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IMPACT OF GLASS POWDER AND AGGREGATES ON CONCRETE

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Abstract

Concrete, the main building material, is constantly evolving. This development raises issues related to the acquisition of raw materials

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that enter into its production, including cement. The production of the latter is associated with environmental problems. In this same spirit, glass waste being solid and generally non-biodegradable (life 4000 years), and given their composition rich in silica, we lead to recover them by recycling them into concrete. This work therefore aims to evaluate the effects that can have the substitution (5%, 10% and 15%) of cement and natural aggregates, respectively, by glass powder and glass aggregates. For this reason, a masonry formulation was applied with a sand/binder ratio (S/B) equal to 1 for the preparation of concrete specimens in order to determine the mechanical and physical characteristics of the hardened specimens. The results showed that glass powder concrete (GPC) with respective substitution rates of 5%, 10% and 15% generally had superior characteristics to other recycled concretes glass aggregates concrete (GAC) and concrete containing powder and glass aggregates (CAGP). This would be due to the effect of the pozzolanic reaction of the glass powder. However, unlike glass aggregates concrete (GAC), the addition of glass powder in concrete aggregate and glass powder (CAGP) for substitution rates of 5% and 10% tended to improve these characteristics. Also, it was noted that glass powder in concrete aggregate and glass powder (CAGP) reduced the expansion of alkali-silica reaction (ASR) ("concrete cancer") to 5 and 10%. However, concretes made from recycled glass have superior properties to traditional concrete.

1. Introduction

Population growth and the average standard of living are driving a high demand for consumer goods. This creates an ever-increasing waste stream. The accumulation of this waste, particularly non-biodegradable industrial waste, which can last for thousands of years, is a potential source of major environmental and economic problems [1]. The incorporation of various industrial wastes (glass fibers, metal fibers, plastic wastes, rubber wastes, etc.) into concrete represents a major solution for recycling these wastes [2]. As glass is not biodegradable, landfill sites do not provide environmental solutions, so we need to find a use for this waste [3]. Today, glass waste is a major environmental problem [4]. Glass has many lives, and can be recycled to infinity [5]. This approach enables glass waste to be recycled, while helping to reduce the carbon footprint of concrete, which is mainly linked to cement production [1]. The diversity of concrete's applications and its intrinsic qualities mean that its demand is constantly growing. As with other industries, the universal need to conserve resources, protect the environment and use energy efficiently is felt in concrete technology. To improve the strength of concrete, researchers have successively developed new concretes such as high-performance concretes (HPC) [6], very-high-performance concrete (VHPC) [7] and reactive powder concrete (RPC) [8]. In this context of sustainable development and waste management, recycling glass in concrete is a solution being considered to reduce the environmental footprint of construction. Nevertheless, the use of glass powder and glass aggregates influences the mechanical properties of concrete, due to their different reactions, namely the pozzolanic reaction (beneficial) and the alkali-silica reaction (ASR). This approach is a part of a drive to protect the environment for sustainable development and improve concrete quality. This work is a part of the search for new applications for integrating glass waste into concrete. The general aim of this work is to recycle waste glass by incorporating it by substitution at different percentages and sizes into concrete, and to study its influence.

2. Materials and Methods

2.1. Raw materials

2.1.1. Natural aggregates

Figures 1 and 2 show the natural aggregates used in this study: granite crushed stone and lagoon sand. They were taken from a construction site at the Félix Houphouët-Boigny University in Cocody, Abidjan. The generally angular gravel (Figure 2) and sand (Figure 1) were sieved to obtain a granular class of 5/13 mm and 0/2 mm, respectively.

Figure 1. Sand.

Figure 2. Gravel.

2.1.2. Cement

The cement used is a class CPJ-CEM II compound portland cement with a normal 28-day strength of 42.5 MPa. It is produced locally.

2.1.3. Glass

Figure 3 shows the waste glass used in this study. The waste glass consists of bottles recovered from various sites (landfill, scrubland, etc.) in the city of Abidjan. The bottles came in various colors and thicknesses. They were washed, dried and then crushed with a hammer to obtain bottle shards. These shards were then introduced into a ball mill for 1 to 2 min 30 s, or 30 to 60 min, depending on whether granulates or glass powder were required.

Figure 3. Glass waste.

2.1.4. Mixing water

Mixing water is the quantity of water added to the concrete mix to hydrate the cement (hydraulic binder). The water used here comes from the Geomaterials laboratory tap, supplied by the Water Distribution Company of Ivory Coast distribution and regulated by standard NF EN 1008 [9]. Mixing water is essential for the manufacture of concrete, as it induces hydration and also the workability and correct placement of fresh concrete [10].

2.2. Characterization of raw materials

2.2.1. Granulometric analysis

In this study, the granulometric analysis was carried out in accordance with standards NF EN 933-1 [11] and NF P94-057 [12]. The test was carried out on the various aggregates (sand, gravel and glass aggregates). Grain size (granulometry) and dimensional distribution of granular fractions were determined using a sieve column with dimensions ranging from 0.08 mm to 31.5 mm. The percentages of cumulative refusal and sieved material were calculated using the following formula [11]:

$$\%\text{refusal of cumulative } = (Ri/Ms) * 100, \tag{1}$$

$$\%\text{passerby } = 100 - \left(\frac{Ri}{Ms} \times 100\right), \tag{2}$$

where *Ri* is the cumulative mass of rejects at each sieve and *Ms* is the mass of the dry sample. The cumulative percentages of rejects or sieves obtained are used in the form of a graph (granulometric curve).

For fine particles with dimensions less than 80 μm, the sedimentometry test was carried out. This test completes the granulometric analysis by sieving the aggregates. The relationship between grain diameter and sedimentation rate is given by the following Stock law [12]:

$$V = g \times (ɤs - ɤw)/18\eta \times D^2, \tag{3}$$

where

V is the particle settling velocity (m/s),

D is the particle diameter in cm,

ɤ*s* is the particle specific gravity in g/cm^3,

ɤ*w* is the liquid specific gravity in g/cm^3, and

g is the acceleration of gravity.

These particle size analyses yield parameters such as the coefficient of curvature (*Cc*) and the Hazen uniformity coefficient (*Cu*). These coefficients are calculated using the following formulas:

$$Cu = \frac{D_{60}}{D_{10}}, \tag{4}$$

$$Cc = \frac{(D_{30})^2}{D_{10} * D_{60}}, \tag{5}$$

where D_{60}, D_{30} and D_{10} are, respectively, the effective diameters of the particles which correspond to 60%, 30% and 10% of the passing.

If $1 < Cc < 3,$ then the material is said to be *well-graded*.

If $Cc < 1$ or $Cc > 3,$ then the material is said to be *poorly graded*.

2.2.2. Fineness modulus

The fineness modulus characterizes the fineness of concrete sands. It was determined according to standard NF EN 12620 [13]. It was obtained by dividing by 100 the sum of the percentages of rejection on 6 sieves (0.125 - 0.25 - 0.50 - 1 - 2 - 4 mm). The more or less fine character of the sand was determined by calculating its fineness modulus (fM). This modulus is determined from the following formula [13]:

$$fM = \frac{1}{100}\Sigma \text{ refusal of cumulative \% } (0.125 - 0.25 - 0.50 - 1 - 2 - 4). \quad (6)$$

According to the proposed spindle for the dimensional distribution of the sand grains, we have:

- $1.8 < fM < 2.2,$ the sand is mainly fine grains which give the concrete good workability to the detriment of resistance;
- $2.2 < fM < 2.8,$ the sand is mostly medium grains which constitute a preferential sand and gives the concrete better strength and good workability;
- $2.8 < fM < 3.3,$ the sand is mostly coarse grains which give the concrete strength, but less workability.

2.2.3. Sand equivalent

This test was used to measure the cleanliness of the sand. It is carried out according to the NF EN 933-8 standard [14], on the fraction of an aggregate passing through a 2 mm square mesh sieve. The sand equivalent is used to measure the cleanliness of the sand which is generally intended for concrete. It consists of suspending the fines (particles < 0.063 mm or 63 μm), then allowing them to settle at the bottom of a transparent tube. The sand equivalent (SE) is the ratio (height of sand to total height of flocculate) expressed as a percentage. It is determined by the following expression: [14]:

$$SE = \frac{h_2}{h_1} \times 100, \tag{7}$$

where h_1 is the height (sand + flocculate) in cm and h_2 is the height (sand) in cm.

2.2.4. Specific weights

The specific weights of the aggregates were determined by the pycnometer method according to standard NF EN 1097-6 [15].

The specific weight (*Ps*) is determined by the following expression [15]:

$$Ps = \frac{M4}{M4 - (M2 - M3)}, \tag{8}$$

where *M*2 is the mass of the pycnometer containing the sample of saturated aggregates, in grams; *M*3 is the mass of the pycnometer filled with water only, in grams and *M*4 is the mass of the test sample, in grams.

2.2.5. Bulk apparent density

The bulk densities of the aggregates were determined in accordance with standard NF EN 1097-3 [16]. It is determined by the following expression [16]:

$$Mvrac = \frac{M}{Ve}, \tag{9}$$

where *Mvrac* is the bulk density (g/cm^3), *M* is the mass of the material (*g*) and *Ve* is the volume of the test piece (cm^3).

2.2.6. Wear resistance test (Micro-Deval)

The Micro-Deval test consists of determining the wear resistance of aggregates under the effect of abrasion in a humid environment for sizes between 4 and 14 mm. This test was carried out on gravel in accordance with standard NF EN 1097-1 [17]. It consisted of measuring the quantity of elements smaller than 1.6 mm produced in the Deval machine by reciprocal friction and moderate impacts of the aggregates.

The *MDE* wear resistance is determined by the following expression [17]:

$$MDE = \frac{m}{M} \times 100, \tag{10}$$

where *MDE* is the Micro-Deval coefficient (%), *m* is the mass of the fraction of the material passing after the test through the 1.6 mm sieve (g), and *M* is the mass of the material subjected to the test (g). When the *MDE* wear resistance is: $\leq 10\%$: Very good to good, between 10% - 20%: Good to average, between 20% - 35%: Average to poor, > 35%: Poor.

2.2.7. Los Angeles trial

The Los Angeles test was used to measure the impact resistance of the gravels used in this study. It is based on the principle of abrasion crumbling of gravels. This test was carried out in accordance with standard NF EN 1097-2 [18]. The Los Angeles coefficient C_{LA} of the gravels subjected to the test is determined by the following expression [18]:

$$LA' = Mi - M1. \tag{11}$$

So, the Los Angeles coefficient is:

$$C_{LA} = \frac{LA'}{Mi} \times 100, \tag{12}$$

where LA' is the Los Angeles value; *Mi* is the initial mass of the sample; *M*1 is the final mass, and C_{LA} is the Los Angeles coefficient in %.

2.3. Formulation of hydraulic concrete specimens with the addition of 5%, 10% and 15% glass powder and aggregates

The purpose of formulation is to select the constituents of the concrete and to choose their proportion. For the formulation of concrete, the all-purpose or "mason" formulation was used, which gives the quantity that for 1 m^3 of concrete, it is necessary:

- 800 liters of gravel;
- 400 liters of sand.

The sand/gravel and binder/sand ratios are, respectively: S/G of 0.5 and B/S of 1. For the different proportions obtained, 4 series of concrete result, 3 of which series (substitution of the quantities of gravel and cement by glass aggregates and glass powder, respectively, at proportions of 5%, 10% and 15%) made it possible to understand the effects of glass powder and aggregates as a substitute in the concrete specimens. The formulations are given in Table 1 below:

- WC: witness concrete without powder and glass aggregate;
- GPC: concrete substituted at 5%, 10% and 15% of the mass of cement by glass powder;
- GAC: concrete substituted with 5%, 10% and 15% of the mass of gravel by glass aggregates;
- CAGP: concrete substituted with 5%, 10% and 15% of the mass of gravel and cement by glass granulate and glass powder, respectively.

Table 1. Concrete formulation

Concrete specimens	WC	GPC			GAC			CAGP		
Substitution	0%	5%	10%	15%	5%	10%	15%	5%	10%	15%
Gravel (kg)	24	24	24	24	22.8	21.6	20.4	22.8	21.6	20.4
Sand (kg)	12	12	12	12	12	12	12	12	12	12
Cement (kg)	12	11.4	10.8	10.2	12	12	12	11.4	10.8	10.2
Glass powder (kg)	0	0.6	1.2	1.8	0	0	0	0.6	1.2	1.8
Glass granulate (kg)	0	0	0	0	1.2	2.4	3.6	1.2	2.4	3.6

Plastic concretes were thus produced with an Abrams cone slump of between 5 cm and 9 cm. However, these quantities of water made it possible to appreciate the effects that glass powder or glass aggregate have on the consistency of our concrete paste.

2.4. Physical and mechanical characterizations of the prepared concrete specimens

The characterizations of the prepared concrete specimens consisted of determining their physical characteristics as well as their mechanical resistance in the hardened state. These characterization tests were carried out at different ages (14, 28 and 60 days) on the concrete specimens.

2.4.1. Physical characterization of concrete specimens

The physical properties were determined in accordance with the NF P18-459 standard [20]. This made it possible to determine the porosity and dry density of the concrete specimens at 14, 28 and 60 days of maturation. The measurements of porosity, dry density and water absorption were made by hydrostatic weighing defined, respectively, by the following formulas [20]:

$$\eta = \frac{M_{air} - M_{sec}}{M_{air} - M_{eau}} \times 100, \quad (13)$$

where η is the porosity of the test piece in percentage (%); M_{air} is the mass in air (g); M_{sec} is the dry mass of the sample (g) and M_{eau} is the mass in water (g). Also,

$$e = \frac{M_{sec}}{M_{air} - M_{eau}} \rho_{eau}, \quad (14)$$

where e is the dry density; M_{sec} is the dry mass (g); M_{air} is the mass in air (g); M_{eau} is the mass in water (g) and ρ_{eau} is the density of water.

2.4.2. Mechanical characterization of concrete specimens

2.4.2.1. Bending tensile test

The flexural tensile test was carried out on prismatic specimens $(7 \times 7 \times 28\,\text{cm}^3)$ according to standard NF P18-407 [21]. The test made it possible to determine the flexural strength (3 points) of the specimens subjected to a centered force exerted using a hydraulic press. The flexural strength was determined by the following formula [21]:

$$A = \frac{3 \times F \times L}{2 \times l \times e^2}, \tag{15}$$

where A is the bending strength in MPa; l is the thickness in mm; L is the length of the prism in mm; e is the height in mm and F is the maximum force causing the prismatic to break in Newton.

2.4.2.2. Compression test

The compression test was carried out on the concrete specimens according to the standard NF EN 12390-3 [22]. The compressive strength test was carried out by applying a load on the specimen until rupture using a hydraulic press. The compressive strength is given by the following formula [22]:

$$Rc = F/S, \tag{16}$$

where Rc is the compressive strength in MPa, F is the compressive force applied in N and S is the surface area of the test piece in mm^2.

3. Results and Discussion

3.1. Results of raw material characterization tests

3.1.1. Physical properties of aggregates

3.1.1.1. Granulometric analysis

Figures 4 and 5 show the curves resulting from the granulometric analysis of sand, gravel and glass aggregates, as well as glass powder. These granulometric curves made it possible to determine parameters such as the fineness modulus (fM), the curvature coefficient (Cc), the uniformity coefficient (Cu), the average diameter (D_{50}) and the granular class d/D (mm) of the different aggregates.

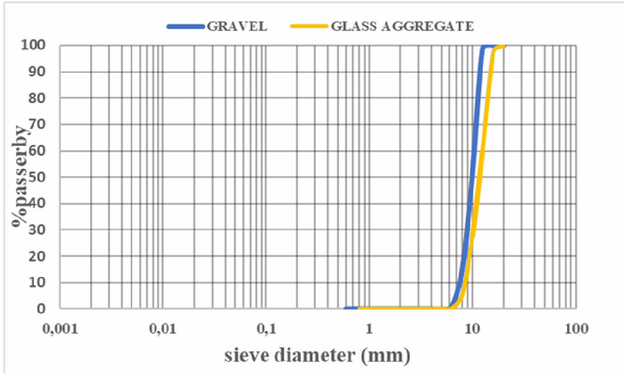

Figure 4. Granulometric curves of gravel and glass aggregates.

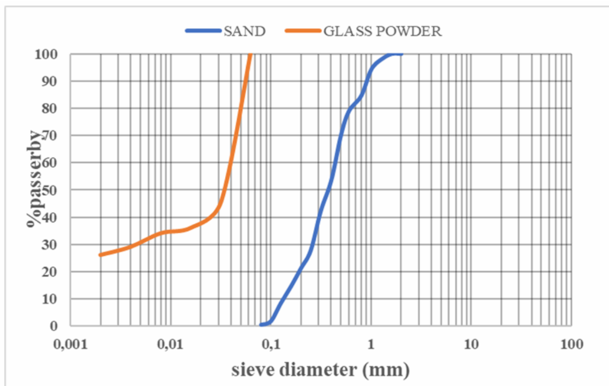

Figure 5. Granulometric curves of sand and glass powder.

Table 2 presents the results obtained following the granulometric analysis. The gravel and the glass granulate have respective granular class 7/13.5 mm and 8/16.2 mm, followed by a common average grain diameter of 10 mm. Their uniformity coefficients are, respectively, 1.58 and 1.56 which are less than 2 and their curvature coefficients are, respectively, 1.02 and 1 which are included in the interval [1; 3]. These results show that the gravel and the glass aggregate have a tight and well-graded granulometry.

As for the sand, it has a granular class of 0/1 mm, an average grain diameter of 0.315, a fineness modulus (fM) of 2.00 which is included in the interval [1.8; 2.2], a curvature coefficient of 1.25 which is included in the interval [1; 3] and a uniformity coefficient (Cu) of 3.2 which is greater than

2. It is deduced from these results that the sand is mainly fine with a spread and well-graduated granulometry. The glass powder has a granular class of 0/0.06 mm and an average grain diameter of 0.032. These characteristics are conducive to a good pozzolanic reaction. Indeed, for the glass powder to have pozzolanic activity, it must be finely ground so that the average powder diameter is less than 38 μm [23].

Table 2. Different physical parameters of granulometric analysis

Raw materials	Cu	Cc	fM	D_{50} (mm)	d/D (mm)
Gravel	1.58	1.02	-	10	7/13.5
Sand	3.2	1.25	2.21	0.315	0/1
Glass granulate (GG)	1.56	1	-	10	8/16.2
Glass powder (GP)	-	-	-	0.032	0/0.06

3.1.1.2. Other physical properties of aggregates

Table 3 presents the results obtained from the sand equivalent (SE), absolute and apparent density, Los Angeles (LA), and Micro-Deval (MDE) tests conducted on the aggregates used to make the concrete specimens.

The sand equivalent value being 97%, it can be said that the sand is clean. This sand is characterized by the almost total absence of fine clayey material. This may lead to a lack of plasticity in the concrete, which will need to be compensated for by increasing the water content (detrimental to cementitious materials) or cement. Also, the results for the absolute and apparent density of gravel and sand are 2.62 g/cm^3 and 1.68 g/cm^3 for gravel and 2.62 g/cm^3 and 1.51 g/cm^3 for sand. These results are consistent with conventional concrete aggregates according to [24] which set the apparent density values in the interval [1.4; 1.6] and the specific weight in the interval [2.5; 2.6]. The coefficient values of the Los Angeles (LA = 33.24%) and Micro-Deval (MDE = 6.3%) tests indicate that the gravel is of good quality. According to French standards [13], this type of gravel has acceptable wear resistance and average fragmentation resistance. Thus, this gravel can be used for making concrete, as it would have a high compactness.

Table 3. Other physical properties of aggregates

Raw materials	SE (%)	*Mvrac* (g/cm^3)	*Ps* (g/cm^3)	C_{LA} (%)	MDE (%)
Gravel	-	1.51	2.62	33.24	6.8
Sand	97	1.68	2.63	-	-
Glass granulate (GG)	-	-	-	-	-
Glass powder (GP)	-	-	-	-	-

3.2. Results of characterization tests on hardened concrete specimens

3.2.1. Physical properties

3.2.1.1. Porosity

Figure 6 shows the test result of the porosity of the specimens by percentage of substitution (5, 10 and 15%) and as a function of the curing days (14, 28, 60).

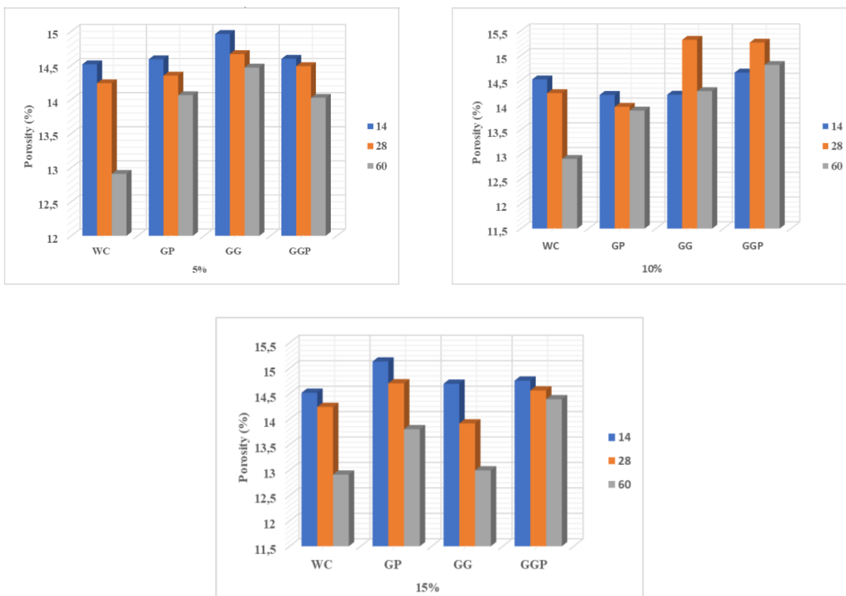

Figure 6. Porosity as a function of the substitution rate.

Witness concrete (WC) has a decreasing porosity depending on its maturity. The porosity of witness concrete at 60 days of age is lower than that of concretes which have undergone substitutions. This reduction in porosity is due to the crystallization of the cement which not only reduces the porosity, but also binds the particles together [26]. Glass powder concrete (GPC) also has a decreasing porosity depending on its maturity. This reduction in porosity may be due to the action of glass powder, which promotes better pozzolanic reactivity and fills pores and micropores due to its fineness. The reduction in porosity is therefore caused by the interaction of glass powder with portlandite involving the production of a gel of hydrated calcium silicate (H-C-S) which will fill more voids [27]. Glass aggregate concrete (GAC) and concrete aggregate and glass powder (CAGP), for their part, also present a decreasing porosity depending on their maturity. However, at 28 days and 60 days, an increase in porosity is observed for substitution rates of 10%. This increase in porosity is due to the poor distribution of 10% glass aggregates in the concrete, contributing to the proliferation of alkali-silica reaction (ASR) which will lead to an increase in porosity. However, the substitution rate of glass powder in the concrete aggregate and glass powder tends to improve its porosity. This result confirms that of [26] who, by substituting (10%, 20%, 35% and 45%) of cement with glass powder in the bottle shard tiles, notes the decrease in porosity compared to the glass shard tiles.

3.2.1.2. Density

Figure 7 shows the result of the dry densities of the test pieces by percentage of substitution (5, 10 and 15%) and as a function of the curing days (14, 28, 60).

The dry densities of concrete specimens increase with curing time. It is noted that witness concrete (WC) at 60 days has the highest dry density of 2.26. Since the dry density values of different concretes are in the range [2 and 2.6], the French standard [29] classifies them in the category of normal (conventional) concrete. The density of glass powder concrete is high, this is due in particular to the combined action of the hydration of the cement and the pozzolanic reaction of the glass powder containing a high quantity of silica. The dry densities of concrete specimens increase with curing time. It is noted that witness concrete (WC) at 60 days has the highest dry density of 2.26. Since the dry density values of different concretes are in the range [2 and 2.6], the French standard [29] classifies them in the category of normal (conventional) concrete. The density of glass powder concrete is high, this is due in particular to the combined action of the hydration of the cement and the pozzolanic reaction of the glass powder containing a high quantity of silica. However, the dry densities of concrete aggregate and glass powder (CAGP) specimens are the lowest regardless of the type of concrete. These results confirm those of [26] who noticed that the density of tiles with glass shards decreased over time when sand is substituted by glass powder in its composition.

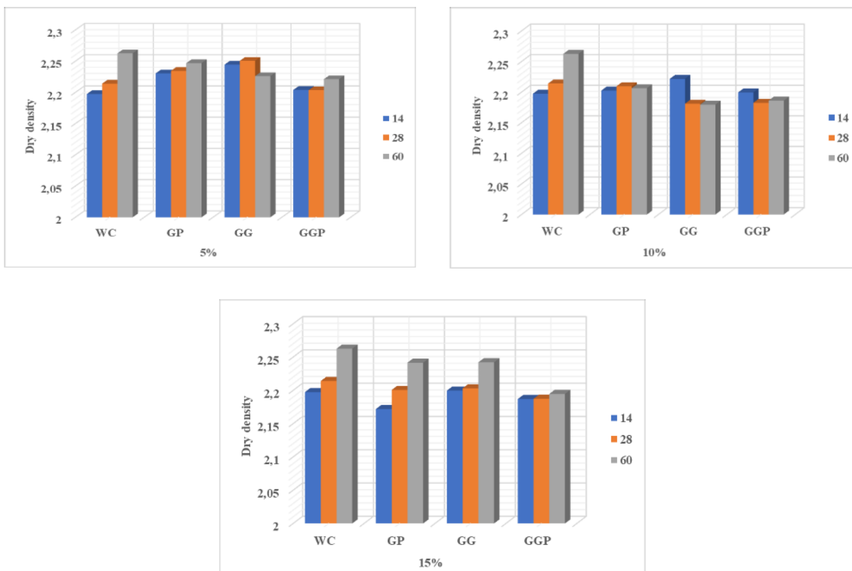

Figure 7. Dry densities as a function of the substitution rate.

3.2.2. Mechanical properties

3.2.2.1. Compressive strength

Figure 8 gives the result of the compressive strengths of the concrete specimens by percentage of substitution (5, 10 and 15%) and as a function of the curing days (14, 28, 60).

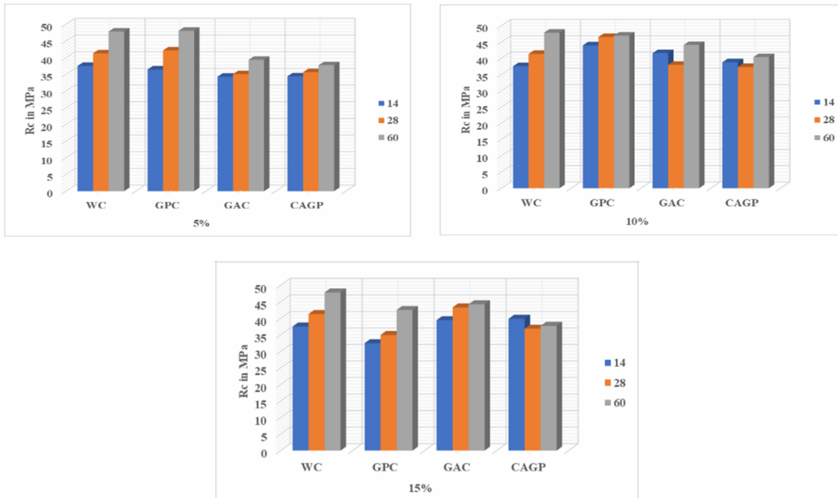

Figure 8. Compressive strengths as a function of the substitution rate.

Generally, an increase in resistance is observed depending on the curing period and regardless of the type of concrete. All resistances at 28 days being greater than 30 MPa, according to [31], are considered as conventional concrete any cubic concrete whose compressive resistances are greater than 30 MPa and can be used for foundation elements, load-bearing elements, etc.

The high compressive strengths of glass powder concrete (GPC) at 5% and 10% compared to witness concrete are due to the combined action of the hydration of the cement and the pozzolanic reaction provided by the glass powder which will form more hydrated calcium silicate (H-C-S) gel in addition to the previous hydration of the cement taking into account the curing time. Glass powder provides concrete with better compressive strength in the medium and long term [23]. The improvement in compressive strength is mainly related to the size of the glass particles (less than 1 mm) [26]. However, at 15%, since glass powder is high in the glass powder concrete (GPC), a decrease in strength is observed, since for this rate, it will take a longer time to reach a pozzolanic reaction. As for glass aggregate concrete (GAC) and concrete aggregate and glass powder (CAGP), the observed decrease in resistance would be due to the alkali-silica reaction (ASR) caused by the glass aggregates in contact with the cement matrix. This decrease is more marked at 28 days for 10% substitution which records a decrease in resistance compared to 14 days. However, it decreases less for concrete aggregate and glass powder (CAGP) due to the action of the pozzolanic reaction of the glass powder which tends to attenuate the expansion of the alkali-silica reaction (ASR). Glass aggregates cannot be used without taking into account their alkali-silica reaction (ASR) properties [28]. These results are consistent with the results of [32] which, using glass aggregates of size (3/8), observes a decrease in compressive strength depending on the replacement rate (10%, 20% and 30%).

3.2.2.2. Flexural tensile strength

Figure 9 shows the result of the flexural strengths of the concrete specimens by percentage of substitution (5, 10 and 15%) and as a function of the curing days (14, 28, 60).

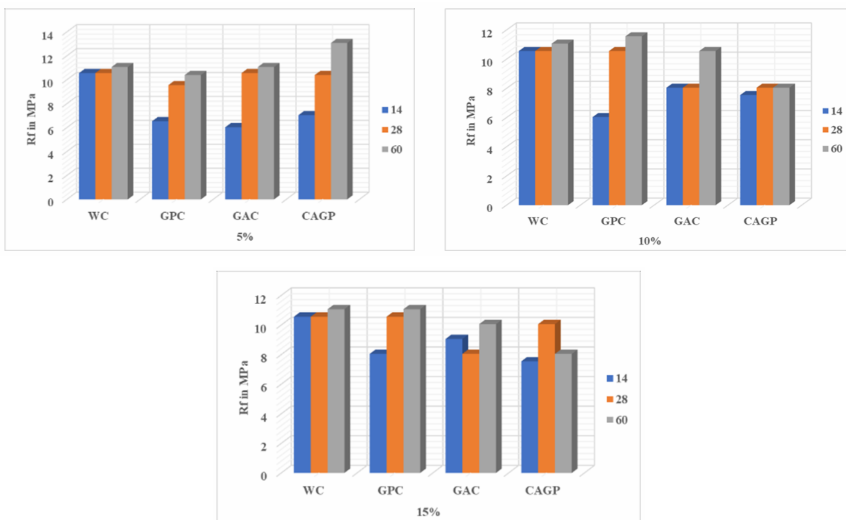

Figure 9. Bending strengths as a function of the substitution rate.

Looking at Figure 9 above, it appears that at 14 days, regardless of the percentage of substitution, witness concrete (WC) has the highest flexural strength which is 10.56 MPa. The flexural strengths at 14 days are marked by the hydration of the cement which contributes to the provision of the first strengths, which means that witness concrete (WC) records the highest strength value.

The flexural strengths at 28 days and 60 days of glass powder concrete (GPC) at 10% and 15% and concrete aggregate and glass powder (CAGP) from 5% to 15% being higher than those of the other concrete specimens would be due to the glass powder which would tend, through its reactivity with the cement, to play the role of joints between the aggregates and at the level of the paste to form a more compact structure when hardening. The glass powder offers the concrete in the medium and long term a good resistance to bending [23]. These results confirm those of [30] who noted that at young age, the resistance to bending of the control concrete was higher than all the percentages of substitution of the glass powder (5% to 25%). However, glass aggregate concrete (GAC) records the lowest flexural strengths compared to witness concrete (WC). This is explained by the alkali-silica reaction (ASR) of the glass aggregates which causes poor adhesion with the cement matrix and weakens the interface between the glass aggregates and the natural aggregates. This could create weak zones within the concrete. These results are consistent with the results of [32] which, using glass aggregates of size (3/8), observes a decrease in flexural strength depending on the replacement rate (10%, 20% and 30%).

4. Conclusion

This study investigated the impact of the combination of glass powder and aggregates on the mechanical and physical properties as a partial substitution of cement and natural aggregates. It can be noted, at the end of this study, that the impact of glass powder and aggregates on the physical and mechanical properties of concrete varies depending on the specific proportions of substitutions. It is shown that a 5% and 10% substitution rate of cement with glass powder produces a pozzolanic reaction contributing to the improvement of the concrete strength. Concerning glass aggregate concrete (GAC), the 5% and 10% substitution rates are marked by the proliferation of alkali-silica reaction (ASR) considered as the “cancer of concrete” which influences the properties of the concrete. However, the recommended substitution rate for glass aggregates is 15%, because it is the only rate which presents desired resistances higher than witness concrete

(WC) and other recycled concretes at medium age (14 and 28 days). For concrete aggregate and glass powder (CAGP), it was noted that the addition of glass powder allowed for the substitution rates of 5% and 10% to attenuate the expansion of the alkali-silica reaction (ASR). However, it can be said that the use of finely ground and crushed bottle glass in concrete allows to obtain desired resistances when used separately or jointly (reduction of the expansion of the alkali-silica reaction). All these concretes studied can be used in the field of public works according to the specific recommendations for each project.

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