

Mechanical Characterization of Composite Materials Based on Plastic Waste and Flint

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Abstract

The aim of this study is to enhance the value of plastic waste and mining residues from flint by proposing a method for recycling these wastes into composite materials that can be used in the construction industry. The methodology adopted consists of using flint mine tailings as reinforcement, mixed with four types of plastic: PET, HDPE, PP and LDPE, each mixed in proportions ranging from 10% to 50% in steps of 10, in order to determine which of the four composite materials offers the best mechanical performance. After the bricks had been made, mechanical tests (compression, splitting and 3-point bending) were carried out in the laboratory. The results obtained were acceptable in terms of mechanical strength. The various results obtained were also compared with the requirements of standards for masonry, road surfacing (pavers) and flooring materials. The results show that the materials can be used in the building and civil engineering sector as bricks, electricity poles, road kerbs and floor tiles.

Keywords

Plastic Waste-Flint-Recycling-Composite Materials, Construction

1. Introduction

Plastic is a non-biodegradable material; it is a source of pollution and creates problems even in developed countries. 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 [1]. Faced with this challenge,

the recycling of plastic waste for the development of new construction materials such as composites appears to be one of the best solutions for the elimination of plastic waste, due to its economic and ecological advantages [2]. This is the background to our work, which focuses on exploring the possibilities of combined recovery of these two types of waste in construction materials. In this study, we will analyze and explain the influence of granulometry on the properties of the material, as well as the effect of the proportion and type of plastic on the mechanical behavior of the new composite material.

2. Materials and Methods

2.1. Raw Materials

2.1.1. Flint

Flint is the main component of our material. It is a by-product of the phosphate beneficiation process. It is obtained from the pre-treatment plant landfill, with a roughly known particle size distribution. Flint is a siliceous sedimentary rock corresponding to a continuous bed of flint. It is composed mainly of quartz, hematite and alkali feldspars, and occurs as blocks with dark cores and white cortexes. The cortex has been eliminated or reduced by dynamic fragmentation of the blocks during the settling process. These flints are extracted to produce 0/3 (Figure 1); 3/8 and 8/16 aggregates [3].



Figure 1. Taïba flint sample.

2.1.2. Plastic Waste

Plastic waste generally breaks down into two basic material categories with a number of sub-categories: Thermoplastics and Thermosets. These families are differentiated by their chemical, thermal and mechanical properties, their processing methods and the properties obtained in composites [4]. Within the framework of this study, we will use the family of thermoplastics, namely high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and polyethylene terephthalate (PET). In order to estimate the quantities of plastic waste available, we are going to carry out mapping operations of the public dumps in the town of Thiès using the Phantom 4 RTK UAV (Figure 2).



Figure 2. Phantom 4 RTK UAV.

2.2. Materials

To produce the samples, the plastic is melted. This method was chosen to exploit the thermoplastic binding properties of polymers. Equipment required for manufacturing components: To ensure the safety and quality of the manufacturing process, the following equipment is used: Personal protective equipment (PPE): a pair of safety glasses, two pairs of gloves, and safety shoes to prevent accidents. Production equipment: a pot, an iron compactor, and a metal plate. Molding tools: two molds (one wooden, one iron), a mason's trowel for handling the mixture, and a finishing trowel for smoothing it. Measuring instruments: a scale for weighing sand and plastic waste, and an infrared thermometer to monitor the temperature of the mixture at the outlet. Auxiliary products: motor oil applied with a brush to lubricate the mold walls. Energy source: butane gas.

2.3. Methods

In the course of our study, we adopted the following general methodology (**Figure 3**).

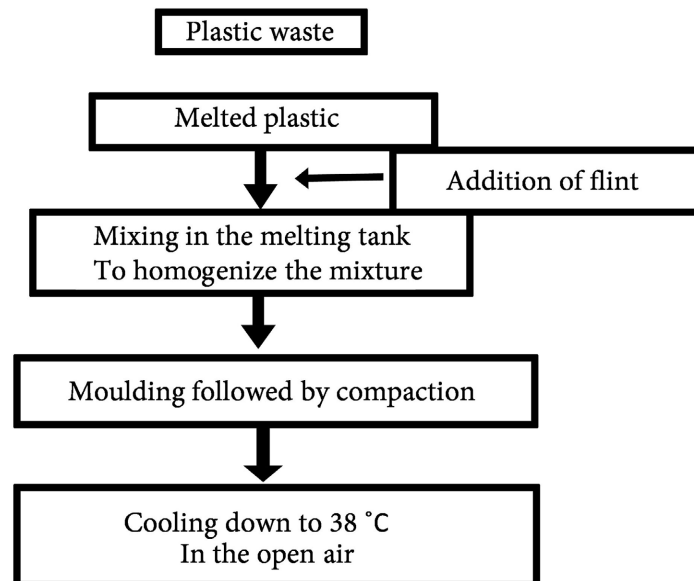


Figure 3. Sample preparation methodology.

2.3.1. Plastic Waste Preparation

It begins by sorting the waste. This is done by first separating plastic waste in general from other waste such as paper, iron, wood and others. Then, within the plastic waste, the different types of plastic are sorted. Care must be taken to ensure that the waste is shredded, washed and then stored in a clean, dry place, away from moisture. The plastics are then crushed into small pieces called pellets to facilitate melting, as shown in the following **Figure 4**.



Figure 4. Crushed HDPE plastic.

2.3.2. Plastic Material Formulation

After sorting, cleaning, weighing and grinding, the material is heated to 180° (or more) in the mixer (the kettle). It's more efficient to heat the mixer before introducing the material. The plastic is then gradually introduced and mixed in the mixer, while the mixture continues to stir. This operation produces a homogeneous, bubble-free paste.

2.3.3. Molding and Finishing

Using the brush, the walls of the molds are lubricated with draining oil to facilitate removal from the mold. The resulting paste is then spread with a trowel and packed into the mold, which is positioned on a metal plate. The compactor is used to compact and press the dough into the mold. On contact with the cold walls, the dough takes on the shape of the mold and solidifies. This operation must be carried out as quickly as possible to avoid premature solidification of the dough. After cooling for 30 minutes, the mould is demolded to produce the components shown in **Figure 5**.



Figure 5. Image of samples.

3. Results and Discussion

3.1. Characterization of Raw Materials

The particle size distribution of the flint used to make our samples is shown in **Figure 6**.

The flint sample has a grain size class of 97% 0/3 and 3% 3/8. The modulus of fineness according to EN 12620 [5] is 2.6 for flint. We can therefore deduce that the flint sample is a preferential sand. To characterize the particle size distribution of the flint, the uniformity coefficient or Hazan (C_u = ratio of the diameter of 60% of the cumulative bypass to the diameter of 10% of the cumulative bypass on the curve) was determined. The flint sample thus has a C_u equal to 11.25. According to the classifications [6], the flint sample has a spread grain size. This means that in the (spread) flint sample, all grain sizes are represented with a majority of fines.

After processing the images captured by the drone at the landfill sites, we determined the geomorphological characteristics for each zone and the corresponding maps. **Figure 7** and **Figure 8** show the mapping of public solid waste landfills in the municipality of Thiès.

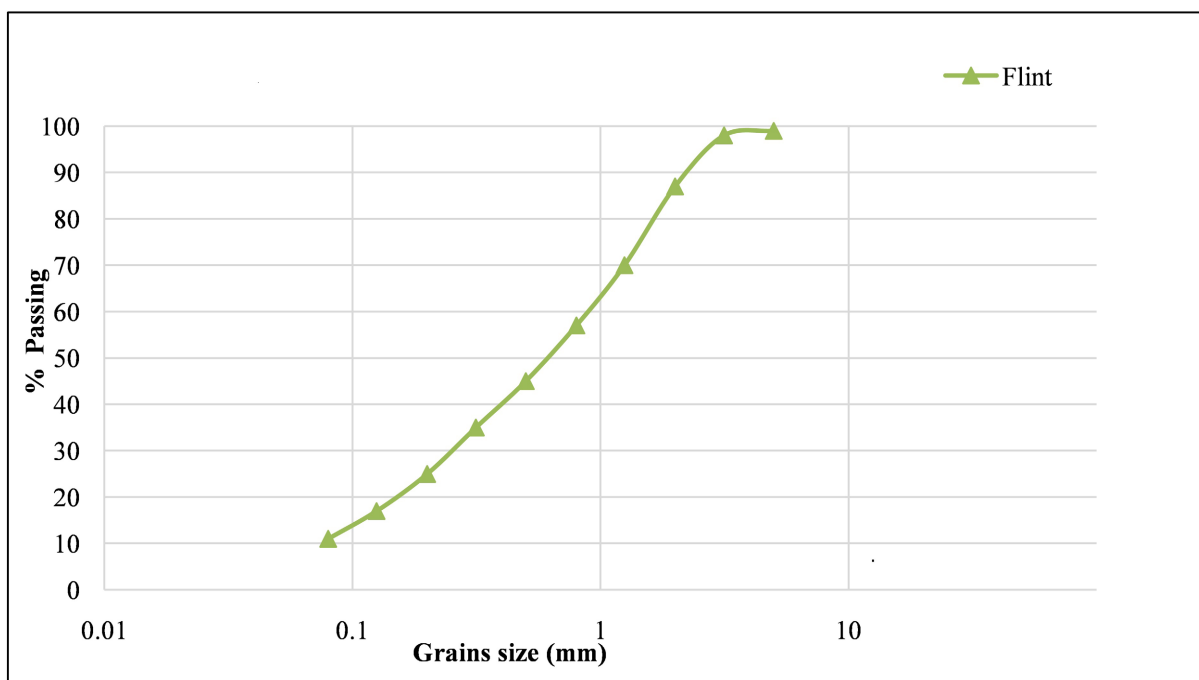


Figure 6. Granulometric analysis of flint.

After processing the data, the N°1 refuse dump at Mbour 4 covers an area of 63080.8 m² and holds a volume of 139382.4 m³ of solid waste, while the N°2 landfill at Medina FALL covers an area of 19189.6 m² and holds a volume of 7624.5 m³ of solid waste at the time of the study. The results obtained, such as the surface areas and volumes of waste specific to each depot, provide a solid basis for initiating recycling and recovery actions. These data provide an essential starting point for concrete initiatives in sustainable waste management and environmental

preservation.



Figure 7. Mapping the Mbour 4 landfill.



Figure 8. Mapping the Medina Fall landfill.

3.2. Mechanical Properties

3.2.1. Compressive Strength of Materials

The compressive strengths of polymer concretes of the four plastic types and flint are shown in **Figure 9**.

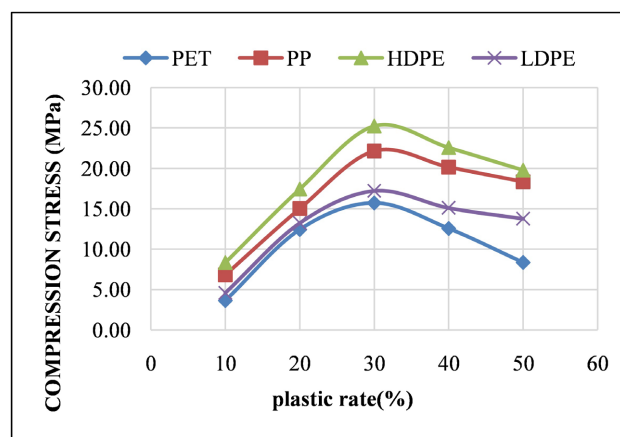


Figure 9. Variation of compressive stress as a function of plastic rate.

We note that the maximum compressive strength at break for each of the for-

mulations increases as the amount of plastic in the mixture increases from 10% to 30%. This strength reaches 25.16 MPa for the silixite sample with the addition of 30% HDPE, 22.16 MPa for the addition of 30% PP, 17.22 MPa for the addition of 30% LDPE, and 15.72 MPa for the addition of 30% PET. Beyond these respective percentages, the strength gradually decreases.

Granulometric analysis and determination of the fineness modulus have shown that Taïba flint (with a maximum diameter of 0.315 mm) is made up of medium and fine particles. As a result, at 10%, there is adhesion, albeit weak, between the flint and the plastic, giving the manufactured components lower mechanical strength. Between 20% and 50% plastic in the mix, whatever the type of polymer, compressive strength increases as the flint grains are bonded or coated, up to the optimum level. Above this level, the material contains more and more plastic, making it less resistant, as plastic is known to have low compressive strength. This result corroborates that of Dr. Traoré Brahiman, who states that when the grains are too small (<355 μm), they are completely embedded in the molten plastic (if the quantity of plastic in the mixture is high), so that the stress is borne only by the plastic.

However, the latter has a low compressive strength, so the compressive strength of the composite drops. We also note that the compressive strengths of HDPE- and PP-based composites are higher than those of PET- and LDPE-based composites. This is due to the degree of crystallization of the polymer melt during solidification [6]. Indeed, high-density polyethylene and polypropylene have much higher levels of crystallinity. Polymer crystallization creates ordered structures called spherulites, composed of crystalline lamellae separated by amorphous zones. These structures influence the material's rigidity, strength and ductility [7]. When the melt of a polymer solidifies, a partial ordering of the molecular chains in the polymer occurs. Crystal formation favors strong intermolecular forces (Van Der Waals bonds) and a chain skeleton favoring an ordered arrangement with maximum packing density to maximize the number of secondary bonds. On the other hand, the density of PET- and LDPE-based polymer concretes is higher than that of HDPE- and PP-based materials. It can be seen that density has no direct influence on the compressive strength of polymer concretes. Indeed, while density is generally linked to compressive strength, this relationship depends on the type of material and its specific characteristics. It is therefore essential to consider other factors, such as composition, internal structure and treatments undergone by the material, in order to accurately assess compressive strength [8].

3.2.2. Bending Strength

Figure 10 shows the 3-point bending strength of materials obtained from four types of plastic, each mixed with the flint sample.

Figure 10 shows a variation in bending strength as a function of the plastic content of the material. Flexural stress increases progressively with plastic content from 10% to 30%. Above 30%, strength decreases despite the increase in plastic. As in compression, composites based on HDPE and PP polymers give much

higher flexural strengths due to their high crystallinity content. We note that failure occurs abruptly when the maximum strength value is reached without plastic deformation. Fracture is therefore brittle in most cases. This mode of fracture could be explained by the material breaking open (Figure 11). During the test, the upper half of the specimen is working in compression, while the lower half is working in tension. The stronger the tension, the closer you get to the lower face and the center of the specimen. Fracture occurs from this face, in line with the support exerting the force. In our case, failure occurs when the molten plastic breaks. As the plastic melts and cools, it becomes brittle. Some authors, such as [9], have made the same observation in their studies of polymer concretes. All possible bonds are therefore broken simultaneously. According to studies by [10], in this case, the crack is oriented perpendicular to the stress, and the tips of the ellipse are subjected to strong traction, causing the crack to propagate unstably, leading to sudden failure.

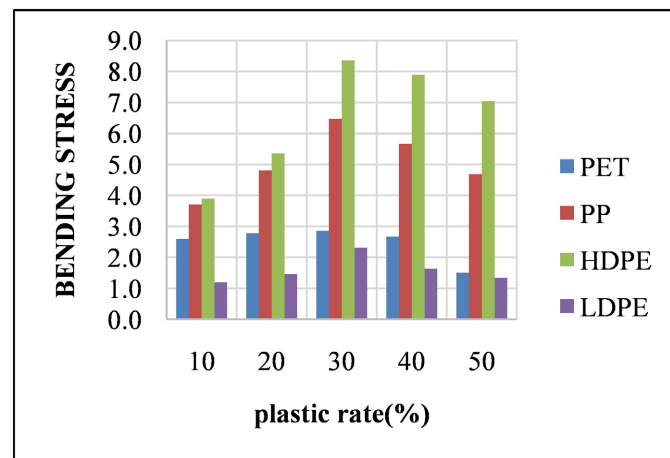


Figure 10. Flexural strength of concrete polymers based on flint.

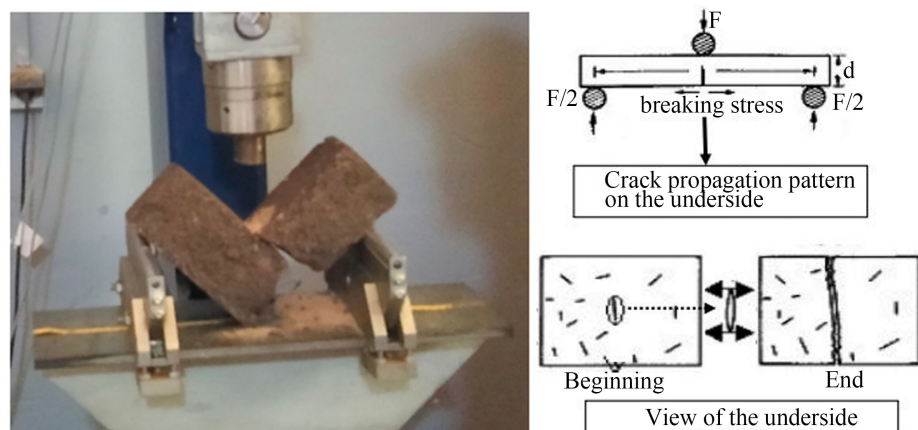


Figure 11. Image of flexural fracture and explanatory diagram of crack propagation.

3.2.3. Splitting Tensile Strength

Figure 12 shows the splitting tensile strength of materials obtained from four

types of plastic, each mixed with the flint sample.

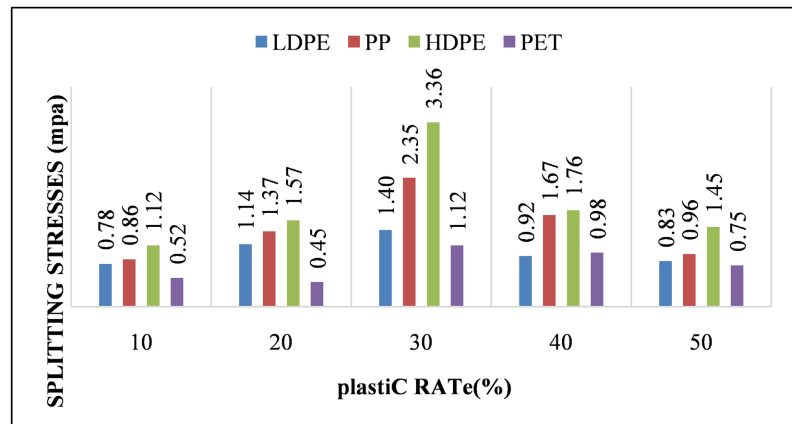


Figure 12. Maximum splitting tensile stress.

As in compression, we note a variation in strength as a function of the plastic content of the material. The tensile stress at break is highest for the flint sample with the addition of 30% HDPE plastic (3.36 MPa), at 30% PP (2.35 MPa), at 30% PET (1.40 MPa) and at 1.12 MPa. Above these percentages, strength decreases for each material. Plastics originally had good tensile strength. It is therefore normal to see an increase in tensile strength as the percentage of plastic in the mix increases for each of the reinforcements used. However, beyond the percentage of plastic that gives each of the different bricks its optimum tensile strength, the latter decreases. This decrease continues in the case of flint, due to the excess binder that causes the material to become brittle; an observation shared by several authors who have worked on the incorporation of plastic waste as a binder in the sand/plastic mix, such as [9] [11]. Other authors such as [12]-[14], who have used plastic waste as coarse aggregate in cementitious matrices, also obtain results where strength increases to the ideal proportion before decreasing. This is due, according to their analysis, to the fact that the increase in plastic in the mix reduces the adhesion of the plastic with the cementitious paste, thus inducing the drop in strength; a result which again is in line with that obtained in this study, although the type of plastic used is different

4. Conclusion

The growing amount of plastic waste generated worldwide poses a major environmental problem due to its non-biodegradable nature and the lack of appropriate means of disposal. One way of recycling this waste is to use it in One way of recycling this waste is to use it as a binder in the design of flint-based materials. The aim of this study was to determine the mechanical characteristics of each of these materials. Based on the results obtained, we can conclude that this waste recovery method is worth using. The materials used in this study are homemade. Improving them would therefore improve the properties of the composite material and reduce the plastic content in the mix, which will reduce the cost of structural work. Consequently, the

introduction of this type of composite material in the building sector could be a promising prospect, provided that further studies are carried out on durability, thermal (ageing and fire-resistance tests), but also to find techniques for installing electrical and plumbing systems.

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Conflicts of Interest

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

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