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Characterization of Recycled Aggregates of Concrete and Bricks in the Central Region of Burkina Faso

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aggregates used in the construction of civil engineering works have an impact on the properties of concrete. For several years the central region is famous because of the effects of extraction of natural aggregates on the environment. We conducted laboratory tests on several recycled aggregates of concrete and bricks to determine their mechanical properties. This choice was guided by a concern to identify and analyze the characteristics of natural and recycled aggregates of concretes that impact the properties of concrete on the one hand and to show the importance of increased use of recycled aggregates in concrete production to better preserve the environment and move towards sustainable development moreover. To better understand the qualities of these aggregates, it is necessary for us to carry out experimental tests in the laboratory.
The objective also guided the choice of the different types of recycled aggregates selected for the measurement of mechanical properties in the central region: Crushed Natural Gravel, Rolled Natural Gravel, Crushed Recycled Gravel, Recycled Spinning Gravel, Alluvionary Natural Sands, Recycled Brick Sands.

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The results show that recycled aggregates of concrete and bricks in the central region can be used for high-quality concretes on the one hand and reduce the impact of artisanal extraction of non-recycled aggregates on the environment on the other hand.
In short, we retain that the characteristics of recycled aggregates are a function of the rate of mortar gangues glued to the mother aggregates.

Keywords: Recycled aggregates; strength; concrete; non-recycled aggregate.

1. INTRODUCTION

Aggregates are a fundamental constituent in the art of construction of buildings and public works. The consumption of aggregates is particularly important in major road, building, and public infrastructure, transport, as well as in the performance of maintenance work. For example, aggregates must be considered at their fair value in economic planning and spatial planning [1,2,8].

This need continues to grow in all African countries and in particular in Burkina Faso. Most aggregates used in concrete come from massive rocks (crushed aggregates) or soft rock deposits (natural aggregates). Although these aggregates offer the advantage of consistent quality and continuous supply, it should be noted that these products are derived from non-renewable resources and are depleted over the years. However, each year, more than 100 million tons of Construction and Demolition Waste (DCD) are produced by the activities of the Building and Public Works according to IRRIM in its book "*Classification and assistance in the choice of recycled granular materials* " in 2011. It is therefore essential to develop new approaches to building materials to limit environmental impacts and take into account the life cycle of the materials used. That's why our study looks at the reuse or recycling of these materials to reduce the occupancy of valuable space in landfills while reducing environmental pollution [19-21].

This study aims to develop the use of recycled aggregate concretes to replace increasingly rare natural materials. This requires a consistent study of the characterization of the recycled materials used, to optimize their impact on the properties of the concrete in the fresh and cured state developed. To do this, we carried out a comparative study of the properties of natural control aggregates and those of recycled aggregates.

2. MATERIALS AND METHODS

2.1 Aggregates Sampling

2.1.1 Choice of sampling points

For reasons of complexity, it is difficult to make a judicious choice of sampling points. However, the recognition of public landfills and aggregates extraction quarries in the central region has made it possible to opt for six sampling points grouped into two major important groups: non-recycled aggregates taken from quarries on the one hand and recycled aggregates taken from public landfills on the other [16].

2.1.2 Sampling

We have a variety of aggregates depending on its origin. During wintering, it was difficult to practice a satisfactory sampling technique [3]. Sampling was used in the dry season withthe advantage of having more or less dry aggregates since in wintering the aggregates are saturated with water. These aggregates are taken according to Table 1 below.

Table 1. Aggregates collected in the central region

Sampling points	Types of Aggregates	Size	Abbreviations
	Natural aggregates		
1	Crushed natural gravel	5/25	CNG
2	Natural Rolled Gravel	5/25	RNG
3	Alluvionary natural sands	0/4	SNA
	Recycled aggregates		
4	Recycled Gravel Back from Toupie	5/25	GRRT
5	Crushed recycled gravel	5/25	RCMP
6	Recycled Brick Sands	0/4	SRB

2.2 Laboratory Work

These are the identification tests. Identifying an aggregate means determining a set of physical, mechanical or chemical properties that make it possible to characterize it. These properties are determined by simple and quick tests called identification tests [13].

2.2.1 Particle size analysis

2.2.1.1 Test portion

This involved going to the site where the aggregates were stored and using wheelbarrows and shovels to remove a sufficient amount of gravel and sand for testing [10-12].

To comply with the granular classes prescribed in the specifications, we have:

- ✓ For the Alluvionary Natural Sands (SNA), carried out a sieve with a 25 mm sieve to collect passers-by who were then passed through a 5 mm sieve to collect refusals.
- ✓ For Recycled Brick Sands (SRB), perform a sieve with a 5 mm sieve to collect passers-by.

2.2.1.2 Washing

Materials exposed to the open air are full of leaf debris, clay and impurities that can interfere with test results. To remedy this, we proceeded to wash the materials (sand, gravel) until complete removal of impurities.

2.2.1.3 Drying

Once washing is complete, we move on to drying the aggregates. This operation allows us to prepare them for particle size analysis and concrete implementation [6]. It took place in two phases, a first in the sun and the second using the gas stove.

2.2.1.4 Sieving

The particle size method used is sieving. Sieving makes it possible to know the different diameters of the grains of sand or gravel. This method consists of deducing the sizes of the aggregates by trying to pass them (admission or refusal) into smaller and smaller orifices. These holes are square meshes [15].

2.2.1.5 Materials

Table 2. Equipment used for particle size analysis

Designations	Utilities	Numbers
A scale	Weighed with ± 1g accuracy	01
A sieve	Sieving	- 08 Recycled Brick Sands (BRT) - 08 Alluvionary Natural Sands (SNA)
A bucket	Levy	02
A brush	Cleaning sieve meshes	01
A shovel	Levy	01

Fig. 1. Series of sieves for particle size analysis. Source: university of technology and management laboratory

2.2.2 Los Angeles Test and Micro Deval

The mechanical properties of resistance to fragmentation and wear were determined by performing Los Angeles and Micro Deval tests according to NF EN 1097-2 [4] and NFEN 1097-1 [4] on 10/14 mm fractions of aggregates [5].

2.2.2.1 Test los angeles

The Los Angeles test evaluates the impact resistance of an aggregate by introducing into a steel cylinder, a load of steel balls that have the function of fragmenting the material. The ball load is adapted to the granularity of the material.

Depending on the granular sample class (mm) the number of pellets varies.

The Table 3 summarizes the number of balls according to the granular class:

The percentage of elements less than 1.6 mm shall be calculated by relating the mass (M 1) passing through a 1.6 mm sieve to the starting mass (M 1). This value is the abrasion coefficient and the expression of L.A is then: [15]

$$LA = \frac{M_1}{M_0} X\ 100$$

Where:
L.A: the value of los-engeles in percentage
M_0 : the mass of the starting sample in grams (g)
M 1: the mass passing through a sieve of 1.6 mm

Table 3. Summary table of los angeles test conditions [9]

Granular sample class (mm)	4/6.3	6.3/10	10/14	14/16
Number of cannonballs	7	9	11	11
Number of rotations (30 to 33 rpm)	500	500	500	500
Amount of material (g)	500	500	500	500

LA (%)	Assessments
LA<15	Very good
15 <LA<25	Medium
25 <LA<40	Weak
LA>40	Very poor

Fig. 2. Sample of aggregates for testing

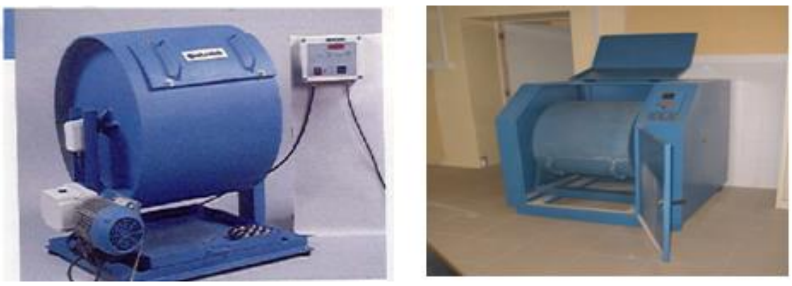

Fig. 3. The los angeles test aircraft

2.2.2.2 Micro-deval wear test

The test consists in evaluating the resistance to wear by friction of grains (diameter between 4 and 50 mm) of a dry aggregate or in the presence of water, by placing a mass sample (M) in steel cylinders (maximum 4) with a volume of 4.5 liters, mounted on 2 horizontal shafts with balls.

The cylinders are rotated 12,000 revolutions in 2 hours.

The bead load varies according to the granular class of the sample (mm) according to the Table 4.

The mass (m) of elements less than 1.6 mm is measured and the micro-Deval coefficient is calculated dry (MDS) in the presence of water (MDE)

$$\mathrm{MDE} = \mathrm{MDS} = 100 * \frac{\mathrm{m}}{\mathrm{M}}$$

Where:
MDS : the micro-Deval coefficient dry in percentage
EDM: the micro-Deval coefficient in the presence of water as a percentage
M : the mass of the starting sample in grams (g)
m : the mass of passing to a sieve of 1.6 mm

2.2.3 Water absorption test

Absorption is the power of a material to absorb and retain water.

The absorption coefficient is the ratio of the increase in the mass of the aggregate after immersion for 24 hours at 22°C to the dry mass of the sample in accordance with standard NF P 18-555 [AFNOR standards].

The absorption coefficient A as a percentage is determined according to:

$$A = \frac{M_2 - M_1}{M_1} \times 100$$

Where:
$\mathbf{M_2}$: mass of the water-saturated material sample
$\mathbf{M_1}$: dry mass of the material sample

2.2.4 Compactness and porosity of aggregates

Compactness is defined by the ratio of the volume of solid matter to the total volume.

While porosity (n) is by definition the complement to the unity of compactness.

The test is carried out according to NFP18-554.

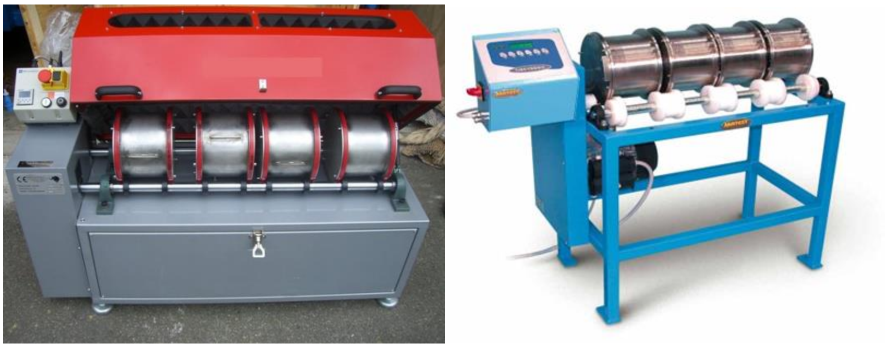

Fig. 4. Micro deval test match

Table 4. Summary table of Micro Deval test conditions [14]

Granular sample class (mm)	4/6.3	6.3/10	10/14
Ball loads (kg)	2	4	5
Quantity of water in l	2,5	2,5	2,5
Amount of material (g)	500	500	500

MDE (%)	Assessments
MDE<10	Very good
10 <MDE<20	Medium
20 <MDE<35	Faible
LA>35	Very poor

2.2.5. Densities

The apparent and specific densities of the various natural or recycled aggregates studied are made according to standard NF P 18-554 and 555 [18].

2.2.5.1 Apparent density

Apparent density is the mass of a body per unit total volume including voids and major constituents. The apparent density noted ρ

$$\rho = \frac{M}{V}$$

Where:
$\mathbf{\rho}$ = density in kg/m^3
$\mathbf{M}$ = body mass in kg
$\mathbf{V}$ = total body volume including voids and constituents in m^3

2.2.5.2 Specific density

The specific density of a body is the mass per unit volume of solid matter of this body without any void between the grains (constituents): absolute volume

$$\rho_s = \frac{Ms}{Vs}$$

Where:
ρ_s : specific density in kg/m^3
M_S : the specific mass of the body in kg
V_s : volume of solid matter of this body without any void between the grains (constituents) in m^3

3. RESULTS AND DISCUSSION

3.1 Particle Size Analyses

3.1.1Sands

3.1.1.1 Table of sieving results

a- Natural alluvial sands (SNA)

Table 5. Results of the sieving of natural alluvionary sand (SNA)

ϕ mm sieve	Partial refusals (g)	Cumulative refusals (g)	Cumulative refusals (%)	Cumulative passers-by (%)
5	0	0	0	100
2,5	115	115	11.73	88.26
1,25	191	306	31.22	68.77
0,63	168	474	48.36	51.63
0,315	231	705	71.93	28.06
0,16	176	881	89.89	10.10
0,080	75	956	97.55	2.46
Bottom	19	975	99.48	0.51
5	0	0	0	100

b- Recycled Brick Sands (BRT)

The results of sieving are recorded in the table 6:

Table 6. Results of sieving of recycled brick sand (BRS)

ϕ mm sieve	Partial refusals (g)	Cumulative refusals (g)	Cumulative refusals (%)	Cumulative passers-by (%)
5	0	0	0	100
2,5	149	149	15.20	84.79
1,25	333	482	49.18	50.81
0,63	175	657	67.04	32.95
0,315	106	763	77.85	22.14
0,16	125	888	90.61	9.38
0,080	68	956	97.55	2.44
Bottom	22	978	99.79	0.20
5	0	0	0	100

3.1.1.2 Particle size curves for Recycled Brick Sands (BRS) and Alluvionary Natural Sands (SNA)

The analysis of the particle size curve of the Alluvionary Natural Sand (ANS) (Fig. 5) shows that the sand taken for concrete belongs to class 0/4. D = 4 mm < 6.3 mm in accordance with standard NF EN 12620 "Aggregates for concrete" and standard XP P 18-545 (Article 10: "aggregates for hydraulic concrete"). (BAROGHEL – BOUNYV; 2004) [17].

3.1.1.3 The fineness module (MF)

The fineness modulus of a sand characterizes its granularity as 1/100th of the sum of the cumulative refusals in percentages, on a series of sieves. This is an important feature that needs to be checked carefully. Generally a concrete sand must have a modulus of fineness between 2.2 and 2.8 [7].

- ✓ 1.8 2.2: the sand is mostly fine-grained, ≤ M_f <
- ✓ 2.22.8: there is preferential sand,≤ M_f <
- ✓ 2.83.2: The sand is a bit coarse. It will give resistant concretes but less maneuverable. ≤ M_f <
- ✓ $M_f \geq 3.2$: the sand is too coarse. Not recommended for concrete.

$$MF = \frac{1}{100}\sum \text{Refus cumulés en \% des tamis } \{0.16 - 0.315 - 0.63 - 1.25 - 2.50 - 5\}$$

We particularly observe at the level of the sandy fraction where recycled sands are coarser than natural sands.

The values obtained by analysis of recycled brick sand (SRB) are therefore higher than those obtained by sieving natural alluvial sand (SNA).

This may be explained by the fact that the appropriate mechanical means were not used for the grinding of the bricks in question.

3.1.2 Gravel

There are no considerable differences between the particle size curves of natural aggregates and those of recycled aggregates.

The particle size and maximum size of the aggregates impact on the relative proportions of the aggregates, the quantities of binder and water required, the maneuverability, pumpability, porosity, shrinkage and durability of the concrete.

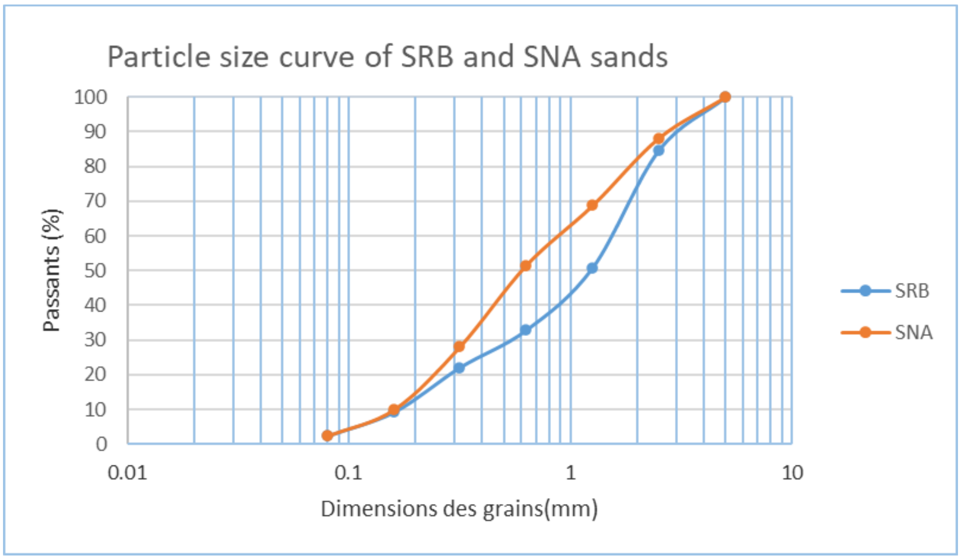

Fig. 5. Particle size curves of the sands of Recycled Brick Sands (BRS) and Alluvionary Natural Sands (SNA)

Table 7. Modulus of fineness of sands

Fineness module	SRB	SNA
	2,99	2,53

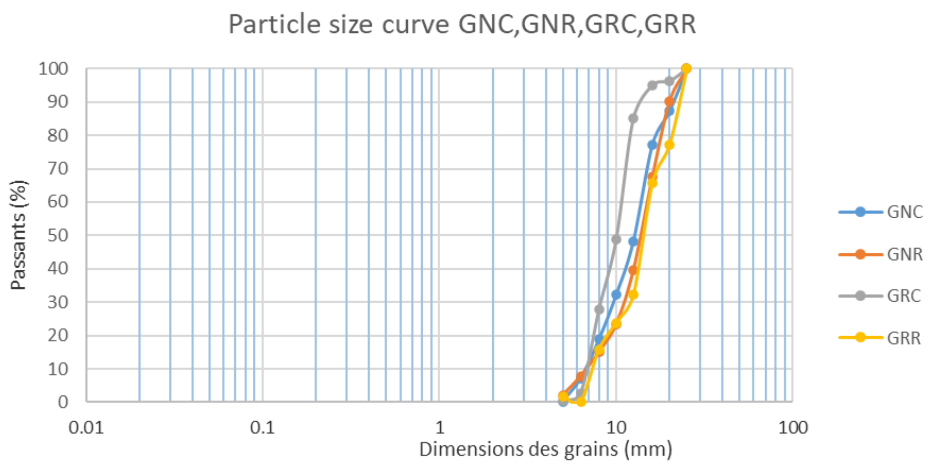

Fig. 6. Gravel particle size curves

3.2 Mechanical Properties

Natural aggregates are on average more resistant than recycled aggregates than recycled aggregates but still have acceptable wear and fragmentation characteristics as aggregates for hydraulic concretes in view of the considerations of the standardization in force in this area.

3.2.1 Test Los Angeles

The results are given in Table 8.

The fragmentation resistance (LA) of recycled aggregates remains within the normative thresholds (>15%). However, although the thresholds are respected, the granular skeleton of recycled aggregates may evolve. A situation that needs to be taken into account in the formulation of concrete.

3.2.2 Micro-Deval test

The wear resistance of recycled aggregates is relatively higher than that of natural aggregates, depending on the type of aggregates.

- ✓ For natural aggregates: Crushed natural gravel (CNG) is stronger than rolled gravel (RNG). This can be explained by the fact that the original concrete comes from demolition and therefore contaminates with waste of all kinds. It is an old concrete that has therefore undergone climatic hazards over time (wind, rain, sun, climate change ...).
- ✓ For recycled aggregates**:** Those from crushed concrete (GRC) are more resistant than gravel from the return of top trucks. This is due to the fact that this concrete is less contaminated and generally younger.

Overall, natural aggregates are more resilient in terms of wear than recycled aggregates.

3.3 Compactness and Porosity of Aggregates

The cement paste attached to natural aggregates in GBRs is much more porous than natural aggregates. GBCs are known to be more porous than natural aggregates, mainly due to the high presence of old adherent cement paste. Therefore, the quality and quantity of this phase are responsible for the properties of GBR compared to those of natural aggregates. In the porosity of the adherent paste two types of pores are distinguished: capillary pores and hydrate pores.

Table 8. Wear and fragmentation resistance

Types	**Natural aggregates**			**Recycled aggregates**		
	SNA	**CNG**	**RNG**	**SRB**	**RCMP**	**GRRT**
Sizes (mm)	0/4	5/15	5/15	0/4	5/15	5/15
LA (%)	-----	21	31,3	-----	36,6	32,43

LA (%)	Assessments
LA<15	Very good
15 <LA<25	Medium
25 <LA<40	Weak
LA>40	Very poor

Table 9. Micro deval wear resistance (MDE)

Types	Natural aggregates			Recycled aggregates		
	SNA	CNG	RNG	SRB	RCMP	GRRT
Sizes (mm)	0/4	5/15	5/15	0/4	5/15	5/15
MDE (%)	-----	1 2.10	18.34	-----	25.2	2 2.15

MDE (%)	Assessments
MDE<10	Very good
10 <MDE<20	Medium
20 <MDE<35	Faible
LA>35	Very poor

Table 10. Compactness and porosity of aggregates

	SNA	SRB	CNG	RNG	RCMP	GRRT
Compactness	1,25	2,5	0,65	8,34	11,5	9,23
Porosity	2,25	3,5	0,35	9,34	12,5	10,23

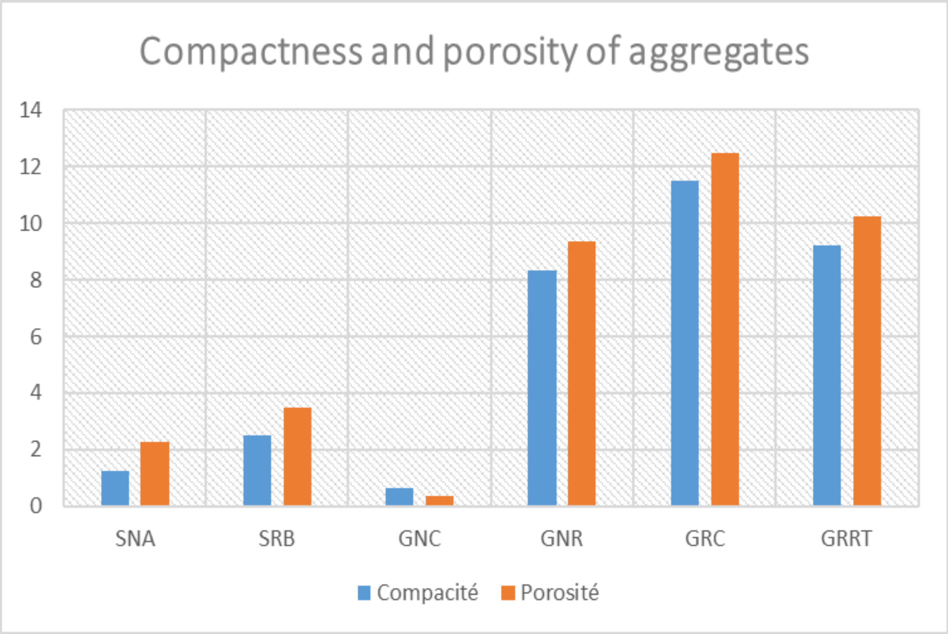

Fig. 7. Trends curves of aggregates compactness and porosity

3.4 Absorption Coefficient

Table 11. Water absorption rate of aggregates

	CNG	RNG	RCMP	GRRT	SNA	SRB
Abs %	1,29	1,23	4,45	5,1	9,85	14,15

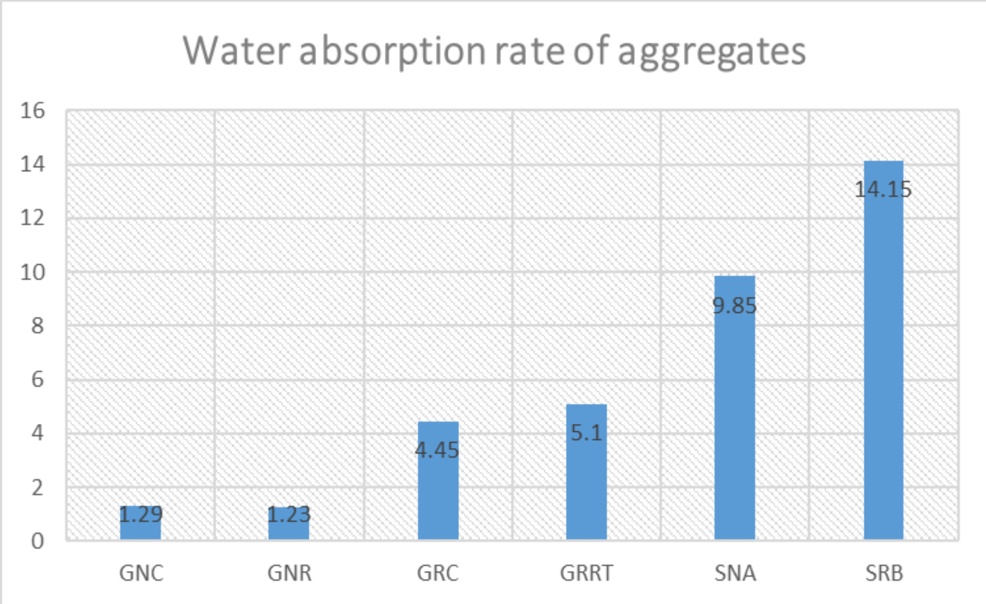

Fig. 8. Trend curves of water absorption rate of aggregates

Regardless of the particle size considered, natural and recycled aggregates generally show different behaviors. Whatever the particle size considered, the water absorption of natural aggregates is significantly lower than that of recycled aggregates: around 10% for natural sands (SNA), 2% maximum for natural gravel (CNG).

Recycled brick sands (BRS) absorb around 15% and about 5% for recycled gravel (GRC, GRRT). Water absorption is constant for natural aggregates and significantly impacted by agitation. For recycled aggregates, there is an increase in the water absorbed when the aggregates are agitated and this is due to their morphology resulting in air retention due to agitation. The presence of mortar and cement paste increases the porosity of recycled aggregates, resulting in a higher water absorption of these aggregates compared to natural aggregates.

We also notice, nearly 80% absorption is done during the first 10 minutes.

This phenomenon of desorption-reabsorption requires further study to determine its impact on the workability of maintaining workability.

3.5 Densities

Recycled aggregates have a lower density than natural aggregates. This property is linked to the presence of the old mortar which is a very porous medium and therefore less dense than the original aggregate. Table 7 presents a comparative summary of the density results between natural and recycled aggregates according to the different particle sizes. Hansen shows that, in general, recycled aggregates [22].

In addition, the density also decreases with substitution rates and this trend is true in both fresh and hardened states. This phenomenon is related to the low density of RGs compared to that of NGs (Table 12). The replacement of dense aggregates (NG) by less dense aggregates (GR) therefore reduces the density of the resulting concretes [23].

Table 12. Densities

	CNG	RNG	RCMP	GRRT	SNA	SRB
Apparent density (Kg/m3)	1675	1380	1279	1345	1710	1455
Specific density (Kg/m3)	2780	2570	2620	2760	2848	1987

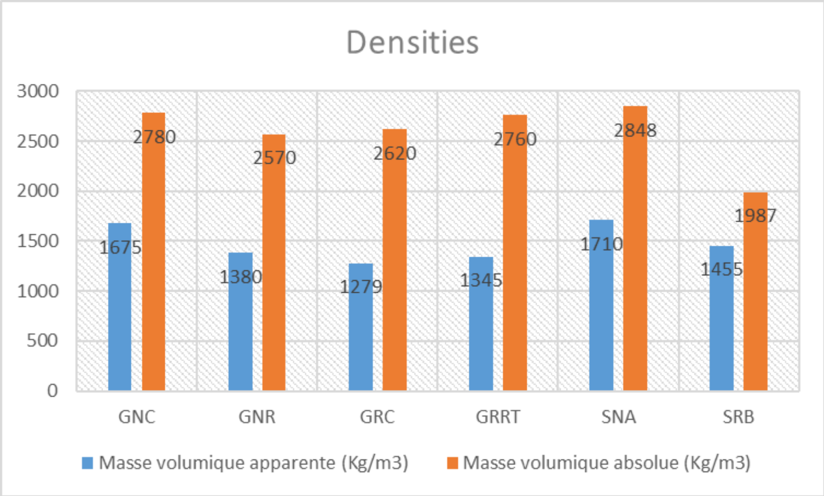

Fig. 9. Trend density curves

4. CONCLUSION

This study opened perspectives on the need to deepen knowledge of the qualities of recycled aggregates. Water demand, the standardized definition of efficient water and the classification of elements need to be studied specifically.

A reflection will have to be carried out on the assessment of the cleanliness of recycled aggregates, depending on the quantification and qualification of these fine elements. The evolution of current standards will need to take sustainable development issues into account.
The results obtained by this study should allow an in-depth analysis on the adaptation of formulation methods in order to obtain characteristic recycled aggregate concretes closer to those of natural aggregate concretes. We will then have to focus on the concrete of recycled aggregates formulated with admixtures, particularly in terms of implementation. The addition of superplasticizers will allow the removal of fine elements in order to retain these fines that can have a beneficial effect on mechanical properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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