PHYSICO-MECHANICAL PROPERTIES OF CONCRETE MADE WITH THE MOST USED TYPES OF CEMENTS ADMIXED WITH POLYCARBOXYLATE SUPERPLASTICIZER IN THE CITY OF GOMA, DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT
The present work deals with the influence of the dosage of polycarboxylate plasticizer on the physico-mechanical properties of concretes made with the most used types of cements in the city of Goma in the Democratic Republic of Congo. The concretes were designed by Bolomey method using the most used types of cement in the city, namely Hima, Simba and Nyiragongo cements with the most commonly used class 32.5R; the aggregates used are crushed sand 0/4 and crushed gravel 5/20 from the SAFRICAS company based in Goma, the admixture used is polycarboxylate superplasticizer dosed at 0.6% (minimum value for experiment) of the cement mass; tests on the physical properties of the aggregates used and the fresh concrete produced were carried out as well as tests on the mechanical properties of the hardened concrete produced. On adding a minimum amount of polycarboxylate superplasticizer to the most used types of cement in Goma, the workability improved by 77% for Hima cement, 80% for Simba cement and 20% for Nyiragongo cement, which shows that the polycarboxylate plasticizer has more influence in terms of improving the workability of Simba and Hima cements than for Nyiragongo cement; Similarly, the 28 day compressive and tensile strengths of concretes made with above cements improved with the use of the superplasticizer (24% for Hima cement, 32% for Simba cement and 48,1 % for Nyiragongo cement), showing that the polycarboxylate plasticizer improved the Nyiragongo cement concrete more than the Hima and Simba cement concretes.
Key words: Admixture, compressive strength, tensile strength, workability, setting, superplasticizer, fresh concrete, hardened concrete.

I- GENERAL INTRODUCTION

I.1 Background

In the last decade, the construction sector has experienced a structural development involving the construction of large-scale works and a new technology of construction, which also requires the presence of suitable materials that can meet the requirements of the above-mentioned types of construction. The concrete is among the widely used construction materials and there is need to have it with high strength. As the W (water) / C (cement) ratio is very important for the mix, when W decreases, the strength increases. It is therefore necessary to choose an admixture for the mix that will make the concrete plastic by reducing the water contained in the mixture and thus increasing the concrete's strength in compression and traction. This admixture can be a plasticizer or a superplasticizer. The superplasticizer reduces the water more than the plasticizer and therefore improves the mechanical properties more than the plasticizer.

I.2 Problem statement

Concrete made with some natural aggregates as the only components in addition to cement and water often has very poor mechanical properties for use in large structures. Therefore, another non-essential component called admixture is often added in small quantities to the above-mentioned concrete components to improve its performance in terms of strength and workability.

I.3 General objective of the research

The general objective of this work is to study experimentally the influence of the polycarboxylate superplasticizer on the physico-mechanical properties of the concretes produced with the most used cements in Goma, in order to identify the type of cement that would be the most compatible and favorable with a polycarboxylate superplasticizer admixture to obtain the expected properties.

II- LITERATURE REVIEW

Some previous works relevant to the present work are presented as follows:

NA 774 defines a plasticizer as an admixture which, when introduced into a concrete, mortar or grout, has the main function of causing a significant increase in the workability of the mixture and its strength.

Guiraud (2018) (2018) worked on the dosage of admixtures function of the weight of cement and the results presented in the table 2.1.

Table 2.1: Dosage of admixture function of the weight of the cement

Admixtures	Dosage in %
Plasticizers	0.1 to 1.2
Superplasticizers	0.6 to 2.5
Setting accelerators	1 to 3
Curing accelerators	0.8 to 2
Setting retardants	0.2 to 0.8
Waterproofing	0.5 to 2
Air trainers	0.05 to 3
Air restrictors	0.1 to 2

The compressive strength values of the concretes formulated and manufactured by Cinamula Bashengezi (2018) which varied between 2.6 and 14 MPa.

Moundom et al (2016) carried out a physical characterization of black volcanic ash from Baïgom, black pozzolans from Ngouogouo and brown pozzolans from Mfosset in the locality of Foumbot. From this study the fineness modulus varied between 2.09 and 4.21 for the different sands, the sand equivalent varied between 78.9, 96.1%, the absolute densities varied from 2.23 to 2.53 g/cm^3 for the pozzolana sands and from 2.06 to 2.37 g/cm^3 for the larger particles.

Dupain R., Saint-Arroman J.-C. (2009) proposed an approach for the formulation of concrete with light, porous, dry or water-containing aggregates.

Moundom et al (2018) carried out the mechanical characterization of lightweight concretes made from granular volcanic materials from the locality of Foumbot with 28-day compressive strength values ranging from 3.87 to 8.26 MPa and proposed their appropriate use in construction.

Muhindo (2017) formulated and manufactured the concretes based on Goma aggregates using cements available in Goma and found compressive strengths ranging from 14.5 to 30.4 MPa.

Vouffo (2022) worked on black and red pozzolanas from Bafoussam 2 and found compressive strength values ranging from 2.39 and 12.548 MPa.

Of all the above-mentioned works, none had experimented with improving the mechanical properties of concretes manufactured in Goma using a superplasticizer such as polycarboxylate. Hence the importance of the present work.

III. MATERIALS AND METHODS

The laboratory tests were carried out in the Civil Engineering Laboratory of the Faculty of Applied Sciences and Technologies of the Free University of the Great Lakes Countries in Goma, Democratic Republic of Congo (DRC)

III.1 Materials

Sand

The sand used is 0/4 crushed sand from the SAFRICAS company based in Goma, North Kivu, Democratic Republic of Congo (DRC).

Gravel

The gravel used is 5/20 crushed gravel from the SAFRICAS company based in Goma, North Kivu, Democratic Republic of Congo (DRC).

Cement

The cements used are the commonly used cements from all the factories in the city of Goma (DRC) and are Hima, Simba, Nyiragongo and of the more commonly used class 32.5 R.

Admixture

The admixture used is polycarboxylate superplasticizer at 0.6% (minimum value) of the mass of the cement for experimentation.

III.2 Methods

III.2.1. Tests to determine the physical properties of the aggregates and binders used

III.2.1.1. Dry particle size analysis of 0/4 sand and 5/20 gravel.

The particle size analysis was carried out by dry method using an electric sieve shaker in accordance with the requirements of standards EN 933-2 (May 1996) and NF P 18-560. At the end of this particle size analysis test, the fineness modulus (FM) was determined on the one hand, and the coefficient of uniformity (Cu) and that of curvature (Cz) on the other.

The fineness modulus (FM) is determined according to the XP P 18-540 standard by relation 1:

$$\mathbf{FM} = \frac{\sum \mathbf{Refus}\ (\mathbf{5;2,5;1,25;0,63;0,315;0,08})}{\mathbf{100}} \qquad \mathbf{(1)}$$

The uniformity coefficient (Cu) and that of curvature (Cz) are defined by relations 2 and 3.

$$\mathrm{Cu} = \frac{\mathrm{d}_{60}}{\mathrm{d}_{10}} \qquad \mathbf{(2)}$$

$$Cz = \frac{d_{30}^2}{d_{10} x d_{60}} \qquad (3)$$

Where d_y is the diameter of the sieve corresponding to y% of cumulative passings.

III.2.1.2. Sand equivalent test

The sand equivalent (SE) test was carried out in accordance with the requirements of standard NF P 18-598.

This test allows us to check the degree of cleanliness of a sand, which is equivalent to highlighting traces of clay, as the presence of clay in the concrete greatly reduces its strengths during hardening, as the clay absorbs part of the water in the concrete to form the sludge that hinders the adhesion of the cement with the aggregates.
The sand equivalent (SE) is the average between visually sand equivalent (SEv) and the piston sand equivalent (SEp). The values of (SE), (SEv) and (SEp) are given by the relations 4, 5 and 6:

$$\mathbf{SE} = \frac{\mathbf{SE_V + SE_P}}{\mathbf{2}} \qquad \mathbf{(4)}$$

$$SE_V = \frac{H_2}{H_1} \text{ x } 100 \qquad (5)$$

$$SE_p = \frac{H_2}{H_1} \text{ x } 100 \qquad (6)$$

Where Height of clean sand plus fines is H_1 and the height of clean sand only is H_2, measured visually for (SEv) or measured with the piston for (SEp).

III.2.1.3. Absolute density test

The absolute density was determined according to the standards NF P 18-554 for gravel and NF P 18-555 for sand. The method used was the graduated cylinder test method. It consisted in measuring the mass per unit volume of solid material without any void between the grains by pouring a known mass of aggregate into a quantity of water. The difference in volume relative to the mass of the material gave the absolute density. The absolute density is given by the relation 7 :

$$\rho_{abs} = \frac{M}{V_2 - V_1} (g/cm^3) \qquad (7)$$

Where: - M is the dry mass of the material and,

- V_1 and V_2 are the readings on the test piece before and after the placement of the aggregate in the test piece.

III.2.1.4. Setting and normal consistency tests on cements

- **Cement setting**

Three types of cement were used: HIMA, SIMBA and NYIRAGONGO, all of which comply with NF P 15-301 and ENV 197-1. The measurement of the setting time was carried out in accordance with the requirements of standard EN 196-3. The presence of setting regulators in the mass of hydraulic binders allows them, after mixing, to set after a few hours. It is therefore necessary to know the setting time of hydraulic binders in order to determine the time available for in situ application of the mortars and concretes from which they are made. The tests are carried out with the help of the Vicat needle which gives two practical reference points: the beginning of setting and the end of setting.

- **Normal cement consistency**

Three types of cement were also used: HIMA, SIMBA and NYIRAGONGO, all of which comply with standards F P 15-301 and ENV 197-1. The consistency of the paste characterises its greater or lesser fluidity. Two standardized tests allow this consistency to be assessed, namely the consistency test carried out with the Vicat apparatus in accordance with standard EN 196-3 and the cone flow test, in accordance with standard NF P 18-358. The consistency of our different types of cement was determined using the Vicat test according to EN 196-3.

III.2.2. Mix design of the concrete

The BOLOMEY method (Dreux and Festa) is used for the design of the different concrete mixes with the design parameters given in Table 3.1.

Table 3.1: Concrete design parameters for the Bolomey method

Materials	**Absolute density**	**Bulk density**
Cement	3.10	1,00
Crushed sand 0/4	2,50	1,57
Crushed gravel 5/20	2,63	1,232
The cement dosage used is 400 kg/m3 for a slump of 14 cm		

III.2.3 Physical test on fresh concrete

- **Abrams Cone Settlement Test**

The workability of the concrete was assessed using the Abrams cone, in accordance with the requirements of standard NF P 18-451. The C/W ratio is kept constant for the design with each type of cement.

The test consisted of introducing fresh concrete into a truncated cone mould (D = 20, d = 10, H = 30 cm) in three layers, where each layer was pitted 25 times with a 16 mm diameter rod, then the mould was slowly removed and the slump measurement was taken.

III.2.4 Mechanical tests on hardened concrete

III.2.4.1. Compression test

This test allows us to determine the compressive strength of a concrete specimen, using a machine called a concrete press.

This determination of the simple compressive strength of concrete after days of immersion was carried out in accordance with standard NF EN 12390-3. The compressive strength (fc) in MPa is the ratio between the compressive force F in N that causes rupture of specimen and the area of the base surface of the specimen (S) in mm^2, given by the relation 8:

$$f_c = \frac{F}{S} \quad \textbf{(8)}$$

III.2.4.2. Tensile test

The values for the tensile strength at d days are calculated using the expression 9:

$$f_t = 0{,}6 + 0.06 f_c. \quad (9)$$

where f_c and f_t are in MPa.

- IV- RESULTS AND DISCUSSION

IV.1 Physical properties of the aggregates and binders used

IV.1.1. Granulometric composition

- **Sand 0/4 studied**

The granulometric composition of the sand studied is presented in Table 4.1.a and Figure 4.1.a.

Table 4.1.a: Size composition of the sand studied

Sieve No.		Opening in mm		Cumulative retained		Cumulative Passing
ASTM	AFNOR	ASTM	AFNOR	g	%	%
3/16"	38	5	5	10	0,512820	99,487179
5	37	4	4	55	2,8205128	97,179487
6	36	3.15	3.15	225	11,538461	88,461538
8	35	2.5	2.5	450	23,076923	76,923076
10	34	2	2	650	33,33333	66,666666
12	33	1.68	1.6	820	42,051282	57,948717
16	32	1.25	1.25	960	49,23076	50,7692
			0.63	1200	61.538	38.461
40	27	0.4	0.4	1430	73,333333	26,666666
50	26	0.315	0.315	1490	76,41025	23,589743
100	23	0.16	0.16	1755	90	10
200	20	0.08	0.08	1890	96,923076	3,0769230

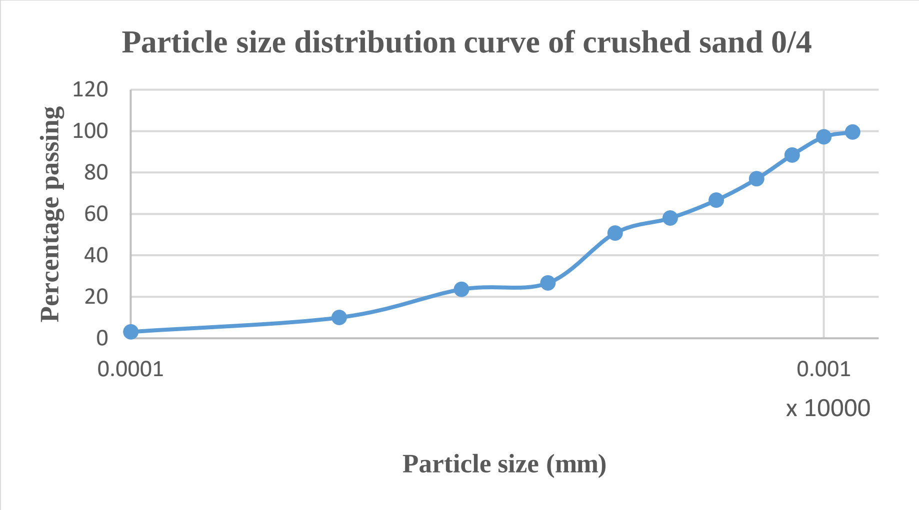

Figure 4.1.a: Particle size distribution curve of crushed sand 0/4 studied

As a result of the sieve analysis of the sand, the coefficient of uniformity and the coefficient of curvature as well as the fineness modulus are presented in Table 4.1.b.

Table 4.1.b: Coefficient of uniformity, coefficient of curvature and fineness modulus of the 0/4 sand studied

Material	d10	d30	d60	Coefficient of uniformity (Cu)	Coefficient of curvature (Cz)	Fineness modulus (FM)
Sand 0/4	0,16	0,47	1,69	**10,59**	**0,80**	**2,7**

The fineness modulus values in Table 4.1.b show that the grain size of our sand is acceptable for making good quality concrete, especially since it is between 2.2 and 2.8. This fineness modulus value of 2.7 similar to 2.76 determined by Muhindo (2017), is higher than the value of 2.09 determined by Moundom et al (2016) on the black volcanic ash sands of Baigom by Foumbot, the 2.4 determined by Cinamula Bashengezi (2018) on the 0/4 sand of Safricas in Goma in DRC, but well below the values of 4.21 for black pozzolan sand and 4.07 for brown pozzolana sand from Mfosset determined by Moundom et al (2016) and also well below the values of 5.43 for black pozzolanas and 4.73 for red pozzolanas from Bafoussam 2 in Cameroon determined by Vouffo (2022).

The values of coefficient of uniformity (Cu) and coefficient of curvature (Cz) are respectively 10.59 and 0,8. Since one of the conditions Cu > 6 and Cz between 1 and 3 is not satisfied, the sand grading is poor (Robitaille and Tremblay, 1997). These values are similar to the values determined by Muhindo (2017) but different from the values found by Moundom et al (2016) and Vouffo (2022).

- **Gravel 5/20 studied**

The granulometric composition of the gravel studied is presented in Table 4.1.c and Figure 4.1.b.

Table 4.1.c: Size composition of the 5/20 gravel studied

Sieve No.		Opening in mm		Cumulative retained		Cumulative Passing
ASTM	AFNOR	ASTM	AFNOR	g	%	%
3/4 "	44	20	20		0	100
2/3"	43	16	16	65	2,1739130	97,826087
½"	42	12.5	12.5	505	16,889632	83,1103679
3/8"	41	10	10	1195	39,9665552	60,0334448
1/3"	40	8	8	1694	56,655518	43,3444816
¼"	39	6.3	6.3	2445	81,772575	18,227424
3/16"	38	5	5	2770	92,642140	7,35785953
5	37	4	4	2940	98,3277592	1,6722408
6	36	3.15	3.15	2985	99,8327759	0,16722408
8	35	2.5	2.5	2990	100	0
10	34	2	2	2990		

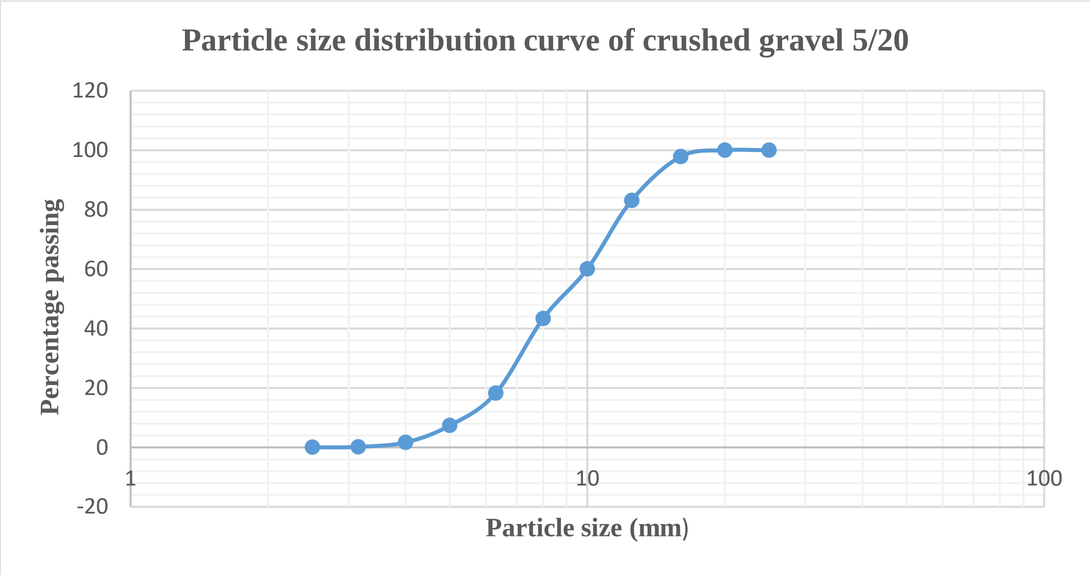

Figure 4.1.b: Particle size distribution curve of crushed gravel 5/20 studied

As a result of the gravel size analysis, the coefficient of uniformity and coefficient of curvature are presented in Table 4.1.d.

Table 4.1.d: Coefficient of uniformity and coefficient of curvature of the gravel 5/ 20 studied

Material	d10	d30	d60	Coefficient of uniformity (Cu)	Coefficient of curvature (Cz)
Gravel 5 /20	5,32	7,1	10,00	**1,88**	**0,95**

According to Tables 4.1.c, 4.1.d and Figure 4.1.b, the values of the Coefficient of uniformity (Cu) and the Coefficient of curvature (Cz) of the gravel are 1.88 and 0.95 respectively. Since one of the conditions Cu > 4 and Cz between 1 and 3 is not satisfied, the gravel grading is poorly graded (Robitaille and Tremblay, 1997). These values are similar to the values determined by Muhindo (2017) but different from the values found by Moundom et al (2016) and Vouffo (2022).

IV.2 Sand equivalent

The values of the sand equivalent studied are presented in Table 4.2.

Table 4.2: Sand equivalent values of the sand studied

Sand	SE_V (%)	SE_P (%)	SE (%)	SE (Mean)
Sample 1	83,38	87,6	85,49	**85,72**
Sample 2	85,6	86,33	85,965	

According to Table 4.2, the sand equivalent value is 85.72 This value is higher than 80 and according to the Dreux classification scale (1981), the sand is very clean. The almost total absence of fine may lead to a plasticity defect in the concrete, which must be corrected by increasing the cement dosage. This value of 85.72 is different from 90.1 and 92.5 determined respectively by Muhindo (2017) and Cinamula Bashengezi (2018) on a sand from the same locality, and also different from the values 91.7 and 94.8 determined by Vouffo (2022) respectively on black pozzolanas and red pozzolanas of Bafoussam 2. The same value is different from the values 78.9, 96.1 and 95.5 determined by Moundom et al (2016) for Baigom volcanic ash sand, Ngouogouo black pozzolana sand and Mfosset brown pozzolan sand by Foumbot respectively.

IV.3 Absolute density

The absolute density values of the studied aggregates are presented in Table 4.3.

Table 4.3: Absolute density of 0/4 sand and 5/20 gravel from SAFRICAS

Aggregates	Mass (g)	V1 (ml)	V2 (ml)	ρ_{abs} (g/ml or g/cm^3)
0/4 sand from SAFRICAS	500	500	690	2,5
5/20 gravel from SAFRICAS	500	500	690	2,63

The value of absolute density found in Table 4.3 meets the condition of the BOLOMEY method that the absolute density of aggregates should be between 2.5 and 2.7 g/cm3. These values are similar to the values of 2.61 g/cm^3 and 2.59 g/cm^3 determined by Muhindo (2017) and 2.6 g/cm^3 and 2.59 g/cm^3 determined by Cinamula Bashengezi (2018) for sand and gravel from Safricas respectively. These values are different from those determined by Vouffo (2022) which vary between 2.68 g/cm^3 and 2.74 g/cm^3, and globally those determined by Moundom et al (2016) which vary between 2.23 and 2.53 g/cm^3 for pozzolana sands and between 2.06 and 2.37 g/cm^3 for larger particles.

IV.4. Setting and normal consistency on cements

IV.4.1. Setting of the cement

The setting values of HIMA, SIMBA and NYIRAGONGO cements present in Goma for a quantity of mixing water obtained during the consistency test and a plasticizer dosage of 0.6% are presented in Table 4.4.

Table 4.4: Setting values of different cements mostly used in Goma

Type of cement	Polycarboxylate free		With 0.6% polycarboxylate	
	Beginning of setting	End of setting	Beginning of setting	End of setting
Hima	4 hr 33 min	6 hr 20 min	7 hr 15 min	9 hr 20 min
Simba	4 hr 20 min	6 hr 10 min	7 hr 25 min	9 hr 40 min
Nyiragongo	4 hr 20 min	6 hr 10 min	5 hr 40 min	7 h min35

The results in Table 4.4 show that the polycarboxylate superplasticizer has an influence on the beginning of setting time of different cements used in Goma, but also on the setting time of the cements.

For Hima cement without polycarboxylate plasticizer, we have a beginning of setting time of 4 h 33 min for an end setting time of 6 h 20 min, and when the plasticizer is used, we see that the beginning of setting time becomes 7 h 15 min for an end setting time of 9 h 20 min. Thus, we can say that the polycarboxylate plasticizer has a great influence on the beginning of setting time for Hima cement, this increase is 2 h 42 min and is explained by the fact that the plasticizer increases the fluidity of the paste, while the setting time also increases by 18 min.

For Simba cement without polycarboxylate plasticizer, we have a beginning of setting time of 4 h 20 min for an end setting time of 6 h 10 min, and when the plasticizer is used, we find that the beginning of setting time becomes 7 h 25 min for an end setting time of 9 h 40 min. Thus, we can say that the polycarboxylate plasticizer also has an influence on the beginning of setting time for Simba cement, this increase is of 3 h 05 min and is also explained by the fact that the plasticizer increases the fluidity of the paste while the setting time also increases by 25 min.

For Nyiragongo cement without polycarboxylate plasticizer, we have a beginning of setting time of 4 h 20 min for an end setting time of 6 h 10 min, and when a plasticizer is used, we see that the beginning of setting time becomes 5 h 40 min for an end setting time of 7 h 35 min. Thus, we can say that the polycarboxylate plasticizer also has an influence on the beginning of setting time for Nyiragongo cement, this increase is of 1h 20 min and is explained by the fact that the plasticizer increases the fluidity of the paste while the setting time also increases by 5 min.

From the results obtained above, we can see that in the presence of the 0.6% polycarboxylate plasticizer, Nyiragongo cement requires less beginning time to set and less time to set than the other two types of cement. These results are similar to those determined by Muhindo (2017) and Cinamula Bashengezi (2018).

IV.4.2. Normal consistency of cement

The results of the consistency of cement mostly used in Goma with and without polycarboxylate plasticizer are presented in Table 4.5.

Table 4.5: Normal consistency values of different cements mostly used in Goma

Types of cements	Quantity of water in %.	
	Without Polycarboxylate	With 0.6% polycarboxylate
Hima	35	27
Simba	31	28,5
Nyiragongo	27,3	27

From the results of Table 4.5, polycarboxylate superplasticizer has an influence on the consistency of different cements mostly used in Goma. Thus, for a polycarboxylate dosage of 0.6 %, we have a reduction in the quantity of mixing water of 8 % for Hima cement, 2.5 % for Simba cement and 0.3 % for Nyiragongo cement. We can say that the action of the polycarboxylate plasticizer on the consistency of the cement is more important for Hima cement than for Simba and Nyiragongo cements, so Hima cement requires less mixing water than the other two cements when polycarboxylate plasticizer is added to its concrete.

IV.5. Concrete mix design

The concrete mix design determined by BOLOMEY method and used in this work is presented in Table 4.6.

Table 4.6: Concrete mix

Components of concrete	Quantity for 1 m^3 of concrete by mass
Cement	400 kg
Sand 0/4	1094.76 kg
Gravel 5/20	378 kg
Water	224.78 kg
Admixture (Polycarboxylate Superplasticizer)	0.6% of cement mass
Total	2097.4 kg+0.6% cement mass for admixture

Table 4.6 shows that the concrete mix by Bolomey method gives for one m^3 of concrete, 400 kg of cement, 1094.76 kg of sand 0/4, 378 kg of gravel 5/20 and 224.78 kg of water. This is in accordance with the current concrete mix ratio of one sand to two gravels and a mass ratio (W/C) of 0.56. These dosages are similar to those determined by Muhindo (2017) and Cinamula Bashengezi (2018).

- IV.6 Physical properties of fresh concrete

- **Subsidence at the Abrams cone**

The slump cone values of fresh concrete are presented in Table 4.7.

Table 4.7: Slump cone values of fresh concrete

Types of cement	Settlement in cm	
	Without Plasticizer	With 0.6% plasticizer
Hima	4.5	8
Simba	5	9
Nyiragongo	5	6

Based on the results of Table 4.7, polycarboxylate has an influence on the workability of the different cement-based concretes produced in Goma, without changing the C/W ratio. We observe an increase of 77% in slump cone values for Hima cement, 80% for Simba cement and finally 20% for Nyiragongo cement. Hence the polycarboxylate has little influence on workability and is less suitable for Nyiragongo cement than for the other two types of cements.

IV.7 Mechanical properties of hardened concrete produced without polycarboxylate plasticizer

- IV.7.1. Compressive strength of hardened concrete without plasticizer

The results after compression of concrete specimens at different ages and cement types studied and without plasticizer are presented in Table 4.8 and Figure 4.2.

Table 4.8: Compressive strength based on the types of cements studied and without plasticizer

Concrete	Compressive strength (without plasticizer) (MPa)		
	7 days	14 days	28 days
With Hima cement	10,54	11,19	13,89
With Simba cement	11,35	12,06	16,25
With Nyiragongo cement	9,86	10,47	13

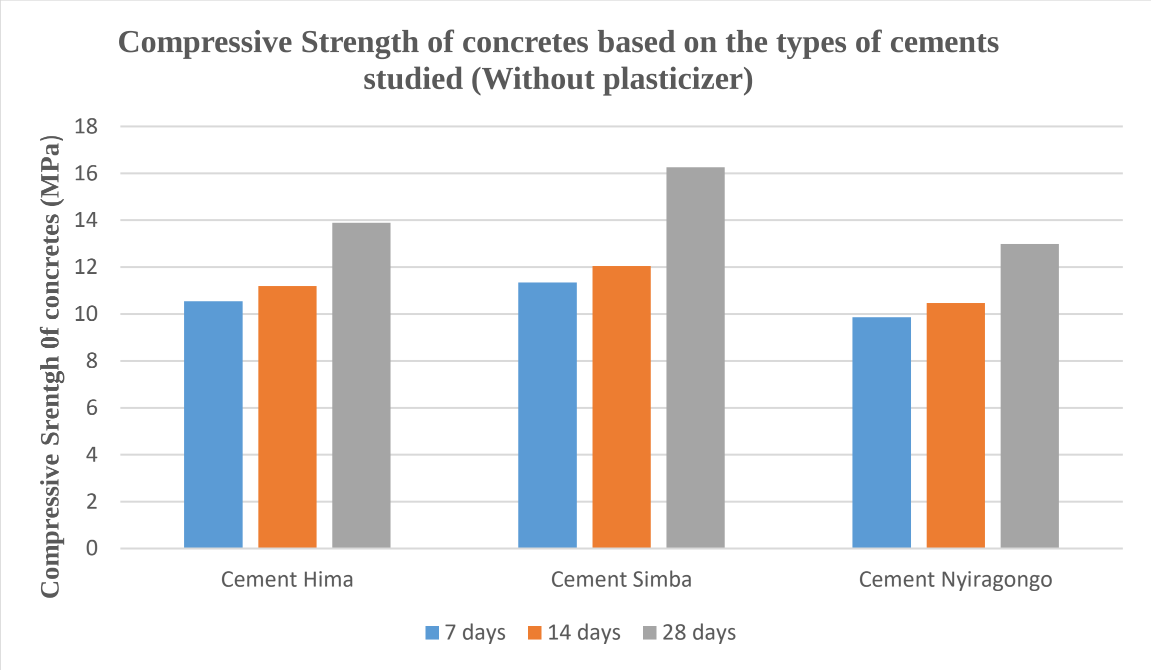

Figure 4.2: Compressive strength of concretes based on the types of cements studied (Without polycarboxylate plasticizer)

From Table 4.8 and Figure 4.2, the compressive strength is increasing with time and for the same mix design, Simba cement provides a higher compressive strength of concrete than the other two cements. The values are higher than the values determined at 28 days by Moundom et al (2018) ranging from 3.87 to 8.26 MPa, globally lower than the values determined by Muhindo (2017) ranging from 14.5 to 30.4 MPa and globally higher than the values determined by Vouffo (2022) on black and red pozzolans of Bafoussam 2 ranging from 2.39 to 12.548 MPa. The values of this study are also globally higher than the values ranging between 2.6 and 14 MPa determined by Cinamula Bashengezi (2018)

IV.7.2. Tensile strength of hardened concrete (Without plasticizer)

The tensile strength of the hardened concretes based on the types of cements studied is presented in Table 4.9 and Figure 4.3.

Table 4.9: Tensile strength according to the types of cements studied and without plasticizer

Concrete	Tensile strength (Without plasticizer)		
	7 days	14 days	28 days
With Hima cement	1,23	1,27	1,43
With Simba cement	1,28	1,32	1,575
With Nyiragongo cement	1,19	1,23	1,38

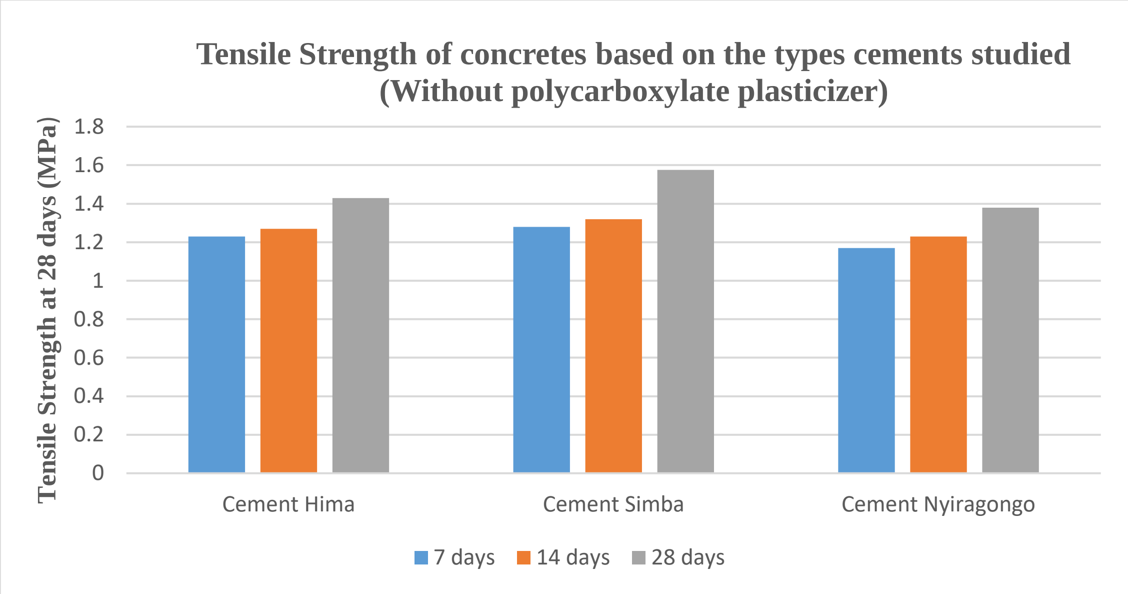

Figure 4.3: Tensile strength of concretes based on the types of cements studied (without polycarboxylate plasticizer)

According to Table 4. 9 and Figure 4.3 the tensile strength is increasing with time and for the same mix design, Simba cement offers higher tensile strength of concrete than the other two cements. The values are higher than the values determined at 28 days by Moundom et al (2018), globally lower than the values determined by Muhindo (2017) and globally higher than the values determined by Vouffo (2022) on the black and red pozzolans of Bafoussam 2. The values in this study are also globally higher than the values determined by Cinamula Bashengezi (2018)

IV.8. Mechanical properties of hardened concretes made with polycarboxylate plasticizer

Three types of test specimens were made for each type of cement with a dosage of 0.6% polycarboxylate plasticizer per specimen, which were subjected to the compression test after 28 days.

IV.8.1. Compressive strength of concretes (With polycarboxylate superplasticizer)

The results after compression of concrete specimens at different ages and Hima, Simba and Nyiragongo cements and with plasticizer are presented in the table 4.10 and figures 4. 4.

Table 4.10: Compressive strength of concretes based on the types of cements studied

Concrete	Compressive strength (without plasticizer) (MPa)		Compressive strength (with plasticizer) (MPa)	
	7 days	28 days	7 days	28 days
Hima cement	10,54	13,89	13,05	17,20
To Simba cement	11,35	16,25	14,97	21,41
At Nyiragongo cement	9,86	13	14,60	19,25

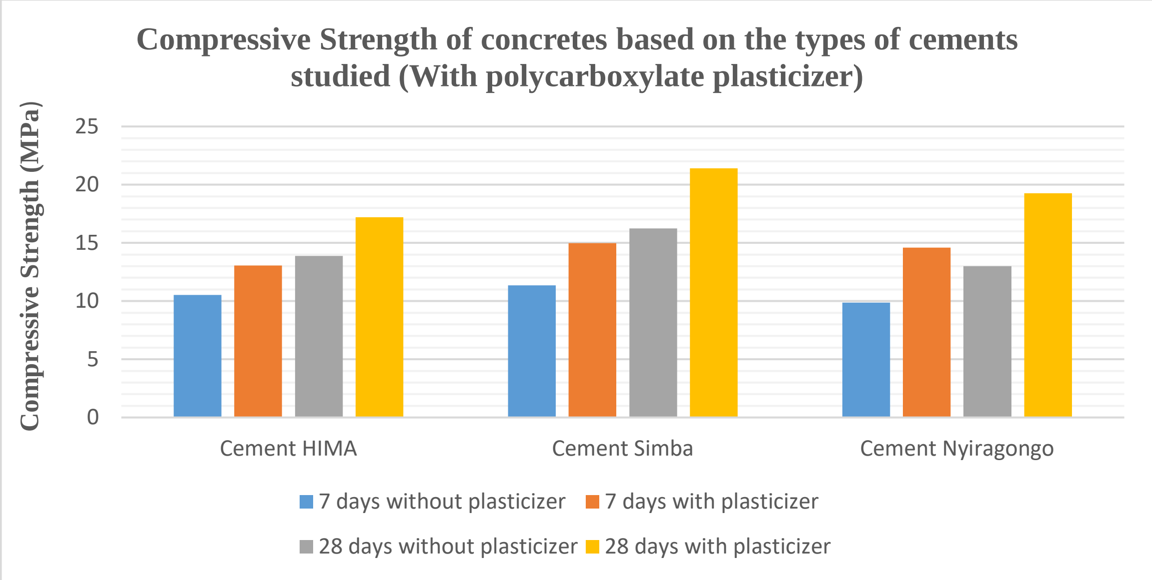

Figure 4.4: Compressive strength of concretes based on the types of cements studied (With polycarboxylate plasticizer)

According to Table 4.10 and Figure 4.4, concretes made with Hima cement without plasticizer gives a 7day compressive strength of 10.5355 MPa and a 28-day compressive strength of 13.889 MPa, while concretes with plasticizer gives a 7-day compressive strength of 13.05 MPa and a 28-day compressive strength of 17.2048 MPa. These results imply that the influence of the polycarboxylate plasticizer on the concretes made with Hima cement is 24%. The values of these strengths are higher than the values determined at 28 days by Moundom et al (2018), globally lower than the values determined by Muhindo (2017) and globally higher than the values determined by Vouffo (2022) on the black and red pozzolans of Bafoussam 2. The values in this study are also globally higher than the values determined by Cinamula Bashengezi (2018).

According again to Table 4.10 and Figure 4.4, concretes made with Simba cement without polycarboxylate plasticizer has a 7-day compressive strength of 11.3515 MPa and a 28-day compressive strength of 16.237 MPa, whereas concretes with polycarboxylate plasticizer has a 7-day compressive strength of 14.9655 MPa and a 28-day compressive strength of 21.406 MPa. These results imply that the influence of the polycarboxylate plasticizer on the concretes made with Simba cement is 32%. The values of these strengths are higher than the values determined at 28 days by Moundom et al (2018), globally lower than the values determined by Muhindo (2017) and globally higher than the values determined by Vouffo (2022) on the black and red pozzolans of Bafoussam 2. The values in this study are also globally higher than the values determined by Cinamula Bashengezi (2018).

Finally, according to the same table and figure, concretes made with Nyiragongo cement without polycarboxylate plasticizer gives a 7-day compressive strength of 9.86 MPa and a 28-day compressive strength of 12.99 MPa, while concretes with polycarboxylate plasticizer gives a 7-day compressive strength of 14.602 MPa and a 28-day compressive strength of 19.25 MPa. These results imply that the influence of the polycarboxylate plasticizer on the concretes made with Nyiragongo cement is 48,1%. The values of these strengths are higher than the values determined at 28 days by Moundom et al (2018), globally lower than the values determined by Muhindo (2017) and globally higher than the values determined by Vouffo (2022) on the black and red pozzolans of Bafoussam 2. The values in this study are also globally higher than the values determined by Cinamula Bashengezi (2018).

IV.8.2. Tensile strength of concretes (With polycarboxylate superplasticizer)

The tensile strength of the concretes with plasticizer based on the types of cements studied is presented in Table 4 11 and Figure 4.5.

Table 4.11: Tensile strength according to the types of cements studied

Concrete	Tensile strength (Without plasticizer) (MPa)		Tensile strength (With plasticizer) (MPa)	
	7 days	28 days	7 days	28 days
With Hima cement	1,2324	1,4334	1,383	1,632
With Simba cement	1,281	1,575	1,4982	1,8846
With Nyiragongo cement	1,1916	1,38	1,476	1,755

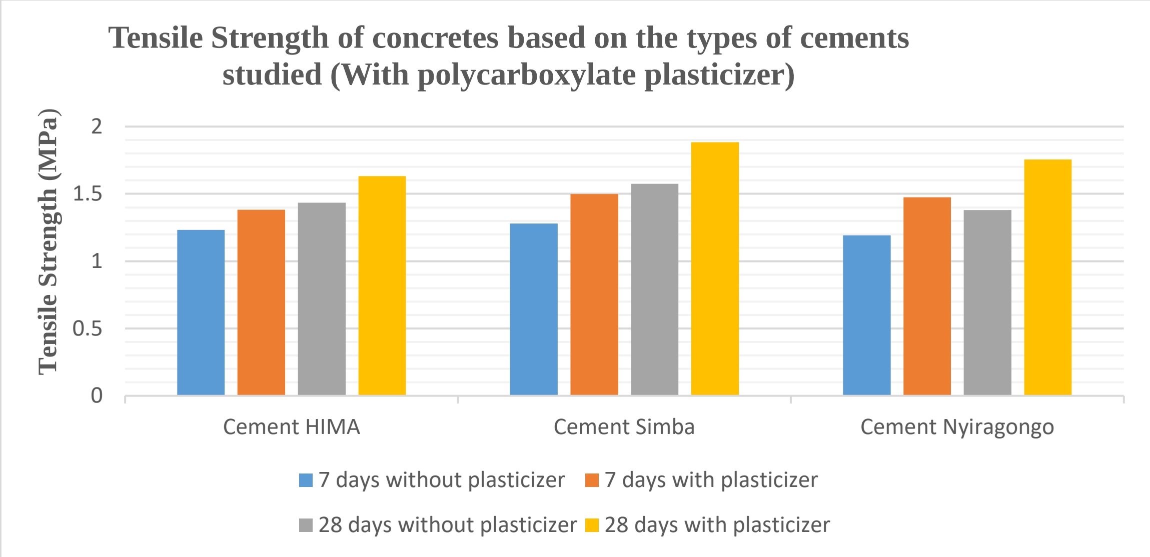

Figure 4.5: Tensile strength of concretes based on the types of cements studied (With polycarboxylate plasticizer)

Table 4.11 and Figure 4.5 show an improvement in strength between the unplasticized and the plasticized concrete of 14% with Hima cement concrete, 20% with Simba cement concrete and 27.17% with Nyiragongo cement concrete. In addition, Simba cement offers a higher tensile strength of the concrete than the other two cements with or without plasticizer.

V- CONCLUSIONS AND RECOMMENDATIONS

The present work deals with the influence of the dosage of polycarboxylate plasticizer on the physico-mechanical properties of concretes made with the most used types of cements in the city of Goma in the Democratic Republic of Congo. The concretes were designed by Bolomey method using the most used types of cement in the city, namely Hima, Simba and Nyiragongo cements with the most commonly used class 32.5R; the aggregates used are crushed sand 0/4 and crushed gravel 5/20 from the SAFRICAS company based in Goma, the admixture used is polycarboxylate superplasticizer dosed at 0.6% (minimum value for experiment) of the cement mass; tests on the physical properties of the aggregates used and the fresh concrete produced were carried out as well as tests on the mechanical properties of the hardened concrete produced. On adding a minimum amount of polycarboxylate superplasticizer to the most used types of cement in Goma, the workability improved by 77% for Hima cement, 80% for Simba cement and 20% for Nyiragongo cement, which shows that the polycarboxylate plasticizer has more influence in terms of improving the workability of Simba and Hima cements than for Nyiragongo cement; Similarly, the 28 day compressive and tensile strengths of concretes made with above cements improved with the use of the superplasticizer (24% for Hima cement, 32% for Simba cement and 48,1 % for Nyiragongo cement), showing that the polycarboxylate plasticizer improved the Nyiragongo cement concrete more than the Hima and Simba cement concretes.

This work was limited to only three out of about seven types of cement in the city of Goma, and the superplasticizer dosage of 0.6% of the cement mass, which is the minimum value for the type of plasticizer, was only taken as an experiment.

Future studies could focus on improving the properties of concretes by varying the dosage of superplasticizer between the lower bound 0.6 and the upper bound 2.5% of cement mass.

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