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Concrete Based on Recycled Aggregates for Their Use in Construction: Case of Goma (DRC)

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Abstract

The following study is aimed at valorizing an important part of waste from building demolition, particularly concrete as a source of aggregates for their usage in new hydraulic concrete formulation. The experimental study mainly consisted of physical characterization of natural and recycled aggregates respectively and the impact of the latter on some properties of the new formulated concrete, actually their respective consistencies for fresh concrete and mechanical strength for the hardened one. The outcome of the study shows that the recycled aggregates are more heterogeneous and have a high capacity of water absorption, but which still respects the current standards of concrete. The need for additional water has been observed for recycled aggregates-based concrete so as to have the same workability. About the compressive strength, mechanical properties obviously show that, at 28 days from setting up, concretes from recycled aggregates can reach compressive strengths range between 20 and 25 MPa without any sophisticated technology. So, these results show that we can efficiently contribute to the protection of environment by valorizing waste from concrete-based building demolition on the one hand; and the preservation of natural reserve on the other. And both advantages contribute to sustainable development overall goals.

Keywords

Demolition, Recycling, Water Absorption, Concrete, Mechanic Resistance

1. Introduction

Waste from building demolition is found almost everywhere in streets, forests and in rivers. They are considered as a great source of nature pollution. Therefore, is can also be seen as a cause of environmental problems such as fauna and flora destruction, underground water pollution, saturation of public waste, unnecessary increase in additional sanitation water to be evacuated, nauseating garbage, insalubrity, flooding, etc. [1].

Recycling of such polluting waste by using it in new concrete formulation remains one of the possible solutions to that problem though Amor Ben Fraj *et al*., 2017 [2]; Wirquin *et al*., 2000 [3] as well as Courard L. *et al.* [4], assumed that usage of demolition materials as substitution aggregates is sometimes very difficult to realize since such materials are porous and so highly water absorbing.

The majority of concrete from buildings demolition-based recycled aggregates are used in road construction. Nevertheless, a better knowledge of its characteristics can contribute to development of that field of construction (Buyle-Bodin *et al.* 2002 [5] and Hussain *et al.* 2003 [6]). This can only be achieved by a deep knowledge of fresh concrete.

However, recycled aggregates could be used as building materials in confection of concrete when the size of the building fits with their respective characteristics. Therefore, this work is aimed to study the strength of concrete formulated by recycled aggregates in order to propose its domain of usage. In so doing, we hope to find a way of protecting the environment against the building demolition waste. The global objective of this study is to take profit from aggregates from concrete building demolition so as to perform new concrete products and contribute to environment protection by reducing building demolition waste in nature.

2. Materials and Methods

In this section, we present all tests which are necessary to describe, both qualitatively and quantitatively, the aggregates as well as the concrete. The most important characteristics for concrete were respectively their consistency and compressive strength at fresh and hardened state. The tests were conducted in the laboratory of the *Université Libre des Pays des Grands Lacs*. Materials that were used in this study are: aggregates (sand and gravels), water, and cement.

2.1. Origin of Constituents

2.1.1. Aggregates

Natural sand 0/5, from Lake Kivu, of density 1.36 and specific unit weight 2.5. Recycled sand 0/5, from concrete blocks fragmentation and sieving in order to obtain sand in conformity to the norm NF EN 933-1 [7]. Natural gravels 5/25, from crushing of basaltic rock. Recycled gravels 5/25 from concrete blocks fragmentation.

2.1.2. Water

Water used form concrete formulation was from "Régie de Distribution d'Eau" (REGIDESO), the water distribution company in Goma.

2.1.3. Cement

The cement used is the Compound Portland Cement CEM II 32.5R RHINO produced in Kenya. Its characteristics are presented in Table 1.

2.2. Experimentation

In this section, we present tests on aggregates on the one hand, which include particle size analysis, sand equivalent and bulk unit weight; and on concrete on the other, which include consistency and compressive strength at fresh and hardened states respectively.

2.2.1. Tests on Aggregates

1) Particle size analysis

a) Purpose

Particle size composition is obtained by standardized particle size analysis NF EN 933-1 [7]. Particle size analysis is aimed to determine the grains weight distribution of aggregates according to their size by plotting a particle size curve.

b) Principle

Particle size analysis is carried out by dividing through a series of sievers the material into different granular classes of decreasing particle size. From that segregation, we obtain the mass of particles retained by the different sievers and passing through them. They are presented in terms of their respective ratios to the initial mass. The cumulated ratio of particles passing through a given siever is obtained by the expression (1).

$$P_j(\%) = \left(1 - \frac{\sum M_i^r}{M_s}\right) \cdot 100 \tag{1}$$

Table 1. Characteristics of the compound Portland cement used.

Commercial name	CEM II 32.5 R cement		
Color	Gray		
Specific density	3.1		
Bulkunit weight (g/cm^3)	1.17		
Setting time	4 hours		
Grains diameter	80 µm		
Specific area	3100		
Realresistance class at 28 days	32.5 MPa		
Constitutive element of cement	Clinker	Gypsum	Pozzolana
	65%	5%	30%

With $\sum M_i^r$: the mass of the particles retained by the siever (i); $1 \le i \le j$ and M_s the total dry of dry material sample.

For sand, from particle size analysis, we obtain the finesse module. This parameter characterizes sand size. Finesse module is obtained by the summation of the percentages of the particles retained on the different sievers of respective opennings 0.16, 0.315, 0.63, 1.25, 2.5 and 5 mm. It is preferable that the finesse module of sand for a motar and/or concrete be comprised between 2.2 and 2.8.

c) Equipment

- A column of sievers
- Sievers vibrator
- A weighing machine

2) Cleanliness of sand

a) Purpose

The degree of sand cleanliness is obtained by the test of sand equivalent, which is a standardized test NF EN 933-8 [8]. The purpose of the sand equivalent test is to determine the degree of cleanliness of a sand. It defines the proportion of raw sand compared to impurities contained in the sand.

b) Principle

The sand equivalent is obtained by pouring a given mass of sand into two burettes containing a wash solution in order to evaluate in percentage the proportion of raw sand compared to impurities in the sand. The Sand Equivalent (SE) is calculated from the expression (2).

$$\text{SE} = \frac{h_1}{h_2} * 100 \qquad (2)$$

With h_1 (cm) the height of visible sand deposit and h_2 (cm) the total height (including the fines in suspension).

c) Equipment

- A stirrer
- A washing tube
- Burettes
- A timer

3) Specific unit weight of aggregates

a) Purpose

The specific unit weight is obtained by the normalized test NF P 18 - 555 [9]. The purpose of the test is to express the mass per volume unit of aggregates particles without taking into account the volume occupied by the voids.

b) Principle

The specific unit weight of a body is generally obtained by measuring the volume of a given liquide (generally water) that the aggregate moves when it is poured into the liquid. The results of the absolute density are calculated by the expression (3).

$$\varphi_{Abs} = \frac{Ms}{V_2 - V_1} \tag{3}$$

With Ms the mass of aggregates, V_1 the volume of water in the burette without the aggregates, V_2 the volume of water in the burette after the pouring of aggregates.

c) Equipment

- A burette
- A weighing machine

2.2.2. Tests on Concrete

1) Consistency

a) Purpose

The consistency of concrete is obtained by the standardized test NF P 18 - 45 [10]. The purpose of the test is to obtain the workability of the concrete so as to make its setting up and implementation easier.

b) Principle

The consistency is obtained by measuring the subsidence of fresh concrete under its own weight in the Abrams' cone.

c) Equipment

- Abrams' cone

2) Compressive strength

a) Purpose

The compressive strength of concrete is obtained by the standardized test NF P 18 - 406 [11]. The test is aimed to determine the compressive strength of concrete.

b) Principle

The test consists of submitting a standardized concrete test tube to an axial compressive force up to its ruin.

c) Equipment

- Mechanical press.

3. Results and Interpretation

3.1. Results of Tests on Aggregates

3.1.1. Particle Size Analysis

The particle size composition was obtained according to the norm NF EN 933 – 1 presented previously. The results of that test are presented in **Tables 2-5** and in **Figure 1** for natural sand, recylcled sand, natural gravels 5/25 and recycled gravels 5/25.

From **Table 2** and **Table 3**, we find out that the fine module of natural sand is 2.5 while that of recycled sand is 3.3. Those results show that recycled sand is very coarse since its finesse module is superior to 2.8. The recycled aggregates-based concrete has lost its workability. In order to perform its workability, we are required to increase the proportion of sand fine particles so that the finesse module be comprised between 2.2 and 2.8.

Table 2. Particle size composition of natural sand.

Siever Number		Openning (in mm)		Cumulative Retained Particles		Passing Particles	Observation
ASTM	AFNOR	ASTM	AFNOR	(g)	(%)	(%)	
3”	50	76.2	80				
21/2”	49	63.5	63				
2”	48	50.8	50				
11/2”	47	38.1	40				
11/4”	46	31.7	31.5				
1”	45	25.4	25				
¾”	44	19.1	20				
2/3”	43	16.9	16				
½”	42	12.7	12.5				
3/8”	41	9.52	10				
1/3”	40	7.93	8				
¼”	39	6.35	6.3			100	
3/16”	38	4.76	5	16	1	99	
5	37	4	4	34	2	98	
6	36	3.36	3.15	58	3	97	
8	35	2.38	2.5	98	5	95	
10	34	2	2	150	7	93	
12	33	1.68	1.6	247	12	88	
16	32	1.19	1.25	409	20	80	
18	31	1	1	617	31	69	
20	30	0.84	0.8	826	41	59	
30	29	0.59	0.63	1086	54	46	
35	28	0.5	0.5	1298	65	35	
40	27	0.4	0.4	1466	73	27	
50	26	0.315	0.315	1599	80	20	
60	25	0.25	0.25	1737	87	13	
70	24	0.2	0.2	1811	91	9	
100	23	0.16	0.16	1867	93	7	
120	22	0.125	0.125	1900	95	5	
140	21	0.1	0.1	1921	96	4	
200	20	0.08	0.08	1937	97	3	

Table 3. Particle size composition of recycled sand.

Siever Number		Openning (in mm)		Cumulative Retained Particles		Passing Particles	Observation
AFNOR	ASTM	AFNOR	(g)	(g)	(%)	(%)	
3"	50	76.2	80				
21/2"	49	63.5	63				
2"	48	50.8	50				
11/2"	47	38.1	40				
11/4"	46	31.7	31.5				
1"	45	25.4	25				
¾"	44	19.1	20				
2/3"	43	16.9	16				
½"	42	12.7	12.5				
3/8"	41	9.52	10				
1/3"	40	7.93	8				
¼"	39	6.35	6.3				
3/16"	38	4.76	5	0	0	100	
5	37	4	4	194	10	90	
6	36	3.36	3.15	392	20	80	
8	35	2.38	2.5	614	30	70	
10	34	2	2	798	40	60	
12	33	1.68	1.6	962	48	52	
16	32	1.19	1.25	1101	55	45	
18	31	1	1	1226	61	39	
20	30	0.84	0.8	1332	67	33	
30	29	0.59	0.63	1442	72	28	
35	28	0.5	0.5	1531	76	24	
40	27	0.4	0.4	1607	80	20	
50	26	0.315	0.315	1689	84	16	
60	25	0.25	0.25	1752	87	13	
70	24	0.2	0.2	1798	90	10	
100	23	0.16	0.16	1851	92	8	
120	22	0.125	0.125	1912	95	5	
140	21	0.1	0.1	1933	97	3	
200	20	0.08	0.08	1972	98	2	

Table 4. Particle size composition of natural gravels 5/25.

Siever Number		Openning (in mm)		Cumulative Retained Particles		Passing particles	Observation
AFNOR	ASTM	AFNOR	(g)	(g)	(%)	(%)	
3"	50	76.2	80				
21/2"	49	63.5	63				
2"	48	50.8	50				
11/2"	47	38.1	40				
11/4"	46	31.7	31.5				
1"	45	25.4	25				
¾"	44	19.1	20	0	0	100	
2/3"	43	16.9	16	446	10	90	
½"	42	12.7	12.5	1854	42	58	
3/8"	41	9.52	10	3058	69	31	
1/3"	40	7.93	8	3655	82	18	
¼"	39	6.35	6.3	4209	95	5	
3/16"	38	4.76	5	4323	97	3	
5	37	4	4	4426	100	0	
6	36	3.36	3.15				
8	35	2.38	2.5				
10	34	2	2				
12	33	1.68	1.6				
16	32	1.19	1.25				
18	31	1	1				
20	30	0.84	0.8				
30	29	0.59	0.63				
35	28	0.5	0.5				
40	27	0.4	0.4				
50	26	0.315	0.315				
60	25	0.25	0.25				
70	24	0.2	0.2				
100	23	0.16	0.16				
120	22	0.125	0.125				
140	21	0.1	0.1				
200	20	0.08	0.08				

Table 5. Particle size composition of recycled du gravels 5/25.

Siever Number		Openning (in mm)		Cumulated retained		Passing	Observation
AFNOR	ASTM	AFNOR	(g)	(g)	(%)	(%)	
3”	50	76.2	80				
21/2”	49	63.5	63				
2”	48	50.8	50				
11/2”	47	38.1	40			100	
11/4”	46	31.7	31.5	289	11	89	
1”	45	25.4	25	596	24	76	
¾”	44	19.1	20	1065	42	58	
2/3”	43	16.9	16	1505	60	40	
½”	42	12.7	12.5	1859	74	26	
3/8”	41	9.52	10	2115	84	16	
1/3”	40	7.93	8	2307	92	8	
¼”	39	6.35	6.3	2430	97	3	
3/16”	38	4.76	5	2473	98	2	
5	37	4	4	2492	99	1	
6	36	3.36	3.15				
8	35	2.38	2.5				
10	34	2	2				
12	33	1.68	1.6				
16	32	1.19	1.25				
18	31	1	1				
20	30	0.84	0.8				
30	29	0.59	0.63				
35	28	0.5	0.5				
40	27	0.4	0.4				
50	26	0.315	0.315				
60	25	0.25	0.25				
70	24	0.2	0.2				
100	23	0.16	0.16				
120	22	0.125	0.125				
140	21	0.1	0.1				
200	20	0.08	0.08				

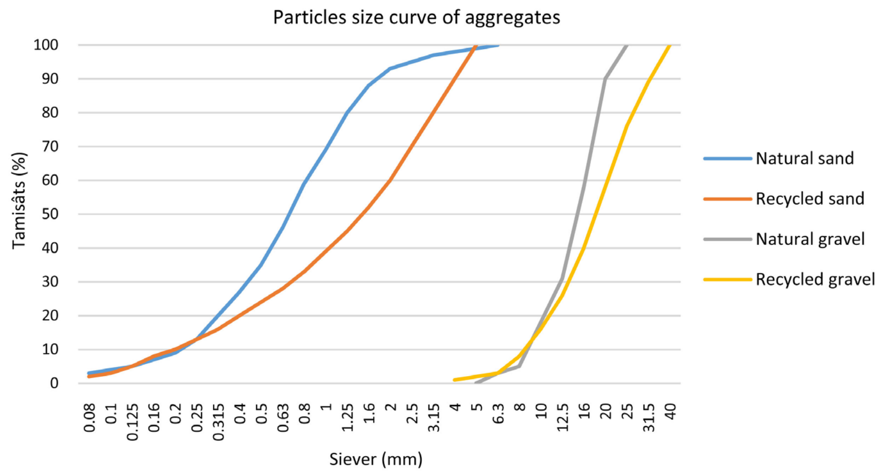

Figure 1. Particle size curve of aggregates.

3.1.2. Sand Cleanliness

The test of sand cleanliness showed that for natural sand, the visual sand equivalent (VSE) is around 70%, while the sand equivalent to piston is 67.6% (SEP). For recycled sand, the respective values are 76.9% and 78%. These results show that the recycled sand is clean and suitable for concrete.

3.1.3. Specific unit Weight of Aggregates

Table 6 presents the different values of specific unit weight of aggregates.

Specific unit weights of recycled aggregates are inferior to those of natural aggregates. This is due to the fact that recycled aggregates, which are porous, contain some quantity of cement still bounding on the aggregates on the one hand, and the nature of the original rock of the aggregates on the other.

3.2. Results of Tets on Concretes

3.2.1. Composition of Concretes

DreuxGoris method [12] was used. Concrete composition is presented in Table 7. Table 8 presents the equivalent composition.

3.2.2. Equivalent Composition

See Table 8.

3.2.3. Consistency Test

The results of subsidence test to Abrams' cone are presented in Table 9.

The different concretes are plastic since their maneuverability is comprised in the interval between 5 cm and 9 cm. The maneuverability of reference concrete is 7 cm while that of recycled aggregates-based concrete is 9 cm. There has been observed the necessity in additional water for recycled aggregates-based concrete in order to obtain the same workability as that of the reference concrete. This shows up the need for additional water in recycled aggregates. The results presented in the Table 9 show that the formulated concretes can be used to build formwork footings, retaining walls, slabs, pavement, beams and columns.

Table 6. Specific unit weight of aggregates.

Aggregates	Natural sand	Recycled sand	Natural gravels	Recycled gravels
Specific unit weight (g/cm^3)	2.5	2.38	2.78	2.38

Table 7. Concrete composition (per cubic meter).

Concrete	Composition			
	Cement (kg)	Sand (kg)	Gravels (kg)	Water (kg)
Reference concrete (Ref) [Natural sand, natural gravels]	350	450	825	170
Recycled concrete 1 (RC_1) [Natural sand, recycle gravels]	350	450	825	170
Recycled concrete 2 (RC_2) [Recycle sand, natural gravels]	350	450	825	170
Recycled concrete 3 (RC_3) [Recycle sand, recycle gravels]	350	450	825	170

Table 8. Concrete composition on cylindrical 16 * 32 cm test-tubes.

Concrete	Composition			
	Cement (kg)	Sand (kg)	Gravels (kg)	Water (kg)
Reference concrete (Ref) [Natural sand, natural gravels]	6.25	11.25	20.625	4.25
Recycled concrete 1 (RC_1) [Natural sand, recycle gravels]	6.25	11.25	20.625	4.25
Recycled concrete 2 (RC_2) [Recycle sand, natural gravels]	6.25	11.25	20.625	4.25
Recycled concrete 3 (RC_3) [Recycle sand, recycle gravels]	6.25	11.25	20.625	4.25

Table 9. Results of the subsidence test.

Concrete	Ref	RC_1	RC_2	RC_3
Subsidence in cm	5	9	9	7

3.2.4. Compressive Strength

The results of the compressive strength test on 16 * 32 cm cylindrical test-tubes of the different concrete samples are presented in Table 10. The concrete samples were formulated by Dreux-Gorisse Method.

4. Conclusion

In order to contribute to construction waste management and environmental protection, it has been studied the properties of concrete formulated by recycled aggregates for its usage in building. The global aim was to analyze the influence of substitution of natural aggregates by recycled aggregates from building

Table 10. Compression test results on 16 * 32 cm cylindrical test-tubes.

Concrete	Compression resistance (MPa)
Ref	25.8
RC_1	18.17
RC_2	17.25
RC_3	21.5

concrete demolition. The compressive strength of recycled aggregates-based concrete was acceptable compared to the natural aggregates-based concrete. The difference is due to the quality of structural concrete used as aggregates source. These mechanical properties show that recycled aggregates can produce concrete of strengths range between 20 and 25 MPa without using any particular sophisticated technology. Usage of recycled aggregates in concrete formulation can offer a sure and helpful solution to demolition waste management. Concrete produced from recycled aggregates is likely to be used for structures of average span and in conditions of low aggressively. However, the study of recycled concrete micro-structure and their durability can complete and improve this study. Such a study can extend the usage range of recycled aggregates-based concrete in civil engineering.

Conflicts of Interest

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

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