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Experimental Evaluating of the Physical, Mechanical and Durability Properties of Natural, Recycled and Both Combined Aggregates Based Concretes

Etienne Malbila[1,2], Arba A.T. Ouedraogo[1], Nicolas Kagambega[1,3], Gilbert G. Nana[2], Sié Kam[2], David Y. K. Toguyeni[4,5]

[1]Ecole Supérieure d'Ingénierie (ESI), Université de Fada N'Gourma (UFDG), Fada-N'Gourma, Burkina Faso
[2]Laboratoire d'Energies Thermiques Renouvelables (LETRE), Université Joseph KI ZERBO, Ouagadougou, Burkina Faso
[3]Laboratoire de Géosciences et Environnement (LaGE), Université Joseph KI ZERBO, Ouagadougou, Burkina Faso
[4]Laboratoire de Physique et Chimie de l'Environnement (LPCE), Université Joseph KI ZERBO, Ouagadougou, Burkina Faso
[5]Ecole Polytechnique de Ouagadougou (EPO), Ouagadougou, Burkina Faso
Email: t.emalbila@gmail.com

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Abstract

This experimental study aims at the reuse of recycled aggregates (RA), resulting from the demolition of concrete, cement block and cement mortar, in the manufacture of common construction in Burkina Faso. The RA can readily replace natural aggregates in concrete. Then five formulations of natural and recycled aggregates based concrete for characteristic strength of 25 Mpa were prepared in addition to the natural aggregates base concrete named reference concrete (BN): two types of recycled aggregates concrete (BR), three types of recycles and natural combined aggregates base concrete (BC). The properties of natural and recycled aggregates were characterized and the physical, mechanical strength and durability properties were also evaluated for all concrete specimens. All the studied concrete formulation present a density between 2000 kg/m^3 $\leq \rho \geq$ 2600 kg/m^3 and an average slump of 4.9 ± 0.1 cm. The obtained results indicate that the recycled aggregates are suitable for current concrete. Two out of the five combinations studied, such as the natural (BN) and combined aggregate (BC2) based concretes satisfy the mechanical characteristics (Rc_{28} > 25 MPa) at 28 days of age and an average absorption coefficient of 2.93% and 3.98%. The recycled aggregate based concrete (BR1, BR2) and combined aggregate based concrete (BC1), gave respective average compressive strength of 21.55 MPa, 20.50 MPa and 20.30 MPa, *i.e.* a difference of 13.80% to 18.80% under the characteristic strength (25 MPa) aimed at 28 days of age. Thus, the recycled aggregates are in conformity with the normative prescriptions and their use for standard concrete gives adequate physical, mechanical and durability properties for the production of the C20/25 concrete series in the common civil engineering applications.

Keywords

Concrete, Demolition Waste Aggregate, Recycled Aggregate, Strength, Water Absorption

1. Introduction

The current context of undeveloped country is marked by demographic growth and an urgent need for urbanisation which have increased the pace of construction industry. With this need of accelerated for modernism, the construction sector is considered as an important element [1] [2] and uses an important quantity of natural resources and rejects significant pollutant waste and their disposal is often expensive [3]. While the universal need to conserve the natural resources, to protect the environment and to well use energies, become one of the world's main concerns. The use of cement-based materials to meet important construction projects, now requires the search for new quarry sites, including alternatives and recycled materials [4]. Indeed, actually the most current concrete materials use the natural aggregate from quarries or from the extraction of rivers and sea and relatively offer the advantage of constant quality and continuous supply [5].

With the demographic growth, the great ecological challenges lead the actors to re-examine their urbanization policy for the non-renewable resources sustainable management. As in many countries, the recycling in construction sector is of vital importance [6] [7] and now provides new supply opportunities of materials for the application such as paving and sidewalks [8] [9], to produce roller-compacted concrete by modifying the recycled aggregates surface roughness [10] and to lower cement demand and reduce associated CO_2 emissions [11]. Indeed, during recent years several studies were carried out worldwide on the properties of recycled aggregates based concrete [6] [12] [13] in civil engineering applications [14] and concluded the possibility to formulate recycled aggregate concrete with mechanical properties comparable to natural aggregate concrete [13] [15] [16]. Even if their valorisation is slower down by the fact that they are considered non-standard aggregates [17] the observation is that each study assumes that the recycled aggregates from cementitious materials (concrete, breeze blocks and cement mortars) are properly implemented [18]. While the conditions of the concrete implementation (concrete plant, concrete mixer or manual mixing, …) constitute an important factor that can affect the concrete granular component. Indeed, an initial lower quality concrete will tend to decrease the characteristics of the recycled aggregate concrete [12] [19] [20] [21]. Concrete has a 28-day compressive strength of 28 MPa was crushed at ages 1, 3 and 28 days to serve as a source of aggregate for new concretes, simulating the situation prevailing in precast concrete plants. Significant differences were observed between the properties of the recycled aggregates of various particle size groups, while the crushing age had almost no effect [22].

In Burkina Faso, the conditions for concrete implementation are not always circumscribed and controlled, whereas the concrete and aggregates mechanical strength are fundamentally link [23] [24]. One of this study concerns, is to check the possible use of recycled aggregate form concrete and cement bricks [1] implemented under uncontrolled technical conditions of three sites can be reused after manual recycling in the manufacture of current concrete. Knowing that the recovery of demolition materials depends on the content of polluting materials (plaster, wood, plastic, paper, ...) [3].

In the supply of natural aggregates for civil engineering application, socio-economic [7], ecological, environmental, pollution, energy consumption [25] constraints appear. Then, it's now necessary to consider the use of materials from demolition as aggregate for concrete in current construction to overcome the above set out constraints [9] [26] [27] and mainly to protect the natural deposits against the opening of new quarries for the extraction aggregates [26].

A synthesis of the methods of aggregate treatment show a various techniques such as heat treatment, carbonation, mechanical rubbing, surface coating, biodeposition and soaking in hydrochloric acid, sodium sulfate solution, sulfuric acid, nitric acid and acetic acid, are used by the researchers to improve the properties of recycled aggregates [28] [29] [30]. These treatments can influence the quality of the aggregates and the concrete behaviour. Based on literature study, the reuse of demolition aggregates without specific treatment or by manual recycle procedure in concrete is underexplored by researchers. With the aim of optimizing the use of natural aggregate, the present work compares the usual performances of standard concrete integrated natural aggregates and manually recycled aggregate from the demolition of concrete, cement blocks and mortar. And then, to contribute to the valorisation of demolition materials in the civil engineering current applications.

2. Materials and Methods

The present work is completely an experimental study and to this end we established a conceptual framework showed in **Figure 1**. The graph in **Figure 1** summarizes the current study methodology based on the main four steps which are described in the following paragraph.

2.1. Raw Materials

The material used in this study included Ordinary Portland Cement, natural and recycled aggregates.

2.1.1. Cement

In this study, the cement used for the formulation of common concretes is standard

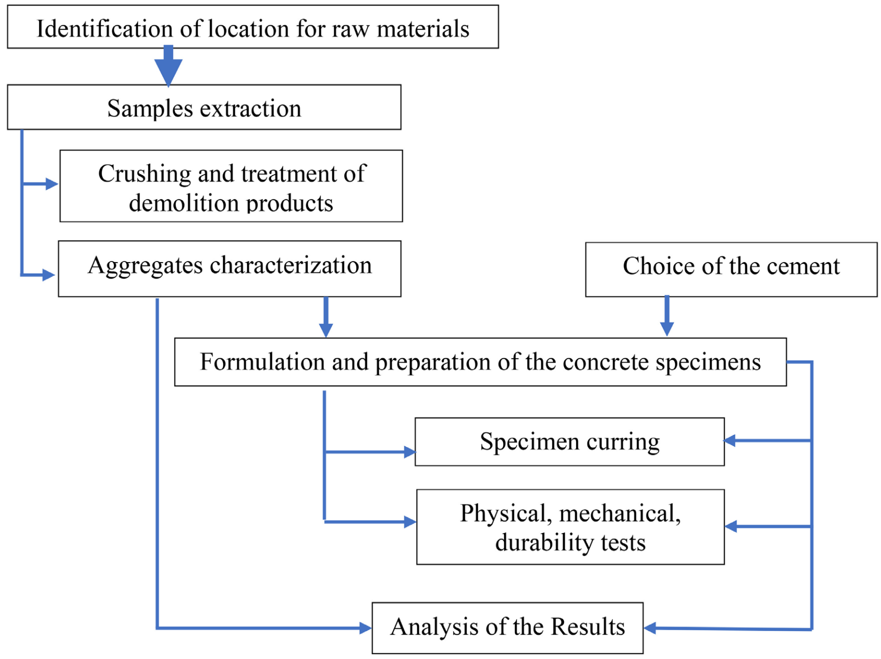


Figure 1. Study framework.

cement from CIMBURKINA. It is CEM II 42.5 R class cement, with a specific mass of 3.10 g/cm^3, manufactured in the Ouagadougou industrial zone in Burkina Faso in accordance with the NBF 02-013 standard.

2.1.2. Aggregate

In this study, four type of aggregate have been used as below:

– Natural sand 0/5 (rolled) from Manga, taken from the Donsin airport site (Figure 2(a));
– Recycled sand 0/2 (rolled) from the crushing of concrete blocks extracted in Kamboinsin (Figure 2(b));
– 16/25 natural aggregates (crushed granite) recovered from the Yiimdi quarry, taken from the Donsin airport site (Figure 2(c));
– 16/25 recycled aggregates (crushed granite) from the fragmentation of structural demolition concrete blocks (relatively clean), from the slab of the Dapoya Shell station being repaired, and from the northern interchange bridge (Figure 2(d)).

The natural and recycled aggregates particle size curves are shown in Figure 3 below.

In Figure 3, we notice that the recycled sand from Kamboinsin (0/2 mm) is finer than the natural sand from Donsin (0/5 mm). This obtained granular class (0/2 mm) can be explained by the crushing non controlled energy and the sifting carried out during the recycled aggregate processing. Also, there is an important quantity of the particle size 0.2/5 mm and 1.6/5 mm respective in the recycled sand from northern interchange and natural sand from Donsin. Their physical and mechanical properties are summarized in Table 1 below.

(a) Natural Sand (rolled)

(b) Recycled Sand (rolled)

(c) Natural granite aggregate

(d) Recycled Granite Aggregate

Figure 2. Aggregate sample.

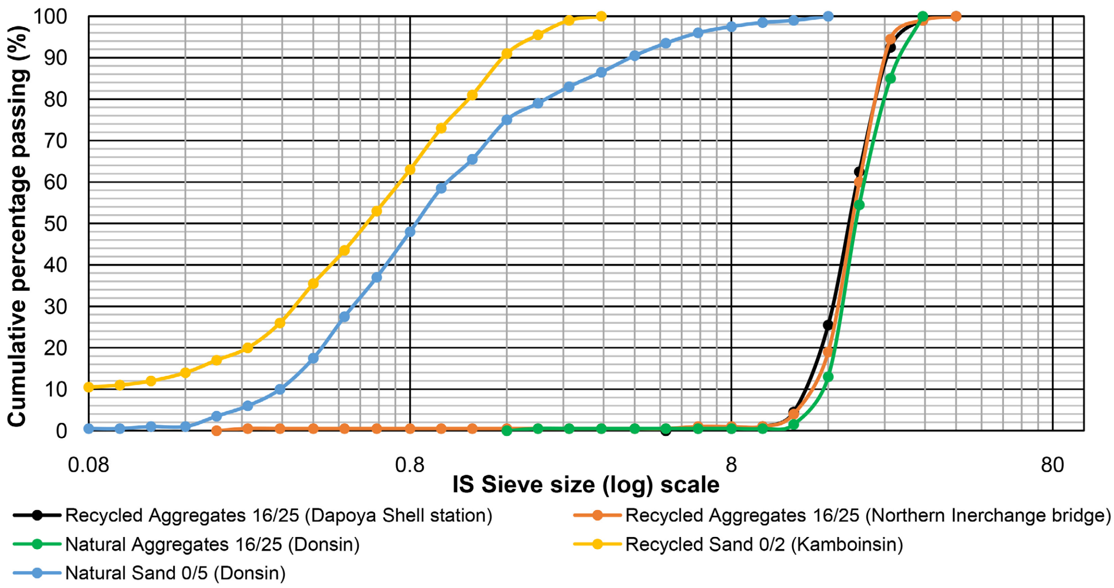


Figure 3. Particle size distribution of natural and recycled aggregates.

Table 1. Summary of requirements of the current concrete.

N°	Caractéristiques	Exigences
1	Type of concrete	Standard
2	Aggregate maximum Diameter (D_{max})	25 mm
3	Aggregate rang	0/2, 0/5 et 16/25
4	Aggregate coefficient Gf (D)	0.5
5	Concrete characteristic strength at 28 days of age (fc28)	25 MPa
6	Cement strength class (σ_c)	43 MPa
7	Slump (A)	3 à 5 cm
8	Concrete vibration	Normal vibration
9	Cement quantity (C)	350 kg/m^3

2.1.3. Mixing Water

The national Lab of Building and publics works (LNBTP) is supplied with water by the National Office of water and sanitation (ONEA) in accordance to standard NF EN 1008 [31]. This water taken from tap for concrete mixing is free of impurities and presents the characteristics of the drinking water.

2.2. Formulation and Preparation Specimens

2.2.1. Concrete Mix

The Dreux-Gorisse method [32] for current concrete formulation was used throughout this study and the specifications and requirements are described in Table 2 below.

The five (05) formulation of concrete were defined and identified in the Table 3 below by the type of aggregate used.

2.2.2. Mixing and Curing of Concrete Specimen

The concrete specimens were made in accordance with standard NF EN 12390-2 [33], and the equipment available to the LNBTP Lab. The mixing procedure is summarized in Table 4 below.

At 24 hours age, the specimen are removed from mold and stored in water tank under laboratory suitable ambient conditions. These conditions are kipped until the crushing tests after 7 days and 28 days age.

Table 2. Description of studied concrete aggregate components.

Concrete Item	Description	Recycled sand from Kamboinsin	Natural Sand from Donsin	Natural granite aggregate from Donsin	Recycle granite aggregate from Dapoya	Recycle aggregate form Northern interchange
		0/2	0/5	16/25	16/25	16/25
BR1	Recycled aggregate (RA) concrete 1	+			+	
BR2	Recycled aggregate (RA) concret 2	+				+
BN	Reference concrete (NA base concrete)		+	+		
BC1	Combined aggregate (CA) concrete 1		+		+	+
BC2	Combined aggregate (CA) concrete 1	+		+		

Table 3. Components dosage per 1m3 of concrete.

Concrete components	Unit	BR1	BR2	BN	BC1	BC2
Recycled granite aggregate 16/25	Kg	1138.18	1138.18		1007.56	
Natural granite aggregate 16/25				985.17		1133.83
Recycled Sand 0/2	Kg	730.44	730.44			730.44
Natural Sand 0/5				870.35	851.83	
Cement CEM II 42,5 R	Kg	350	350	350	350	350
Mixing Water	Kg	190.22	190.22	190.22	190.22	190.22
Ratio C/W		1.84	1.84	1.84	1.84	1.84

Table 4. Summary of the mixing procedure.

Time	$t_0 - 2\,\text{min}$	$t_0 - 30''$	t_0	$t_0 + 1\,\text{min}$	$t_0 + 2\,\text{min}$
Addition	G + S		Cement		Water
Mixing	Mixing	Rest	Mxing	Rest	Mixing

2.3. Tests Performed

2.3.1. Physical Characteristic Test

1) Charaterization of aggregate

The fine and coarse aggregate used in the concrete must have characteristics that comply with the standards in force, in particular the granularity [34], the shape of the aggregate, [35] the densities and the water absorption [36] [37] the cleanliness [38] [39] and the hardness [40]. To obtain a quality concrete, it's necessary to use components in quantities naturally or after recycling and/or treatment, as discussed by [41] for the aggregates.

2) Workability of concrete

The tests carried out on fresh concrete concern its workability. Its consistency was determined by measuring slump, in accordance with standard NF EN 12350-2 [42].

3) Bulk density (ρ_{ap})

By weighing the masses of the specimens subjected to the compression and tensile tests, the apparent density is obtained by applying the following formula:

$$\rho_{ap} = \frac{M}{V} \tag{1}$$

with:

– ρ_{ap}: *the apparent density of the hardened concrete at "j" days (in kg/m*^{3}*)*;

– *M: the mass of the specimen of hardened concrete at "j" days (in kg)*;

– *V: the volume of the specimen (in m*^{3}*)*.

The weighing of the samples concerned six samples of each formulated concrete, at the 7th and 28th days of hardening age.

2.3.2. Mechanical Strength Test

1) Compressive strength (F_c)

It is determined by axial compression of straight cylinders of revolution and of a height twice their diameter [32] according to standard NF EN 12390-4 [43]. The cylinders used are the cylinder of 16 (Ø = 15.96 cm) whose section is 200 cm^2 and the cylinder of 15 (Ø = 15 cm) whose section is 177 cm^2. It is determined on the 7th and 28th days of hardening, on 3 samples of each type of common concrete (*i.e.* 15 test specimens in total).

The compressive strength values: F_c are obtained by applying the following formula:

$$F_{cj} = \frac{F}{S} = \frac{F}{\pi \cdot r^2}\ (\text{MPa}) \tag{2}$$

with:

- F_{cj}: *Compressive strength at "J" days of age (in MPa)*;
- F: *value of the breaking load (in N)*;
- S: *section of the specimen (in mm²)*;
- r: *radius of the specimen (in mm)*.

2) Tensile strength (F_t)

The tensile strength is determined by a tensile test by splitting on cylindrical specimens (16 cm × 32 cm and 15 cm × 30 cm), in accordance with standard NF EN 12390-6 [44]. The test consists of crushing a cylinder of concrete along two opposite generatrices between the plates of a press [45]. It is determined on the 7th and 28th days of hardening, on 3 samples of each type of common concrete (*i.e.* 15 test specimens in total). The tensile strength values: F_t are obtained by applying the following formula:

$$F_{tj} = 2 \times \frac{P}{\pi \cdot D \cdot L} \tag{3}$$

with:

- F_{tj}: *tensile stress at "D" days of age (in MPa)*;
- P: *value of the breaking load (in N)*;
- *D and L*: *diameter and length of the cylinder (in mm)*.

2.3.3. Durability Characterization Test

The characterization of the durability of hardened concrete is measured by the Water Absorption test (Abs) and its measurement is a macroscopic characterization tool of its porous network [17]. Concrete is a porous material, making these pores critical aspects for the strength and durability of concrete. Indeed, a low porosity constitutes the best means of defense of concrete against all aggressive agents. Thus, water absorption by immersion is used in this study to characterize the porosity of formulated concretes. It is determined on the 28th day of hardening age, on 3 samples of each type of common concrete, by application of the following formula:

$$A_{bs} = \frac{M_{\text{humide}} - M_{\text{seche}}}{M_{\text{seche}}} \times 100\,(\%) \tag{4}$$

with:

- M_{humide}: *the constant wet mass of the specimen after immersion (in g)*;
- M_{seche}: *the constant dry mass of the specimen after drying in the oven (in g)*.

3. Results

3.1. Properties of the Naturals and Crushed Aggregates

Size distribution curve of the naturals and recycled aggregates prepared from the old concrete blocks crushed are presented in **Figure 2**. The aggregates were divided in three size fraction (coarse, medium, fine) in order to distinguish between properties that might be related to their particle size. **Table 5** shows the physical and mechanicals properties of the naturals and recycled aggregates, such as:

The recycled aggregates are of type CR_b according to standard NF EN 206/CN

Table 5. Physical and mechanical properties of the naturals and recycled aggregates.

Features	Units	Sand		Crushed granites			Specification for hydraulic concrete [45] [46]
		Natural sand (from Donsin)	Sand recycled (from Kamboinsin)	Natural crushed (from Donsin)	Recycled Crushed (form North Interchange)	Recycled crushed (from Shell Dapoya station)	
Granular class (d/D)	mm	0/5	0/2	16/25	16/25	16/25	-
Fineness modulus (MF)		2.27	3.1	-	-	-	1.8 ≤ MF ≤ 3.2
Flattening coefficient (A)	%	-	-	16.47	7.63	9.87	Vss (A) ≤ 20 and Vss (C) ≤ 40
% fine < 0.08 mm	%	0.5	10.5	-	-	-	Vss (A) ≤ 12 and Vss (C) ≤ 18
Apparent volumetric mass	g/cm^3	1.47	1.35	1.45	1.46	1.48	ρ_{ap} > 1200 kg/m^3
Absolute density (ρa)	g/cm^3	2.63	2.66	2.65	2.65	2.65	2200 kg/m^3 < ρ_a < 3000 kg/m^3
Actual density after oven drying	g/cm^3	-	-	2.63	2.6	2.61	2200 kg/m^3 < ρ_{rd} < 3000 kg/m^3
Actual saturated dry surface density	g/cm^3	-	-	2.64	2.61	2.62	2200 kg/m^3 < ρ_{rsd} < 3000 kg/m^3
Water absorption coefficient	%	-	-	0.22	0.93	0.57	Vss ≤ 2.5 and Vss (C) ≤ 6
Visual Sand Equivalent	%	89.3	72	-	-	-	PVC > 65%
Equivalent of sand on piston	%	85	66	-	-	-	ESP > 60
Superficial cleanliness	%	-	-	0.51	0.56	0.54	Vss ≤ 1.5 or 3
Los Angeles (LA) coefficient		-	-	28	19	18	LA ≤ 30

[47]. The results show that the aggregates correspond to the physical and mechanical characteristics required by standards XP P 18-540 and NF P 18-545 [45] [46], for use for the manufacture of concrete.

3.2. Physical Properties of New Concrete Made of Naturals and Recycled Aggregate

The characterization of the physical properties resulted in the measurement of the Abrams cone slump of the fresh concrete according to standard NF EN 12350-2 [42] and the densities of the hardened concrete.

3.2.1. Water Dosage

The cement dosage being constant (C = 350 kg/m^3), the required water dosage for the mi essentially depends on the nature of aggregates used for concrete composition. The obtained results for each concrete are presented in **Figure 4** and **Figure 5** below.

Figure 4 shows that for each new concrete formulated we add a supplementary quantity of water for the mix. And, this addition depends on the concrete

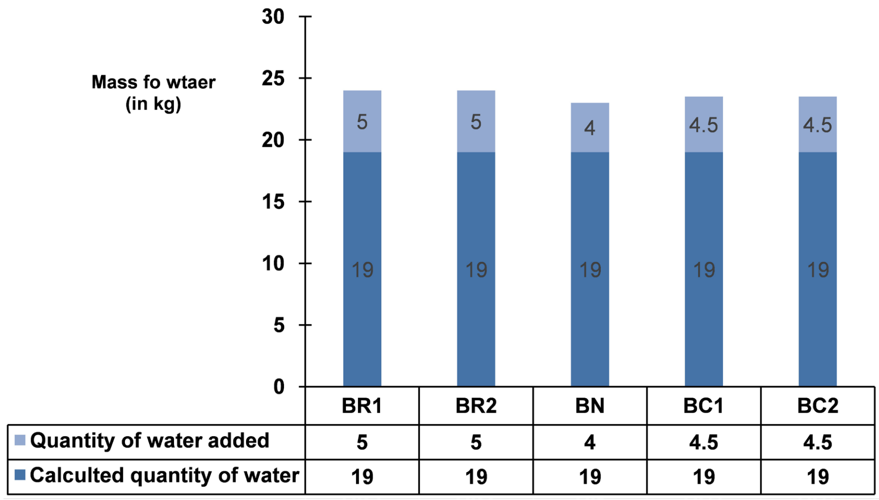


Figure 4. Water dosage for the mixing of the concrete.

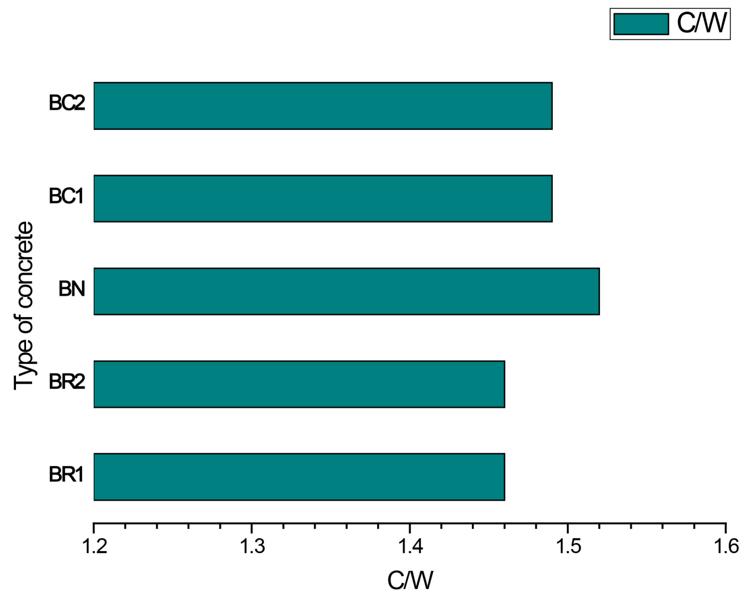


Figure 5. C/W ratio for formulated concretes.

composition. Indeed, the nature of aggregates and the time of crushed concrete storage can influence the water quantity during the mixing of the concrete. It should be recalled here that in the context of this study, the concretes were not produced during the same period. Thus, the aggregates have had more or less time to dry depending on the storage environment. To do this, if the aggregates are stored in a very humid environment, the water supply will be reduced during the manufacture of the specimens and vice versa. Furthermore, the aggregates used were relatively dry during the batches.

The quantities of water added in the recycled aggregates based concretes (BR1 and BR2) mix, as well as the combined aggregates based concretes (BC1 and BC2) required a high addition of water compared to natural aggregate based concrete (BN). This can due to the importance of fines and mortars attached to the aggregates which caused this additional water demand. In Figure 5, the C/W ratio changed from 1.84 to 1.46, 1.52 and 1.49 respectively for BR, BN and BC. It can therefore be deduced that recycled aggregates absorb relatively more water than natural aggregates for the concrete mixing.

Finally, the percentage of recycled aggregate in the standard concrete composition also has an influence on the water content. Indeed, the observation is made with the combined aggregates based concretes (BC1 and BC2), where the addition of water (4.5 liters) is less important compared to that (5 liters) of the recycled aggregates based concretes (BR1 and BR2).

3.2.2. Workability of Formulated Concretes

The results of consistency of the different concretes by measuring the slump test are presented in Figure 6 below.

Figure 6 shows that the obtained value of slump for the five (05) types of concrete vary from 4.7 to 5 cm. These are therefore firm concretes of the desired consistency (3 to 5 cm) like the results obtained by [24]. In addition, the differences that appear between the slump of these concretes are small (*i.e.* 0.2 cm to 0.3 cm). Moreover, with the respected dosage, the nature of the aggregate does not greatly influence the workability.

3.2.3. Density

The determination of the average value of the formulated concretes apparent density was carried out through the weighting of the specimens before the crushing at 7 and 28 days of age of cure. The results are presented in Figure 7 below.

In Figure 7, we note that recycled and combined aggregates (CA) based concretes (BR1, BR2, BC1 and BC2) have low apparent density, whether at 7th and 28th days of age, compared to natural aggregate (NA) based concrete (BN) similar

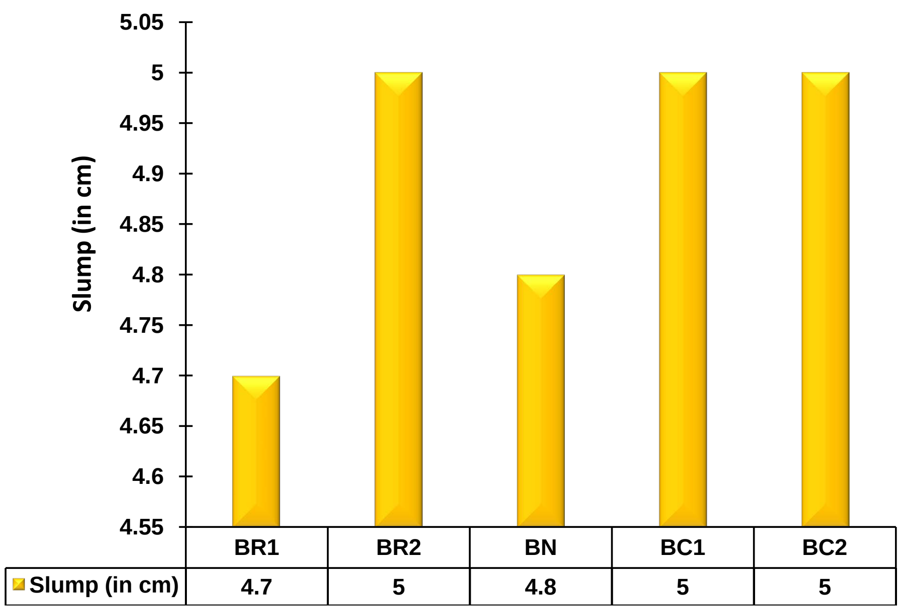
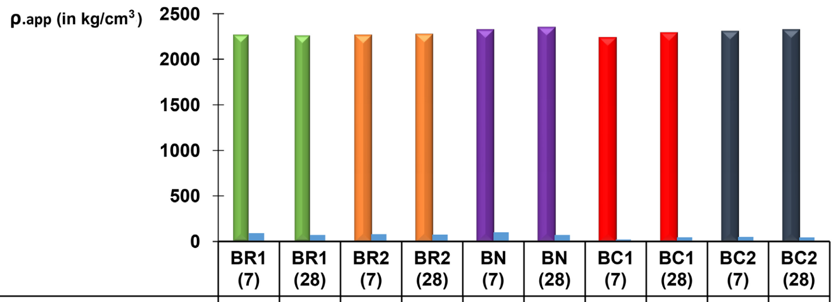


Figure 6. Consistency of formulated concretes.



	BR1 (7)	BR1 (28)	BR2 (7)	BR2 (28)	BN (7)	BN (28)	BC1 (7)	BC1 (28)	BC2 (7)	BC2 (28)
Bulk density of concrete(in kg/m^3)	2268	2260	2255	2265	2313	2342	2225	2283	2298	2312
Standard deviation	92	71	80	76	100	72	22	46	51	44

Figure 7. Density of concretes specimen at 7 and 28 days of age.

to the results of [24]. This difference can be explained by the quantity of recycled materials entering into the granular composition of the concretes studied. Indeed, the average apparent densities of the combined aggregate based concretes (BC1 = 2283 kg/m^3; BC2 = 2312 kg/m^3) are much higher than those of recycled aggregates (RA) based concretes (BR1 = 2260 kg/m^3; BR2 = 2265 kg/m^3) on the 28th days of age.

Moreover, the calculated standard deviations on the formulated concretes the apparent densities, respectively on the 7th and 28th days of hardening are low (65.4 on average).· This means that the apparent densities are concentrated around the mean values

3.3. Mechanical Strength of the Formulated Concretes at 7 Days of age

3.3.1. Compressive Strength

The results of the compressive strength at 7 days of the formulated concretes and their calculated standard deviations are indicated in **Figure 7**.

After 7 days of suitable curing, the formulated concretes have different average compressive strengths. Indeed, **Figure 8** shows that concrete BC2 and BN have a high average resistance compared to BR1, BR2 and BC1. Moreover, theses concretes specimen have an average resistance lower than the minimum values 16.56 MPa and 17 MPa required at 7 days of hardening, respectively in reference to BAEL 91 revised 99 and to Eurocode 2 Rules [48] [49]. For all the samples tested and with reference to the calculated standard deviations, the compressive strength values are concentrated around the average which is 15.56 MPa for recycled aggregate based concrete, 19.65 MPa for natural aggregate bases concrete and 14.00 MPa and 20.30 MPa respectively for combined aggregates based concrete BC1 and BC2.

It was also found that, the BC2 concrete (containing recycled sand) shows great performance compared to BC1 (containing recycled crushed stone). This could be explained by the fact that there is less recycled aggregates in concrete BC2 (*i.e.* 39% recycled sand) compared to BC1 (*i.e.* 54% *recycled crushed*). Thus, the type and the quantity of aggregate are the factors that may support this difference

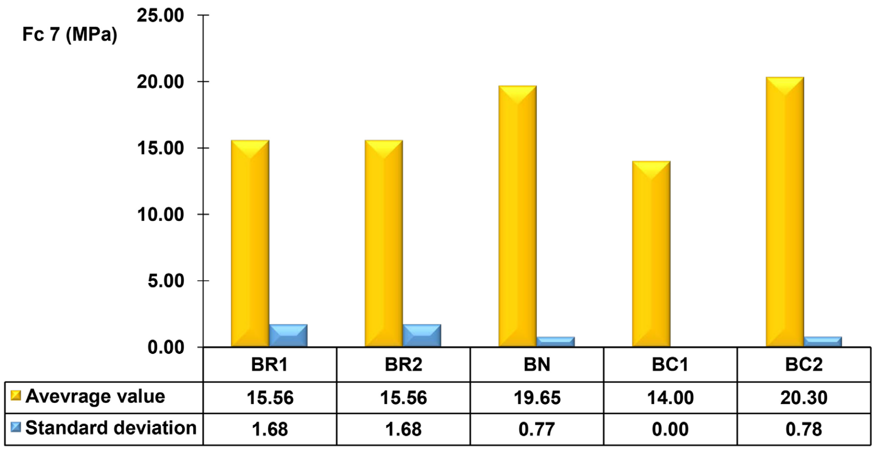


Figure 8. Compressive strength of concrete at 7 days of age.

in the performance of BC2 and BC1. The rate of substitution of natural aggregates by recycled aggregates could therefore have an influence in the long term evolution of the concrete the compressive strength. It is also the effect of the nature of the element of substitution (the recycled crushed in the present case) knowing that the aggregates represent 80% of the resistance of the concrete.

3.3.2. Tensile Strength

Figure 9 presents the evolution of the tensile strength measured by splitting at the 7th days of age and the standard deviations of the different type of formulated concrete.

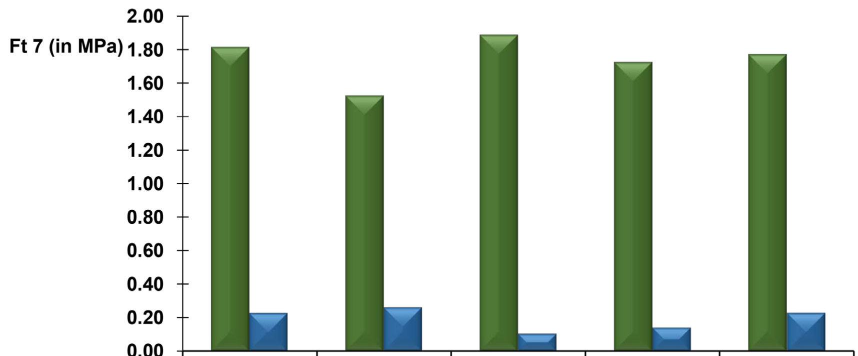
The results shown in **Figure 9** show the lower tensile strength for the recycled aggregate is based concretes (BR2). The obtained average values of abstained results are 1.89, 1.81 Mpa, 1.77, 1.72 MPa, and 1.52 MPa respectively for BN, BR1, BC2, BC1 and BR2. The concretes integrating only aggregates from demolition (BR1 and BR2) have quite different resistances with a difference of 0.29 MPa while those of the combined concretes (BC1 and BC2) are almost similar at 7 days of age, with a deviation of 0.05 MPa. Furthermore, the tensile strengths at 7 days of age are concentrated around these average values, given the low values of the standard deviations calculated on the results of the tensile strengths by splitting of the samples (BR1 = 0.23; BR2 = 0.26; BN = 0.10; BC1 = 0.14; BC2 = 0.23).

3.4. Mechanical Strength at 28 Days of Age

3.4.1. Compressive Strength

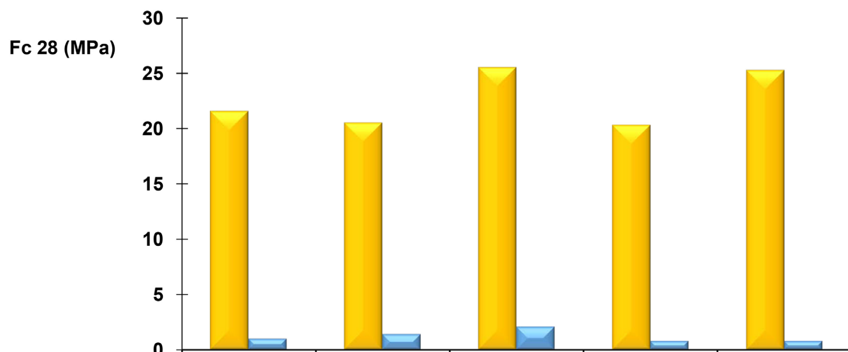
Figure 10 presents for each type of concretes specimen, the compressive strength.

At 28 days of age, the obtained results show that only the BN and BC2 concretes have an average compressive strength strictly greater than 25 MPa. It was also found on recycled aggregates concrete type, that BR1 has an average strength (21.55 MPa) slightly higher than that of BR2 (20.50 MPa) at 28 days of age. This difference could be explained by the presence of fines, aggregated mortars and waste (wood residues) in the recycled aggregates during the preparation of the



	BR1	BR2	BN	BC1	BC2
Averrage value	1.81	1.52	1.89	1.72	1.77
Standard deviation	0.23	0.26	0.10	0.14	0.23

Figure 9. Tensile strength of concrete at 7th days of age.



	BR1	BR2	BN	BC1	BC2
Averrage value	21.55	20.5	25.5	20.3	25.25
Standard deviation	0.99	1.39	2.06	0.78	0.78

Figure 10. Compressive strength at 28 days of age.

batches. Thus, mixing these two types of concrete did not achieve the desired strength, given the action of contaminants (fines, waste, etc.). The average values of compressive strength obtained give a difference of 3.45 MPa and 4.5 MPa compared to the characteristic strength (25 MPa).

Among the two types of combined aggregate based concrete (BC1 and BC2), only concrete BC2 acquires at 28 days of age an average strength (25.25 MPa) strictly greater than 25 MPa. This implies that the mixture between recycled sand (39%) with crushed sand (61%) can ensure better compressive strength; contrary to the mixture between natural sand (46%) and recycled crushed (54%) whose average resistance (20.30 MPa). In addition to the type and proportion of aggregates in the mix, the difference in mechanical strength could be explained by the presence of more polluting elements (fines, wood waste, etc.) in BC1 than BC2 concrete. It is also noticed that the combined concrete BC1 has an average resistance (20.30 MPa) strictly lower than that of the concretes BR1 (21.55 MPa) and BR2 (20.50 MPa). This difference in resistance could be explained by the action of contaminants due to the time and storage conditions of the recycled crushed stones. These pollutants (contaminants) occur during recycling and the rather long storage period of recycled aggregates. Finally, the low standard deviations lead to the conclusion that the compressive strength values are concentrated around the average values.

Figure 11 presents the tested concretes specimens, the relationships between the compressive strength at 28 days of age and the crushed/sand ratio on the one hand and with the density on the other. It was found that there is no established dependence between the C/S ratio and the compressive strength. Moreover, in Figure 11, the graph (11.b) shows that the evolution of the compressive strength linked to the density of the specimens with a correlation coefficient of 0.87.

Depending on the average compressive strengths at 28 days obtained and according to standard NF EN 206-1 [50], the studied concrete can be classified as follows:

– BR1 is in class C20/25;
– BR2 is in class C20/25;
– BN is in class C25/30;
– BC1 is in class C20/25;
– BC2 is in the C25/30 class.

3.4.2. Tensile Strength

The results of tensile strength at 28 days of age of the studied specimens are presented in Figure 12 below.

For the specimens tested at 28th day of age, the obtained results shown in Figure 12, show a high average tensile strength by splitting of the BN concrete, compared to the other types of concrete. Indeed, the minimum values are observed at the level of concrete BR2 (2.08 MPa) and BC1 (2.09 MPa), while concrete BR1 is located a little in the center with an average resistance of 2.51 MPa. Moreover, concrete BC2 has a tensile strength by splitting close to concrete BN, that is to say 2.70 MPa.

The concretes integrating only recycled aggregates (BR1 and BR2) give very divergent average resistances on the 28th day of age. The BR1 has an average tensile strength by splitting of 2.51 MPa, while that of concrete BR2 is 2.08 MPa.

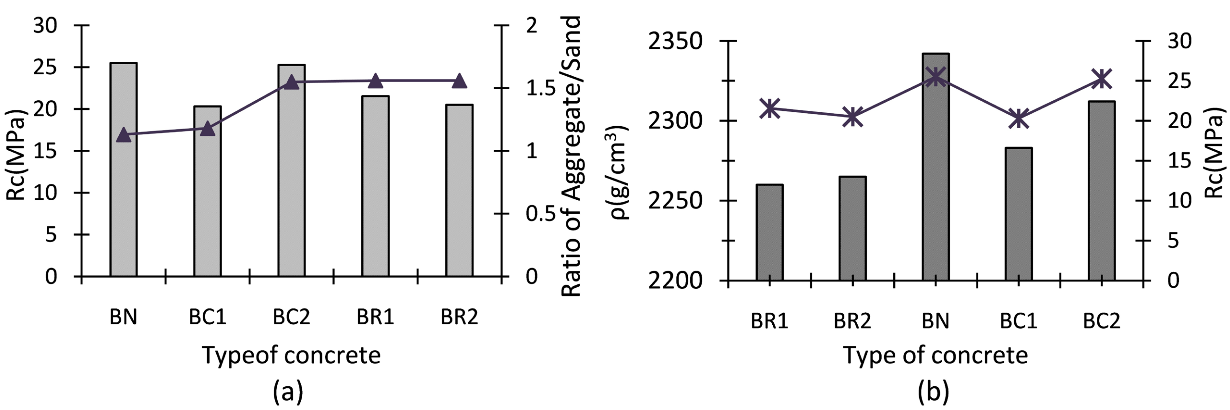


Figure 11. Compressive strength as a function of (a) C/S and (b) *ρ*.

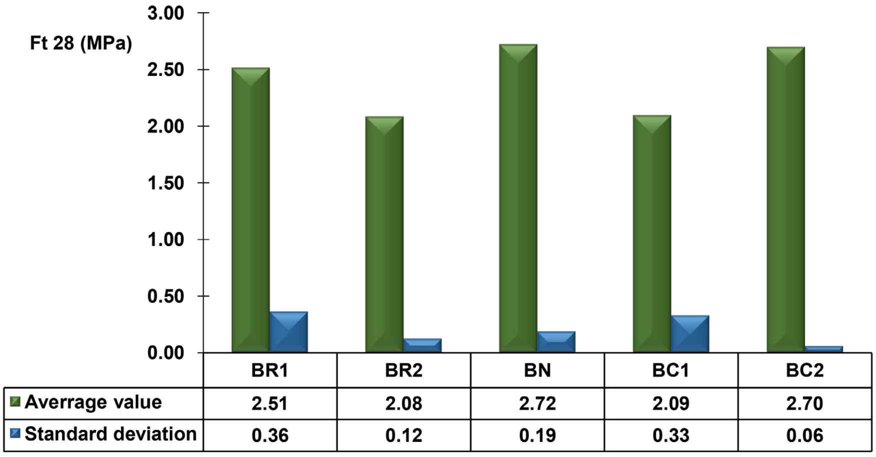


Figure 12. Tensile strength at 28 days of age.

This gives a difference of 0.43 MPa, which can be linked to the action of contaminants (fines, wood waste, etc.). As regards the case of the combined concretes, the average tensile strength by splitting of the concrete BC2 (2.70 MPa) is greater than the concrete BC1 (2.09 MPa) at 28th day of age. As mentioned in the previous paragraph, the presence of contaminants can explain this difference in resistance. In addition, it should be noted that the incorporation of recycled aggregates is in different proportions according to the quantities defined in the formulation of the combined aggregate concretes. To do this, it is possible that the rate of contaminants is higher for concrete BC1 compared to that of BC2. Finally, the standard deviations show that the tensile strengths are around the average values.

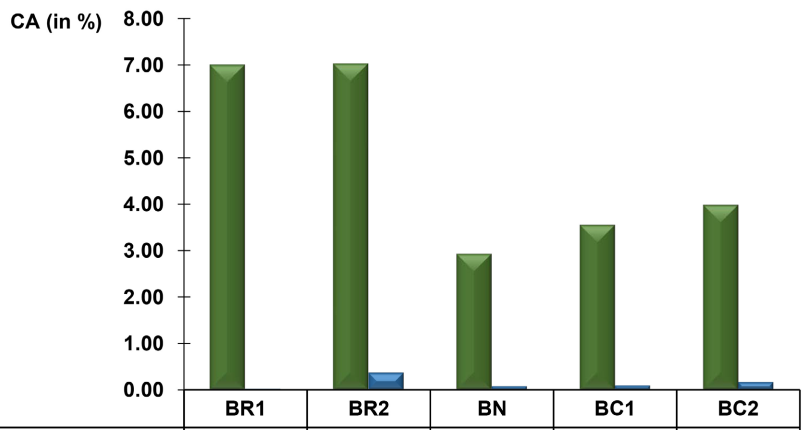
3.5. Durability of Formulated Concretes Specimens

Three samples of each type of formulated concrete are kept for up to 28 days in the laboratory's immersion tank in order to quantify their water absorption. At this immersion time, the wet mass is determined followed by the dry mass after keeping the concrete specimens in an oven at 105˚C for 72 hours. The results obtained are shown in **Figure 13**.

The graph in **Figure 13** gives values of the water absorption coefficient of 7%, 7.02%, 2.93%, 3.55% and 3.98% respectively for the concretes BR1, BR2, BN, BC1 and BC2. This reflects that manually recycled [17] [51] and combined aggregate based concretes are more porous than natural aggregate based concrete. The increase in the absorption coefficient is respectively 2.39% and 1.35% for RA based concrete and CA based concrete. However, the absorption coefficients of the samples tested are concentrated around the average values

4. Discussion

The demolition of concrete, bricks and coatings from the construction sites of the North interchange and the Shell station in the city of Ouagadougou were treated and classified in the type CR_b according to standard NF EN 206/CN.



	BR1	BR2	BN	BC1	BC2
Average value (%)	7.00	7.02	2.93	3.55	3.98
Standard deviation (%)	0.02	0.36	0.08	0.09	0.16

Figure 13. Water absorption coefficient of concrete specimen at 28 days of age.

Like natural aggregates (NA), they have sufficient properties to be used in the formulation of standard concretes, despite physical and manual treatment. The values of these characteristics are summarized in **Table 4** and the particle size curves in **Figure 2** show the granular classes of recycled and natural aggregates. They present a continuous granularity, and those of the crushed ones (natural/recycled) are almost confused with an almost similar morphology.

The introduction of recycled aggregates (RA) in the formulation of concrete increase the need of water for the mixing, which has increased the C/W ratios from 1.84 to 1.46 on average, *i.e.* a surplus of 17.39% at 20.65%. Thus, the formulated concretes are classified in the category of firm concrete with an average value of slump of 4.9 ± 0.1cm with normal vibration as the tightening mode according to standard NF EN 206-1 [50].

The physical properties give values of average apparent densities of RA and CA based concretes are lower compared to that of NA based concrete, like the results of [24] [52]. Nevertheless, the average apparent densities of the formulated concretes follow the same logic as the densities of the aggregates obtained and are within the range of concrete normal density value (2000 kg/m^3 ≤ ρ ≥ 2600 kg/m^3) according to standard NF EN 206-1 [50].

Mechanical characterization reveals that NA based concrete (BN) has average compressive and tensile strengths higher than those of RA (BR) and CA (BC) based concretes. The study on "the influence of the nature of aggregates on the properties of concretes" revealed that the characteristic strengths of the various ordinary recycled concretes are generally satisfactory (C35/45). Indeed, the substitution of NA by RA at a percentage of 30%, the limit found in the literature, did not influence the properties of these concretes, whether on the mechanical or durability aspects; particularly with that of recycled gravel whose substitution rate can reach 50% [53]. Then, in their study on the "valorization of aggregates from demolition concrete in the manufacture of new concrete" [4], obtained a drop in compressive strength of 11% with 100% recycled gravel (the characteristic resistance targeted is 26 MPa). In addition, the "Experimental characterization and multi-scale modeling of the mechanical properties and durability of concretes based on recycled aggregates", it shows that it is possible to obtain high-performance concrete after compressive strength tests (approximately 60 MPa at 28 days), by replacing up to 40% of natural aggregates with recycled aggregates [54]. Also, the compressive strength of concrete decreases when the percentage of recycled aggregates increasing [53] [55]. Thus, the results of the present study are in line with the conclusions of previous studies. Indeed, compared to our results, we note that the use of 39% recycled sand with 61% natural crushed in the production of CA based concrete BC2, gave a resistance beyond the resistance aimed at 28 days. On the other hand, the combination of more than 50% of crushed materials recycled in the production of CA based concrete BC1 with natural sand, did not make it possible to achieve the expected resistance; *i.e.* a difference of 4.7 MPa corresponding to a drop in the average compressive strength of 18.80% (*i.e.* 19.60% and 20.39% difference respectively with respect to BC2 and BN). To finish, the mechanical performance varies according to the substitution rate: the more the rate of substitution of recycled crushed stone increases, the greater its effect on the decrease in compressive strength. In the same logic, if the substitution rate of the recycled sand is low then its impact on the regression of the compressive strength is minimal. This finding has been confirmed by other studies which show that the introduction of RA not only decreases the mechanical properties of concrete, [8] [13] [22] but the speed of the damage as well as the deformation threshold of damage [13]. Thus, the results presented in this study showed that the mechanical performances of the concrete containing total of partial RA (BR1, BR2, and BC1) are certainly weaker than those of natural concrete (BN) but remain acceptable and can be used in current constructions (buildings for residential, school, commercial use, etc.), knowing that the growth of the mechanical strength of concrete is continuous over 90 days.

The durability of the concretes studied gives average absorption coefficients of 7.01% and 3.78% respectively for recycled and combined aggregate concretes, higher than that of natural concrete (2.93%). Recycled aggregates being absorbent materials due to the presence of attached mortar residues and fines [56], and their incorporation into the concrete increases the concrete water absorption coefficient in the hardened state and therefore makes it less durable. However, the use of concrete of combined aggregates (natural and recycled) makes it possible to have a relatively low absorption rate, therefore less porous. The analysis carried out, on "the use of the water absorption of concretes as a criterion of their durability. Application to concretes made from recycled aggregates" showed that concretes made from recycled aggregates are characterized by a greater strong water absorption capacity [24] [56] [57]. This is due to the larger size of the large capillaries and the greater proportion by volume of the small capillaries, which makes them a priori more vulnerable to the penetration of aggressive agents [57]. And these concretes made from recycled aggregates have a high water absorption coefficient compared to concrete made from natural aggregates [58] [59]. The results show that the water penetration of the concretes produced increases according to the percentage of substitution in recycled aggregates and can reach double that of concrete based on natural aggregates. Thus, the results of the present study are in line with the conclusions of previous studies. Indeed, compared to our results, we note that concretes BR1 and BR2 (integrating recycled aggregates) have respectively average water absorption coefficients (7.00% and 7.02%) high compared to concretes BC1 and BC2 (3.55% and 3.98%) integrating natural and recycled aggregates and compared to BN concrete (based on natural aggregates, with an average water absorption coefficient equal to 2.98%). However, the physical and mechanical properties of recycled concrete seem to be acceptable [3] [58] and can be an alternative to natural aggregates for the sustainable construction [25] of single-storey buildings.

5. Conclusions

This study focused on the comparative study of formulation and characterization of conventional concretes with the use of natural and recycled aggregates. The objective is being the recovery of aggregates from demolition and recycled in the construction sector. The following main conclusions emerge:

- the aggregates studied, despite the rudimentary method of recycling, correspond to the requirements recommended according to the standards XP P 18-540 and NF P 18-545, to be used in the manufacture of hydraulic standard concrete;
- It was also found that the RA based concrete BR1 and BR2 have the same average compressive strengths at 7 days of age. It is therefore likely that the recycled aggregates used for their production come from the same source rock. Indeed, they have almost the same characteristics (the resistance to fragmentation, the apparent density and the absolute density or the specific weight) and there is any difference in quantities of mixture obtained;
- Aggregates from demolition taken from Donsin airport and the northern interchange sites can be reused in the production of conventional concrete. But in an exposed environment or an aggressive environment, it is necessary to take special measures to compensate the high rate of water absorption;
- The formulation of natural (BN) and combined (BC2) aggregate based concrete resulted in satisfactory mechanical performance at 7 and 28 days of age. Their low water absorption coefficient shows that they are less absorbent, so less porous;
- The RA (BR1, BR2) and CA (BC2) based concretes gave respective average resistances of 21.55 MPa, 20.50 MPa and 20.30 MPa which are lower than the characteristic resistance (25 MPa) aimed at 28 days;
- The RA based concrete BR1 (7.00%) and BR2 (7.02%), CA based concrete BC1 (3.55%) and BC2 (3.98%) have a high average absorption coefficient compared to NA based concrete BN (2.93%). On the other hand, the use of CA based concrete (BC1 and BC2) makes it possible to reduce relatively the

absorption rate;

- Concretes based on recycled (BR) and combined (BC) aggregates can be used respectively for class C20/25 and C25/30 concrete according to standard NF EN 206-1.

For sustainable construction, the possibility of reusing these recycled aggregates from demolition in the current context of developing countries, is an interesting alternative to study in order to meet the growing need for development work.

Conflicts of Interest

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

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Nomenclature

Acronyms and abbreviations

AFNOR	*French Association for standardization*
B20	*Concrete with a characteristic strength at 28 days of 20 MPa*
B25	*Concrete with a characteristic strength at 28 days of 25 MPa*
BC1	*Combined aggregates based conccrete 1*
BC2	*Combined aggregates based conccrete 2*
BN	*Natural aggregates based concrete*
BR1	*Recycled aggregates based concrete 1*
BR2	*Recycled aggregates based concrete 2*
BTP	*Building and Public Works*
CA	*Combined aggregate*
C/W	*Ratio Cement/Water*
EN	*European Standard*
ES	*Equivalent of Sand*
ESP	*Equivalent of sand on piston*
ESV	*Visual Equivalent of sand*
FD	*Fascicule de Documentation*
G/S	*Ratio Granular/Sand*
LA	*Los Angeles Coefficient*
LNBTP	*National Laboratory of Building and Public Works*
MDE	*Micro Deval Coefficient*
MF	*Modulus of smoothness*
NA	*Natural aggregate*
NF	*French standardization*
NF P	*Norme Française applicable au Bâtiment et de génie civil*
ONEA	*National Office of Water and Sanitation*
RA	*Recycled aggregate*
VB	*Valeur de Bleu de méthylène*
Vss	*Valeur spécifiée supérieure*

Symbols

ρa	*Absolute density in* kg/m^3
ρ_{ap}	*Apparente density in* kg/m^3
ρ_{rd}	*Real density after oven drying*
ρ_{rsd}	*Real density saturated dry surface*
A	*Flattening coefficient*

Continued

Ab	*Water absorption coefficient*
Abs	*Hardened concrete water absoption Coefficient*
D	*diameter of the cylinder in mm*
$D_{\max}$	*Maximum diameter of the aggregates in mm*
F or P	*value of the breaking load* (*in N*);
Fc	*Compressive strength in MPa*
Fc_{28}	*Compresssive characteristic strength at* 28 *days of age in MPa*
Ft	*Tensile strength in MPa*
Ft_{28}	*Tensile characteristic strength at* 28 *days of age in MPa*
$Gf(D)$	*Aggregate coefficient*
σ_c	*Cement strength class in MPa*
L	*length of the cylinder in mm*
M	*Mass of specimen in kg*
V	*Volume of specimen in* m^3
$P\%$	*Surface cleanliness of coarse aggregates*
r	*radius of the specimen* (*in mm*).
S	*section of the specimen* (*in* mm^2)

Highlights

<The demolition aggregates from concrete, cement blocks and mortar are recycled by manual procedure>, <The physical properties of natural and recycled aggregates have been studies and its adaptability to standard concrete>, <We characterize the mechanicals strength and water absorption of combined naturals and recycled aggregates based concrete>, <The different results of NA, RA and CA based concrete are presented> <We established the classification of recycled and combined aggregates based concrete according to standard NF EN 206-1>.