



Research Article

Valorisation of LDPE Waste Reinforced with PET as a Binder in Development of Construction Materials

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Abstract

The proliferation of plastic waste represents one of the major environmental challenges facing modern society. This study aims to valorise lightweight plastic waste, which is currently subject to low recycling rates, in order to reduce its environmental impact. To this end, a mixture of low-density polyethylene (LDPE) waste and polyethylene terephthalate (PET) waste was melted at a temperature of 250 °C. Following complete melting, sand was incorporated into the molten polymer, and the mixture was progressively mixed until a homogeneous paste was obtained. Composite materials were produced with plastic contents of 10%, 20%, 30%, 40% and 50%, the remainder consisting of sand. The resulting paste was then cast into moulds and compacted using an electric impact compactor applying 60 blows per mould. The manufactured materials were subsequently subjected to physical and mechanical testing. The best performance was achieved by the formulations containing 40% and 50% plastic. The corresponding compressive strengths reached 10.13 MPa and 21.85 MPa, respectively, while the flexural strengths were 4.33 MPa and 10.55 MPa, respectively. The mechanical properties of the developed composites comply with the requirements of the relevant standards. These findings demonstrate that the developed materials have significant potential for use in road pavement applications.

Keywords

Low-density Polyethylene, Polyethylene Terephthalate, Sand, Compressive Strength, Flexural Strength

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1. Introduction

Global population growth, estimated at more than eight billion inhabitants, has been accompanied by a continuous increase in the consumption of manufactured goods, particularly plastic materials [21]. Owing to their properties, including light weight, durability, corrosion resistance and low production cost, plastics are now widely used in numerous sectors, such as packaging, construction, transportation and agriculture [3]. However, their often short service life contrasts sharply with their extremely long persistence in the environment, making plastic waste management one of the major environmental challenges of the twenty-first century.

Since the 1950s, global plastic production has grown steadily. Between 2000 and 2019, it doubled to reach 460 million tonnes, generating approximately 353 million tonnes of plastic waste [15]. Worldwide plastic production is expected to continue increasing over the coming decades [11]. Due to their poor biodegradability, plastic wastes accumulate in terrestrial and aquatic environments, causing soil pollution, blockage of drainage systems, flooding and ecosystem degradation. This situation has become a major concern for both public authorities and the scientific community.

In Togo, particularly in Greater Lome, rapid urbanisation, population growth and changing consumption patterns have led to a significant increase in the generation of solid waste. Among these wastes, plastics account for a substantial proportion, with low-density polyethylene (LDPE) flexible plastics being particularly predominant and their recovery pathways remaining very limited [18]. Although Decree No. 2011-003/PR of 5 January 2011 regulates the management of plastic bags and packaging and promotes their recycling, large quantities of plastic waste continue to be discarded into the environment, thereby exacerbating pollution problems.

In response to this challenge, the valorisation of plastic waste into construction materials has emerged as a promising approach that aligns with the principles of the circular economy and sustainable development. Several studies have demonstrated that incorporating plastic waste into composite materials not only reduces the volume of waste destined for landfill but also produces materials with mechanical properties suitable for various civil engineering applications. Accordingly, Agyeman et al. [1] demonstrated that recycled plastic waste can be used as a binder in the production of paving blocks with satisfactory mechanical performance for road applications. Similarly, Thiam et al. [19] reported that plastic-sand composites exhibit favourable mechanical properties together with low water absorption, making them suitable for building and infrastructure applications. Furthermore, Awoyera et al. [2] confirmed that plastic-sand composites constitute an effective route for plastic waste valorisation through the production of paving blocks, masonry blocks and other infrastructure components. Collectively, these studies demonstrate that plastic-sand composites provide a sustainable solution for mitigating the environmental impacts of

plastic waste while reducing the consumption of conventional construction materials.

Nevertheless, despite these advances, limited research has focused on the combined use of low-density polyethylene (LDPE), the predominant lightweight plastic waste requiring valorisation, and polyethylene terephthalate (PET) as a reinforcing material in the production of plastic-sand composites intended for road pavement applications. In particular, the influence of plastic content on the physical and mechanical properties of such composites remains insufficiently documented, especially in the context of developing countries.

Against this background, the present study aims to valorise low-density polyethylene (LDPE) waste, regarded as lightweight plastic waste, through the development of plastic-sand composites for road pavement applications. To enhance the mechanical performance of the composite, a proportion of polyethylene terephthalate (PET), a stiffer polymer, was incorporated into the LDPE matrix. Different formulations were produced by varying the plastic content in order to evaluate its influence on the physical and mechanical properties of the resulting composites and to assess their potential suitability for road pavement applications.

2. Materials and Methods

2.1. Raw Materials

2.1.1. Plastic Waste

Two types of plastic waste were used in this study: low-density polyethylene (LDPE) and polyethylene terephthalate (PET). The selection of these two polymers was based on two main considerations.

Firstly, characterisation studies of solid waste generated in the city of Lome showed that LDPE and PET are among the most abundant categories of plastic waste, accounting for 85.76% and 5.70%, respectively [18]. LDPE, which is mainly found in plastic bags, carrier bags and flexible plastic packaging, is regarded as lightweight plastic waste for which recovery and recycling pathways remain limited. Its recycling is constrained by its low density, widespread dispersion in the environment and frequent contamination after use. PET, on the other hand, is mainly found in beverage bottles and other rigid plastic packaging.

Secondly, PET possesses superior mechanical properties compared with LDPE, particularly higher stiffness and mechanical strength. It was therefore incorporated into the LDPE matrix to enhance the mechanical performance of the developed composite. This combination makes it possible to simultaneously valorise two abundant plastic waste streams while producing a composite material with potential for a wide range of construction applications.

2.1.2. Sand

Sand is composed of detrital sediments, the most common of which is quartz. It is used as a filler material in order to improve the properties of the final product. The sand used in this study was sourced from the Mono River. It was washed and dried, and subsequently sieved using a 5 mm sieve.

2.2. Specimen Preparation

2.2.1. Method of Specimen Fabrication

After collection, the plastic waste was sorted to remove all impurities. Scissors were used to cut the plastics into small pieces. The sand used was sieved through a 5 mm sieve in order to obtain particles with better packing and

improved cohesion within the mixture. It was used as a filler in the composite material and plays a role in improving dielectric properties. Both the plastic waste and the sand were weighed separately to obtain the desired mix proportions. In this study, five different plastic contents (10%, 20%, 30%, 40% and 50%) were investigated in order to determine the optimal mechanical and physical properties of the material. The specimens were prepared according to the following relation:

$$P = \frac{M_P}{M_P + M_S} \times 100 \quad (1)$$

- 1) P: mass percentage of plastic
- 2) M_P : mass of plastic
- 3) M_S : mass of sand

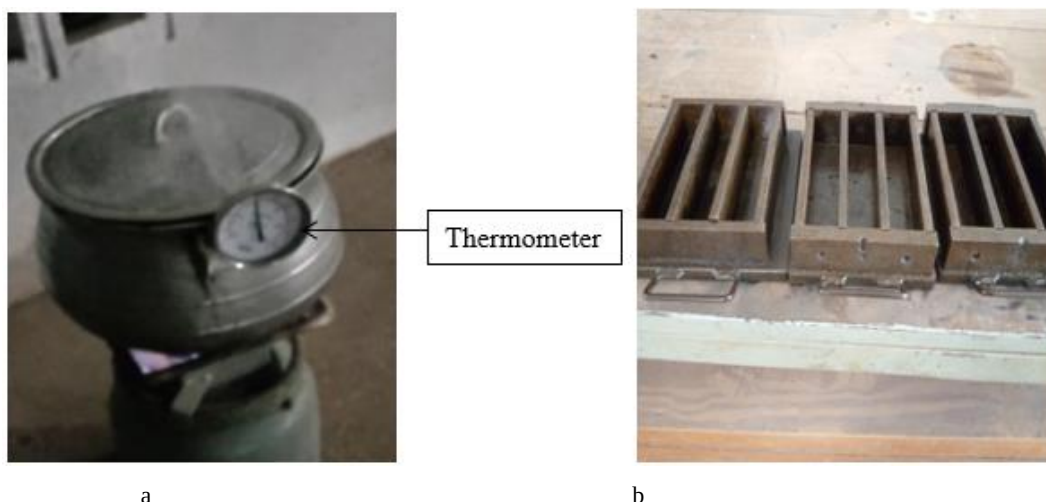


Figure 1. a. Heating pot placed on the gas cylinder b. $4 \times 4 \times 16$ cm moulds.

2.2.2. Melting and Mixing

This stage consists of melting the plastic materials into a liquid state. After being shredded into small pieces, they are weighed and then introduced into a pot that has been preheated for 5 to 8 minutes (Figure 1a). The contents are gradually stirred using a spatula until white fumes appear. After complete melting at 250°C , sand is added, and the mixture is progressively kneaded until a homogeneous blend is obtained.

2.2.3. Moulding, Compaction, Cooling and Demoulding

A trowel was used to scoop the obtained paste and transfer it

into the moulds. The moulds were coated with waste engine oil to facilitate demoulding. To prevent the mixture from solidifying before casting, the pot was kept under moderate heating throughout the process. Moulding is a rapid operation that must be carried out quickly in order to allow the paste to properly take the shape of the mould and ensure effective compaction.

The fresh mixture placed in the moulds was compacted using an electric impact compaction device applying 60 blows per mould. The surface of the moulds was then levelled and the specimens were stored indoors. Compaction aims to reduce the presence of air voids within the material after cooling. The specimens were left to cool in ambient air for 24 hours before being demoulded by loosening the mould bolts.



Figure 2. a. Casting into a mould b. Compacting of the material in the mould.



Figure 3. Demoulding process.

2.3. Characterisation of the Specimens

2.3.1. Water Absorption

The presence of water within the material is due to absorption. This absorption significantly reduces many of the material's properties. The water absorption test was carried out in accordance with standard NBN B 15-215: 1989 [17].

The dry mass of the specimen was first measured. The specimens were then immersed in a tap water bath for 24 hours. After 24 hours, the samples were removed from the water bath, lightly wiped to remove surface water, and weighed again (wet mass). Water absorption by immersion was expressed as a percentage and determined using Equation (2).

$$Ab = \frac{m_w - m_d}{m_d} \times 100 \quad (2)$$

- 1) m_w : wet mass after immersion,
- 2) m_d : dry mass.

2.3.2. Flexural Strength

In order to use the manufactured material in structural applications such as façade cladding, raised floor slabs, and similar uses, information on its flexural strength is essential. The test was carried out using a 50 kN manual hydraulic press of THEKAMAT brand. The flexural failure of each specimen was performed in accordance with Figure 4.

Let F_f be the failure load of the flexural specimen; the bending moment at failure is given by $F_f l/4$, and the corresponding tensile stress (flexural strength) on the lower face is given by:

$$R_f = \frac{1.5F_f l}{b^3} \quad (3)$$

- 1) R_f : flexural strength (MPa)
- 2) b : specimen width (m)
- 3) F_f : failure load (N)
- 4) l : span between the two supports (m)

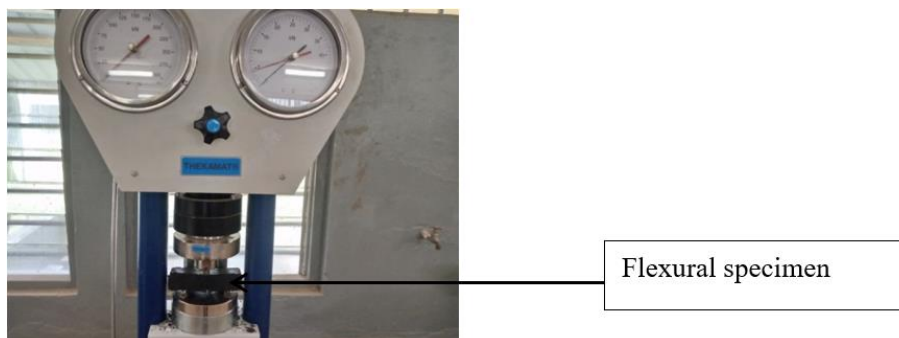


Figure 4. Hydraulic press.

2.3.3. Compressive Strength

Compressive strength is an important parameter in construction;

therefore, it is essential to obtain information provided by the material regarding its compressive strength. The half-prisms obtained after flexural failure were subsequently subjected to compression testing, as shown in Figure 5.

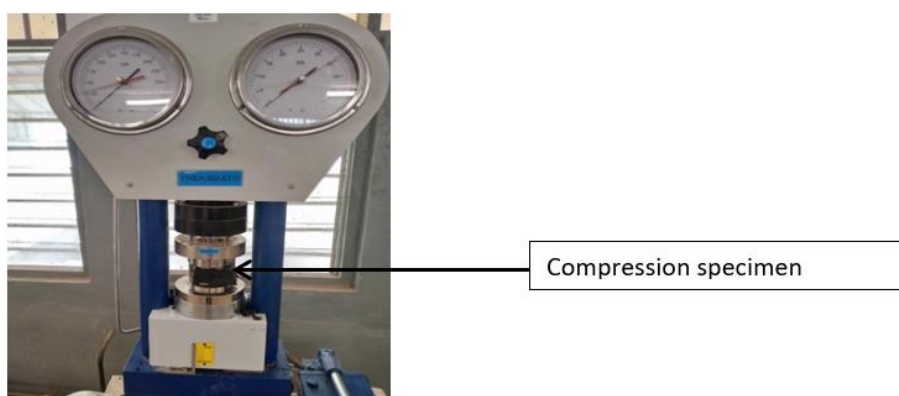


Figure 5. Hydraulic press.

Let F_c be the failure load of the compressive specimen; the corresponding failure stress (compressive strength) is given by:

$$R_c = \frac{F_c}{b^2} \quad (4)$$

- 1) R_c : compressive strength (MPa)
- 2) F_c : failure load (N)
- 3) b : specimen width (m)

2.4. Statistics

To evaluate the results, several statistical parameters were determined. The results obtained for each specimen were used to calculate the mean value. Standard deviations were also

computed. Finally, the coefficient of variation was calculated in order to assess the dispersion of the experimental results.

3. Results and Discussion

3.1. Physical Property: Water Absorption Test

Figure 6 presents the different absorption values as a function of the plastic content. The absorption values range from 3.92% to 0.58%. Absorption decreases as the proportion of plastic increases in the material. The absorption rate provides information on the porosity of the material. It depends on the compaction pressure applied to the paste using the impact compaction device.

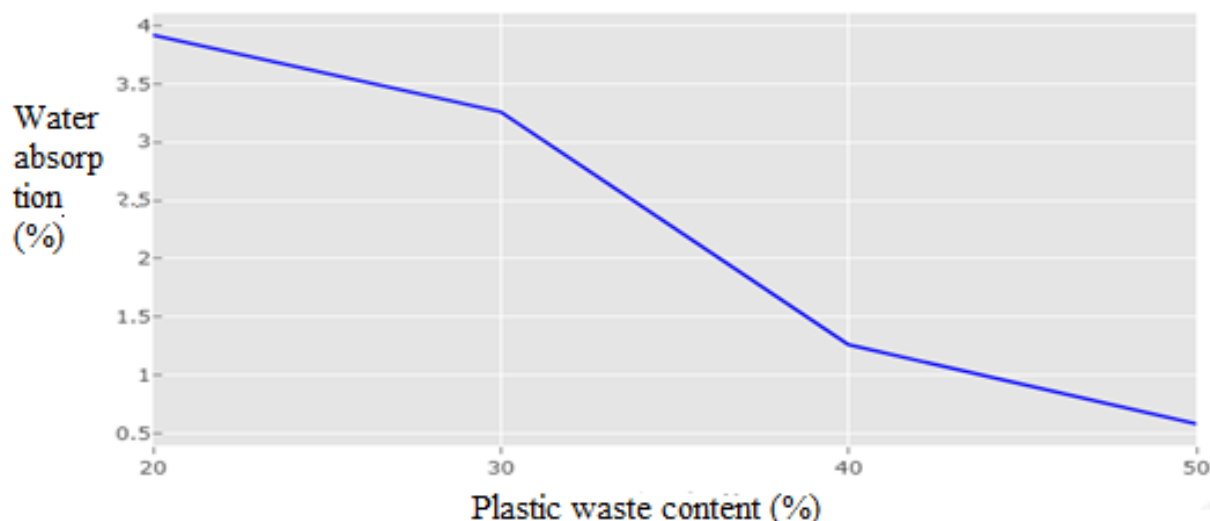


Figure 6. Water absorption values of the material.

The results of the water absorption test showed that the material containing 50% plastic exhibited the lowest water absorption (0.58%) compared with the other compositions. Two main reasons may explain this result. Firstly, plastic is hydrophobic; therefore, an increase in its content within the material reduces water penetration. Secondly, since plastic acts as a binder, its increasing proportion promotes better adhesion between sand particles, leading to a significant reduction in voids within the material. The findings reported by Traore et al. [20] and Ndepete et al. [14] corroborate these results. When compared with the NBN EN 1338 standard, which specifies that a material is considered to have good quality when the water absorption rate is $\leq 6\%$, it can be concluded that the materials

produced at different proportions exhibit satisfactory quality.

3.2. Mechanical Properties

3.2.1. Flexural Strength

Figure 7 presents the flexural strength curve of the materials obtained at different proportions. The results show a variation in strength depending on the plastic content in the material. It can be observed that as the plastic content increases, the flexural strength increases from 1.27 to 10.55 MPa. The value of 10.55 MPa corresponds to the highest plastic content (50%) investigated in this study.

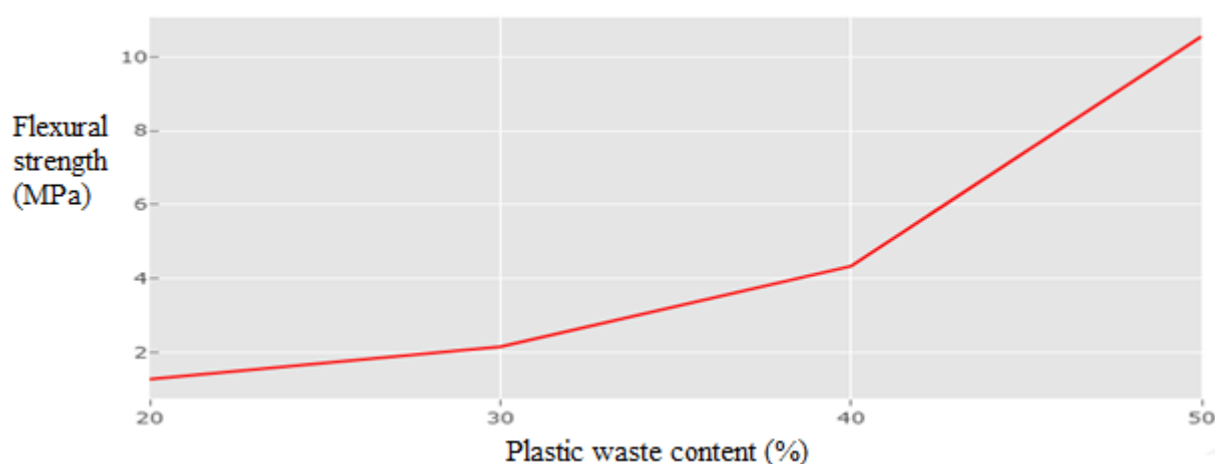


Figure 7. Variation of flexural strength as a function of plastic content.

However, the scientific studies conducted by Traore et al. [20] showed that, for a mixture of low-density polyethylene (LDPE) and sand, the plastic content threshold is 35%; beyond this limit, the compressive strength begins to decrease. The

contrasting results between these two studies may be explained, firstly, by the type of plastic used. In the present study, a (50-50) mixture of LDPE and PET was used to manufacture the material. Since PET is more resistant than LDPE, it may help to maintain or improve the strength of the material even

at higher plastic contents. In addition, PET has a significantly higher elastic modulus than LDPE (3.2 GPa compared with 0.3 GPa), which contributes to the reinforcement of the material, as a higher stiffness generally corresponds to a higher elastic modulus [4, 8].

Secondly, the sand used in this study is coarse, whereas that used in the referenced study is fine. This difference in particle size may explain why no reduction in strength was observed beyond 35% plastic content. Indeed, coarse aggregates require a higher amount of plastic binder to ensure proper bonding between particles [13, 20].

Although PET was incorporated into the mixture to enhance the mechanical strength of the material, it is observed that the results obtained by Traore et al. [20] are higher than those of the present study. This difference in strength may be attributed, on the one hand, to the moulding time, as both studies used a

compaction method. Indeed, moulding must be carried out very rapidly in order to prevent premature hardening of the material before casting. On the other hand, the difference is also related to the nature of the sand. Coarse sand was used in the present study, whereas several studies have shown that materials manufactured with fine sand generally exhibit significantly higher strengths than those produced with coarse sand [13, 20].

3.2.2. Compressive Strength

Figure 8 presents the compressive strength curve of the materials obtained at different proportions. As in the case of flexural strength, the results show a variation in strength depending on the plastic content in the material.

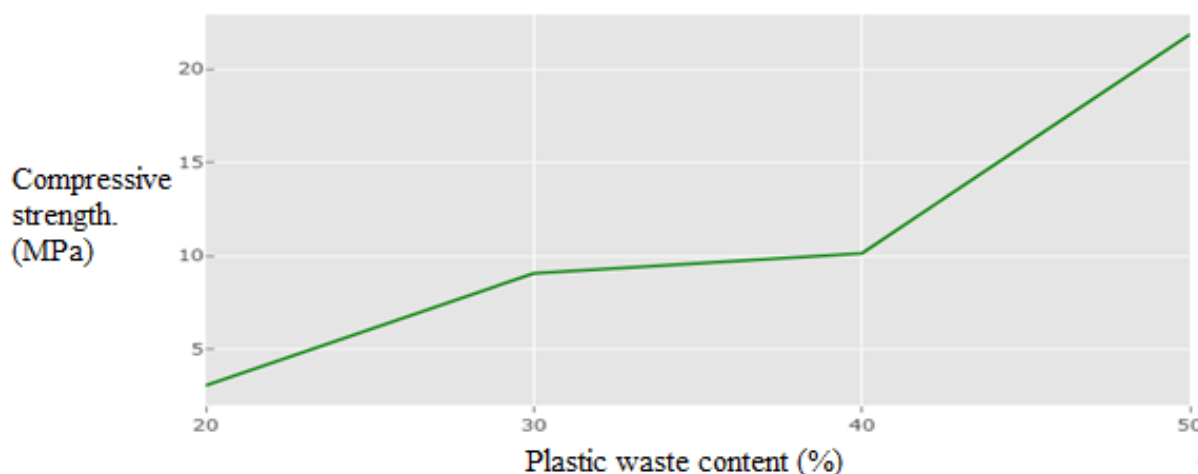


Figure 8. Variation of compressive strength as a function of plastic content.

Figure 8 shows that as the plastic content increases in the material, the compressive strength increases from 3.07 to 21.85 MPa. As observed in flexural behaviour, the strength increases as sand particles become more effectively bonded, thereby reducing the presence of pores within the material. However, several studies have reported that when the binder (plastic) content becomes excessive, a reduction in mechanical strength is observed. Indeed, when the plastic proportion becomes too high relative to sand, adhesion problems occur, leading to a decrease in strength, which tends to approach the intrinsic strength of the plastic itself [9, 12, 16]. This is why the present study was limited to a maximum plastic content of 50%, since plastic acts as a binding material replacing cement. It is therefore not desirable for the binder content to exceed the aggregate fraction.

3.2.3. Application Domains

In order to assess the potential use of the manufactured material for covering applications (buildings and roads), a comparison is made with paving blocks. A paving block is a unit made of stone, concrete or fired clay. It is commonly used for the surfacing of buildings and pavements [5, 10].

In addition to their functional use (contribution to spatial readability) and architectural role (their shapes and colours enhance aesthetics), paving blocks are also used for structural purposes, particularly for resisting varying levels of traffic loads. Accordingly, paving blocks are classified according to traffic type [6].

Table 1 presents information on flexural and compressive strength requirements according to standards EN 1339 [6], as well as water absorption limits for paving blocks according to standards EN 771-1 [22], NBN EN 206-1: 2001 and NBN B 15-001: 2004 [17].

Table 1. Mechanical strength and water absorption according to traffic type.

Traffic class	Compressive strength (MPa)	Flexural strength (MPa)	Water absorption (%)
T5	20	3,5	≤ 3
T4	25	4	≤ 5
T3	25	5	≤ 6
T2	$25 < R_c \leq 60$	6	≤ 7
T1	$R_c > 60$	≥ 6	Not specified

The standards indicate that the minimum flexural strength for the first traffic class, which concerns pedestrians and light vehicles (T5), is set at 3.5 MPa. Thus, the results obtained for the manufactured materials fall within the range specified by these standards, since the flexural strength recorded for the 40% plastic composition is 4.33 MPa.

Similarly, the standards require a minimum compressive strength of 20 MPa for the first traffic class (T5). The results obtained also comply with this requirement, as the compressive strength measured for the 50% plastic content is 21.85 MPa.

Regarding water absorption, the limit value specified by the standards ranges between 3% and 7%. However, the absorption values obtained for the manufactured materials range from 3.92% to 0.58%. Compared with the standard requirements, a significant reduction in water absorption is observed in the produced materials. This reduction is mainly attributed to the presence of plastic within the material, which is hydrophobic and provides a waterproofing effect.

Considering the flexural strength requirements, it can be suggested that materials containing 40% plastic may be suitable for traffic classes T5 and T4 (urban roads). In the same perspective, materials containing 50% plastic may be suitable for traffic classes T3, T2 and T1 (urban roads and heavy-duty parking areas), as their flexural strength (10.55 MPa) is higher than the values required by the standards.

Furthermore, the coefficient of variation (0.0995) indicates that the materials containing 50% plastic exhibit low data dispersion and good homogeneity [7]. Additionally, given the relatively low water absorption, these materials could be used for ground paving to prevent water infiltration, particularly in swampy areas, for wall protection in moisture-exposed environments, and in septic tanks to limit water diffusion. Due to their lightweight nature, they may also be used as insulating panels in high-rise buildings.

4. Conclusion

This study focused on the valorisation of PELD (low-density polyethylene) and PET waste plastics in the formulation

of plastic-sand composites. PELD, a lightweight and predominant waste plastic, was used as the main matrix, while PET, which is more rigid and has a higher elastic modulus, was incorporated to improve the mechanical performance of the material. The results show that increasing the plastic content enhances both flexural and compressive strengths, while significantly reducing water absorption. This improvement is attributed to better cohesion between sand particles and the reinforcing effect of PET within the PELD matrix. The materials obtained at different plastic proportions were considered for building, pedestrian, and road surfacing applications, with generally satisfactory performance in relation to the relevant standards, particularly at higher plastic contents. However, the 10% plastic formulation is not recommended due to weak particle cohesion and insufficient mechanical performance. Overall, this study confirms the potential of PELD-PET-sand composites as alternative construction materials within a circular economy approach.

Abbreviations

PELD	low-density Polyethylene
PET	Polyethylene Terephthalate
P	Mass Percentage of Plastic
M_p	Mass of Plastic
M_s	Mass of Sand
mw	Wet Mass After Immersion,
md	Dry Mass
Rf	Flexural Strength
B	Specimen Width
Ff	Failure Load
l	Span Between the two Supports
Rc	Compressive Strength
Fc	Failure Load
b	Specimen Width

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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