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# VALORIZATION OF PLASTIC WASTE IN THE CIVIL ENGINEERING FIELD

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## Abstract

The valorization of plastic waste is an essential solution to mitigate the environmental problems resulting from their accumulation. This Project focuses on developing an innovative recycling method aimed at transforming plastic waste into suitable materials for use in road surfacing and masonry. After a series of prototypes and experiments, we have identified concrete formulations using plastic bottle waste that have proven relevant for the production of various products such as paving stones, bricks, and concrete blocks. To assess their functionality, we subjected these new composites to a battery of rigorous tests that confirmed their properties and suitability for the intended use. The production process offers advantages both from an environmental and socio-economic perspective. From an environmental point of view, this approach contributes to ecosystem preservation and reduces greenhouse gas emissions. Our plastic waste recycling project for the production of materials for civil engineering represents a promising advancement in environmental preservation and offers interesting opportunities for a circular economy. The results obtained through our in-depth studies and conducted tests support the efficiency and viability of this approach, thus paving the way for broader use of these new materials in the construction and urban development industry.

**Keywords:** Recycling, Concrete blocks, Industry, Environment, Economy.

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## 1- Introduction

Climate change has become a severe issue where the Earth continues to warm at an accelerated rate. The uninterrupted increase in the emissions of greenhouse gas is from non-renewable energy sources, which is the primary driver of global warming[1]. In addition to this, there is the issue of overexploitation of natural resources. The constantly increasing total resources use seems to pose a significant threat to global sustainability and the safe operating space for humanity[2]. Plastic, essential in many domains, is a major environmental concern from its production to its end-of-life, closely linked to global challenges. The production of plastics emits enough greenhouse gases. Their use, combined with linear economic models that ignore the externalities of waste and an expanding "throw-away" culture have exacerbated the problem[3], [4]. Plastic waste contaminates all major ecosystems on the planet, with concern increasing about its potential impacts on wildlife and human health[5]. Work on the origin and fate of plastic pollution in aquatic environments suggests that land-based plastics are one of the main sources of marine plastic pollution[6]. Furthermore, The overall construction industry is responsible for consuming a significant portion of natural resources[7]. Concrete is one of the most abundantly used materials in the World, and its demand has resulted in carbon emissions at an extensive level posing threat to the environment[8]. Essential inputs of energy and material resources are required during the production process[2]. It's increasingly clear that energy usage has a significant impact on environmental quality[9]. In recent times, environmentalists have asserted that every society dwells among the three E's of energy, economy, and environment; and are symmetrically or asymmetrically associated with each other[9]. In the context of preserving and sustainably using natural resources and ecosystem restoration, engaging in sustainable development is essential. It is with this perspective that the recycling of plastic waste, especially polyethylene terephthalate, becomes critically important. Current methods of reuse are insufficient to address the problem. The primary goal of this initiative is to solve an environmental problem by recycling plastic waste, specifically polyethylene terephthalate, in the field of civil engineering. The idea is to determine an efficient manufacturing process and design new materials that meet the required quality standards for flooring and wall coatings. By incorporating plastic waste as a binder in concrete, we can achieve two objectives: combating plastic pollution and optimizing natural resources and energy. In addition to the environmental benefits, this process could also have positive socio-economic impacts. Recycling plastic waste through this innovation in civil engineering would be a significant step towards a more sustainable and environmentally friendly future.

## 2- Methods

### <u>Raw materials</u>

During the realization of this work, the main materials used are:

- Plastic Waste - Polyethylene Terephthalate (PET)

Used plastic bottle waste comes from the import by beverage production companies and supermarkets in Madagascar. The bottles used during the project come from the garbage cans on the university campus of the École Supérieure Polytechnique d'Antananarivo located in Vontovorona.

- Aggregates

In this study, two types of siliceous aggregates were used. On the one hand, rolled fine sand (SR 0/2), collected from the river that crosses Vontovorona. On the other hand, crushed gravel (GC 4/8), extracted from the quarry located in Ankadivoribe, near Anosizato. *Table 1* reports some characteristics of the aggregates.

## Equipment

Several pieces of equipment were also used, including a manual mixer, a scale, a trowel, shovels, metal molds, and protective equipment.

## Methods

## Manufacturing process

The composition of concrete based on PET waste for the production of concrete blocks is based on a specific method, which consists first heating the aggregates to around 250°C before mixing. To do this, a gravel-to-sand ratio of 2 and a PET dosage of 20% by mass for bricks and blocks and 50% for interlocking pavers were adopted. The implementation process is summarized in *Figure 1*.

After demolding, the desired materials were obtained. *Hollow blocks* with dimensions of 10cm × 20cm × 40cm, *solid bricks* and *hollow bricks* with dimensions of 8cm x 8cm x 19.5cm, and hexagonal *interlocking pavers* with dimensions of 20cm x 17.5cm x 10cm.

## Concrete identification

B20: Concrete composed of 20% PET for bricks and blocks;
B50: Concrete composed of 50% PET for interlocking pavers.

## Assessment of material quality

Several tests were conducted for this purpose.

- Density

The density is obtained from the following formula:

$$\rho = \frac{\boldsymbol{m}}{\mathbf{V}}$$

Where: m: mass (Kg); V: volume ($m^3$).

- Water absorption

The operation consists of immersing the samples in water for 24 hours and 48 hours, then measuring the increase in mass. The mass of absorbed water corresponds to the porosity of the sample.

Porosity is calculated using the following formula:

$$\omega = \frac{mf - mi}{mi} \times 100$$

Where: mf: final mass after immersion; mi: initial dry mass.

- Compressive strength

To perform this test, cubic samples with dimensions of 10cm x 10cm x 10cm were prepared. In order to determine this compressive strength Rc, a 'Wolpert TESTWELL Universal Testing Machine' with a sensitivity of 12.000 daN is used.

Compressive strength is determined by the ratio of the breaking force Fc to the cross-sectional area S of the sample:

$$Rc = \frac{Fc}{S}$$

Where: Rc: compressive strength in MPa; Fc: breaking force of the sample in N; S: cross-sectional area of the sample in mm².

**Mortar compatibility tests**

Several types of mortar were tested to serve as a joints between blocks and bricks. Among them are cement mortar (1 part cement to 3 parts sand), lime mortar (1 part lime to 3 parts sand), and bastard or hybrid mortar (1 part cement and 1 part lime to 8 parts sand). This test is performed manually using the traction pull-out method.

**Other quality tests**

Here, the conducted tests are as follows:

- Nail penetration: the test was conducted using different nail sizes (30mm, 40mm, 50mm, and 60mm);
- Varnishing: performed using water-based paint and iron oxide-based paint;
- Temperature resistance involved placing the materials in an oven and varying the temperature from 50°C to 250°C in 50°C increments every 60 minutes. Once at 250°C, the materials were left in the oven for 180 minutes.

**Evaluation of the economic profitability of the designed materials**

The cost of aggregates and firewood was directly obtained from local suppliers near the experimentation site (Vontovorona). Regarding the plastic waste, it is free as it is collected from garbage bins. In addition to these, transportation and labor costs are incurred. To facilitate a better comparison between the new products and traditional ones, prices of cement blocks, cement pavers, and clay bricks were gathered from vendors in the vicinity of Vontovorona.

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## 3- Results

For each physical and mechanical test, the recorded result is the average of three measurements taken on three samples.

### Appearance of the obtained products

The newly manufactured materials are all gray in color. However, those with a 20% PET content have a rough appearance, while those with a 50% PET content, on the contrary, exhibit smooth surfaces.

### Density

The density of the bricks and blocks (B20) is 1980 kg/m³, while the density of the interlocking pavers (B50) is 1803 kg/m³. *Figure 6* illustrates the variation of density as a function of the polyethylene terephthalate content.

### Water absorption

The water absorption rate of B20 is 4.9% at 24 hours and 7.12% at 48 hours. However, that of B50 is 0.39% at 24 hours and 0.5% at 48 hours. *Figure 7* illustrates the variation of water absorption rate over time as a function of the polyethylene terephthalate content.

### Compressive strength

The compressive strength of B20 is 5.8 MPa. It increases with the proportion of PET and reaches a value of 11.26 MPa for B50. *Figure 8* presents the results of the compressive strength tests.

### Mortar compatibility

With all the mortars tested, the B20 are the most compatible. Furthermore, cement mortar has the best result. *Table 2* provides the results of the tests conducted with the different mortars.

### Other quality tests

The other quality tests conducted revealed that:

- For nail penetration, a 60 mm or more nail is required to nail the B20 blocks; otherwise, the nail will deform as the materials are very hard;
- As for varnishing, the paints used have good adhesion to the concrete blocks. However, better adhesion is observed with iron oxide-based paints;
- Concerning temperature resistance, although 5 hours of gradual heating took place, no particular reaction was recorded. It was only during the 180 minutes of maintaining at 250°C that odors from the materials were noted. However, no sign of visual deformation was observed during this test phase.

The results of these tests are summarized in *Table 3*.

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**Economic profitability assessment of the designed materials**

Calculating the cost of different designed of products is essential to assess their economic profitability. *Table 4* presents the estimated cost of one square meter of paving. *Table 5* presents the estimated cost of one square meter of solid or hollow brick wall. *Table 6* presents the estimated cost of one square meter of a 10 cm block wall.
According to these tables :

- One square meter of paving, 10 cm thick, costs 46,634 Ar, and that of 5 cm thick costs 27,617 Ar ;
- The cost of a brick is 519 Ar ;
- And the cost of a block is 2,030 Ar.

## 4- Discussion

The focus is initially on the fineness modulus of the sand used. Indeed, fine sand with a fineness modulus of 1.4 is generally considered unsuitable for concrete production due to its particle size. However, by adding small aggregates with a size of 4/8, the sand becomes more suitable for experimentation. The use of these small aggregates enhances the characteristics of the mixture by introducing a more varied particle size distribution. The manufacturing method used for the production of these materials is derived from the CERVALD method, which originated in Chad in 1998[10]. This method has been improved over the years by other researchers, making it the most commonly used approach for producing concrete with plastic waste. It is an approved method endorsed by numerous researchers who do not hesitate to praise the characteristics of products resulting from this approach. However, the derived method used during this implementation proved to be faster and much less polluting. In the CERVALD method, the process starts with plastic melting, which generates more abundant fumes. Then, aggregates are added, which cools the mixture due to the temperature difference as well as the quantity of aggregates compared to that of the PET. In comparison, the CERVALD method appears to be time-consuming and environmentally polluting. In contrast, the improved and innovative technique is faster and, above all, less polluting. This is manifested through limited and controlled smoke emissions. This difference is explained by the fact that the preheating of the aggregates, followed by the addition of PET, has a minimal effect on the mixture's temperature, primarily due to the aggregates' ability to store heat. Consequently, the plastic melting phase only occurs in the final stage of the operation. This operating procedure challenges the use of the CERVALD method, which has been adopted by the majority of researchers such as Saïfoullah et al. (2020) and Bagayoko (2011)[10]–[12]. Other researchers, like Jacques Perrin, also criticize this process, going so far as to label it as the 'devil's kitchen'[13]. During the mixing phase, vigorous mixing, requiring slightly more energy, proves to be necessary. This observation aligns with that of Doublier et al.[10]. During the molding phase, compacting is required for bricks and blocks to eliminate internal voids. However, this step is not necessary with interlocking pavers. The high concentration of PET results in a rather fluid mixture and, consequently, a more impermeable material, which is confirmed by water absorption tests. In this work, the manufactured materials underwent several tests to demonstrate their suitability and effectiveness. The bricks and blocks have a density of 1980 kg/m³, an absorption rate of 4.9% in 24 hours, and a compressive strength of 5.8 MPa. As for the pavers, they exhibit a density of 1803 kg/m³, an absorption rate of 0.39% in 24 hours, and a compressive strength of 11.26 MPa. These results align perfectly with the expected mechanical and physical characteristics of these materials. The rough B20 reveals a lack of plastic, resulting in a relatively high porosity and, consequently, an average compressive strength. On the other hand, the smooth B50 reflects an optimal combination of aggregates with the PET binder, allowing for greater compactness and achieving higher mechanical properties. The B50 sample (50% PET) is lighter than the B20 (20% PET), which is logical since PET is lighter than aggregates. The absorption results for B20 do not correspond to those reported by Bagayoko, who indicates a rate of 0%. However, the results for B50 slightly differ from those of Bagayoko, as well as from Saifoullah et al., who reported an absorption rate of 0.95%[11], [12]. The discrepancies in the results of physico-chemical tests with those of other researchers such as Bagayoko, Saifoullah et al., and Traore can be attributed to the use of the 4/8 aggregate, which drastically altered the mixture's granularity [11], [12], [14]. It is worth noting that most researchers in this field have confined themselves to finer particle sizes, using only sand or sand mixed with clay. The choice of a higher granulometry is beneficial, as it allows the production of bricks and especially concrete blocks without giving up the production of interlocking pavers. The various tests conducted after the physicochemical tests, such as compatibility with mortars, nailing, varnishing, and temperature resistance, have confirmed the hypothesis of a possible use of these materials in the field of civil engineering. These more resistant pavers can be laid on roads with heavy traffic, thereby surpassing the recommendations of Doublier et al., who advocate for interlocking pavement for pedestrian traffic [10]. From an economic standpoint, most concrete blocks made from plastic waste are significantly cheaper than their traditional counterparts. In June 2023, one square meter of paving, 10 cm thick, costs 46,634 Ar, and that of 5 cm thick costs 27,617 Ar, compared to 71,990 Ar and 45,000 Ar, respectively, in the concrete paving market. Concrete blocks cost 2,030 Ar, compared to 2,500 Ar in the concrete block market, and bricks cost 518 Ar, compared to 450 Ar to 500 Ar in the clay brick market. The slight profitability of clay bricks can be explained by the fact that clay is readily available to manufacturers. Furthermore, the water used in their production is typically not potable water but rather river and rainwater. However, the technologies used in brick manufacturing, such as firing generally below 700°C, result in lower-quality bricks. The superior quality-to-price ratio of materials, especially interlocking pavers, is a fact unanimously recognized by other researchers such as Bagayoko, Doublier et al., Saïfoullah et al., Georges, and Martin (2010), including those who criticize the process for health and/or environmental reasons like Kamgaing [10]–[12], [15], [16]. This high quality-to-price ratio also reflects social benefits such as cleanliness, hygiene, and, most importantly, job creation.

## 5- Conclusion

The direct consequences of environmental degradation are mainly felt in island countries, making them the most vulnerable to the impacts of climate change. This change is partly due to pollution caused by plastic waste, which continues to escalate, especially in developing countries. The work on recycling plastic waste using PET as a binder for the production of new materials aligns with a major concern to preserve the environment and build a sustainable future. By adopting an innovative approach to recycling, we have succeeded in transforming plastic waste into a useful and beneficial material for various applications, particularly in the field of civil engineering. The results obtained from the mechanical strength tests are remarkable, with a value of 5.8 MPa for bricks and blocks and 11.26 MPa for pavers. Furthermore, the water absorption rates are also satisfactory, reaching 4.9% for bricks and blocks and only 0.39% for pavers. These results are not only promising from a technical standpoint, but they are also positive from an economic perspective. Indeed, the cost differences between paving stones and concrete blocks are significant: a saving of 470 Ar for concrete blocks and an impressive reduction of 25,356 Ar per square meter of 10 cm thick paving and 17,383 Ar per square meter of 5 cm thick paving compared to traditional materials. For bricks, although a slight increase of 69 Ar is observed, we still insist on the superior quality-to-price ratio of the material. All of these data clearly demonstrate the feasibility of our materials and their potential for use in various application areas. Unlike traditional materials, especially cement concrete, this circular approach offers multiple advantages. In addition to contribute to the reduction of plastic waste, it promotes the preservation of natural resources, water conservation, and the reduction of carbon emissions. Indeed, the processes of cement production and water treatment require significant energy consumption, leading to significant greenhouse gas emissions. Faced with these challenges, this work addresses the current issues related to waste management and environmental protection. Thus, this work is not only innovative in terms of the technique used but also socially and environmentally responsible. This approach makes a significant contribution to addressing a major issue of our time by offering a sustainable alternative to plastic waste recycling and creating new opportunities for responsible use of resource. However, it is essential not to exclude further improvement of the process, given that the fuel used is not appropriate, especially for environmental reasons, and that the smoke emissions released during the manufacturing process are extremely toxic and harmful to humans and biodiversity. Potential solutions could involve designing a concrete mixer that runs on renewable energy and implementing a smoke capture and treatment system to reduce their harmful impact. Another possibility is to use rice husks for heating energy and the resulting ash as a replacement for sand.

## 6- Acknowledgements

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## 7- References

[1] A. A. Ansari, S. Khoso, et M. T. Naqash, (2021) « Experimental study on performance of various thermal insulation materials under severe temperature conditions », *International Journal of Energy, Environment, and Economics*, vol. 29, nº 2, p. 144-156.

[2] C. Mentis et C. Tsirimokos, « The economy – resources link under variable economic conditions. Evidence from Germany and Greece », *International Journal of Energy, Environment, and Economics*, vol. 24, nº 2-3, p. 214-230Volume.

[3] W. W. Y. Lau *et al.*, (2020) « Evaluating scenarios toward zero plastic pollution », *Science*, vol. 369, nº 6510, p. 1455-1461, doi: 10.1126/science.aba9475.

[4] Z. E.- ICI.Radio-Canada.ca, (2018) « Un béton écologique à base de déchets plastiques conçu à Ottawa | L'ennemi plastique | Radio-Canada.ca », Radio-Canada, accessed on August 07, 2023. [Online]. Available online at: https://ici.radio-canada.ca/nouvelle/1089340/beton-ecologique-dechets-plastiques-ottawa-innovation-moussa-thiam.

[5] R. Geyer, J. R. Jambeck, et K. L. Law, (2017) « Production, use, and fate of all plastics ever made », *Science Advances*, vol. 3, n° 7, juill. 2017, doi: 10.1126/sciadv.1700782.

[6] L. J. J. Meijer, T. van Emmerik, R. van der Ent, C. Schmidt, et L. Lebreton, (2021) « More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean» , *Science Advances*, vol. 7, n° 18, avr. 2021, doi: 10.1126/sciadv.aaz5803.

[7] S. Khoso *et al.*, « An experimental investigation using recycled coarse aggregate as an alternative material for sustainable concrete », *International Journal of Energy, Environment, and Economics*, vol. 29, n° 4, p. 444-455.

[8] S. Khoso, J. Raad, et A. Parvin, (2023) « State of the art review on the properties of sustainable concrete using hybrid fibers », *International Journal of Energy, Environment, and Economics*, vol. 30, n° 1, p. 38-52.

[9] S. A. Aladejare, « Energy utilization, economic prosperity, and environmental quality in west africa: is there an asymmetric nexus? » *International Journal of Energy, Environment, and Economics*, vol. 28, n° 3, p. 166-191.

[10] G. Doublier et O. Sorgho, (2009) « Valorisation des déchets de sachets plastiques Utilisation comme liant dans la fabrication de matériaux composites : Application dans les villes subsahariennes », *conférence internationale sur la valorisation des déchets et de la biomasse dans les pays en développement, Ouagadougou, Burkina-Faso 9-11 Juillet 2009.*

[11] D. Saïfoullah, A. L. Pahimi, A. Gové, et J. D. Housseini, (2020) « Valorisation des déchets plastiques dans la production des matériaux de construction: cas des paves dans la ville de garoua (nord-cameroun) » , *American Journal of Innovative Research and Applied Sciences*, vol. 10, n° 6, p. 215-221.

[12] M. Bagayoko, (2011) « Mémoire pour l'obtention du master spécialise en énergie renouvelable », *International Institute for Water and Environmental Engineering*, Burkina-Faso, *September 23, 2011.*

[13] J. Perrin, « La technique paves plastiques-sable est à condamner ». accessed on June 29, 2023. [Online]. Available online at : https://pdfprof.com/PDFV2/Documents1/32797/37/3#gsc.tab=0

[14] B. Traore, K.Atcholi, M.Boffoue, R.Lachat, E.Emeruwa (2017) «Elaboration and Characterization of Composite Materials made of Plastic Waste and Sand: Influence of Clay Load», *International Journal of Scientific Engineering and Technology*, vol. 6, n° 7, p. 220-223.

[15] Z. Georges et Y. Martin, (2010) « Rapport étude socio-économique sur le pavé plasitque », Projet Stratégie de Réduction des Déchets de Ouagadougou Création d'Emplois et de Revenus par des actions de collecte, de tri, et de valorisation, December 2010, accessed on August 07, 2023. [Online]. Available online at: https://pdfprof.com/PDFV2/Documents1/32797/37/1#gsc.tab=0

[16] P.-C. Kamgaing, (2021) « Établir des modes de consommation et de production durables (ODD-12) : cas de la lutte contre la pollution plastique », *Journée Camerounaise des Objectifs de Développement Durable*, November 2021, Yaoundé, Cameroun.

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## 8- Tables

*Table 1 : Several characteristics of the aggregates used*

| Characteristics | SR 0/2 | GC 4/8 |
|---|---|---|
| Fineness modulus | 1.4 | / |
| Absolute density (kg/m$^3$) | 2617 | 2635 |
| Apparent density (kg/m$^3$) | 1500 | 1520 |

*Table 2 : Results of compatibility tests with mortars*

| Rate | Cement | Lime | Mixture |
|---|---|---|---|
| 20% | Very good | Good | Low |
| 50% | Very low | Very low | Very low |

*Table 3 : Summary of other quality tests*

| Formulation | Nailing | Varnishing | Temperature resistance |
|---|---|---|---|
| 20 % | Good with the 60-point nail | Very good | Good |
| 50% | Incompatible | Very good | Good |

*Table 4 : Estimated cost of 1m$^2$ of paving*

| Designations | Units | Quantities | Unit price [Ar] | Amount [Ar] |
|---|---|---|---|---|
| Plastic bottles | Kg | 55.4 | 450 | 24,948 |
| Coarse aggregates | m$^3$ | 0.0564 | 70,000 | 3,948 |
| Sand | m$^3$ | 0.0286 | 30,000 | 858 |
| Wood | Kg | 82.8 | 100 | 8,280 |
| Transportation | / | | | 2,000 |
| Labour | / | | | 6,600 |
| **TOTAL AMOUNT** | | | | **46,634** |

*Table 5 : Estimated cost of 1m$^2$ of solid or hollow brick wall*

| Designations | Units | Quantities | Unit price [Ar] | Amount [Ar] |
|---|---|---|---|---|
| Plastic bottles | Kg | 30.7 | 450 | 13,824 |
| Coarse aggregates | m$^3$ | 0.0674 | 70,000 | 4,718 |
| Sand | m$^3$ | 0.0341 | 30,000 | 1,023 |
| Wood | Kg | 71.2 | 100 | 7,122 |
| Transportation | / | | | 2,000 |
| Labour | / | | | 4,480 |
| **TOTAL AMOUNT** | | | | **33,167** |

*Table 6 : Estimated cost of 1m$^2$ of concrete block wall*

| Designations | Units | Quantities | Unit price [Ar] | Amount [Ar] |
|---|---|---|---|---|
| Plastic bottles | Kg | 21 | 450 | 9,450 |
| Coarse aggregates | m$^3$ | 0.041 | 70,000 | 2,870 |
| Sand | m$^3$ | 0.021 | 30,000 | 630 |
| Wood | Kg | 70 | 100 | 7,000 |
| Transportation | / | | | 2,000 |
| Labour | / | | | 2,400 |
| **TOTAL AMOUNT** | | | | **24,350** |

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## 9- Figures

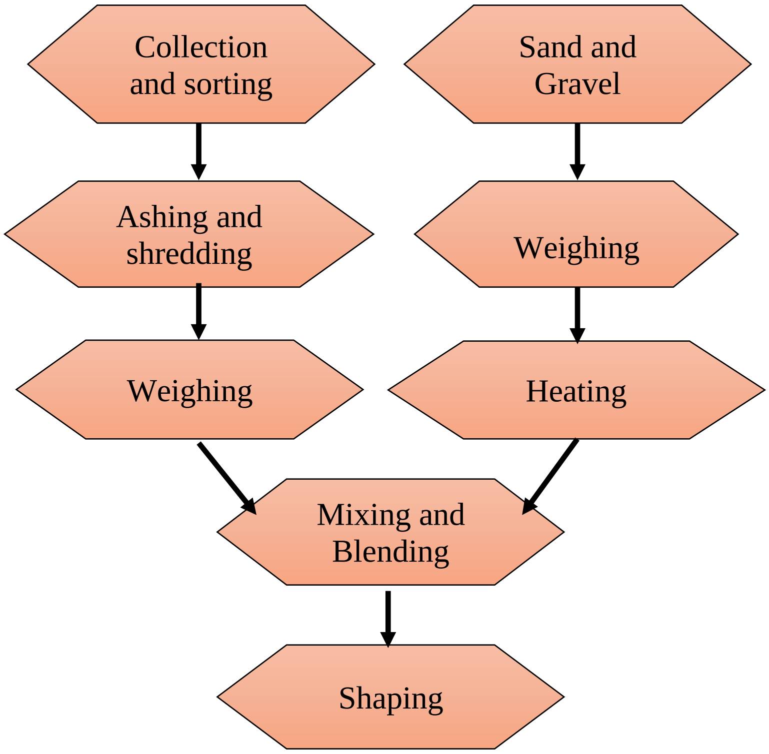


*Figure 1 : Implementation process*

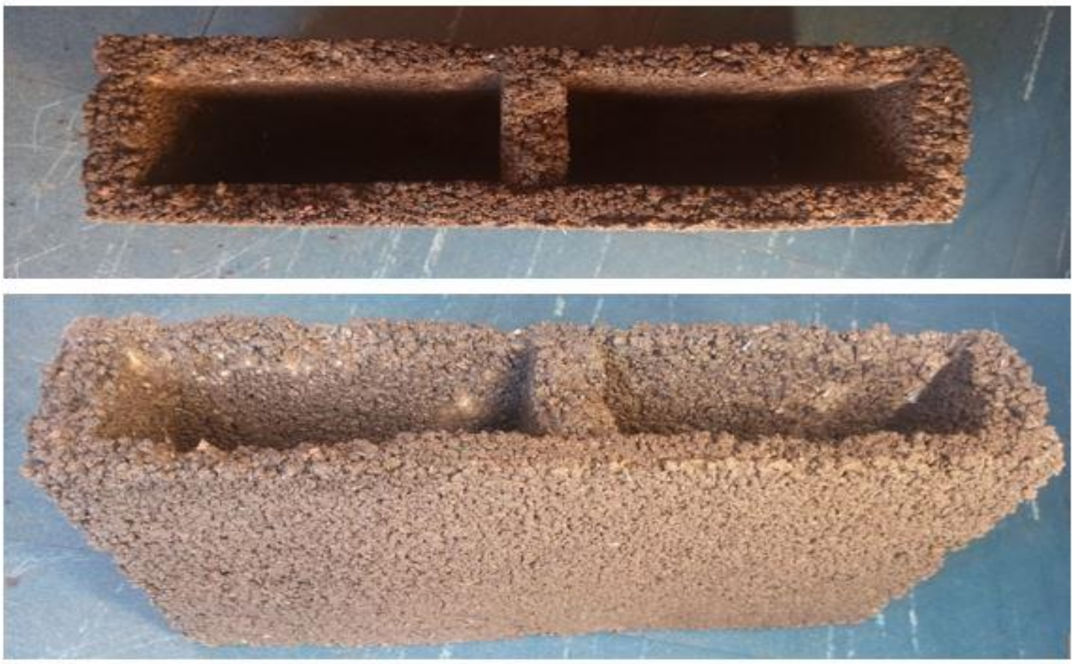

*Figure 2 Hollow blocks*

*Figure 3 Solid bricks*

*Figure 4 Hollow bricks*

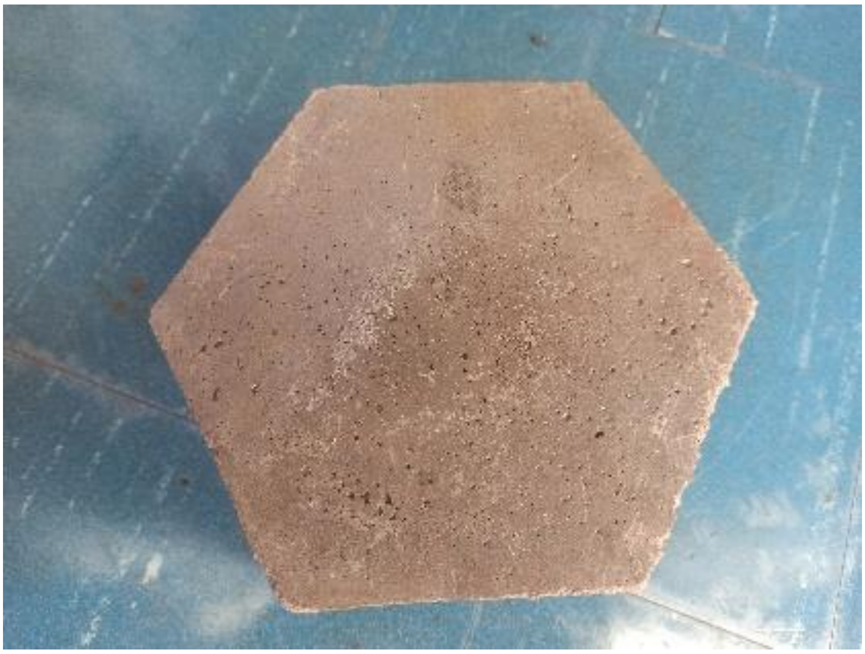

*Figure 5 Interlocking pavers*

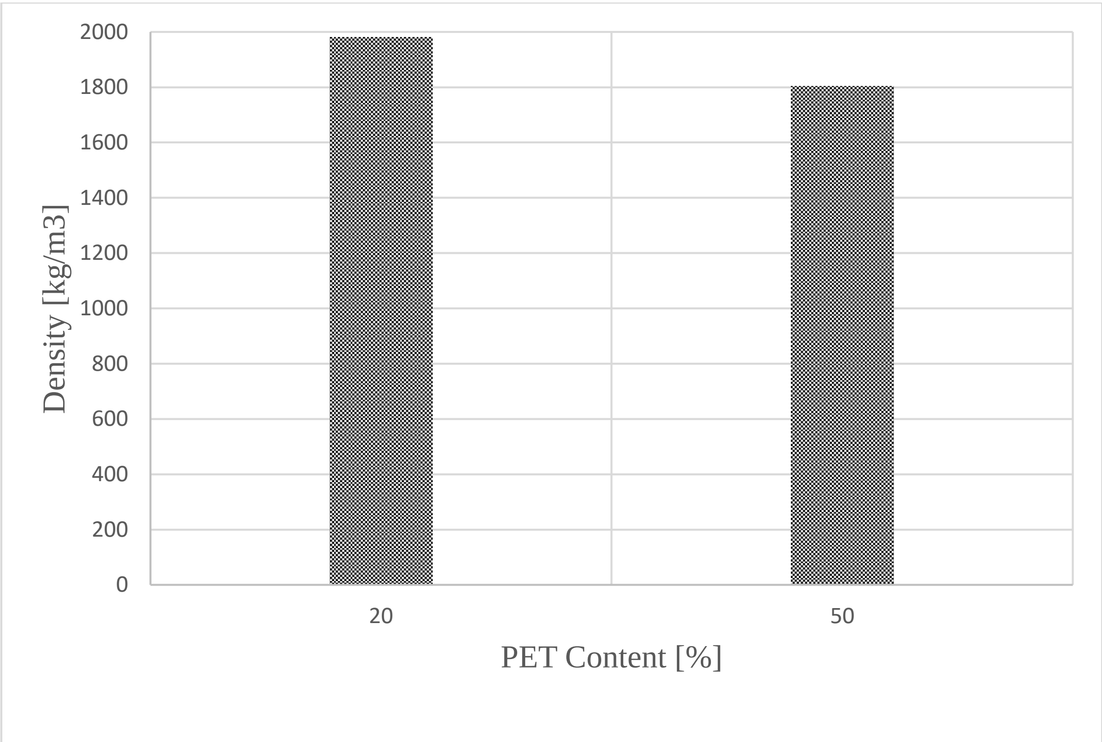


*Figure 6 : Illustration of the variation of density as a function of PET rate*

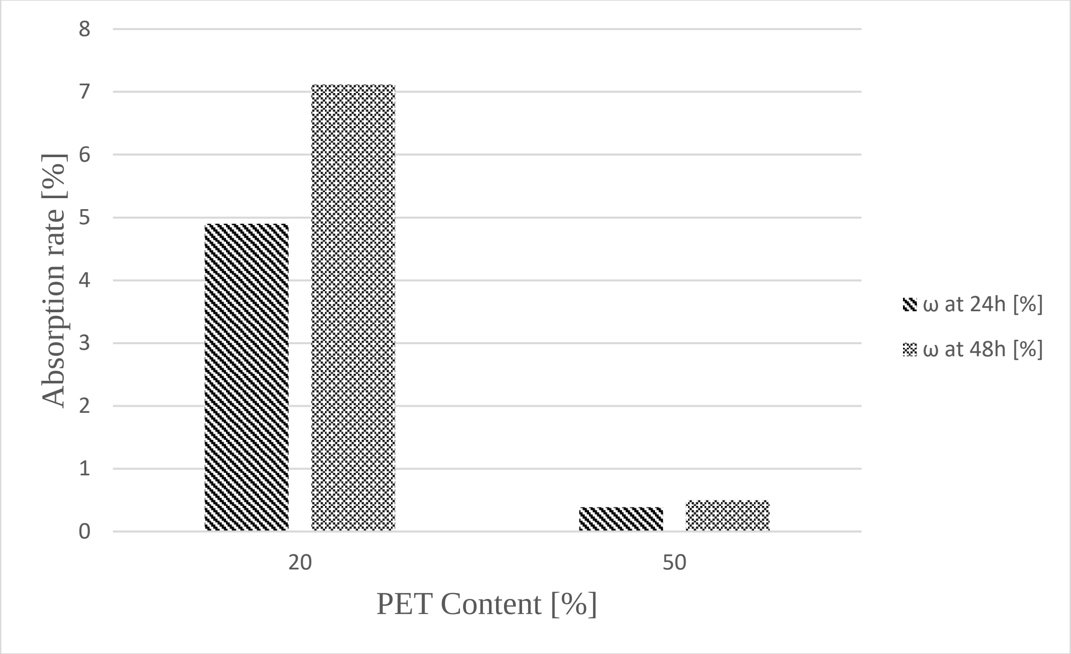


*Figure 7 : Evolution of absorption rate over time as a function of PET*

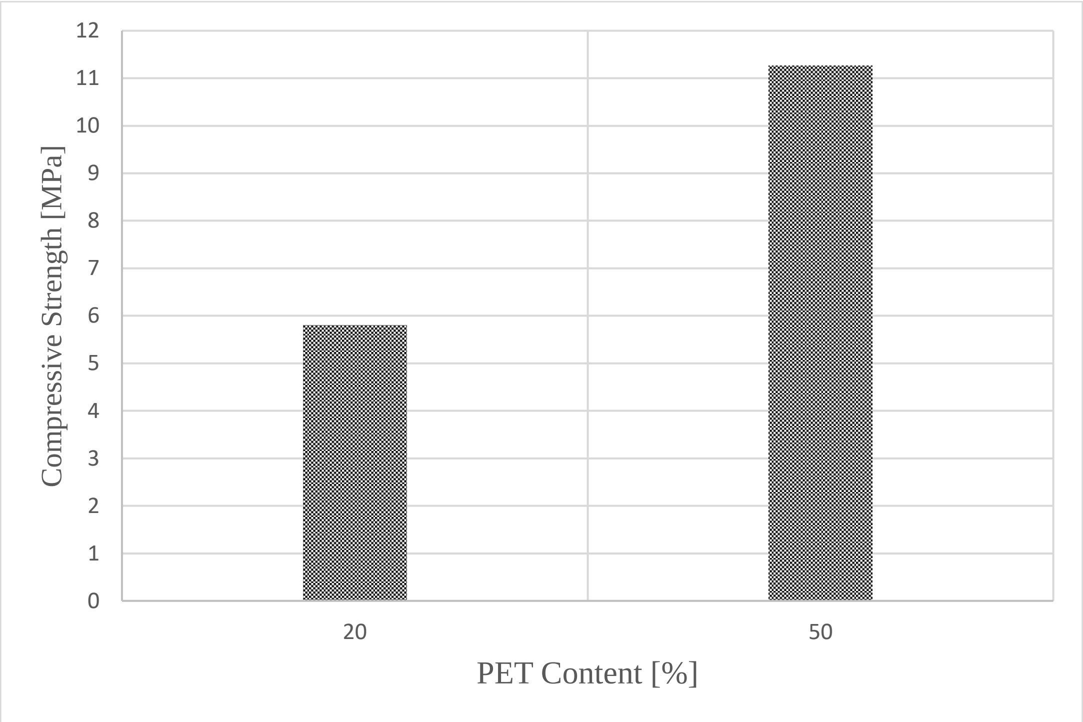


*Figure 8 : Compression strength in relation to the PET binder content*