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Influence of Types of Fillers on Workability, Bleeding, Compressive Strength, and Degree of Compaction of Hydraulic Concrete

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Abstract

This study aims to determine the optimal quantity of fillers to add to hydraulic concrete and to assess the influence of these fillers on its rheological characteristics and mechanical properties. The characterization of the aggregates shows that they meet the specifications for the formulation of hydraulic concrete according to the Dreux-Gorisse method. Normalizing the formula to the cubic meter enables to define the standard concrete. The cement content is 350 kg/m^3. The mineral materials added to the concrete to increase its characteristics and properties are limestone, basalt, and sandstone fillers with a weight percent of 4%, 5%, and 3% respectively. Changes in concrete properties with the addition of fillers were determined through geotechnical tests. The results obtained show a decrease in the workability measured by slump test which returned 7.8 cm for the standard concrete sample, 7.2 cm with 5% of basalt, 7.3 cm with 4% of limestone, and 6.1 cm with 3% of sandstone. Regarding the bleeding, the results show that it decreases leading to a substantial improvement in stabilization reaching 26% with 5% of basalt fillers, 29% with 4% of limestone fillers, and 31% with 3% of sandstone fillers. The compressive strengths noted R_{c28} at 28 days increases compared to that of the standard concrete, which is 31.5 MPa. They increase to 34.3 MPa with 5% of basalt fillers being 8.9%, 36.2 MPa with 4% of limestone fillers being 14.9%, and 36.8 MPa with 3% of sandstone fillers being 16.8%. Finally, the addition of fillers increases the degree of compaction values to 83.62% with 5% of basalt fillers, 84.2% with 4% of limestone fillers, and 84.34% with 3% of sandstone fillers.

Keywords

Basalt, Limestone, Filler, Sandstone, Hydraulic Concrete

1. Introduction

The durability of structures in the construction sector is closely linked to the type and quality of the materials used, in particular those intended for hydraulic concrete. Hydraulic concrete is defined as a material formed by mixing cement, sand, gravel, and water, and to which may be added adjuvants, fibers, and whose properties develop through hydration [1].

From the choice of its components to its processing, hydraulic concrete allows it to carry out the most complex works by taking the shape of the formwork panel due to its workability. Its degree of compaction and strength, on the other hand, control its durability.

Apart from the natural aggressions due to geodynamic processes, the main causes of the decrease in the service life (durability) of a concrete structure are notably the corrosion of reinforcement steel, the action of aggressive water, the alkali-reaction causing swelling in concrete [2].

Thus, in order to reduce the shrinkage caused by the high heat of hydration of the cement used, the addition of filler to the concrete was considered in this study. High filler contents are often used to realize self-compacting concrete [3].

Filler is defined, according to the standard NF EN 1097-7 [4], as aggregates, most of which pass through a 0.063 mm sieve, which can be added to construction materials to obtain certain characteristics. Fillers are designated by class $0/D$ such that $D \leq 2$ mm with at least 85% passing through the 1.25 mm sieve and 70% at least passing through the 0.063 mm sieve.

Depending on the standard considered, the filler used in hydraulic concrete can be of the main following types: pigments, silica fumes, granulated blast furnace slag, meta-kaolin, or siliceous and limestone additions. As with fines, their natures must be determined and their harmfulness assessed [5].

Cement production estimation reached 88.5 million metric tons in the United States in 2019, in comparison to the 4.1 billion metric tons of cement produced worldwide [6]. This makes it the most used manufacturing material in the world. This material enables to conduct construction works of all kinds and, in particular, buildings, roads, bridges, thermal and nuclear power stations, dams, tunnels as well as offshore oil platforms. The development of the use of building material is based on technical and economic criteria.

The consistency of hydraulic concrete describes its manœuvrability or workability. It determines the ease of placing concrete in the formwork panels and is influenced by the water and cement content. The consistency of concrete can be measured by one of the following methods: slump test according to EN 12350-2 [7], tightening index according to EN 12350-4 [8], spread table test according to EN 12350-5 [9], Abrams cone spreading test according to EN 12350-8 [10].

The objective of this work is to see from a cubic meter of concrete formulated with the Dreux-Gorisse method (basic formula), what is the quantity of filler that can be added without exceeding the cubic meter of concrete. These additions, made up of basalt, limestone, and sandstone fillers of different geological nature, have a different influence on the parameters tested, namely workability, density, bleeding, compressive strength, and the degree of compaction of concrete.

2. Experimental

The most commonly used method to determine the concrete consistency is the Abrams cone slump test. There are five classes of concrete consistency with a tolerance specified in **Table 1**.

Hardened concrete is a solid-state concrete that has gained noticeable strength after 28 days of curing [11]. Its bulk density is determined on specimens previously dried in an oven. The different classes of hydraulic concrete as a function of bulk density are given in **Table 2**.

The compressive strength of hardened concrete is the ratio between the load causing the failure and the section of the specimen on which the load is applied. The specimen can be cubic or cylindrical but, in Senegal, the cylindrical specimen 32/16 of slenderness 2 (height: 32 cm; diameter: 16 cm) is more used.

The strength classes as a function of compressive strength at 28 days of concrete curing are given in **Table 3**. A distinction must be made between the minimum characteristic strength on cylinders (with diameter over height dimensions in mm 150 - 300, 160 - 320, 110 - 220; 160 - 320 being more common) and the minimum characteristic strength on cubes at 28 days of curing (100 or 150 mm edge).

Table 4 gives the classification of reinforced and unreinforced concrete according to the maximum size of the aggregates.

2.1. Petrographic Description of the Aggregates Used

In this study, the basalt aggregates of grain size 0/3, 3/8, and 8/16 come from Diack

Table 1. Consistency classes based on Abrams slump tests cone [5].

Class	Slump value according to standard EN 12350-2 (mm)	Tolerance (mm)	Comments
S1	10 to 40	±10	Firm
S2	50 to 90	±20	Plastic
S3	100 to 150		Very plastic
S4	160 to 210	±30	Fluid
S5	≥220		

Table 2. Classes of concrete as a function of bulk density [5].

Concrete type	Density (kg/m³)
Light concrete	from 800 to 2000
Concrete with normal density	from 2000 to 2600
Heavy concrete	Greater than 2600

Table 3. Strength classes of concrete at 28 days of curing as a function of compressive strength [5].

Compressive strength classes for normal and heavy concrete			Compressive strength classes for lightweight concrete		
Class	fck-cylind (N/mm^2)	fck-cubic (N/mm^2)	Class	fck-cylind (N/mm^2)	fck-cubic (N/mm^2)
C 8/10	8	10	LC 8/9	8	9
C 12/15	12	15	LC 12/13	12	12
C 16/20	16	20	LC 16/18	16	18
C 20/25	20	25	LC 20/22	20	22
C 25/30	25	30	LC 25/28	25	28
C 30/37	30	37	LC 30/33	30	33
C 35/45	35	45	LC 35/38	35	38
C 40/50	40	50	LC 40/44	40	44
C 45/55	45	55	LC 45/50	45	50
C 50/60	50	60	LC 50/55	50	55
C 55/67	55	67	LC 55/60	55	60
C 60/75	60	75	LC 60/66	60	66
C 70/85	70	85	LC 70/77	70	77
C 80/95	80	95	LC 80/88	80	88
C 90/105	90	105			
C 100/115	100	115			

Table 4. Classification of reinforced and unreinforced concrete according to the maximum size of the aggregates.

Reinforced concrete		Unreinforced concrete
Upper diameter	Types de pile	
32 mm and 1/4 of bar to bar spacing longitudinally	For bored piles and diaphragm walls	Cyclopean concrete: Made for basement walls. Composed of large blocks of stone, rubble stones, pebbles.
32 mm and 1/3 of bar to bar spacing longitudinally	For piles with reverse flow	Bedding concrete (D_{max} = 25 mm): Carried out under all structures with a base in contact with the ground
16 mm and 1/4 of bar to bar spacing longitudinally	For micro-piles	Ground slab concrete (D_{max} = 15 mm)
1/6 of the inside diameter of the dip tube	In case of installation in submerged conditions	Stonework concrete: Stepping of lips and runs, filling of material shortages

quarries located in the eastern limit of the Thiès Plateau, about 30 km from the city of Thiès. Diack's basalt belongs to Miocene volcanism. Three textures have been identified for this material, namely, fine-grained, medium-grained, and coarse-grained one [12].

The sand was collected at the Beer borrow material source. It is mainly made up of silica sand in the form of coastal dunes, lagoon sediments, and red dunes dated to the Quaternary.

Limestone filler produced from calcareous rocks from Bandia quarries (consisting of a very hard yellowish sandstone limestone with a massive aspect) and sandstone filler from Toglou quarries (sedimentary formations dated to the Maastrichtian) are used in this study.

Litho-stratigraphic studies show that the Toglou quarries are made up of fine-grained siliceous cement sandstones. The deposit presents some heterogeneity marked by an alternance of hard and soft layers, covered by a lateritic cuirass [13]. **Table 5** gives the specifications according to standard NF P 18-545 [14] as well as the grain sizes of the filler.

2.2. Concrete Composition Calculated Using Dreux-Gorisse Method

This method is one of the most used among the concrete composition calculation methods [15]. It enables to determine, according to the manœuvrability and strength criteria of the concrete defined in the specifications, the nature and the quantities of the components necessary to make one cubic meter of concrete.

For this study, CEM II/B-M 42.5 cement from Sococim Industries with a density (ρ_c) of 3.1 kg/liter was used. The cement quantity used is 350 kg/m^3. The main parameters of the concrete used in this study are:

- the nominal strength in uniaxial compression at 28 days (σ'_n) which is 30 MPa; the average compressive strength at 28 days targeted on site (σ'_{28}) equal to the value of (σ'_n) increased by 15%, that is: $\sigma'_{28} = 1.15 \times \sigma'_n = 34.5$ MPa;
- An Abrams slump test value of A = 80 mm which characterizes the desired workability.

2.3. Water Content

The *Bolomey* relation [16] that allows to determine the ratio between cement and water (C/E), is described by Equation (1).

$$\sigma'_{28} = G \times \sigma'_c \times \left(\frac{C}{E} - 0.5\right) \quad (1)$$

where:

Table 5. Specifications according to standard (NF P 18-545 [14]) and grain size of filler.

Specifications (Standard NF P 18-545)		**Grain size of fillers (%)**		
		Basalt filler	Limestone filler	Sandstone filler
Percent by weight of passing to 2 mm (%)	100	100	100	100
Percent by weight of passing to 0.125 mm (%)	85 - 95	92	92	92
Percent by weight of passing to 0.063 mm (%)	70 - 80	78	78	78

σ'_{28} : average compressive strength desired (at 28 days) in MPa,

G : granular coefficient (0.6),

σ' : class of cement (MPa),

C : cement content in kg/m^3,

E : water content on dry materials in liters for 1 m^3,

So, the ratio $\frac{C}{E} = 1.565$.

2.4. Aggregate Content

The grain size distribution of the aggregates used for the concrete and the partition curve of Figure 1 gives the different granular proportions. Figure 1 shows a composition of 58%, 8%, and 34% respectively for 8/16, 3/8, and 0/3 granular classes of the total dry volume of the aggregates.

Thus, the mass and volumetric proportions of the various components which should make up the theoretical cubic meter of fresh concrete are given in Table 6.

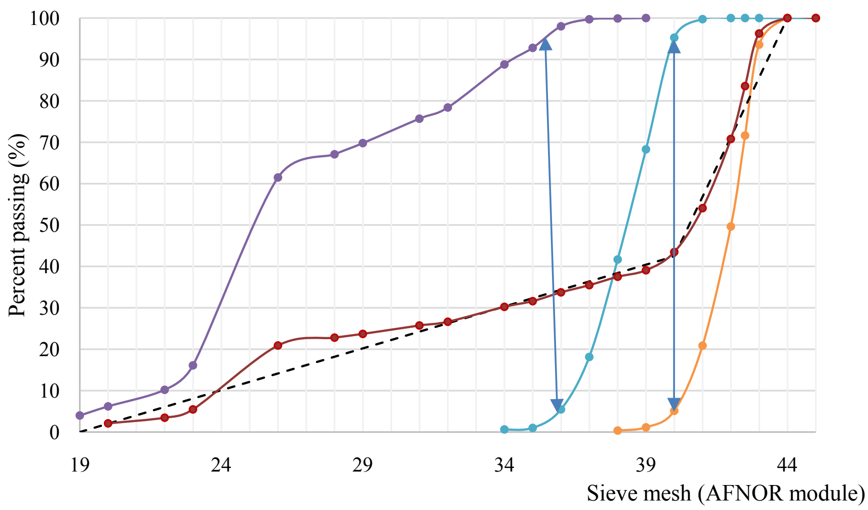

Figure 1. Grain size distribution of aggregates used for the concrete.

Table 6. Theoretical composition of concrete per cubic meter.

Theoretical composition of concrete per m^3					
Concrete components	Percentage	Volume	ρ_r	Quantity	20 liters
	%	l	kg/l	kg/m^3	kg
Basalt 8/16	58	407	2.976	1212	24.23
Basalt 3/8	8	56	2.978	167	3.34
50% dune sand + 50% basalt 0/3	34	239	2.765	660	13.20
Cement CEM II/B-M 42.5	-	113	3.1	350	7.00
Water (tap water)	-	211	1	211	4.25
Total	100	1023	-	2600	52.03

Theoretical bulk density of fresh concrete ρ_{th} = (2600/1000) = 2.600 kg/liter.

2.5. Normalization to One Cubic Meter and Optimization by Adding Filler

2.5.1. Normalization of Dreux's Formula to a Cubic Meter of Concrete

In general, in the reference formula, the sum of the components, including water, does not give the exact weight per cubic meter of fresh concrete used. The targeted quantities may therefore require an adjustment to the cubic meter that only a measurement of the fresh concrete density can make possible (weighing of cylindrical specimens).

This task consists of making a mix of three specimens (*i.e.* 20 liters of the theoretical cubic meter of concrete) from the reference formula and measure, by weighing, the density of the fresh concrete.

The workability and plasticity tests, to determine the desired manœuvrability or consistency (A = 70 to 80 mm), generally result in a correction of the water content. The amount of water added when mixing is 211 liters per m^3 of concrete.

And, for a theoretical bulk density of fresh concrete noted ρ_{th} = (2600/1000) = 2600 kg/m^3 we have, at the end of the test, a density of ρ_r = 2525 kg/m^3.

As $\rho_r < \rho_{\text{th}}$, this means that there is a bit more aggregate than needed to make exactly one cubic meter of concrete at the desired cement content. This corresponds, compared to the cubic meter of fresh concrete, to an excess of mass of m = 1000 × (2600 − 2525) = 75 kg.

This mass must be reduced proportionately on the aggregates by applying an adjustment coefficient given by Equation (2):

$$\gamma_{aj} = 1 + \frac{1000 \times (\rho_r - \rho_{\text{th}})}{M_G + M_S} \gamma_{aj} = 1 + \frac{1000 \times (2.525 - 2.600)}{1212 + 167 + 660} = 0.963 \quad (2)$$

ρ_{th}: theoretical density of fresh concrete;

ρ_r: current density of fresh concrete;

M_G: mass of gravel (3/8, and 8/16);

M_S: mass of sand (mass of the mixture of dune sand + basalt 0/3);

γ_{aj}: concrete adjustment coefficient per cubic meter.

Thereafter, the mass and volumetric content of the aggregates in the reference composition obtained by Dreux-Gorisse are multiplied by this adjustment coefficient to have a new composition of the concrete normalized to the cubic meter. At the end of this adjustment of the reference formula, the mass and volumetric proportions of the various components per actual cubic meter of fresh concrete are given in **Table 7**.

This formula constitutes the reference one resulting in concrete with intergranular voids. This study aims to allow to determine the quantity of limestone, basalt, and sandstone filler that can be incorporated into the concrete to fill their voids.

2.5.2. Optimal Quantity of Filler

Whatever the type of filler, the optimal quantity corresponds to that which offers maximum compactness and beyond which the cubic meter of concrete is exceeded.

Table 7. Summary table of the composition of the concrete after normalization to the cubic meter.

Concrete composition after adjustment to m^3					
Concrete components	Percentage	Volume	ρ_r	Quantity	45 liters
	(%)	l	kg/l	kg/m^3	kg
Basalt 8/16	58.0	392.0	2.976	1167.0	52.52
Basalt 3/8	8.0	54.0	2.978	161.0	7.25
50% dune sand + 50% basalt 0/3	34.0	230.0	2.765	636.0	28.61
Cement CEM II B-M 42.5	-	113.0	3.1	350.0	15.75
Water (tap water)	-	211.0	1.0	211.0	9.50
Total	100	1000.0	-	2525.0	113.62

Theoretical bulk density of fresh concrete ρ = (2 525/1000) = 2.525 kg/liter.

By keeping the quantity of aggregates, cement, and water content constant, the determination of the optimal quantity of filler is done by an experimental protocol which is described and carried out as follows.

Figure 2 shows the type of fillers used.

The device consists of a set formed by a vibrator at a frequency of 60 Hz, a cylindrical hollow steel mold with a height of 400 ± 10 mm, an internal diameter of 140 ± 10 mm, and a thickness of 3 mm for a total volume of 6.158 liters. Inside the mold, we have a piston made up of a full steel cylinder with an outside diameter equal to the inside diameter of the mold minus 1 mm, *i.e.* 139 mm (to allow it to slide freely inside the mold). The piston has a weight which, depending on its actual density, can apply a pressure of 10 kPa to the fresh concrete sample (1.693 liters).

This piston is provided with a socket of cylindrical solid shape in steel and having an outside diameter of 43 mm and a height of 250 mm. It is welded in the middle of the piston and makes it easier to use (Figure 3).

To have a pressure of 10 kPa, the mass of the piston is calculated as follows in Equation (3):

$$P = \frac{F}{S} = \frac{mg}{\pi r^2} = \frac{mg}{\pi \frac{d^2}{4}} = 10\ \text{kPa} = 1\ \text{N/cm}^2 \tag{3}$$

$$m = \frac{1 \times \pi \frac{d^2}{4}}{g} = \frac{1 \times \pi \times \frac{13.9^2}{4}}{10} = 15.175\ \text{kg}$$

with:

P: pressure (N/cm^2); *F*: strength (N); *m*: piston weight (kg).

g: gravity constant (m/s^2); *d*: piston diameter (cm); *r*: piston radius (cm).

A very thin geomembrane of 142 mm diameter to prevent the concrete from leaking during the vibration, a lubricant to facilitate the free rotation of the piston in the mold, a rag to wipe the mold after use and a non-absorbent metal ring for the sampling are also used.

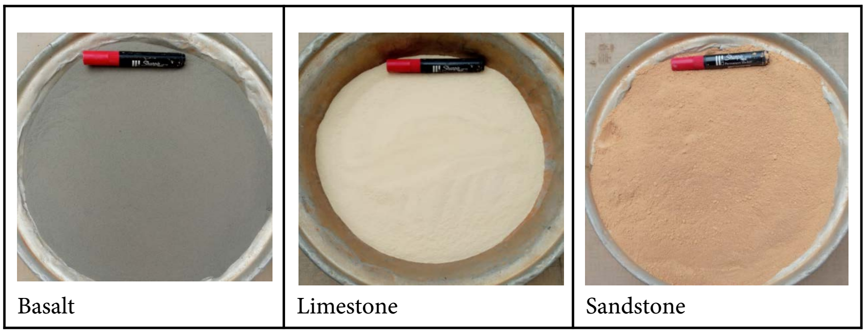

Figure 2. Types of filler used.

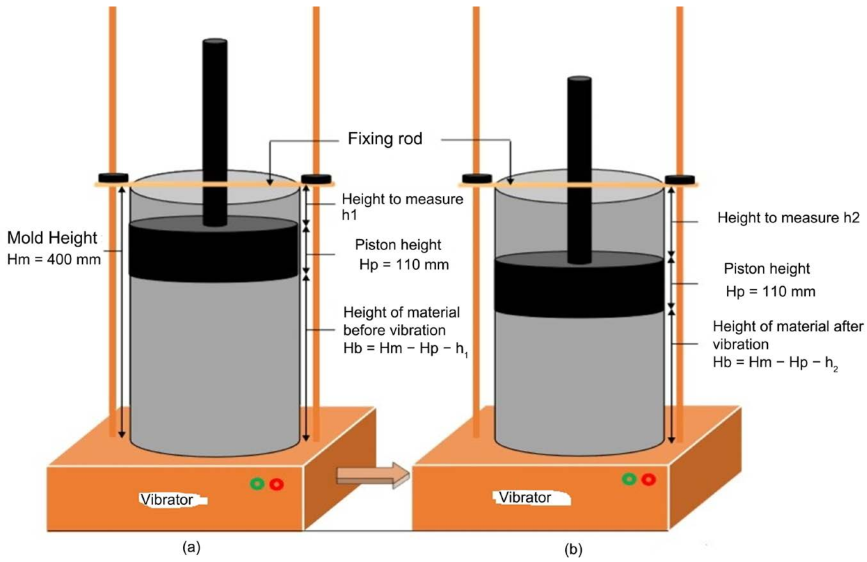

Figure 3. Apparatus for the determination of the concrete compactness. (a) Measure before vibration; (b) Measure after vibration.

The materials must first be well dried in a ventilated oven adjustable to 105˚C. Since the concrete is measured per m^3, the volume of the batch of concrete corresponding to the test specimen is chosen according to the remaining volume of the mold. The latter is the volume of the mold minus the volume that the piston would occupy in the mold (4.465 liters).

3. Results and Discussion

3.1. Geotechnical Characterization of Aggregates

The particle size distribution curves of the basalt aggregates of 3/8 and 8/16 classes are respectively shown in Figure 4. Those of sand dune (0/1), basalt (0/3) and their mixture in equivalent proportion (50% of each), are shown in Figure 5.

The results of the geotechnical characterization of the aggregates are given in Table 8.

The respective particle size curves of the granular class 0/3 of basalt, limestone and sandstone are shown in Figure 6. These particle size distributions, carried

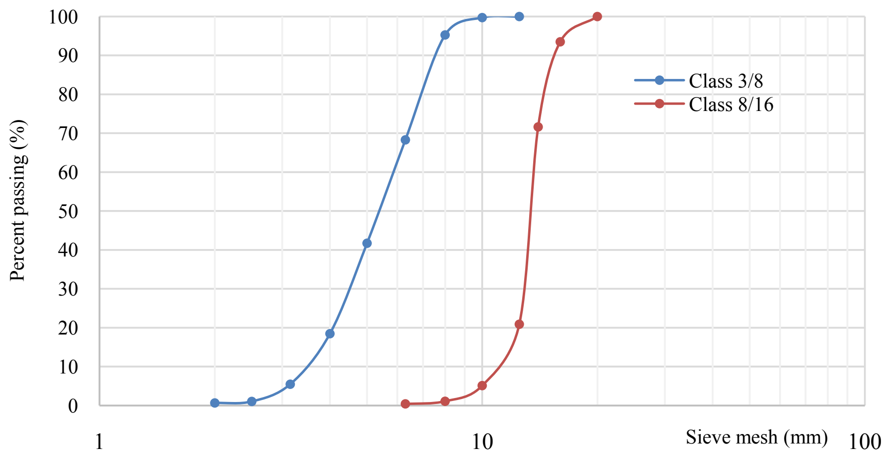

Figure 4. Particle size curves of basalt samples 3/8 and 8/16 classes.

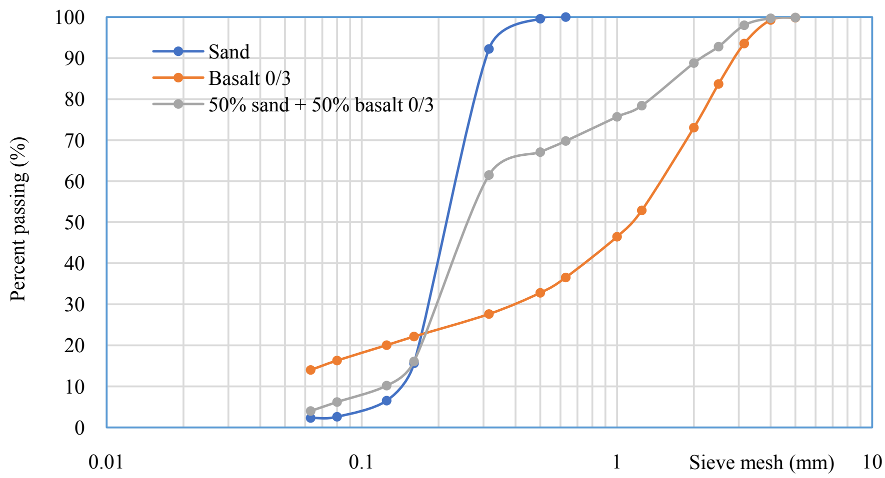

Figure 5. Particle size curves of dune sands, basalt 0/3 and their mixture (50% dune sands + 50% basalt 0/3 class).

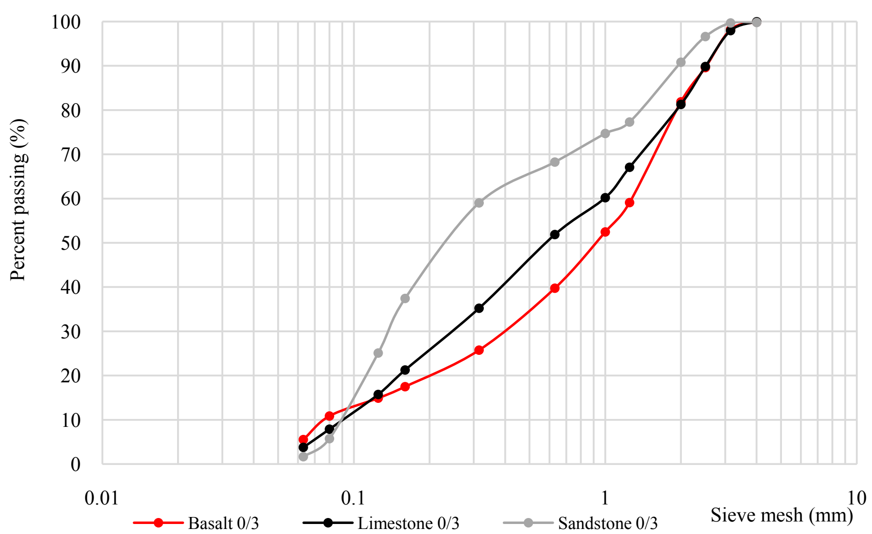

Figure 6. Particle size distribution of crushed sand of basalt, limestone and sandstone 0/3 class.

Table 8. Summary table of the geotechnical characterization of aggregates.

Geotechnical characteristics of aggregates	Granular classes								Technical specifications/ Category A
	Gravel		Sand			Filler			
	Basalt 8/16	Basalt 3/8	Basalt 0/3	Dune sand	Basalt 0/3 + sand	Basalt	Limestone	Sandstone	
Geometric characteristics									
Aggregate shape—Flakiness index, FI (%)	18	22_B	-	-	-	-	-	-	≤20
Sand fineness module, Mdf	-	-	2.79	0.92	1.86	-	-	-	--
Physical and chemical characteristics									
Sand equivalent, ES	-	-	63	74	66				>60%
Surface cleanliness of gravel, P (%)	0.39	0.88	-	-	-	-	-	-	≤5%
Methylene blue test MB (g/kg)	-	-	3.46	2.33	3.08	8.48	7.23	4.27	≤10 g/kg
Physical and mechanical characteristics									
Micro-Deval test, MDE (%)	18	16	-	-	-	-	-	-	<25
Los Angeles test, LA (%)	14	16	-	-	-	-	-	-	<30
Water absorption coefficient; W_{A24} (%)	0.699	0.676	1.24	0.676	0.954	1.25	3.73_B	6.51_B	≤2.5%
Apparent bulk density in (kg/l)	1.595	1.598	1.621	1.492	1.563	-	-	-	--
Inter-granular porosity	0.46	0.46	0.45	0.44	0.43	-	-	-	--
Bulk density (kg/l)	2.976	2.978	2.921	2.657	2.765	-	-	-	--
Filler bulk density (kg/l)	-	-	-	-	-	3.021	2.722	2.397	--

The index B designates the characteristics which meet the category B aggregates (NF P18-545 [14]).

out by dry sieving, allow the determination of the quantity of fines (passing through a sieve of 0.063 mm) which can be obtained from this granular class (0/3) which is the smallest size particle produced in quarries in Senegal. It is this quantity that defines how many fillers can be produced. These grain size curves show that the percentage of passing through 0.063 mm sieve are 2%, 4% and 6% respectively for sandstone, limestone, and basalt. These percentages of fines obtained reflect the degree of hardness of these three geological materials.

After the sieving, respectively with 0.063, 0.125 and 1 mm of sieve diameter, the three fractions obtained are mixed in proportions specified to have the filler. Indeed, aiming to fill the microstructure of the concrete, the fillers were cut to a maximum diameter of 1 mm which is well between 0.125 and 2 mm.

3.2. Concrete Composition

Taking into account the measurements to be made after vibration, a volume of three (3) liters was chosen. The concrete components, which must correspond to this volume, serve as a reference formula from which we add limestone, basalt, and sandstone fillers in increasing proportions (2%, 4%, 6%, and 8%) compared to the cement content. Table 9 gives the details of sampling for determining the optimum filler addition.

Table 9. Sampling for determining the optimum filler addition.

Dosage	Dosage (m^3)		Dosage for 3 liters (0.003 m^3)			
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Percentage of filler	0%	0%	2%	4%	6%	8%
The components	**Reference formula**		**Filler addition**			
Basalt 8/16	**1167**	3.501	3.501	3.501	3.501	3.501
Basalt 3/8	**161**	0.483	0.483	0.483	0.483	0.483
Basalt 0/3	**318**	0.954	0.954	0.954	0.954	0.954
Dune sand	**318**	0.954	0.954	0.954	0.954	0.954
Filler	**0**	0	0.021	0.042	0.063	0.084
Cement CEM II B/M 42.5	**350**	1.050	1.050	1.050	1.050	1.050
Water (tap water)	**211**	0.633	0.633	0.633	0.633	0.633
Total	**2525**	7.575	7.596	7.617	7.638	7.659

Thus, once the sampling settled up, the test is carried out for the three types of fillers in order to know their effect on the concrete. Figure 7 shows the optimum for each type of filler. It is 4.2% for basalt, 3.8% for limestone and 2.3% for sandstone. Two (02) values framing the optima on the three different curves and the value of 5% for limestone were then used to know the behavior of the concrete beyond the optimum. Seven (7) formulas were then used to be compared to the reference formula (composition without filler).

Table 10 presents percentages of filler implemented in order to investigate the effect they would have on the physical, chemical, and mechanical properties of hydraulic concrete.

The optimization enables to define the quantities of fillers that can be incorporated into the microstructure of concrete without exceeding the cubic meter of concrete. It should also be noticed that these quantities are linked to the fineness (specific surface) of the filler as well as to their actual density.

3.3. Influence of Additions of Filler on the Workability of Concrete

The test is carried out in accordance with standard NF EN 12350-2 [17]. It consists in compacting by chipping the fresh concrete in a mold having the shape of a cone. When the cone is removed vertically, the slump test of the concrete allows its consistency to be measured. A batch of concrete for seven (7) cylindrical specimens of dimensions 160 mm in diameter and 320 mm in height is made for each given formula. The results obtained on the different formulas used are shown in Figure 8.

Figure 8 shows that the slum test decreases with the addition of filler. For formulas with the addition of basalt and limestone fillers, the slump test values are smaller to that of the reference formula. This could be explained by the fact that basalt and limestone generate much more fines than sandstone does because of their mineralogical composition. However, it is important to notice that, despite

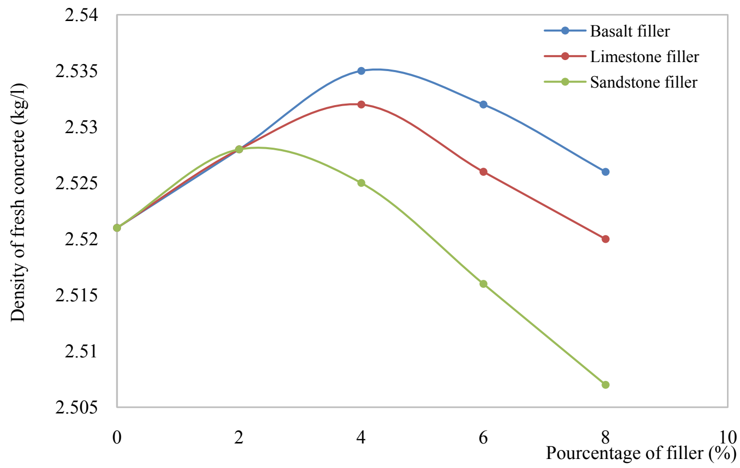

Figure 7. Variation of the bulk density of fresh concrete as a function of the percentage of filler added.

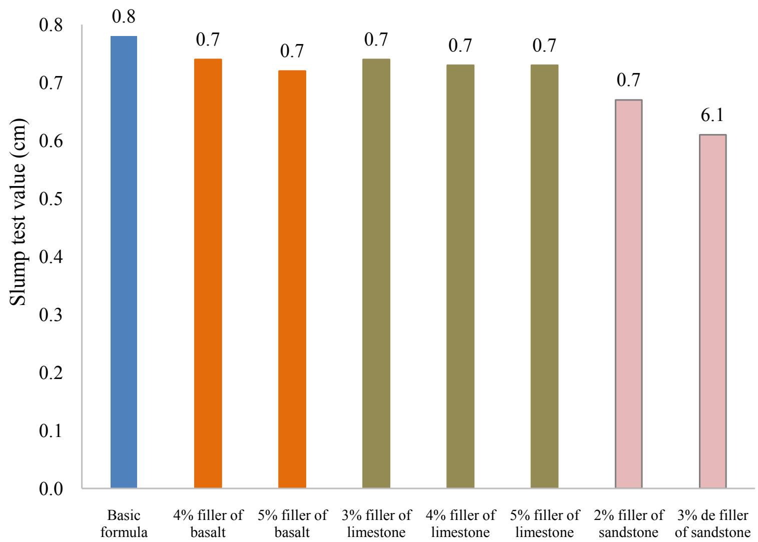

Figure 8. Variation of the slump test as a function of the percentage of mineral additions.

Table 10. Composition per cubic meter of concrete to be prepared.

Composition per cubic meter of concrete to be prepared								
Components	**Reference formula (Bf)**	Bf + basalt filler		Bf + limestone filler			Bf + sandstone filler	
Fillers (%)	**0%**	4%	5%	3%	4%	5%	2%	3%
				kg/m³				
Basalt 8/16	**1167**	1167	1167	1167	1167	1167	1167	1167
Basalt 3/8	**161**	161	161	161	161	161	161	161
Basalt 0/3	**318**	318	318	318	318	318	318	318
Dune sand	**318**	318	318	318	318	318	318	318
Filler	**0**	14	17.5	10.5	14	17.5	7	10.5
Cement CEM II B/M 42.5	**350**	350	350	350	350	350	350	350
Tap water	**211**	211	211	211	211	211	211	211

the addition of filler, the concrete produced still remain in the slump class S2 of plastic consistency (from 50 to 90 mm with a tolerance of ±2 mm). The addition of filler, therefore, does not affect the need for water in the mixture.

3.4. Influence of Additions of Filler on the Density of Concrete

The test is carried out according to standard NF EN 12390-2 [18]. Six (06) specimens are made to determine the unconfined compressive strength of concrete at 7 and 28 days (**Figure 9**).

Figure 10 gives the variation of the bulk density of the fresh concrete according to the addition of *x* (%) of filler.

The slight increases in density compared to that of the reference formula show that the fillers have been well incorporated into the concrete (its voids), hence the improvement in compactness. However, beyond the optimum for limestone

Figure 9. Tests specimens.

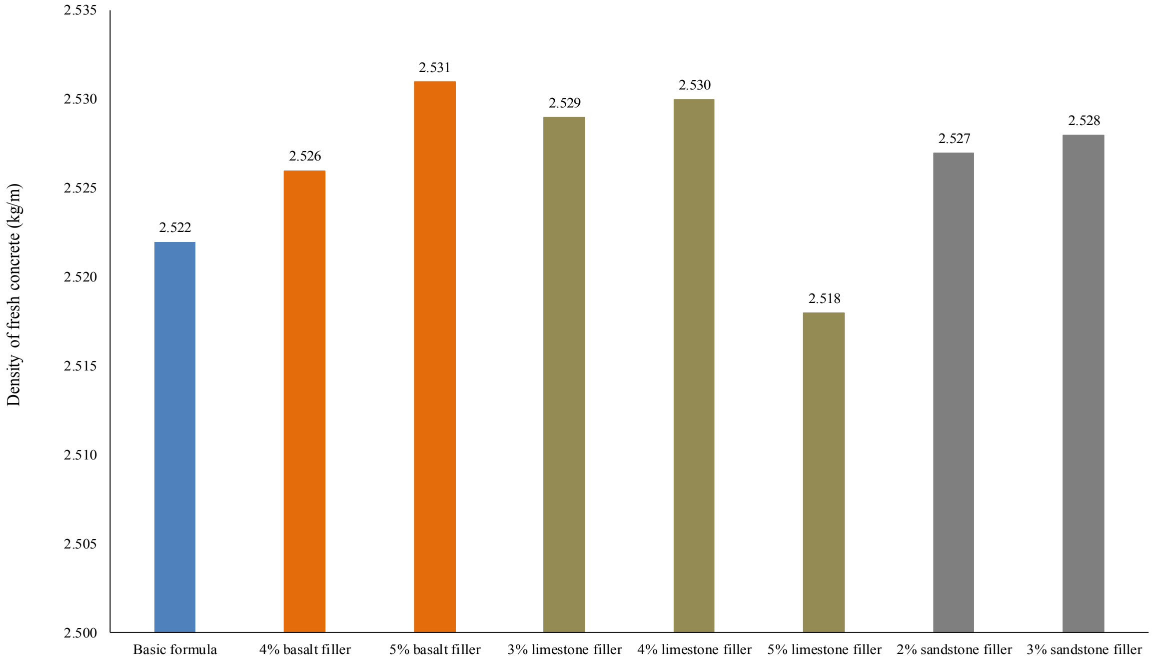

Figure 10. Variation of the density of fresh concrete.

filler (5%), the decrease in density results in an increase in volume because the cubic meter of concrete is exceeded at this percentage.

3.5. Influence of Addition of Filler on the Concrete Bleeding

Bleeding occurs when a freshly mixed cement-based material starts to settle. It is the phenomenon of exudation of the mixing water from concrete before it starts its setting (X P18-468) [19]. The bleeding and the water evaporation of concrete affect plastic shrinkage cracking.

This process is often due to an insufficiency of fines, an excess of vibration or high water content.

The total bleeding is expressed by the ratio RT (mm/min), and is calculated by Equation (4):

$$R_T = \frac{Ec_{\text{totale}}}{V_{\text{beton}}} \quad (4)$$

with: $Ec_{\text{total}} = \sum E_i$ and $V_{\text{concrete}} = \frac{m_2 - m_1}{D}$,

Ec_{total}: total cumulative volume of water (ml),

V_{concrete}: volume of the concrete sample (l),

E_i: volume of water sampled (ml) at time t_i,

m_1: mass of container (g),

m_2: mass of sample and container (g) at the start of the test,

D: density of fresh concrete (kg/l),

R_T: total bleeding of the concrete (mm/min).

The curves for variation of bleeding E_i as a function of time (t) are given in Figure 11.

Figure 11 shows that the curve of the reference formula is above the curves of the formulas with addition of filler. The latter, being more or less overlapped,

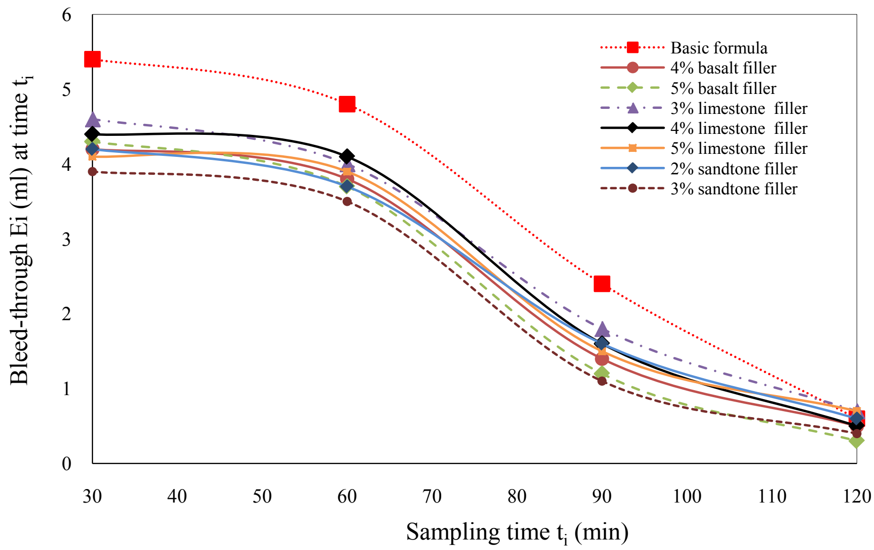

Figure 11. Variation of bleeding (E_i) as a function of time (t).

show a natural variation in the quantities of water sampled (E_i) depending on the type, and quantity of filler. The curves show overall that the bleeding of the concrete is reduced by the addition of filler. Topsu and Elgun [20] show that concrete mixes containing high cement contents yielded minimum quantities of bleeding and concrete mixes containing more mixing water yielded the maximum amount of water evaporation.

Thus, the finer and more absorbent the filler, the more it reduces bleeding. The reduction in the bleeding of the concrete is a favorable consequence of the incorporation of filler in it because it allows stabilization of the concrete used. The filler is more absorbent because its incorporation into the concrete increases the specific surface.

Figure 12 gives the bleeding in a sample and the recovery of water taken.

The values of the total bleeding as well as their corresponding stabilization percentages are given in **Table 11**. These percentages are calculated according to the bleeding value of the reference formula (4.2 mm/min).

The percentages of stabilization are respectively 26% for basalt, 29% for limestone, and 36% for sandstone fillers. This is linked not only to their different water absorption coefficient at 24 hours (ωA24) but also to the kinetics of their water absorption because bleeding is measured within two hours after the preparation of the concrete. For Elyamany *et al.* [21], filler type has a significant effect on the segregation resistance and bleeding resistance of self-compacted concrete and flow-able concrete.

(a) (b)

Figure 12. Water bleeding (a) and water recovery form bleeding (b).

Table 11. Total bleeding and percentage of stabilization as a function of percentage of filler.

Formulas	reference formula	4% basalt filler	5% basalt filler	3% limestone filler	4% limestone filler	5% limestone filler	2% sandstone filler	3% sandstone filler
Drained water (ml)	13.2	9.9	9.5	11.1	10.6	10.2	10.1	8.9
Concrete bleeding (mm/min)	4.2	3.2	3.1	3.3	3.0	2.9	3.0	2.7
Stabilization (%)	0	24	26	21	29	31	29	36

3.6. Influence of Additions of Filler on the Unconfined Compressive Strength of the Concrete

The test is carried out in accordance with standard NF EN 12390-3 [22]. The unconfined compressive strength of concrete is an important parameter in measuring the durability of concrete. It is measured at seven (7) and twenty-eight (28) days of concrete curing (NF P18-430-2/NF EN 12390-2 [23]). The maximum load reached is recorded and the compressive strength is calculated by Equation (5):

$$R_c = \frac{F}{A_c} \tag{5}$$

R_c: compressive strength, expressed in MPa (N/mm^2);

F: maximum load causing failure, expressed in Newton (N);

A_c: surface of the section of the test specimen to which the compressive force is applied (mm^2).

The variations in the compressive strength of the basic formula and the different other concrete formulas at 7 and 28 days of age are given in Figure 13.

Figure 13 shows that, compared to the reference formula, the formulas with mineral addition to the optima have higher strengths at 7 and 28 days. It's observed that addition of filler has a positive effect (so called "filler effect") on strength and strength development of concrete. This effect is not chemical but is due to the filling of the voids of the matrix grains by the fillers whatever their nature.

Thus, the formulas with the addition of sandstone filler have higher compressive strength than those with the addition of limestone which in turn are superior to those with the addition of basalt filler.

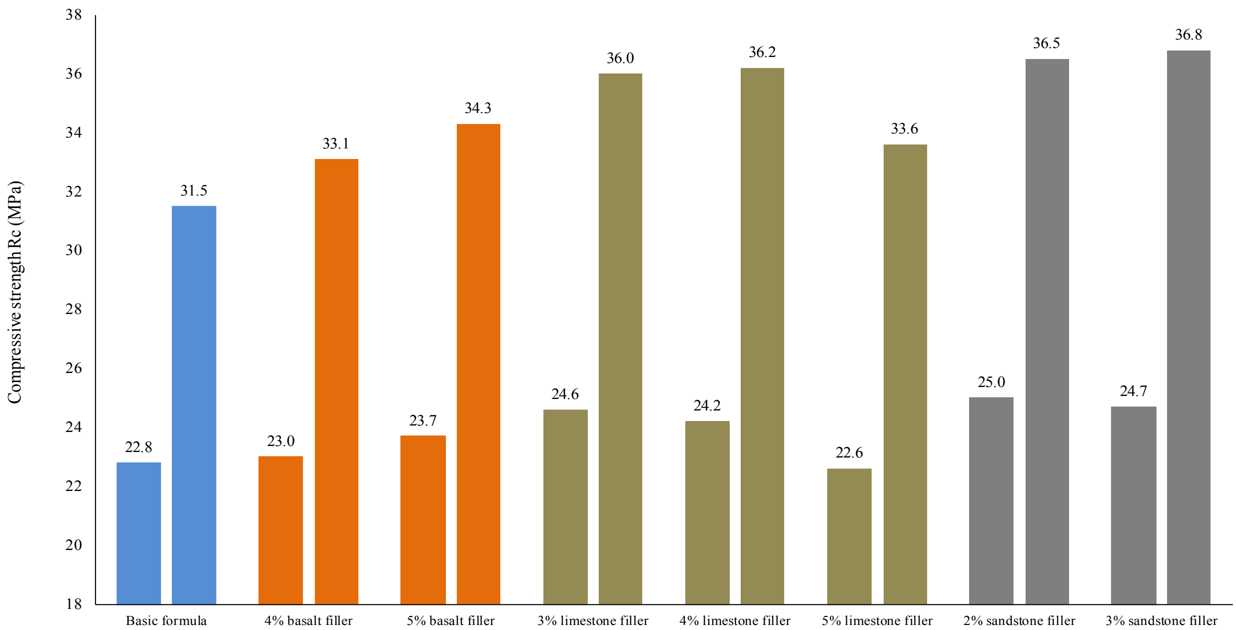

Figure 13. Variation of the compressive strength as a function of the percentages of filler added.

Indeed, these results can be explained by the fact that the sandstone filler are chemically cleaner than the other two (value of methylene blue 4.27 < 10 g/kg). In addition, the silica grains (main components of sandstone filler) constitute nucleation sites, which gives a better distribution and homogenization of the hydrated cement products.

For formulas with the addition of limestone filler, the low hardness of the filler (much lower than that of sandstone filler) as well as their relatively high harmfulness compared to that of sandstone, are largely balanced by their "binding" activity effect. Here, the compressive strengths are controlled by this chemical effect. Indeed, $CaCO_3$ and the aluminates of the cement (C_3A, C_4AH_{13}) would react chemically in presence of water to form a hydrated calcium mono-carbo-aluminate $C_3A \cdot CaCO_3 \cdot 11H_2O$, which crystallizes in fine hexagonal pads thus increasing the quantity of hydrated products.

For the formulas with the addition of basalt filler, despite their hardness, the strength, lower than those of the other two formulas, appears to be a consequence of the relatively high harmfulness of these fillers. In fact, in addition to having no binding activity, the relative importance of the methylene blue value influences the mechanical performance of the concrete. Here, hardness and compactness are responsible for the improvement of the compressive strengths compared to the reference formula. Esfahani *et al.* [24] in comparing various types of filler (steel filler, cast iron filler, and stone powder filler) on mechanical properties of concrete show that inclusion of stone powder filler increased the concrete's strength.

For Moosberg *et al.* [25], the fillers can interact with cement in several ways, to improve particle packing and give the fresh concrete other properties, and even to reduce the amount of cement in concrete without loss of strength.

3.7. Influence of Addition of Filler on the Degree of Compaction of Concrete

The compactness of concrete is the most important parameter to take into account to ensure its durability in front of physical and chemical attacks. It is equal to the ratio of the absolute volume of all the components of hardened concrete to the volume of their container. In other words, it is the ratio of the apparent density (ρ_a) of the hardened and dried concrete over the bulk density (ρ_r), Equation (6).

The degree of compaction is determined in accordance with standard NF EN 1097-6 [26].

$$C = \frac{\rho_a}{\rho_r} \times 100 \tag{6}$$

ρ_a : concrete apparent density (kg/l);

ρ_r : concrete bulk density (kg/l);

C : degree of compaction (%).

The results obtained are shown in **Figure 14**.

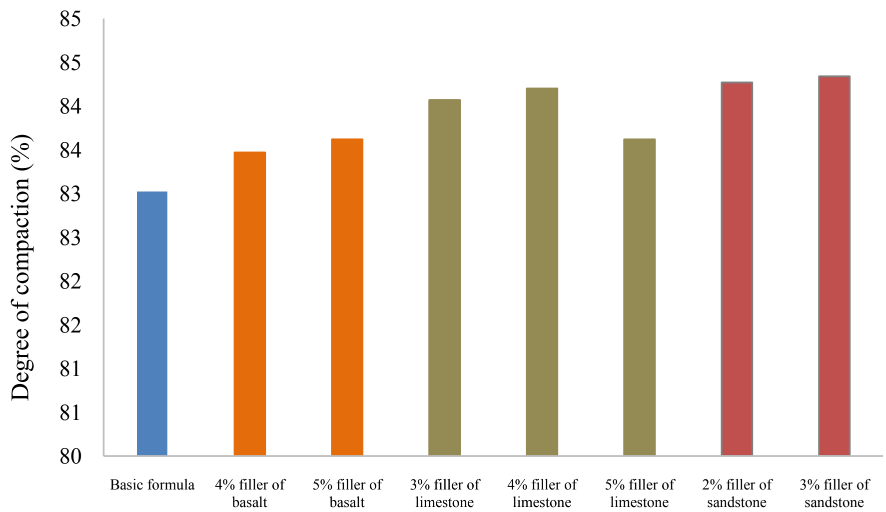

Figure 14. Degree of compaction variation by vibration as a function of mineral additions.

Figure 14 shows that the values obtained on the compactness of formulas with mineral additions are greater than that of the reference formula. For the optima, the best compactness is obtained with sandstone filler (2% and 3%). THE batches with limestone filler (3% and 4%) have a greater degree of compaction than those of the formulas with the addition of basalt filler (4% and 5%). These degrees of compaction values are well correlated with the values of unconfined compressive strengths. Limestone filler speeds up hydration reactions and provide a finer porous structure [27]. The values obtained also show that it should not go beyond 4% with limestone because the compressive strength values as well as the degree of compaction decrease.

The filler addition to concrete plays a good role due to its positive influence on viscosity and segregation resistance. The powder added has an important effect on the concrete mobility and on the hardening rate in the first hour of curing.

4. Conclusions

The workability of concrete is slightly reduced with the addition of limestone (4%) and basalt (5%) filler. However, it decreases rapidly with sandstone (3%). Adding filler to hydraulic concrete does not change its plasticity.

In terms of bleeding, the sandstone gives the best concrete stabilization capacities (36%) with the lowest dosage (3%) at the optimum. Limestone filler stabilizes better (29%) than basalt filler (26%). This reduction in bleeding corresponding to an increase in stabilization results in lowering the shrinkage.

Compressive strength at 28 days is markedly more increased with limestone (+4.7 MPa) and sandstone (+5.3 MPa) filler than with basalt filler (+2.8 MPa). The best value is obtained with the optimum sandstone filler (3%).

The degree of compaction of formulas with the addition of filler is improved compared to the basic formula. Sandstone filler give the best results (+1.32%), followed by limestone filler (+1.18%) and finally basalt filler (+0.60%).

This study shows that for better durability of hydraulic concrete, it is important or even necessary to add a filler to increase its physical and mechanical performance.

The study of the fineness modulus, as well as the addition of admixture, will allow a better appreciation of the durability of the concrete. Thin blade sections must be made also to see the internal structure of the concrete.

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Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

[1] NF EN 197-1 (2012) Ciment-Partie 1: Composition, spécifications et critères de conformité des ciments courants.

[2] Ranjith, A., Baladji Rao, K. and Manjunath, K. (2016) Evaluating the Effect of Corrosion on Service Life Prediction of RC Structures—A Parametric Study. *International Journal of Sustainable Built Environment*, **5**, 587-603. https://doi.org/10.1016/j.ijsbe.2016.07.001

[3] Poppe, A.-M. and De Schutter, G. (2005) Cement Hydration in the Presence of High Filler Contents. *Cement and Concrete Research,* **35**, 2290-2299. https://doi.org/10.1016/j.cemconres.2005.03.008

[4] NF EN 1097-7 (2005) Essais pour déterminer les caractéristiques mécaniques et physiques des granulats—Partie 7 Détermination de la masse volumique absolue du filler, Méthode au pycnomètre.

[5] NF EN 206+A1 (2016) Béton—Spécification, performance, production et conformité.

[6] Wang, T. (2020) U.S Cement Production: Clinker 2007-2019. Statista.

[7] NF EN 12350-2 (2012) Essais pour béton frais—Partie 2: Essais d'affaissement au cône d'Abrams.

[8] NF EN 12350-4 (2009) Essais pour béton frais—Partie 4: Indice de serrage.

[9] NF EN 12350-5 (2009) Essais pour béton frais—Partie 5: Essai d'étalement à la table à choc.

[10] NF EN 12350-8 (2010) Essais pour béton frais—Partie 8: Béton auto-plaçant: Essai d'étalement au cône d'Abrams.

[11] Murat, M. (1983) Hydration Reaction and Hardening of Calcined Clays and Related Minerals. I. Preliminary Investigation on Metakaolinite. *Cement and Concrete Research*, **13**, 259-266. https://doi.org/10.1016/0008-8846(83)90109-6

[12] Roger, J., Noël, B.J., Barusseau, J.P., Serrano, O., Nehlig, P. and Duvail, C. (2009) Notice explicative de la carte géologique du Sénégal à 1/500,000, Feuilles Nord-

Ouest, Nord-Est et Sud-Ouest, Ministère des Mines, de l'Industrie et des PME, Direction des Mines et de la Géologie, Dakar, 61 p.

[13] Roger, J., Duvail, C., Barusseau, J.P., Noël, B.J., Nehlig, P. and Serrano, O. (2009) Carte géologique du Sénégal à 1/500,000, feuilles Nord-Ouest, Nord-Est et Sud-Ouest. Ministère des Mines, de l'Industrie et des PME, Direction des Mines et de la Géologie, Dakar, 3 coupures.

[14] NF P 18-545 (2011) Granulats: Éléments de définition, conformité et codification.

[15] Dreux, G. and Festa, J. (1998) Nouveau guide du béton et de ses constituants, 8ème édition, Eyrolles, Collection Blanche, Paris, 416 p.

[16] Bolomey, J. (1935) Granulation et prévision de la résistance probable des bétons. *Travaux*, **19**, 228-232.

[17] NF EN 12350-2 (2019) Essais pour béton frais—Partie 2: essai d'affaissement.

[18] NF EN 12390-2 (2012) Essais pour béton durci—Partie 2: confection et conservation des éprouvettes pour essais de résistance.

[19] X P18-468. (2016) Béton—Essai pour béton frais—Ressuage.

[20] Topçu, İ.B. and Elgün, V.B. (2004) Influence of Concrete Properties on Bleeding and Evaporation. *Cement and Concrete Research*, **34**, 275-281. https://doi.org/10.1016/j.cemconres.2003.07.004

[21] Elyamany, H., Elmoaty, M.A., Elmoaty, A. and Mohamed, B. (2014) Effect of Filler Types on Physical, Mechanical and Microstructure of Self Compacting Concrete and Flow-Able Concrete. *Alexandria Engineering Journal*, **53**, 295-307. https://doi.org/10.1016/j.aej.2014.03.010

[22] NF EN 12390-3 (2019) Essais pour béton durci—Partie 3: Résistance à la compression des éprouvettes.

[23] NF P 18-430-2/NF EN 12390-2 (2012) Essais pour béton durci, Partie 2: Confection et conservation des éprouvettes pour essais de résistance.

[24] Esfahani, M.S., Janbaz, S. and Mirmazhari, S. (2016) Effect of Various Types of Fillers on Mechanical Properties of Concrete. *International Journal of Civil Engineering, Construction and Estate Management*, **4**, 20-28.

[25] Moosberg-Bustnes, H., Lagerblad, B. and Forssberg, E. (2004) The Function of Fillers in Concrete. *Materials and Structures*, **37**, Article No. 74. https://doi.org/10.1007/BF02486602

[26] NF EN 1097-6 (2014) Essais pour déterminer les caractéristiques mécaniques et physiques des granulats—Partie 6: Détermination de la masse volumique réelle et du coefficient d'absorption d'eau.

[27] Valcuende, M., Marco, E., Parra, C. and Serna, P. (2012) Influence of Limestone Filler and Viscosity-Modifying Admixture on the Shrinkage of Self-Compacting concrete. *Cement and Concrete Research*, **42**, 583-592. https://doi.org/10.1016/j.cemconres.2012.01.001.