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Research paper

Proposal for formulation of blocks to guarantee the sustainability of buildings in the Abidjan real estate park

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Abstract

A recurring fall of buildings in recent years (2013-2023) in the city of Abidjan has caused enormous material and human damage. This study was initiated in order to propose a formulation for the development of concrete blocks to guarantee the sustainability of buildings in the Abidjan real estate. The raw materials used are aggregates composed of sand, granite powder and a hydraulic binder (portland cement) then water for mixing. The aggregates were characterized before being used for the manufacture of the various FSB, FPS and FPG concrete blocks. The materials were subjected to physical and mechanical tests. The results showed that the sand and granite powder aggregates have a granular class of 0/1 and 0/2 respectively. Concerning concrete blocks, the density increases with the maturation time, namely 28 days maximum and when they are composed of both sand and granite powder (FPS). This significantly reduces the number of pores in the material. The compressive strength test showed that at 28 days of maturation, the FPS are more resistant than the FPG and FSB with respective values of 6.50 MPa; 5.31 MPa and 3.10 MPa. It appears that the addition of granite powder to the composition of the concrete blocks improves the density, porosity and compressive strength of the latter. The promotion of this formulation among concrete block manufacturers would make it possible to improve real estate construction, guarantee the durability of buildings in the Abidjan real estate park and thus avoid the possible fall of buildings.

Keywords: *Proposal; Formulation; Concrete Blocks; Sustainability; Buildings Abidjan.*

1. Introduction

Concrete block, commonly called brick, is an agglomeration, mostly made of 85% aggregates and cement then 15% water [1]. It is the most used construction material today in developed countries, but also developing countries. This construction material has been widely used since antiquity for its strength, its aesthetic qualities and its flexibility of use.

Its mechanical capabilities, particularly in compression, have been exploited largely from experience [2]. The manufacturing of this material is governed by standards and regulations in order to know and control its quality. In recent years, several homes have collapsed in the city of Abidjan, causing enormous material and human damage. The recurring fall of these buildings made it possible to initiate this study in order to identify the different causes. Thus, this study proposes formulations of concrete blocks to guarantee the durability of buildings in the Abidjan real estate stock.

2. Material and methods

2.1. Raw materials

In general, concrete blocks are made from "sand-cement" mortar. The sand constitutes the aggregate then the cement, the binder. As part of this study, part of the sand was replaced by granite powder. The different raw materials used for the manufacture of the concrete blocks offered are sand, granite powder, cement and water.

2.2. Study methods

The concrete blocks were developed following three formulations summarized in Table I. These are the formulation from sand (FSB), granite powder (FPG) and the sand-granite powder mixture (FPS).

Table 1: Formulation شnd Different Dosages of Raw Materials

Raw materials / Formulations	Sand	granite powder	Cement	Manufacturing equipment
Sand (FSB)	128 Kg	-	25,6 Kg de classe 42,5	manual mold
Sand + granite powder (FPS)	64 Kg	64 Kg	25,6 Kg de classe 42,5	manual mold
Granite powder (FPG)	-	128 Kg	25,6 Kg de classe 42,5	manual mold

The water dosage which translates into the water/cement ratio (W/C) is a determining parameter with respect to the porosity, strength and therefore durability of the concrete. This ratio is between 0.4 and 0.6. For each formulation, the W/C ratio is given. See the table below:

Table 2: Water/Cement Ratio of Different Formulations

Formulation	FSB	FPS	FPG
Water/cement ratio	0,35	0,42	0,58

The different concrete blocks produced are observed in Figure 1. From left to right, these are the formulation from sand (FSB), granite powder (FPG) and the sand-granite powder mixture (FPS).

Fig. 1: Different Made Concrete Blocks.

2.2.1. Characterization of raw materials

The tests carried out on the aggregates (sand and granite powder) are the particle size analysis and the sand equivalent.

2.2.1.1. Particle size analysis

Particle size analysis makes it possible to determine the particle size (size of grains) and the granularity (dimensional distribution of grains) of an aggregate or soil. This analysis was carried out by sieving according to standard EN 933-2 [3] with an electromechanical sieve column consisting of square meshes of 63 µm, 125 µm, 250 µm, 500 µm, 1 mm and 2 mm. The percentages obtained were reported in graphic form (particle size curve). The fineness modulus (Mf) was also determined according to the European standard EN 12620 [4]. It is equal to 1/100th of the sum of cumulative refusals expressed as percentages on mesh sieves: 0.125- 0.25- 0.5- 1- 2- 4 mm. The calculation is given by relation 1.

$$\mathrm{Mf} = \frac{1}{100}\sum \mathrm{Rc}(\%) \text{ sieves } \{0{,}125 - 0{,}25 - 0{,}5 - 1 - 2 - 4\} \quad (1)$$

Depending on the granularity of the sand, a good concrete sand must have a Fineness modulus between 2.2 and 2.8. According to DREUX and GORISSE [5], good concrete sand must have a fineness modulus of 2.5. The uniformity and curvature coefficients were also determined. They are given respectively by the following relations:

$$C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \quad (3)$$

Where Cu and Cc respectively represent the uniformity coefficient and the curvature coefficient, as for D10, D30 and D60, they respectively designate the diameters corresponding to 10%, 30% and 60% of cumulative passing.

2.2.1.2. Sand equivalent

The sand equivalent is a sand cleanliness test. It makes it possible to highlight the relative proportion of harmful fine particles or clay elements in the sands. The test was carried out according to standard NF EN 18-598 [6] using a sand equivalence measuring device. The values are obtained from the following relationship:

$$ES = 100\frac{h2}{h1} \quad (4)$$

h_1: height of sand + flocculate; h_2: height of sand

2.2.2. Characterization of concrete blocks

The concrete blocks were subject to physical and mechanical characterization. The physical characterization concerns the geometric characteristics, the density and the porosity accessible to air. For the mechanical test, this is the compressive strength.

2.2.2.1. Geometric characteristics

The dimensions (length, width and height) of the concrete blocks were measured manually using a rolling meter.

2.2.2.2. Apparent density and porosity accessible to water of the blocks

Apparent density is the mass of a body per unit of apparent volume of this body. It is expressed in g/cm^3; kg/m^3; T/m^3. As for the porosity accessible to water or open porosity [7], it is defined as the intermediate space from which fluid mass exchanges take place, it corresponds to the pores connected with the exterior.
Porosity and density are two important physical quantities of cementitious materials; they play a major role in the durability of concrete.
To determine the porosity accessible to water and the apparent density, water porosimetry is the method used. It makes it possible to estimate the overall porosity or open porosity. The instructions for use are those proposed by the AFPC – AFREM recommendations [7]. The principle of the method is based on measurements of the hydrostatic masses of the samples. Namely the mass of the sample immersed in water M_{eau}, the mass of the body weighed in air M_{air} and the mass of the dry sample (dried at 105°C) M_{sec}. The sample is previously saturated with water.
The apparent density ρ is given by the following equation:

$$\rho = \frac{Msec}{Mair - Meau} \quad (5)$$

The porosity accessible to water η is given by the equation below

$$\eta = \frac{Mair - Msec}{Mair - Meau} X100 \quad (6)$$

2.2.2. Compressive resistance

The test was carried out according to standard NF EN 772-1 [8] using a universal compression press equipped with a hydraulic pressure system. The loading unit is made up of a rigid frame supporting two plates. Loading is carried out by hydraulic pressure which moves the lower part upwards until the block breaks.
Resistance is determined according to the formula below. The unit of measurement is MPa.

$$Rb = \frac{Fb}{Sn} 100 \quad (7)$$

With, Rb (MPa): Crushing resistance; Fb (KN): Maximum breaking load; Sn (cm²): Net section of the block.

3. Results and discussion

3.1. Characterization of raw materials

3.1.1. Particle size analysis

Figure A and B. present the results of the particle size analysis of the sand and granite powder.

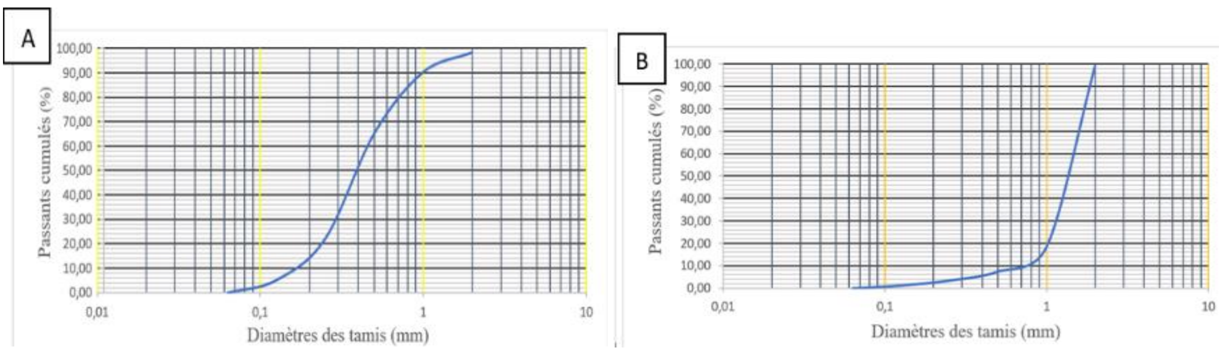

Fig. 2: Particle Size Analysis of Sand (A) and Granite Powder (B).

The analysis of graph A shows that the sand used is a sand of granular class 0/1 and fineness modulus 2.2. Its coefficients of uniformity (Cu) and curvature (Cc) are respectively equal to 2.5 and 1.03. According to the zone proposed for the grain size of the sand, this sand has a spread grain size and a well-distributed continuity. It is made up of 14% fine grains, 60% medium grains and 26% coarse grains. It is

therefore a preferred sand for making concrete blocks. Fine sand nevertheless requires an additional addition of cement and water due to its large specific surface area.
This specificity is not taken into account in the making of materials on construction sites. However, the increase in cement and water in cementitious materials promotes desiccation removal and increased porosity in the absence of appropriate curing provisions [9].
Figure B, corresponding to the results of the particle size analysis of the granite powder, gives a granular class equal to 0/2 and a fineness modulus of 3.4. Its uniformity (Cu) and curvature coefficients are respectively equal to 2 and 2.9. This aggregate has a well-distributed continuity consisting of 2.5% fine grains, 5.5% medium grains and 92% coarse grains. Its particle size is therefore tight.
The mixture of these two aggregates for the production of concrete blocks could be advantageous given that the granite powder is mainly composed of coarse grains and the sand of fine grains which will fill the void in the material.

3.1.2. Sand equivalent

The results of the sand equivalent test are recorded in Table 2.

Table 2: Sand Equivalent of Different Sands Used by Manufacturers

Raw materials	Sand	Granite powder
ES (%)	92	93,5

The results show that the sand and granite powder have a sand equivalent of 92 and 93.5% respectively. These aggregates are almost devoid of fine and clay particles, their values are greater than the interval [70%; 85%] recommended by [5] for clean sands. This is confirmed by [10], who says that sands should not contain harmful elements. So these aggregates could be advantageous for good strength of the concrete block and disadvantageous for workability. [11] mentioned that fine elements can settle on the surface of the grains and prevent good adhesion between the binder and the aggregates.

3.2. Physical characterization of concrete blocks

3.2.1. Geometric characteristics

The concrete blocks have a length of 40 cm, a width of 15.1 cm and a height of 20 cm. These results comply with the geometric specification according to the European standard NF EN 771-3 [12] and its French national supplement NF EN 771-3/CN [13]. These results are valid for both the controls and the blocks containing the granite powder. Granite powder therefore has no influence on the geometric characteristics.

3.2.2. Apparent density and porosity accessible to water of the blocks

The different results obtained from the characterization tests at 10, 14 and 28 days of maturation on the apparent density and porosity of the concrete blocks are presented in Figure 3.

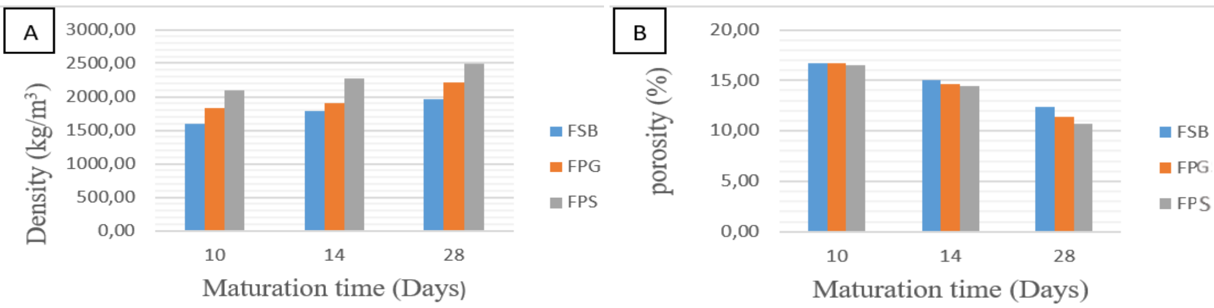

Fig. 3: A) Apparent Density of Concrete Blocks and B) Porosity Accessible to Water.

Figure 3.A shows that the bulk density of the concrete blocks increases with maturation time for all samples. Also, the density of concrete blocks made with the sand-granite powder mixture (FPS) is higher than that of concrete blocks made with granite powder (FPG) and sand (FSB). At 10 days of maturation, the data are respectively 2090; 1825 and 1599 kg/m^3. On the 14th day of maturation, the data is 2275; 1905 and 1790 kg/m^3 then 2491.43; 2220 and 1965.56 kg/m^3 on the 28th day.
The results show that the granite powder and sand mixture is very advantageous for making concrete blocks. Indeed, dry uncompacted sand has a density equal to 1600 kg/m^3 and that of granite is between 2643 and 2755 kg/m^3. Also, the fine particles of the sand fill the void left by the coarse elements of the granite powder. This allows the material to be further densified. This is not the case for concrete blocks made with granite powder. Although the density of granite is between 2643 and 2755 kg/m^3, they have a lower density than that of FPS concrete blocks.
This result can be explained by the high presence of pores in the material as observed in Figure 3.B. The porosity of the concrete blocks decreases with the maturation time but also as a function of their composition. FPS concrete blocks are less porous than FPG, which in turn is less porous than FSB. The values are respectively 16.51; 16.74 and 16.73% at 10 days of maturation. At 14 days, they are respectively 14.47 %; 14.61% and 14.98% and at 28 days, 10.67; 11.39 and 12.38%. According to [14] and [15] high compaction pressure leads to a reduction in porosity. The reduction in porosity in turn leads to densification and therefore an increase in density.
Granite powder mixed with sand therefore has a positive influence on the density and porosity of concrete blocks generally made only with sand or granite powder. The density of the concrete blocks produced falls within the range 1800 to 2100 kg/m^3 which corresponds to the density of good concrete according to [16] CERIB.

3.2.3. Compressive strength

The results of the compressive strength test are shown in Figure 4

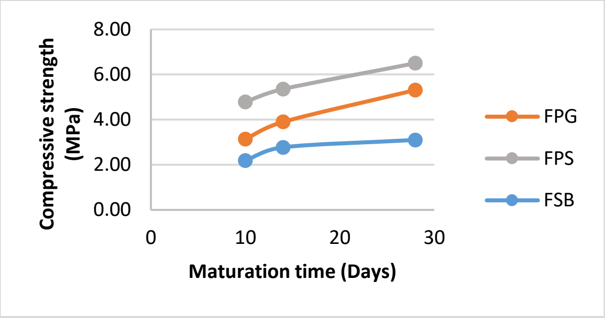

Fig. 4: Compressive Resistance of Concrete Blocks.

The results show that the compressive strength of the different concrete blocks increases with the maturation time but also depending on the materials produced. Concrete blocks made with sand and granite powder (FPS) are stronger than those made with granite powder (FPG), which in turn are stronger than blocks made with sand (FSB). At 10 days of maturation, the results are respectively 4.78; 3.14 and 2.18 MPa. At 14 days, the compressive strength is respectively equal to 5.36; 3.90 and 2.78 MPa then 6.50; 5.31 and 3.10 MPa on the 28th day.
Indeed, the compressive strength is characterized by the rupture of the material. In the case of FSB concrete blocks, these are composed of fine grains. This leads to rapid and immediate rupture of the material without encountering any obstacle. In the case of FPGs composed of coarse grains, the rupture is slow and we observe a deviation of this rupture by the coarse grains. Finally, for FPS concrete blocks, where there is a combination of fine and coarse grains, rupture is even slower. Figure 5 perfectly illustrates this explanation.

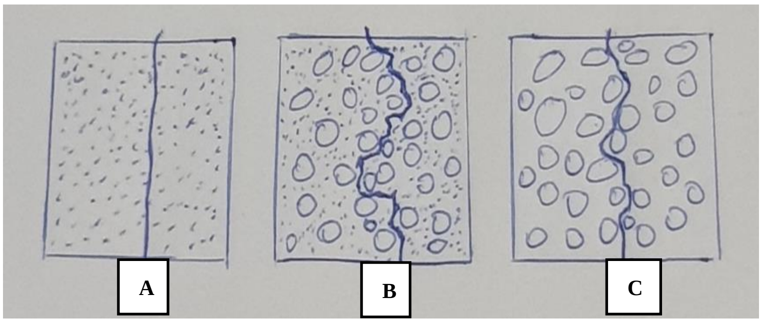

Fig. 5: Internal Behavior of the Different Concrete Blocks in Relation to Mechanical Resistance, FSB(A); FPS(B); GIF (C).

At 28 days, designated as the maximum maturation time for concrete, the compressive strength values of the FPS and FPG concrete blocks obtained are greater than the minimum values (4 MPa) mentioned by the standards NF EN 771-3 [12] and NF EN 771- 3/CN [13] which corresponds to the minimum compressive strength of a quality hollow concrete block. In fact, concrete is made up of a granular skeleton and an adjuvant suspended in water. The skeleton is itself composed of a set of solid grains of different sizes, from microns (for cement fines or mineral additions) to ten millimeters (for gravel). This large extent of the granular class allows for a compact and resistant granular skeleton [17], [18].

4. Conclusion

At the end of this study, it appears that the addition of granite powder to the composition of the concrete blocks improves the density, porosity and compressive strength of the latter. The promotion of this formulation among concrete block manufacturers would make it possible to improve real estate construction, guarantee the durability of buildings in the Abidjan real estate portfolio and thus avoid the possible fall of buildings

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