed through mechanical tests, including flexural and compressive strength evaluations, comparing the results to unreinforced mortars.

Analyzing the results facilitates assessing the impact of peanut shell reinforcement on the mechanical properties of mortars. The variations in the dosage of fine and slightly coarse peanut shell powder provide insights into the influence of the quantity of reinforcement on the performance of composite materials. Additionally, comparing the two types of reinforcement helps identify which one exhibits superior characteristics in terms of strength and durability.

This research aims to explore potential applications of peanut shells in construction as an unconventional form of reinforcement in composite materials. Utilizing peanut shells as a reinforcing agent in composite materials presents an intriguing opportunity to improve mortar properties. The study aims to thoroughly characterize and optimize these materials by examining various reinforcement proportions. The findings from this research have the potential to significantly contribute to advancing sustainable solutions in the construction industry, offering an environmentally friendly and economically feasible alternative to conventional materials.

II. EXPERIMENTAL PROCEDURES

A. Materials used

We used to make the mortar for this study the following local materials (cement, sand, water, and vegetable filler from the peanut shell):

Cement: The cement utilized in all formulations of the study is CEM II/A-L 42.5, primarily composed of 94% clinker and gypsum, accompanied by 6 to 20% limestone. This cement adheres to Algerian standards NA 442 (NA 442, 2013) and European standard EN 197-1, maintaining consistent quality across the study's parameters. The chemical composition of the cement includes calcium (CaO ≈ 59.4%), silicon (SiO2 ≈ 20.65%), aluminum (Al_2O_3 ≈ 4.92%), iron ($Fe2O_3$ ≈ 2.97%), magnesium (MgO ≈ 1.01%), potassium (K_2O ≈ 0.8%), sodium (NaO ≈ 0.19%), sulfur (SO_3 ≈ 2.75%), and chlorine (Cl^- ≈ 0.02%), along with traces of free lime and insoluble residue [10-11, 19-21].

Sand: The sand used in the study is sourced from the Oued Zhor Skikda area in Algeria and is classified as dune sand with a particle size of 0/1. It has an apparent bulk density of 2.6 g/cm³. The chemical elements present in the sand include sulfur (SO_3 ≈ 0.24% and ($CaCO_3$ ≈ 1.6%), chlorine (Cl^- ≈ 0.21%), organic matter (≈ 1.04%), and a pH value of (≈ 8.34).

Water: The mortar in our study was prepared by mixing it with readily available tap water. The use of potable water in mortar mixing is a conventional and accepted practice, ensuring safety and compliance with the necessary standards.

Peanut Shells: Peanuts are cultivated in numerous countries for their edible seeds, celebrated for their high content of proteins, fats, and fibers [6, 12]. The tough and arid outer coverings surrounding peanut seeds are known as peanut shells. These shells consist of approximately 40 to 45% crude fibers, primarily comprised of cellulose, hemicellulose, and lignin.

Peanut shells have diverse applications across various sectors, contributing to purposes such as composting wet materials, litter, fuel, wastewater treatment, filling material, natural fertilizer, wardrobes, activated carbon, insulation board, metal casting, and acting as a medium for pesticides [6-7, 12-15]. Furthermore, the lightweight nature, rigidity, and strength of peanut shells make them suitable for incorporation into composite materials, offering the potential to enhance the mechanical properties of such materials.

The integration of peanut shells into composites presents advantages such as reduced production costs and minimized environmental impact **[6-7, 15-19]**. For our study, we sourced peanut shells from peanuts grown in the Algerian desert, subsequently cleaning and grinding them to produce two types of vegetal fillers : a fine powder and a slightly coarser powder. The pictures in ***Fig (1)*** show these preparations.

Fig (1): Peanut shells before and after cleaning, and their powder after crushing.

B. Specimens preparation

According to the standard, the mortar samples were formulated with a Water-to-Cement ratio (W/C) of 0.6 and a Cement-to-Sand ratio (C/S) of 1/3.

The preparation protocol involved introducing the ingredients in a prescribed order, commencing with the addition of cement and sand into the mixer tank, followed by thorough mixing.

Next, we added the peanut shell powder as the reinforcement, thoroughly mixing the mixture. Then, we added water and continued mixing the ingredients until they became homogeneous.

After that, we made mortar specimens with dimensions of (4 × 4 × 16) cm³ for bending and The specimens were cast in pre-oiled metal molds. The three-cavity metal mold and its riser were firmly secured to the impact table or vibrating table, and the first of the two layers of mortar was introduced. The total layer was spread uniformly.

The procedures for positioning the specimens adhered to the guidelines outlined in the standard NBN EN 1015-2 (NBN EN 1015-2, 2007). Following casting, the molds were maintained at room temperature in the laboratory for a duration of 24 to 48 hours. After demolding, the specimens were appropriately marked and stored until the various tests were conducted, which were performed after a curing period of 28 days. The pictures in Fig (2) give a general idea.

Fig (2): Different steps are involved in sample preparation.

C. Formulation

In this study, we adopted a formulation approach that emphasizes a simple composition of mortar, as well as a mortar reinforced with vegetal charges derived from peanut shell in the form of fine and slightly coarser powder. These proportions were chosen to ensure the durability of the mortars. The water content was fixed for each formulation. The incorporation of peanut shell powder as the vegetal charge was done at rates of *0.5%, 1%,* and *2%.* Table (1) summarizes the diverse compositions of the mortars studied for each type. The different samples produced are represented by the images in fig (3).

Fig (3): Different samples of fine ***(MCa)*** and slightly coarser ***($MCa_{(g)}$)*** peanut shell powder.

Table (1): Different compositions of the mortars studied

	Control Mortar (CM)	*Mortar with peanut shell by fine powder (Ca)*			*Mortar with peanut shell by Slightly coarse ($Ca_{(g)}$)*		
Percentage%	***0% (Tm)***	***0.5%(Ca)***	***1%(Ca)***	***2%(Ca)***	***0.5%($Ca_{(g)}$)***	***1%($Ca_{(g)}$)***	***2%($Ca_{(g)}$)***
Sand (g)	**1350**	**1343.25**	**1336.5**	**1323**	**1343.25**	**1336.5**	**1323**
Marble (g)	**0**	**6.75**	**13.5**	**27**	**6.75**	**13.5**	**27**
Fibre (g)	**450**	**450**	**450**	**450**	**450**	**450**	**450**
Cement (g)	**270**	**270**	**270**	**270**	**270**	**270**	**270**
Water (g)	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**

III. RESULTS AND DISCUSSIONS

In order to understand the behavior of cementitious composites reinforced with vegetal fibers, we conducted destructive tests such as tension and flexural compression, as well as non-destructive tests to evaluate the bulk density and capillary water absorption.

A. Flexural Tensile Test

The flexural strength and flexural tensile ***(R_f)*** tests were performed on prismatic specimens with dimensions of ***4x4x16 cm³***. The preparation and testing of these specimens followed a ***28-day*** curing period to examine the evolution of flexural tensile strength over time. For each mix composition, the reported values represent the average of three tests. From the first visible crack, the bending strength of the mortars was measured. The following formula is implemented to calculate flexural strength.

$$R_f = 1,5\frac{F_f}{b^3}L \quad \text{.....................} \ (1)$$

R_f: Flexural strength in ***MPa***;
F_f: Failure load of the specimen in bending ***(N)***;
L : Length between the two lower supports in ***(mm)***;
b : Side of the specimen in ***(mm)***.

Table (1): The results of the flexural tensile strength test (three-point bending)

	Ff (N)	L(mm)	b (mm)	Rf(MPa)
CM	**1900**	**100**	**40**	**4.446**
M Ca 0,5%	**2900**			**6.786**
M Ca 1%	**2700**			**6.318**
M Ca 2%	**2600**			**6.084**
M Ca(g) 0,5%	**2800**			**6.552**
M Ca(g) 1%	**2700**			**6.318**
M Ca(g) 2%	**2000**			**4.68**

Fig (4): The images represent flexural strength testing (***three-point bending***)

Table (2) summarizes the findings from tests on the flexural strength of samples of plain mortar, mortar reinforced with a fine peanut shell powder, and mortar reinforced with slightly coarser peanut shell powder. Furthermore, Fig (**4**) shows the advancement of the laboratory experiments on the samples. One can see that the flexural strength increases with the addition of both the fine peanut shell powder and the slightly coarser peanut shell powder mortar. This improvement is evident in the first sample, which contains *0.5%* of both samples and shows a *52%* increase in flexural strength for fine powder and a *47%* rise for somewhat coarser powder, respectively. The flexural strength drops by *42%* and *36%*, respectively, in the second sample *(1% content)* and the third sample *(2% content)*.

Evidence suggests that the addition of small quantities of both finely ground and slightly coarser peanut shell powder enhances the flexural tensile strength of materials. This enhancement is attributed to the presence of plant-based fillers in the mortars, which reinforce the structure by absorbing flexural forces. Furthermore, the observed phenomenon, occurring post-rupture of tested specimens, indicates that the inclusion of fine peanut shell powder and modest amounts of slightly coarser powder effectively mitigate crack propagation upon reaching the material's breaking point.

These findings align with existing research supporting the enhancement of mechanical properties through the integration of peanut shells into composite materials. Despite variances in matrix composition and compatibility with peanut shell reinforcement, studies by Kisan et al [29] and Zaaba et al [30] corroborate these results. However, Usman et al [38] noted similar outcomes when reinforcing recycled polyethylene with groundnut shell powder (GSP). Their study revealed that utilizing finer particle sizes and increasing particle loading lead to heightened flexural strength in the GSP-recycled composite, a trend mirrored in findings by Binici et al [36] Notably, the flexural strengths of samples incorporating peanut and onion skin fibers surpassed those of control samples.

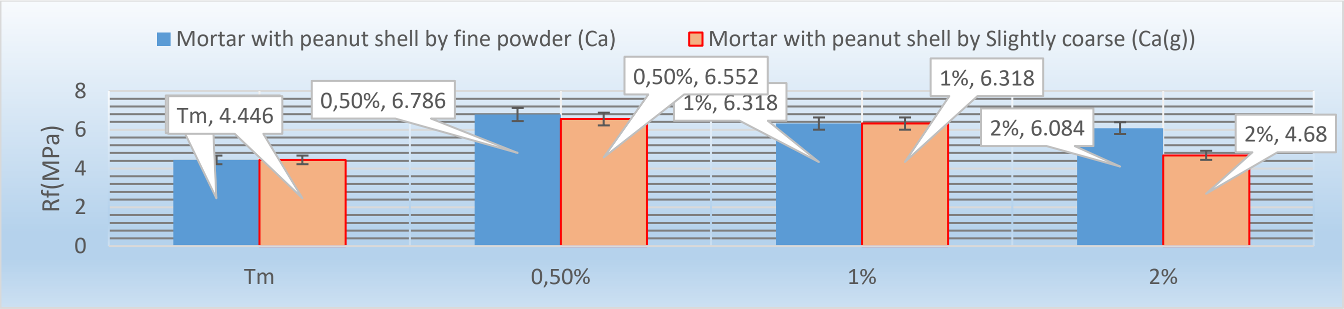

Fig (5): Flexural Strength Results of mortar reinforced with ***(black line)*** fine peanut shell powder ***(MCa)***, ***(red line)*** slightly coarser peanut shell powder ***($MCa_{(g)}$)***.

When comparing the results of the flexural tensile strength between the mortars reinforced with slightly coarser peanut shell powder and those reinforced with fine peanut shell powder *Fig (5)*, we observe that the latter exhibit better results for all proportions, except for the *2%* content. These findings suggest the advantage of using fine powder to achieve significant performance improvements. In other words, the incorporation of fine peanut shell powder in the mortar appears to be more beneficial in terms of flexural strength, except when the dosage reaches *2%*. This highlights the importance of finding the optimal dosage for each type of reinforcement to obtain the best mechanical performance.

B. Compression Test

In compression testing, the compressive strength of a material refers to its ability to withstand loads that tend to compress or crush it. It represents the maximum uniaxial compressive force reached when the material fails completely. The compression tests measure this strength by subjecting the material to a compressive load following a standardized protocol, usually conducted on the same machine as the tensile test.

In our study, the compression strength tests (R_c) were performed on prismatic specimens according to the *NFP 18-406* standard. The compression strength was calculated by taking the average of three tests conducted on identical specimens.

To assess the compression strength of witness mortar and fiber-reinforced mortars, half-specimens resulting from the three-point bending tests were crushed after *28 days* to determine their compression strengths. The reported values represent the average of three tests and are calculated using the following equation:

$$Rc = \frac{F_{c.max}}{b\times h} \quad \text{.................................... (2)}$$

R_c : Compressive strength of the mortar *(MPa);*
$F_{c,max}$: Maximum compressive load causing failure *(N);*
b, h : Width and height of the specimen, respectively *(b = h = 40 mm).*

The compressive strength tests on *28-day* mortars revealed the impact of adding fine peanut shell powder and slightly coarser peanut shell powder on their properties. They are shown in detail in *Table (7)* and *Fig (6)*.

The use of peanut shell powder in mortar improves compressive strength, with the first sample showing a *47%* increase. However, the second and third samples show a slight decrease due to poor fiber distribution, leading to increased defects in the mortar matrix. The higher dosage of fibers results in decreased mortar cohesion and increased porosity, causing a substantial drop in compressive strength. The third sample shows a *9%* decrease due to poor fiber distribution. The use of slightly coarser peanut shell powder in mortar also improves compressive strength by *22%* and *56%* in the first and second samples, respectively. However, the third sample experiences a *43%* decrease due to poor fiber distribution, resulting in increased defects in the mortar matrix. In an experiment conducted by Sada et al [37]. with a *1:2:3* mix ratio and groundnut shells as a substitute for fine aggregate, they found that the concrete's compressive strength rose at 5% replacement compared to the control concrete. The same characteristic of results published by Usman et al. [38]. In general, it was discovered that the samples containing peanut and onion skin fibers had greater compressive strengths than the control samples. The findings of Zaaba et al [30] of their study revealed that the integration of peanut shell powder (PSP) into recycled polypropylene (RPP) composites yielded various effects on their properties, notably demonstrating a significant enhancement in their compressive strength properties. Moreover, the research conducted by Sareena et al [31] in their investigation, which concentrated on the utilization of Peanut Shell Powder (PSP) as a filler in Natural Rubber (NR), validated the enhancement in compressive strength, indicating an evaluation of technological performance. Recent investigations Kisan et al [29], Zaaba et al [30], and Samsunan et al [33] have confirmed our observations regarding the increased compressive strength characteristics linked to the inclusion of peanut shells in composite materials.

Table (3): The results of the tensile strength test

	Control mortar	Mortar with peanut shell by fine powder (Ca)			Mortar with peanut shell by Slightly coarse (Ca(g))		
Percentage%	**0% (Tm)**	**0.5%(Ca)**	**1%(Ca)**	**2%(Ca)**	**0.5%(Ca(g))**	**1%(Ca(g))**	**2%(Ca(g))**
$F_{c,max}$ (N)	**28550**	**42200**	**38600**	**21300**	**34500**	**39800**	**42400**
h (mm)	**40**						
b (mm)	**40**						
R_c (MPa)	**17.84**	**26.34**	**24.93**	**15.78**	**21.91**	**28.01**	**25.55**

Fig (6): The images represent of the tensile strength test.

The higher dosage of fibers (fine powder or a slightly coarser peanuts shell) leads to a decrease in mortar cohesion and an increase in porosity, ultimately resulting in a substantial drop in compressive strength. Therefore, it is crucial to find the optimal dosage of the filler reinforcement to achieve the best performance in terms of compressive strength of the mortar. Excessive dosages can have a negative effect on the material's mechanical properties.

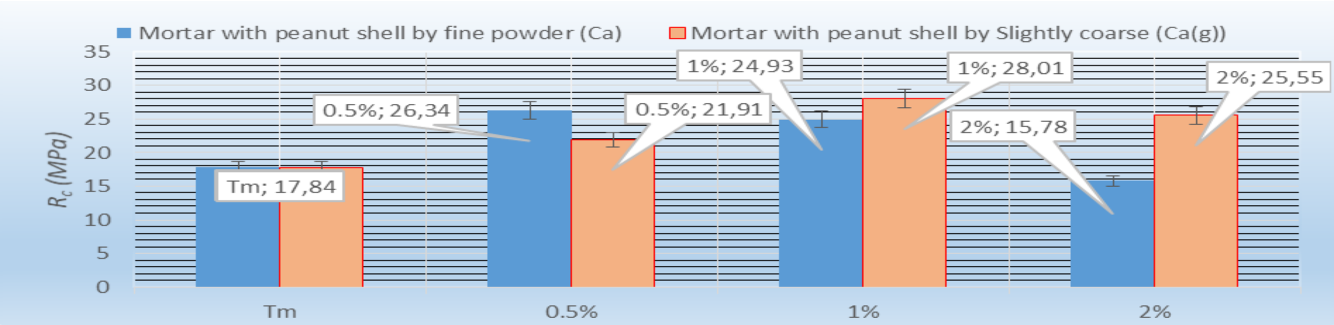

Fig (7): Compressive Strenght Results of mortar reinforced with ***(black line)*** fine peanut shell powder ***(MCa)***, (***red line)*** slightly coarser peanut shell powder ***(MCa$_{(g)}$)***

By comparing the compressive strength results between mortars reinforced with slightly coarser and fine powder of peanut shells, as shown in *Fig (7)*. It is clear that the fine powder of peanut shells performs better in the first sample with a *0.5%* proportion. However, the results for the slightly coarser powder are more significant with proportions of *1%* and *2%*.

It is essential to carefully study dosages and proportions to achieve the best performance in terms of compressive strength. Excessive dosages can have a negative impact on the mechanical properties of the mortars.

Furthermore, research conducted by Tata et al [32] on incorporating peanut shells into lightweight concrete, along with studies by Samsunan et al [33] and Tong et al [34] on the utilization of peanut shell waste in concrete, confirms a decrease in compressive strength with an increasing percentage of peanut shells.

C. Capillary Water Absorption Test

The capillary water absorption test characterizes the movement of water through the pores or capillaries of porous materials. In our study, capillarity measurements were performed following AFPC-AFREM standards on samples with dimensions of 4x4x16 cm^3. The samples were coated with a waterproof material on their lateral surfaces to ensure uniaxial water absorption.

The samples were dried at 60°c until their mass stabilized and then weighed in their dry state (M_0). Subsequently, they were immersed in containers containing water with a 5 mm immersion depth. After each immersion period, the samples were taken out, wiped, superficially dried, and weighed (M_x).

The values obtained represent the average of three tests. The specimens were covered with plastic film to ensure unidirectional water ascent and prevent any water exchange with the ambient environment. Water absorption is measured through successive weighings using the following expression:

$$Ca_t = \frac{M_x - M_0}{A} \dots\dots\dots\dots (3)$$

Ca_t : Capillary absorption coefficient *(kg/m^2);*
M_x : Mass of the specimen at a given time *(kg);*
M_0 : Initial mass of the specimen *(kg);*
A : Cross-sectional area of the specimen *(m^2).*

The mass:

The absorption capacity of a mortar gives a general idea about the presence and importance of voids (pores). It is the one way to test the compactness of the mixture. The more compact the mortar is, the lower its absorption capacity, and therefore, the more waterproof it is. This absorption capacity is determined by a simple method. The Table (4) represents the masses of different samples over time.

Table (4): The masses of different samples over time

	Control mortar	*Mortar with peanut shell by fine powder (Ca)*			*Mortar with peanut shell by Slightly coarse ($Ca_{(g)}$)*		
Percentage%	**0% (Tm)**	**0.5%(Ca)**	**1%(Ca)**	**2%(Ca)**	**0.5%($Ca_{(g)}$)**	**1%($Ca_{(g)}$)**	**2%($Ca_{(g)}$)**
0 min	**507**	**510.6**	**488**	**475.8**	**511.6**	**497.4**	**475.8**
5min	**509**	**513.9**	**490.4**	**477.8**	**516.7**	**501.9**	**477.8**
10min	**510**	**514.5**	**490.7**	**478.1**	**517.7**	**502.7**	**478.1**
15min	**510**	**514.5**	**491.**	**478.1**	**518.6**	**503.3**	**478.1**
30min	**511**	**515.6**	**491.6**	**478.4**	**520.2**	**504.8**	**478.4**
1h	**60**	**516.5**	**492.3**	**478.8**	**521.9**	**506.2**	**478.8**
2h	**120**	**517.6**	**493.1**	**479.2**	**524.2**	**508.1**	**479.2**
3h	**180**	**518.2**	**493.6**	**479.4**	**525.5**	**509.4**	**479.4**
12h	**720**	**519.9**	**495**	**480.8**	**530.7**	**513.9**	**480.8**
24h	**1440**	**521.9**	**496.3**	**481.3**	**535.7**	**518.7**	**481.3**
48h	**2880**	**523.5**	**497.4**	**482**	**540.4**	**523.4**	**482**
72h	**4320**	**524.7**	**498.3**	**482.6**	**543.6**	**526.7**	**482.6**

Indeed, the absorption capacity of a simple mortar is significantly higher than that of a mortar reinforced with fine peanut shell powder ***Fig (8)***. This measurement helps test the compactness of the mixture. The more compact the mortar, the lower its absorption capacity, making it more waterproof. The use of fine peanut shell powder in the mortar enhances its compactness and reduces its absorption capacity, promoting better waterproofing. This demonstrates the beneficial effect of adding this powder on the physical properties of the mortar.

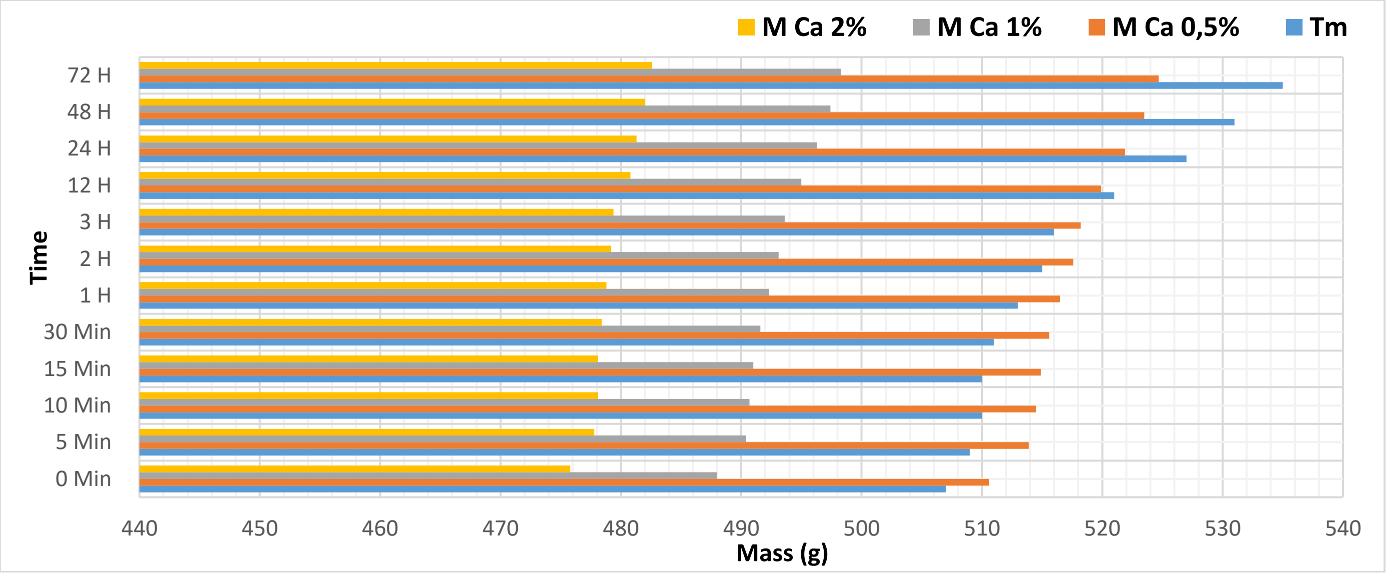

Fig (8): Histogram represent the masses of different samples ***((M Ca).***

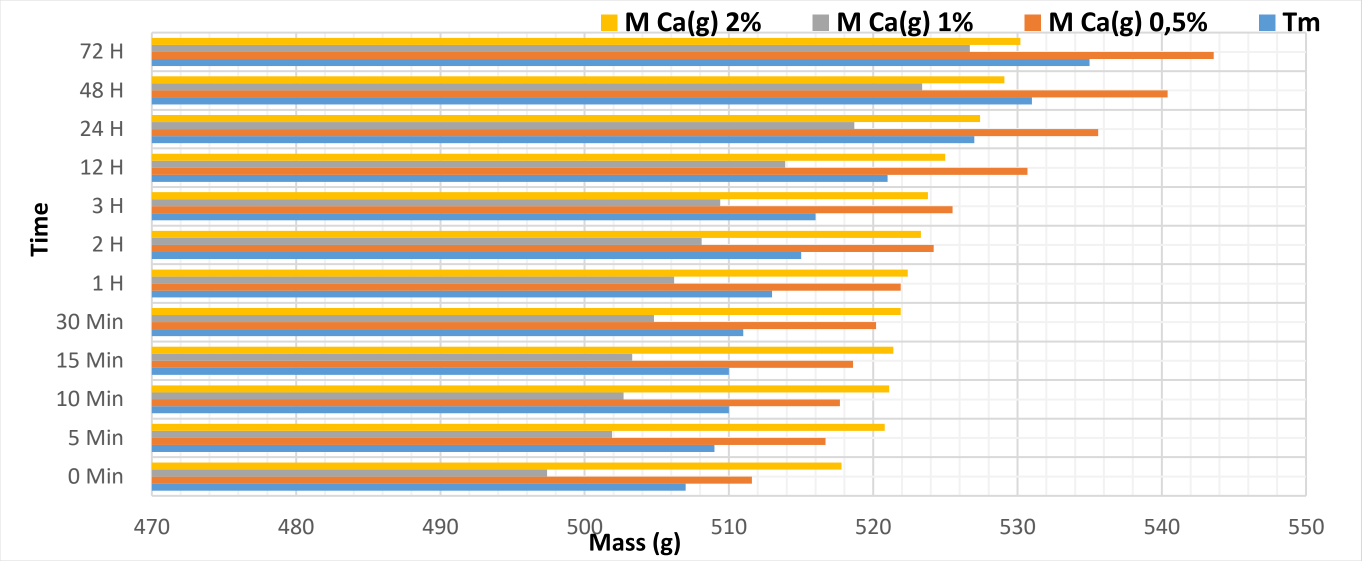

Fig (9): Histogram represent the masses of different samples ***(M Ca$_{(g)}$)***.

In the case of a simple mortar compared to a mortar reinforced with a slightly coarser peanut shell powder, there is a much higher absorption capacity ***Fig (9)***. This measurement helps assess the compactness of the mixture. It is essential to note that adding the slightly coarser peanut shell powder improves the compactness of the mortar, thereby reducing its absorption capacity. This characteristic is a crucial indicator of the material's waterproofing. These results emphasize the positive effect of adding this powder on the physical properties of the mortar.

The density:

Density is an important factor for determining porosity and evaluating the durability of mortars. The Table (5) summarizes the results of the densities in the hardened state of each variant developed in 28 days. The results represent the average of three measurements in each case.

Table (5): The Densities of different samples

	Control mortar	**Mortar with peanut shell by fine powder (M Ca)**			**Mortar with peanut shell by Slightly coarse (MCa$_{(g)}$)**		
Percentage%	***0% (Tm)***	***0.5%(Ca)***	***1%(Ca)***	***2%(Ca)***	***0.5%(Ca$_{(g)}$)***	***1%(Ca$_{(g)}$)***	***2%(Ca$_{(g)}$)***
0 min	1.98	1.99	1.91	1.86	2	1.94	2.02
5min	1.99	2.01	1.92	1.87	2.02	1.96	2.03
10min	1.99	2.01	1.92	1.87	2.02	1.96	2.04
15min	1.99	2.01	1.92	1.87	2.03	1.97	2.04
1h	2.01	2.02	1.92	1.87	2.04	1.98	2.04
2h	2.01	2.02	1.93	1.87	2.05	1.98	2.04
3h	2.02	2.02	1.93	1.87	2.05	1.99	2.05
12h	2.04	2.03	1.94	1.88	2.07	2.01	2.05
24h	2.06	2.04	1.94	1.88	2.09	2.03	2.06
48h	2.07	2.05	1.94	1.88	2.11	2.05	2.07
72h	2.09	2.05	1.95	1.89	2.12	2.06	2.07

The density of mortar samples reinforced with fine peanut shell powder and slightly coarse peanut shell powder was determined, and the results are depicted in *Fig (10)* and *Fig (11)*.

One can see that the density of mortar samples reinforced with fine peanut shell powder and slightly coarse peanut shell powder showed a decrease in density with increasing filler proportion, and this decrease in bulk density in samples is attributed to mixing ratios.

Mortars prepared with higher proportions of fine peanut shell powder demonstrate a lower density compared to the control mortars. However, in the samples reinforced with 0.5% and 1% proportions of slightly coarse peanut shell powder, there is an observed increase in bulk density.

These observations can be elucidated by considering the nature of the mixture and the shape of the vegetal reinforcement. The mortar's porosity could increase due to the fine peanut shell powder, which could cause a decrease in density. The distribution of vegetable charges and their interactions with other components of the mortar can significantly influence the physical properties of the mixture.

The decrease in bulk density in the sample reinforced with a 1% proportion can be attributed to increased porosity resulting from the incorporation of the slightly coarse powder of peanut shells. This leads to an overall reduction in mortar density.

On the other hand, in the samples reinforced with *0.5%* and *2%* proportions, we observe an increase in bulk density. This increase can be explained by better filling of void spaces in the mixture, thanks to the presence of the slightly coarse powder of peanut shells. This can result in higher density in the mortar.

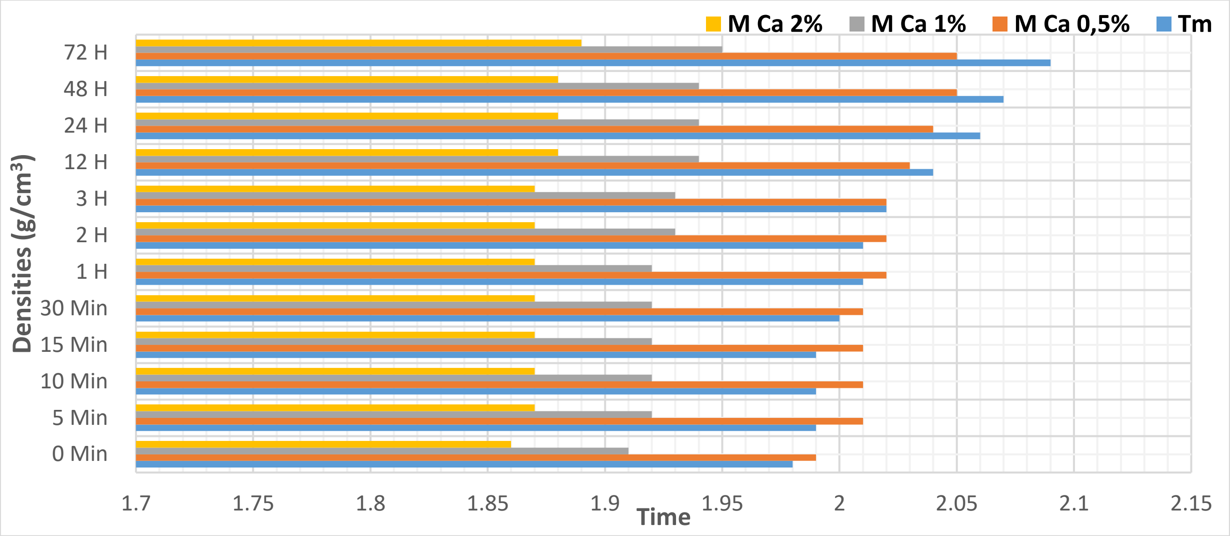

Fig (10): Histogram representing the densities ***(g/cm^3)*** of different samples ***((M Ca).***

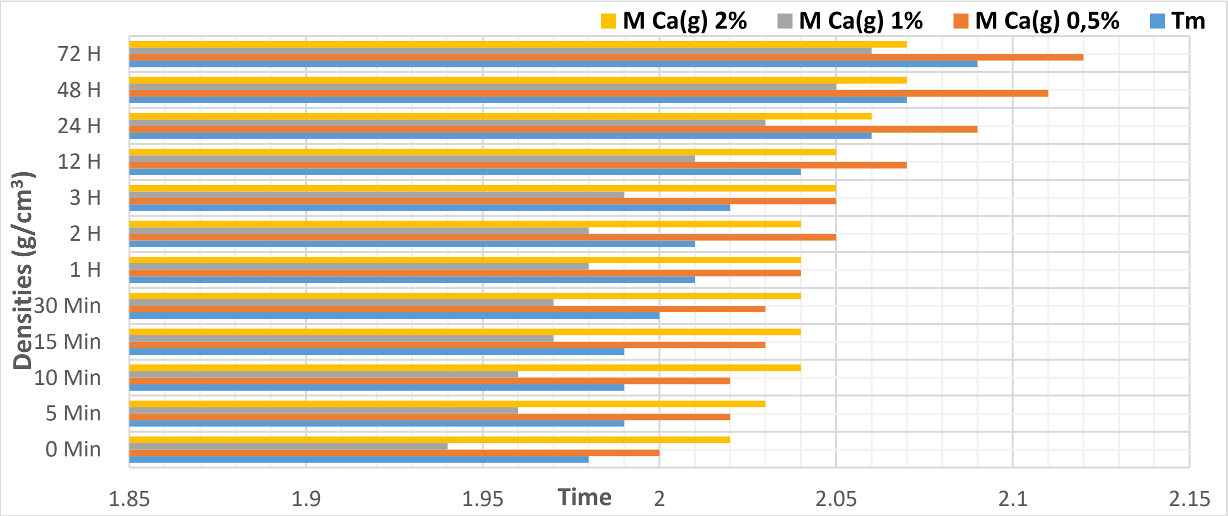

Fig (11): Histogram representing the densities ***(g/cm^3)*** of different samples ***(M $Ca_{(g)}$).***

Results of Capillarity Water Absorption:
The determination of the capillary water absorption coefficient for hardened mortars after different curing times was conducted on specimens with dimensions of 4x4x16 cm³. The results of the water absorption evolution in the mortars are presented in the following Table (6):

Table (6): The results of the water absorption evolution in the mortars **Ca_t (%)**

	Control mortar	**Mortar with peanut shell by fine powder (M Ca)**			**Mortar with peanut shell by Slightly coarse ($MCa_{(g)}$)**		
Percentage%	***0% (Tm)***	***0.5%(Ca)***	***1%(Ca)***	***2%(Ca)***	***0.5%($Ca_{(g)}$)***	***1%($Ca_{(g)}$)***	***2%($Ca_{(g)}$)***
0.5 h	0.004	0.005	0.0036	0.0026	0.0086	0.0074	0.0041
1h	0.006	0.0059	0.0043	0.003	0.0103	0.0088	0.0046
12h	0.014	0.0093	0.007	0.005	0.0191	0.0165	0.0075
24h	0.02	0.0113	0.0083	0.0055	0.024	0.0213	0.0096
48h	0.024	0.0128	0.0094	0.0062	0.0288	0.026	0.0113
72h	0.028	0.0141	0.0103	0.0068	0.032	0.0293	0.0124

Table (6) displays the findings of capillarity tests performed on samples of control mortar, mortars reinforced with fine peanut shell powder, and mortars reinforced with somewhat coarser peanut shell powder after **30** days.

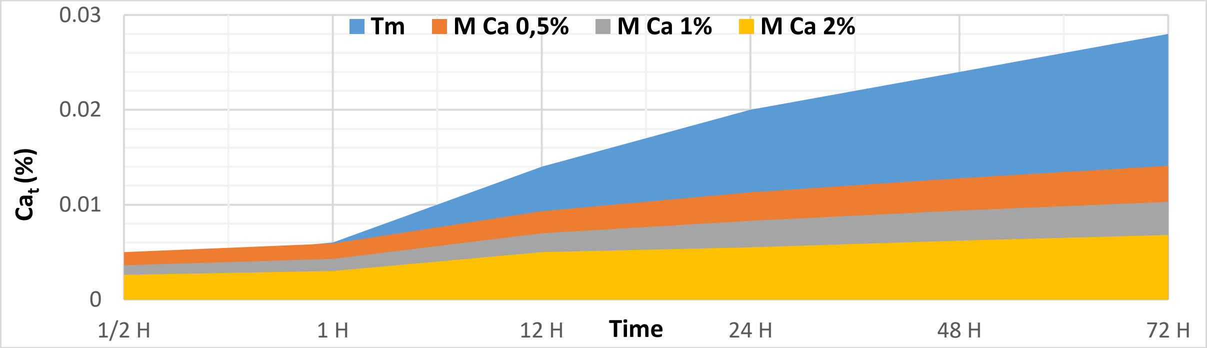

Fig (12): Histogram representing the results of water absorption by capillarity **Ca_t (%)** ***(M Ca).***

In comparison to the control mortar, mortars reinforced with a fine peanut shell powder exhibit less absorption, This explains what ***Fig (12)*** shows. This suggests that including this vegetal reinforcement helps to increase the mortar's resistance to capillary absorption. However, compared to the control mortar, sorption is higher in mortars reinforced with ***0.5%*** and ***1%*** of slightly coarse peanut shell powder. This shows that the addition of this small-scale vegetal reinforcement helps to increase the mortar's capillary absorption capability.

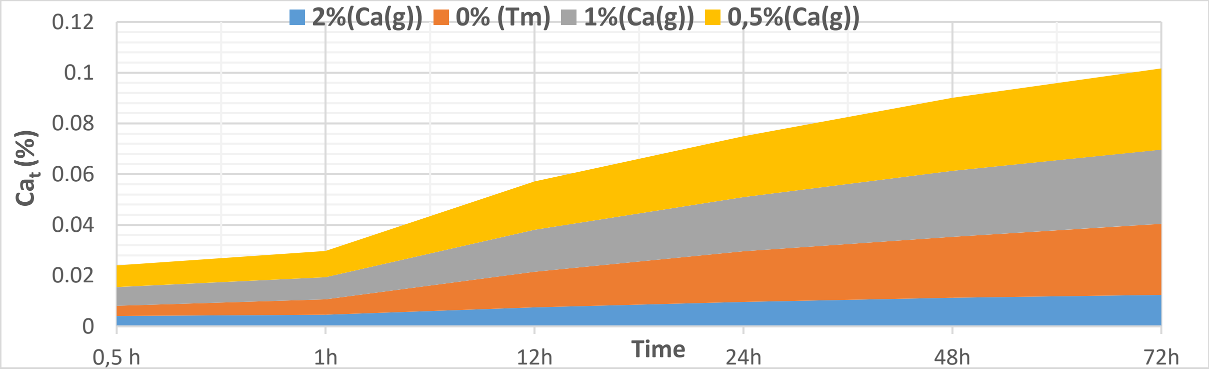

Fig (13): Histogram representing the results of water absorption by capillarity **Ca_t (%)** ***(M $Ca_{(g)}$).***

The absorption gradually decreases as the amount of filler reinforcement (peanut shell fine (MCa) and slightly coarse ($MCa_{(g)}$) powder) is increased. This is clear from Fig (12) and Fig (13).

The ability of the vegetal reinforcement to reduce the porosity of the mortar, which in turn limits the flow of water through the capillaries, is responsible for the decrease in absorption. The absorption decreases significantly for both samples after 48 hours, indicating that the mortar reinforced with the two types of reinforcement has successfully attained a high level of capillary tightness. This enhances the resilience to moisture and durability of constructions made with this mortar. As we can see from the Fig (14), the results demonstrate a reduction in the absorption of the samples as the proportion of fine peanut shell powder in the mix increases.

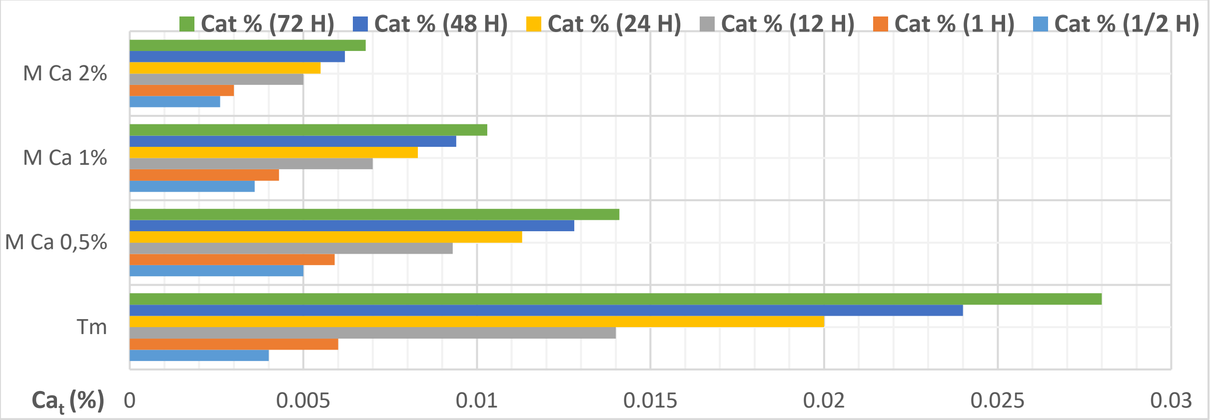

Fig (14): Histogram representing the water absorption by capillarity of the different samples **Ca_t (%)** ***(M Ca).***

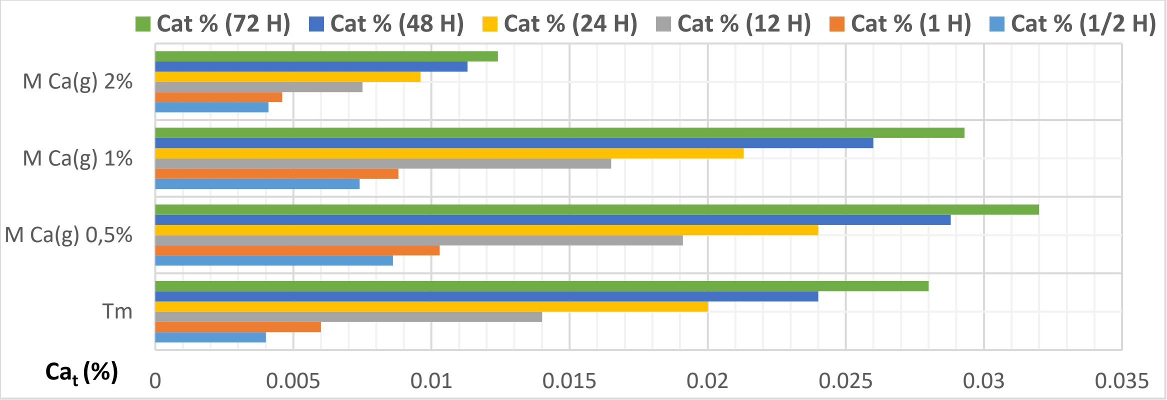

Fig (15): Histogram representing the water absorption by capillarity of the different samples **Ca_t (%)** ***(M $Ca_{(g)}$).***

The results shown in *Fig (15)* show that the absorption decreases as the proportion of slightly coarse peanut shell powder increases. However, the mortars reinforced with a proportion of *0.5%* and *1%* of slightly coarse peanut shell powder exhibit higher absorption than the control mortar.

Initially, there is compatibility with Zaaba et al [30].'s study. Their findings indicate that the incorporation of peanut shell powder (PSP) into recycled polypropylene (RPP) composites results in a decrease in absorption. However, contrary to this, Zaaba et al [30].'s study suggests a potential increase in the equilibrium water absorption percentage, implying a different long-term behavior.

Tata et al [32]'s study similarly supports the idea that higher proportions of peanut shells result in increased water absorption in concrete, indicating a trade-off between compressive strength and water absorption. This contradicts our conclusions entirely, as our results demonstrated a decrease in sample absorption with an increase in the proportion of fine peanut shell powder in the mix.

Contrary to our findings, Bobet et al [35], in their study on the characterization of peanut shells for their utilization in earth brick production, discovered that peanut shells possess a high water absorption capacity, with water absorption reaching approximately 198% within 72 hours. However, our results demonstrate that mortars reinforced with fine peanut shell powder exhibit lower absorption. This indicates that incorporating this vegetal reinforcement enhances the mortar's resistance to capillary absorption.

IV. CONCLUSION

This research significantly contributes to the expansion of sustainable options in composite material construction. The use of plant-based reinforcements, exemplified by peanut shells, not only diminishes reliance on traditional materials but also advocates for an environmentally friendly approach. Furthermore, employing agricultural waste as reinforcements presents an economical and ecologically sound solution.

The study underscores the promising potential of peanut shells as unconventional reinforcement in constructing composite materials. The findings convincingly illustrate the advantages of incorporating both fine and slightly coarse peanut shell powder to enhance the mechanical properties of mortars.

The use of peanut shells as reinforcement in composite materials offers significant improvements. Adding fine peanut shell powder enhances flexural strength, while incorporating slightly coarse powder reinforces compression strength. However, finding the optimal dosage is crucial to achieve the best performance, as excessive proportions may have a negative impact on mechanical properties.

Nevertheless, further research is crucial to deepen our understanding of the physical and chemical properties of composite materials reinforced with peanut shells. Comprehensive studies could delve into additional variables, such as exploring surface treatments for peanut shells or improving mixing processes, with the aim of further enhancing material performance.

Finally, using peanut shells as unconventional reinforcement in composite materials opens new perspectives for sustainable construction. This research contributes to expanding knowledge in this emerging field, while emphasizing the importance of finding a balance between improving mechanical properties and practical considerations of dosage and implementation. Harnessing these natural resources can lead to significant advancements in sustainability, performance, and environmental stewardship in the construction sector.

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DECLARATION OF INTEREST

The authors reported having no potential conflicts of interest.

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