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Prospective Study and Physico-Mechanical Characterisation of Granular Materials Used in the Manufacture of Ordinary Concrete in Congo

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Abstract

This research is an experimental study aimed at identifying and determining the physico-mechanical properties of various granular materials used in current concretes based on local aggregates (sands, gravels) from different quarries, highlighting their intrinsic properties. The aim was also to test their specific influence on the cementitious matrix of hardened concrete. Several laboratory tests were conducted on samples from Brazzaville and Pointe-Noire. To develop a variety of concrete formulations meeting rheological criteria (deformability, bleeding, segregation) and create an optimal concrete formulation approach considering its microstructural and compacting matrix, a good granular distribution was planned, using two types of sand (rolled and crushed). This involved correcting the rolled sand with variable proportions (30% to 50%) of crushed sand. The results from the eight concrete formulations studied, using the Dreux-Gorisse method, showed that six formulations produced the expected results. Compressive strengths at 28 days ranged from 25 to 36.75 MPa. As a result, formulation 3 appears to be the best, with a mechanical strength of 36.75 MPa at 28 days, compared to formulation 1 (33.75 MPa), formulation 4 (27.25 MPa), and formulation 2 (26.65 MPa) for the Brazzaville locality. For the Pointe-Noire locality, formulation 8 was judged the best, with a characteristic mechanical strength of 29.70 MPa at 28 days, followed by formulation 7 (27.30 MPa), formulation 5 (22.80 MPa), and formulation 6 (18.30 MPa). In summary, the concretes formulated with raw sand showed better results than those with improved sands. The same was true for concrete formulations using rolled sand and gravel.

Keywords

Sand, Gravel, Cement, Formulation, Identification, Concrete, Physical-Mechanical Properties

1. Introduction

The use of concrete as a building material for diverse infrastructure projects is of great interest. It remains one of the most widely used materials in civil engineering. Whether for industrial construction, bridges, other engineering structures, or real estate projects, concrete is essential.

However, aside from cement, which is used as a hydraulic binder in its manufacture, the quality of concrete depends largely on the intrinsic characteristics of the aggregates used. It is necessary to choose materials with better physico-mechanical characteristics, such as particle size, fine particle content of sand, porosity of aggregates, and other significant parameters. Understanding these physico-mechanical characteristics of concrete's constituent elements (aggregates) is crucial. Concrete is particularly important concerning specific and normative requirements on concrete quality [1].

The impact of grain morphology on stacking properties significantly affects the performance of concrete in both its fresh and hardened states. Concrete is a complex, multiphase material primarily composed of aggregates (sand, gravel) and hydraulic binders (cement). It gradually hardens after mixing until it reaches optimal strength at 28 days [2].

According to popular belief, the technical studies and characterization of granular materials conducted in various Congolese laboratories focused on facilitating concrete formulation for building construction and infrastructure projects. These studies primarily emphasized mechanical resistance to compression and tensile strength after 28 days. In this context, admixtures are sometimes used to enhance the physico-mechanical properties of concrete, particularly its compressive strength. However, the specific performance of these structures often raises concerns. Formulating concrete is not enough; it is essential to ensure it meets technical specifications for strength and durability to optimize its rheological behavior. In addition, formulating concrete requires mastering several aspects, such as the compactness of the granular skeleton, the microstructure, the absorption rate, and many other specifics.

To achieve a good granular or continuous distribution with fine, medium, and coarse grains in relation to the sampled sands, we used two types of sand (rolled and broken) in varying proportions between 30% and 50%, along with natural and crushed gravel.

A field study was conducted in the Brazzaville and Pointe-Noire departments of Congo to assess the qualitative physico-mechanical performance of aggregates and the quality of the formulated and manufactured concrete. Material samples were taken from the Kombé quarries in Brazzaville and from Boubissi and Louvoulou in Pointe-Noire. These samples were then identified and characterized through laboratory tests.

The main objective of this experimental study is to identify, characterize, and formulate common concrete made from local aggregates taken from different sites and quarries and classify them according to their physico-mechanical performance.

2. Materials and Methods

2.1. Geographical Location

For Brazzaville, the area for removing materials (aggregates) is in the southern part of the city. This quarry, Kombé, is situated at an altitude of 287 meters, nearly 20 km from the capital, on the banks of the Congo River. Its geographical coordinates are 4˚21'06" south latitude and 15˚10'25" east longitude.

On the other hand, for Pointe-Noire and the department of Kouilou, the Louvoulou quarry (Figure 1) is located at an altitude of 100 meters, about 5 km from Malélé on National Road No. 6 (RN6), in the district of Kakamouéka. Its geographical coordinates are 4˚24'50" south latitude and 11˚45'16" east longitude. Similarly, the Boubissi quarry (Figure 2) is located at an altitude of 43 meters in the district of Hinda, less than 30 km from Pointe-Noire. Its geographical coordinates are 4˚38'45" south latitude and 12˚10'41" east longitude [3].

2.2. Climate Data

Recent research by SAMBA and NGANGA (2011) shows that Congo has two climate

Figure 1. Material borrowing areas for Brazzaville (Kombé quarry).

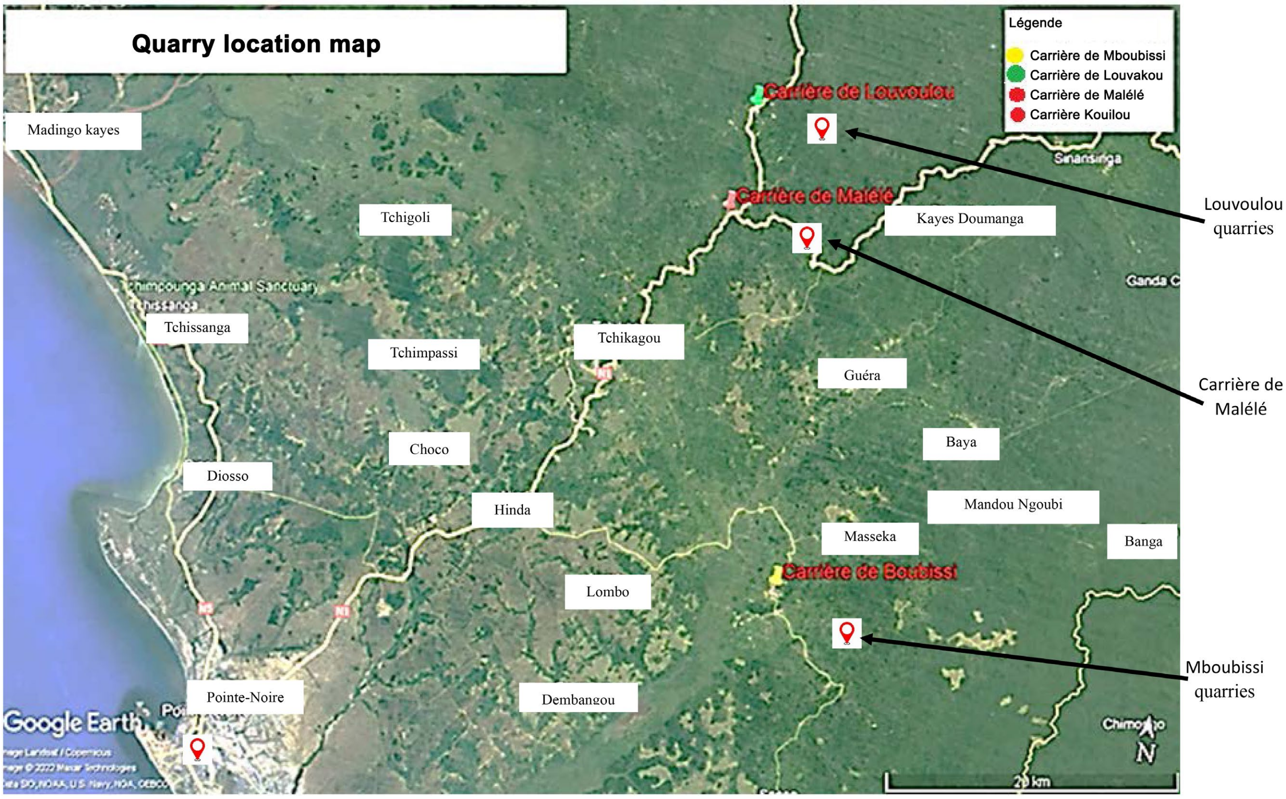

Figure 2. Material borrowing area for Pointe-Noire (Boubissi and Louvoulou quarries).

types: the equatorial climate in the north and the humid tropical climate in the south [4]. In the north, the annual average temperature is around 26˚C, while in the south, it is about 25˚C, with precipitation nearing 1200 mm. The quarries of Mboubissi and Louvoulou are in the southern zone and share the humid tropical climate, known as "Low Congolese Climate", classified in the Guinean forest climate group, characterized by high rainfall. This climate is mainly influenced by intertropical low pressure from October to May and by southern subtropical high pressure from June to September.

2.3. Tests for the Identification and Characterisation of Materials

These tests have identified and classified materials according to their specificities and granular classes. The tests conducted are as follows: granular analysis (NFP18540), the fineness module (NFP18-540), the equivalent of sand (XP18-597), bulk density (NFEN1097-6 and NFP18-555), specific weight (NFP94-054), the methylene blue test (NFP94-068), the Los Angeles mechanical test (NF P18-578), cleanliness testing (NF P18-591), porosity (EN 1097-6), and compactness (EN 1097-6).

The characterization of the materials identified deficiencies in their quality, particularly in the sands, which had an excessive percentage of fine elements. Additionally, the natural gravel of MBoubissi had a high Los Angeles coefficient, classifying it as less impact resistant. To address this, the sands were improved by adding crushed sands at different percentages (30%, 40%, and 50%) to enhance their fineness modulus and align the granular curves with the requirements of the Dreux-Gorisse method for concrete sands. Similarly, improvements on gravels have been made by using different types of crushed gravel, classified by particle size.

The cement used for the formulation of concrete is Portland cement, type CEM II, class 42.5N. This cement, with a specific weight of 3.10 t/m^3 (commonly accepted average value), contains 95% clinker and 5% gypsum. It meets the requirements of the EN 197-1 standard and the Congolese standard NCGO 0004-1:2017-09. The chemical composition of this cement is detailed in **Table 1**. A verification study was conducted to determine its physico-mechanical properties and setting time.

Table 1. Chemical properties of the cement used.

S_iO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	PAF
19.66	4.75	4.03	62.76	2.73	2.14	1.08	0.13	1.38

2.3.1. Sands

The study focused on five types of sand samples: three from Brazzaville and two from Pointe-Noire. These included three rolled sands and two crushed sands. The rolled sands were improved with crushed sands from each locality.

For the locality of Brazzaville, the rolled sands of the Congo River and the Mfilou River were improved with crushed sand derived from the Inkissi sandstone from the Nkombé quarry in Brazzaville. In Pointe-Noire, the rolled sand was improved by crushed sand derived from the Louvoulou granite in Pointe (**Figures 3-7**).

The proportions of sand used in the case study are presented as follows:

- The sands of the Congo River and Mfilou were enhanced with crushed sand from Brazzaville, with proportions ranging from 30% to 50%.

Figure 3. Sand from Congo River (SF).

Figure 4. Sand from Mfilou River (SMF).

Figure 5. Sand from Pointe-Noire (SPN).

Figure 6. Crushed sand from Kombé in Brazzaville (SCB).

Figure 7. Crushed sand from Pointe-Noire (SCP).

- Pointe-Noire sand was improved with crushed sand from Pointe-Noire, with proportions ranging from 30% to 50%.

The proportions of the sands used in the case study are as follows:

- The sands of the Congo River and Mfilou were enhanced with crushed sand from Brazzaville, with proportions ranging from 30% to 50%.
- Pointe-Noire sand was improved with crushed sand from Pointe-Noire, with proportions ranging from 30% to 50%.

The characterization of the raw and improved sands allowed for the assessment of the granular curves of the sands in relation to the concrete sand spindle (Figures 8-10).

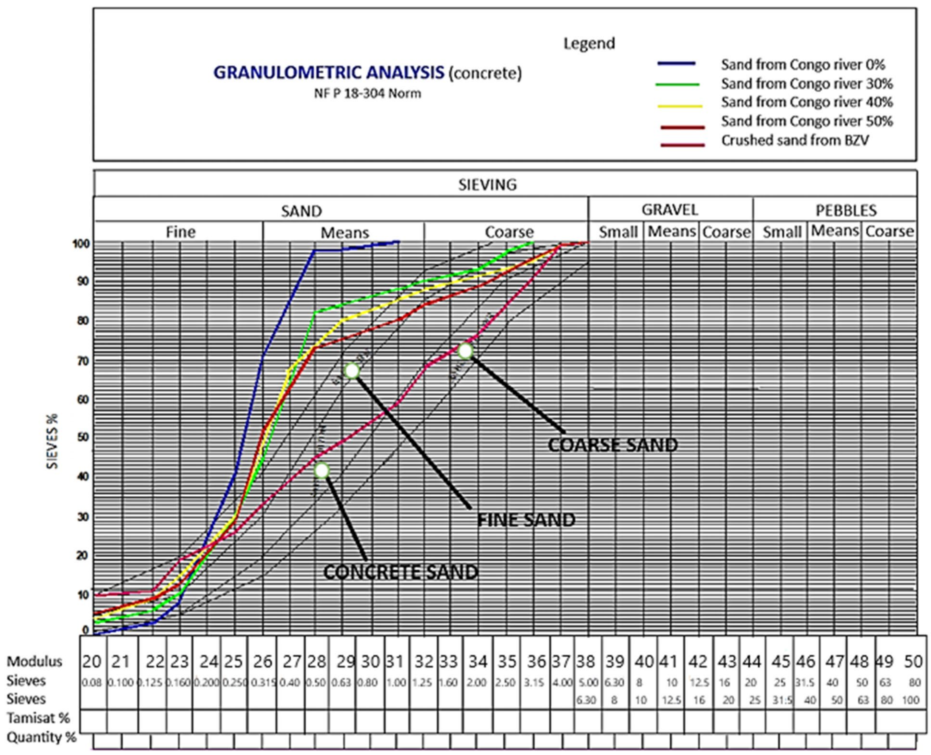

Figure 8. Curves for improved sand from the Congo River at 30%, 40% and 50%.

These curves (**Figure 8**) represent the appearance of the sand in relation to the concrete sand spindle. The blue curve represents the particle size of the raw sand from the Congo River. After improvement with crushed sand from Kombé in Brazzaville at 30%, 40%, and 50%, we find the curves in green, yellow, and orange, respectively, which are close to the concrete sand spindle.

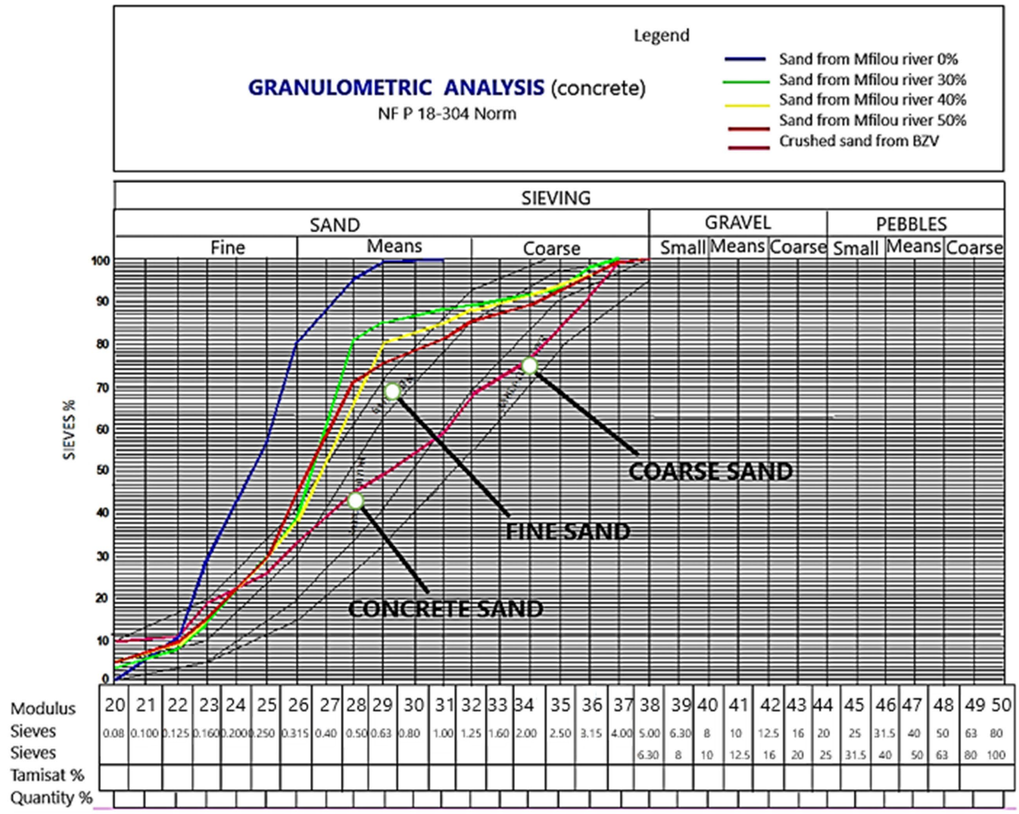

Figure 9. Curves for improved sand in the Mfilou River at 30%, 40% and 50%.

The curves in **Figure 9** illustrate the appearance of the sand in relation to the concrete sand spindle. The blue curve represents the particle size of the raw sand from the Mfilou River. After mixing with crushed sand from Kombé in Brazzaville at 30%, 40%, and 50%, the resulting curves, shown in green, yellow, and orange, respectively, are close to the spindle of concrete sands.

The curves in **Figure 10** show the appearance of the sand in relation to the concrete sand spindle. The blue curve represents the particle size of the raw sand from Pointe-Noire. After improvement with crushed sand from Louvoulou to Pointe-Noire at 30%, 40%, and 50%, the curves appear in green, yellow, and orange, respectively, and remain outside the concrete sand zone.

The blue curves represent the raw sands (0% crushed sand), while the glass, yellow, and orange curves represent the improved sands with crushed sand (red) at 30%, 40%, and 50%, respectively.

The evolution of these curves clearly shows that as the sand is improved, the curve approaches the spindle of concrete sands.

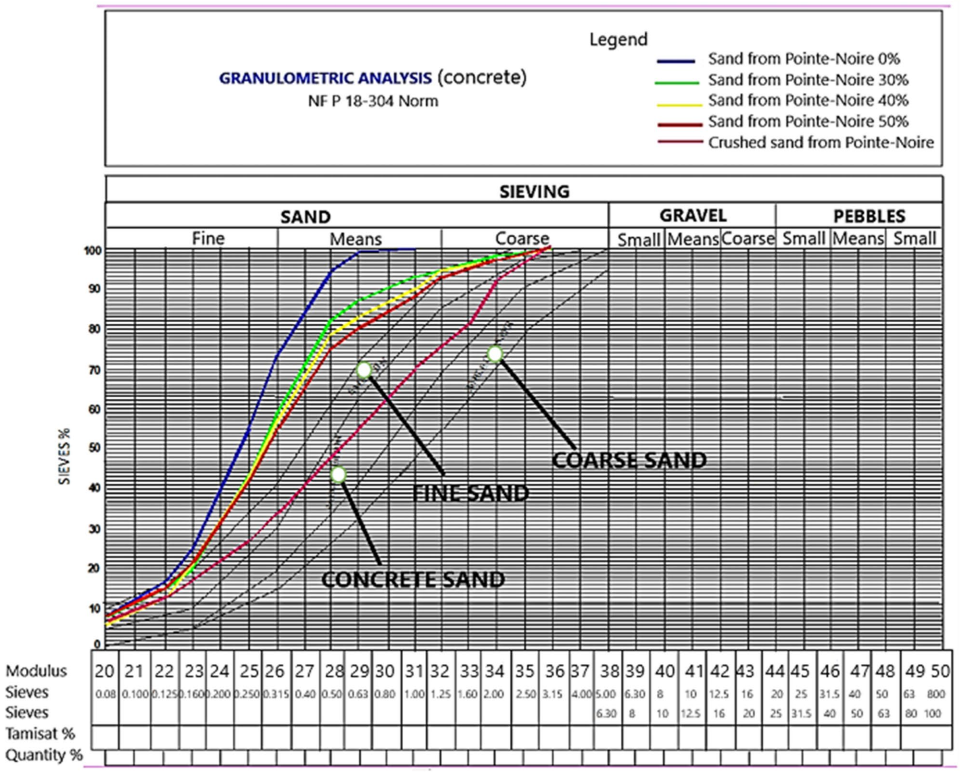

Figure 10. The shape of the curves of the improved sand of the locality of Pointe-Noire at 30%, 40% and 50%.

2.3.2. Gravel

The gravels used come from two localities: the Inkissi sandstone from Brazzaville, and the natural gravel of Mboubissi and the granite of Louvoulou from Pointe-Noire. These materials have the recommended physico-mechanical characteristics, except for the natural Boubissi gravel, which is fragile in terms of impact resistance.

The gravel used adheres to the NP P 18-555 standard and originates from Brazzaville and Pointe-Noire. In Brazzaville, the Inkissi sandstone was used as crushed gravel for concrete formulation, while in Pointe-Noire, two types of gravel were considered: Louvoulou granite and Boubissi natural gravel (Figures 11-13).

Figure 11. Le gré from Inkissi de Kombé at Brazzaville (GIK).

Figure 12. Granite from Louvoulou at Pointe-Noire (GCL).

Figure 13. The natural gravel of MBoubissi (GRB).

1) Porosity (EN 1097-6)

It is the ratio of the volume of voids in a material to its total volume, representing the degree to which its volume is occupied by voids. This is an important parameter in formulating quality concrete.

2) Compactness (EN 1097-6)

This parameter is crucial in concrete formulation as it influences the concrete matrix and its durability.

2.3.3. Concrete Formulations

The study of the concrete formulations was conducted using the Dreux-Gorisse approach for concrete dosed at 350 kg/m^3. To ensure good granular distribution and compensate for the excessive fine elements in the sands, improvements were made to the sands at different percentages to integrate them into the concrete sands spindle (Figures 14-16).

Eight formulations of concrete were selected and manufactured using local materials from Brazzaville and Pointe-Noire, considering the following requirements:

Figure 14. The slum test.

Figure 15. Fresh concrete test pieces.

Figure 16. Crushing of concrete specimens.

- Cement dosage: 350 kg/m^3.
- Type of cement: CEM II 42.5 N.
- Maximum diameters of aggregates: 8 mm for rolls and 15 mm for crushed ones.
- Vibration: normal.
- Sagging at the Abrams cone sought: 6 cm (plastic concrete).
- Desired compressive strength on 28 days for 15 × 15 × 15 cube moulds: 25 to 30 MPa.

A theoretical study of concrete formulation was conducted to determine the percentages of each constituent. Cubic specimens, made using the theoretical data to manufacture fresh concrete (**Figure 15**), were kept in a tank containing drinking water for 7, 21, and 28 days to determine the characteristic strengths of each formulated concrete (**Figures 17-24**).

The theoretical study of the concrete formulation resulted in the creation of the following eight graphs:

Formulation 1: Sand from the Congo River (SF) and two classes of crushed gravel from Kombé (GIK)

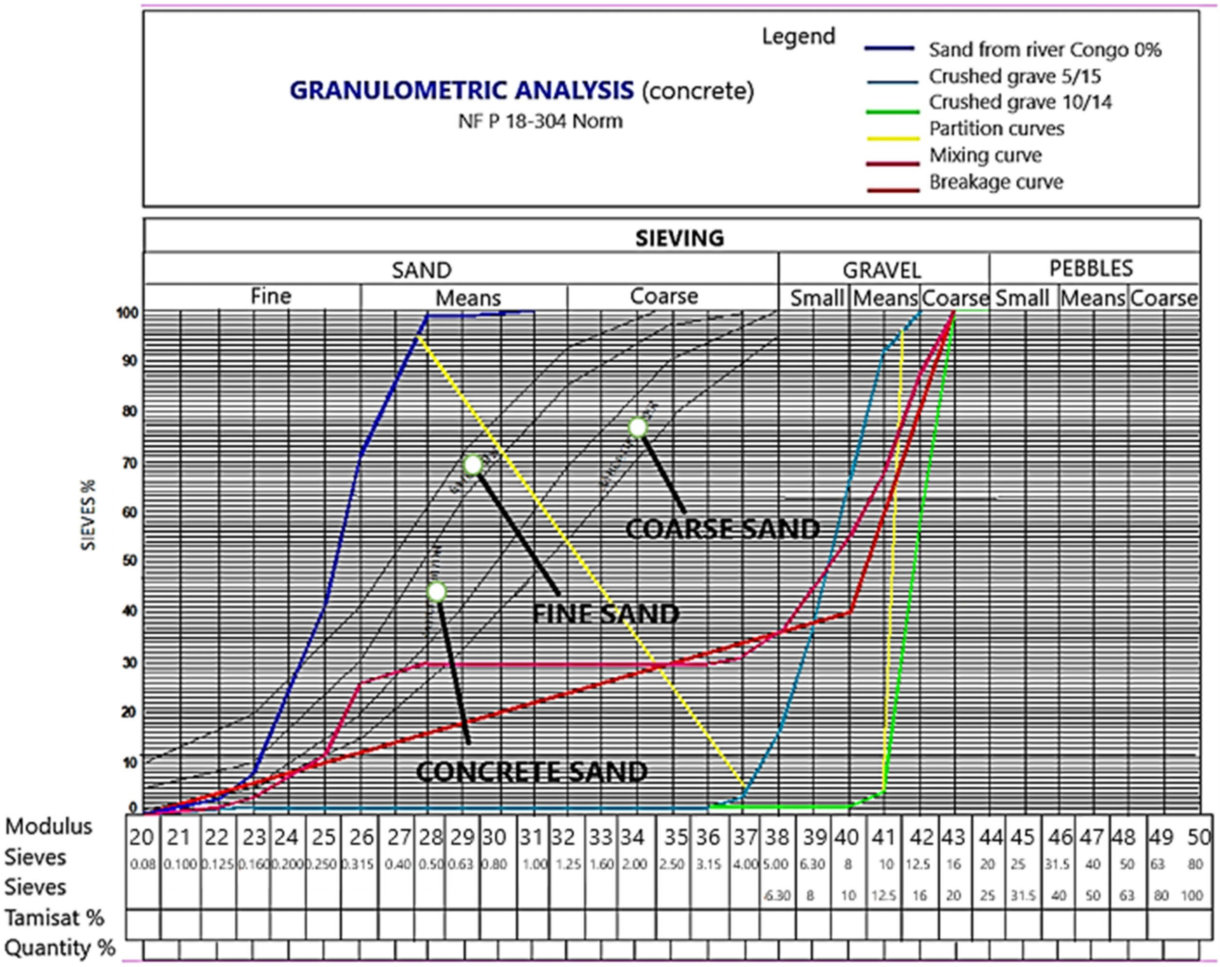

Figure 17. Theoretical formulation of the Congo River sand with 10/14 and 5/15 gravels.

Figure 17 shows the graphs used to determine the percentages of each aggregate in the concrete formulation. This formulation consists of raw sand from the Congo River and two classes of crushed gravel from the Kombé quarry in Brazzaville.

Formulation 2: Improved sand from the Congo River (SF 50%) and two classes of crushed gravel from Kombé (GIK)

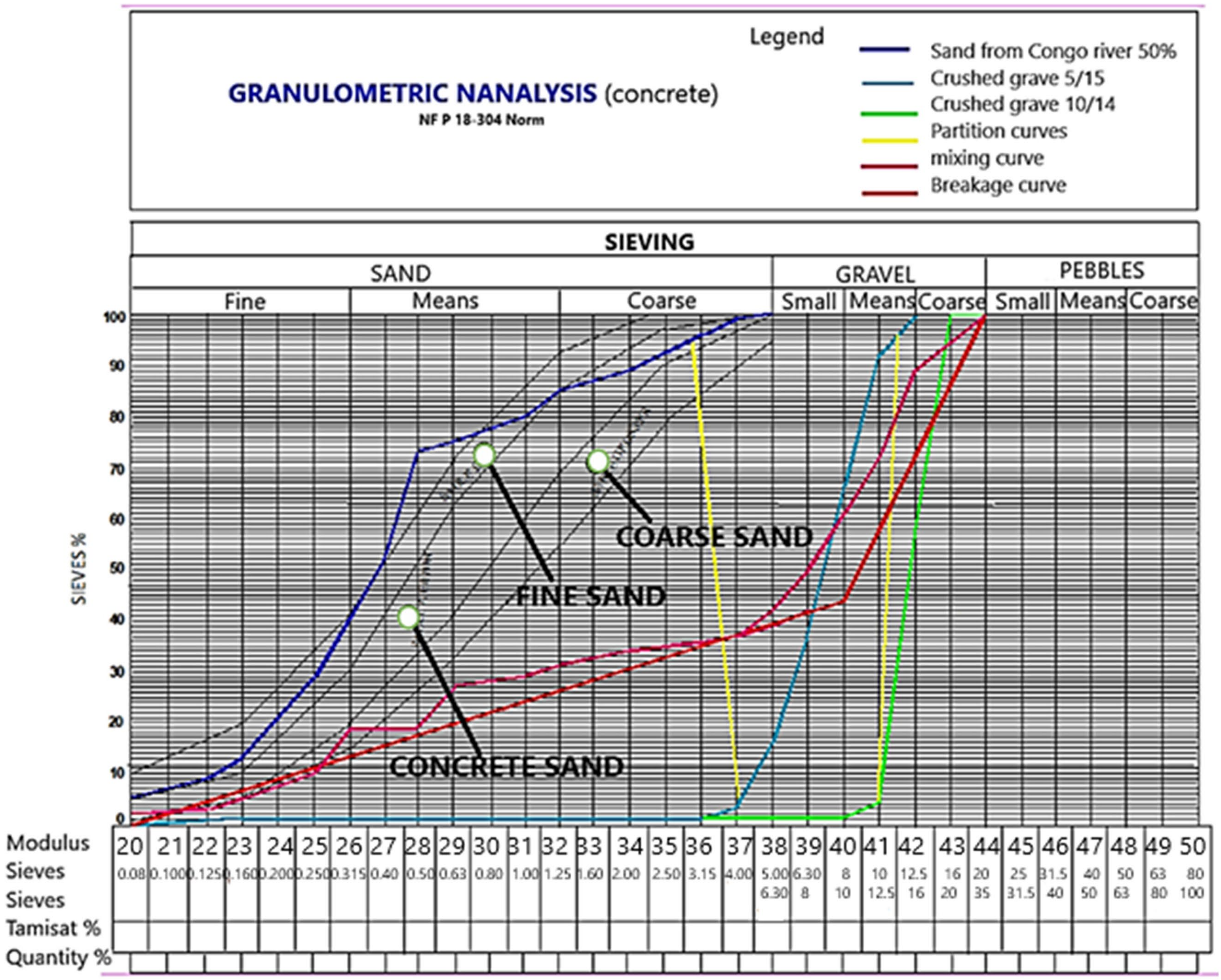

Figure 18. Theoretical formulation of Congo River sand improved with 10/14 and 5/15 gravels.

Figure 18 presents graphs used to determine the percentages of each aggregate in the concrete formulation made from improved sand from the Congo River and two classes of crushed gravel from the Kombé quarry in Brazzaville.

Formulation 3: Mfilou River Sand (SMF) and two classes of Kombé Crushed Gravel (GIK)

Figure 19 presents graphs used to determine the percentages of each aggregate for the concrete formulation made from raw sand from the Mfilou River and two classes of crushed gravel from the Kombé quarry in Brazzaville.

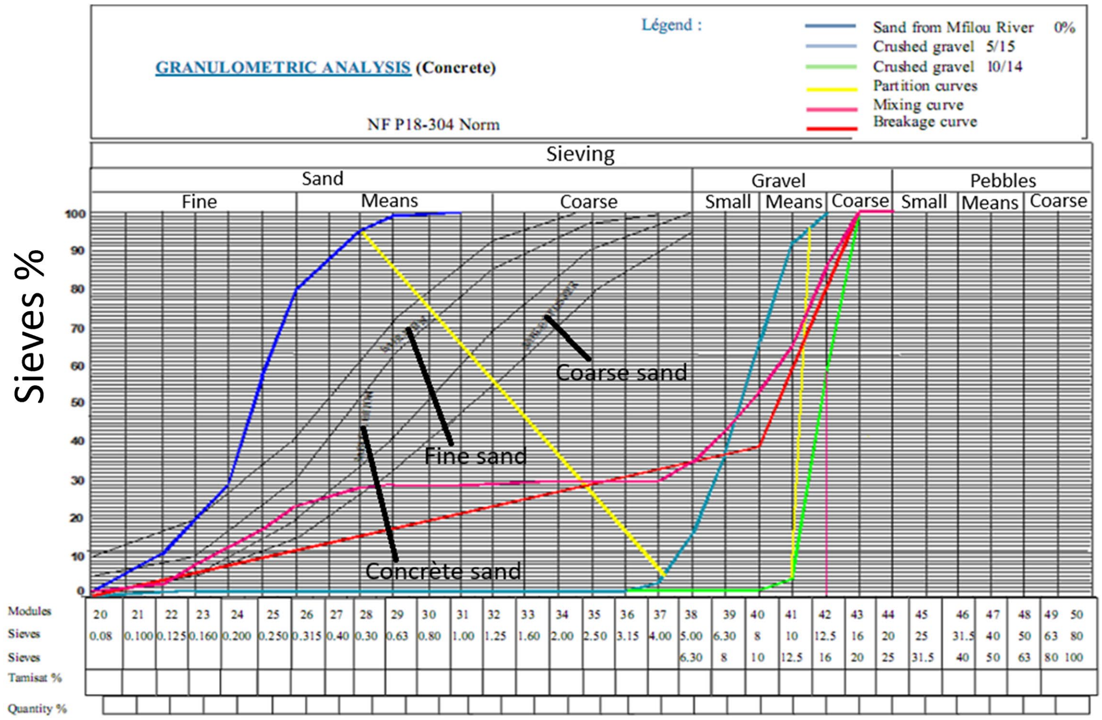

Figure 19. Theoretical formulation of Mfilou River sand with 10/14 and 5/15 gravels.

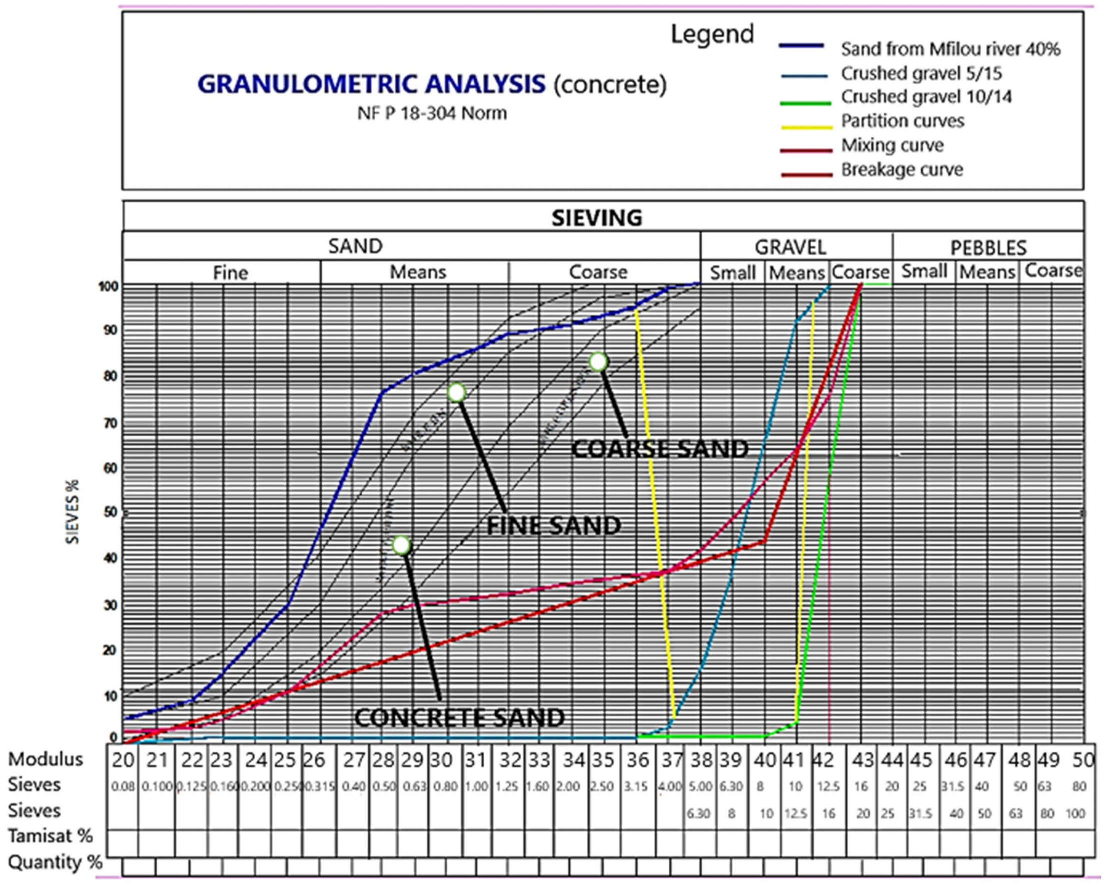

Figure 20. Theoretical formulation of Mfilou River sand improved with crushed gravel 10/14 and 5/15.

Formulation 4: Improved Mfilou River sand (SMF 40%) and two classes of crushed gravel from Kombé (GIK)

Figure 20 presents the graphs used to determine the percentages of each aggregate for the concrete formulation, consisting of improved sand from the Mfilou River and two classes of crushed gravel from the Kombé quarry in Brazzaville.

Formulation 5: Pointe-Noire sand (SPN) and Boubissi rolled gravel (GRB)

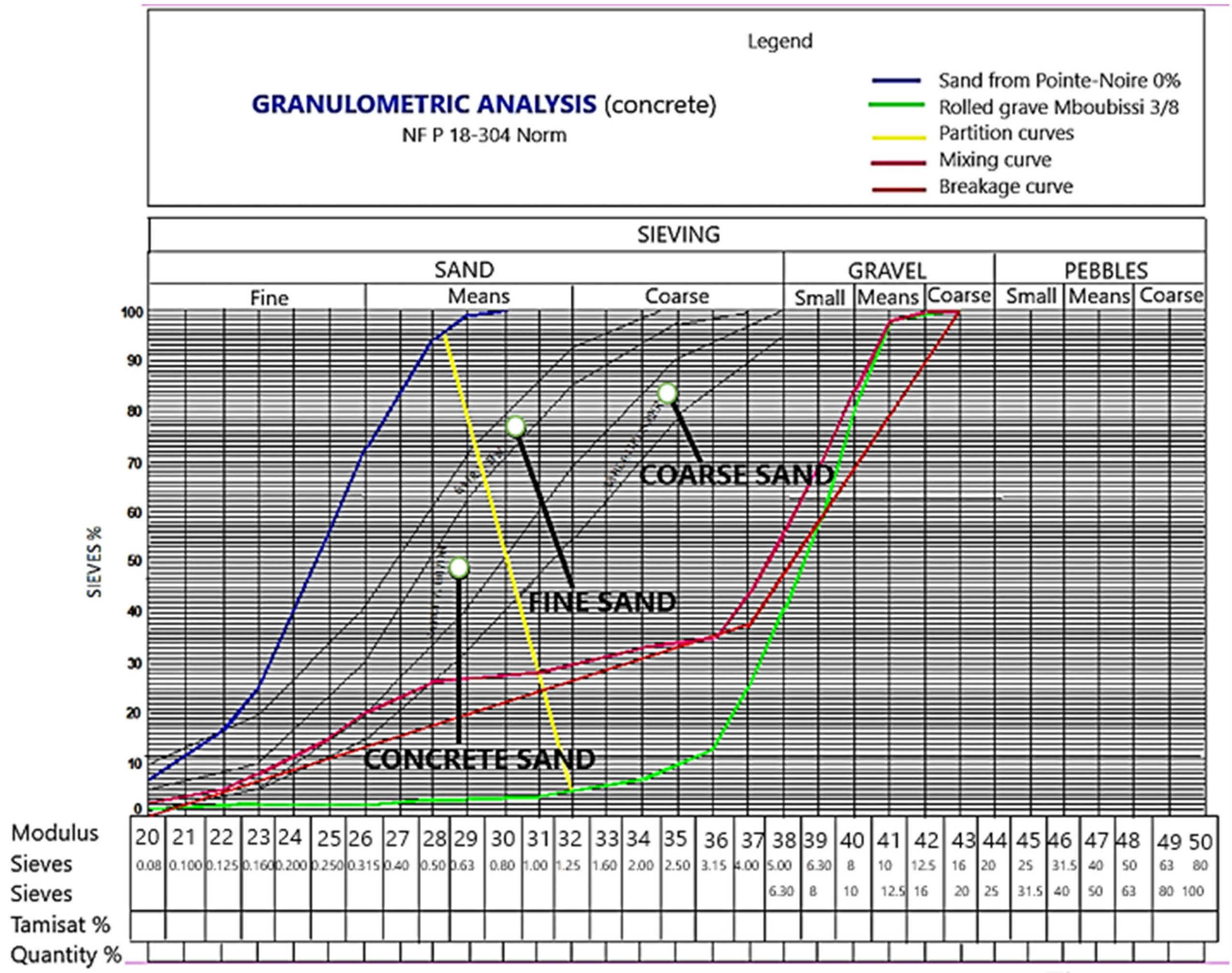

Figure 21. Theoretical formulation of sand from Pointe-Noire with rolled gravel 3/8.

Figure 21 shows the graphs used to determine the percentages of each aggregate in a concrete mix design. This mix consists of raw sand from Pointe-Noire and rolled gravel from the Boubissi quarry in Pointe-Noire.

Formulation 6: Improved Pointe-Noire sand (SPN 50%) and Boubissi rolled gravel (GRB)

Figure 22 shows the graphs used to determine the percentages of each aggregate in the concrete formulation, consisting of improved sand from Pointe-Noire and rolled gravel from the Boubissi quarry in Pointe-Noire.

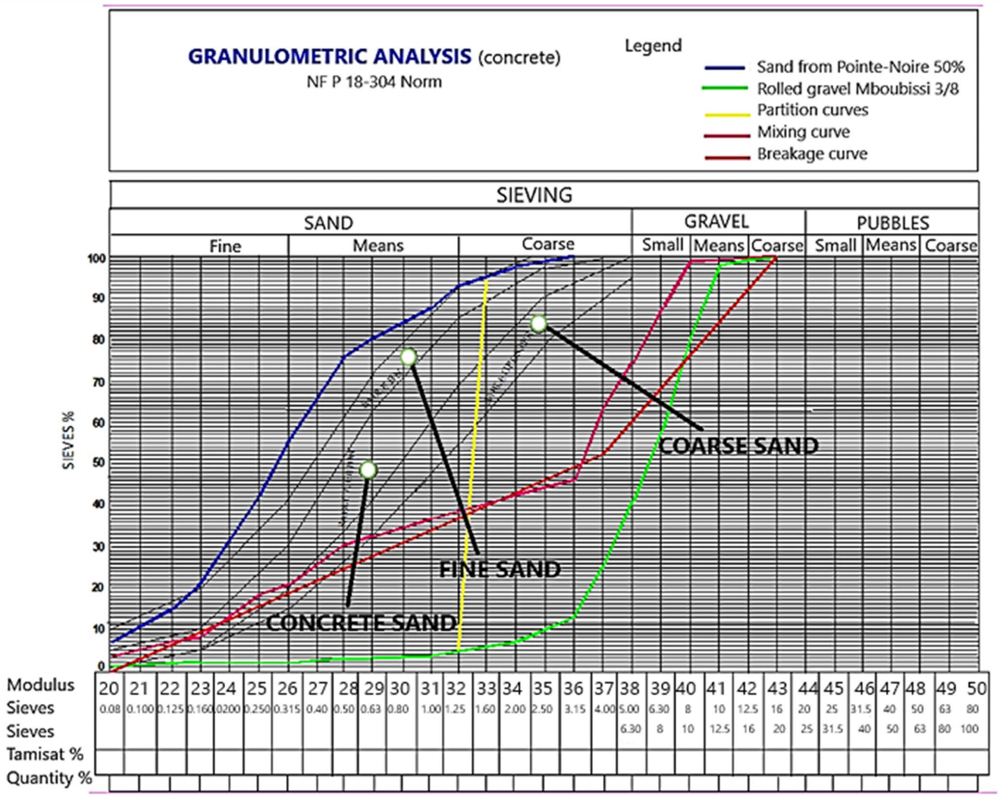

Figure 22. Theoretical formulation of Pointe-Noire sand improved with rolled gravel 3/8.

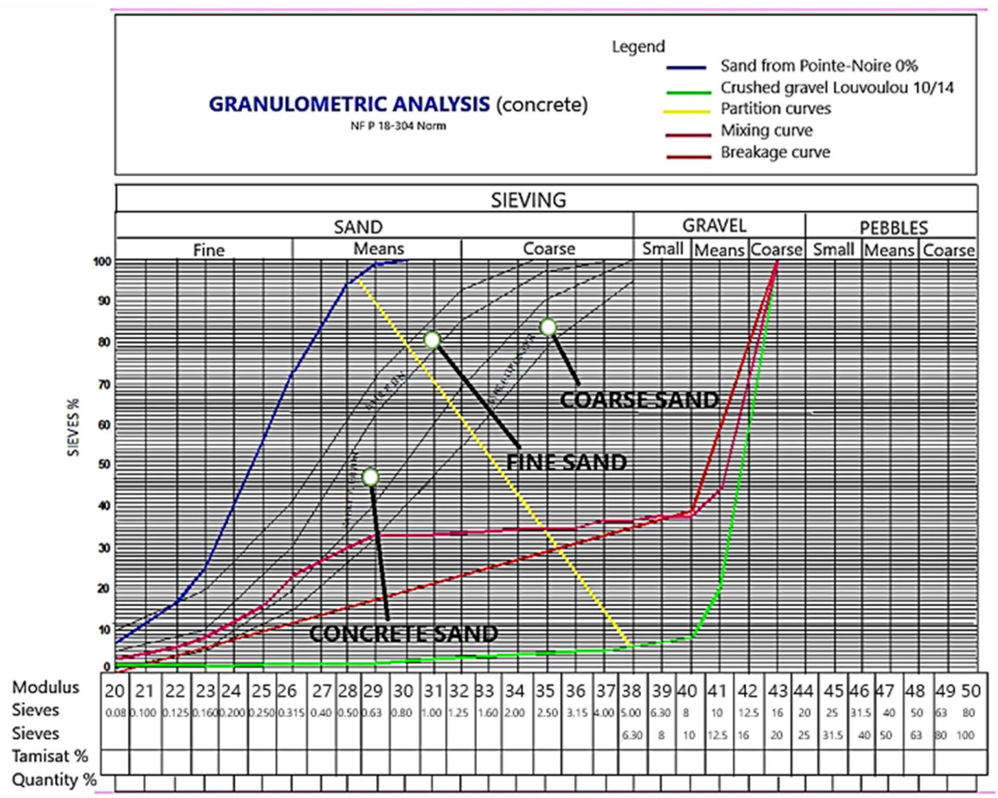

Figure 23. Theoretical formulation of Pointe-Noire sand with Louvoulou crushed gravel 10/14.

Formulation 7: Pointe-Noire sand (SPN) and Louvoulou crushed gravel (GCL)

Figure 23 shows the graphs used to determine the percentages of each aggregate for a concrete mix design consisting of raw sand from Pointe-Noire and crushed gravel from the Louvoulou quarry in Pointe-Noire.

Formulation 8: Improved Pointe-Noire sand (SPN 50%) and crushed gravel from Louvoulou (GCL)

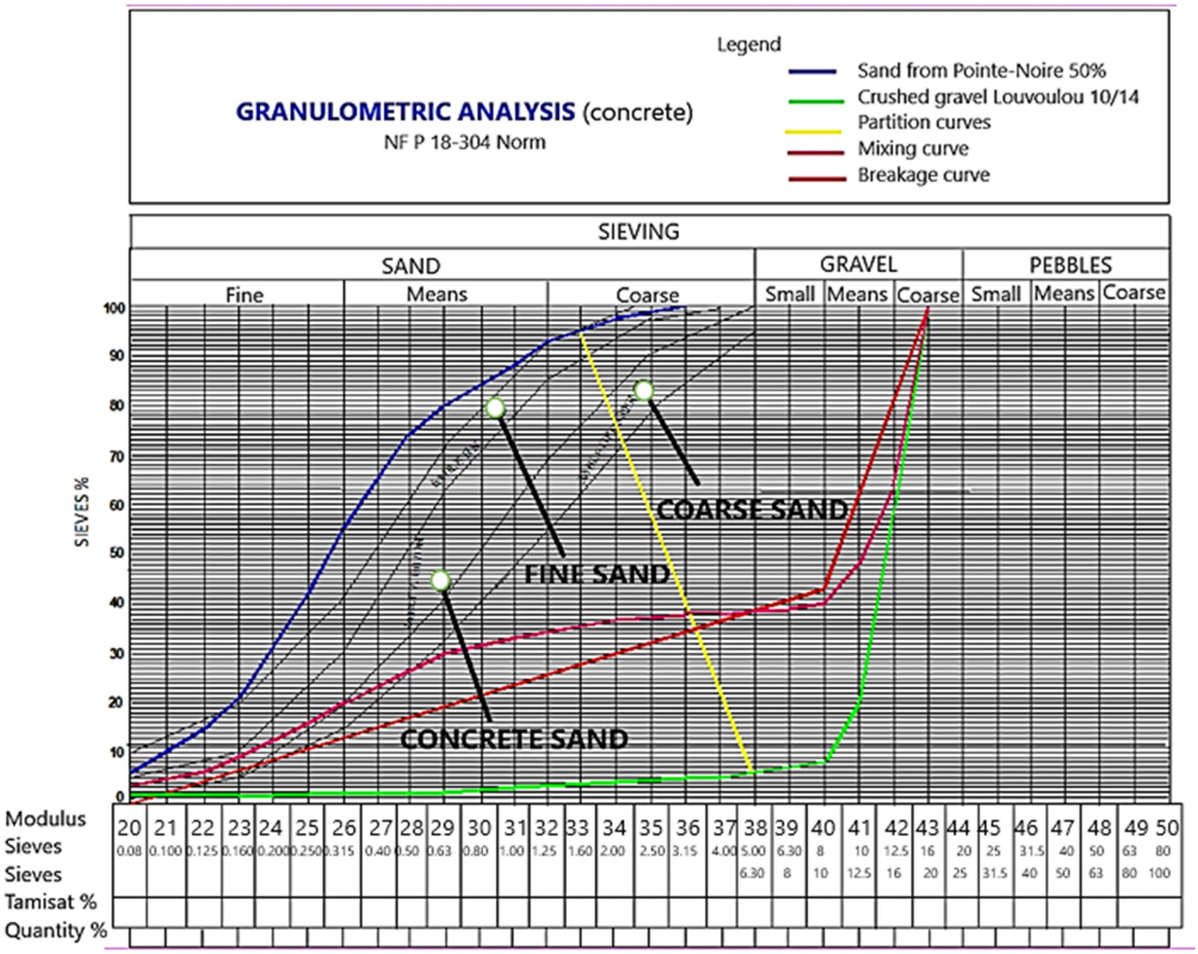

Figure 24. Theoretical formulation of Pointe-Noire sand improved with Louvoulou crushed gravel 10/14.

Figure 24 shows the graphs used to determine the percentages of each aggregate for concrete formulated with improved sand from Pointe-Noire and crushed gravel from the Louvoulou quarry in Pointe-Noire.

These curves clearly show the evolution of concrete based on raw sands and their improvement in formulation.

3. Results, Interpretation and Discussion

3.1. Cement

The following results (Table 2) were obtained from tests conducted on CEM II-type Portland cement, class 42.5N.

Table 2. Physico-mechanical properties of the cement.

Physical properties	Values obtained	Specifications EN 197-1
Early setting (mn)	90	≥60 mn
End of setting (mn)	123	≤720 mn
Bulk density (t/m³)	0.95	0.95 - 1.10
Lechatellier expansion	0.0	≤10
80 µm sieve %	3.5	≤5
Mechanical properties		
Compressive strength Rc 28 days	42.08	42.5 - 62.5 MPa
Tensile strength Rt 28 days	6.4	≥6.5 MPa

These results indicate that the true class of this cement is 42.08 instead of 42.5, and setting begins after 33 minutes. This binder meets the standard requirements and can be used to formulate concrete without issues. The tests conducted according to standards EN 196-1 and EN 196-3 show that the physical test results comply with the specifications of standard EN 197-1.

3.2. Sands

The study on the physico-mechanical properties of aggregates, specifically the sands used for the Brazzaville and Pointe-Noire sites, showed that the fineness modulus of the sands does not comply with standard NF P18-540. The untreated sands showed fineness moduli between 0.93 and 1.20 (Table 3), compared to 1.5 and 1.9 for improved sands (Table 4). These values, which are lower than the preferred sand fineness moduli for quality concretes, do not comply with standard NF P18-541 [5].

It is possible to modify the fineness modulus of sand by adding another type of sand with a different fineness modulus according to Abrams' rule [5] [6]. Additionally, in cases where it's necessary to replace fine elements that may be detrimental, it's important to enhance concrete sands by introducing new substitute elements that improve the quality of the concrete [7]. These substitutes can be derived from industrial by-products or waste, such as blast furnace slag [8].

Table 3. Physical characteristics of raw sands.

Raw sand	Slimness modules	Percentage of fines in 80 µm sieve (%)	Sand equivalent (%)	Specific weight (t/m³)	Apparent density (t/m³)	Methylene blue mass
Sand from Congo River (SF)	1.2	0.3	88	2.62	1.49	1.69
Sand from Mfilou (SMF)	0.93	0.7	89	2.64	1.62	1.15
Crushed sand from Brazzaville (SCB)	2.5	10	46	2.64	1.54	2.32
Sand from Pointe-Noire (SPN)	1.00	6.5	78	2.62	1.56	1.01
Crushed sand from Pointe-Noire (SCP)	2.20	7	63	2.63	1.54	2.04

Table 4. Physical characteristics of sands improved with crushed sand at different percentages.

Improved sands	Slimness modules	Percentage of fines in 80 μm sieve (%)	Sand equivalent (%)	Specific weight (t/m^3)	Apparent density (t/m^3)	Methylene blue mass
SF (30%)	1.7	3	82	2.62	1.59	1.49
SF (40%)	1.8	4.5	83	2.62	1.58	1.50
SF (50%)	1.8	5	81	2.62	1.58	1.50
SMF (30%)	1.7	3.6	83	2.61	1.59	1.52
SMF (40%)	1.8	4.5	71	2.62	1.57	1.49
SMF (50%)	1.9	5.5	64	2.62	1.60	1.49
SPN (30%)	1.5	6.7	76	2.61	1.62	1.01
SPN (40%)	1.6	5.8	79	2.62	1.61	1.00
SPN (50%)	1.7	6.2	71	2.60	1.60	0.99

Nevertheless, in the present study, we propose using other substitute materials: crushed sands from the Inkissi sandstone for the Brazzaville locality and Louvoulou granite for the Pointe-Noire locality. These materials will correct the granulometry of fine sands and reconstitute quality sands for concrete.

The fine content in the raw and improved materials ranged from 0.3% to 6.5%, compared to 7% and 10% for the crushed sands, aligning well with standard XP P18-540, which requires values of 12% or less. The fines in the sand provide the fresh concrete with a water-holding capacity that prevents bleeding and cohesion that maintains homogeneity (absence of degradation).

These tables show the performance evolution of materials when improved, particularly regarding the fineness modulus and the percentage of fines in the sands studied.

3.3. Gravel

The aggregates studied (5/15 and 10/14) for Kombé in Brazzaville, and (3/8 and 10/14) for Louvoulou in Pointe-Noire, show a small difference between the initial and residual mass after washing and weighing. The samples subjected to the action of the 11 pellets only underwent slight wear, as in the case of crushed aggregates. The crushed gravels from Kombé and Louvoulou are fairly resistant, whereas the rolled gravel from Mboubissi, due to its geological characteristics and the Los Angeles test, has low impact resistance. This leads us to conclude that this rolled gravel is not very resistant.

3.4. Concrete Formulations

The results obtained when the concretes were formulated up to the point of crushing are shown in Table 5 and Figure 25 and Figure 26. All the concretes studied have a plastic consistency, with slumps varying between 6 cm and 9 cm. Notably, concretes made with 0% crushed sand have better resistance than those made with improved sand. This could be due to the continuity of the granular skeleton between the sand and gravel in Brazzaville (formulations 1 to 4) and Pointe-Noire (formulations 5 and 6). Conversely, the absence of a continuous granular skeleton in concrete made with the single class 10/14 (formulations 7 and 8) yields better results when the sand is improved. This highlights the impact of sand quality in the formulation of quality concretes.

Table 5 summarises the results obtained when formulating concrete at 7 and 28 days.

Table 5. Physical and mechanical characteristics of the concretes studied.

Type of concrete mixture	Age of concrete/days	Resistance (MPa)	Theoretical density of concrete (g/cm^3)	Real density of concrete (g/cm^3)	Report E/C	Report G/S	Subsidence (cm)	Consistency
Formulation 1	7	27.75	2.37	2.38	0.49	2.45	6	Plastic
	28	33.75		2.41				
Formulation 2	7	20.50	2.38	2.37	0.49	1.80	6	Plastic
	28	26.65		2.37				
Formulation 3	7	23.85	2.37	2.42	0.49	2.43	7	Plastic
	28	36.75		2.44				
Formulation 4	7	18.10	2.37	2.41	0.49	1.70	6	Plastic
	28	27.25		2.39				
Formulation 5	7	16.50	2.36	2.25	0.47	3.06	7	Plastic
	28	22.80		2.26				
Formulation 6	7	12.60	2.35	2.22	0.47	1.70	9	Plastic
	28	18.30		2.25				
Formulation 7	7	21.50	2.38	2.37	0.49	2.36	9	Plastic
	28	27.30		2.37				
Formulation 8	7	22.10	2.37	2.36	0.49	1.89	6	Plastic
	28	29.70		2.35				

This table summarizes the results and their evolution during the formulation of concrete and crushing at 7 and 28 days of age.

These graphs represent the evolution of theoretical and real densities, the E/C and G/S ratios, consistency, and characteristic strengths of the concretes studied at 7 days. Formulation 1 shows better results than all other formulations, while formulation 6 has the lowest strength.

These graphs represent the evolution of theoretical and real densities, the E/C and G/S ratios, consistency, and the characteristic strengths of the concretes studied at 28 days. The results show that formulation 3, using Mfilou River sand and two classes of crushed gravel, performs best, followed by formulations 1, 8, 7, 4, 2, 5, and finally 6. All formulations achieving the expected characteristic strengths at 28 days used crushed gravel, highlighting the influence of rock in concrete formulation, as seen with the Boubissi natural gravel in formulations 5 and 6.

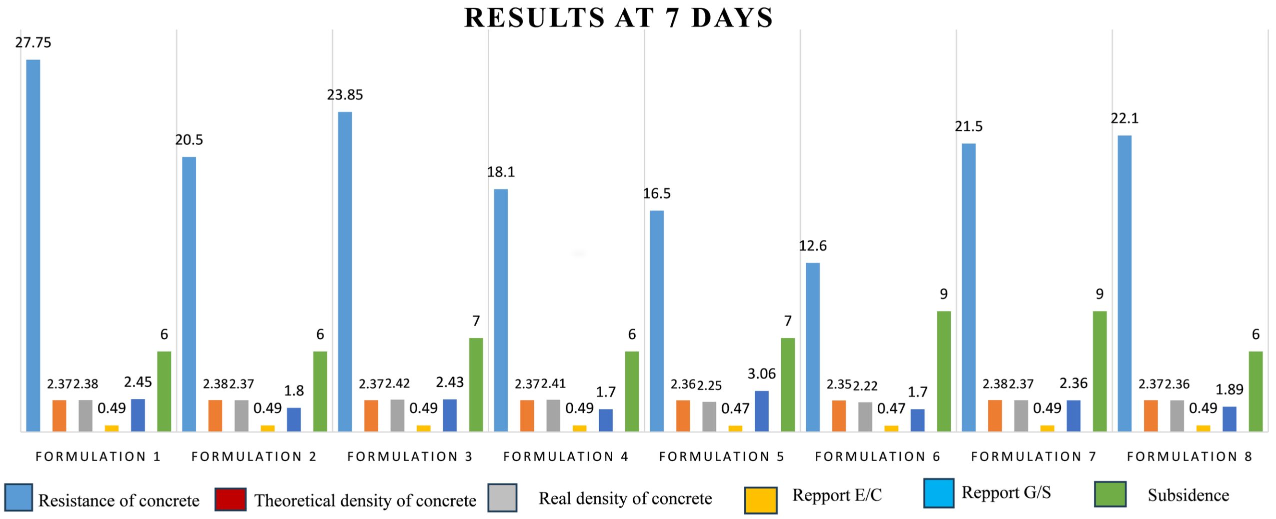

Figure 25. Results of concrete formulations at 7 days.

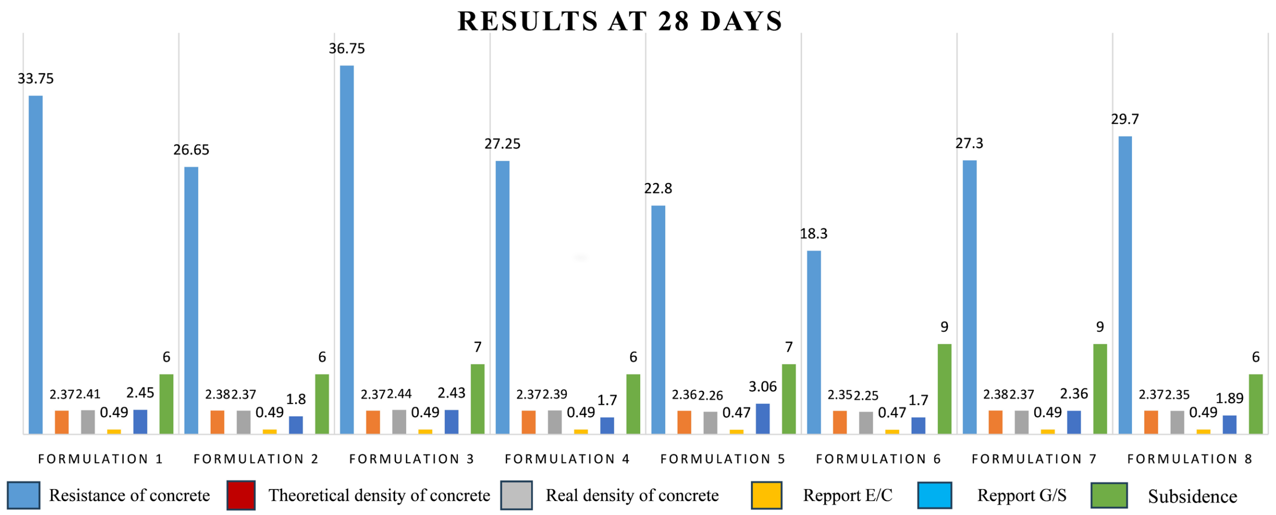

Figure 26. Results of concrete formulations at 28 days.

4. Discussion

Several researchers have studied the identification and characterization of aggregates for concrete manufacturing. The works of De Larrard (2000), Malanda *et al.* (2019), Zeghichi *et al.* (2019), and Ali Abderrahmane *et al.* (2018) have addressed improving fine sands with other compliant materials, such as glass, which positively influence the fineness modulus and fines rate, leading to a continuous granular skeleton.

The choice of aggregates is crucial in concrete manufacturing, as their qualities significantly impact the concrete's strength, durability, and structural performance.

The characterization of aggregates has helped us understand the impact of each constituent in the formulation of fresh and hardened concrete. Improving sands positively affected the granular curves of concrete sands. The results from crushing the concrete specimens showed good compressive strength at 28 days for concretes made with sand not improved with crushed gravel (Brazzaville: formulations 1 to 4) and those made with 50% crushed sand with crushed gravel (Pointe-Noire: formulations 7 and 8). However, formulations 5 and 6 (Pointe-Noire) did not achieve the expected characteristic strength at 28 days.

Studies by Malanda *et al.* [2] on Congo River sand from the Mfilou and Djiri quarries in Brazzaville concluded that these sands did not meet the technical requirements of the standard. However, they were improved by adding a 0.63/5 aggregate during concrete placement to enhance their granular curves in the 0.63/5 fraction (NFP 15-403). Regarding these technical specifications, the sands possess the physical properties needed for quality mortars and concretes. Concrete formulations using these improved sands have produced quality concrete with expected strengths at 28 days, along with good workability and durability.

Concretes made with unimproved sands have better results than those with improved sands in terms of expected characteristic strength at 28 days. However, concretes made with crushed gravel have an even better expected characteristic strength at 28 days.

The compacting granular coefficients of the materials are acceptable compared to studies by De Larrard [9], which state that the coefficients for crushed aggregates range from 0.53 to 0.58, while those for rolled aggregates range from 0.6 to 0.64. These values indicate that concrete made from these aggregates is classified as porous concrete, with compactness values between 0.5 and 0.6.

These results are consistent with those obtained by Ali Abderrahmane *et al.* [10], who show that:

- The addition of crushed sand to fine sand positively influences the modulus of fineness and reduces the rate of fines, resulting in a continuous granular structure.
- The bulk density of concrete varies with the percentage of crushed sand, likely due to increased void volume between grains as the percentage of crushed sand increases.
- Concrete formulations with optimized percentages will likely achieve compressive strength values comparable to other concrete formulations.

Similarly, studies by Zeghichi *et al.* [11] have shown that adjusting the grain size of fine sand does not improve concrete properties. The workability of the concrete is affected by such a substitution because the substitute aggregates have a non-rounded shape, requiring additional water for wetting. However, the mechanical compressive strength increases when sand is used as the improvement material instead of glass.

As a result, this study has shown that the aggregates sampled and used for current concrete formulations, particularly sands, lack the granular proportion recommended by the Dreux-Gorisse method and fall into the category of fine sands based on granulometric curves [12]. Adding crushed sand from Brazzaville and Pointe-Noire to rolled sands in proportions of 30%, 40%, and 50% has improved the material, but it still exhibits the physico-mechanical characteristics of fine sands. This likely results in better mechanical outcomes because, as shown by Tiegoum Wembe *et al.* [13], compressive strength strongly depends on the percentage of fines. Japhet Tiegoum also demonstrated the importance of using large quantities of fines in sands as a substitute for other sands, enabling the production of high-performance concrete with 65% crushed sand and 35% river sand.

Furthermore, Elat *et al.* [14] showed that concrete made with only crushed sand has higher drying shrinkage at a young age than concrete made with river sand. Compared to conventional concrete (made with 100% river sand), concrete with 50% crushed sand has reduced slump value, lower porosity, and a compressive strength very similar to that of conventional concrete.

Concretes made with raw sand and crushed gravel have yielded better results than those with improved sand, likely due to high shrinkage at a young age [14].

5. Conclusions

In this study, rolled sands from Brazzaville and Pointe-Noire were improved with crushed sands from the same localities to formulate concrete meeting recommended specifications. To develop an optimal mix, the aggregates were characterized and studied in the laboratory. Physico-mechanical tests indicated that the aggregates, particularly the sand, needed improvement to meet the Dreux Gorisse method requirements. Consequently, an improvement with proportions ranging from 30% to 50% enhanced the raw sands with crushed sands from each locality. The physico-mechanical characteristics of the formulated concretes achieved the expected mechanical strengths.

These results indicate good compressive strength at 28 days for concretes made with sand not enhanced with crushed gravel (Brazzaville: formulations 1 - 4) and those made with 50% crushed sand with crushed gravel (Pointe-Noire: formulations 7 and 8). However, formulations 5 and 6 (Pointe-Noire) did not achieve the expected characteristic strength at 28 days. The compensation by granular elements in the gravel (5/15 and 3/8) and the percentage of fines in the aggregates led to an improvement in the granular curves and positively impacted the characteristic and mechanical strength of the concretes.

Although some authors claim positive results when formulating concrete with these categories of sand, an in-depth microstructural study (DRX, ATG/ATD, MEB, microstructural analysis by mercury intrusion) [15] will allow us to examine the concrete matrix to deduce the impact of this improvement.

Conflicts of Interest

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

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