Ecological Reinforcement of Cementitious Mortars with Jute Fibres: Effects on Mechanical Performance

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GRAPHICAL ABSTRACT

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In recent years, there has been considerable interest in the use of plant fibers in the construction sector. These fibers can represent an alternative to traditional fibers used in building materials, such as polypropylene fibers. Sustainable development requires materials that are environmentally friendly, *i.e.*, natural and recyclable. Therefore, the aim of this article was to examine the mechanical performance (compressive and flexural strength) and properties of cementitious mortars reinforced with small-scale jute fibers. The jute fibers used in this work were pre-treated with demineralized water and cut into small sizes with a maximum length of 5 mm to eliminate the use of superplasticizers to make the mix homogeneous. The results obtained showed that mortars reinforced with 0.5% plant fibers had higher tensile and compressive strength than ordinary mortars. Furthermore, whatever the percentage, the fibers retained the interior temperature during cool periods, which could help reduce the power consumption of home air-conditioning systems. Therefore, the introduction of fibers saves cement, admixture, and water for each percentage. These results point to a promising future for the use of plant fibers in cementitious materials.

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Keywords: Jute fibers; Reinforced mortars; Cement; Superplasticizer

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INTRODUCTION

Access to decent housing is a major challenge, particularly in developing countries where demand for housing is constantly increasing due to demographic growth and rapid urbanization (UN-Habitat 2020). However, high construction costs remain a major obstacle to housing affordability for a large proportion of the population. The market for plant fibers is expanding worldwide. Among these natural fibers, jute stands out for its availability, low cost, and favorable mechanical properties (UN-Habitat 2020). The global market for jute bags was estimated at 2.71 billion USD in 2023, with a projection of 4.92 billion USD by 2030, reflecting the growing demand. Global jute production ranged between 3 and 3.7 million tonnes, with India and Bangladesh as the main producers (Maximize Market Research 2024).

In Benin, many traders use jute bags to transport agricultural produce. This growing demand for jute bags has enabled manufacturing companies to set up in Benin's industrial zone, producing tons of jute bags every year. After use, these jute bags are often thrown away. Waste from jute bags, because of their bulky nature, poses a major problem for environmental protection. This waste is either burned by the population, thus increasing CO_2 levels, or dumped in the countryside, creating environmental management problems. One of the modern trends in construction is the move towards bio-based materials (Sodomon 2022). Bio-based materials are materials that can be used as insulation in building envelopes to meet occupants' comfort requirements (Pierre 2020).

Superplasticizers are chemical admixtures used in mortars and concrete to enhance workability. Their main functions are to fluidize the mixture, facilitate placement, and improve the mechanical strength of the final material. There are several types of superplasticizers used to improve the fluidity of mortar or concrete. One example is the MasterGlenium ACE 456, a high-range water-reducing superplasticizer based on polycarboxylate ethers. It is compatible with the cement used and enhances the workability of fresh concrete (Page 2017). Its main characteristics are: density = 1.06±0.02; solid content = 30.0±1.5%; pH = 4 to 7; total chloride ion content ≤ 0.01%; sodium oxide equivalent ≤ 3%. Another example is Sika ViscoCrete-850 Vegetal, a versatile high-range water-reducing superplasticizer also based on polycarboxylates. This type of admixture increases the contact surface between binder particles and water, effectively lubricating the components and improving the rheology of the resulting mix (Matthieu 2022). Its properties include: density = 1.07±0.02; solid content = 30.0±1.5%; pH = 5±1.0; total chloride ion content ≤ 0.1%; sodium oxide equivalent ≤ 1.0%. However, in developing countries, the use of superplasticizers remains limited due to their high cost and occasional lack of availability. This economic constraint has led researchers to explore alternative solutions that are local, cost-effective, and sustainable. One such approach involves incorporating short jute fibers into mortars to eliminate the need for superplasticizers. Taiwo *et al.* (2025) demonstrated that the addition of jute fibers in cementitious panels maintained good workability without the use of these admixtures. Similarly, Toha *et al.* (2025) showed that construction blocks reinforced with jute fibers exhibited satisfactory mechanical performance while remaining free of superplasticizers. Lekshmi *et al.* (2023) conducted an analysis of variance to examine the statistical significance of coconut fiber reinforcement on the flexural and compressive strengths of masonry mortar. The results of the study revealed that a 0.5% coconut fiber reinforcement improved the flexural strength of high-strength mortars by 18 to 22%, moderate-strength mortars by 21%, low-strength mortars by 10%, and again high-strength mortars by 16 to 19%, thereby contributing to early-age strength development. Additionally, coconut fiber-reinforced mortars met the compressive strength requirements for high-strength mortars intended for use in masonry walls, in accordance with Indian standards (Lekshmi *et al.* 2023). The use of such fibers thus offers a promising alternative for developing economical, eco-friendly, and context-appropriate mortars in developing countries.

Therefore, it is essential to assess the extent to which the addition of finer jute fiber can overcome the mechanical deficiencies of conventional mortars and improve their performance. What are the effects of this incorporation on the mechanical strength and properties of fresh mortar? In what proportions and under what conditions is this improvement optimal? This study aimed to answer these questions by analyzing the mechanical behavior of mortars enhanced with jute powder, to determine their suitability for structural and non-structural applications.

EXPERIMENTAL

Jute fibers are long, soft, and shiny. Its length ranges from 1 to 4 m and its diameter from 17 to 20 microns. It is essentially composed of plant cellulose and lignin, the main components of plant fibers. Once isolated, jute fibers were cleaned, dried, and spun into coarse threads, which were then woven into strong cloth. These cloths are widely used to make jute bags for packaging and transporting agricultural products (coffee, cocoa, rice, onions, etc.) because of their strength, air permeability, and biodegradability.

After the products contained in the jute bags had been transported and sold, they were collected (purchased at reduced cost) from the saleswomen at the Dantokpa market in Benin. Once collected, the bags were immersed in drinking water for 24 h to soften the fibers. After this time, the bags were carefully washed by hand, without the use of soap, and then left to air-dry. Once dry, the jute fibers were extracted by hand, then cut into small segments no more than 5 mm long. The manual fiber extraction method involves manually removing the fibers from the bags. The fibers are then manually defibrated using a fine and pointed tool, such as a needle or any similar sharp object. After cutting, the fibers were soaked in demineralized water to remove residual impurities and ensure optimum cleanliness. Finally, they were naturally air-dried under controlled conditions to avoid contamination.

It should be pointed out that, in the literature, the problem of mixture homogeneity frequently arises. Some authors use superplasticizers to ensure good fiber dispersion. In order to avoid the use of superplasticizers, the current authors proposed cutting the fibers into small segments, which promotes better homogeneity of the sand–cement–jute fiber mixture. On this subject, Mathieu (2022) emphasized the prospect of "analyzing the state of dispersion of the fibers in the mixture in the fresh state, and seeing whether finer and/or more precise cutting would make it possible to dispense with the use of superplasticizer."

The idea, then, is to cut the fibers into smaller sizes so as to dispense them without the need for superplasticizer. In the existing literature, the length of fibers for mortar making is not uniformly fixed, but generally it ranges between 5 and 50 mm. The aim of the current work is to use fibers of up to 5 mm in the mix. The method of preparing the fibers from the jute material is shown in Fig. 1.


Cleaning the bags with potable water


Drying


Cutting jute bags


Defibration + cutting to maximum length of 5 mm


Cleaning fibers with demineralized water


Natural drying

Fig. 1. Fiber extraction stages

The authors tested the addition of fibers at the following percentages: 0.5%, 1%, 1.5%, and 2% by weight of cement. Tests were stopped as soon as the 28-day compressive strength of a mix fell below that of ordinary mortar (the percentages retained are defined on the basis of existing literature data). The hydraulic binder used was Portland cement CEM I 52.5 N-PM, produced by the NOCIBE plant in Benin. The 0/2 lagoon sand used in this study came from Cocotomey Zounga, located in southern Benin. The water used to prepare the mortars came from the Société Nationale des Eaux du Bénin (SONEB) network. The physical and mechanical properties of sand, cement, and jute fibers were initially characterized in order to better understand the behavior of these materials and to evaluate their suitability for use in mortar.

Following this step, the mortar mixes were prepared according to the specified formulation. Once mixing was completed with the different fiber content percentages, tests were conducted on both fresh and hardened mortar. Each test was repeated six times, and the average of the recorded values was considered as the representative result for each test.

Production of Specimens

The production of mortar specimens for mechanical characterization tests followed a rigorous protocol, starting immediately after mixing. As described in (Mathieu 2022), the mixture was poured into metal molds measuring 4 x 4 x 16 cm^3, with three compartments. A first layer of mortar was poured into each compartment, followed by compaction using an impact table. This compaction process was carried out with 60 shocks in accordance with EN 196 (2016). Tests on the mortar and its constituents were carried out in accordance with the regulations applicable to mortar constituents (NF EN European standards adopted by AFNOR, the French NF P standard, and some ISO standards as appropriate).

RESULTS AND DISCUSSION

Material Characterization

Sand

It can be seen that the sand curve integrated with the spindle, so the sand complied with the requirements for use in mortar.

Table 1. Summary Table of Sand Test Results

Parameter	Method	Unit	Average	Specification
Real density	NF EN 1097-6 (2023)	Mg/m³	2.62	Declared value
Water absorption coefficient		%	0.5	≤ 2.5 AbA / ≤ 5.0 AbB
Fineness modulus (FM)	NF EN 12620 + A1 (2008)	-	1.97	1.5 ≤ FM ≤ 4
Fines content	NF EN 933-1 (2012)	%	1.0	≤ 10 fA / ≤ 16 fB
Sand equivalent (SE)	NF EN 933-8 (2012)	%	77	≥ 65 PA / ≥ 60 PB
Friability coefficient (FS)	NF P 18-576 (1990)	%	18	-
Methylene blue value (MB)	NF EN 933-9 + A1 (2022)	g/kg	1.0	≤ 1.5 (PA and PB)
Prohibited impurities	XP P 18-546 (2002)	-	<0.01	≤ 0.1
Water-soluble chlorides	NF EN 1744-1 + A1 (2013)	%	0.004	To be declared
Total sulfur	NF EN 1744-1 + A1 (2013)	%	0.12	≤ 1 (SA and SB)
Acid-soluble sulfates	NF EN 1744-1 + A1 (2013)	%	0.04	≤ 0.2 (SA and SB)
Humic matter	NF EN 1744-1 + A1 (2013)	-	Absence	Absence
Water-soluble active alkalis	XP P 18-544 (2006)	% Na_2Oeq	0.0300	Declared value
Alkali-aggregate reaction	FD P 18-542 (2011)	-	NR	To be declared

The results in Table 1 indicated that the sand met the necessary requirements for use in mortar.

Table 2. Physical and Mechanical Characteristics of the Cement Used

Designation		Average Value	Standard Recommended Value
Physical Characteristics			
Water demand (%)		28	ns
Initial setting time (min)		170	≥ 45 min
Setting duration (min)		74	ns
Final setting time (min)		244	ns
Soundness (mm)		0.5	< 10
Blaine specific surface (cm²/g)		3238	ns
Specific gravity (g/cm³)		3.122	ns
Bulk density (g/cm³)		0.934	ns
Compressive Strength (MPa)	2 days	20.5 MPa	≥ 20 MPa
	7 days	33 MPa	ns
	28 days	53.1 MPa	≥ 52.5 MPa
Tensile Strength (MPa)	2 days	5 MPa	ns
	7 days	7 MPa	ns
	28 days	8 MPa	ns

*ns : Not specified by the standard

From Table 2 it can be observed that the cement used is a CEM I 52.5 N (2024) compliant with the NF EN 197-1 (2012) standard.

Mixing water

The mixing water used is SONEB drinking water from Benin.

Jute fiber

Table 3. Fiber Test Results

Designation	Alpha Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Density (%)	pH
Average Value	45.50	23.0	3.9	0.58	1.46 g/cm³	5.63

Mortar Characterization

Selected mortar mix design

Table 4. Proportion Of Mortar Constituents

Materials	Proportion for 1 m³
Cement	450 kg
Sand	1350 kg
Water	247.5 liters
Water/Cement Ratio (W/C)	0.55

Table 5. Mortar Coding

Designation	Codification
Control Mortar	M
Mortar + 0.5% fibers	M1
Mortar + 1% fibers	M2
Mortar + 1.5% fibers	M3
Mortar + 2% fibers	M4

Setting time

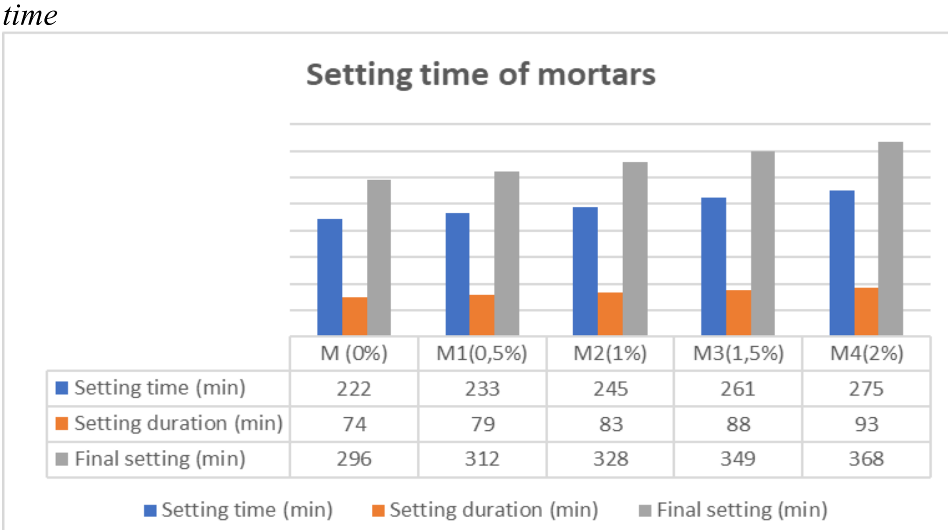

Fig. 2. Setting time of mortars

The incorporation of jute fibers, in proportions ranging from 0.5% to 2% by weight of cement, tended to cause a slight delay in mortar setting time compared with ordinary mortar. At low dosages (0.5%), the impact was moderate, but at higher levels (2%), the delay became more noticeable due to the increased disruption of the cementitious network. These results are in line with those found in the literature (Chafei 2014; Page 2017; Mathieu 2022), which have shown the disruptive effect of plant fiber addition on the hydration process. Sedan (2007) attributed the setting delay observed to the action of the pectins contained in the fiber on the calcium ions that are released as a result of the binder's hydration reactions. The coefficient of variation was less than 10 for all tests, which confirmed the conformity of the tests.

Flow table

It was observed that as the fiber content increased, the flow (or spread) of the mortar decreased. This agrees with Mathieu (2022), who observed that the more fibers are added, the more the spread decreases.

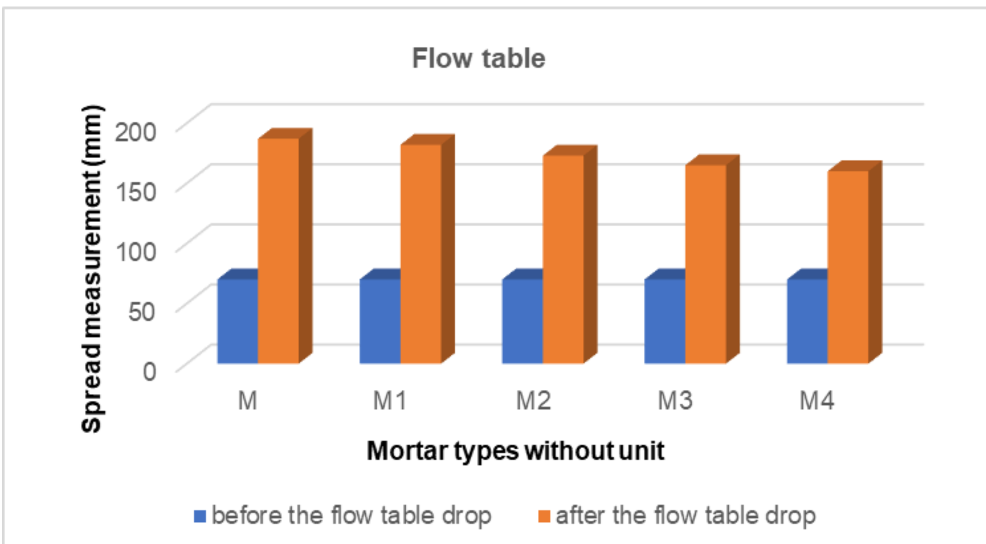

Fig. 3. Flow table

Thermal Monitoring of Hydration

It was noted that the fibers slightly delayed the kinetics of hydration but increased the heat accumulated in the long term and maintained the freshness. As illustrated in Fig. 4, on 13/09/2024 at 13:54, the ambient outdoor temperature was 37.30 °C. In contrast, the temperature measured at the same time within the fiber-reinforced mortar increased progressively with the fiber content: 44.5 °C at 0%, 44.7 °C at 0.5%, 45.8 °C at 1%, 45.8 °C at 1.5%, and 45.9 °C at 2%, as shown in the graph of Fig. 4. This trend indicates a gradual increase in the internal temperature of the mortar as the fiber content increases, suggesting a non-negligible thermal effect of plant-based fibers on heat retention within the material.

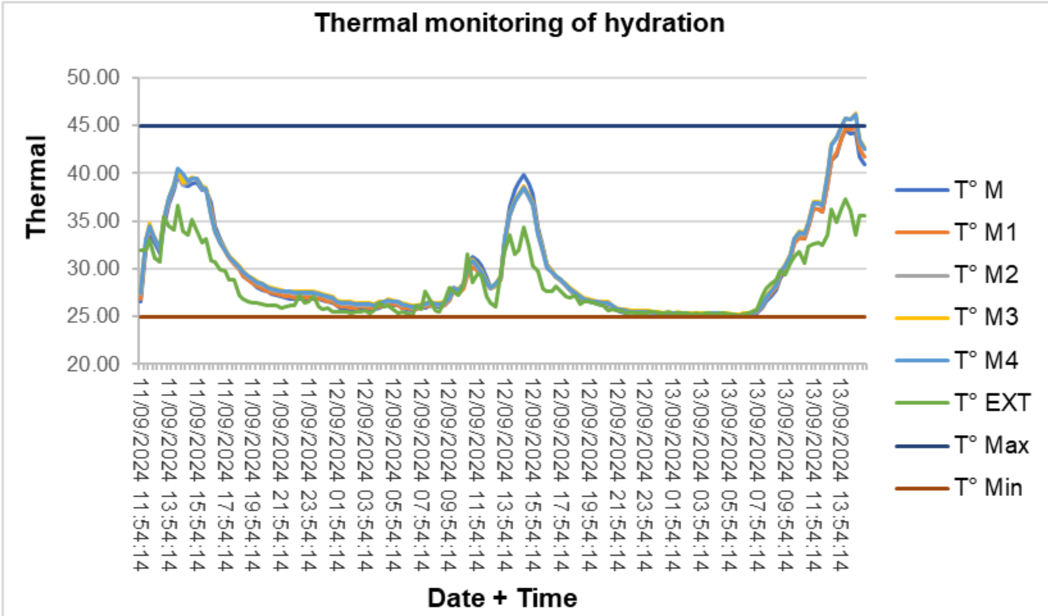

Fig. 4. Thermal monitoring of hydration

This is the same case as observed by Mathieu (2022), who explained that this delay is related to the reaction between the chemical elements contained in the plant particles and the calcium ions present during the hydration reaction of the binder.

Water Absorption Test by Saturation – Mortar

According to Table 6, the mortar was not porous, as evidenced by its low water absorption rate, ranging from 5.8% to 6.5%. This limited absorption capacity indicated good homogeneity of the mix, regardless of the percentage used. Borhan and Mohamed Sutan (2011) reported water absorption values between 7% and 15.7% for mortars modified with polymers.

Table 6. Water Absorption Test by Saturation – Mortar

Mixture Designation	M (0%)	M1 (0.5%)	M2 (1%)	M3 (1.5%)	M4 (2%)
Water Absorption (%)	5.80	6.00	6.3	6.5	6.5

Three-point Flexural Tensile Test

It was noted that the incorporation of short-spun fibre fibres into cement mortar had a positive effect on improving the bending resistance of mortars. The 0.5% fibre mortar level resulted in the best result from the point of view of strength after 28 days. Abdessamed (2017) found that the best tensile strength was with 0.6% date palm fibre in the mortar (An increase of 0.05% more than the reference mortar was observed). Ezziane (2010) has shown that the addition of fibers in the mortar has more pronounced consequences on tensile strength; with the addition of 0.58% of steel fibers, the flexural strength increases 25% compared to that of non-reinforced mortar. The coefficient of variation is less than 10 for all tests, which confirms the conformity of our tests.

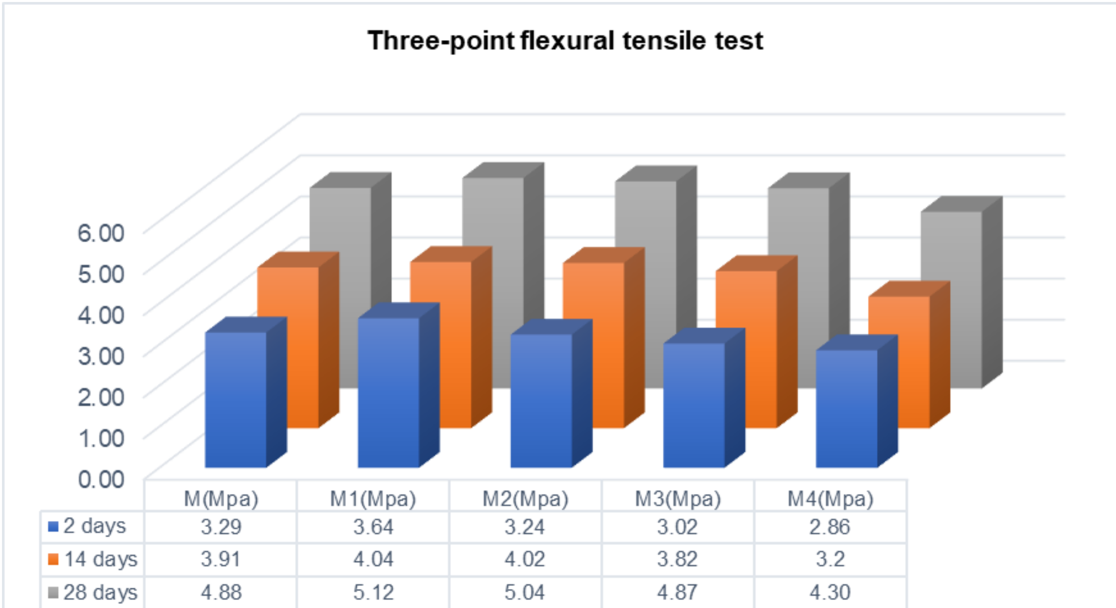

Fig. 5. Three-point flexural tensile test

Compression Test

It can be observed from Fig. 6 that 0.5% yielded the highest compressive strength at 28 days. An increase of 0.10% was recorded compared to the reference mortar at 0.5%. The higher the inclusion rate of these plant fibers in the studied mortars, the more the compressive strength of the resulting composites decreased. These results are consistent with the literature. As the fiber content increased, the cohesion of the mortar decreased and porosity increased, which subsequently leads to a significant drop in compressive strength (Kriker 2005).

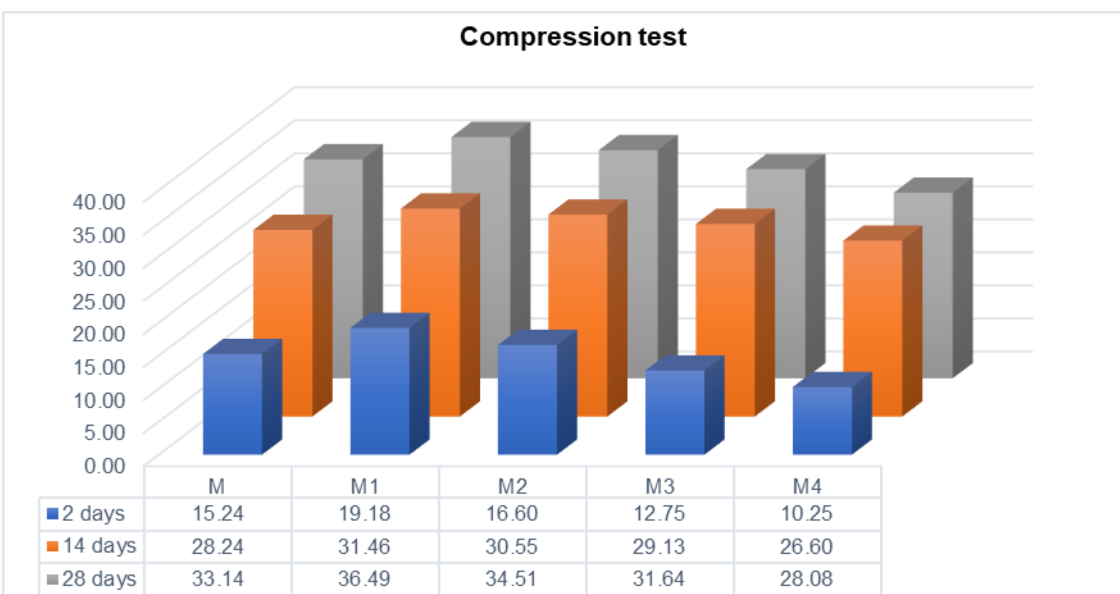

Fig. 6. Compression test

CONCLUSIONS

The following conclusions can be drawn from the results of the experimental program on improved cement mortars, in which four different percentages of jute fibers were incorporated:

1. The incorporation of jute fibers at low dosages improved both the compressive and tensile strengths of the mortars. The highest compressive strength was achieved with 0.5% fiber content. However, higher fiber percentages had a negative effect on these mechanical properties.
2. Due to the small size of the fibers (0 to 5 mm), a homogeneous mix was achieved during the tests, which eliminated the need for a superplasticizer in the mortar formulations.
3. The addition of jute fibers increased the internal temperature of the mortar during hot periods and helped retain coolness during colder conditions.
4. The incorporation of fibers also allowed for the elimination of chemical admixtures and a reduction in cement content, which contributes to a reduction in overall construction costs.

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