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Plastic Waste Recycling In Cameroon: Characterization of a Thermoplastic Sand Composite

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Abstract

In order to contribute to the protection of the environment and the development of secondary resources, this study focuses on the transformation of plastic waste into polymer matrix composite materials. For this purpose, test pieces based on sand + polyethylene and sand + polypropylene mixture, brought to 4500C were developed and subjected to water absorption, bending and compression tests. The highest water absorption rate is 0.34%. The average compressive strength is between the M 20 and Md classes (d = 25 N / mm 2) of the mortars (NBN EN 998-2). The volumic masses for their part are between 1213 kg / m3 and 1565 kg / m3.

Keywords: *Composites; Plastic waste; Water absorption; bending test; Compression test.*

Introduction

Urban waste in Cameroon, is collected in various town by HYSACAM, as part of a partnership between this private company and local authorities [1]. This waste consists of a mixture of plants, minerals (concrete) and plastics. Much of this waste escapes from daily collection and is found in nature (fields, gutters, streams etc.). The amount of waste increases with the increase of the urban population. The gap between the collection capacity and the volume of waste is growing and communities are finding it increasingly difficult to master the flow. The objective of this work is to analyze the possibility of integrating plastic waste as a binder in the production of cobblestones as well as topographic boundaries.

Indeed the introduction of plastic residues in the manufacture of cobblestones would certainly limit the volume of this material that pollutes our farms, our gutters, our streams and in the case of low thicknesses, kills animals (goats, pigs, fish ...). At the same time, they improve the quality of our towns and countryside.

To this end, various mechanical and physical tests will be carried out for different levels of binders and binding types, and their analysis will show the ability of the composite to be used as building materials environmental alternative to landfilling or incineration [2-5].

The re-use of plastic waste, which is already an environmental problem, for the manufacture of new materials is a particularly attractive Several works have already been carried out or are underway to evaluate the physical, mechanical and thermal properties of mortars or lightweight concretes containing different types of plastic waste as aggregates, fibers or fillers [2, 5-14], or even as binder [15-16].

Materials and methods

Materials

Plastics

Plastics, also known as plastics or polymers, are synthetic materials, mostly derived from petroleum [17]. They are found in our environment in various forms (bottles, packaging, etc.). Figures 1a and 1b below show the accumulation of plastic bottles upstream of a bridge in Douala.

We will focus only on thermoplastic polymers and more mainly Polypropylene (PP), Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE).

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Figure 1 a Figure 1 b

Figure 1: Circulation of water blocked by plastics at the sis-cocoa bridge of Douala

Quantitative Justification

Table 1 gives the daily quantities produced by the same cities while Table 2 gives the composition of waste in some cities of Cameroon, [18].

Table 1 shows that, on average, plastic waste represents 2.8% of urban residues and by analyzing both tables, we have a daily volume of plastics of 33.6 tons, or about 12264 tons per year.

This volume is large enough to justify the establishment of a plastic waste processing unit by region.

Table 1: Solid waste production in some cities of Cameroon in 2002 [18]

towns	Daily production in kg / inhabitant	Total daily production in tonnes
Douala (Littoral Region)	**0,88**	**2200**
Yaounde (center region)	0,85	1700
Bafoussam (west region)	0,57	210
Garoua (north region)	0,37	190
National average	**0,37**	**12000**

Table 2: Composition of some percentage waste (%) in some cities of Cameroon in 2002 [18]

components	Yaounde	Douala	Bafoussam	Garoua	Average
Paper/Cardboard	3,5 %	3,7 %	1,3%	1,7%	2,2 %
Glass/ ceramic	4,1 %	1,6 %	0,8%	0,1%	1,8 %
Textile/ leather	1,6 %	2,4 %	0,9%	1,5%	1,5 %
Plastics	**4,6 %**	**3,4 %**	**2,3%**	**6,1%**	**2,8 %**
Metals	4,6 %	2,3 %	0,6%	1,0%	1,6 %
Rubble	5,9 %	5,1 %	1,7%	2,5%	2,4 %
Wood and chips	-	1,5%	0,5%	1,9%	0,9 %

Sand

Table 3 shows the physical characteristics of the sand used and Figure 2 the particle size curve. The maximum grain size is 5 mm. It has been sieved on several stained sieves.

Table 3: Characteristics of the sand used

Designation	Sand 0/5
Type	Sand of Wouri Cameroon
apparent Mass vol. (kg/m³)	**1758**
Real Mass vol. (kg/m³)	**2663**
Equivalent of visual sand (Esv) in%	**96,61**
Piston sand equivalent (Esp) in%	**84,75**
Finesse module	**2,72**

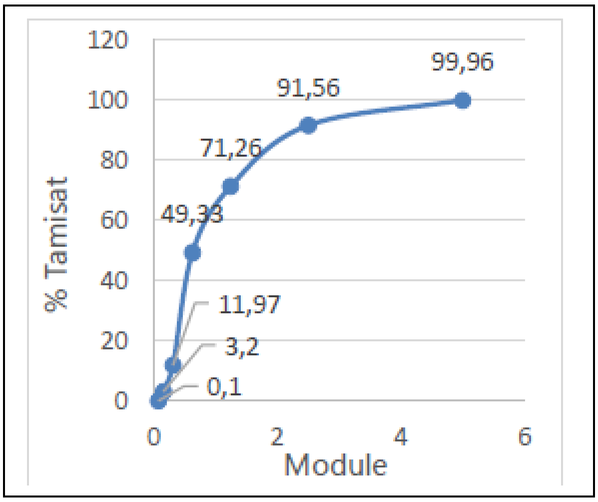


Figure 2: Granulometry curve of the sand used

Equipments

a) Plastic melting

Plastics used for this study are wastages collected at many homes, the point of deposit, the dumps and also via the support of Hysacam company. The binder used is obtained by heating the plastic waste which has been recovered and then cleaned, sorted, crushed and weighed. The heating is performed on an electric plate that can be adjusted to temperatures up to 500°C (Figure 3).

Figure 3 : Steps of manufacturing binders

b) Obtaining test specimens

The circular saw made it possible to obtain 160X40X40 mm^3 specimens to be used for the bending and compression tests. The FELIX cutter made it possible to obtain specimens with a diameter of Ø60 mm and a thickness of 5 mm (weighing less than 5 kilograms according to NBN EN 1338) for the water absorption test (Figure 4).

b$_1$) Prismatics specimens of 160x40x40 mm^3

b$_2$) cylindrical specimens of Ø60

Figure 4: Presentation of FELIX test specimens, circular saw and cutting machine

Methods

Sorted plastics, cleaned, dried and crushed by type of plastic are heated in an enclosure at 450 °C, then the sand is introduced gradually by turning until the mixture becomes homogeneous. The latter is left in the open air for 24 hours and then demolded and the ingot thus obtained is Ø210mm in diameter to a height of 70mm. After cooling, the test pieces 160x40x40 mm^3 and those of Ø60 mm and thickness 5mm are obtained from the ingot thus manufactured, by sawing.

Figure 5 shows the methodology used for the implementation of the specimens

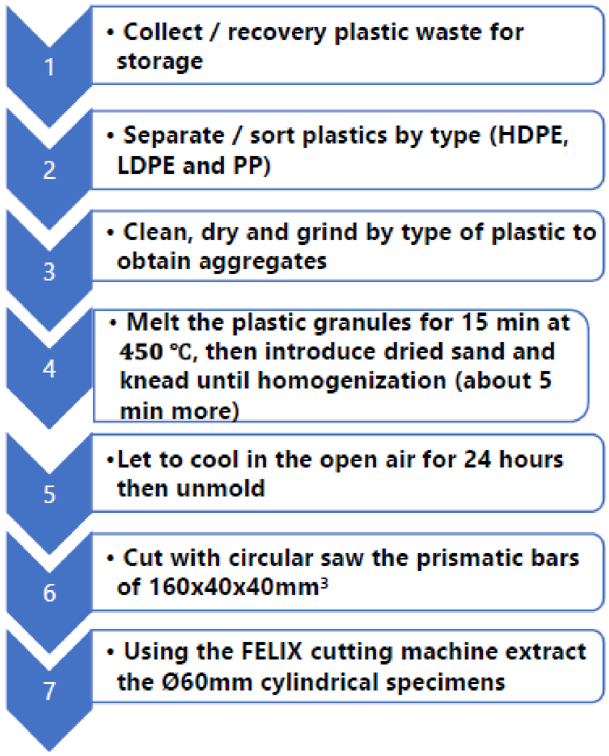


Figure 5: Methodology for manufacturing test specimens

Physical characterization

Water absorption

Before starting the test, the specimens were dried in an oven at $105^{\pm5}$°C to constant mass. The test consists in immersing these specimens in a water tank at $22^{\pm2}$°C up to constant wet mass. The specimens are dewatered every 24 hours and then weighed and then submerged again in the water tank.
The absorption of water by immersion denoted Abs is expressed as a percentage of the dry mass and is calculated by the following relation:

$$\% \, Abs = \frac{m_{moist} - m_{dry}}{m_{dry}} \times 100 \qquad (1)$$

With:

- m_{moist}, the constant wet mass of the test piece after immersion;
- m_{dry}, the constant dry mass of the test piece after drying in an oven.

Mechanical Characterization

Three-point bending test

The test was carried out according to EN 196-1 at a rate of $50^{\pm 10}$N/s [19]. It was made on

160×40×40 mm^3 specimens (Figure 6) and under the following conditions: % humidity $55^{\pm 2}$ and temperature $22^{\pm 2}$°C. The maximum stress σ_{max} in three-point bending is expressed by the relation:

$$\sigma_{max} = -\frac{M_{fmax}}{\frac{I_{Gz}}{V}} \qquad (2)$$

Where $\mathbf{M_{fmax}}$ is the maximum bending moment; $\mathbf{I_{G_Z}} = \frac{a^4}{12}$ is the quadratic moment of square section et $\mathbf{V} = \frac{a}{2}$ is the furthest distance from the average line.

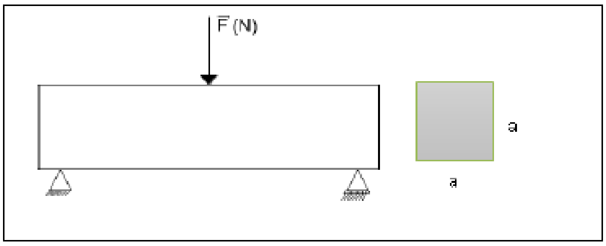


Figure 6: Geometry of the cross-section of the specimen for three-point bending test

Compression test

The test was carried out according to EN 196-1 under a load increase rate of $\mathbf{2400^{\pm 200}} \boldsymbol{N/s}$ [19]. It was made on specimens of dimension 80×40×40 mm^3 (Figure 7) and under the following conditions: % humidity $\mathbf{55^{\pm 2}}$ and temperature $\mathbf{22^{\pm 2}}$°C.

The maximum stress σ_{max} in compression is expressed by the relation:

$$\sigma_{max} = \frac{F_{max}}{S} \qquad (3)$$

Where: F_{max} is the normal effort and

$S = a^2$ is the cross-section of the test piece.

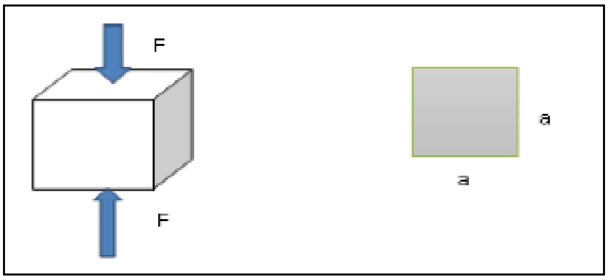


Figure 7: Experimental arrangement for compression test.

Results and discussions

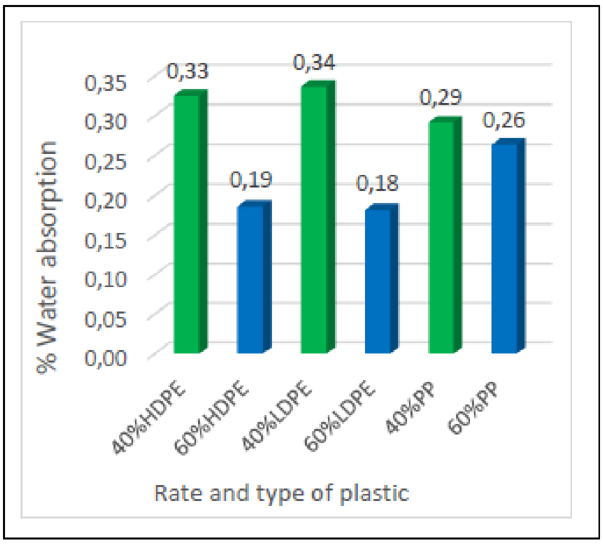
Water Absorption

Chart 1 shows that samples containing more plastics absorb less than those with more sand. Thus, compared to plastic types, Sable / LDPE and Sable / HDPE mixes absorb less than sand / PP blend. The highest absorption rate is less than 0.35%. These results are as interesting as when PET is used as a concrete additive, in substitution for sand [10, 20].

Table 4: Values of the water absorption rate (in%) of the test pieces.

Combination type	Water absorption (%)
40%HDPE	0,33
60%HDPE	0,19
40%LDPE	0,34
60%LDPE	0,18
40%PP	0,29
60% PP	0,26

Chart 1: Water absorption of specimens depending on the type and rate of plastics.



Three-point bending tests

Table 5 summarizes the results of the 3-point bending test and Figure 8 shows a trend of the bend-force curves. These curves show that under the same load, samples with more plastics increase rapidly in displacement. Table 5 shows that the highest peak loading of 5372.5 N and maximum stress of 13.17 MPa are those of 60% LDPE samples with 40% sand. Our results are affordable and, moreover, very interesting for most compared to those of other authors who use PET [10] and HDPE [14] as aggregates; LDPE powder [11] and PET fibers [11, 21] substituted for sand for 7 and 28 day tests. However, there is an increase in resistance for the use of LDPE as a binder and even more with the addition of clay as a filler [15].

Moreover, our results for flexural modulus of elasticity are well above those of some authors [14, 15]. 60% HDPE and PP-based samples have the least stress and loading values. The densities of the samples, from each other are close when the plastic is 60% (1213 to 1394 Kg / m^3). It is the same when the sand is also 60% (1508 to 1565 Kg / m^3). These samples have the density values belonging to those of light concretes (400 to 2000 Kg / m^3) [22]. From Chart 2, depending on the type of plastic, the Young's modulus of 40% HDPE and 40% PP are the highest. Plus the rate of waste As plastics increase, the Young's modulus of the composite decreases. The smallest value of "E" is 854.92 MPa.

Table 5: Average values of three-point bending test

	average (**standard deviation**)	average (**standard deviation**)	Average (**standard deviation**)
Plastic type	**HDPE**	**LDPE**	**PP**
% of plastic	40%HDPE 60%HDPE	40%LDPE 60%LDPE	40%PP 60%PP
F_{max} (N) at the breakup	3700,8 (**263,2**) 1896,9 (**160,4**)	4665,6 (**327,6**) 5372,5 (**308,3**)	2416,3 (**13,0**) 2572,9 (**72,2**)
σ_{max} (N/mm^2)	9,15 (**0,6**) 3,88 (**0,5**)	10,06 (**0.6**) 13,17 (**0,5**)	4,83 (**0,0**) 5,58 (**0,2**)
ρ (kg/m^3)	1565 (**3,1**) 1394 (**48,7**)	1518 (**14, 1**) 1265(**23,2**)	1508 (**0,1**) 1213 (**1,0**)
E (N/mm^2)	2275,64 1337,36	1588,34 854,92	2264,02 2002,46

Figure 8: Three-point bending test curves.

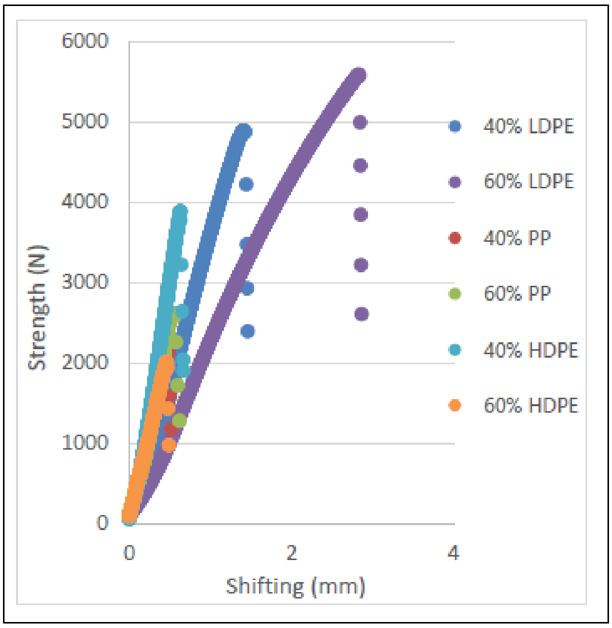
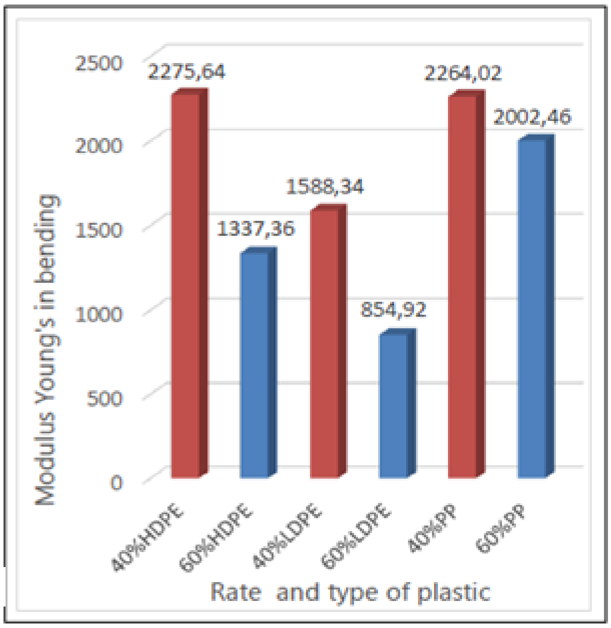


Chart 2: Variation of the Young's modulus according to the rate and type of plastic



Compression Tests

Table 6 summarizes the results of the compression test and shows that samples of 40% HDPE with 60% sand have the best values of load at break and resistances. However, the smallest values are those of 60% HDPE samples. In addition to the 60% HDPE samples, the compressive strength values are between the M 20 and Md classes (d=25N/mm^2) of the mortars (NBN EN 998-2) [22].

Figure 9 shows the shape of the stress-strain curves. The latter exhibit brittle behavior for samples containing polypropylene and high density polyethylene and ductile behavior for those containing more low density polyethylene. It is observed that for the same constraint, the deformation is higher for the samples having 60% of plastic than for those having 60% of sand. From Chart 3, it is observed that, depending on the type of plastic, the Young's modules of 40% HDPE and 40% PP are the highest. In addition, the Young's modulus of the composite decreases when the plastic content is 60%. Our results are affordable and satisfactory compared to those of some authors who obtain at 7 days a slight increase in the compressive strength for a use of PET fibers [21] and a slight decrease of them for a use of the aggregates of HDPE [14] and PP [23] all substitute sand. However, even at 28 days, some work still shows a decrease in resistance for the use of PP [23]; a substitution increase of sand for the use of HDPE [14], PET fibers [21]; equality in the use of LDPE powder and PET fibers [11]. Moreover, with the use of LDPE as a binder [15], the compressive strength is increased and even more so when the clay is added.

Table 6: Average compression test values

	average	average	average
Type of plastic	**HDPE**	**LDPE**	**PP**
% of combinaison	40%HDPE 60%HDPE	40%LDPE 60%LDPE	40%PP 60%PP
F_{max} (N) à la rupture	41884 26311	32378 33303	33855 37923
σ_{max} (N/mm^2)	26,18 16,44	20,24 20,81	21,16 23,70
E (N/mm^2)	1170,35 563,0025	659,04 440,82	1089,90 908,87

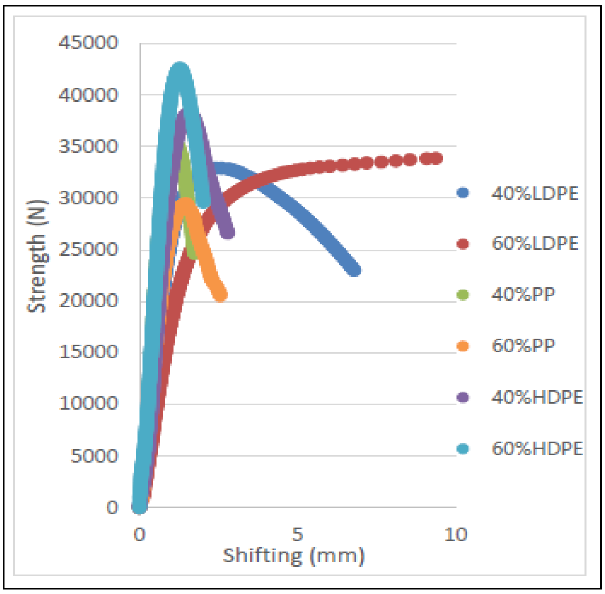
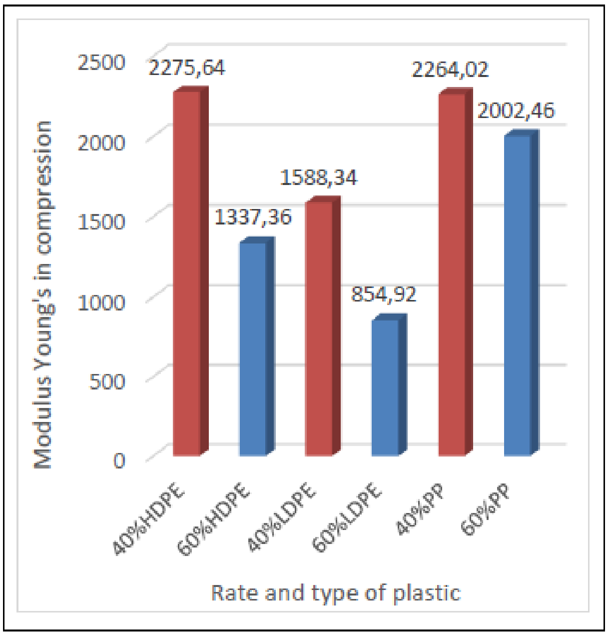


Figure 9: Compression test curves.

Chart 3: Young's modulus variation E according to the rate and type of plastic



Conclusion and Perspectives

The objective of the present work was to valorize plastic waste by using it as a binder in the manufacture of new composites. The highest water absorption rate is less than 0.35%. For a mixture of 60% LDPE with 40% of sand, we had in flexion test F_{max}=5372,5N; σ_{max}=13,17 MPa and in compression test

F_{max}=33303N ; σ_{max}=20.24 MPa with

ϱmax=1265 kg/m^3. The highest compressive stress is that of samples having 40% of HDPE With 60% of sand (σ_{max} = 26.18 MPa). From the results obtained, we can say that this method of recovery of plastic waste can be adopted and even used for the production of cobblestones and topographics landmarks.

Apart from studies done so far in this work, it would be desirable in addition to perform slipperiness tests, wear ... and even see how to add clay.

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References

[1]. Ministère de l'environnement et de la protection de la nature (Yaoundé 2007). Stratégie nationale de gestion des déchets, DRAFT. V04/09/2008.

[2]. Nabajyoti, Saikia., Jorge, de Brito. (2012) Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Construction and Building Materials, 34, pp, 385–401.

[3]. Rafat, Siddique., Jamal, Khatib., Inderpreet, Kaur. (2008) Use of recycled plastic in concrete : A review. Waste Management, 28, pp, 1835-1852.

[4]. Semiha, Akçaözoğlu., Cengiz, Duran, Atiş., Kubilay, Akçaözoğlu. (2010) An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete. Waste Management, 30, pp, 285–290

[5]. Malek, Batayneh., Iqbal, Marie., Ibrahim, Asi. (2007) Use of selected waste materials in concrete mixes. Waste Management, 27, pp, 1870–1876.

[6]. Semiha, Akçaözoğlu., Kubilay, Akçaözoğlu,. Cengiz, Duran, Atiş. (2013) Thermal conductivity, compressive strength and ultrasonic wave velocity of cementitious composite containing waste PET lightweight aggregate (WPLA). Composites: Part B ,45, 721-726.

[7]. Pacheco-Torgal, F., Yining, Ding., Said, Jalali. (2012) Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview. Construction and Building Materials, 30, pp, 714–724.

[8]. Ismail, Zainab, Z., AL-Hashmi, Enas, A. (2008) Use of waste plastic in concrete mixture as aggregate replacement. Waste Management, 28, pp, 2041–2047.

[9]. Luiz, A., Pereira, de Oliveira., João, P., Castro-Gomes. (2011) Physical and mechanical behaviour of recycled PET fibre reinforced mortar. Construction and Building Materials, 25, pp, 1712–1717.

[10]. Hossain, MB., Bhowmik, P., Shaad, KM. (2016) Use of waste plastic aggregation in concrete as a constituent material. Resources, Conservation and Recycling. Progressive Agriculture, 27(3), pp, 383-391.

[11]. Guendouz, M., Debieb, F., Boukendakdji, O., Kadri, EH., Bentchikou, M., Soualhi, H. (2016) Use of plastic waste in sand concrete. J. Mater. Environ. Sci. 7, 2, pp, 382-389.

[12]. Semiha, Akçaözoğlu., Cengiz, Duran. Atiş. (2011) Effect of Granulated Blast Furnace Slag and fly ash addition on the strength properties of lightweight mortars containing waste PET aggregates. Construction and Building Materials, 25, pp, 4052–4058.

[13]. Saikia, N., De Brito, J. (2014) Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate. Construction and Building Materials. DOI: 10.1016/j.

[14]. Santhosh, M., Malkapur., Ashish, A., Prakash, Pandey. A., Ojha, A., Mani, N., Mattur. Chandrashekara. N. (2014) Effect of Mix Parameters on the Strength Performance of Waste Plastics Incorporated Concrete Mixes. Hindawi Publishing Corporation Journal of Structures, Article ID 389014, 8 pages.

[15]. Brahiman, T., Kokou, Esso.A., Olivier, M. B., Remy, L., Edjikémé, E. (2017) Elaboration and Characterization of Composite Materials made of Plastic Waste and Sand: Influence of Clay Load. International Journal of Scientific Engineering and Technology, 6, Issue No. 7, pp, 220-223.

[16]. Kossi Bollanigni AMEY., Kouma NEGLO., Ouro –Djobo SAMAH., Agbéko Yaovi KOUTO et Abalo P'KLA., (2014) Etude expérimentale de la formulation de mortier a base de sable silteux du Togo et de liant de sachets plastiques type << voltic >>. Afrique SCIENCE 10(3), pp,48-59.

[17]. Adolphe TOMASIMO et Al, physique chimie, 2e éditions, Natan-1997, Mechain Paris ISBN 209172193.

[18]. Tanawa E., Djeuda Tchapnga H.B., Ngnikam E., Wethe J., (2002). La propreté urbaine dans une grande ville d'Afrique centrale : le cas de Yaoundé au Cameroun. In : Bota H., Barbier C. et Deleuil J.M. (eds) "Enjeu de la propreté urbaine", Presse Polytechniques et Universitaires Romanes, Lausane, janvier (2002). Chapitre 8, pp, 123-141.

[19]. Institut Belge de Normalisation (IBN). (2005) Méthodes d'essais des ciments - Partie 1: Détermination des résistances mécaniques. NBN EN 196-1.

[20]. Albano C., Camacho N., Hernandez M., Matheus A., Gutierrez A. (2009). Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios. Waste Management, 29, pp 2707–2716.

[21]. Hemn Boiny U., Younis Alshkane M., Serwan Rafiq Kh. (2016). Mechanical properties of cement mortar by using polyethylene terephthalate fibbers. Modern Materials and structures in civil Engineering, 5th National and International conference on.

[22]. Holcim. Memento technique ; Le béton prêt à l'emploi : conseils techniques et solutions. Force. Performance. Passion ; Holcim Bétons (Belgique) S.A.

[23]. Heru P., Gandjar P., Madsuri S. (2017). Influence of uncoated and coated plastic waste coarse aggregates to concrete compressive strength. MATEC Web of Conferences SICEST2016, DOI: 10.1051.

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