Scientific Research Publishing

Study of the Effect of Plastic Aggregates on Drying Shrinkage and Expansion of Concrete

Kouamou Nguessi Arnaud[1,2]*, Yamb Emmanuel[1], Ndigui Billong[3], Ngwem Bayiha Blaise[1], Mbuh Moses Kuma[2], Tchemou Gilbert[1], Christian Hyeng Bock[4], Madouma Madouma Arnold[5]

[1]Mechanics Laboratory, ENSET of the University of Douala, Douala, Cameroon
[2]Department of Civil Engineering and Forestry Techniques, Higher Technical Teacher Training College, University of Bamenda, Bamenda, Cameroon
[3]Materials Analysis Laboratory, MIPROMALO, Yaoundé, Cameroun
[4]Department of Civil Engineering and Urban Development, National High School Polytechnic of Yaoundé 1, University of Cameroon, Yaoundé, Cameroon
[5]Higher Technical Teacher Training College, Omar Bongo University, Libreville, Gabon
Email: *nguessiarnaud@gmail.com

Abstract

The aim of this work was to propose a possibility of using plastic aggregates from waste to reduce the shrinkage and expansion observed in concrete. The process of obtaining plastic aggregates was presented. Natural aggregates were partially substituted by plastic aggregates in the percentages: 0%, 5%, 10%, 20% and 30%. Drying shrinkage, water absorption and expansion tests were carried out on three families of concrete: control concrete (BT), concrete with addition of BAgP-PEHD high-density polyethylene plastic aggregate and with polyvinyl chloride BAgP-PVC. Given the slow appearance of the internal sulfate attack (ISA), an experimental technique was proposed to accelerate the appearance of this pathology. This technique involves heat treatment which stimulates the heating of the concrete at a young age, followed by a cycle of drying and cooling and ends with total immersion in water. The method of measuring expansions through sample image correlation was also proposed. The results showed an increased skrinkage of BAgP-HDPE compared to BT. On the other hand, a significant decrease in shrinkage was observed in BAgP-PVC samples. Water absorption increased in BAgP-HDPE and BAgP-PVC compared to BT. Greater expansion was observed at the cement paste-plastic aggregate interface than at the cement paste-natural aggregate interface. Given these properties, BAgP-PVC can be recommended for paving surfaces exposed to the hard weather conditions.

Keywords

Wastes Plastic, Internal Sulfate Attack, Physical Properties, Mechanical

Properties

1. Introduction

Plastic was a highly useful material and its applications were expected to increase as more new products and plastics were developed to meet demands. The increased use and production of plastic in developing and merging countries was a particular concern, as the sophistication of their waste management infrastructure may not be developed at an appropriate rate to deal with their increasing levels of plastic waste [1]. However, environmental concerns associated with increasing plastic waste and the extraction of non-renewable natural aggregates has led to the search for sustainable alternatives. Plastic consumption has been raising exponentially for several decades [2]. According to the Plastics Europe Report, the global production of plastic in 2013 was around 241 million tons, with Europe and China as the major consumers [2]. Plastics were also known as polymers or a "long chains of monomers," which were bonded to other identical subunits to form a polymer [3]. The inclusion of an artificial aggregate made from waste plastics to produce lightweight concrete has been widely studied [4]. Of all the pathologies of concrete, expansion and drying shrinkage continue to be a concern in our construction.

The mechanism according to which the expansion generated by the ISA would originate from the formation of ettringite at the paste/aggregate interface was based on the hypothesis of the development of high crystallization pressures in the large pores. The observations made attest to the presence of so-called compressed ettringite around the aggregates [5] [6]. If the cracking of the paste, filled by ettringite crystals, has been observed, it has been observed for already very high levels of expansion and well after the first observations of ettringite at the paste/aggregate interface [6]. In addition, the observations made by [7] highlight slower expansion kinetics for cement pastes compared to concretes, which attests that, if the presence of aggregates was not essential, it plays an important role in the development of the deleterious phenomena of ISA. The experimental observations of [8] [9] have shown that the type of aggregates used could have an impact on the appearance of ettringite at the paste/aggregate interface and on the importance of expansive phenomena. This confirms the importance of the role of aggregates on expansions induced by ISA. There was therefore a significant difference in behavior between the concretes affected by ISA composed of siliceous and calcareous aggregates. If the type of aggregate used can influence the expansion at the paste/aggregate interface, non-siliceous and non-calcareous aggregates such as plastic aggregates which were inert aggregates deserve to be studied.

However, other phenomena such as concrete shrinkage were often the cause of cracking, loss of prestressing, redistribution of stresses, and even, more rarely,

the collapse of the structure [10]. This dimensional variation depends on several parameters such as the composition of the concrete, the quality of its constituents, the size of the elements as well as the external storage conditions [10]. Three major classes of shrinkage were known: endogenous, drying and total shrinkage. The improvement of concrete shrinkage by the use of waste plastics was increasingly observed. The high cement content of high performance concrete results in improved strength, but also high shrinkage. The substitution of natural aggregates by recycled aggregates notably affects these properties in conventional concretes [11] [12]. The Role of aggregate and fibre in strength and drying shrinkage of alkali-activated slag mortar had been studied, the author has presents an investigation on the influences of aggregate-to-binder ratio, aggregate size, polypropylene (PP) and steel fibre dosages on the strength and drying shrinkage of alkali-activated slag mortar [13]. The drying shrinkage and creep properties of prepackaged aggregate concrete reinforced with waste polypropylene fibers was investigated [14]. Given that concrete structures were increasingly exposed to the problem of elevated temperatures, normal conventional concrete was less and less resistant to this sudden change in temperature which negatively influences shrinkage in general. The incorporation of plastic waste, in particular PET (Polyethylene terephthalate), in granular form into concrete increases the shrinkage of concrete [15] [16]. But the influence of other types of plastics on shrinkage was very little known. This work aims to use other types of plastic waste in the form of aggregate to solve the problem of drying shrinkage, that was why the choice was made on HDPE and PVC.

The objective of this research was to propose the use of two types of plastic waste (HDPE and PVC) as substitute aggregates for natural gravel to solve the problem of drying shrinkage and expansion due to ISA, and also to understand the behavior of the material in the presence of water. The study of the expansion of concrete with plastic aggregates remains little known, which makes this work a scientific novelty. The expansion phenomena seem more marked and faster with plastic aggregates (HDPE and PVC) than with natural aggregates due to the greater detachment of the plastic aggregates under the effect of the expansion of the paste. The reduction of drying shrinkage by the use of PVC-type plastic aggregates in concrete could be a scientific novelty that was in the past very little demonstrated in previous research work.

2. Materials and Methods

2.1. Nature and Source of Materials

Portland Cement used was from Dangoté (Douala-Cameroon); River sand 0/5 was siliceous nature, coming from Sanaga (Ebebda-Cameroon); Quarry gravel (Gneiss) crushed 6/10 was from Yaoundé-Cameroon; Plastic waste: Rigid HDPE was from used Communal garbage bins and PVC from rigid pressure pipes collected in landfills from PVC pipe manufacturing and recycling industries (Bafoussam-Cameroon); tap water was from CAMWATER-Cameroon.

2.2. Preparation and Characterization of Raw Materials

2.2.1. Cement

The cement used was gray cement. It was of class CEM II/B-P 42.5 R produced locally according to the Cameroonian Standard NC 234: 2009-06. The chemical composition and the specific surface of the cement were recorded in Table 1 below.

2.2.2. Sand and Gravel

The sand was first washed with a 0.063 mm sieve, and then dried in an oven for 24 hours at a temperature of 105˚C. The particles greater than or equal to 6.3 mm were eliminated by sieving before its use in the formulation of the concrete. The gravel was also washed and then dried in an oven for 24 hours at a temperature of 105˚C. Then the particles greater than or equal to 14 mm were eliminated by sieving. Table 2 presents the physical characteristics of the quarry sand and gravel used.

2.2.3. Preparation of Plastic Waste

The preparation of plastic waste was a very important phase. It began with the collection of plastic waste, then passing through sorting, washing, shredding and ending with crushing and sieving. Figure 1 presents the mode of preparation of the HDPE and PVC plastic aggregates used.

2.2.4. Characterization of Plastic Aggregates

Table 3 presents the physical characteristics of the plastic aggregates used.

Table 1. Chemical composition and specific surface area of the Dangoté cement powder used [17].

Sample	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	M_gO	N_iO	P_2O_5	PbO	SO_2	SiO_2	TiO_2	ZrO_2	H_2O	Total	Specific surface area $g \cdot m^{-2}$
Dangoté Cement	3.34	0.04	62.23	0.01	2.50	0.95	0.00	0.01	0.00	0.01	5.01	19.22	0.33	0.09	2.50	96.25	1.26

Table 2. Physical characteristics of sand and gravel used.

| Characteristics	River Sand	Quarry Gravel
d/D ratio	0/5	6/10
Fineness modulus (M_f)	2.91	3.8
Coefficient of Curvature C_c	0.79	1.0
Uniformity Coefficient C_u	3.13	1.6
Bulk density M_{Vapp} (Kg·m^{-3})	1532.45	1497.07
Absolute density M_{Vabs} (Kg·m^{-3})	2.73	3.0
Water absorption coefficient C$_{Abs}$ (%)	7.2	9.6
Porosity of aggregates P (%)	-	0.60
Los Angeles Coefficient C_{LA} (%)	-	36.80
Equivalent of visual sand after washing ESV (%)	82	-
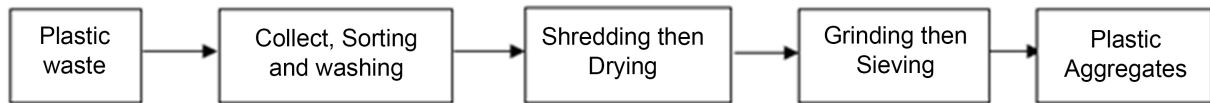
Figure 1. Method of preparation of plastic waste aggregates.

Table 3. Physical characteristics of plastic aggregates used.

Characteristics	HDPE aggregates	PVC aggregates
d/D ratio	6/10	6/10
Fineness modulus (M_f)	3.03	3.9
Coefficient of Curvature C_c	0.99	1.02
Uniformity Coefficient C_u	1.6	1.6
Bulk density M_{Vapp} (Kg·m^{-3})	428.19	657.71
Absolute density M_{Vabs} (Kg·m^{-3})	-	1.250
Porosity of aggregates P (%)	6.60	4.50
Water absorption coefficient C_{Abs} (%)	10.8	7
Los Angeles Coefficient C_{LA} (%)	0.42	0.72

The particle size curves of the aggregates used were shown in **Figure 2** below:

2.3. Experimental Protocol

2.3.1. Mix Optimization

The concrete was made in accordance with the NF EN 206-1 standard, valid for concrete whose density was >800 kg·m^{-3} [18]. Gravel, Sand and Cement were mixed with water in the following proportions: 0.4 m^3 of cement, 0.785 m^3 of Sand, 1.2 m^3 of Gravel and 0.22 m^3 of water. The gravel to sand G/S ratio was 1.53 and the E/C ratio was 0.55. Several dosages were carried out with the aim of gradually replacing natural gravel with plastic aggregate waste. The plastic aggregates of the HDPE and PVC type were in the proportions: 0%, 5%, 10%, 20% and 30% of the density of the gravel (1.2 m^3). The proportion of sand, cement and water remained constant. The constant quantity of water stopped (0.22 m^3) depending on the standard consistency on each dosage. These operations were recorded in **Table 4** below.

In addition to the reference concrete (control concrete), two families of plastic aggregate concrete were produced. The families of concretes produced have been listed below as follows:

BT: Control concrete.

BAgP-PEHD: Concrete with high density polyethylene plastic aggregates.

BAgP-PVC: Concrete with polyvinyl chloride plastic aggregates.

The mixing was carried out mechanically using a concrete mixer for homogenization of the constituents of the concrete in accordance with standard XP-P 18-305 [19]. Contrary to the reference concrete, an increase in the mixing time was applied on the plastic aggregate concretes to optimize the mixture.
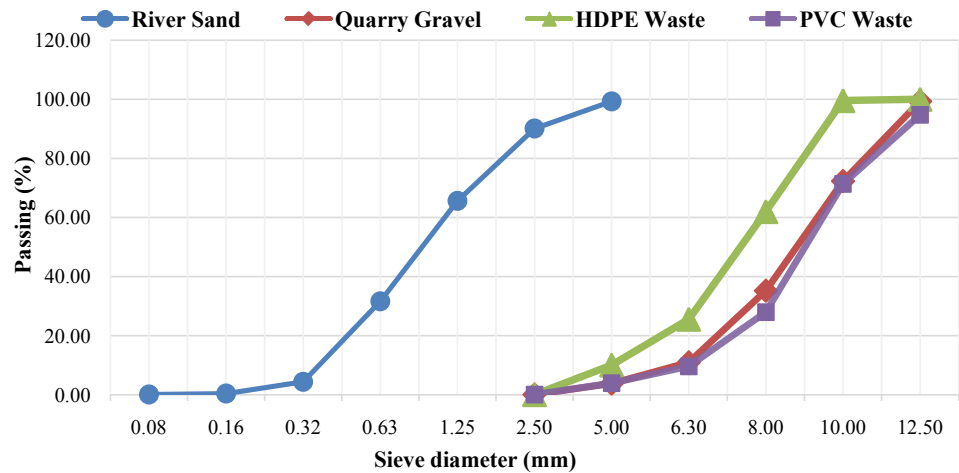
Figure 2. The particle size curves of the aggregates used.

Table 4. Dosage of concrete constituents in HDPE and PVC plastic aggregates.

Composition For 1 m^3 of concrete	Cement (m^3)	River Sand (m^3)	Wastes PEHD or PVC (m^3)	Crushed gravel (m^3)	Water (m^3)
B.T	0.4	0.785	0	1.2	0.22
BAgP. 5%	0.4	0.785	0.06	1.14	0.22
BAgP. 10%	0.4	0.785	0.12	1.08	0.22
BAgP. 20%	0.4	0.785	0.24	0.96	0.22
BAgP. 30%	0.4	0.785	0.36	0.84	0.22

2.3.2. Preparation and Conservation of Test Specimens

In accordance with standard NF EN 12390-1 [20], the molds and test specimens were made as follows: the pressure PVC pipe 100 mm in diameter and 4m long was used for this purpose. The pipe was cut in lengths of 20 cm to make standardized molds allowing to have cylindrical test specimens with a section of 78.5 cm^2. These specimens were called "10/20 specimens", *i.e.* 10 cm in diameter and 20 cm in height. Then the prismatic wooden molds were made to have the prismatic specimens of dimension $7 \times 7 \times 28$ cm. All specimens must remain in the mold and protected against impact. Vibrations were avoided for a minimum of 16 hours and a maximum of 3 days. The specimens were then kept at a temperature of 20°C ± 2°C inside the laboratory until the time of the tests. **Figure 3** below shows the cylindrical and prismatic specimens after their demolitions.

2.3.3. Drying Shrinkage

Drying shrinkage at ambient air and humidity on concrete specimens was performed in accordance with standard NF P 15-433. The shrinkage was measured at the following different times: 0 days, 7 days, 14 days, 21 days, 28 days, 60 days, 90 days, 120 days, 150 days and 180 days. The variation in length of the $7 \times 7 \times 28$ specimens was compared at different times t with respect to its length at a time t_0 taken as origin. A demometer (**Figure 4**) equipped with a comparator
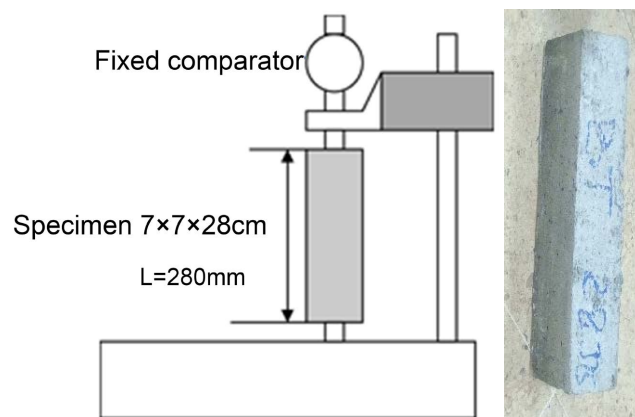
Figure 3. Cylindrical and prismatic specimens.

Figure 4. Demometer for shrinkage test on prismatic specimen.

made it possible to carry out measurements with an accuracy less than or equal to 0.005 mm. A 280 mm long rod was used to adjust the zero of the demometer. This rod was made of Invar so that the temperature variations it may experience during handling do not cause any appreciable change in its length. At the time of measurement, the comparator was put at zero on the standard Invar rod of length L = 280 mm. Let $dl(t)$ be the value read on the comparator at time t: the specimen has a length at the considered time:

$$l = L + dl(t) \tag{1}$$

Let $l(t_0)$ be the length of the specimen at time t_0 chosen for origin taken at the time of demoulding, *i.e.* 24 or 48 hours after the specimens were made. The change in length at time t was:

$$\Delta l = l(t) - l(t_0) = dl(t) - dl(t_0) \tag{2}$$

The relative length variation denoted by ε has the expression:

$$\varepsilon(t) = \frac{\Delta l(t)}{L} \tag{3}$$

$\Delta l(t)$ was obtained by taking the average of the 3 specimens from the same mould. When the test specimens were stored in air, $\Delta l(t)$ was generally negative due to specimen shrinkage. **Figure 3** shows the device used.

2.3.4. Water Absorption

In accordance with the NBN B 15-215 standard, after 28 days the specimens were demolded then placed in an oven at a temperature of 65˚C until the specimens were completely dehydrated. Then they were weighed, this was the dry mass (M_1), then they were immersed in water for 48 hours and weighed again to get the wet mass (M_2). The water absorption coefficient C_{Abs} was:

$$C_{Abs} = \frac{M_2 - M_1}{M_1} \times 100 \qquad (4)$$

2.3.5. Expansion

Three days after making the 10 × 20 cm cylindrical specimens, they were removed from the mold and underwent a significant heating test of the concrete at a young age to observe the delayed formation of ettringites for one year (without the addition of external sulphate). The formation of ettringites was likely to cause expansion in hardened concrete. The phenomenon of internal sulphate expansion can be manifested by the appearance on the surface of the concrete of multidirectional cracking with a relatively large mesh of 10 to 30 mm. The specimens were removed from the mold and then placed in an oven at a temperature of 85˚C, the temperature maintained for 3 hours. The test consisted in characterizing the risk of expansion of a concrete with respect to the ISA. The test had four distinct steps:

- Manufacture of cylindrical concrete specimens

    Several cylindrical specimens of 10/20 were made according to the two types of plastic waste used (HDPE and PVC) and at different dosages (0%, 5%, 10%, 20%, 30%). The measurement of the expansion at each age of the concrete was carried out on each cylindrical specimen.

- Heat treatment simulating the heating of concrete

    The specimens were removed from the mold and then placed in an oven at a temperature of 85˚C for 3 hours.

- Drying and cooling cycle

    After 3 hours of maintaining the temperature, the specimens were cooled by immersion in water for 2 hours. Then they were again underwent the same heat treatment and the same drying-cooling cycle before their total immersion in water. Then the measure of expansion was calculated. Given the small dimensions of the samples and the sensitivity of the paste-aggregate interface, the choice was made to apply a shorter duration of the maintenance of the temperature than that generally accepted for macroscopic samples [21].

- Total immersion in water and monitoring of longitudinal deformations

    The specimens were completely immersed in a tank of unrenewed water for 12 months at a water temperature of between 13˚C ± 2˚C. During the first month, the longitudinal expansion was only measured closely (1 day, 7 days, 25 days and 30 days), then the follow-up of the longitudinal deformations each month for 1 year (365 days).

- Expansion Tracking

To carry out the follow-up of the expansions of the samples, the method by image correlation proved to be the most suitable method for the size and the conditioning of the samples. This method consisted of depositing a speckle (**Figure 5(a)** and **Figure 5(b)**) on one side of the sample after heat treatment simulating the heating of the concrete and then photographing this side every 1 month during the development of the pathology. The speckle was applied here by spraying white paint on the surface of the sample previously tinted in black (**Figure 5(c)**). The expansion was measured by calculating the distances between well-identified points given in (mm) (**Figure 6**). Samples of the same assay were photographed for image correlation every 30 days for 365 days (**Figure 7**). Then the variation of these distances was calculated $\Delta l_0(t)$ and $\Delta l_1(t)$ on each sample according to the equations (Equation (5) and Equation (6)). And finally the expansion ε_1 and ε_2 were calculated on each cylindrical specimen.

$$\Delta l_0(t) = l_0(t) - l_0(initial) \tag{5}$$

$$et \quad \Delta l_1(t) = l_1(t) - l_1(initial) \tag{6}$$

$$\varepsilon_1 = \frac{\Delta l_0(t)}{l_0(initial)} \tag{7}$$

$$\varepsilon_2 = \frac{\Delta l_1(t)}{l_1(initial)} \tag{8}$$

The expansion at the interface of the composite can be deduced on each sample by the average of two expansion measurements given as a percentage by the following equation:
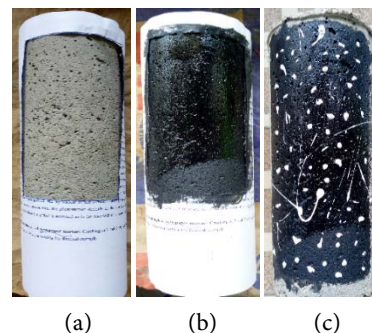

(a)   (b)   (c)

Figure 5. Realization of the speckle.

Figure 6. Expansion measurement.

<div align="center">(a)   (b)</div>

Figure 7. Image correlation. (a) BT; (b) BAgP-PVC.

$$\varepsilon_i(t) = \frac{\varepsilon_1 + \varepsilon_2}{2} \times 100 \tag{9}$$

$l_0(t)$ and $l_1(t)$ was the length measured at time t on a specimen, $l_0(initiale)$ and $l_1(initiale)$ was the initial length measured after 24 hours from the first immersion in water on a specimen. As the test pieces were kept in water, $\Delta l(t)$ was positive due to the expansion of the specimen. This method of measuring expansion via image correlation has been well developed by [22].

3. Results and Discussion

3.1. Drying Shrinkage

Figure 8(a) and Figure 8(b) represent the drying shrinkage (drying shrinkage) of three families of concrete (BT, BAgP-PEHD and BAgP-PVC). There was generally an increase in shrinkage as a function of the age of the three families of concrete and it was significant during the first month of the concrete and then tends to stabilize over the next month. Figure 8(a) shows an increase in drying shrinkage when the percentage of HDPE plastic aggregates increases in the concrete. On the other hand, Figure 8(b) shows a decrease in drying shrinkage when the percentage of PVC plastic aggregates increases in the concrete.

The presence of honeycombs (empty) on the surface of the BAgP-PEHD concretes could be responsible for this increase in shrinkage because the evaporation of the water contained in the pores of the hardened concrete led to the shrinkage. In addition, the free surfaces of the BAgP-PEHD subjected to the ambient air have a lower degree of humidity than that of the concrete, which facilitated the removal of the BAgP-PEHD. This drying process generates a reduction in the volume of the concrete due to the progressive loss of water in the mass of concrete. The risk of cracks appearing was probable in this family of BAgP-PEHD concrete. Some authors, notably Koide H and Marques da Silva A, rather thought that the increase in shrinkage observed was due to the low modulus of elasticity of concretes containing plastic aggregates than common concretes [15] [16] [23] [24]. On the other hand, the low presence of honeycombs (empty) on the surface of BAgP-PVC concretes could be responsible for this decrease in shrinkage compared to BAgP-PEHD. In BAgP-PVC, shrinkage was very slow and increases less quickly than normal BT reference concrete. The low heat exchange
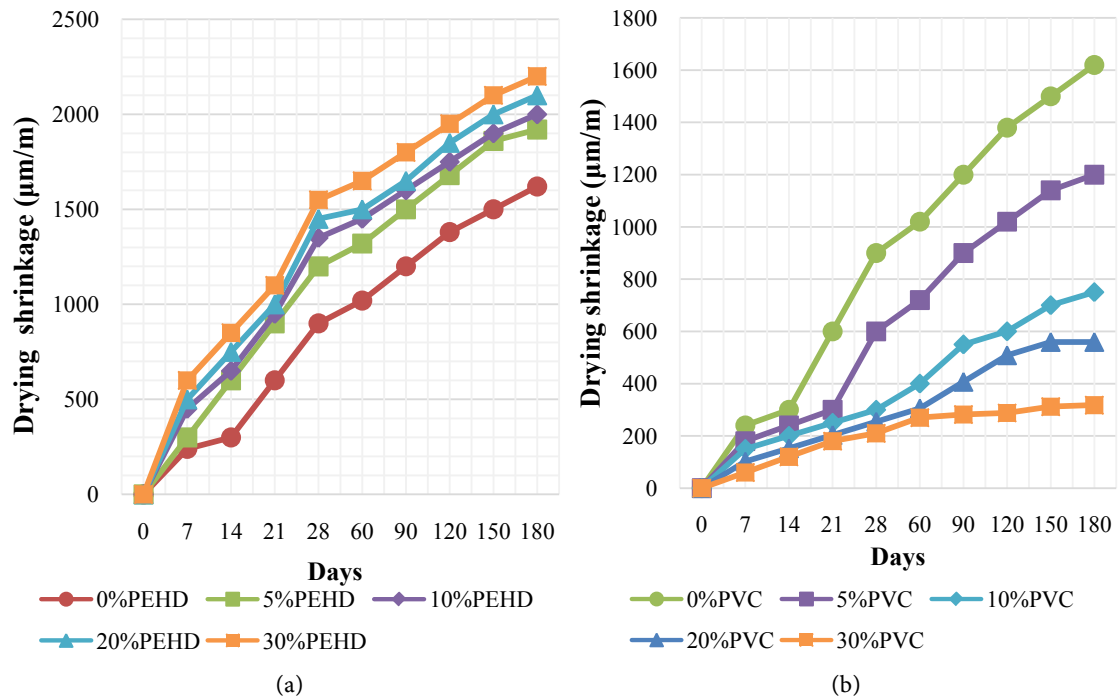
Figure 8. Drying shrinkage on concrete.

caused by the present of PVC aggregates could be responsible for this behavior. Indeed, the evaporation of the water contained in the pores of the hardened concrete was slowed down by the PVC aggregates. It can also be thought that the low thermal conductivity of PVC plastic aggregates was responsible for this behavior. In this family of BAgP-PVC concrete, the risk of cracks appearing was very low, this was because the water evaporation process was very slow and progressive in the mass of concrete. Kou *et al.*, who had replaced natural sand with PVC plastic aggregates, had also observed a decrease in drying shrinkage with an increasing content of plastic aggregates [25].

3.2. Water Absorption

Figure 9 below shows the water absorption of three families of concrete (BT, BAgP-PEHD and BAgP-PVC). It can be seen that the water absorption evolves according to the type of plastic aggregate used and the dosage. For a BT the water absorption is 5.21%, it evolves according to the percentage of addition of plastic aggregates. At 30% HDPE aggregate it reaches 9.35% water absorption against 6.61% with PVC aggregates.

One of the reasons that may explain this increase in the rate of water absorption was the porosity of the plastic aggregate concretes. In addition, plastic aggregates alone, especially HDPE, showed high porosity compared to natural aggregates (gravel), which contributed to a rapid increase in water absorption. On the other hand, PVC plastic aggregates being less porous than natural aggregates (gravel), this did not prevent an increase in water absorption because the increase in volume of plastic aggregates in the concrete creates an increase in porosity.
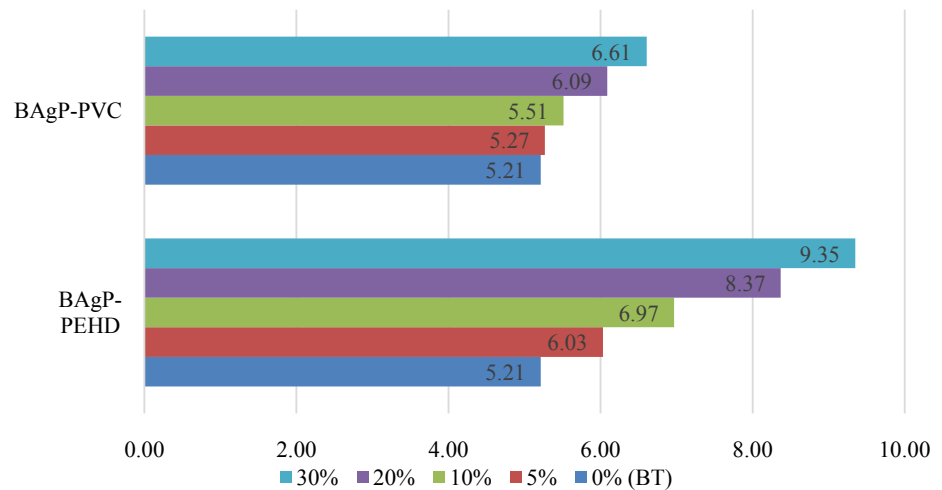
Figure 9. Water absorption of concretes.

One of the reasons which can explain the increase in water absorption was the weak bond between the cement paste and the plastic aggregates. This weak bond has been widely demonstrated in previous works, notably by Dame K, Hannawi K *et al.* and Safi, B *et al.* [26] [27] [28]. In fact, the voids created were very quickly occupied by water increasing the absorption of water. The rough texture of the PVC aggregates somewhat slowed down the fragility of the cement paste-PVC plastic aggregate bond, hence the low absorption of the concrete.

3.3. Heat Treatment Simulating the Heating of Concrete

The cracks located on the surface of the cylindrical specimens due to the heat treatment simulating were observed (**Figure 10**).

After the first heating cycle, diffuse cracks were observed on the surface of the specimens. In general, the figure shows that the microcracks observed on the surface of the specimens decreased as a function of the increase in plastic aggregates. The BAgP-PVC samples showed an absence of microcracks at 10% PVC aggregates, unlike the BAgP-PEHD samples. During the high temperature, the samples containing the plastic aggregates progressively prevented the opening of the microcracks when the plastic aggregates were increased. Unlike the BAgP-PVC samples, the high porosity of the BAgP-HDPE samples was responsible for the microcracks observed after 10% addition of plastic aggregates.

3.4. Expansion

Figure 11 and **Figure 12** below show the expansion of three families of concrete (BT, BAgP-PEHD and BAgP-PVC) over the course of one year (365 days). The expansion due to the development of ISA which was an endogenous pathology responsible for the delayed formation of ettringites. It can be seen that the development of the pathology evolves according to the type of aggregate used, but also according to the dosage of plastic aggregates and the age of the concrete. The figures show that the pathology increases when the plastic dosage increases
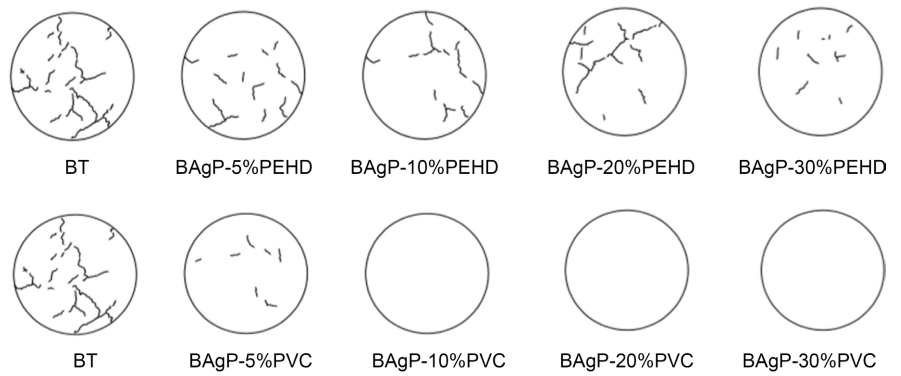
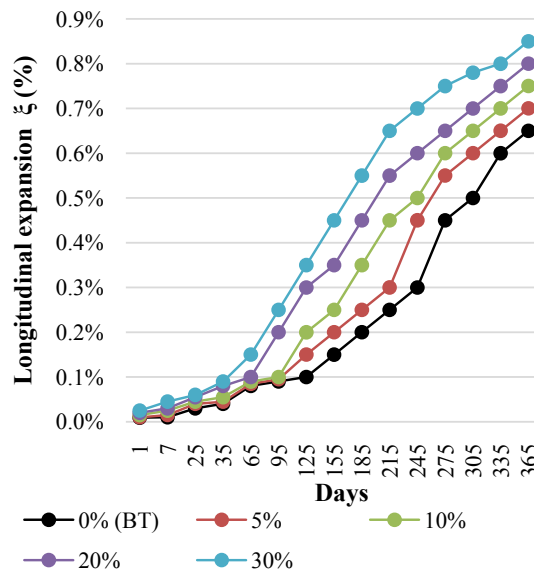Figure 10. Mapping of the cracks located on the surface of the specimens.

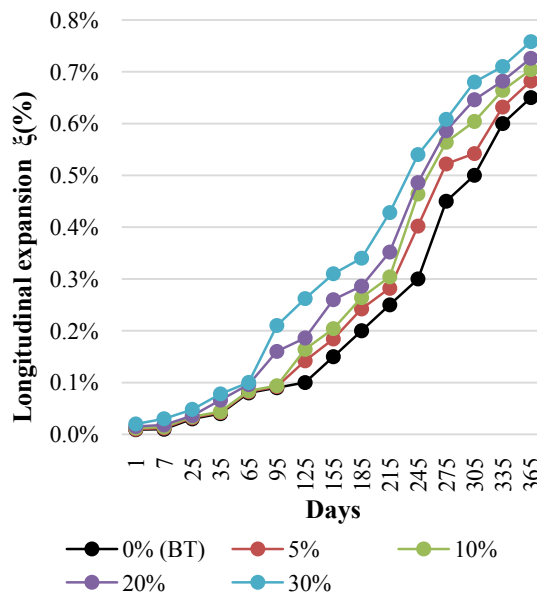Figure 11. Expansion of BAgP-PEHD concretes.

Figure 12. Expansion of BAgP-PVC concretes.

in the concrete. For BT, the expansion does not exceed 0.65% over the course of a year. But it can evolve quickly and reach an expansion of 0.85% in one year with an addition of 30% HDPE. On the other hand, the expansion tightens up to 0.76% in one year with an addition of 30% of PVC.

The expansion observed in BAg-PEHD was due to the porosity and significant water absorption compared to normal BT reference concrete. In the concretes with addition of HDPE plastic aggregates there was a significant development of the pathology. More ettringites were probably formed at the cement paste-PEHD plastic aggregate interface compared to the cement paste-natural aggregate interface, which explains the significant expansion of BAgP-PEHD compared to BT. The cement paste-plastic aggregate interface played an important role in the development of deleterious ISA phenomena, which increased the expansion of concrete over time. Since the expansion of simple cement paste was less important than the expansion of concrete according to Yvan Thiebaut [29]. During the expansion of the cement paste alone, there was a detachment between the cement paste and the HDPE plastic aggregate, the voids created facilitate transfers within the material, which were then privileged sites of crystallization. These phenomena were linked to the loosening of the aggregates under the effect of the expansion of the paste. This difference in behavior between the natural aggregate (gravel) used and the inert HDPE plastic aggregate may be due to a weaker bond at the interface with the paste. Unlike the natural aggregate (gravel) used, plastic aggregates were not chemically reactive with cement paste. This leads to a more marked and faster expansion with plastic aggregates.

Not against in concretes with addition of PVC plastic aggregates (BAgP-PVC) the same phenomenon in general was observed, but a significant decrease in expansion was observed in these concretes. At the cement paste-PVC plastic aggregate interface, expansion was reduced. The detachment of the PVC aggregates from the cement paste during the expansion of the cement paste alone was more or less prevented by the rough texture of the PVC plastic aggregates which slowed down the increase in the expansion of the concrete. This expansion phenomenon could also be impacted by the fineness of the aggregates used according to Al Shamaa [30]. Indeed, the fineness modulus of the natural gravel and the PVC plastic aggregate being very close and higher than the HDPE plastic aggregates, this contributed to the reduction in the expansion of the concrete observed. The role played by the size of the aggregates used may also be responsible for this phenomenon, although this has not yet been clearly identified [29].

4. Conclusions

This experimental study made it possible to appreciate the effect of plastic aggregates on drying shrinkage and expansion of concrete. The drying shrinkage (drying), water absorption and expansion of the three families of concretes were studied. The results showed that:

1) The drying shrinkage increased in BAgP-PEHD because of the porosity of

this concrete, and on the other hand the drying shrinkage decreased thanks to the low thermal conductivity and the low presence of voids in the concrete mass;

2) Water absorption increased in plastic aggregate concretes as the percentage of aggregates increased in the concrete. The porosity and the weak bond between the cement paste and the plastic aggregate were responsible for this behavior;

3) The expansion of the concrete was greater in BAgP-PEHD than in BAgP-PVC; porosity and water absorption were responsible for this behavior. The evaporation of water in the BAgP-PVC was delayed and slowed down by the presence of the plastic aggregates thus reducing the expansion compared to the BAgP-PEHD.

Given the low shrinkage and acceptable expansion compared to the standard. BAgP-PVC concretes could be recommended for slabs exposed to bad weather.

The expansion measured via the image correlation deserves to be confirmed by a more detailed observation under a scanning electron microscope (SEM). The expansion measured by image correlation over 1 year can extend up to 2 years to have more complete information on these materials. The behavior of concretes in the face of drying shrinkage beyond 180 days can be studied.

Acknowledgements

Author's Contributions

Arnaud Nguessi Kouamou: initiated the project and project administration, investigation and writing-original draft; **Emmanuel Yamb:** Supervision, formal analysis, validation, writing review and editing; **Billong Ndigui:** Methodology, Data curation, Visualization, **Blaise Bayiha Ngwem** and **Mbuh Moses Kuma**: Formal analysis, Validation; **Gilbert Tchemou**, **Christian Hyeng Bock** and **Madouma Madouma Arnold**: read and approved the final manuscript, Validation.

Conflicts of Interest

The authors declare that they have no known competing interests.

References

[1] Manzoor, J., *et al.* (2021) Plastic Waste Environmental and Human Health Impacts. In: Manzoor, J., *et al.*, Eds., *Plastic Waste Environmental and Human Health Impacts*, IGI Global, Hershey, 29-37.

[2] Gurbir, K. and Sara, P. (2021) Physical Properties and Microstructure of Plastic Aggregate Mortars Made with Acrylonitrile-Butadiene-Styrene (ABS), Polycarbonate (PC), Polyoxymethylene (POM) and ABS/PC Blend Waste. *Journal of Building En-*

gineering, **31**, Article ID: 101341. https://doi.org/10.1016/j.jobe.2020.101341

[3] Niyitanga, E., Sarmad, A.Q., Muhammad, B., Damià, B. and Hafiz, M.N.I. (2021) Plastic Waste and Its Management Strategies for Environmental Sustainability. *Case Studies in Chemical and Environmental Engineering*, **4**, Article ID: 100142. https://doi.org/10.1016/j.cscee.2021.100142

[4] del Rey Castillo, E., *et al.* (2020) Light-Weight Concrete with Artificial Aggregate Manufactured from Plastic Waste. *Construction and Building Materials*, **265**, Article ID: 120199. https://doi.org/10.1016/j.conbuildmat.2020.120199

[5] Aubert, J.E., Escadeillas, G. and Leklou, N. (2009) Expansion of Five-Year-Old Mortars Attributable to DEF: Relevance of the Laboratory Studies on DEF. *Construction and Building Materials*, **23**, 3583-3585. https://doi.org/10.1016/j.conbuildmat.2009.08.015

[6] Leklou, N., Aubert, J.E. and Escadeillas, G. (2008) Microscopic Observations of Samples Affected by Delayed Ettringite Formation (DEF). *Materials and Structures*, **42**, 1369-1378. https://doi.org/10.1617/s11527-008-9456-9

[7] Barbarulo, R. (2002) Comportement des matériaux cimentaires: actions des sulfates et de la température. Ph.D. Thesis, Ecole Normale Supérieure de Cachan, Île-de-France.

[8] Brunetaud, X. (2005) Étude de l'influence de différents paramètres et de leurs interactions sur la cinétique de l'amplitude de la réaction sulfatique interne au béton. PhD Thesis, Châtenay Malabry, École centrale Paris, Paris.

[9] Malbois, M., Divet, L., Lavaud, S. and Torrenti, J.M. (2017) Influence de la nature pétrographique des granulats et de cycles de séchage sur le développement de la réaction sulfatique interne dans le béton. 23*ème Congès Français de Mécanique*, Lille, 28 Août au 1er Septembre 2017, 3-8.

[10] Chaib, O., Benosman, A.S., Kazi Tani, N., Senhadji, Y., Mouli, M., Taïbi, H. and Hamadache, M. (2017) The Evolution of Shrinkage Strain of Pet-Mortar Composite Eco-Materials. *Journal of Fundamental and Applied Science*, **9**, 136-152. http://www.jfas.info https://doi.org/10.4314/jfas.v9i1.10

[11] Hossein, M., Shek, P.N., Rayed, A. and Mahmood, M.T. (2021) Synergistic Effects of Waste Plastic Food Tray as Low-Cost Fibrous Materials and Palm Oil Fuel Ash on Transport Properties and Drying Shrinkage of Concrete. *Journal of Building Engineering*, **42**, Article ID: 102826. https://doi.org/10.1016/j.jobe.2021.102826

[12] Víctor, R.C., Luís, E., Jorge de, B., Vanesa, O.L. and Juan, M.M. (2021) Effect of the Maturity of Recycled Aggregates on the Mechanical Properties and Autogenous and Drying Shrinkage of High-Performance Concrete. *Construction and Building Materials*, **299**, Article ID: 124001. https://doi.org/10.1016/j.conbuildmat.2021.124001

[13] Chen, W., Xie, Y., Li, B., Li, B., Wang, J. and Thom, N. (2021) Role of Aggregate and Fibre in Strength and Drying Shrinkage of Alkali-Activated Slag Mortar. *Construction and Building Materials*, **299**, Article ID: 124002. https://doi.org/10.1016/j.conbuildmat.2021.124002

[14] Fahed, A., Hossein, M., Mahmood, M.T., Rayed, A., Hussam, A., Yousef, A. and Abdulaziz, A. (2020) Drying Shrinkage and Creep Properties of Prepacked Aggregate Concrete Reinforced with Waste Polypropylene Fibers. *Journal of Building Engineering*, **32**, Article ID: 101522. https://doi.org/10.1016/j.jobe.2020.101522

[15] Koide, H., Tomon, M. and Sasaki, T. (2002) Investigation of the Use of Waste Plastic as an Aggregate for Lightweight Concrete. https://doi.org/10.1680/scc.31777.0018

[16] Marques da, S.A., Brito, J. and Veiga, M. (2014) Incorporation of Fine Plastic Aggregates in Rendering Mortars. *Construction and Building Materials*, **71**, 226-236.

[17] Alyousef, R., Ahmad, W., Ahmad, A., Aslam, F., Joyklad, P. and Alabduljabbar, H. (2021) Potential Use of Recycled Plastic and Rubber Aggregate in Cementitious Materials for Sustainable Construction: A Review. *Journal of Cleaner Production*, **329**, Article ID: 129736. https://doi.org/10.1016/j.jclepro.2021.129736

[18] Benamrane, D.Z. (2017) L'effet de la méthode de formulation sur la résistance à la compression du béton. Université KASDI Merbah Ouargla.

[19] AFNOR, norme XP-P 18-305 (1966) Béton prêt à l'emploi.

[20] Norme européenne NF EN12390-1 (2001) Essai pour béton durci, partie: Forme, dimensions et autres exigences relatives aux éprouvettes et aux moules.

[21] LCPC (2007) Recommandations pour la prévention des désordres dus à la réaction sulfatique interne. Journée technique du LCPC, Octobre 2007, Paris.

[22] Mouad, J., Frédéric, J., Céline, P. and Moulay, S. (2018) Caractérisation de l'expansion due à la réaction sulfatique interne à l'échelle de l'interphase pâte de ciment-granulat. 36èmes Rencontres Universitaires de Génie Civil de l'AUGC, Saint Etienne, France. hal01898237.

[23] Frigione, M. (2010) Recycling of PET Bottles as Fine Aggregate in Concrete. *Waste Management*, **30**, 1101-1106. https://doi.org/10.1016/j.wasman.2010.01.030

[24] Mounanga, P., Gbongbon, W., Poullain, P. and Turcry, P. (2008) Proportioning and Characterization of Lightweight Concrete Mixtures Made with Rigid Polyuethane Foam Wastes. *Cement and Concrete Composite*, **30**, 806-814. https://doi.org/10.1016/j.cemconcomp.2008.06.007

[25] Kou, S.C., Lee, G., Poon, C.S. and Lai, W.L. (2009) Properties of Lightweight Aggregate Concrete Prepared with PVC Granules Derived from Scraped PVC Pipes. *Waste Management*, **29**, 621-628. https://doi.org/10.1016/j.wasman.2008.06.014

[26] Dame, K. (2014) Etude du béton à l'échelle microscopique: Simulation numérique et tests de microindentation. Génie civil. INSA de Rennes. Français.

[27] Hannawi, K., Kamali, B.S. and Prince, W. (2010) Physical and Mechanical Properties of Mortars Containing PET and PC Waste Aggregates. *Waste Management*, **30**, 2312-2320. https://doi.org/10.1016/j.wasman.2010.03.028

[28] Safi, B., Sebki, G., Chahour, K. and Belaid, A. (2017) Recycling of Foundry Sand Wastes in Self-Compacting Mortars: Use as Fine Aggregates.

[29] Yvan, T. (2018) Evaluation de structures en béton armé atteintes de réaction sulfatique interne. Génie civil. Université Paul Sabatier—Toulouse III, Français. NNT: 2018TOU30271. tel-02366251.

[30] Al Shamaa, M. (2012) Étude du risque de développement d'une réaction sulfatique interne et de ses conséquences dans les bétons de structure des ouvrages nucléaires. PhD Thesis, Université Paris-Est, Paris.

Abbreviations

ISA: Internal Sulfate Attack

EN: European Norm

CEM: Portland Cement

NF: French Standard

NBN: Belgian Standard

CAMWATER: Cameroon Water Utilities Corporation

W/C: Water-Cement Ratio

HDPE: High Density Polyethylene

PVC: Polyvinyl Chloride