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Research Article

Influence of Physical Parameters on the Mechanical Properties of a Material Produced from PET Plastic Waste into Paving Blocks

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Abstract

This study is part of a circular economy approach aimed at valorizing polyethylene terephthalate (PET) waste in cementitious matrices through a materials science and engineering approach. PET waste from used containers underwent a controlled thermomechanical transformation (melting at 260 ℃, cooling, grinding, and sieving), yielding two distinct fractions: plastic aggregates (> 5 mm) and a fine powder. These two forms were incorporated into hydraulic concrete using two formulation strategies: (i) partial substitution of natural gravel with PET aggregates and (ii) partial substitution of sand with PET powder, at rates ranging from 0 to 18% by mass. The concrete's performance was evaluated after 7 days by measuring uniaxial compressive strength and water absorption capacity. The results show that the morphology and incorporation rate of PET significantly influence the concrete's properties. Substituting gravel with PET aggregates leads to a progressive decrease in mechanical strength and, at high concentrations, an increase in water absorption. Conversely, substituting sand with PET powder exhibits more favorable behavior at low concentrations (≤ 6–8%), characterized by a densification effect on the cementitious matrix. An optimal range of 5 to 8% PET powder is thus identified for non-structural hydraulic concrete applications.

Keywords

Hydraulic Concrete, Waste Valorization, Recycled PET, Aggregate Substitution, Compressive Strength, Water Absorption

1. Introduction

The management of non-biodegradable plastic waste has become a major concern for society worldwide, as it is widely used and leaves an impression of desolation. The proliferation of plastic waste is one of the major environmental challenges of our time. Characterized by high durability and often very

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short life cycles, synthetic polymers, primarily from the packaging sector, accumulate in terrestrial and aquatic ecosystems. With the global plastic recycling rate remaining below 10%, the majority of generated waste ends up being buried or dispersed in the environment [1, 2]. This problem is particularly pronounced in developing countries, notably Chad, where waste collection and recovery infrastructure remains limited. In N'Djamena, rigid plastic waste, especially polyethylene terephthalate (PET) containers, represents a persistent source of urban pollution.

Faced with this situation, the incorporation of recycled plastic waste into construction materials appears as a promising avenue for a circular economy. This approach simultaneously reduces the consumption of natural resources (sand and gravel) and limits the environmental impact of the construction sector [3].

In the interest of sustainability and improving material properties, scientifically proven solutions have been found, including recycling. Among the proposed solutions is the total and/or partial replacement of plastic waste with conventional cement in the manufacture of concrete pavers, in order to improve their mechanical properties [4]. Several studies have demonstrated the feasibility of using recycled plastics as partial substitutes for natural aggregates in hydraulic concrete [5, 6]. However, some artisanal practices involving the direct melting of plastics mixed with sand to produce construction elements present significant health and environmental risks (emissions of volatile organic compounds, lack of control over the microstructure, and low durability). These processes do not meet the reproducibility and safety requirements for large-scale application.

In this context, the present study proposes a more controlled alternative approach, based on the incorporation of recycled PET in solid form (aggregates or powder) into conventional hydraulic concrete. The objective is to evaluate the influence of PET morphology and substitution rate on the mechanical and durability properties of the concrete, in order to identify an optimal formulation suitable for non-structural applications [7].

2.Materials and Methods

2.1. Materials

The materials used are: CPJ 35 cement, natural sand, 4/10 crushed gravel, mixing water and plastic waste consisting exclusively of PET cans.

2.2. Methods

Before being incorporated into the hydraulic concrete mix, the collected plastic waste underwent a series of transformation processes to obtain a suitable granular form. The method is that established by [4, 8-10] The process implemented is described below.

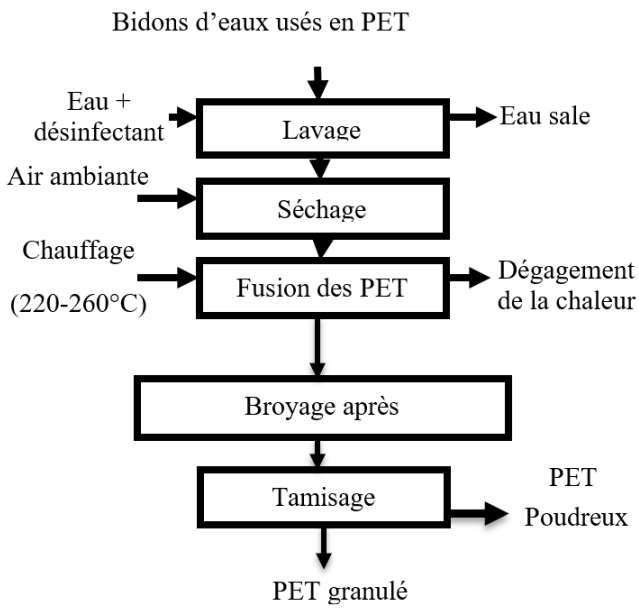

Figure 1. *Concrete production diagram.*

Initially, the pre-washed and dried plastic waste is introduced into a stainless steel reactor.

There, it is heated to a melting temperature of approximately 260 ℃, consistent with the thermal data reported in the literature for these polymers [7]. Heating is provided by a butane gas system, coupled with a continuous stirring device to ensure thermal and rheological homogenization of the molten material. Once melting is complete, the fluid plastic mass is poured onto a metal sheet and spread into a uniform layer. Rapid cooling causes spontaneous cracking of the solidified material, facilitating its removal from the support plate. The next step involves the mechanical fragmentation of these cracked plates. They are crushed and then sieved to classify the resulting particles according to their size. This step allows for the separation of two distinct fractions:

Plastic aggregates larger than 5 mm, intended for the partial (mass) replacement of natural gravel in the mix design;

Plastic powder smaller than 5 mm, used to partially replace sand in the mix design.

These aggregates and powders are then incorporated into the concrete mix according to defined proportions, in order to evaluate their effects on the properties of fresh and hardened concrete.

2.3. Experimental Method

he mixture was prepared according to the 350 ratio obtained using the DREUX AND GORISSE method. The homogeneous mixture of all the materials is illustrated in the production diagram below (Figure 2). The reference mix design for the control concrete (M0) was established with the following proportions: 16% cement, 39% sand, 35% gravel, and 10% water (by mass).

From this control mix, two series of formulations were prepared:

1) Substitution of gravel with PET aggregates: for mass substitution rates of 6%, 9%, 12%, 15%, and 18% (labeled M1 to M5).
2) Substitution of sand with PET powder: for the same mass substitution rates of 6%, 9%, 12%, 15%, and 18% (labeled M1' to M5').

The mixing of the constituents was carried out according to a standardized protocol to ensure the homogeneity of the concretes, as shown in the Figure.

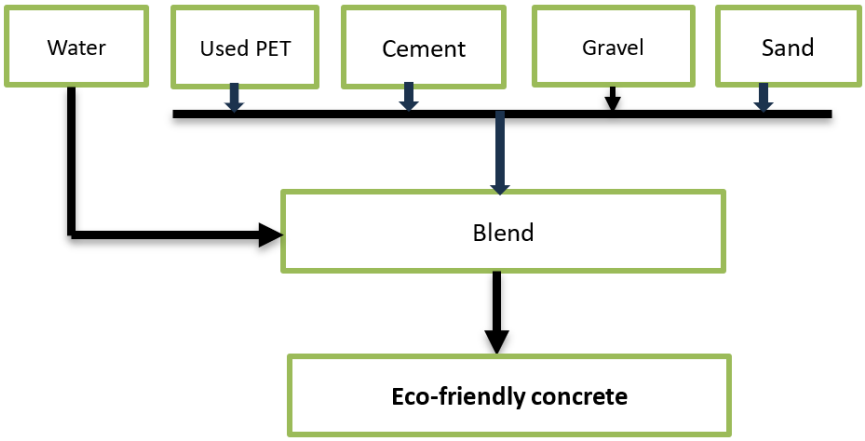

Figure 2. *Hydraulic concrete production diagram.*

2.4. Characterization of the Hydraulic Concrete Obtained

The samples were characterized with respect to their mechanical and physical properties by bending and compression tests, as well as by measurements of density and water absorption.

2.5. Compressive Strength

Compressive strength was measured on cubic specimens of hardened concrete, crushed between the platens of a hydraulic press until failure. The maximum load, expressed in MPa, defines the compressive strength. The tests were carried out after 7 days.

2.6. Water Absorption Capacity

Water absorption capacity (WAC) was determined to assess the potential durability of concrete. It measures the amount of water absorbed by a dried sample after immersion for 24 hours and is expressed as a percentage of the dry mass. This parameter is indicative of the accessible porosity of the material.

3. Results

The results show that the mechanical properties (flexural and compressive) of the composite materials increase or decrease significantly depending on the PET filler content. Furthermore, the density and water absorption of the samples decrease with increasing PET filler content [8].

The results of compressive strength and water absorption capacity tests for concretes incorporating PET are presented in Table 1 below.

Table 1. *PET Substitution for Gravel.*

Case of PET as a substitute for gravel		
PET rate	**Compressive Strength (MPa)**	**Water absorption capacity (%)**
0	13,26	6,7
6	12,95	7,2
9	11,68	7,3
12	9,16	7,4
15	7,89	7,5
18	7,27	7,5

The results in Table 1 show that incorporating PET as a substitute for gravel negatively affects the compressive strength of concrete. Indeed, as the PET content increases, the strength decreases. It drops from 13.26 MPa at 0% PET to only 7.27 MPa at 18% PET, representing a loss of approximately 45%. Simultaneously, the water absorption capacity increases with the PET content, rising from 6.7% to 7.5%. This indicates an

increase in porosity or reduced compactness of the material. This change is explained by the nature of PET: less rigid and less adherent than gravel, it creates fragile interfaces within the cementitious matrix, reducing mechanical strength. The increased water absorption reflects higher porosity, likely due to poor adhesion between the PET and the cement paste, as well as possible segregation during mixing. In conclusion, a PET content of up to 6% may be acceptable for non-structural applications, but beyond that, mechanical performance degrades significantly, limiting the use of this concrete to lightly stressed structures or for weight reduction purposes.

Table 2. *Cases of PET substitution for sand.*

Cas de substitution PET au sable		
PET rate	**Compressive Strength (MPa)**	**Water absorption capacity (%)**
0	13,26	6,7
6	12,31	4,5
9	11,37	4,6
12	10,11	5,0
15	7,90	5,9
18	6,32	6,0

Table 2 shows the effect of partially replacing sand with PET (recycled plastic) on two properties of a material: compressive strength and water absorption capacity.

The higher the PET substitution rate, the more the compressive strength decreases continuously.

1) At 0% PET, the strength is 13.26 MPa.
2) At 18% PET, it drops to 6.32 MPa, a decrease of approximately 52%.

This decrease is explained by the difference in rigidity and adhesion between PET and sand, as well as a possible increase in internal porosity.

Water absorption follows a U-shaped curve:

1) It is highest at 0% PET (6.7%).
2) It drops sharply at 6% PET (4.5%), then remains low up to 9% (4.6%). - Starting at 12%, the concentration gradually increases to reach 6.0% to 18% PET.

This evolution can be interpreted as a pore-filling effect of PET particles at low concentrations, improving sealing; then, at higher concentrations, the heterogeneity of the mixture and reduced adhesion create micro-cracks or voids, again increasing absorption.

The addition of PET degrades mechanical strength but can improve water absorption for moderate substitutions (between 6 and 9%). A compromise between mechanical performance and durability (absorption) could be considered at around 6 to 9% PET, depending on the intended application.

4. Discussion

Our work, like that of several other researchers, notably [11-20], aims to evaluate the influence of coarse aggregates on the mechanical and physical properties of PET waste in paving stones. The procedure, as mentioned above, involved the partial substitution of natural gravel with PET aggregates and the partial substitution of sand with PET powder. Melted PET waste is mixed as a binder with sand and coarse aggregates to manufacture paving stones for road surfacing. In the conventional paving stone manufacturing process, cement paste is used as a binder. Cement can technically be replaced by melted plastic waste to make the paving stones more flexible, as concrete blocks are primarily used for rigid pavements. Paving stones containing PET, sand, and coarse aggregates in varying proportions were prepared, tested, and the results were analyzed.

4.1. Influence of PET Aggregates on the Properties of Hydraulic Concrete

The substitution of natural gravel with PET aggregates leads to a progressive decrease in compressive strength, reflecting a weakening of the concrete's granular skeleton. This behavior is consistent with observations reported in the literature for concretes incorporating recycled plastic aggregates [4, 5].

This performance loss is primarily due to the low modulus of elasticity of PET, significantly lower than that of mineral aggregates, which limits the efficient transfer of stresses within the composite. Furthermore, the smooth, hydrophobic surface of PET aggregates reduces adhesion to the cement paste and promotes the formation of a more porous and less cohesive Interfacial Transition Zone (ITZ), as highlighted by Siddique et al. (2008) [21] and Frigione (2010) [22]. The degradation of this ITZ creates a prime location for the initiation of microcracks under load.

In parallel, the systematic increase in water absorption capacity is attributed to this increased interfacial porosity and the potential formation of continuous capillary pathways around the plastic aggregates.

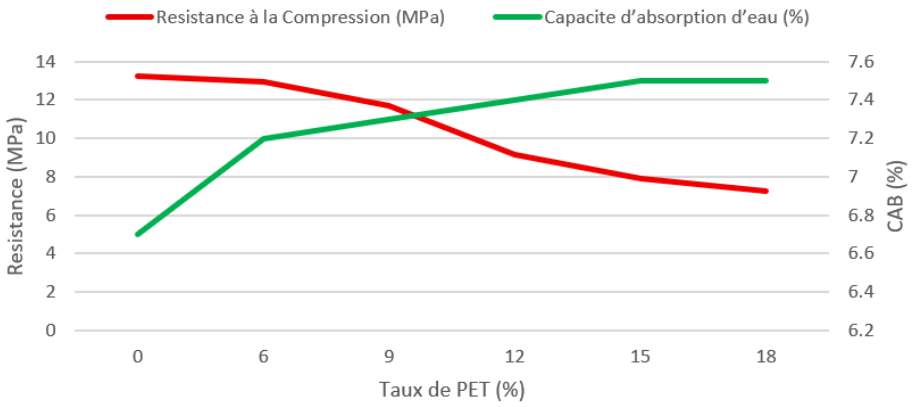

Figure 3. *Influence of PET granules on the compressive strength and water absorption capacity of hydraulic concrete at 7 days.*

4.2. Influence of PET Powder on the Properties of Hydraulic Concrete

Unlike aggregates, the incorporation of PET powder induces a more balanced behavior. At low substitution rates (≈ 6%), the reduction in water absorption and the moderate loss of strength indicate a beneficial filler effect. The fine PET particles contribute to filling intergranular voids and improving matrix compactness [23].

Conversely, when the substitution rate exceeds a critical threshold (≥ 12%), the PET powder acts primarily as an inert filler, locally reducing the amount of hydratable cement. This matrix dilution results in a less dense microstructure and a marked decrease in mechanical strength, consistent with the results reported by Saikia and de Brito (2012) [3, 24]. Furthermore, the excessive introduction of non-absorbent fine particles can disrupt the rheology of fresh concrete and generate compaction defects, contributing to increased porosity and water absorption capacity at high dosages.

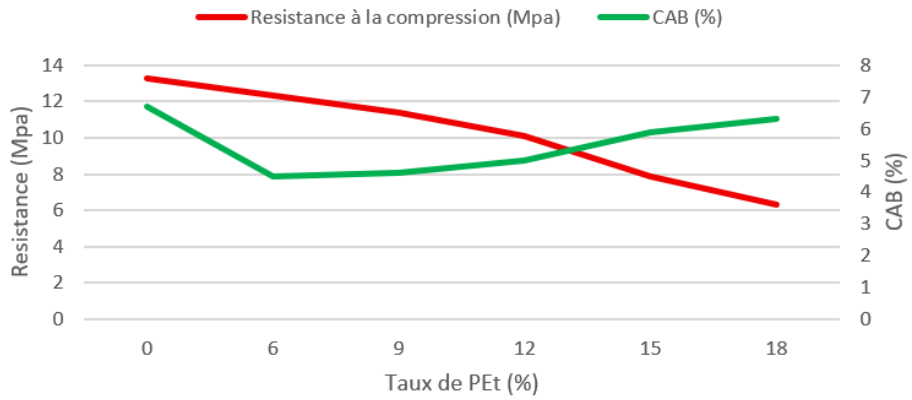

Figure 4. *Influence of powdered PET on the compressive strength and water absorption capacity of hydraulic concrete at 7 days.*

An experimental study, which we found in the article "THE EFFECT OF PET AND LDPE PLASTIC WASTES ON THE COMPRESSIVE STRENGTH OF PAVING BLOCKS" (2023) [7], was conducted to investigate the effect of low-density polyethylene (LDPE) and polyethylene terephthalate (PET), used as substitutes for fine aggregates, on the compressive strength of paving stones. In this study, the paving stones were of grade C (outside of plan C), with a minimum compressive strength of 12.5 MPa. For our research, the compressive strength ranged from 6.32 to 7.27, depending on the PET content and quality. The article demonstrates that plastic waste (LDPE and PET) is used as a partial replacement for fine aggregates, with volume variations of 0%, 5%, 10%, and 15%. In our case, we used up to 18%. For the article, they added fly ash to the LDPE (LDPE-PF) mixtures at a rate of 15%, replacing the cement by weight. In our experiments, we used cement.

The results show that using LDPE and PET plastic waste as a partial replacement for fine aggregates reduced compressive strength by 35.26%, 37.69%, and 40.68% for LDPE; by 34.15%, 52.22%, and 56.53% for PET; and by 23.14%, 18.01%, and 24.65% for LDPEF plastic waste. However, the compressive strength of the tested pavers far exceeds the minimum requirement of 12.5 MPa for grade C pavers. In our case, and particularly regarding the variance between PET granules and PET powder in terms of PET substitution for sand, as

shown in Table 2, the compressive strength results are 6.32 MPa, 7.90 MPa, 10.11 MPa, 11.37 MPa, 12.31 MPa, and 13.26 MPa. However, in the case of PET substitution for gravel, Table 1 shows the compressive strengths for the same PET content, respectively 7.27 MPa, 7.89 MPa, 9.16 MPa, 11.68 MPa, 12.95 MPa, and 13.26 MPa. The same observation is also made on both sides regarding the Water Absorption Capacity (%) which varies in both scenarios.

5. Conclusion

This study demonstrates that the morphology and incorporation rate of recycled PET govern the evolution of concrete properties. Substituting gravel with aggregates leads to a marked and progressive degradation of strength and durability, primarily due to mechanical incompatibility and a weakened Interfacial Transition Zone (ITZ).

Conversely, incorporating PET powder presents a trade-off: a beneficial "filler" effect at low dosages (≤ 6–8%), improving compaction and reducing water absorption, while at high dosages (>12%), dilution of the cement matrix and disruption of the microstructure predominate. An optimal formulation lies within the range of 5 to 8% sand substitution by PET powder, enabling significant environmental valorization of plastic waste while limiting the impact on mechanical properties. This approach opens the way to the eco-design of concretes for non-structural applications, subject to rigorous control of formulation and implementation.

Abbreviations

ITZ	Interfacial Transition Zone
PET	Polyethylene Terephthalate
LDPE	Low-density Polyethylene
WAC	Water Absorption Capacity

Author Contributions

Hassan Alaguid Ibrahim Sofo: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft

Haroun Ali Adannou: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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