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Formulation and Physico-Mechanical Characterization of Bricks Composed of Recycled Thermoplastics and Toukra Soil

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Abstract

The recovery of thermoplastics has a major impact on our cities, both in terms of the environmental impact of waste disposal and the economic impact of its use in construction materials. The aim of this study is to manufacture bricks from recycled thermoplastics, more specifically low-density polyethylene (LDPE) packaging from households and landfill sites in the 9th arrondissement. The technological evolution that humanity has undergone in recent years has made a wide variety of building materials available, and the use of earth as a material will make use of certain secondary products known as additives. These additions may be of mineral, animal or vegetable origin, and also of low purchasing power, but create a very strong bond once they are combined. The main aim of the present work is to contribute to the characterization of bricks produced from thermoplastics and a soil sample taken from the bank of the Chari at Toukra in the 9th arrondissement of the capital, which are resistant to natural hazards such as bad weather and flooding, which always cause enormous losses with each passing season. The results of the various tests carried out show that the material can help to overcome not only the lack of mechanical strength, but also the impermeability that is the cause of the deterioration and ruin of the building in clay without any addition modifying its properties.

Keywords

Characterization, Brick, Thermoplastic, Clay, Waste

1. Introduction

The enhancement of local construction materials has become a significant response to societal and economic challenges, particularly in developing countries.

Earth, as a natural raw material that remains underutilized, represents one of the least developed sectors in these regions. However, it has recently attracted renewed attention due to the ongoing housing crisis, especially prevalent in developing nations [1].

For various reasons, earthen materials have seen a resurgence of interest on the international stage, a trend that has been accompanied by advancements and modernization in production techniques [2].

A material historically employed in construction, particularly in rural settings, is found throughout much of the national territory and has served as a locally sourced building material for thousands of years [3].

Readily available, this material has been utilized through various techniques, which differ by region and depend on its specific properties. In order to enhance these properties, numerous innovative technological research pathways are currently being explored—many of which are emerging, low-energy, and emit minimal greenhouse gases [4].

At times, its use has been complemented by other matrices of mineral, plant, or animal origin, selected based on particular properties relevant to its application.

In addition, the management of plastic waste represents a significant environmental challenge both globally and, more acutely, in Chad. Population growth, alongside evolving consumption patterns, has led to an increase in various types of waste, notably plastic packaging waste. The widespread dissemination of plastic waste—including bags, plastic sacks, containers, tires, and PVC pipes—discarded in the environment is a major contributor to urban environmental degradation.

According to Doublier [5], these materials are non-biodegradable and make a substantial contribution to environmental pollution. In response to the issues posed by this waste, a number of studies [6]-[8], have proposed various recovery methods, including the incorporation of plastic bags into the manufacture of construction materials.

Building on this body of work, the present study investigates the feasibility of incorporating plastic waste (LDPE—low-density polyethylene) into a clay matrix, with the aim of reducing the overall cost of the resulting material. The effects of varying the proportion of plastic waste on the physical and mechanical properties of the new composite material have been systematically examined and analyzed.

2. Materials and Methods

Materials collected for the determination of physical characteristics

2.1. Materials

Study Area

The TOUKRA site, chosen for this study, is situated south of the city of Ndjamena, at the following GPS coordinates:

512128°27'36''/1331123°12'3.6''

512218°42'46.8''/1330888°47'20.4''

512344°2'38.4''/1330545°44'52.8''II

512428°1'15.6''/1330328°34'26.4''

2.2. Materials

This area is located along the Chari River, on the southern side of the capital, N'Djamena.

The experimental investigations were conducted in various laboratories: physical and geotechnical tests were performed at the laboratory of the National School of Public Works, while mechanical tests were carried out at the Building and Public Works Laboratory.

2.2.1. Description of Materials

1) Description of the Clayey Soil Material

Raw earth consists of various particles, including quartz, clay minerals, feldspars, micas, carbonates, and hydroxyls. The physical properties of the soil are therefore determined by the nature of its constituent minerals. The interaction between water and clay particles imparts cohesion to the soil.

2) Presentation of Plastic Waste

Thermoplastics refer to plastic packaging waste that is disposed of into the environment following the consumption of their contents; such waste primarily consists of polyethylenes. Polyethylene is among the simplest and most cost-effective polymers. It is also the most commonly used plastic, accounting for approximately half of all plastic packaging materials (**Figure 1**).

Figure 1. Plastic waste collection.

2.2.2. Sampling Method and Sample Collection

The sample was collected at a depth of 1 meter and stored in plastic bags to shield it from sunlight and other environmental factors that might adversely alter its properties (**Figure 2**).

Figure 2. Soil sampling.

2.2.3. Material Characterization

In order to incorporate a material into a composite like ours, it is essential to determine its preliminary properties, as these directly influence the characteristics of the resulting composite.

Accordingly, the following identification tests were conducted: (**Figure 3**)

1) Particle Size Distribution Analysis by Sieving

(a) (b) (c)

Figure 3. (a) After washing; (b) Sieve stack; (c) Balance.

The procedure involves disaggregating clumped particles from a known mass of material by agitation in water (**Figure 3(a)**). After drying, the soil is separated using a series of sieves (**Figure 3(b)**), and the cumulative residue retained on each sieve is sequentially weighed with a balance (**Figure 3(c)**). The percentages of retained and passing fractions are then calculated using formulas (1) and (2).

$$\%\text{ refuse} = \frac{Mr}{Mi} * 100 \quad (1)$$

$$\%\text{ passing} = 100 - \%\text{ refuse} \quad (2)$$

2) Atterberg Limits

These tests are employed to determine parameters such as the liquid limit (Wl), plastic limit (Wp), and the plasticity index (PI). The analyses were conducted using the Casagrande method, adhering to the established standards, specifically: NFP, NF P 94-056, and NF P 94-057 (**Figure 4**).

(a) (b) (c)

Figure 4. (a) Casagrande apparatus; (b) Clay rod; (c) Tare weight measurements.

3) Bulk Density

The mass of the solid particles is determined by weighing, while their volume is measured using a pycnometer. This method is applicable to all intact or remolded soils in which the largest particle size does not exceed 2 mm (**Figure 5**).

Figure 5. Water pycnometer for density measurement.

3. Formulation

3.1. Manufacture of Soil-Reinforced Thermoplastic Bricks

After selecting and proportioning the raw materials, the process of producing soil-thermoplastic blocks commences. This production is conducted through several successive stages.

1) The first step involves preparing the soil to achieve a dry and homogeneous mixture, which comprises three successive operations: drying, screening, and disaggregation (**Figure 6(a)**). Screening removes undesirable materials such as roots, leaves, and particles with diameters exceeding the specified limit; typically, only soil particles smaller than 5 mm are retained. Disaggregation serves to break down clay-bound gravel agglomerates and to crush certain gravel particles, ensuring that at least 50% of the material consists of grains smaller than 2 mm in diameter.

2) The third step involves melting the plastic at a temperature of at least 175˚C, carefully monitoring the duration of this process (Figure 6(b)).

3) In the fourth step, the pre-weighed soil (1200 g) is added to the molten plastic, and the mixture is stirred continuously over heat to maintain the temperature until a homogeneous paste is formed (Figure 6(c)).

4) The fifth step entails fabricating test specimens with dimensions of 4 × 4 × 16 cm, in accordance with the relevant standard, and compacting them by tamping (Figure 6(d)).

5) Finally, the sixth step consists of demolding the specimens after three hours, once the material has sufficiently cooled (Figure 6(e)).

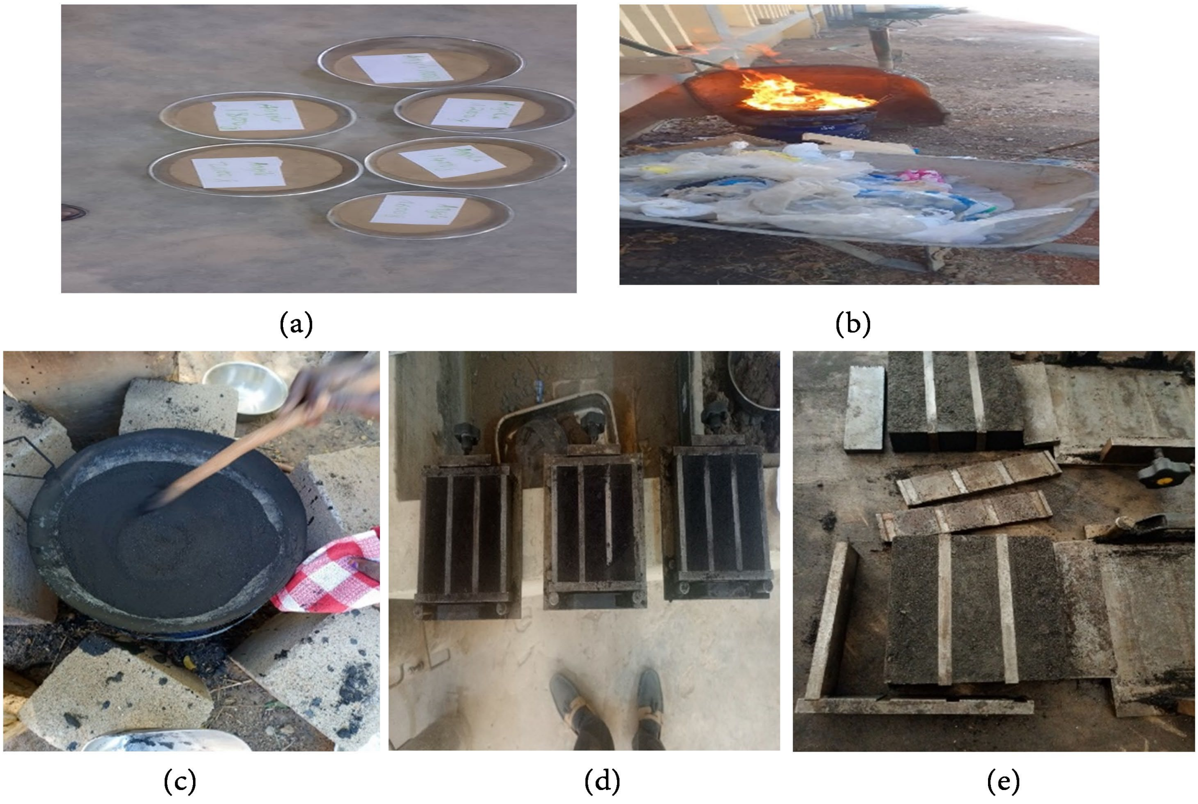


Figure 6. (a) Soil proportioning; (b) Proportioning and melting of plastic waste; (c) Hot mixing; (d) Molding of the mixture; (e) Demolding.

3.2. Characterization of Specimens

Physical Properties

1) Water Absorption by Total Immersion

Water absorption is determined in accordance with the NF EN 14617-1 73 standard, which specifies the principle, procedure, and result calculation. The purpose of this test is to determine the mass of water that the specimens can absorb after being completely immersed for a specified period (Figure 7).

$$W\% = \frac{m_2 - m_1}{m_1} \times 100$$

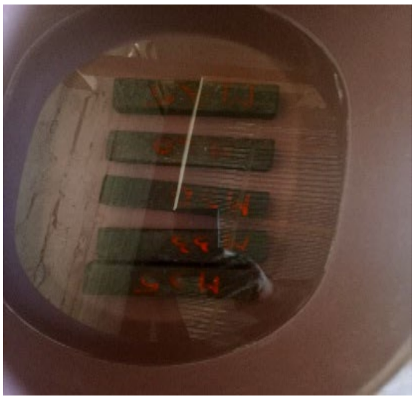


Figure 7. Immersion of specimens in water.

2) Mechanical Testing

Mechanical properties were characterized by measuring flexural and compressive strengths on $4 \times 4 \times 16$ cm^3 specimens, in accordance with standard NF P 18-407.

i) Compression Testing

The objective of the test is to determine compressive strength.

The failure load corresponds to the maximum load recorded during the test.

Compressive strength measurements were performed at 7 and 28 days of curing using a hydraulic compression testing machine with a maximum capacity of 150 kN, equipped with a compression fixture suitable for 4x4x16 cm molds. The reported compressive strength value represents the average crushing stress obtained from two specimens.

ii) Flexural Tensile Strength Test

Specimens measuring $4 \times 4 \times 16$ cm were employed to assess the tensile strength. Measurements were conducted using a press conforming to the NF P 18-407 standard, fitted with a three-point bending apparatus. This test is used to determine the flexural tensile strength of the material under investigation and is the most widely adopted method. The procedure involves subjecting a specimen to flexural loading until failure (Figure 8).

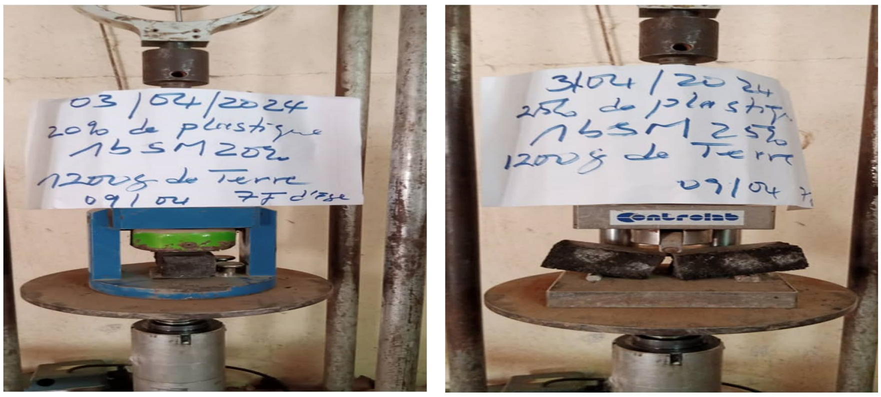
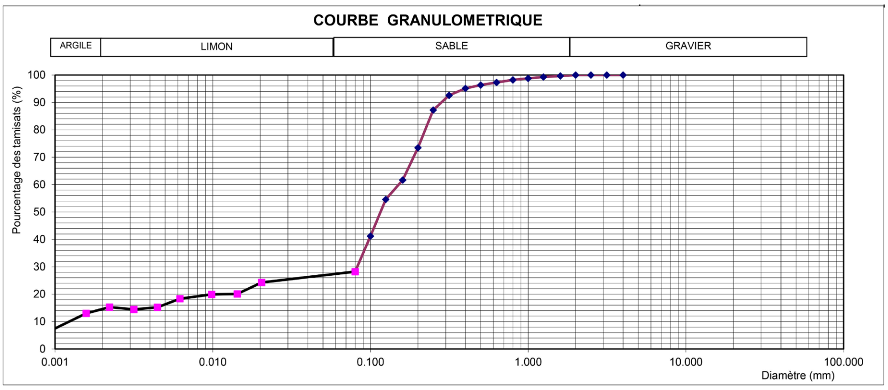


Figure 8. Compression testing and flexural tensile strength.

4. Results and Discussion

1) Particle Size Analysis (Curve 1)

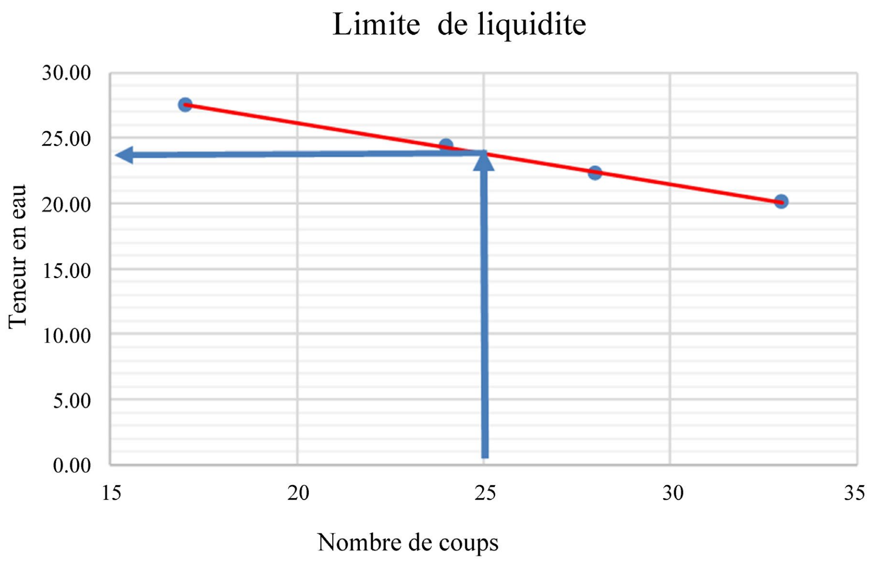


Curve 1. Particle size distribution analysis of the Toukra site.

The objective of particle size analysis is to determine the distribution by weight of soil grains based on their size. This analysis is performed by sieving for the fraction with particle sizes greater than 0.08 mm, and by sedimentation for the fraction with particle sizes less than 0.08 mm. The particle size distribution curve provides an initial means to identify the material type present in the analyzed sample. Specifically, upon examining the particle size distribution curve of a clay-based sample, the respective proportions of each soil type, expressed as percentages, are summarized in the following table (Table 1):

Table 1. Results of the particle size distribution analysis.

Composition	Clay	Slit	Fine Sand
Percentage	40	29.85	26.36



Curve 2. Liquid limit.

Based on the results of the Atterberg tests performed on the sample, which enable the determination of precise values for the plastic and liquid limits—parameters that are crucial for soil classification—the tests yielded a liquid limit of 23.52%, a plastic limit of 17.66%, and a plasticity index of 5.85% (**Curve 2**). According to the CASAGRANDE chart, these values indicate the presence of a low-plasticity organic material, classifying the soil as organic (**Table 2**).

Table 2. Atterberg limits.

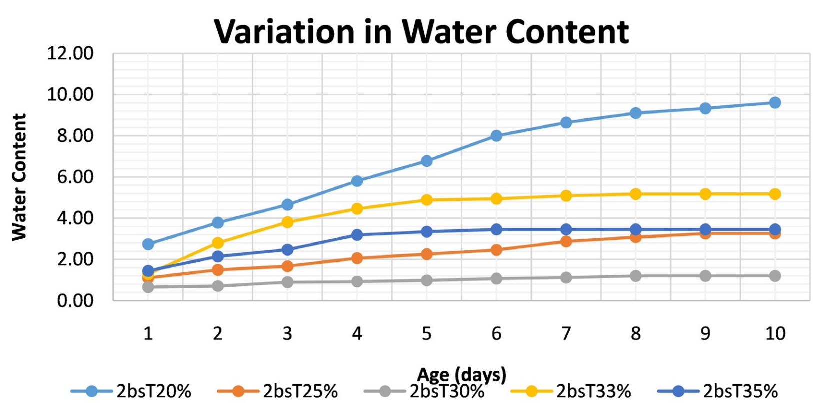
WL:	23.52
Wp:	17.66
IP:	5.86

2) Physical Analyses (Table 3)

Table 3. Particle density.

Pycnometer with stopper (g)	m1	110	110
Soil + pycnometer with stopper (g)	m2	230	230
Soil + distilled water + pycnometer with stopper (g)	m3	443.9	444.1
Distilled water + pycnometer with stopper (g)	m4	370	370
Density of water (g/cm^3)	$\rho\omega$	1	1
Particle density (g/cm^3)	ρs	2.64	2.61
Mean value (g/cm^3)			2.63

Note: This value ranges from 2.6 to 2.8 as specified by the standard.



Curve 3. Variation in water content with age for different mix proportions.

3) Determination of Water Absorption Rate

The water absorption rate (ρ) of the sample mass as a function of immersion time was determined using the following equation:

$$\rho = \frac{m_2 - m_1}{m_1}$$

where m_2 is the wet mass after immersion and m_1 is the dry mass prior to immersion. The mass of the specimens before and after immersion was measured using an electronic balance with a digital display, accurate to 0.1 mg (Curve 3).

Mechanical Properties

For each test, the mechanical strength results of the sand concrete correspond to the average of three measurements performed on three specimens at 7 and 28 days of curing, as illustrated in the following figures (Figure 9 and Figure 10):

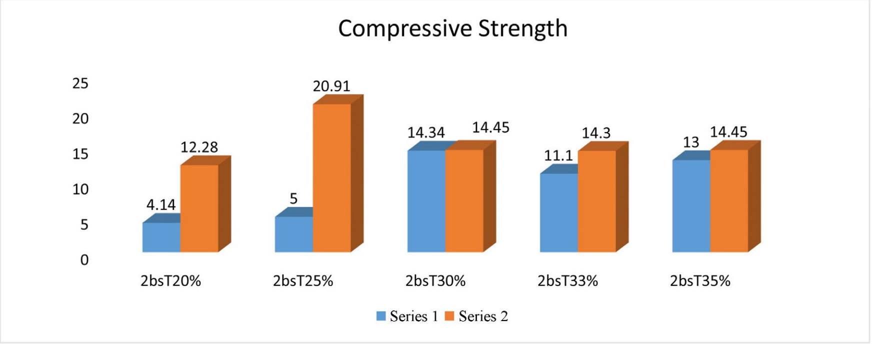


Figure 9. Compressive strength.

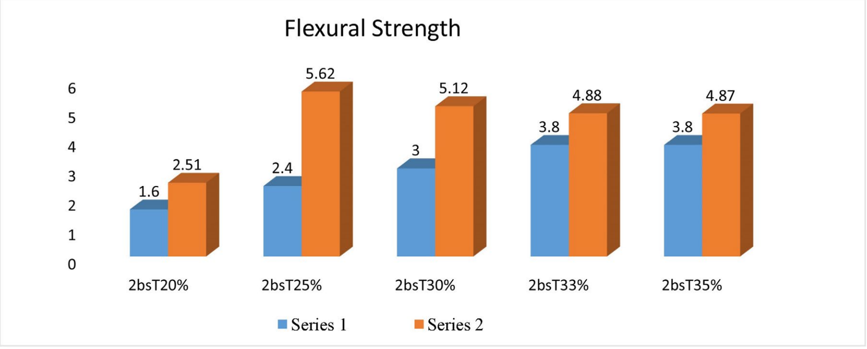


Figure 10. Flexural strength.

In accordance with the specimen preparation protocol for compressive testing, each series of specimens was subjected to crushing at designated intervals (7 days and 28 days). The results indicate that compressive strength values exhibit fluctuations, which can be attributed not only to the proportion of thermoplastics incorporated but also to the compaction conditions during molding. Specifically, at 7 days, compressive strength increases from 4.14 MPa to 14.34 MPa before declining to 13.00 MPa. At 28 days, the compressive strength ranges from 12.28 MPa to 20.91 MPa before decreasing to 14.45 MPa. Regarding flexural strength, at 7 days, there is a notable increase from 1.6 MPa to 3.8 MPa. At 28 days, the flexural strength exhibits variability, ranging from 2.61 MPa to 5.62 MPa before decreasing to 4.87 MPa.

Overall, the thermoplastic present in the clay exhibits advantageous properties for its intended applications, notably conferring superior compressive and flexural strength compared to other materials—parameters that constitute a central focus of our study.

5. Discussion

The results obtained indicate that our material adequately addresses the requirements of the context. When benchmarked against other civil engineering materials, it demonstrates high quality. In alignment with the findings of Cyrille Prosper Ndepete [9], who investigated the incorporation of plastic waste as a binder in construction and reported water absorption rates ≤ 6% in accordance with NBN EN 1338 standards, we assert with confidence that bricks containing at least 25% plastic exhibit excellent quality.

From the perspective of mechanical performance, the material displays remarkable compressive strength, with a maximum value of 20.91 MPa observed at a 25% plastic content. However, this strength decreases to 14.45% as the plastic proportion surpasses the optimal threshold, a phenomenon attributable to increased shrinkage during cooling [10].

Regarding flexural tensile strength, the results reveal that at the same 25% plastic content, the 28-day flexural strength reaches 5.62 MPa, but subsequently decreases to 4.87 MPa as the plastic content increases further. This trend is consistent with the observations reported by Guendouz *et al.* [11] and Ganiron [12], indicating that exceeding this plastic content results in diminished mechanical resistance.

6. Conclusion

This study addresses the development of bricks utilizing low-density plastic waste, a matter of growing concern in contemporary society. The primary aim is twofold: firstly, to mitigate plastic waste pollution in urban environments; and secondly, to propose a recycling strategy that incorporates these wastes as binders within a clay matrix for brick production, subsequently assessing their physical and mechanical properties. The outcomes of the various property tests indicate that the valorization of materials derived from low-density thermoplastics presents a promising solution to several challenges, as demonstrated in the context of this research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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