ORIGINAL ARTICLE

FORMULATION AND CHARACTERISATION OF A TILE BASED ON PLASTIC WASTE AND ALLUVIAL SAND SANAGA-CAMEROON

FORMULATION ET CARACTÉRISATION D'UNE DALLE À BASE DE DÉCHETS PLASTIQUES ET DE SABLE ALLUVIAL SANAGA-CAMEROUN

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ABSTRACT

Background: Plastic bottles of the PET type are still one of the most common pollutants found in Cameroon's cities, particularly in its two major metropolises. They are most often found in periods of flooding irrigated by rivers and agglomerated in catchment areas and in discharge works. Government policies to collect them are weak and do not mainly promote their reuse in view of current research. **Objective**: The aim of this study is to valorise the use of Polyethylene Terephthalate (PET) plastic waste as a binder in the production of roof tiles. **Methods**: To this end, the melted plastic waste was mixed at different ratios with a 2 mm sieve fraction of Sanaga alluvial sand. The said sand was initially tested and found to be a clean sand, 88.60% sand equivalent, fine grained with a good gradation within the range recommended by NPF18-560. The plastic/sand ratios formulated were: 90/10, 80/20, 30/70, 40/60, 50/50, 60/40, 70/30, 80/20 and 90/10. **Results**: These samples were subjected to some analysis and it was found that: all the formulations with more than 20% of plastics have a water absorption rate lower than 2.25%, which is in line with the ISO 62: 2008 standard which defines a limit rate of 6% for roof tiles. Furthermore, the porosity test, for the same formulations, shows a rate lower than 4.37%. As for the mechanical characteristics, a high flexural strength ranging from 2.66 to 5.31 MPa was found for formulations ranging from 10 to 50% plastic. Beyond these formulations, the strengths fall continuously for values below 1 MPa. For compressive strength, the following three ratios show better characteristics: 30/70, 20/80 and 90/10 with values of 7.31 MPa, 7.08 MPa and 6.88 MPa respectively. **Conclusion**: In the end, the ratio with the best characteristics (30/70) made it possible to formulate a Romaine II type tile with optimal impact resistance and waterproofing valued at 540 FCFA per unit.
Keywords: *formulation, characterisation, tile, plastic waste, alluvial sand.*

1. INTRODUCTION

In Cameroon, the demographic boom has led to the abusive use of plastics. These materials are in great demand in various fields, particularly in the purchase and sale of packaging and containers. A study conducted by CREPD (Centre de Recherche et d'Education Pour le Développement) in 2017 in Cameroon showed that Low Density Polyethylene (LDPE) is the most produced, i.e. 35%, followed by Polyethylene Terephthalate (PET) at 31%, High Density Polyethylene (HDPE) at 10%. As for PVC and polyisoprenes, the study estimates their production at 8%. This plastic waste poses a serious problem because of its estimated lifespan of 500 years and is also a conspicuous waste.

In order to solve this problem, several governmental policies have been developed, such as the use of biodegradable plastics, which is still struggling to be implemented due to its low production in view of the ever increasing need. However, several plastic bottles can be seen at the foot of crossing structures, thus preventing the free circulation of waterways and encouraging flooding during periods of high water. While developed countries have numerous collection, sorting, recycling and innovation initiatives around plastic waste [1], developing countries are still very much left out [2,3]. Despite the collections carried out by municipalities, pollution is still observable. However, plastics have beneficial properties that are often sought after in the field of civil engineering, namely: elasticity, longevity, durability, lightness, impermeability, corrosion resistance and low cost [4, 5, 6, 7]. All these properties have direct implications on the three key words in civil engineering: "cost", "quality" and "time". Of these, it is the over-consumption of this material without a recycling method that makes it detrimental.

Thus, within the framework of the valorization of local materials and the manufacture of composite materials, for economic and ecological reasons [8, 9], materials with thermoplastic and thermosetting matrix have been elaborated with PET type plastic bottles as a binder in the implementation of tiles. The objective of the present study is to use PET plastic as a binder in the production of roof tiles. It will be a question of providing a palliative to the problem of inflation of the price of construction materials and the problem of pollution caused by the discharge of plastic bottles into nature, by considering them less as a nuisance and more as a resource generating employment and income. The raw materials were characterised using the following analytical methods: particle size analysis, fineness modulus and sand equivalent. The composite products were physically characterised by water absorption and porosity tests, and mechanically characterised by compression and flexural tests.

2. MATERIALS AND METHODS

2.1. Materials used in the study

The inputs used in this study were mainly: Sanaga alluvial sand and Polyethylene Terephthalate (PET) plastic bottle waste. The Sanaga-Cameroon alluvial sand used in this study was collected from the locality of Ebebda in the Central Region. This sand is highly solicited because of its gritty fraction with good mechanical properties. It was first dried in an oven for a period of 24 h at a temperature of 105°C and then sieved with a 2 mm sieve. The fraction passing this sieve was used in our study. The interest in this fraction is based on the cohesion effect sought on the product, the minimisation of pores or interstitial voids that could favour the infiltration of water into the material. This fraction was subjected to particle size analysis, fineness modulus and sand equivalence.

The PET plastic waste was collected from municipal waste bins in the commune of Yaoundé VI. Their lids and labels were removed, then they were washed to eliminate impurities, dried and cut into flakes to facilitate cooking as shown in Figure 1. This waste has already been the subject of a detailed study by NAÏT-ALI Kako Linda [10]. Thus, for barrier properties the data in Table 1 and for physical-mechanical and thermal composition those in Table 2.

Table 1: Barrier properties of amorphous and semi-crystalline Polyethylene Terephthalate, T=25OC [10].

	Permeability coefficient (cm^3 x 10^{13})	Diffusion coefficient ($cm^2.s^{-1}$ x 10^6)	Solubility (cm^3 x 10^6)
	amorphe PET		
Nitrogen N_2	0,011	0,0019	0,55
Oxygen O_2	0,044	0,0045	0,98
Carbon dioxide CO_2	0,227	0,0008	28
	Semi-crystalline PET (40%)		
Nitrogen N_2	0,005	0,0013	0,45
Oxygen O_2	0,026	0,0035	0,72
Carbon dioxide CO_2	0,118	0,0006	20

PET: Polyethylene Terephthalate.

Table 2: Main properties of amorphous and semi-crystalline PET [10].

Properties	amorphe PET	Semi-crystalline PET
	PHYSICALS	
Volume mass ($g.cm^{-3}$)	1,30–1,34	1,47
Water absorption (24H, en %)	0,16	0,1
	MECHANICS	
Threshold stress (MPa)	56	75
Elongation at threshold (%)	5	2,5
Young's modulus (MPa)	2000–2200	2600–2800
Elongation at break (%)	200–300	70–100
	THERMAL	
Melting temperature (^oC)	-	255
Glass transition (^oC)	67	81

PET: Polyethylene Terephthalate.

Figure 1: PET plastic bottles cut into flakes.

2.2. Formulation of the composite material

The formulation of our composite material was carried out at different sand and plastic contents as identified in Table 3. For each content, 3 samples were used, i.e. 27 samples in total. The flakes were first heated in a pot through a temperature range of 170 to 260O C constantly monitored with a testo 925 AG Germany thermocouple. Once the flakes are liquefied and homogeneous, the steamed sand is added and the whole is mixed together to form a monolith. Our mixture is then introduced into previously designed metal prismatic moulds of 4x4x16 cm. This mixture is compacted to avoid honeycombing, which has a negative influence on the properties of the material.

Table 3: Formulations of composite material samples.

Formulation	Sample of composite material	Proportion of PET plastic	Proportion of alluvial sand Sanaga	Number of 4x4x16 cm samples
Form. 1	100 %	10 %	90 %	3
Form. 2	100 %	20 %	80 %	3
Form. 3	100 %	30 %	70 %	3
Form. 4	100 %	40 %	60 %	3
Form. 5	100 %	50 %	50 %	3
Form. 6	100 %	60 %	40 %	3
Form. 7	100 %	70 %	30 %	3
Form. 8	100 %	80 %	20 %	3
Form. 9	100 %	90 %	10 %	3
		Total		**27**

Figure 3: Steps in the mixing process (a-heating the flakes, b-adding the sand, c-checking the TO with a thermocouple, d-molding the product).

Figure 4: Test tubes formulated and labelled according to the different contents.

2.3. Raw material and product tests

The raw material analysed in this study was sand, and the following tests were carried out particle size analysis, fineness modulus and sand equivalent. Grain size is the factor governing the compactness and workability of a mix. For a given aggregate, it characterises the grain size class, which is obtained from a particle size analysis. The latter aims to determine the grain size of the material and the percentage of grains of each size. The handling and handling conditions are described in the NF P 18-560 standard. The modulus of fineness (MF), based on the EN 12620 standard, is determined by the relation

(1) and allows us to know if we are in the presence of a coarse sand or not, in spite of the 2 mm fraction previously adopted during this study.

$$MF = \frac{1}{100}\sum \text{Cumulative rejects in \% of sieves } [0.125-0.25-0.5-1-2-4] \qquad (1)$$

In order to appreciate somewhat the mineralogical nature of our sand, a sand equivalent test was carried out in order to deduce the degree of cleanliness of the latter through the relation (2).

$$ES(\%) = \frac{h_2}{h_1}\times 100 \qquad (2)$$

With h_1 the height of clean sand + fine elements (cm) and h_2 the height of clean sand only (cm).

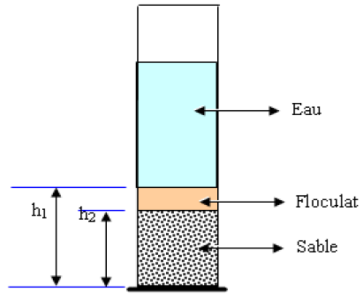

Figure 5: Schematic representation of the sand equivalent test.

The formulated samples were subjected to: bending, compression, water absorption and porosity tests. The physical characterisation of the formulated materials was carried out through the water absorption and porosity tests. The formulated materials after weighing (PS) were soaked in water for 24 h in order to obtain their wet weight (Ph). The procedure for this process was carried out according to ASTM C 20. In contact with water, the composite material sample absorbs water according to the formula (3) and the amount of water absorbed during these 24 hours is determined by the relation (4).

Figure 6: Water absorption test.

$$M(t) = A\times\sqrt{t_w} \qquad (3)$$

$$A = \frac{(P_h - P_s)\times 100}{P_s} \qquad (4)$$

With $M(t)$: mass of water absorbed per unit area (kg/m^2) for a period t, A : water absorption coefficient (kg/m^2.s$^{1/2}$), t_w : contact time with water (s), P_h : wet weight of block (N) and P_s : dry weight of block (N).

At the end, the porosity of the sample is quantified by the relation (5). The procedure was carried out in accordance with standard NF P18-459.

$$n(\%) = A\times\frac{P_s}{100} \qquad (5)$$

Figure 7: Porosity test.

The mechanical characterisation of the composite material was carried out according to two tests: the bending test and the compression test. The determination of the mechanical resistance to bending was carried out on our 4x4x16 cm samples using a materials characterisation machine equipped with a three-point bending device. The handling and handling conditions were carried out according to EN 196-1. The strength was calculated according to relationship (6).

$$\sigma_{\max} = \pm \frac{3}{2} \times \left(\frac{F \times L}{b \times h^2}\right) \qquad (6)$$

With F : the load applied at the centre (N), L : the length between supports (mm), b : the width of the specimen (mm) and h : the height of the specimen (mm).

After bending, each half-prism was reused to determine the compressive strength [11]. The procedure was carried out in accordance with ISO 17892-7 and the strength was deduced according to the relation (7).

$$R_C = \frac{F}{S} \qquad (7)$$

Equation in which R_C is the compressive strength or breaking stress in MPa, F he compressive force at break in N and S the area of force application in mm^2.

Figure 8: Compressive strength test.

After all these different tests, a sample tile with optimum characteristics in view of the previous tests was developed. This tile was subjected to two tests, namely the impact test and the permeability test. The impact test was evaluated according to the ISO 179-459 procedure with the aim of determining the breaking strength and resilience of a material. It is performed with a ball of mass 200G.

Figure 9: (**a**) weighing the mass, (**b**) performing the test.

The permeability test on the other hand was carried out over a period of 24 hours in accordance with the NF P31-305 standard, so the steps consisted of:

- The tile channel (convex part) is blocked on both sides by clay;
- The distance between the two flanges must not exceed 50% of the length of the channel;
- The resulting basin is filled with water;
- The tile is laid flat over a void for 24 hours.

Figure 10: Permeability test on the optimal tile.

3. RESULTS AND DISCUSSION

3.1. Sand characteristics

Particle size analysis

The particle size curve in Figure 11, plotted according to the results in Table 4, shows a continuous, uniform and spread out pattern. Therefore, there are no discontinuities in the grain size distribution. Either this sand presents a good grading which is within the range recommended by the NPF18-560 standard.

Table 4: Granular data Sanaga alluvial sand.

Screen mesh (mm)	Cumulative Refuse Weight (g)	Cumulative refusals (%)	Cumulative sieves (%)
10	0	0	100
6.5	11.1	0,658168	99.34183
4	17,64	1.045953	98.95405
2	35.97	2.132819	97.86718
1	69.29	4.108509	95.89149
0.5	429.56	25.4705	74.5295
0.4	766.32	45.43848	54.56152
0.315	1394.5	82.68604	17.31396
0.25	1563.5	92.70679	7.293211
0.2	1632	96.76846	3.231545
0.1	1673.5	99.22917	0.770827

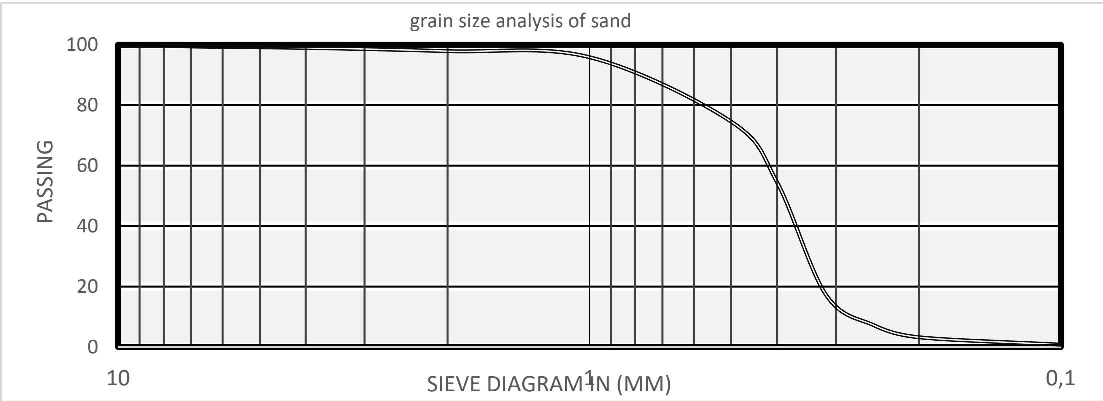

Figure 11: Sieve size curve of the Sanaga alluvial sand.

The fineness modulus

The modulus of fineness of a sand is equal to the centimetre of the rejections expressed in weight percentage on the different sieves. During this study the modulus determined was $MF = 2,03$. Our fineness modulus is between (1.8-2.2) so the sand is predominantly fine-grained.

The sand equivalent

The result obtained was 88.60%. According to the NF P933-8 standard, very clean sand with almost or total absence of clayey fines.

3.2. Characteristics of the composite material

Physical characteristics: water absorption rate and porosity

Water absorption

The total immersion water absorption capacity of the composite material decreases drastically with the addition of PET at formulations ranging from 10%PET+90%S to 20%P+80%S for average values of 14.52% and 2.25% respectively. At more than 20% PET as a substituent, the decrease in water absorption is substantially uniform and progressive due to the decrease in pores on the one hand and the increase in PET which is a hydrophobic material on the other. Thus, for this property, PET really influences our composite from 20% of its content. This is in line with the ISO62:2008 standard, which assumes a maximum water absorption of 6% for a tile.

Table 5: Values of water absorption rates as a function of sand and PET plastic content.

Formulations	N°	Dry Mass (g)	Wet Mass (g)	Absorption (g)	Average (g)	GAP in average values
10%PET+90%Sable	1	220	260.00	18.18	14.52	**12.27**
	2	235.25	262.98	11.79		
	3	227.73	258.66	13.58		
20%PET+80%Sand	1	209.12	212.55	1.64	2.25	**0.06**
	2	215.72	220.16	2.06		
	3	208.99	215.35	3.04		
30%PET+70%Sand	1	180.5	183.10	1.44	2.19	**0.52**
	2	150	155.80	3.87		
	3	207.8	210.43	1.27		
40%PET+60%Sand	1	283.17	287.65	1.58	1.67	**0.07**
	2	236	239.79	1.61		
	3	235.25	239.52	1.82		
50%PET+50%Sand	1	226.53	230.16	1.60	1.60	**0.23**
	2	235.07	238.40	1.42		
	3	260.84	265.45	1.77		
60%PET+40%Sand	1	302.41	306.85	1.47	1.37	**0.17**
	2	301.83	305.20	1.12		
	3	256.93	260.83	1.52		
70%PET+30%Sand	1	205.5	207.25	0.85	1.20	**0.20**
	2	187	190.70	1.98		
	3	201.9	203.45	0.77		
80%PET+20%Sand	1	179.6	181.65	1.14	1.00	**0.38**
	2	277.74	280.35	0.94		
	3	170.57	172.16	0.93		
90%PET+10%Sand	1	255.93	258.01	0.81	0.62	**-**
	2	250	251.60	0.64		
	3	249	250.00	0.40		

PET: Polyethylene Terephthalate.

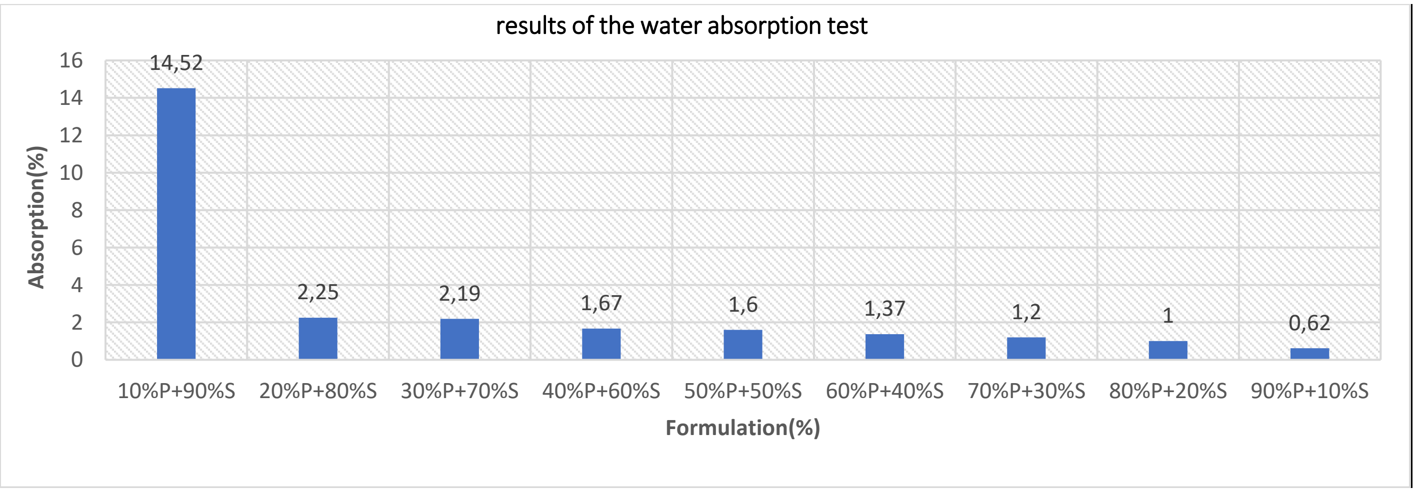

Figure 12: Histogram of water absorption in the material as a function of PET content. **(PET**: Polyethylene Terephthalate).

Porosity

The porosity of the materials shown in Table 6, where the results of the porosity tests are presented. The observation made is the drop in average porosity values between 10 and 20% PET in the composites and a progressive and uniform decrease at more than 20% PET in our composites. These results are similar to those of the water absorption rate, which is explained by the relationship established between the existence of pores and the water capacity of our samples. Figure 13 shows the variation of porosity as a function of PET content in the material.

Table 6: Porosity values of composites as a function of sand and PET plastic content.

Formulation	N°	Dry Mass	Wet Mass	Archimedean Mass	Porosity	Average	GAP in average values
10%PET+90% Sand	1	220	260.00	141.00	33,61	27.64	**23.27**
	2	235.25	262.98	143.43	23.20		
	3	227.73	258.66	140.17	26.10		
20%PET+80% Sand	1	209.12	212.55	106.11	3.22	4.37	**0.62**
	2	215.72	220.16	109.68	4.02		
	3	208.99	215.35	107.09	5.87		
30%PET+70% Sand	1	180.5	183.10	107.35	3.43	3.75	**0.33**
	2	150	155.80	98.87	5.42		
	3	207.8	210.43	100.35	2.39		
40%PET+60% Sand	1	283.17	287.65	147.86	3.20	3.42	**0.61**
	2	236	239.79	125.43	3.31		
	3	235.25	239.52	125.11	3.73		
50%PET+50% Sand	1	226.53	230.16	104.90	2.90	2.81	**0.01**
	2	235.07	238.40	102.81	2.46		
	3	260.84	265.45	115.20	3.07		
60%PET+40% Sand	1	302.41	306.85	158.52	2.99	2.80	**0.15**
	2	301.83	305.20	156.74	2.27		
	3	256.93	260.83	135.93	3.12		
70%PET+30% Sand	1	205.5	207.25	107.48	1.75	2.65	**0.94**
	2	187	190.70	110.20	4.60		
	3	201.9	203.45	105.87	1.59		
80%PET+20% Sand	1	179.6	181.65	76.20	1.94	1.71	**0.45**
	2	277.74	280.35	112.40	1.55		
	3	170.57	172.16	75.20	1.64		
90%PET+10% Sand	1	255.93	258.01	132.71	1.66	1.26	**-**
	2	250	251.60	129.54	1.31		
	3	249	250.00	128.00	0.82		

PET: Polyethylene Terephthalate;

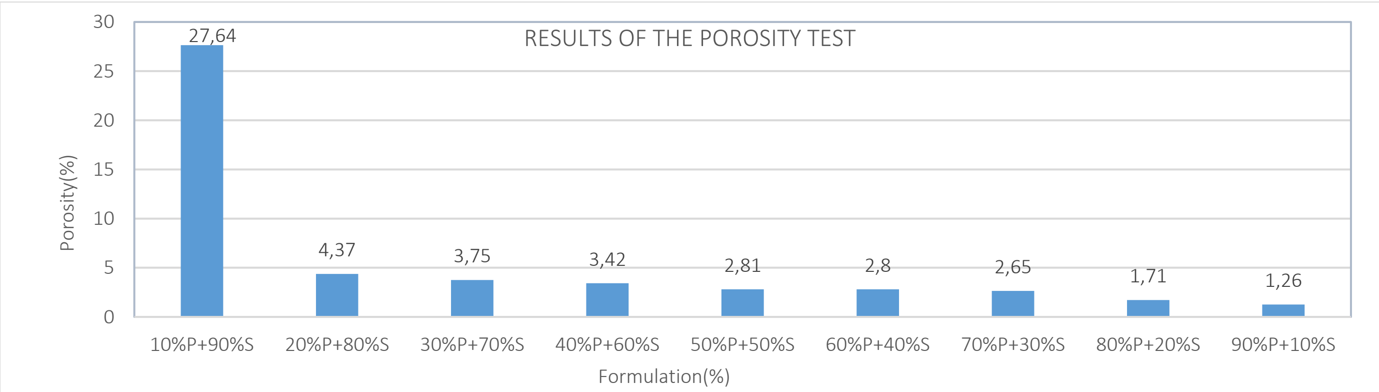

Figure 13: Histogram of material porosity versus PET content. **(PET**: Polyethylene Terephthalate).

Mechanical characteristics: flexural strength, compressive strength and impact strength

Flexural strength

The flexural strength increases from 2.66 to 5.31 MPa up to the 50%P+50%S formulation before dropping to a value of 0.47 MPa at the next 60%P+40%S formulation (Table 7). From the said formulation, the strength will continue to decrease continuously and end at a value of 0.23 MPa. Thus the 50%P+50%S formulation will be the threshold strength of the composite before sudden failure.

This variation is observed also in other previous work [12, 13]. The flexural strength does not evolve continuously, however the threshold strengths are obtained at different formulations, either due to the formulation methodology or the nature of the plastic used. Furthermore, in view of the analysis protocols for raw materials and finished products at the Laboratory [14], which prescribe the admissible load of 6mm thick tiles at 300N, i.e. 0.7 MPa for a 40cm thick and 40cm wide specimen. The results obtained by the composite used are largely superior to this prescription. The maximum strength obtained is 5.33 MPa.

The results of the effect of plastic content and sand content on flexural strength are shown in Figure 14.

Table 7: Flexural strength values of composites as a function of sand and PET plastic content.

Formulation	N°	Bending force (KN)	Flexural strength (MPa)	Average (MPa)	GAP in average values
10%P+90%S	1	1.2	2.81	2.66	**0.78**
	2	1.2	2.81		
	3	1	2.34		
20%P+80%S	1	1	2.34	3.44	**0.54**
	2	1.8	4.22		
	3	1.6	3.75		
30%P+70%S	1	1.8	4.22	3.98	**1.25**
	2	0.2	0.47		
	3	3.1	7.27		
40%P+60%S	1	2.2	5.16	5.23	**0.08**
	2	2.1	4.92		
	3	2.4	5.63		
50%P+50%S	1	2.2	5.16	5.31	**-4.84**
	2	2.4	5.63		
	3	2.2	5.16		
60%P+40%S	1	0.2	0.47	0.47	**-0.02**
	2	0.2	0.47		
	3	0.2	0.47		
70%P+30%S	1	0.075	0.18	0.45	**-0.14**
	2	0.4	0.94		
	3	0.1	0.23		
80%P+20%S	1	0.2	0.47	0.31	**-0.08**
	2	0.1	0.23		
	3	0.1	0.23		
90%P+10%S	1	0.1	0.23	0.23	**-**
	2	0.1	0.23		
	3	0.1	0.23		

PET: Polyethylene Terephthalate.

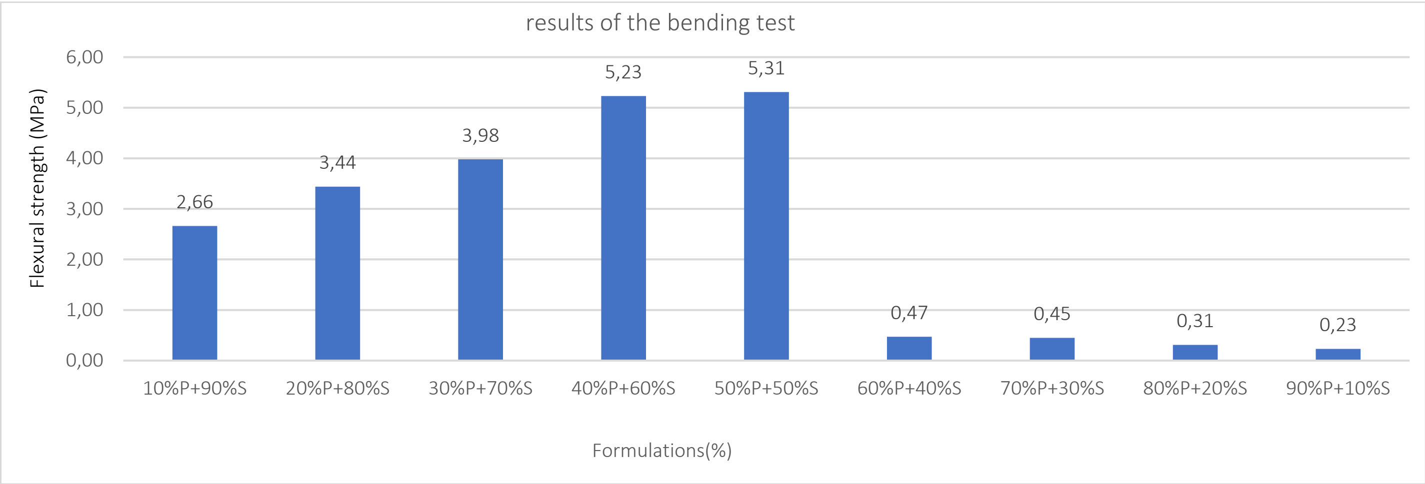

Figure 14: Histogram of the bending strength of the material as a function of the PET content.

Compressive strength

The mechanical strength of the mix increases with the addition of PET and then drops between 30% and 40% PET and then starts to increase steadily again. The optimum strength before breakage of 7.13 MPa at 30%+70% formulation. This observation is similar to previous work [15, 16] who use waste plastics as coarse aggregate in cementitious matrices. They also obtain results where the strength increases to the ideal proportion before decreasing. This could be explained by the fact that the excess plastic in the mix changes the matrix of the composite from solid to semi-crystalline in view of the low molecular weight of PET [17]. The results of the effect of plastic content and sand content on the compressive strength are shown in Figure 15.

Table 8: Compressive strength values of composites as a function of sand and PET plastic content.

Formulation	N°	Compression Force (KN)	Compressive strength (MPa)	Value Average (MPa)	gap in average values
10%PET+90%S	1	8	5.00	5.00	**2.08**
	2	10	6.25		
	3	6	3.75		
20% PET+80%S	1	14	8.75	7.08	**0.05**
	2	8	5.00		
	3	12	7.50		
30% PET+70%S	1	10.2	6.38	7.13	**-2.46**
	2	12	7.50		
	3	12	7.50		
40% PET+60%S	1	0.4	0.25	4.67	**0.83**
	2	12	7.50		
	3	10	6.25		
50% PET+50%S	1	2.2	1.38	5.50	**0.38**
	2	14	8.75		
	3	10.2	6.38		
60% PET+40%S	1	10.2	6.38	5.88	**0.37**
	2	10	6.25		
	3	8	5.00		
70% PET+30%S	1	8	5.00	6.25	**0.42**
	2	8	5.00		
	3	14	8.75		
80% PET+20%S	1	14	8.75	6.66	**0.21**
	2	10	6.25		
	3	8	5.00		
90% PET+10%S	1	4	2.50	6.88	**-**
	2	12	7.50		
	3	6	3.75		

PET: Polyethylene Terephthalate.

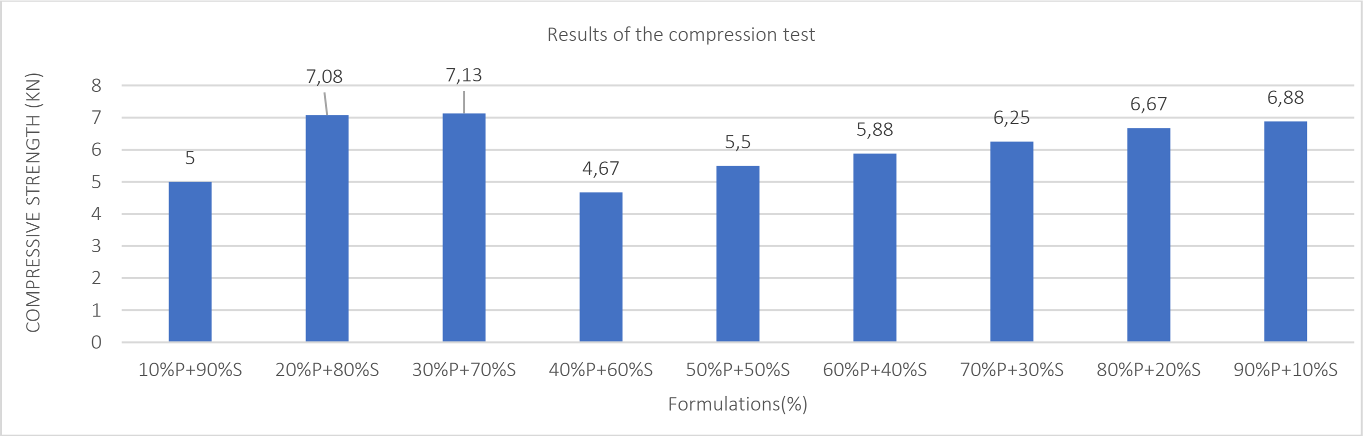

Figure 15: Histogram of the compressive strength of the material as a function of PET content. (**PET**: Polyethylene Terephthalate).

Impact resistance

From these different characteristics obtained, it is noted that:

Water absorption and permissible porosity $[20\%PET + 80\%Sand, 90\%PET + 10\%Sand[$

Flexural strength $[10\%PET + 90\%Sand, 50\%PET + 50\%Sand[$

Compressive strength $\{20\%PET + 80\%Sand, 30\%PET + 70\%Sand, 90\%PET + 10\%Sand\}$

All of this information allowed us to note that the optimal composite is $\{30\%PET + 70\%Sable\}$, , so the tile formulated with these optimal characteristics was subjected to the shock of a ball of 200 g dropped at a height of 20 cm, it is noted no deformation or faience on the tile.

Physical characteristics: Impermeability test

The permeability test carried out on the installed tile did not show any water infiltration during the 24 hour test.

3.3. Evaluation of the cost per m2 of optimally formulated roof tiles

Table 9 shows the results of the evaluation of the production cost of one tile per unit. From this table, it can be seen that the cost of a tile of standard size 50cm × 22.5cm (Romane II tile) is 540 FCFA (see Figure 16). Given the size of our tiles, we need 12.5 tiles for a square metre, which costs CFAF 6,750.

Figure 16: Elaborate composite Romane II roof tile.

Table 9: Estimated cost per unit of tile implemented.

N-	Designations	Unit	Quantity	Unit Price	Total Price
1	Plastique PET	kg	0.6	200	120
2	Sable	kg	1.4	10	140
3	Bois	fagot	1/2	200	100
4	Oxyde de fer	kg	0.03	6000	180
		Total			**540**

PET: Polyethylene Terephthalate

Thus, the cost per m2 of the elaborated tile is slightly higher than the one manufactured and marketed by MIPROMALO, which is 4750 FCFA (See Figure 17). On the other hand. the m2 of roofing surface with concrete tiles in the city of Yaoundé costs CFAF 6500. Nevertheless, the one implemented has better physical and mechanical characteristics than the commercialised micro-concrete ones.

Figure 17: Romane II micro-concrete roof tile marketed at MIPROMALO.

4. CONCLUSION

The impact of plastic waste in the environment poses a major problem on recycling methods given its life span. Several international and national policies have been set up to manage this waste, but it is clear that the pollution remains high in view of the ever-increasing production and the waste collected is not recycled very much in view of national policies that are poorly equipped and poorly funded. Current work shows that it is possible to recover PET plastic waste in the manufacture of roof tiles. As a result, at less than 20% plastic we have a high water absorption rate beyond that prescribed by ISO 62:2008. As water absorption is a factor of porosity, the same observations are made in this respect. In terms of mechanical properties, the interesting formulations are those containing 10 to 50% plastics for flexural strengths of 2.66 MPa to 5.31 MPa and 20 to 30% plastics for compressive strengths of 7.08 MPa and 7.31 MPa. The optimum formulation was found to be 30% plastic and 70% fine grained sand. A tile sample with this formulation was made and its impact strength and permeability were evaluated. The material was found to be impermeable and resistant to the impact emitted. The cost study of the tile showed a value of 540 FCFA per unit for standard sizes of Romaine II tile.

5. REFERENCES

[1] - Kaza S., Yao L.C., Bhada-Tata P., Van Woerden F., 2018, what a waste 2.0. A global snapshot of solid management to 2050, Washington, DC, World Bank. https://openknowledge.worldbank.org/handle/10986/30317.
[2] - Jambeck J., Hardesty B.D., Brooks L.A., Friend T., Teleki K.,Fabres J., Beaudoin Y., Bamba A., Francis J., Ribbink J.A., Baleta T., Bouwman H., Knox J., Wilcox C., 2018. Challenges and emerging solutions to the land-based plastic waste issue in Africa, Marine Policy; 96, 256-263. https://doi.org/10.1016/j.marpol.2017.10.041.
[3] - PNUE (Programme des Nations Unies pour l'Environnement, 2015. Côte d'Ivoire. Evaluation environnementale post-conflit, Nairobi, Programme des Nations unies pour l'environnement.http://ci.chm-cbd.net/cooperation/articles-scientifiques-et-techniques/evaluation-environnementale-post-conflit-en-cote-d-ivoire/download/fr-BE/1/%C3%A9valuation_environnementale_post-conflit.pdf.
[4] - Zulkernain N. H., Gani P., Chuck Chuan N., Uvarajan T. Utilisation of plastic waste as aggregate in construction material. *Construction and Building Materials*. 2021; 296: 123669, 19p. https://doi.org/10.1016/j.conbuildmat.2021.123669
[5] - Bejan G., Bÿrbutÿ M., ÿtefan V. R., Burlacu A. Lightweight Concrete with Waste - Review. *Procedia Manufacturing*. 2020; 46: 136–143. https://doi.org/10.1016/j.promfg.2020.03.021
[6] - Singh S., Dwivedi S. P., A., Kumar et al., A critical review on the utilization of waste PET and marble dust in the development of composite material, Materials Today: Proceedings (2021), 7p. https://doi.org/10.1016/j.matpr.2021.04.535
[7] - Haque, M. Sustainable use of plastic brick from waste PET plastic bottle as building block in Rohingya refugee camp: a review. *Environ Sci Pollut Res*. 2019;26: 36163– 36183. https:// doi.org/10.1007/s11356-019-06843-y
[8] - A. Djoudi, M. Khenfer et al, " Etude d'un nouveau composite en plâtre renforcé avec des fibres végétales du palmier dattier ", in SBEIDCO 1st International Conference on sustainable Built Environment Infra-structures in Developing Countries ENSET Oran (Algeria), (2009).
[9] - E.G.L. Mbei, A. Atangana et al. Contribution à la caractérisation ultrasonore en vue de la détection du gondolement des fibres dans un matériau composite plâtre/fibres de Rhectophyllum Camerunense. *Afrique Science*. 2015 ; 11(3) :1-9.
[10] - Naït-Ali Kako Linda, le pet recycle en emballages alimentaires : approche expérimentale et modélisation, 220p. Thèse: Chimie des Matériaux: Montpellier: 2008.
[11] - Aarfane A, Salhi A, El Krati M, Tahiri S, Monkade M, Lhadi EK, Bensitel M. Kinetic and thermodynamic study of the adsorption of Red195 and methylene blue dyes on fly ash and bottom ash in aqueous medium. *Journal of Materials and Environmental Science*. 2014; 5(6): 1927–1939. https://www.researchgate.net/publication/273764865
[12] - Doublier G. (2008). Dossier « les plastiques », 13 p.
[13] - Brahiman Traore. Elaboration et caractérisation d'une structure composite (sable et déchets plastiques recyclés) : Amélioration de la résistance par des charges en argiles. Thèse de doctorat en Géo-matériaux. Université Bourgogne Franche-Comté; Université Félix Houphouët-Boigny (Abidjan, Côte d'Ivoire), 2018, 213p. Français. ffNNT : 2018UBFCA029ff. fftel-02088767f.
[14] - Elimbe Antoine, Ndigui Billong, « protocoles d'analyse des matières premières et des produits finis au Laboratoire », II-produits finis Normes d'analyses et de controles de qualite Programme MSD-Création et développement des entreprises, septembre 2005.
[15] - Benimam Samir, Debieb Farid, Bentchikou Mohamed et Guendouz Mohamed, « Valorisation et Recyclage des Déchets Plastiques dans le Béton », MATEC Web of Conferences 11, 01033 (2014), EDP Sciences. doi : 10.1051/matecconf/20141101033,
[16] - Ghernouti Y., Rabehi B., Safi B., et Chaid R. Use of recycled plastic bag waste in the concrete. *Journal of International Scientific Publications: Materials, Methods and Technologies*. 2014; 483-484.
[17] - Ceretti, E., Zani, C., Zerbini, I., Guzzella, L., Scaglia, M., Berna, V., Donato, F., Monarca, S., Feretti, D. Comparative assessment of genotoxicity of mineral water packed in polyethylene tetephtalate (PET) and glass bottles. *Water Research*. 2010; 44: 1462-1470.

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