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Impact of low-density polyethylene (LDPE) waste on the physico-mechanical and durability behavior of lime-stabilized adobe bricks

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Abstract:
Earth-based construction techniques, such as adobe, are valued for their low cost and reduced environmental impact. However, their limited mechanical strength and poor water resistance reduce their overall durability. This study investigates the improvement of adobe bricks through the addition of lime and low-density polyethylene (LDPE) plastic waste derived from greenhouse cleaning activities, in varying proportions (2–6%) and fiber lengths (10–30 mm). The research aims to evaluate the physical, mechanical, and durability characteristics of the modified earth blocks. The results show a reduction of 23.57% in density, 17.95% in ultrasonic pulse velocity, and 37.80% in compressive strength. While the lower compressive strength reflects a mechanical limitation, the decrease in density could be beneficial for lightweight applications or for improving the thermal and acoustic insulation of walls. Conversely, notable improvements were recorded in tensile strength and abrasion resistance, which increased by 71.42% and 90.47%, respectively. Despite these benefits, the mixtures exhibited slightly higher water absorption and swelling, indicating increased sensitivity to moisture. Nevertheless, the reduced mass loss after wetting-drying cycles highlights an overall improvement in the long-term durability of the material.

Keywords:
plastic waste, adobe, lime stabilization, LDPE plastic fibers, mechanical strength, sustainability

1. Introduction

Adobe, among the oldest and most eco-friendly construction materials, is a natural composite primarily composed of clay-rich soil, sand, and water [1], shaped into bricks and sun-dried. It is recognized for its low construction energy demand [2,3], reduced embodied energy during production [4], minimal water consumption [5], cost-effectiveness, and ease of use in building applications [6]. It has been widely used in traditional construction for its affordability, thermal performance, and low environmental impact. However, its mechanical limitations and vulnerability to moisture have led researchers to explore ways of improving its properties.

To improve these weaknesses, stabilization methods are applied and are usually divided into two types: chemical and physical approaches. Chemical stabilization includes the addition of lime, cement, or a combination of both [7,8]. Walker [9] observes that quicklime works better for stabilizing cohesive soils, while cement is more suitable for granular soils. On the other hand, physical stabilization involves particle size optimization and fiber reinforcement [7].

Both natural and synthetic fibers have been effectively used to reinforce soils, aiming to improve mechanical strength and reduce swelling in problematic soils [10]. These fibers significantly improve crack resistance, enhance mechanical strength, and extend the service life of building components, thereby contributing to overall structural durability.

Recent studies have investigated the incorporation of various waste materials into earth bricks as reinforcing fibers or additive aggregates to enhance their strength, durability, and environmental value. Parisi et al. and Millogo et al. [11,12] investigated the effects of waste such as straw and Hibiscus cannabinus, respectively, on soil stabilization, and observed significant improvements in mechanical performance. Rômulo et al. [13] showed that the use of glass fiber waste reduced both linear shrinkage and bulk density in adobe bricks. Additional enhancements in soil block performance using binders and wastes are reported by Danso et al. [14,15]. Date palm waste has been used as fibers or aggregates by several authors [7,16,17,18] for the stabilization of earth blocks and to enhance their properties. Although a reduction in compressive strength was reported, the use of such organic waste contributed positively to other performance aspects. Various types of polymer waste have been investigated, each demonstrating distinct effects on the overall performance of the blocks.

Donkor et al. [19] examined the effect of polypropylene fibers on flexural performance, and the test results indicated an enhancement in post-crack flexural behavior. Layachi et al. [20] conducted a study to assess the impact of incorporation polystyrene beads on the mechanical performance of lightweight earth blocks. The findings revealed that incorporating 65% polystyrene beads led to a significant reduction in flexural and compressive strengths, by 90.50% and 96.59% respectively. In contrast, Puy Alquiza et al. [21] examined the physical and mechanical properties of recycled adobe stabilized with expanded polystyrene and reported that the addition of 5% to 6% polystyrene resulted in a 56.53% increase in compressive strength.

In concrete technology, numerous studies have investigated the impact of incorporating plastic waste (e.g., Oddo et al. [22]; Gunat et al. [23]). For instance, Vivek et al. [24] investigated the mechanical performance of concrete in which fine aggregates were partially replaced with LDPE waste, observing a measurable decrease in compressive strength. Beyond concrete, plastic waste has also been incorporated into bricks, insulation products, and mortar. Haoura et al. [25] conducted a study on incorporating high-density plastic waste into mortar, revealing that the mechanical properties decreased because of this addition, with the dual aim of enhancing their physical and mechanical properties and reducing the environmental footprint of plastic disposal.

In earthen construction, few studies have examined the incorporation of waste plastic in the production of earth blocks. According to Dominguez-Santos [26] incorporating high-density polyethylene plastic (HDPE) into traditional adobe lowers its density by between 6% and 11%. Sarath et al. [27] conducted an in-depth study on incorporating low-density polyethylene (LDPE) plastic waste into laterite soil for the production of stabilized earth bricks, placing particular emphasis on the effect of LDPE shredding. Their findings revealed that LDPE significantly enhances the thermal resistance and reduces water absorption of the bricks, while also contributing to environmental pollution mitigation. The integration of LDPE with lateritic soils represents a promising and innovative approach aligned with the goals of sustainable construction [27]. This paradigm shift in modern architecture seeks to reduce environmental impact while optimizing the use of natural resources.

In this context, the valorization of plastic waste, particularly low-density polyethylene obtained from used greenhouse films, represents an innovative solution to enhance adobe. As plastic waste continues to pose a growing environmental challenge, low-density polyethylene, widely used in greenhouse coverings, is among the most frequently discarded types of plastic.

Plastic films used in greenhouses are essential components in contemporary agricultural techniques. According to a recent report by the Food and Agriculture Organization (FAO) of the United Nations in 2019 [28], the global area dedicated to greenhouse crop production was estimated at approximately 4.9 million hectares, with the majority in Asia (59%), followed by Europe (21%) and North America (16%). In Algeria, greenhouse cultivation is predominantly concentrated in the southern regions, particularly in the Biskra region [29], which accounts for over 49% of the national greenhouse-covered area [30]. However, once their service life ends, these plastic films are typically discarded, contributing to environmental pollution and posing significant challenges in terms of waste management and disposal.

Among the key advantages of LDPE waste utilization in construction are its low density and inherent resistance to moisture, chemicals, and degradation. These characteristics make it a compelling additive for improving flexibility, impact resistance, and thermal insulation in a variety of building materials. Moreover, recycling LDPE waste contributes to landfill volume reduction, minimizes environmental pollution, and promotes circular economy practices in the construction sector. LDPE is defined as a flexible, lightweight polymer with a typical density ranging between 0.91 and 0.93 g/cm³, making it particularly suitable for applications where weight reduction is advantageous [31]. Its integration into construction materials not only contributes to waste management but can also improve the mechanical and physical characteristics of adobe blocks. Adobe, however, has inherent limitations that include low mechanical strength, poor water resistance, and limited durability.

This study investigates the combined effects of lime stabilization and fiber reinforcement using recycled low-density polyethylene (LDPE) sourced from greenhouse plastic waste on the mechanical properties (compressive and tensile strength), physical characteristics, and durability of adobe bricks. Durability is assessed through total water absorption, swelling, abrasion resistance, and wetting-drying cycle tests. The resulting composite is evaluated in terms of its mechanical performance, durability, and suitability for sustainable building applications.

2. Materials and methods

2.1. Materials

2.1.1. Soil

The soil used in this study was prepared and conditioned prior to testing; it was sieved through a 2 mm mesh. Its particle size distribution was assessed in accordance with the standards NF P 18-560 and NF P 94-057 in succession (Fig. 1). Both apparent and absolute densities were measured. The Atterberg limits and plasticity index were determined following the NF P 94-051 standard, with the results outlined in Table 1. Mineralogical composition was assessed using X-ray diffraction (XRD) on untreated soil samples (Fig. 2). The analysis revealed a dominance of calcite, dolomite, and quartz, with smaller amounts of kaolinite and gypsum. Furthermore, the chemical composition was examined using X-ray fluorescence (XRF), and the results are summarized in Table 2.

2.1.2. Lime

The binder used in this study is quicklime, and its physical and chemical properties are provided in Table 3.

Table 1. Physical characteristics of the soil

Atterberg limits						
WL	WP	IP	Bulk density	Absolute density	BMV	pH
(Liquid Limit)	(Plastic Limit)	(Plasticity Index)	(kg/m^3)	(kg/m^3)	(Methylene Blue Value)	
47.85	22.65	25.2	1194.5	2307.69	1.06	8.27

Table 2. Elemental chemical analyses performed by fluorescence XRF

Oxid	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	TiO_2	Na_2O	Cl	P_2O_5	MnO	Loss on Ignition
%	30.4	25.3	8.45	7.53	2.95	1.91	1.31	0.62	0.45	0.24	0.18	0.13	20.98

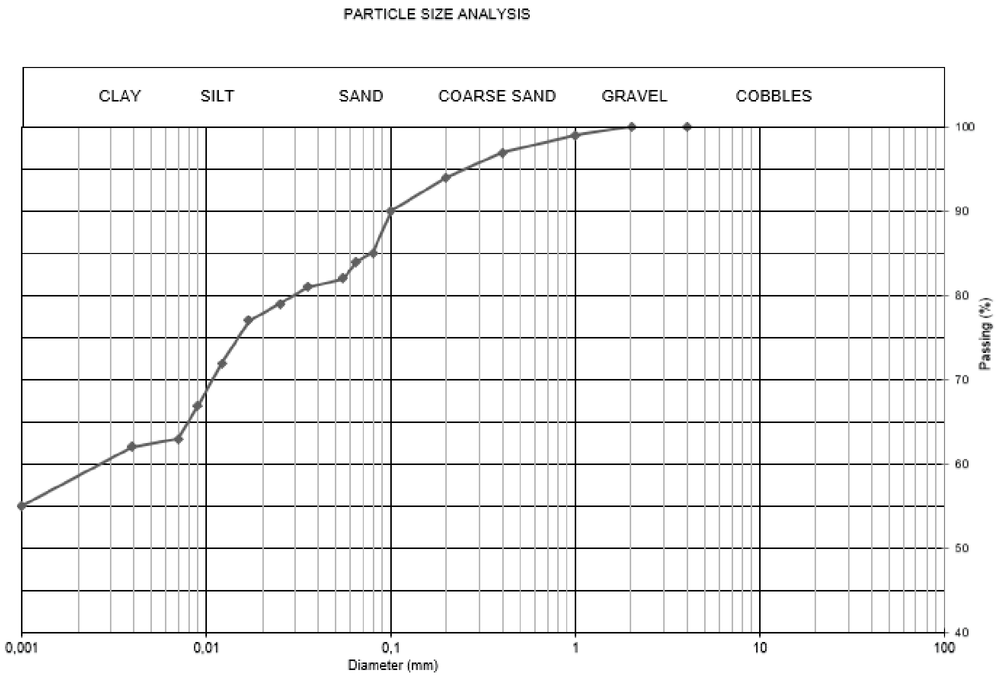

Fig. 1. Particle size distribution curve

Table 3. Properties of lime used in this work [17]

Physical properties	Apparent density (g/l)	600 – 900
	More than 90 µm (%)	< 10
	More than 630 µm (%)	0
Chemical properties	CaO (%)	< 83.3
	MgO (%)	<0.5
	Fe_2O_3 (%)	< 2
	Al_2O_3 (%)	< 1.5
	SiO_2 (%)	< 2.5
	SO_3 (%)	<0.5
	Na_2O (%)	0.4-0.5
	CO_2 (%)	< 5
	$CaCO_3$ (%)	<10
	Insoluble material (%)	< 1

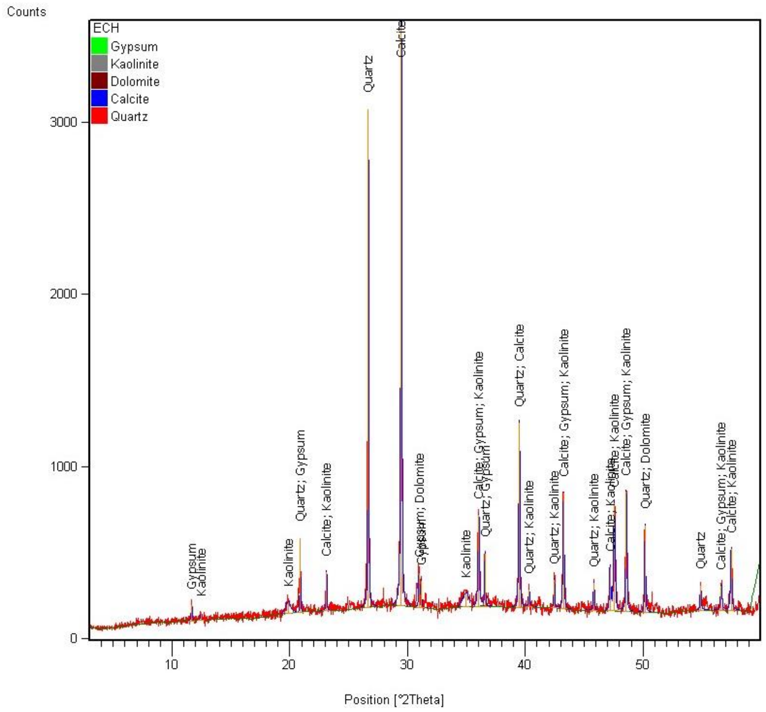

Fig. 2. Soil mineralogical composition identified through X-ray diffraction (XRD)

2.1.3. Water

The water used in preparing the mixtures was potable and maintained at a temperature of 20 ± 2 °C. It complied with the quality standards specified by the NF P 18-404 standard for drinking water, ensuring suitability for construction applications.

2.1.4. Low-density polyethylene (LDPE)

Recycled low-density polyethylene (LDPE) fibers used in this study were sourced from post-consumer agricultural greenhouse film waste. These plastics came from old and deteriorated greenhouses damaged by harsh environmental conditions, particularly strong desert winds. The materials were collected with the aim of reuse them, promoting environmental sustainability and reducing waste from abandoned structures (Fig. 3). The LDPE fibers were incorporated into adobe mixtures at contents of 2%, 4%, and 6%. They were cut into three different lengths to study the effect of fiber size on material performance. Table 4 presents the principal physical and mechanical properties of LDPE. Additionally, tensile strength tests were conducted to examine the mechanical behavior of the LDPE fibers, and the outcomes are graphically displayed in Fig. 4.

Table 4. The physical and mechanical properties of LDPE

Length	Width	Density	Young's modulus	Tensile
(mm)	(mm)	(g/cm^3)	MPa	MPa
10/20/30	2	0.91	600	2090.5

2.2. Methods

2.2.1. Preparation of samples

The clayey soil was first passed through a 2 mm sieve and then dried in an oven at 65°C for 24 hours to ensure total moisture elimination [7,32]. The soil was then mixed with various proportions of quicklime, specifically 6, 8, 10, and 12% by weight, and cured in an oven for periods ranging from 6 to 12 days. This procedure enhanced hydration kinetics and intensified the pozzolanic interaction between lime and the soil minerals to determine the optimal stabilization dosage. Compressive strength was selected as the key criterion for identifying the most effective quicklime content. The moisture content of the mixture was set at 35% of the dry soil weight, corresponding to the average of the Atterberg liquid limit (WL) and plastic limit (WP), calculated using the formula:

$$W\ (\%) = (WL + WP) / 2 \qquad (1)$$

According to the recommendations of the Service d'études sur les transports [33] and Cabane [34], water should be added gradually based on the lime content by weight, then the mixture should be thoroughly blended until it reaches a uniform, properly hydrated paste-like consistency.

This approach, which balances plasticity for optimal workability, has been validated in previous studies [7,35]. The mixing procedure began by combining the dry components (soil and quicklime) for two minutes. Water was then added, and manual mixing continued for an additional two minutes until a homogeneous paste was obtained. The mixture was then manually cast into prismatic molds measuring 4 × 4 × 16 cm and left to air-dry for 72 hours [7]. After demolding, specimens were sealed in airtight plastic bags and cured in an oven at 65°C for seven days, following the protocol described in [36].

Fig. 3. Greenhouses are the source of Recycled low-density polyethylene (LDPE) plastic fiber

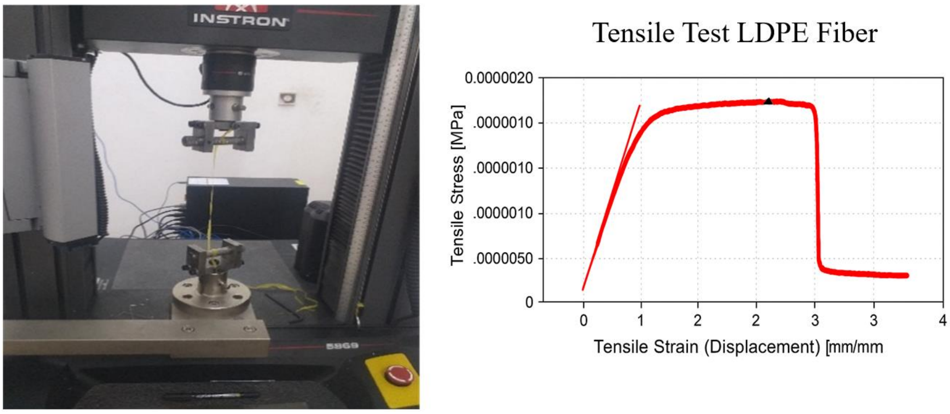

Fig. 4. Tensile strength test of LDPE plastic and its graph curve

Following the determination of the optimal quicklime content, adobe samples were prepared incorporating low-density polyethylene (LDPE) plastic fibers. The dry soil was stabilized using optimal quicklime content, and the dry components were manually mixed for two minutes. Subsequently, the water was added, and the mixture was further agitated for two minutes to ensure homogeneity. Thereafter, plastic fibers were introduced at proportions of 2%, 4%, and 6%, and thoroughly mixed until a uniform blend was achieved. The same procedure was applied to all mixtures prepared with the optimal quicklime content and different fiber proportions to evaluate their combined effect. Each test was conducted using the average of three samples.

The preparation of the lightweight adobe blocks reinforced with low-density polyethylene (LDPE) fibers was carried out according to the proportions summarized in Table 5.

This table presents the composition of the mixtures, including the percentage (quantity) of plastic fibers relative to the soil weight, the fiber length, the lime content, and the amount of water added.

These parameters were selected to investigate the influence of the length and amount of fibers on the mechanical and physical properties of the stabilized adobe blocks

Figure 5 illustrates the procedure for fabricating adobe reinforced with (LDPE) plastic fibers, showing the main stages of preparation, mixing, molding, drying, and curing.

This figure provides a clear overview of the preparation process and helps visualize the different stages involved in the fabrication of the blocks.

Table 5. Proportion of lightweight blocks

Mixture	LDPE Plastic (%) (relative to the weight of soil)	Length of plastic (mm) (relative to the weight of soil)	Lime (%) (relative to the weight of soil)	Water (%) (relative to the weight of soil)	Soil
01	0	/	10	45	90
02	2	10	10	45	88
03	4	10	10	45	86
04	6	10	10	45	84
05	2	20	10	45	88
06	4	20	10	45	86
07	6	20	10	45	84
08	2	30	10	45	88
09	4	30	10	45	86
10	6	30	10	45	84

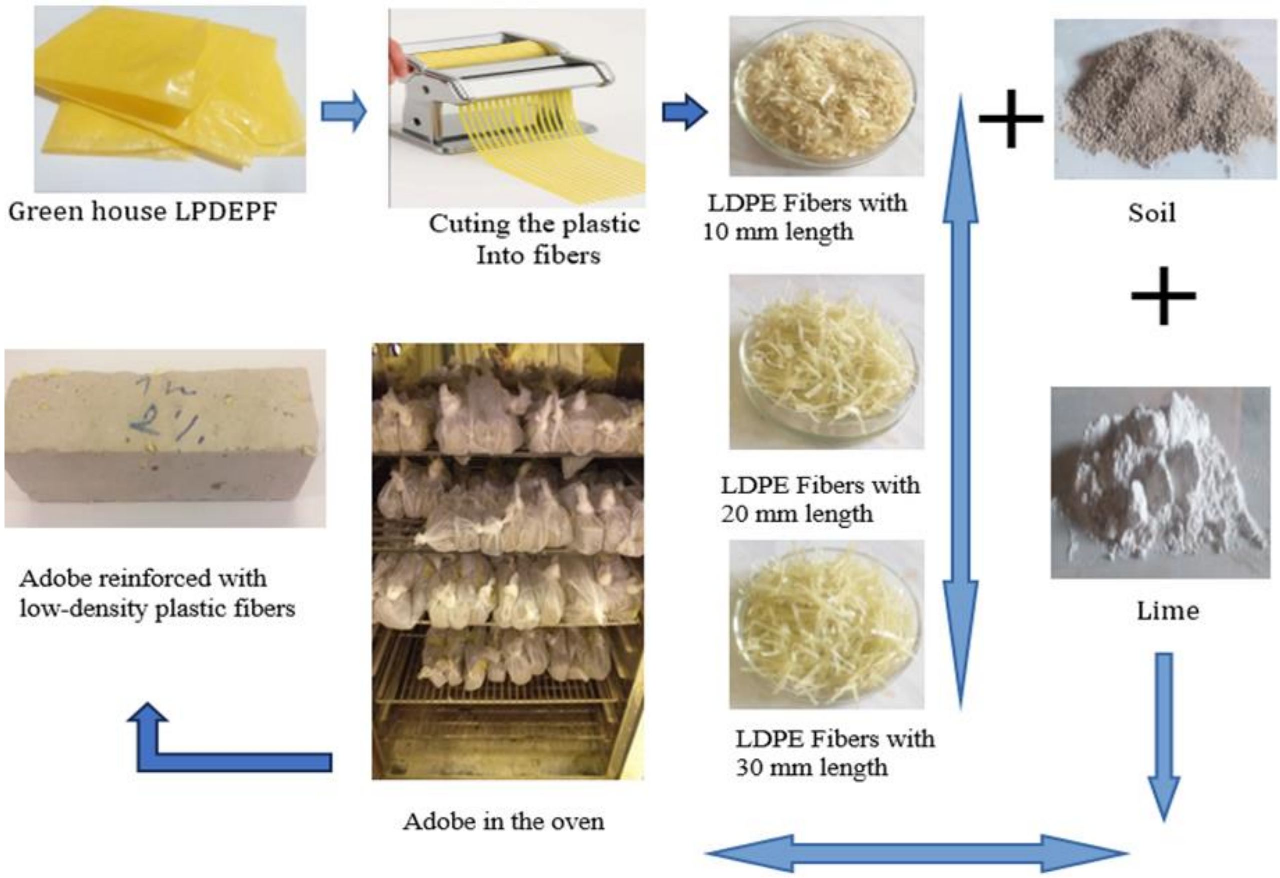

Fig. 5. Procedure for making adobe reinforced with (LDPE) plastic fibers

3. Experimental methodology

This experimental investigation evaluated the prepared specimens through various assessments, including bulk density, ultrasonic and compressive strength tests, tensile tests, total absorption tests, swelling tests, abrasion resistance tests, and wetting-drying evaluations, as illustrated in Table 6.

Table 6. The tests used with standards

Tests	Standards
Physical tests	
The bulk density	NF EN 1015–10/A1
Ultrasonic pulse velocity test (UPV).	EN 12 504–4.
Mechanical tests	
Compressive strength test	NF P 18-406
Splitting Tensile strength test	NF P 18-406
Durability tests	
• Total water absorption test	BS 3921 1985
• Swelling test	XP 13 901
• Abrasion resistance test	XP P13-901
• - wetting- drying	ASTM D559-1989

4. Results and discussion

4.1. Optimization of lime

The optimization process aimed to determine both the most effective quicklime content and the optimal curing duration for soil stabilisation. Compressive strength was selected as the key parameter to evaluate performance.

Different lime dosages (6%, 8%, 10% and 12% by weight) were tested, and for each composition, specimens were cured for 3, 5, 7 and 9 days under controlled conditions. This allowed assessing the combined effect of lime proportion and curing time on strength development and material stability.

The results indicated that both factors significantly influenced the mechanical behavior of the treated soil. An optimal quicklime content of 10% and a curing duration of 7 days provided the best compromise between compressive strength, workability, and pozzolanic reactivity, as shown in Fig. 6.

These findings are consistent with previous studies validating similar curing periods for lime-treated soils [7,35,36].

4.2. Physical tests

This section presents the results of two key physical assessments conducted on the samples: bulk density measurements and ultrasonic pulse velocity (UPV) tests. These evaluations provide insights into the material's structural integrity, porosity, and overall quality.

4.2.1. Bulk density

Figure 7 clearly illustrates that increasing both the percentage and the length of low-density polyethylene (LDPE) plastic fibers in the mix leads to a noticeable reduction in density compared to the control sample. Specifically, the bulk density decreased by around 23.57% relative to the control mixture. This decline is primarily because of the low density of LDPE fibers (0.91 g/cm³), which creates a more porous internal structure and results in lighter adobe bricks when compared to those made from pure clay. According to Laborel-Préneron et al. [37] the typical density range for high-quality, traditionally manufactured adobe bricks falls between 1650 kg/m³ and 1370 kg/m³.

Similar trends were observed in the study by Ranjbar et al. [38], where the use of synthetic polypropylene fibers showed a consistent reduction in density with increasing fiber content from 1387 kg/m³ at 0% LDPE Plastic Fibers to 1060 kg/m³ at 6%. Moreover, increasing fiber length also contributed to the reduction in density. For instance, at 6% fiber content, the density decreased to 1122 kg/m³ with a fiber length of 10 mm, 1101 kg/m³ at 20 mm, and 1060 kg/m³ at 30 mm. This decline is mainly caused by fiber entanglement, which results from longer fibers. The increased length reduces the mixture's homogeneity and bonding efficiency, while also increasing void formation due to fiber displacement and crossing during demolding. These results are consistent with findings reported by several authors, including [13,15]. Among all the parameters studied, fiber content exhibited a more significant influence on bulk density than fiber length.

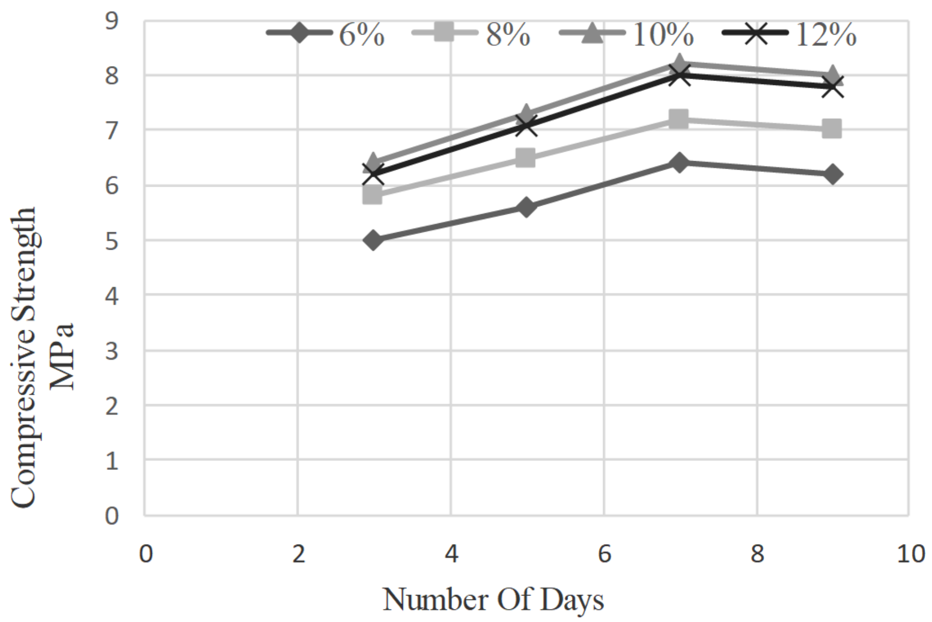

Fig. 6. Variation of compressive strength of adobe bricks as a function of oven curing time

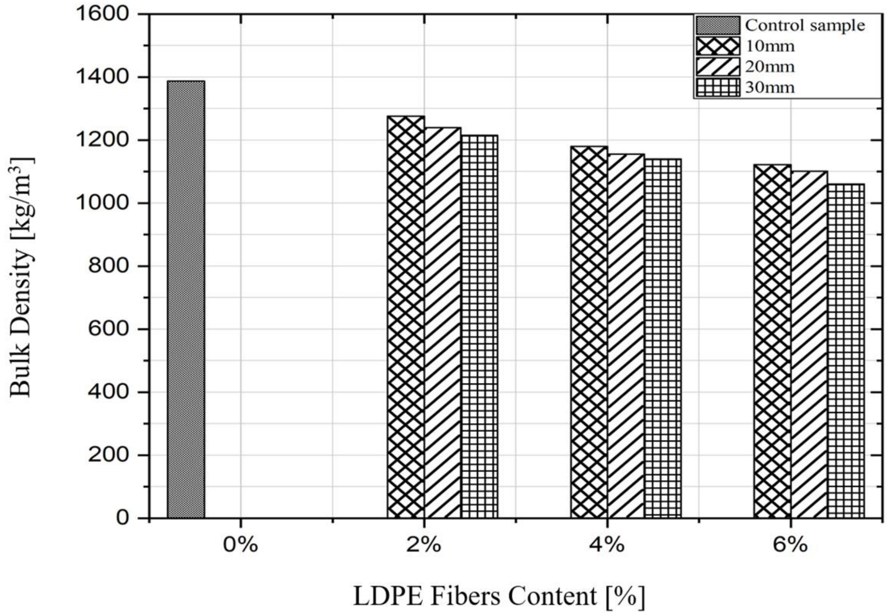

Fig. 7. Bulk density curb of adobe with LDPE plastic fibers

4.2.2. Ultrasonic pulse velocity

The ultrasonic pulse velocity (UPV) test is a widely adopted non-destructive method for assessing mortar consistency and identifying internal flaws such as voids, cracks, or defects [39]. As illustrated in Fig. 8, a clear trend is observed: the ultrasonic pulse velocity (UPV) decreases noticeably with the increase in both the content and length of LDPE plastic fibers incorporated into the clay matrix. This reduction, estimated at around 17.95% relative to the control mix, represents the relative difference derived from the variation between the maximum and minimum measured values over the full range of fiber lengths, reflecting a decline in material density and structural cohesion, which is consistent with the increase in porosity and the formation of voids.

Previous studies Khoudja et al. [7], have established an inverse relationship between porosity and ultrasonic speed: as porosity rises, UPV values fall. The lowest recorded velocity in this study was 1206 m/s for the sample containing 6% LDPE plastic fibers with a fiber length of 30 mm, marking a notable drop from the control value of 1470 m/s. This decrease reflects greater attenuation of ultrasonic waves, primarily due to the increased presence of voids that disrupt the continuity of wave transmission – air, being a poor medium for ultrasonic propagation, significantly slows the wave compared to solids. These findings agree with [40], who found that materials reinforced with date palm fibers also exhibited improved sound absorption characteristics. This reduction in UPV is attributed to the creation of voids, likely caused by the rectangular geometry, smooth surface texture, and entanglement of the LDPE fibers. The fiber length also has a significant impact on UPV. A steady decline in velocity is noted as the fiber length increases from 10 mm to 30 mm. For instance, at 2% LDPE Plastic Fibers content, the UPV decreased from 1400 m/s to 1320 m/s; at 4%, it declined from 1340 m/s to 1280 m/s; and at 6%, from 1305 m/s to 1206 m/s.

Longer fibers hinder soil particles from compacting tightly and filling micro-pores, contributing further to porosity. As a result, the reduction in ultrasonic speed reflects a decline in material compactness and a rise in its acoustic absorption potential.

In conclusion, both fiber content and length influence the ultrasonic pulse velocity of the material; however, fiber content has a more pronounced effect.

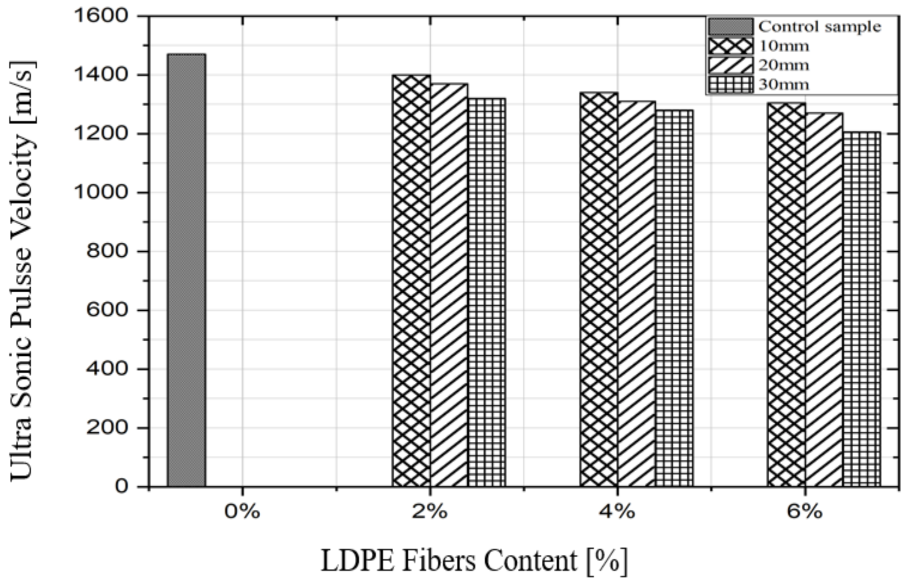

Fig. 8. Effect of LDPE plastic fiber content and length on the bricks ultrasonic pulse velocity of adobe bricks

4.3. Mechanical tests

This section presents the results of two mechanical assessments:

- Compression strength test
- Splitting tensile strength test

4.3.1. Compression strength test

Figure 9 illustrates the effect of varying LDPE plastic fibers content on the dry compressive strength (DCS) of the bricks, a critical parameter for assessing the structural performance of masonry materials. The results reveal a clear decline in compressive strength with increasing fiber content and length across all samples, compared to fiber-free control bricks. The DCS values exceeded the 2 MPa minimum defined by the New Mexico standards were achieved [41], ranging from 8.2 MPa for control samples to 5.1 MPa for the most heavily reinforced specimens. It dropped by about 37.80%, which represents the overall reduction calculated from the maximum and minimum DCS values across all fiber lengths.

This reduction in strength is primarily attributed to the dominant influence of the plastic waste inclusion over the stabilizing effect of quicklime. The limited formation of hydration products cannot compensate for the increased voids introduced by the fibers, which reduce inter-particle contact and friction. The resulting porous network within the bricks adversely affects their load-bearing capacity.

The observed decline in dry compressive strength (DCS) in this study can also be attributed to poor adhesion between the LDPE plastic fibers and the soil matrix, caused by the heterogeneous dispersion of the fibers within the mixture. This suboptimal interfacial bonding leads to fiber agglomeration and insufficient mixing, thereby increasing porosity [42] and resulting in structurally weaker bricks. Consequently, the presence of fibers adversely affects the load transfer efficiency at the waste/matrix interface, which directly compromises the compressive strength of the bricks, especially the fiber content, which had a greater effect than its length. These findings are consistent with previous research [16,43,44] reporting reductions in compressive strength with higher fiber contents. Similarly, [45] demonstrated that increasing coconut fiber content weakened the internal bonding within soil composites, thereby diminishing their compressive strength. This body of evidence underscores the critical influence of fiber-matrix interactions on the mechanical performance of fiber-reinforced earth materials.

4.3.2. Splitting tensile strength test

Figure 10 illustrates the tensile strength of adobe as a function of the (LDPE) plastic fibers content. The data reveal a clear trend of increasing tensile strength with higher fiber proportions and longer fiber lengths. Specifically, tensile strength values increased from 1.4 MPa at 0% LDPE plastic fibers up to 2.4 MPa at 6% LDPE plastic fibers. As an average across all lengths, the increase reached about 71.42%. These values meet the minimum requirement set by both the Masonry Standards Joint Committee (MSJC, 2008) [46,47], which specifies a threshold of approximately 0.21 MPa for earth blocks, and the British Standard BS 6073 (BSI, 1981) [48], which requires a value of 0.65 MPa.

The improvement is primarily attributed to the fibers' ability to enhance cohesion within the soil matrix, as shown in Fig. 11 and Fig. 12, thereby mitigating crack initiation and propagation, which enhances the material's ductility. Moreover, effective fiber-matrix adhesion enables the fibers to share and resist tensile stresses, contributing to the overall mechanical reinforcement [49,50].

In addition, the rise in tensile strength with the increased LDPE Plastic Fibers content is attributed to: first, the intrinsic tensile strength of the (LDPE) fibers themselves, which contributes directly to enhancing the tensile resistance of the adobe blocks, as well as the ability of the fibers to hold the soil matrix together even when fracture begins, and their ability to share some tensile load due to their sliding restriction within the soil matrix [50,51]. Second, the fibers' ability to bridge micro-cracks and prevent their propagation within the soil structure. By redistributing the tensile stresses that develop under tensile loading, the fibers reduce stress concentration and delay the initiation and widening of cracks, which ultimately contributes to a more stable and durable structural performance of the adobe blocks [50,51]. Previous studies [52,16] have similarly demonstrated that incorporating various fiber types into adobe and other earthen materials effectively reduces shrinkage-induced cracking and improves tensile strength. The beneficial effects of combining waste materials with lime stabilization were also visually confirmed during accelerated drying tests, where specimens exhibited no fissures or cracks.

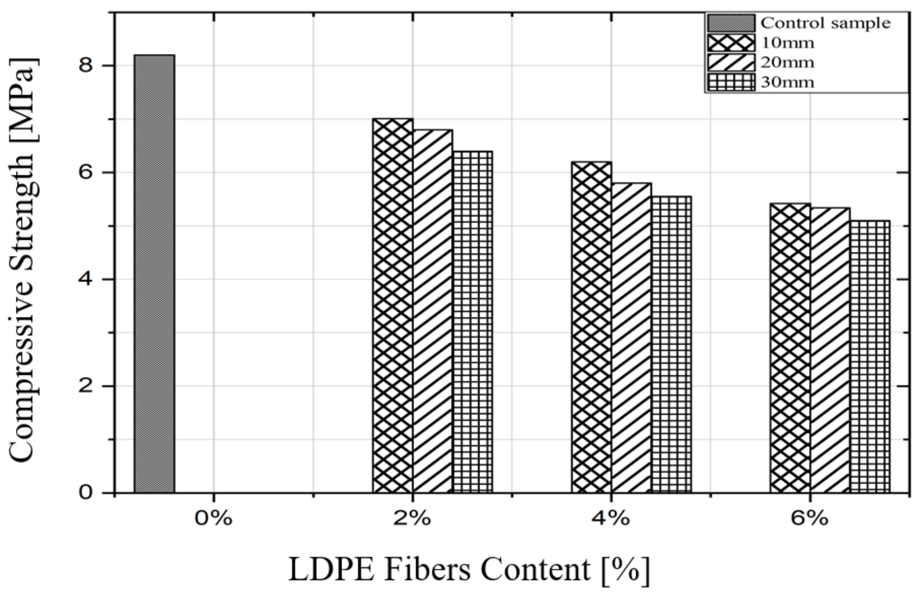

Fig. 9. Effect of LDPE plastic fibers content and length on the compressive strength of adobe bricks

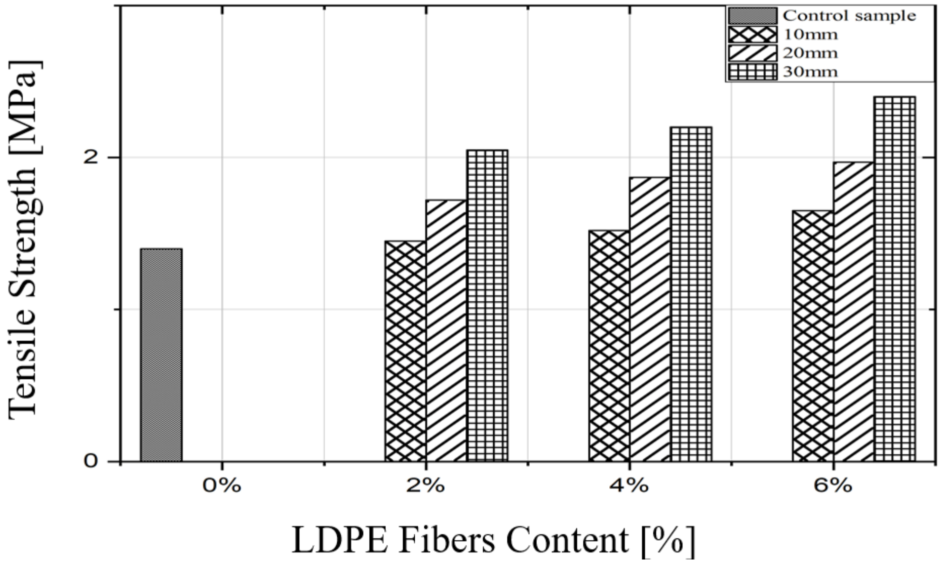

Fig. 10. Effect of LDPE plastic fibers content and length on the splitting tensile of adobe bricks

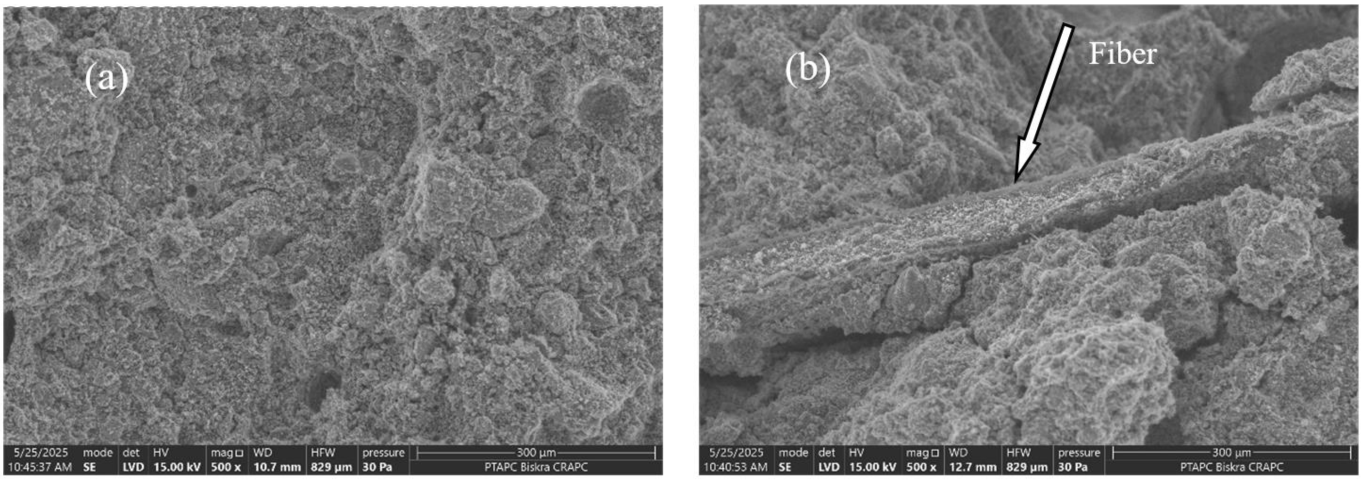

Fig. 11. SEM image (a): adobe without LDPE plastic fiber (b): adobe with LDPE plastic fiber

Fig. 12. Tensile strength test of adobe with LDPE plastic fibers

4.4. Durability tests

This section presents results from four durability assessments: total water absorption, swelling, abrasion resistance, and wetting- drying cycles.

4.4.1. Total water absorption test

Figure 13 presents the influence of LDPE plastic fibers content and fiber length on the total water absorption (TWA) of the bricks after 24 hours of immersion. The results indicate an increase of approximately 29%, rising from 18.5% at 0% LDPE fibers to 23.9% at 6% LDPE fibers with a fiber length of 30 mm. For fibers of 10mm length, water absorption values rise more moderately, registering approximately 19.5%, 21.6%, and 23.5% for fiber contents of 2%, 4%, and 6%, respectively. Overall, the data demonstrate a positive correlation between fiber content and fiber length and the total water absorption of the adobe bricks.

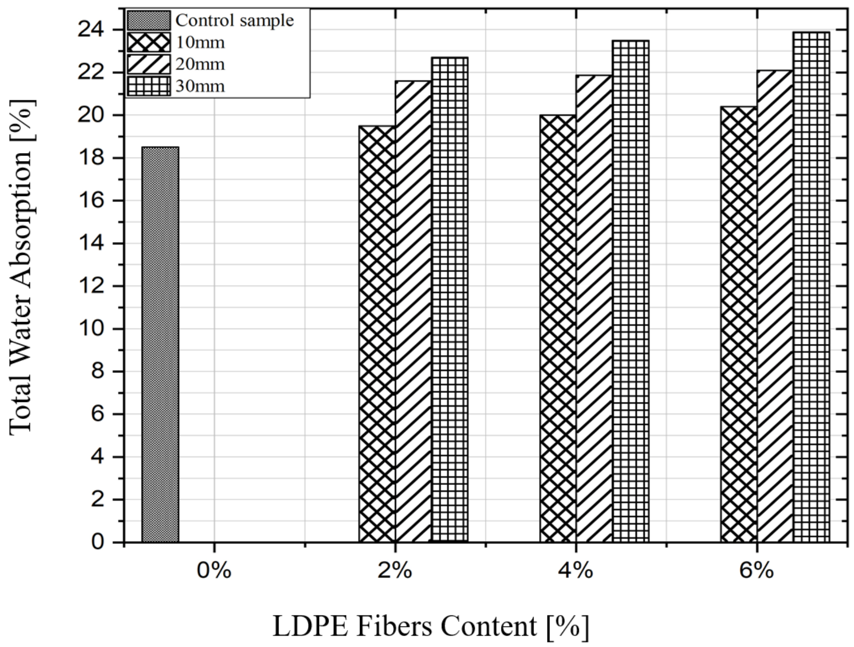

Fig. 13. Effect of LDPE plastic fibers content and length on the total water absorption of adobe bricks

The water absorption test is commonly employed to evaluate the durability of adobe bricks under humid conditions and acts as an indicator of their resistance to water exposure. The inclusion of fibers in adobe bricks increases porosity, which in turn raises water absorption levels [53]. When the bricks are submerged, the pores become filled with water, allowing it to infiltrate the material more easily. The ease of water penetration is influenced by the pore structure and how well pores are connected. These results corroborate the findings reported by Rômulo [13], who observed that water absorption increased with higher glass fiber content. This trend is indicative of enhanced water ingress within the specimens, which can be attributed to the increased permeability and porosity caused by the addition of fibers. Several factors significantly influence water absorption behavior, including the cohesive properties of clay minerals in the soil, particle size distribution, and overall porosity of the material.

4.4.2. Swelling test

Figure 14 illustrates the changes in swelling behavior of adobe bricks after four days of water immersion, as a function of varying LDPE plastic fibers content and fiber length. The results reveal a positive correlation between swelling degree and both fiber content and fiber length. The swelling values for all tested bricks ranged from 0.33% to 0.43%. It rose by about 30.30% based on the mean of all lengths. Specifically, for bricks reinforced with 10 mm fibers, swelling values were recorded at 0.34%, 0.36%, and 0.38% for fiber contents of 2%, 4%, and 6%, respectively, compared to 0.33% for the control samples without fibers. For bricks containing 20 mm fibers, swelling increased to 0.36%, 0.39%, and 0.41%, while those with 30 mm fibers exhibited swelling values of 0.38%, 0.40%, and 0.43%.

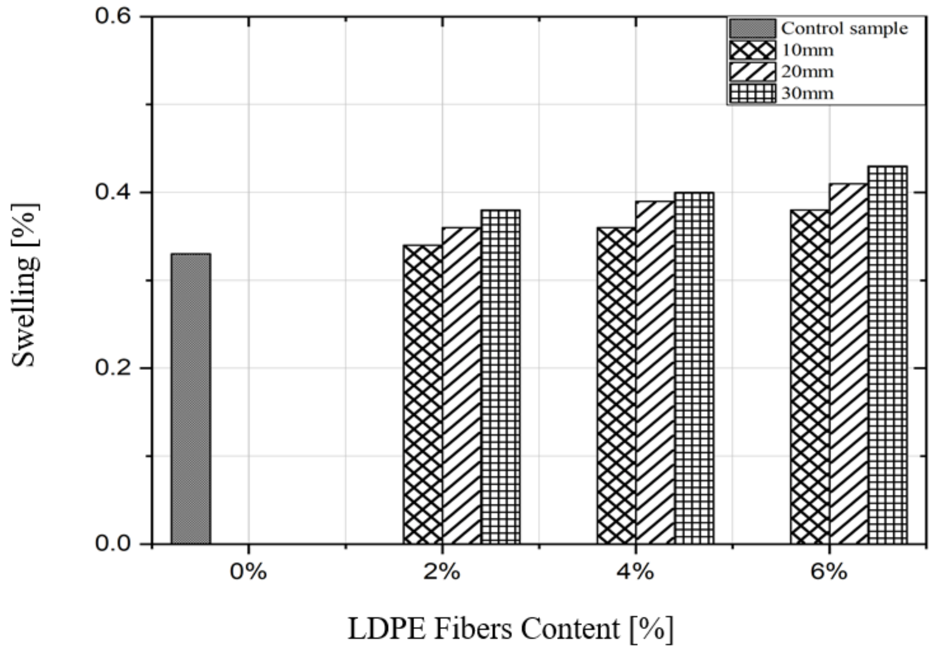

Fig. 14. Effect of LDPE plastic fibers content and length on the swelling of adobe bricks

The minimum swelling (0.34%) was observed in bricks with 2% LDPE plastic fibers and 10 mm fiber length, whereas the maximum swelling (0.43%) corresponded to bricks reinforced with 6% LDPE plastic fibers and 30 mm fibers. This swelling behavior is attributed to the interaction of water with the soil's physico-chemical constituents, namely gypsum, calcite, quartz, and kaolinite. Additionally, the curing process may influence the distribution and bonding of the fibers within the matrix, which can lead to an increase in internal porosity. The enhanced water absorption associated with longer fibers and higher fiber content leads to greater porosity, thereby weakening the bond between the matrix and fibers. In summary, swelling increases with higher fiber content and longer fiber length, corroborating the findings reported in [16,17].

4.4.3. Abrasion resistance test

The abrasion resistance test assesses how well a material can endure wear caused by friction or abrasive forces. During this test, particles are dislodged from the sample at points of contact, acting as abrasive agents that progressively wear down the material.

This process effectively simulates the impact of climatic conditions typical of arid environments. As shown in Fig. 15, the abrasion resistance of all tested adobe bricks ranges between 2.1 and 4 cm^2/g. It rose by about 90.47%, specifically for fiber length of 10 mm.

All abrasion coefficient values surpass the minimum limit of 2 cm^2/g specified by the XP P13 901 standard [18]. These results confirm the beneficial effect of incorporating LDPE plastic fibers on abrasion resistance, with resistance generally increasing alongside fiber content. The improvement in abrasion resistance observed with increasing LDPE fiber content can be mainly attributed to its mechanical reinforcing effect. Although there is no adhesion between these fibers and the clay matrix, their presence promotes effective physical anchorage, which limits the detachment of surface particles and allows for the redistribution of shear stresses during friction. This behavior is explained by the ability of the fibers to connect weak zones and delay the propagation of micro-cracks, thereby enhancing the material's toughness. Moreover, their flexibility and ability to deform under stress provide an efficient crack-bridging and energy-dissipation mechanism, which compensates for the lack of adhesion and overall improves the material's wear resistance. Indeed, a higher abrasion coefficient is commonly associated with improved brick longevity, consistent with findings reported in [16].

4.4.4. Wetting-drying test

Almost all adobe bricks, whether reinforced or unreinforced, tend to absorb water when fully immersed, followed by shrinkage and crack formation during the drying phase due to evaporation. In this context, [54] recommends strict limits on weight loss according to ASTM D559 [55], especially for buildings located in urban areas, where the maximum acceptable weight loss is set at 5% for locations with an annual rainfall of 500 mm. Figure 16 illustrates the relationship between the proportion of LDPE Plastic Fibers waste and the weight loss after twelve wetting-drying cycles. The results demonstrate a positive effect of LDPE plastic fibers incorporation in reducing weight loss. Specifically, weight retention improved progressively with increasing fiber content at 0%, 2%, 4%, and 6%. LDPE fibers exhibit high stability under wetting–drying cycles and do not undergo significant degradation. Consequently, the mass loss observed during these cycles tends to decrease due to the partial replacement of the earthen matrix by these hydrophobic fibers, a trend supported by findings from [16]. It was noticed that the mass loss decreases as the content and the length of LDPE plastic fibers increases from 3% with 0% LDPE plastic fibers to 1.01% with 6% LDPE plastic fibers.

After the wetting-drying cycles, the mass loss was reduced by 66.33% when averaged over all lengths. Importantly, all observed weight loss values remained below the 5% threshold, thereby meeting the sustainability criterion. The inclusion of LDPE fibers notably reduced weight loss and enhanced the durability of the adobe bricks, confirming that all tested specimens-maintained weight losses within acceptable limits.

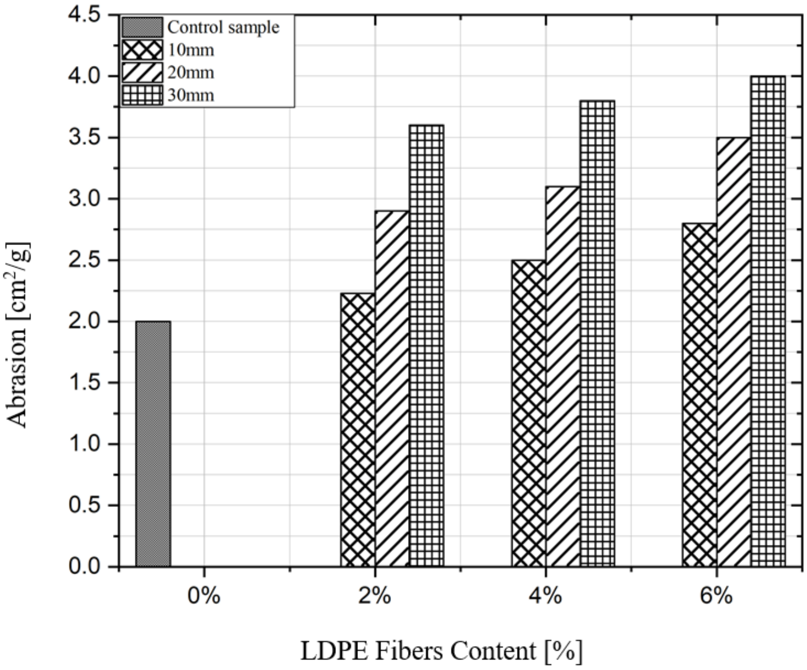

Fig. 15. Effect of LDPE plastic fibers content and length on the abrasion resistance of adobe bricks

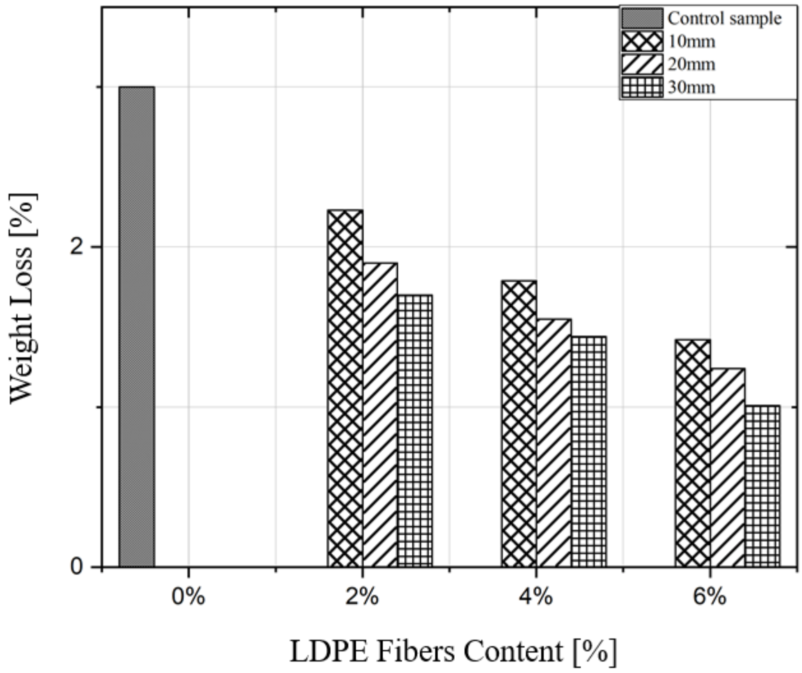

Fig. 16. Effect of LDPE plastic fibers content and length on the weight loss of adobe bricks

5. Conclusions

This experimental study primarily aimed to evaluate the mechanical properties and durability of adobe blocks reinforced with plastic fibers, specifically low-density polyethylene (LDPE) plastic fibers of varying lengths and proportions. Based on the findings, the following conclusions have been reached:

- The highest compressive strength of the adobe blocks was achieved with an optimal lime content of 10% within a curing period of 7 days.
- Both the bulk density and the ultrasonic pulse velocity decreased with increasing LDPE plastic fibers, content and fiber length, showing maximum reductions of 23.57% and 17.95%, respectively.
- An increase in LDPE plastic fibers content, regarding both fiber length and quantity, generally resulted in a decrease in compressive strength of around 37.80%, while still meeting the minimum performance requirements set by earthen construction standards.
- Conversely, tensile strength improved significantly with the increase in both fiber length and content, reaching a rise of 71.42% in adobe bricks containing 6% fiber with a length of 30 mm.
- The incorporation of LDPE plastic fibers caused an increase in total water absorption and swelling of the adobe bricks.
- The durability of the adobe was enhanced in both wetting-drying and abrasion resistance tests as the LDPE plastic fibers content increased from 0% to 6%.
- Both the length and the content of LDPE plastic fibers influence the physical and mechanical properties and the durability of adobe blocks. However, the fiber content plays a more influential role than the fiber length.

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