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Study of the Physical and Chemical Properties of Bricks Made from Plastic Waste and Flint

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ABSTRACT

The aim of this article is to determine the physical and chemical properties of composite bricks based on waste plastics and flint, in order to predict the durability of these materials. The methodology adopted consists in using flint mine tailings as reinforcement, mixed with four types of plastic: PET, HDPE, PP and LDPE, each blended in proportions ranging from 10 to 50% in steps of 10, to determine which of the four materials offers the best performance. Once the bricks had been made, laboratory tests were carried out on density, water absorption and fire resistance. The results obtained were satisfactory in terms of durability. The various results obtained were also compared with the requirements of standards for masonry, road surfaces (pavers) and flooring materials. The results show that the materials can be used in the building and civil engineering sector as bricks, utility poles, road kerbs and floor slabs.

Keywords: Composite bricks, plastic waste, Flint, durability.

INTRODUCTION

Plastic is a non-biodegradable material; it is a source of pollution and creates waste even in developed countries [1]. In Senegal in particular, the presence of plastic waste is destroying the environment and damaging the aesthetics of cities. What's more, in the construction sector, the scarcity of materials on the one hand, and their very high cost on the other, pose a real threat [2]. To solve these environmental problems, a great deal of thought the design of new materials. Today, the recycling of plastic waste is the subject of numerous studies. In most works, waste plastics are incorporated into cementitious matrices [3]. Other methods of using waste plastics to design new materials are also being are also the subject of numerous studies.

This is the background to our work, which focuses on exploring the possibilities of combined recovery of these two types of plastic and mining waste in construction materials.

Controlling the deformation of materials is a major challenge for civil engineering today, as it enables us to predict their behavior when subjected to different loads. This requires knowledge of mechanical, physical and chemical properties. In the case of polymer concrete, a great deal of work has been carried out to determine the influence of plastic on the material's mechanical properties.

In this study, we focus on the influence of the proportion and type of plastic on the physicochemical behaviour of the new composite material.

MATERIALS & METHODS

1.Materials

To produce the samples, the plastic is melted. This method was chosen to exploit the thermoplastic binding properties of polymers. To this end, the equipment used to manufacture the components is:

- Personal protective equipment (PPE) to limit physical damage in the event of an accident (one pair of glasses, two pairs of gloves and safety shoes).
- A pot
- An iron compactor
- One metal plate
- Two wooden and iron molds
- Scales for weighing sand and plastic waste
- A mason's peel
- A trowel to smooth the mixture
- Infrared thermometer to measure mixture outlet temperature
- Motor oil and brush to lubricate mold walls
- Energy source: butane gas

2.Methods

After mixing, the plastic-flint assembly is heated in a melting tank at 170°C for five (10) minutes.

During heating, mixing is carried out simultaneously with the mixer.

After this step, the mixture is placed in a mold and compacted using a hand compactor. Cooling is then carried out under the same pressure to 38°C before demolding.

The diagram in Figure 1 illustrates the manufacturing process.

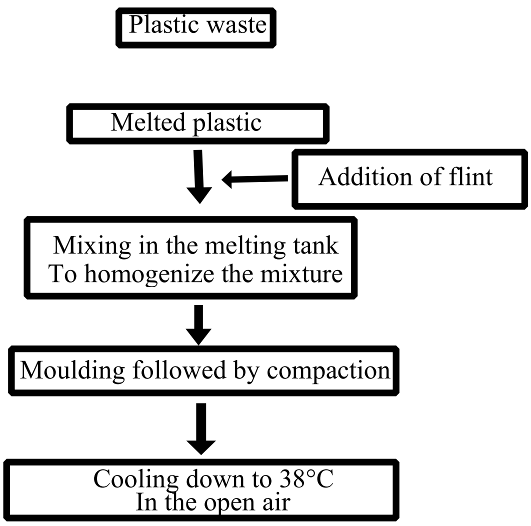

Figure 1: Sample preparation methodology

After cooling for 30 minutes, the sample is demolded to produce the components shown in Figure 2.

Figure 2: Image of sample

RESULTS AND DISCUSSIONS

1. Effect of plastic ratio on bulk density

Figure 3 shows the variation in bulk density of materials obtained from four types of polymer, each mixed with the flint sample.

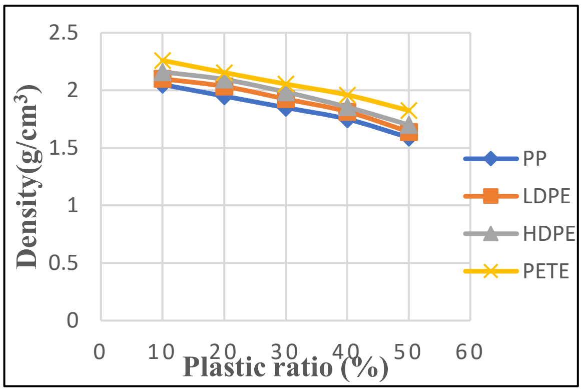

Figure 3: Bulk density as a function of plastic content

Figure 3 shows the variation in bulk density as a function of the plastic content of the material.

We note that the apparent density for each of the formulations decreases when the amount of plastic in the mixture increases from 10% to 30%. It decreases from 2.245 to 1.825 g/cm3 for the PET-based silexite sample; from 2.16 to 1.7 g/cm3 for the addition of HDPE; from 2.135 to 1.68 g/cm3 for the addition of LDPE; and from 2.10 to 1.64 g/cm3 for the addition of PP.

Beyond these respective percentages, we observe that the density continues to decrease

more rapidly. This is because the materials contain too much plastic, which is by nature a lighter material, leading to a significant decrease in the density of the composite material [4], [5], [6].
We also note that the density of PET- and HDPE-based composite materials is higher than that of PP- and LDPE-based composites. This is due to the density of the polymers, which varies according to their chemical structure, crystallinity and chemical composition. High-density polyethylene and polyethylene terephthalate have much higher densities than LDPE and PP. Crystal formation promotes strong intermolecular forces and a rigid chain backbone because molecules prefer an ordered arrangement with maximum packing density to maximise the number of secondary bonds [7], [8].

1.1. Correlation between actual density and apparent density

Based on the law of mixtures, the actual density of composite materials is determined to correspond to that of their constituent elements. Figure 4 below shows a correlation between the apparent and actual density of materials obtained from four types of polymers, each mixed with the silexite sample.

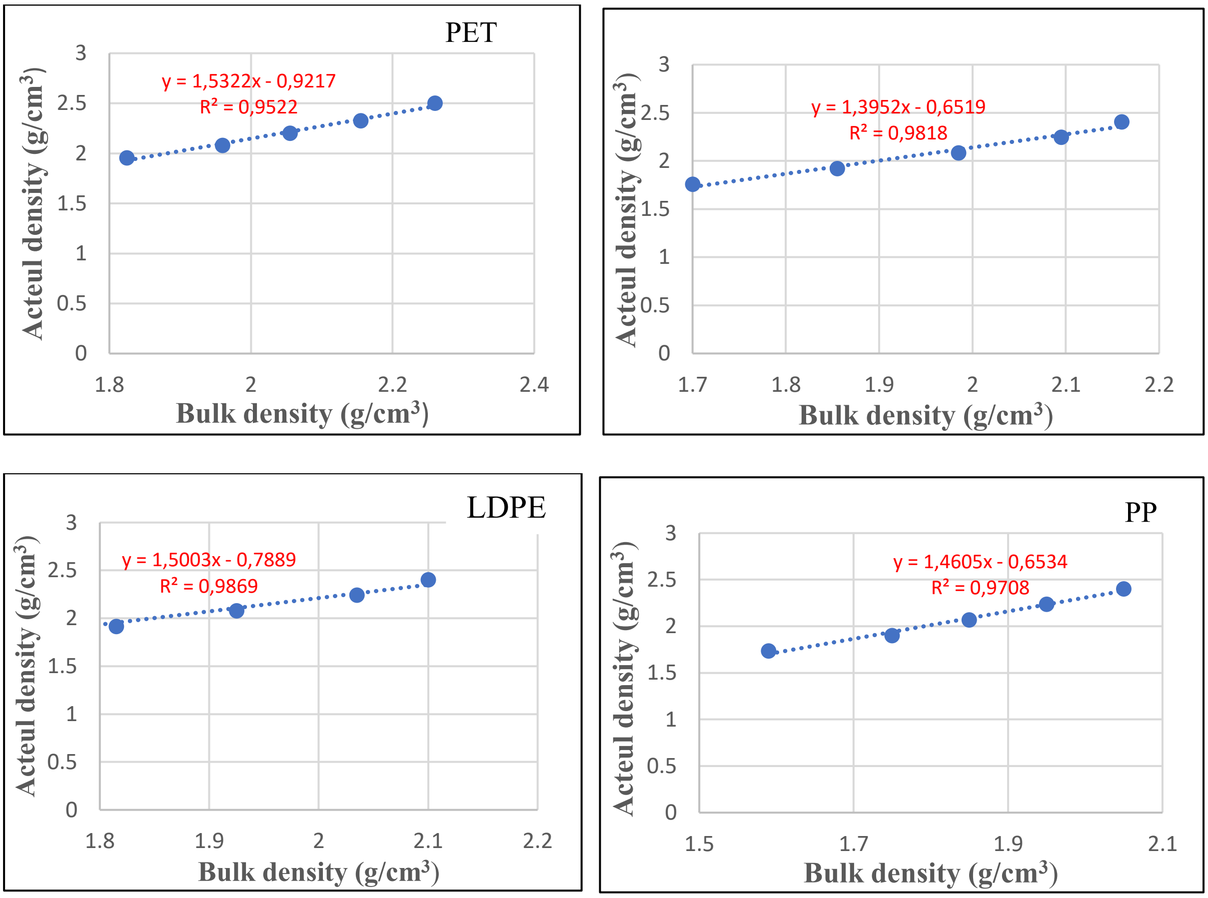

Figure 4: Correlation between the actual and apparent density of composite materials

A linear regression trend line can be observed for all samples. This shows that the actual density results obtained using the mixture law are similar to those obtained using the experimental method, with a standard deviation of 0.23 for PP-based components, 0.219 for HDPE-based samples, 0.22 for LDPE-based components and 0.18 depending on the PET content. For all samples, very low standard deviation values are obtained, reflecting a slight dispersion of the values obtained with the two methods.

2. Effect of rate and type of plastic on porosity

The porosity of a material can be calculated using its actual density and apparent density. The basic formula for porosity (P) is given by:

$$P = \frac{D - D\prime}{D} x100 \qquad (1)$$

Where D is the actual density and D' is the apparent density.

The variation in porosity depending on the rate and type of plastic is shown in Figure 5 below.

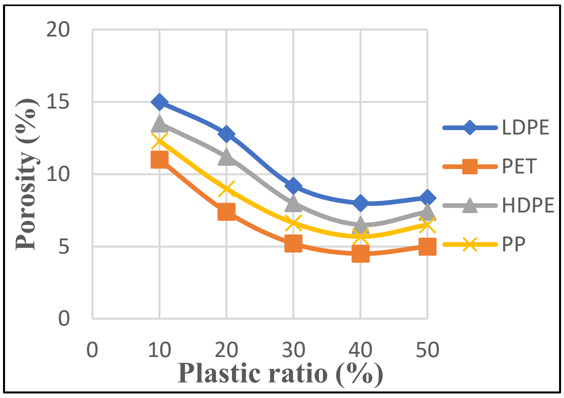

Figure 5: Variation in porosity depending on the amount and type of plastic

Figure 5 illustrates the variation in porosity of the components as a function of plastic content. For all of the materials studied, a significant decrease in porosity is observed when the plastic content in the material increases from 10% to 40%. This trend can be explained by the fact that the addition of plastic fills the voids between the flint grains, thereby improving the internal cohesion of the composite. Above 40%, there is an increase in porosity for all components due to excess plastic in the material, which causes poor compaction and bubble formation. The porosity rate obtained for all components varies between 4.5 and 15.5% and remains below the 20% value required by the standard for good concrete.

In fact, components based on PET (polyethylene terephthalate) and PP (polypropylene) have lower porosity due to their good resistance to moisture and are therefore less permeable. On the other hand, materials made of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) are more porous.

3. Water absorption test

Figure 6 shows the variation in the absorption coefficient as a function of plastic content.

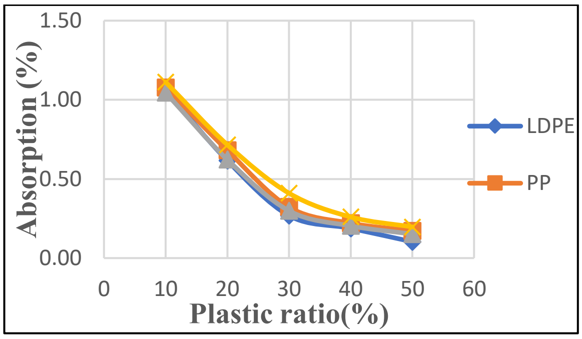

Figure 6: Variation in absorption coefficient as a function of plastic ratio

Absorption decreases proportionally as the plastic content of all components rises from 10% to 30%. Above 30% plastic, the absorption rate remains very low, despite the increase in plastic in the material. The increasing addition of plastic, which is hydrophobic, will prevent water from entering the material.

This result partly confirms that of density, since a material with more intergranular voids (less dense material) absorbs more water. However, the absorption curve for flint-low-density polyethylene (LDPE) remains below that of other materials, as LDPE is more hydrophobic than other polymers.

Standard NF EN 1338 requires absorption ≤ 6%, whereas the absorption obtained on the samples varies from 1.10 to 0.20% for all components.

4. Thermal conductivity

The variation in thermal conductivity depending on the percentage and type of plastic is illustrated in Figure 7 below.

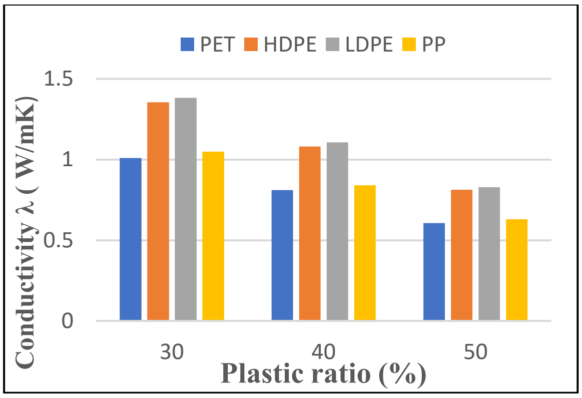

Figure 7: Variation in conductivity depending on the rate and type of plastic

We observe that for each silexite/plastic mixture, conductivity decreases as the amount of plastic increases in the plastic/silexite mixture. Analysis of Figure 7 shows that thermal conductivity decreases with increasing plastic content for all formulations.

The highest thermal conductivity values are obtained with the plastic mixtures that gave the best mechanical performance. After grinding the bricks, it was found that the most resistant components were compact and solid, demonstrating very good adhesion between the material and the plastic. The absence of voids in each of these formulations contributed to the increase in thermal conductivity. On the other hand, the low thermal conductivities obtained with the other formulations may be related to:

The presence of voids due to a compaction defect related to either a deficit or an excess of plastic in the mixture. These voids allow air to pass through, which reduces conductivity and weakens the adhesion between the material and the binder.

In addition, the conductivity of high- and low-density polyethylene-based components is much higher due to the intrinsic nature of these plastics, which have higher thermal conductivity. In contrast, for materials composed of polyethylene terephthalate and polypropylene, conductivity is lower due to their lower conductivity.

4.1. Influence of plastic on cooling and solidification speed

Figure 8 shows the variation in the cooling rate of the materials obtained depending on the proportion and type of plastic.

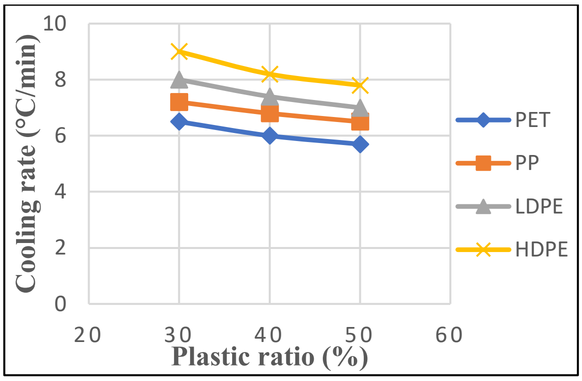

Figure 8: Temperature variation as a function of cooling time

Figure 8 shows the variation in temperature as a function of the cooling rate of the components. For all the materials studied, a gradual decrease in the cooling kinetics over time can be observed. However, for all types of polymers, an increase in the plastic content of the material leads to a reduction in the cooling rate. This is due to the insulating properties of the plastics used, which belong to the thermoplastic family and generally have low thermal conductivity.

For components based on HDPE and LDPE, the cooling rate is relatively fast, which can be explained by their semi-crystalline structure, which facilitates heat transfer to a certain extent. On the other hand, for PET and PP-based composite materials, cooling is slower. This difference is mainly related to their higher thermal insulation capacity, resulting from their more amorphous molecular structure (in the case of PET and PP) which limits heat transfer.

4.2. Correlation between thermal conductivity and density

The correlation between thermal conductivity and bulk density for samples containing 10% to 50% plastic is shown by the curve in Figure 9. The expression proposed for this correlation is a linear relationship presented by the following equation.

Y= aX+b; Y (W/m. K): conductivity and X (g/cm3): density

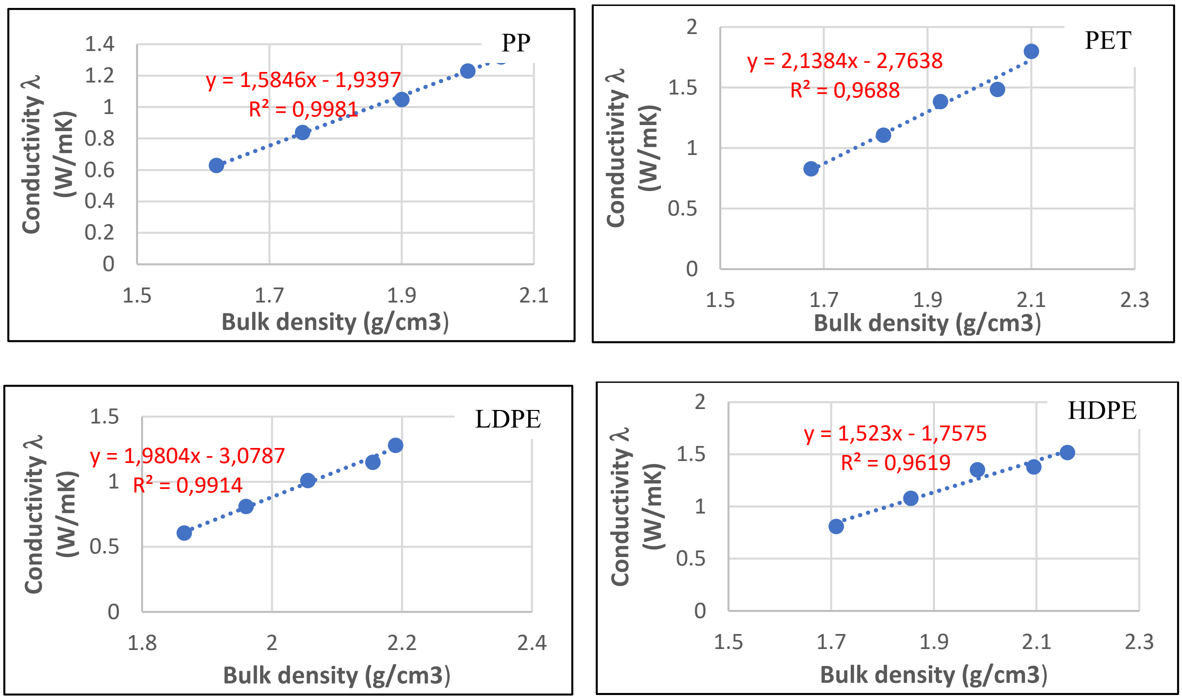

Figure 9: Correlation between thermal conductivity and bulk density

The correlation equations obtained also made it possible to calculate conductivity based on the type of plastic. The results are shown in Figure 10.

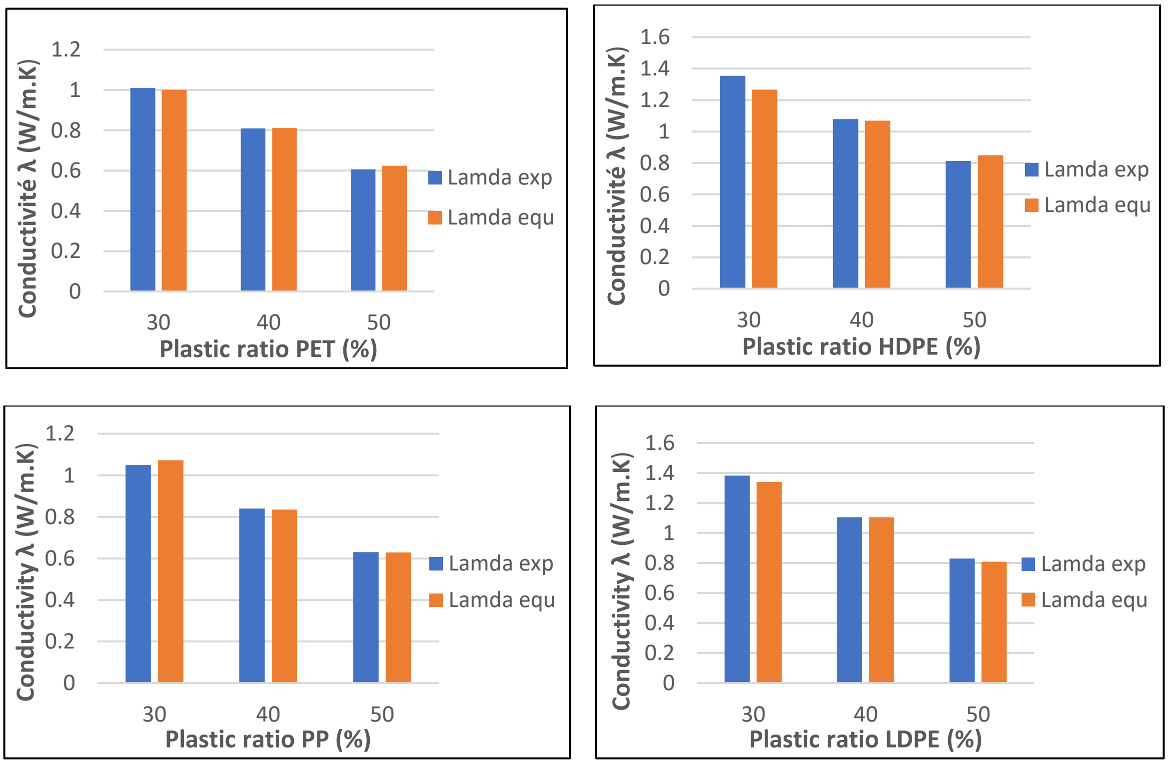

Figure 10: Experimental and equation-based thermal conductivity as a function of plastic content

The experimental results are similar to those obtained using the equation, with a standard deviation of 0.19 for PP-based materials, 0.24 for HDPE-based samples, 0.216 for LDPE-based components and 0.17 for PET.
For all samples, standard deviation values close to 1 were obtained, reflecting a slight dispersion of the values obtained with the two methods. The results therefore confirm that the predictive equations are reliable for estimating the thermal conductivity of polymer concrete according to the type and proportion of plastic used.

4.3. Combined method

To compensate for erroneous results and improve the reliability of thermal conductivity estimates through control, it is essential to calibrate the measurement values obtained from the two tests (density + porosity). Correlation relationships between the results (porosity and density) were therefore established. The values are plotted in graphs, then MATLAB software is used to draw a curve giving an equation.
Figure 11 shows a surface estimating a relationship between conductivity, density and porosity.

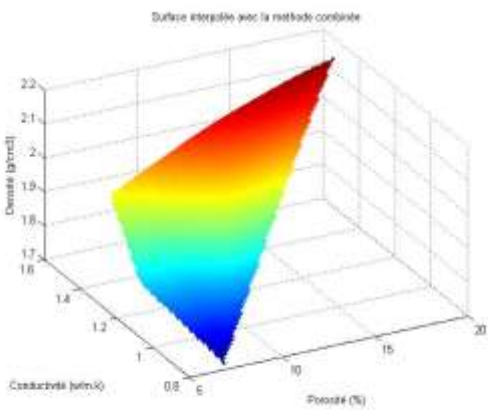

Figure 11: correlation between conductivity, density and porosity

L'expression proposée à cette corrélation est une relation de forme polynôme présentée par l'équation suivant
Z = 2,35X-0,09Y-2,77 ; Z : Conductivité (W/m. K) ; X : Densité du matériau (g/cm3) ; Y : Porosité (%).

L'équation de corrélation obtenue a également permis de calculer la résistance en compression en fonction du taux de plastique (PEHD). Les résultats sont présentés sur la figure 12.

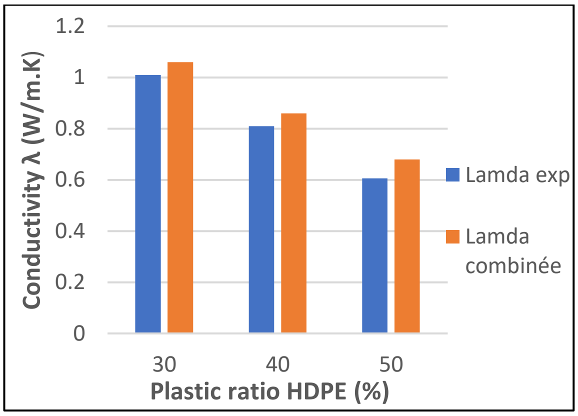

Figure 12: Compressive strength by crushing and by combined method depending on the HDPE content.

It can be seen that the results obtained experimentally differ little from those obtained by the equation, with a standard deviation of 0.224 depending on the HDPE content.
The correlation equation is acceptable with a correlation coefficient R2 = 0.96. This method therefore provides more reliable results and reduces measurement errors in the results.

5. Resistance to chemical attack

At the end of this test, the following aspects will be observed from a macroscopic point of view:

- Alteration of the shape of the material
- Alteration of the mechanical quality of the material
- Corrosion of the material

The compression test was then carried out on samples immersed in acid and base solutions using a 50 KN mechanical press. The maximum stresses were compared with those of the non-immersed samples.
Figure 13 shows the variation in compressive stresses of the immersed and non-immersed samples as a function of plastic content.

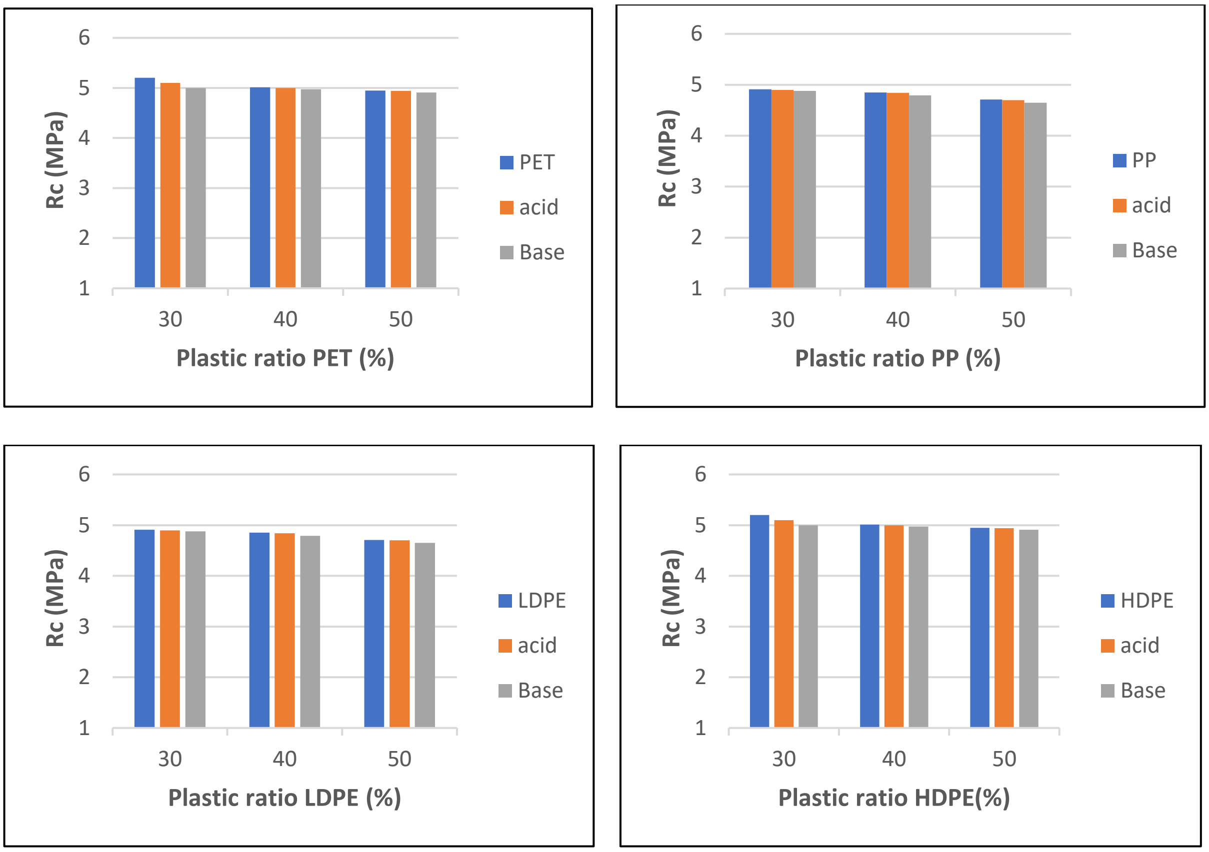

Figure 13: Variation in stress of submerged samples depending on the type of plastic

Figure 13 illustrates the variation in compressive strength of samples immersed in acidic and basic solutions, depending on the plastic content. The results show that, for all materials, the maximum compressive strengths are around 5 MPa. However, as shown in Figure 7, samples immersed in acidic or basic environments have slightly lower strengths than non-immersed samples, regardless of the type of plastic used.

From a macroscopic point of view, no deterioration or corrosion was observed on the surface of the materials in the acid and base chemical solutions. Some authors, such as [5], made the same observations in their work.

CONCLUSION

The aim of this study is to recycle plastic waste and silexite residues for the development of a new composite material, but also to study the effect of the proportion and type of plastic on the physical and chemical behaviour of the materials obtained. The results obtained allow us to conclude that this waste recycling method should be adopted. These components are suitable for foundation masonry and offer good resistance to moisture and corrosion, unlike traditional materials such as wood or raw earth. In order to broaden the scope of application of the materials obtained, further studies, such as improving fire resistance through the use of flame retardants, need to be carried out.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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