

# Granular Mixture Improving the Properties of Abidjan Alluvial Sands

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## Abstract

This study is part of the search for solutions to disasters linked to the non-conformity of construction materials. It aims to propose quality granular mixtures aimed at improving the properties of Abidjan's alluvial sands. The raw materials used are sands from the Koumassi, Bingerville and Yopougon lagoons and granite powder. The raw materials were subjected to several characterization tests (granulometric analysis, sand equivalent, bulk density, absolute density), mixtures were formulated by partially substituting alluvial sands at 30%, 50%, and 80% with granite powder, and they were subjected to the same characterization tests as the raw materials. The granulometric analysis revealed that all the alluvial sands were of granular class 0/1 and the granite powder of granular class 0/4. The sands of Bingerville and Yopougon were spread and well graded while that of Koumassi was spread but poorly graded. The compactness of the Koumassi mixtures increased from 62% to 65%, that of Bingerville also increased from 58% to 62% and that of Yopougon slightly increased from 64% to 65%. This increase in compactness was followed by a correction of the particle size class from 0/1 to 0/4 for the mixtures. The results obtained indicate that a 50% substitution provides an optimal balance of properties, thus enhancing the potential of these local materials for construction.

## Keywords

Alluvial Sands, Granite Powder, Granular Mixture, Granular Class

## 1. Introduction

The construction sector represents a powerful lever for development policies that have a strong impact on the environment [1]. Concrete is one of the most widely

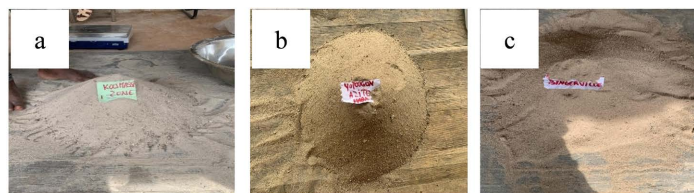
used construction materials on the planet, whether in construction or public works [2]. It is composed of a mixture, in well-defined proportions, of aggregates (sand and gravel), hydraulic binder (most often cement), water and possibly an additive. Sand is an essential element in the composition of concrete and mortar. Its use ensures the necessary granular continuity between the cement and the gravel for good cohesion of the concrete [3]. It constitutes approximately 30% to 40% as the main component of the entire mass of concrete [4]. The use of sand has increased in recent years following the progress made in the construction and public works sector [5]. The increase in demand for construction sand in the district of Abidjan over the years has made the grain size of these sands finer. The fineness of the sand grains in Abidjan today leads to a decrease in the strength of construction products, and this decrease in strength reduces the performance of materials and the lifespan of structures. The exploitation of alluvial sand as an aggregate in concrete for centuries has contributed to the depletion of good quality river sand, thus this observation has led to the search for a suitable alternative. One of the most used alternatives is crushing sand which is a by-product of the coarse aggregate manufacturing process [6]. However, granite powder is rarely used due to the high fines content it contains [5]. In an effort to optimize the alluvial sands of Abidjan, a partial substitution with granite powder will be carried out in order to confer useful properties to the mixtures. This study focuses on the valorization of granite powder in the district of Abidjan, with the aim of reducing pressure on natural resources and responding to environmental issues. The objective of this study is to propose a granular mixture consisting of alluvial sand and granite powder, in order to improve the granulometric and physical properties of alluvial sands in Abidjan.

## 2. Materials and Methods

### 2.1. Raw Materials

#### 2.1.1. Alluvial Sands

The sands used for this study come from three (3) quarries in Abidjan. These are the quarries of Koumassi, Yopougon Azito and Bingerville. They are designated by the abbreviations KS, YS and BS respectively Koumassi sand, Yopougon sand and Bingerville sand. These sands are extracted from the lagoon by dredging and are generally used in the construction of current buildings in the district of Abidjan [7]. The sands were dried and sieved to remove impurities (Figure 1).



a) Koumassi sand      b) Yopougon sand      c) Bingerville sand

**Figure 1.** Alluvial sands of Abidjan.

### 2.1.2. Granite Powder

The powder used is granite powder extracted from the granite quarry (bee quarry). It is a waste product from the crushing or grinding of granite blocks (**Figure 2**).



**Figure 2.** Granite powder.

## 2.2. Characterization of Raw Materials

### 2.2.1. Granulometric Analysis

In this study, the granulometric analysis was carried out according to the NF EN 933-1 standards [8]. The test was carried out on the different aggregates (sand and granite powder). It made it possible to determine the grain size (granulometry) and the dimensional distribution of the granular fractions using a series of square mesh sieves of the following dimensions (in mm): 0.08; 0.16; 0.315; 0.63; 1.25; 2.5; 4; 5; 6.5; 8; 10. The sieves are mounted on an electromechanical sieve. The cumulative and sieved residue percentages were calculated using the following formula [8]:

$$\% \text{refusal of cumulative} = (R_i/M_s) * 100 \quad (1)$$

$$\% \text{passerby} = 100 - \left( \frac{R_i}{M_s} \times 100 \right) \quad (2)$$

with,  $R_i$ , the cumulative mass of rejects at each sieve and  $M_s$  the mass of the dry sample. The cumulative percentages of rejects or sieves obtained are used in the form of a graph (granulometric curve).

From these granulometric analyses, parameters such as: the HAZEN uniformity coefficient ( $C_u$ ) and the curvature coefficient ( $C_c$ ) are derived. These coefficients are calculated using the following formulas:

$$C_u = \frac{D_{60}}{D_{10}} \quad (3)$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} \quad (4)$$

with  $D_{60}$ ,  $D_{30}$ , and  $D_{10}$ , respectively, the effective particle diameters corresponding to 60%, 30%, and 10% of the passing particle.

If:  $1 < C_c < 3$ , the material is said to be well-graded.

If:  $C_c < 1$  or  $C_c > 3$ , the material is said to be poorly graded.

### 2.2.2. Fineness Modulus

The fineness modulus of alluvial sand and granite powder was determined accord-

ing to standard NF EN 12620 [9]. 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). It is given by the following formula [9]:

$$Mf = \frac{1}{100} \sum \text{refusal of cumulative (0.125 - 0.25 - 0.50 - 1 - 2 - 4)} \quad (5)$$

Depending on the fineness modulus obtained, we have:

1.8 < Mf < 2.2, the sand is mostly fine grains which gives the concrete good workability and poor resistance;

2.2 < Mf < 2.8, the sand is mostly medium grained, which makes it a preferred sand and gives the concrete better workability and good strength. This is the sand recommended for making concrete;

2.8 < Mf < 3.3, the sand is mostly coarse grains which gives the concrete poor workability and good strength.

### 2.2.3. Sand Equivalent

This test was used to measure the cleanliness of sand and granite powder. It is carried out according to standard NF EN 933-8 + A1 [10], on the fraction of an aggregate passing through a 2 mm square mesh sieve. It indicates the content of fine elements, mainly of clayey, vegetable or organic origin on the surface of the grains. 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 [10]:

$$SE = \frac{h_2}{h_1} \times 100 \quad (6)$$

with,  $h_1$ : height (sand + flocculate) in cm and  $h_2$ : height (sand) in cm.

### 2.2.4. Specific Weights or Absolute Density

The specific weights of the aggregates were determined by the pycnometer method according to standard NF EN 1097-6 [11]. This method is used to measure the actual density of the aggregates. The specific weight  $\gamma_s$  is determined by the following expression [7]:

$$\gamma_s = \frac{M2 - M1}{(M4 - M1) - (M3 - M2)} \quad (7)$$

with,  $M1$ : mass of the empty pycnometer,  $M2$ : mass of the pycnometer + material,  $M3$ : mass of the pycnometer + water,  $M4$ : mass of the pycnometer + water + material.

### 2.2.5. Apparent Density

The bulk densities of the aggregates were determined in accordance with standard NF EN 1097-3 [12]. The apparent density  $M_{vapp}$  is determined by the following expression [8]:

$$M_{vapp} = \frac{M}{V_e} \quad (8)$$

with,  $M_{vapp}$  the apparent density ( $\text{g}/\text{cm}^3$ ),  $M$  the mass of the material (g) and  $V_e$  the volume of the test piece ( $\text{cm}^3$ ).

### 2.2.6. Intergranular Porosity

Intergranular porosity is the space or void that exists between sand grains. It was determined using the formula (9):

$$P_{\text{inter}} = \frac{\rho_r - \rho_a}{\rho_r} \times 100 \quad (9)$$

with,  $\rho_a$ : apparent density,  $\rho_r$ : absolute density.

### 2.2.7. Compacity

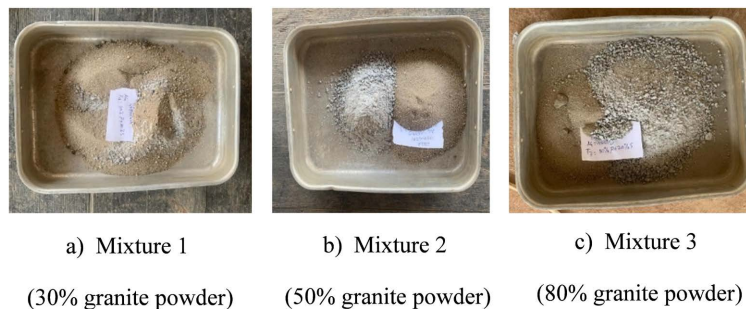
The compactness of a material is the proportion of its volume actually occupied by the solid matter that constitutes it. It is the ratio between the apparent density and the absolute density of the material, given by the ratio (10):

$$C = M_{vapp} / M_{abs} \quad (10)$$

with,  $M_{vapp}$ : apparent density,  $M_{abs}$ : absolute density.

## 2.3. Formulation of Mixtures

The formulation aims to define the proportion of the constituents of the mixture. Granular mixtures were made with alluvial sands and granite powder. The proportions of granite powder in each alluvial sand were varied (Figure 3).



**Figure 3.** Granular mixtures of alluvial sand and granite powder.

The proportion of each constituent of the mixtures is presented in Table 1 below:

**Table 1.** Formulations of granular mixtures.

Mixture	% Sand	% Granite powder
Witness	100	0
Mixture 1	70	30
Mixture 2	50	50
Mixture 3	20	80

## 2.4. Physical Characterization of Granular Mixtures

The formulated granular mixtures were subjected to characterization tests. These tests are the same as those used for the characterization of the raw materials. These tests are particle size analysis, fineness modulus, sand equivalent, absolute density, apparent density, intergranular porosity and compactness.

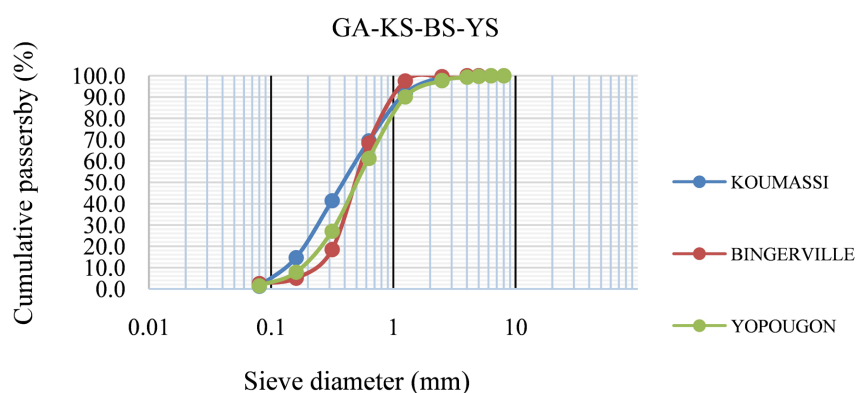
## 3. Results and Discussion

### 3.1. Results of Raw Material Characterization Tests

#### 3.1.1. Granulometric Analysis

##### 1) Alluvial sand

**Figure 4** shows the granulometric curves of the alluvial sands. These curves made it possible to determine the granulometric characteristics of the different sands.



**Figure 4.** Granulometric curves of alluvial sands.

The results of the granulometric analysis by sieving of the alluvial sands of Koumassi, Bingerville and Yopougon made it possible to determine the granulometric characteristics of the sands. **Table 2** shows the granulometric characteristics of the sands such as the granular class, the Hazen uniformity coefficient ( $C_u$ ), the curvature coefficient ( $C_c$ ) and the fineness modulus ( $M_f$ ).

**Table 2.** Characteristics of alluvial sands.

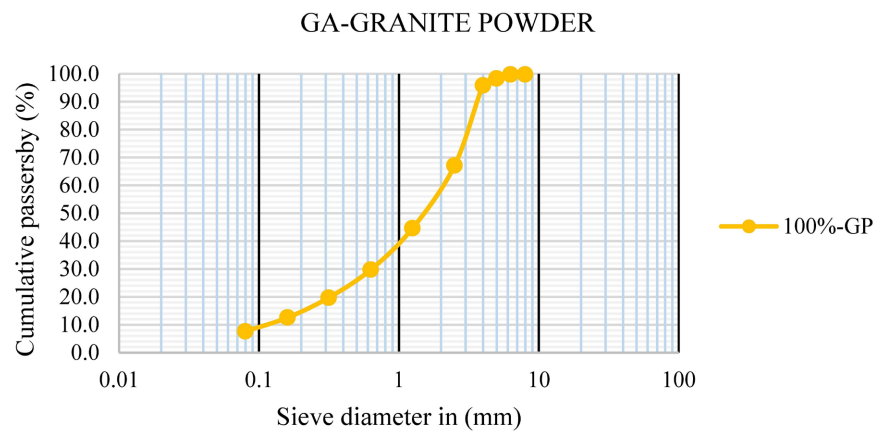
Sands	Granular class	$C_u$	$C_c$	$M_f$
KS	0/1	3.5	0.9	1.85
BS	0/1	2.95	1.1	2.1
YS	0/1	3.4	1.03	2.2

**Table 2** shows  $C_u$  values greater than 2 for the three sands and  $C_c$  values between 1 and 3 for Bingerville (BS) and Yopougon Azito (YS) sands. According to the literature, sand has a spread and well-graded grain size if its  $C_u > 2$  and its  $C_c$  is between 1 and 3. Koumassi (KS) sand, although spread, is poorly graded because its  $C_c$  is less than 1. The poor graduation of Koumassi sand indicates that one

grain fraction predominates. This type of sand can influence the quality of the manufactured materials [7]. The table also indicates that (KS), (BS) and (YS) have a fineness modulus between 1.8 and 2.2. Depending on the grain size range, these sands are fine. These fine sands give the concrete good workability, but poor strength. [13].

## 2) Granite powder

**Figure 5** shows the results of the granulometric analysis carried out on the granite powder. This curve made it possible to determine the granulometric characteristics of the granite powder used.



**Figure 5.** Granite powder particle size distribution curve.

**Table 3** shows the granulometric characteristics of granite powder such as granular class, Hazen uniformity coefficient ( $C_u$ ), curvature coefficient ( $C_c$ ) and fineness modulus ( $M_f$ ).

**Table 3.** Characteristics of granite powder.

	Granular class	$C_u$	$C_c$	$M_f$
Granite powder	0/4	20	1.8	3.3

Granite powder has a granular class 0/4. It is spread and well graduated, because its  $C_u > 2$  and its  $1 < C_c < 3$ ; its fineness modulus 3.3 shows that it is a granite powder which has enough coarse elements. This powder will give poor workability to the concrete, which can lead to segregation of the aggregates during its installation. However, the workability of concrete formulated from crushed aggregates is often less good because of the crushing process which induces aggregates of random, irregular shape and creates preferential fracture planes according to [14] [15].

### 3.1.2. Other Physical Properties of Raw Materials

#### 1) Alluvial sand

**Table 4** shows from the point of view of their cleanliness that the two alluvial

sands (KS and YS) are very clean, because their  $SE > 80$ . These two (2) sands can cause plasticity defects making the placement of concrete difficult [16]. As for Bingerville sand (BS), it can also be considered clean because according to [17], it is perfectly suitable for making concrete and is within the recommended range [70; 85]. The values of density (apparent and real) obtained indicate that they are common aggregates. Indeed, for [18], the apparent density varies between  $1.4 \text{ g/cm}^3$  and  $1.6 \text{ g/cm}^3$  and the real density is between  $2.5 \text{ g/cm}^3$  and  $2.6 \text{ g/cm}^3$ . Regarding the intergranular voids, the three sands are the interval [25; 50] recommended by [19]. However, the intergranular porosity studied is not negligible, however the voids must be completely filled by the cement paste to obtain a quality concrete or mortar. It is in the same vein that [2] states that the index of the granular mixture is an important parameter in the formulation of concrete, because it influences several of its properties including in particular its compactness, workability and its mechanical properties, it is therefore necessary to pay particular attention to the characteristics, because a mixture with a high void index will give a less economical and less workable concrete.

**Table 4.** Other physical properties of alluvial sands.

Sands	SE (%)	$\rho_r \text{ (g/cm}^3\text{)}$	$\rho_a \text{ (g/cm}^3\text{)}$	P inter (%)
KS	83.17	2.6	1.6	38.46
BS	73.70	2.6	1.5	43
YS	80.46	2.5	1.6	36

## 2) Granite powder

**Table 5** below indicates that it is a slightly clayey granite powder, provided with fine and clayey particles, because its sand equivalent is included in the interval [60%; 70%]. This powder can be used for making concrete according to [16]. According to [20], certain impurities present in the aggregates are likely to disturb the hydration of the cement and cause poor adhesion between the aggregates and the paste, which can lead to a reduction in strength, but it can also disturb the durability of the materials. The values of the apparent and real density of the powder show that it is a common aggregate and its intergranular porosity is included in the recommended interval [25; 50].

**Table 5.** Other physical properties of granite powder.

Granite powder	SE (%)	$\rho_r \text{ (g/cm}^3\text{)}$	$\rho_a \text{ (g/cm}^3\text{)}$	P inter
	66.5	2.6	1.5	42.30

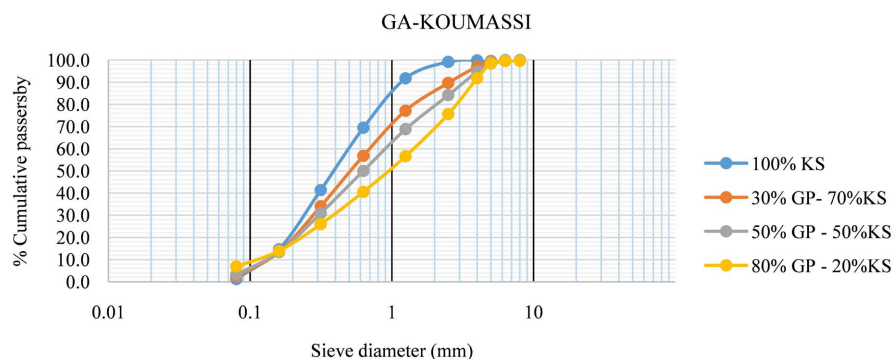
## 3.2. Results of Characterization Tests on Granular Mixtures

For each alluvial sand (KS, BS, YS), we made a partial substitution with granite powder at different percentages (30%, 50% and 80%) in order to obtain a granular mixture.

### 3.2.1. Granulometric Analysis

#### 1) Koumassi mixture

The mixtures were designated (KS1, KS2, and KS3) for Koumassi. **Figure 6** shows the particle size curves of the different granular mixtures of Koumassi.



**Figure 6.** Granulometric curves of the different granular mixtures of Koumassi.

The results of the sieving granulometric analysis of the Koumassi mixtures made it possible to determine the grain sizes of the mixtures. Observing the different curves, it can be seen that the percentages of coarse sand in the different mixtures increase as the proportion of granite powder increases. **Table 6** presents the granulometric characteristics of the Koumassi mixtures.

**Table 6.** Characteristics of Koumassi granular mixtures.

Sands	Granular class	Cu	Cc
KS	0/1	3.8	0.9
KS1	0/4	5	0.8
KS2	0/4	6.9	0.76
KS3	0/4	13.5	0.9

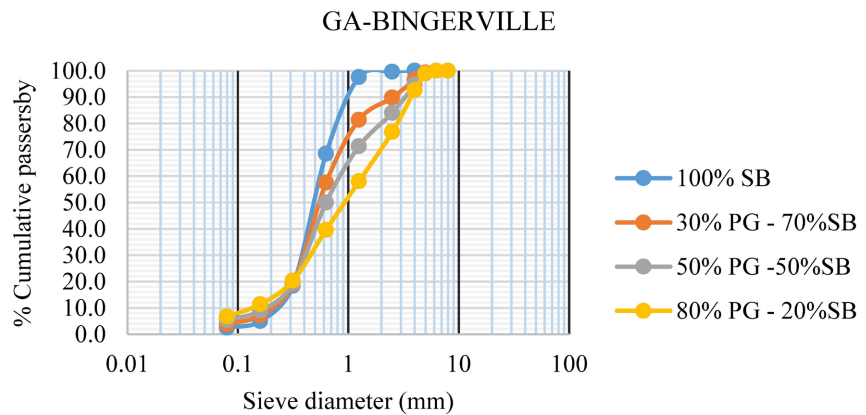
The analysis of the curves of the Koumassi (KS) mixtures shows that they are of granular class 0/4, whatever the percentage of substitution of alluvial sand by granite powder at (30%, 50% and 80%). These mixtures are poorly graduated, because their  $C_c < 1$ . But they have a spread granulometry because  $C_u > 2$ . These mixtures are poorly graduated because they are made up of a few fine grains, enough medium grains and coarse grains.

#### 2) Bingerville mixture

The mixtures were designated (BS1, BS2, and BS3) for Bingerville. The curves of the different mixtures are shown in **Figure 7** below.

The results of the sieving granulometric analysis of the Bingerville mixtures made it possible to determine the grain sizes of the mixtures. Looking at the different curves, it can be seen that the percentages of coarse sand in the different mixtures increase as the proportion of granite powder increases. **Table 7** presents

the granulometric characteristics of the Bingerville mixtures.



**Figure 7.** Particle size distribution curves of Bingerville mixtures.

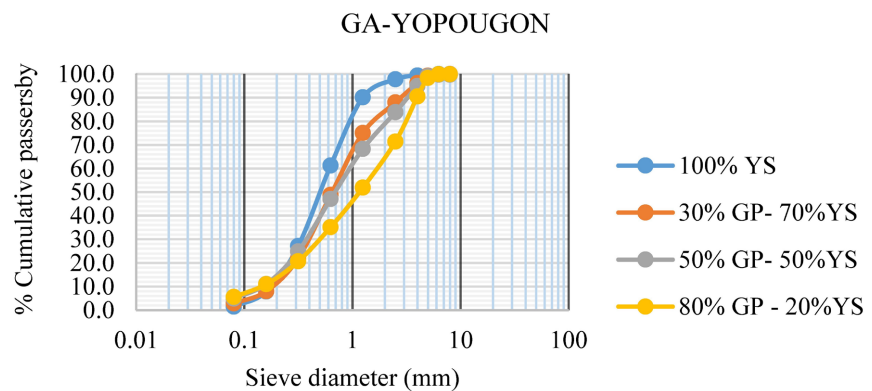
**Table 7.** Characteristics of Bingerville granular mixtures.

Sands	Granular class	Cu	Cc
BS	0/1	2.2	1.03
BS1	0/4	3.4	1.1
BS2	0/4	4.8	1.1
BS3	0/4	9.3	1

The curves of the analyzed Bingerville (BS) mixtures show that all the sands now belong to the 0/4 granular class; they are well graduated, because their Cc is between 1 and 3, and their granulometry is spread. The Bingerville mixtures have a good granulometric distribution, the fine grains, the medium grains and the coarse grains that constitute them are in adequate proportion.

### 3) Yopougon mixture

The mixtures were designated (YS1, YS2, and YS3) for Yopougon Azito. The curves of the different mixtures are shown in **Figure 8** below.



**Figure 8.** Particle size curves of Yopougon mixtures.

The results of the sieving granulometric analysis of the Yopougon Azito mixtures made it possible to determine the grain sizes of the mixtures. The percentages of coarse sands in the different mixtures increase as the proportion of granite powder increases. **Table 8** presents the characteristics of the Yopougon mixtures.

**Table 8.** Characteristics of Yopougon mixtures.

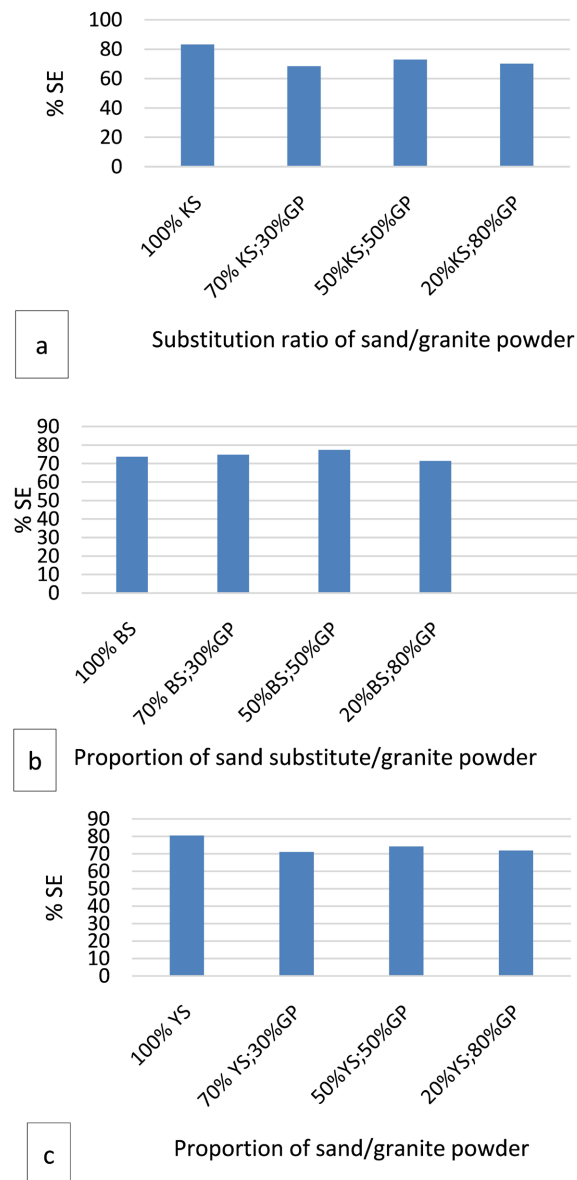
Sands	Granular class	Cu	Cc
YS	0/1	3.3	1.03
YS1	0/4	4.4	1
YS2	0/4	6.3	1
YS3	0/4	12	0.9

The analysis of the curves of (YS1, YS2 and YS3) shows that the sands are of class 0/4 mm, the mixtures are well graduated for the substitutions of sand by granite powder of 30% and 50% with a spread grain size. The mixtures have a good grain size distribution, and the high percentage of fine grains has been reduced. However, for a substitution of 80% of granite powder in the mixture, it is observed that the sand is poorly graded. This is due to the dominance of a particular fraction. This analysis reveals that substituting up to 50% of Yopougon sand with granite powder gives an optimal mix of particle size, unlike a substitution rate of 80%.

### 3.2.2. Influence of Granite Powder on the Cleanliness of Alluvial Sands

**Figure 9** below shows the evolution of the cleanliness of the alluvial sand of the communes of Koumassi (a), Bingerville (b) and Yopougon (c) with the addition of granite powder.

Through **Figure 9**, it appears that the addition of granite powder to the alluvial sand of Koumassi brings the cleanliness of the mixture into the interval [68%; 73%]. According to [21], this interval places our mixture in the category of sands that could be used for making concrete. The cleanliness of the sand was reduced because of the fine rate provided by the granite powder. The observation of the Bingerville graphs allows us to notice that the values of the sand equivalents of the mixtures of 30% and 50% of granite powder have improved the cleanliness criterion of the Bingerville sand and at 80% of granite powder, we see that the cleanliness of the sand decreases, but still remains a clean sand perfectly suited to the making of quality concrete [16]. The decrease in the cleanliness criterion of this mixture is due to the influence of the high rate of fines contained in the granite powder. The Yopougon graphs allow us to observe a decrease in the cleanliness of the sand for all mixtures of 30%, 50% and 80% of granite powder, but these sands are suitable for the production of quality concrete [16]. This decrease is due to the increase in the percentage of fines in the mixture.



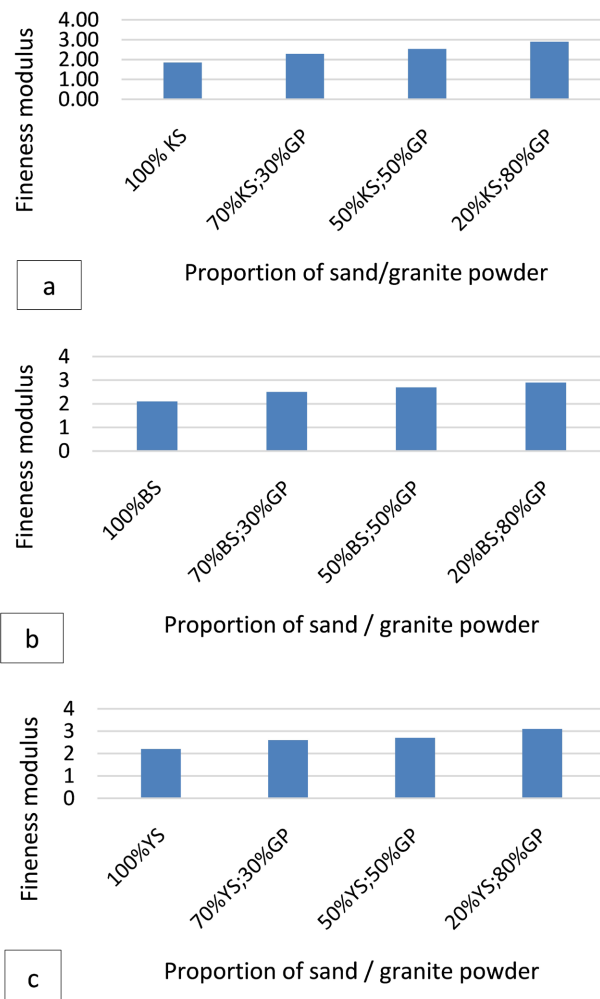
**Figure 9.** Evolution of the sand equivalent as a function of the sand/granite powder substitution proportions of the mixtures, (a) Koumassi, (b) Bingerville and (c) Yopougon.

### 3.2.3. Influence of Granite Powder on Fineness Modulus and Fine Percentage

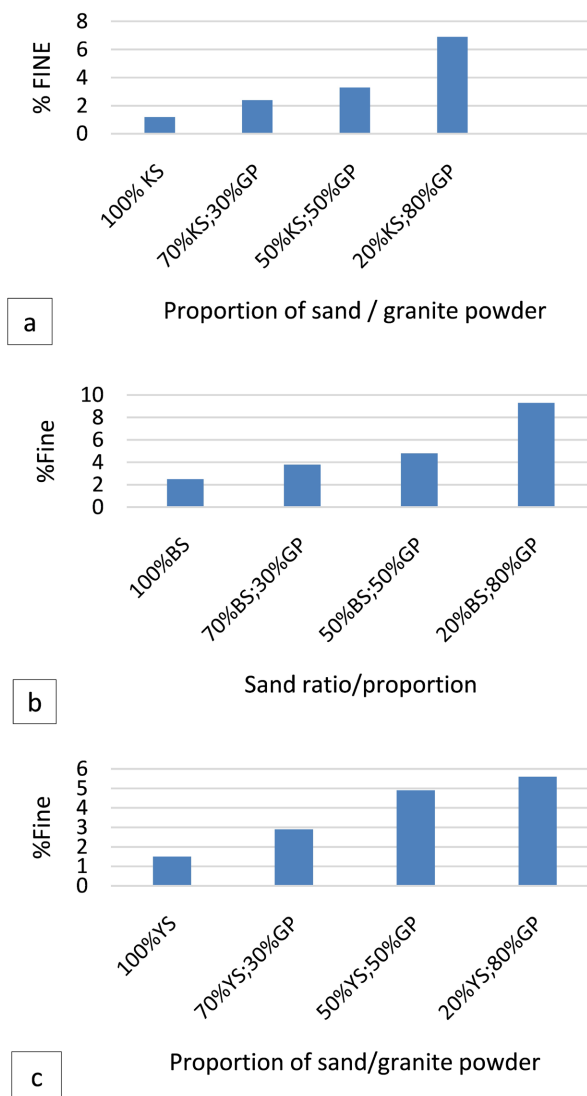
The graphs (**Figure 10** and **Figure 11**) below represent the evolution of the fineness modulus and the percentage of fine as a function of the proportion of granite powder in the mixtures.

The fine fraction of Koumassi mixtures varies from 1.2 to 6.9. It is noted that as the percentage of granite powder increases in the sands, the percentage of fines also increases. Indeed, crushed sands have a fairly high fine particle content compared to alluvial sand. Although crushed sands have a high fines content compared to alluvial sand, it is observed that the sands have a fineness modulus between 2.3 and 2.9. They can therefore be used for making concrete with a limited

risk of segregation [22]. The high fines content and the fineness modulus can however influence the workability of the mortar or concrete [23] [24]. The fine fraction of Bingerville mixtures varies from (2.5 to 6.7); the percentage of fine increases with that of the granite powder. We also observe a variation of the fineness modulus depending on the rate of fine in the sands (2.5 to 2.9). They are made up mainly of medium grains, which constitutes a preferential sand and gives better workability and good resistance. These mixtures can be recommended for the production of concrete [16]. The increase in these parameters is due to the quantity of fine elements contained in the granite powder. The fine fraction of the Yopougon Azito sand increases with the percentage of granite powder in the mixtures, influencing the fineness modulus which now varies from (2.6 to 3.1). It is therefore a sand with a majority of coarse grains which gives the concrete poor workability, but good resistance [16]. The percentage of coarse grains in the mixtures has increased because of the coarse grains contained in the granite powder, therefore a new particle size distribution has been established.



**Figure 10.** Evolution of the fineness modulus as a function of the proportions of sand/granite powder substitution in the mixtures, (a) Koumassi, (b) Bingerville and (c) Yopougon.



**Figure 11.** Evolution of the percentage of fine according to the proportions of substitution of sand/granite powder of the mixtures, (a) Koumassi, (b) Bingerville and (c) Yopougon.

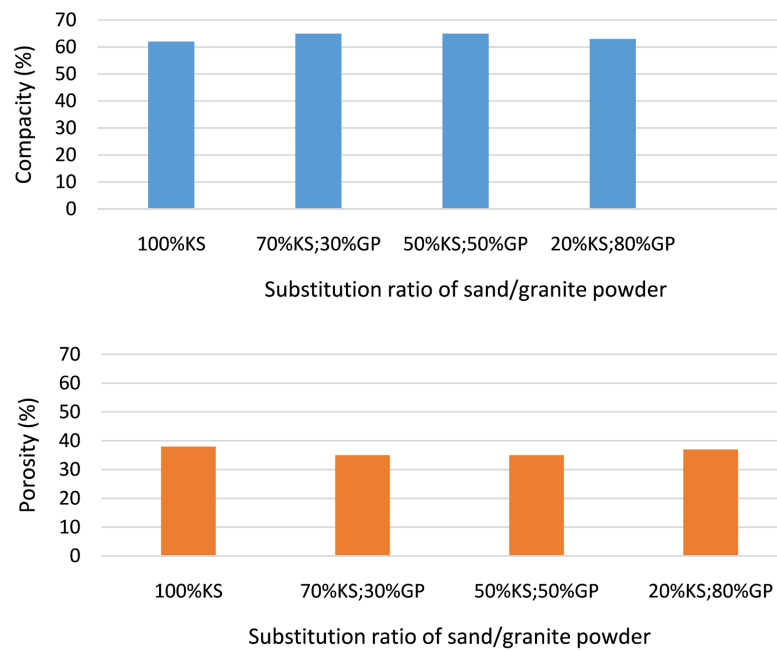
### 3.2.4. Compacity and Porosity of Mixtures

#### 1) Koumassi mixture

The graphs below show the evolution of compacity and porosity as a function of the percentage of granite powder in the Koumassi mixtures.

**Figure 12** shows the variation of compactness and porosity of Koumassi granular mixtures. It is noted that the compactness of the mixtures increases from 62% to 65% and conversely the porosity decreases from 38% to 35% for the percentages of 30% and 50% of granite powder. However, at 80% of granite powder, the compactness increases slightly from 62% to 63% and the porosity decreases slightly from 38% to 37%, thus they are almost identical to the values of the control sand. The increase in the percentages of compactness and the decrease in porosity reveal that the voids that existed in the mixtures were filled by fine grains and medium grains. Crushed sand (granite powder) has a sufficient amount of fine elements

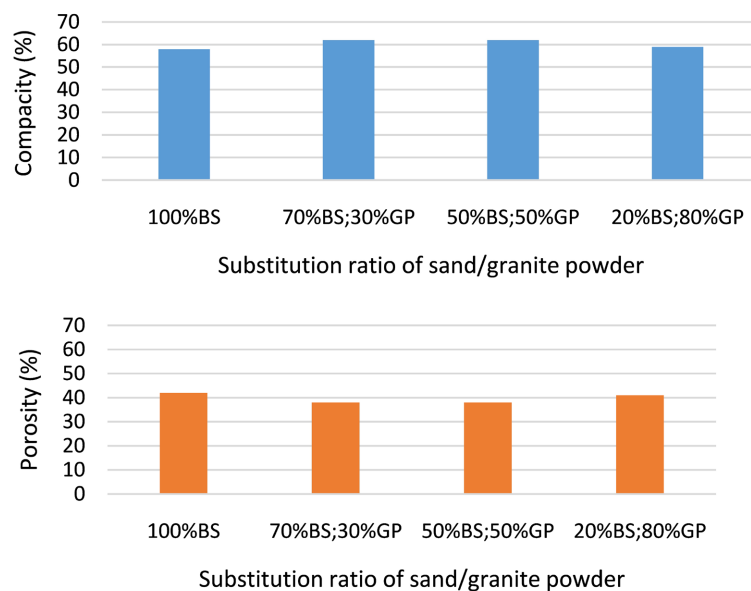
that fill the remaining voids between the large particles improves the adhesion between the cement and the aggregates [25].



**Figure 12.** Evolution of compactness and porosity as a function of the sand/granite powder substitution proportions of Koumassi mixtures.

## 2) Bingerville mixture

The graphs below show the evolution of compactness and porosity as a function of the percentage of granite powder in the Bingerville mixtures.

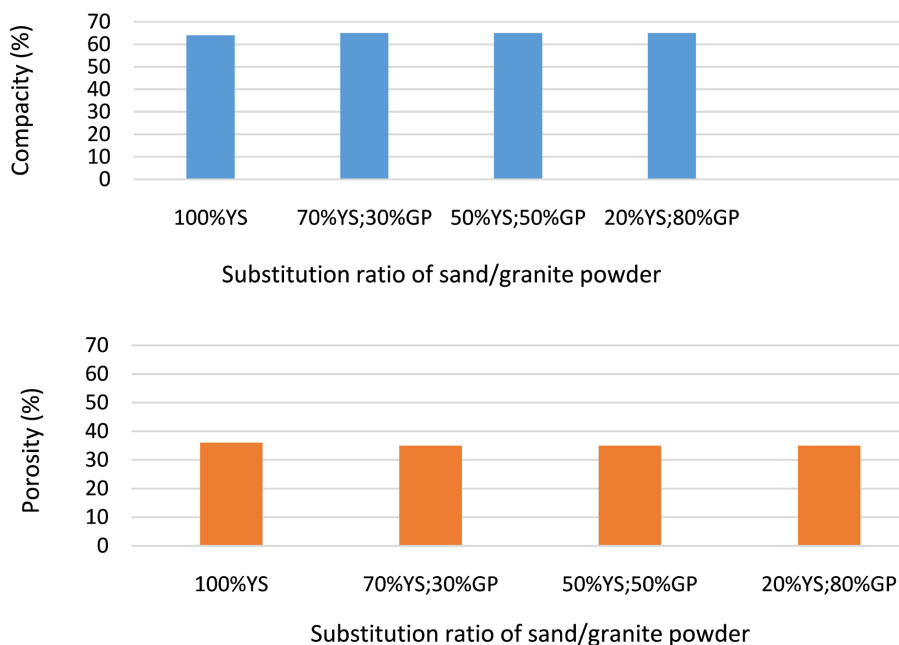


**Figure 13.** Evolution of compactness and porosity as a function of the sand/granite powder substitution proportions of Bingerville mixtures.

**Figure 13** shows the variation of the compactness and porosity of the Binger-ville granular mixtures, with the addition of granite powder. It is noted that the compactness of the mixtures increases from 58% to 62% and the porosity decreases from 42% to 38% for the percentages of 30% and 50% of granite powder. However, it is noted that at 80% substitution, the porosity decreases slightly from 42% to 41% and the compactness increases slightly from 58% to 59% compared to the control sample. The increase in compactness percentages and the decrease in porosity are due to the presence of certain grains that have occupied the voids between the large particles of the mixtures. The increase in the compactness of the granular mixtures is due to the size of the grains [26]. The decrease in porosity is due to the increase in fines in the granular mixture which helps fill the voids [27].

### 3) Yopougou mixture

The graphs below show the evolution of compactness and porosity as a function of the percentage of granite powder in the Yopougou mixtures.



**Figure 14.** Evolution of compactness and porosity as a function of the proportions of sand/granite powder substitution in Yopougou mixtures.

**Figure 14** shows the variation of the compactness and porosity of the granular mixtures of Yopougou, as a function of the granite powder. The compactness of the mixtures increases slightly from 64% to 65% and the porosity decreases slightly from 36% to 35% for the percentages of 30%, 50% and 80% of granite powder. The compactness of the granular mixtures increases with the size of the grains [26]. According to [27], the porosity that exists between the large particles decreases with the increase of the fine particles, which allows us to say that the voids have been filled by the fine particles.

## 4. Conclusion

This study highlighted the influence of granite powder on the physical properties of alluvial sands in Abidjan. Indeed, granite powder, considered as waste, was used to improve the properties of alluvial sands. Three mixtures were made for each of the three alluvial sands in the Abidjan district and characterized in the laboratory; a total of 9 granular mixtures were formulated. The results of the compactness of the different mixtures obtained (Koumassi evolves from 62% to 65% and Binger-ville evolves from 58% to 62% and that of Yopougon evolves from 64% to 65%), indicate that the mixtures are more compact than alluvial sand, which will promote more resistant concretes. Indeed, the increase in compactness reveals that the voids that existed in the mixtures have been filled by fine and medium grains. Thus, the correction of the three alluvial sands of the Abidjan district for a partial substitution of crushed granite sand improves the different physical properties. In view of this study, it should be emphasized that the association of these two types of aggregates, precisely the partial substitution of sand by 50% of granite powder, could have a positive impact on the resistance and quality of the materials as well as on the durability of the works made from this mixture.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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