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Study of the performance of concrete based on recycled aggregates

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Abstract

The deposition of solid waste throughout the city is a threat to the population and to the ecosystems. The objective of the work is to seek a solution to this environmental problem. The work consists in studying the performance of concrete with aggregates from recycling. The experimental analyses involved two types of concrete: a concrete with ordinary gravels (BGO) and a concrete with 100% of recycled gravels (BGR) then the results are compared. The results of the particle size analysis show that the recycled gravels contain on the one hand a lot of elements lower than 5 mm (10.84%) which is the sandy part whereas the ordinary gravels contain less (1.32%). On the other hand, the recycled gravels contain a lot of coarse elements, compromising in the concrete the inter-granular compactness. The real densities are 2.39 g/cm^3 and 2.53 g/cm^3 respectively for Recycled Gravel (GR) and Ordinary Gravel (GO). The porosity of recycled gravel is higher than that of ordinary gravel. The density of recycled gravel concrete is lower than that of ordinary gravel concrete. The value of 40 of the Los-Angeles coefficient characterizes a poor aggregate in terms of impact resistance. As for the mechanical parameters, the compressive strength is 19 Mpa against 22 Mpa of ordinary gravel concrete. To have a better compactness of the granular mixture, the reconciliation of the biggest elements is necessary. This has been observed on the compressive strength which is 20 Mpa.

Keywords: Recycled aggregate, concrete, performance, characteristic, compressive strengths.

Introduction

In the city of N'Djamena and in its neighbourhoods, solid waste of all kinds is deposited and the environment becomes difficult to live in because of its negative effects on the population and the ecosystem. This solid waste does not only come from households (low density plastics), but also from the demolition of civil engineering works (concrete, masonry, tiles, paving stones, etc.).

Small groups of vulnerable women are engaged in the practice of hand crushing these civil engineering demolition products into gravel. This activity, which is still in its infancy, makes it possible to carry out small-scale landscaping work, repair works, etc.

Certainly the waste resulting from the demolitions is constituted of natural aggregates but those underwent during some years of their service, solicitations and bad weather likely to modify some of their properties. It is thus necessary for their valorisation, to characterize them in order to know their new properties as well as the performance of the concrete formulated on base of these aggregates.

Previous studies have been done on the concrete with recycled gravels including those of Debieb Farid in 2007, Guerzou Tourkia in 2019 and Serifou Mamery in 2013[1-3].

Materials and Methods

Recycled Aggregates: Demolition waste is often dumped in open areas and sold at low prices to poor women who in turn recycle the waste into gravel for resale.

Figure-1: Concrete waste.

Characterization of recycled aggregates: To use a material in a composite such as concrete, it is important to know the characteristics on which the characteristics of the composite in question depend. Thus, the following tests were carried out:

Density: The density is a property that is determined in the laboratory according to well defined standards.

Figure-2: Apparent (or bulk) density [4]: (a) Container, (b) Scale (c) Oven.

The test consists in weighing a container of known volume, filled with aggregate. The density is calculated by the formula:

$$\rho_{app} = \frac{m_1 - m_2}{V} \quad (1)$$

Where: ρ_{app} is the bulk density, m_1 : Mass of the container filled with aggregates; m_2: Mass of the empty container, V: Volume of the container, For recycled gravel, $\rho_{app} = 1.12 T/m^3$, For sand, $\rho_{app} = 1.60 T/m^3$

Figure-3: Density determination: Graduated test tube method.

Absolute density (graduated cylinder method): It is determined for the aggregates using a graduated cylinder. The test tube is filled with water up to the mark V_1. A mass of aggregate M is weighed and poured into the test tube. We take the new volume (volume of water + aggregate) V_2. The density is calculated by:

$$\rho_s = \frac{M}{V_2 - V_1} \quad (2)$$

For this study, it is 2390 Kg/m^3 for recycled gravel against 2590 Kg/m^3 for ordinary crushed gravel. This difference is due to the fact that recycled gravel contains a significant amount of mortar and therefore has a high porosity whereas ordi y gravel is denser and more compact.

Absorption (porosity): Generally speaking, the porosity of a material is the ratio of the volume of voids to the total volume of the material.

$$P = \frac{\text{volumeofvoids}}{\text{totalvolume}} \quad (3)$$

According to the principle, the test consists in soaking the material until total saturation of the pores. After this operation, each grain of aggregate is wiped and the whole is weighed. The porosity is calculated by:

$$P(\%) = \frac{M_1 - M_0}{M_0} * \rho_{app} * 100 \quad (4)$$

M_1 : Mass after saturation; M_0 : Initial mass; ρ_{app} : Density of the aggregate.

Particle size analysis[5]: The test consists in separating the agglomerated grains from a known mass of material by stirring under water, to fractionate this soil, once dried, by means of a series of sieves and to weigh successively the cumulated refusal on each sieve. On each sieve, the percentages of refusal and sieve are calculated.

Figure-4: (a) oven, (b) scale (c) sieve.

$$\% \text{ refus} = \frac{Mr}{Mi} * 100 \quad (5)$$

$$\% \text{ tamisât} = 100 - \% \text{ refus} \quad (6)$$

The particle size curve is plotted on a logarithmic diagram with the sieve diameters and the percentages of sieves in ordinate and abscissa respectively. This allows us to calculate the coefficients of uniformity Cu and curvature C_c:

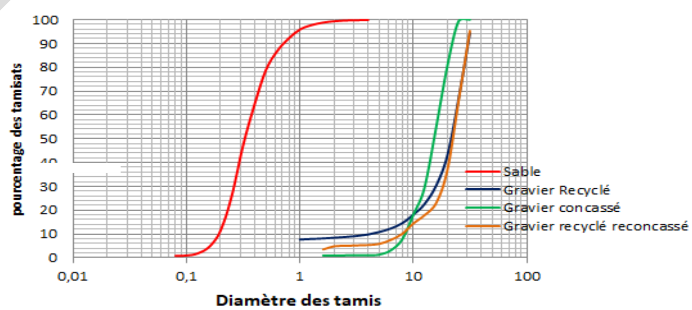

Figure-5: Granulometric curves.

$$C_u = \frac{d_{60}}{d_{10}} \quad (7)$$

$$C_c = \frac{d_{30}^2}{d_{60}\, d_{10}} \quad (8)$$

$M_f = \frac{1}{100}\sum$ refusal in percentage on sieves of modulus : 23; 26; 29; 32; 35 and 38 (9)

Sand equivalent: Pour a test sample of sand and a small amount of flocculent solution into a graduated cylinder and shake to loosen the clay coatings from the sand particles in the test sample. After 20 min, measure the heights: H_1: total height of flocculated sand, H_2: height of sediment on sight, H_3: height of sediment at the piston (NF EN 933-8 standard[6]).

Figure-6: Equivalent sand device.

The sand equivalent (SE) is calculated as the ratio of the sediment height to the total height expressed as a percentage.

Los-Angeles test: It is a question of making roll the aggregate mixed with steel balls in a rotary drum and to recover at the end, the quantity of material retained on the sieve of 1.6 mm allowing to calculate the coefficient Los Angeles (NF EN 1097-2 standard[7]) starting from the following equation:

$$LA = \frac{5000 - m}{50} \quad (10)$$

m: Mass of refusal at 1.6mm, in this case, m = 2755g.

The flattening coefficient: The test consists in performing a double sieving. First, the sample is divided into different elementary aggregates di/Di by means of test sieves. Each of the elementary aggregates di/Di is then sieved by means of parallel slotted grids with a width Di/2. i. di : dimension of the smallest element of the granular class i; ii. Di: dimension of the largest element of the granular class i; (NF EN 933-3/A1 standard [8]).

Figure-7: (a) slotted grid (b) sieve (c) scale.

The overall flattening coefficient A is calculated from the following equation:

$$A = \frac{M_2}{M_1} * 100 \quad (11)$$

M_1: Sum of the masses of the elementary aggregates di/Di, in grams; M_2 Sum of the masses of the passers-by on the corresponding slotted grids of spacing Di /2, in grams.

Formulation of concrete: Batching calculation: The calculation of dosage consists in determining the optimal quantity of each component of a material. Several methods are proposed among which the one of DREUX GORISSE is used for this study[9]. The method of formulation of DREUX passes by three phases: i. Obtaining the C/E ratio from the strength and therefore the quality of the target paste; ii. Determination of the maximum granular skeleton compactness resulting from the desired workability; iii. The balance of the quantities of each of the constituents (masses of C, E, S, G) and theoretical density of the concrete Y.
The Cement/Water ratio, noted C/E is calculated by the formula

$$fcm = G * Fcc\left(\frac{C}{E} - 0{,}5\right) \quad (12)$$

fcm: Average compressive strength at 28 days in MPa, Fcc: Trueclass of cement at 28 days in MPa, C: Cement dosage [kg/m^3], E: Total water content on dry material in kg/m^3 and G : Granular coefficient, depending on the size of the largest aggregate and the quality.

Cement and water dosage: For this study, the cement dosage is set at 350 Kg/m^3 because it is the most used. The cement used is a CPJ 35 compound Portland cement manufactured locally in Djarmaya (N'Djamena), called Cimentde l'Afrique (CIMAF). The water content is deduced from the calculated C/E ratio.

Aggregate dosage: A reference line OAB is drawn on the same graph as the particle size curves, with O(0 ;0) ; B(D_{max}; 100) et A(X_A ;Y_A). X_A function of D_{max}, and

$$Y_A = 50 - \sqrt{Dmax} + K \quad (13)$$

K being a correction coefficient, depending on the dosage, the vibration and the shape of the aggregates.

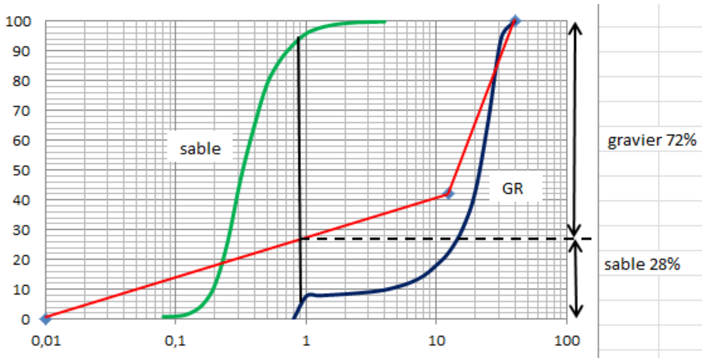

Figure-8: Reference curve.

The percentages of the aggregates are determined:
X% (G+S) (14)

Manufacture and storage of test specimens: The concrete is mixed with a concrete mixer, the slump is measured (standard NF EN 12350-2[10] and the specimens are then manufactured NF EN 12390-2[11]. 24 hours after the manufacture, the specimens are demolded and then kept in a water soaking tank to be subjected to crushing according to the age Indicated in days (3, 7 and 28).

Figure-9: Slump measurement and specimen fabrication.

Figure-10: conservation of concrete specimens.

Mechanical tests: The test consists in loading a specimen until rupture in a compression test machine (standard EN 12390-3[12], EN 12390-4: characteristics of the device). The load reached at breakage is recorded, and we calculate the compressive strength.

Tensile test: A cylindrical specimen is subjected to a compressive force applied to a narrow zone along its entire generatrix. The resulting orthogonal tensile stresses cause the specimen to break by traction (splitting standard NFEN 12390-6[13]).

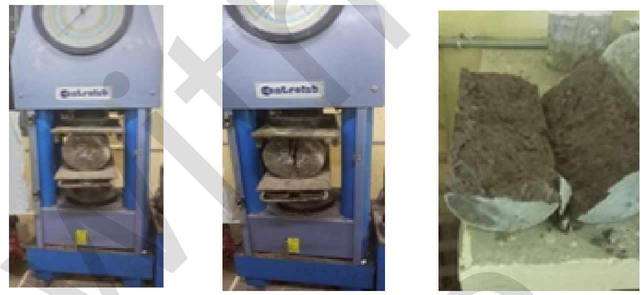

Figure-11: Splitting traction.

Results and discussion

Characterization of recycled gravel: The density of the recycled gravel is 2390 Kg/m^3. This value shows that it is common gravel because its density is higher than 2000 Kg/m^3. According to the technical report - Buildings exemplars, Fiche 4.1: The use of recycled aggregates, recycled aggregates for foundations and pavements must have a density of more than 1950 kg/m^3. This criterion for use is met by our GR.

Table-1: Physical and mechanical properties.

Test	Parameter	Material			
		S	GCO	GR	GRR
Real density (Kg/m3)	ρ_s	2590	2530	2390	2000
Absorption	-	-	-	-	-
Flattening coefficient	A		4,9	6,17	5,8
Inter-granular porosity	v	-	-	53%	32,5%
Porosity	-	-	7,95%	9,37%	9,98%
Granulometric analysis	C_u	1,75	2,06	2,67	3
	C_c	0,93	1,14	1,34	1,69
	M_f	1,64	5,98	5,73	5,84
Sand equivalent(%)	ES	93	-	-	-

Los Angeles	LA	-	-	45	48

According to the grading, the proportion of fine elements in the recycled gravel is significant (10.84% are smaller than 5 mm). This confirms the presence of residual mortar on the natural gravel. The sand is qualified as fine because Mf = 1.63. The cleanliness test measured on the sand (93%) indicates that the sand is very clean. Sandrine Braymand qualifies sand as clean when its ES is between 60% and 80% [14].

Mechanical testing: The mechanical tests are compression and tensile splitting tests.

Compressive strength: In terms of compression, the strength at 3 days is 5Mpa compared to 7Mpa for ordinary crushed gravel concrete and 6Mpa for recycled gravel. At 7 days, these strengths are 10Mpa, 15Mpa and 12Mpa, respectively for GR, GC and GRR. Finlay, at 28 days they are 19.3Mpa, 22.13Mpa and 20Mpa.

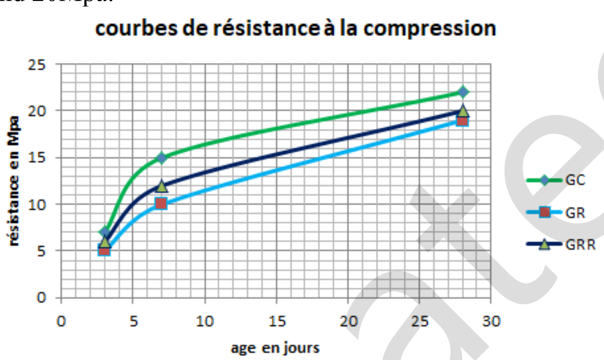

Figure-12: Concrete strength curves.

It can be seen that the strength of concrete with recycled gravel and that of concrete with ordinary gravel do not differ much (0.32 to 2.83Mpa). Also, the BAEL 91 modified 99 indicates that the strength of concrete increases with age, and that from the 28th day onwards it varies very little[15]. With these values found, the concrete with recycled gravel obeys the rule.

After the recycled gravel has been crushed, there is an improvement in the compressive strength. This may be due to the decrease in inter-granular porosity, providing an increase in the compactness of the granular mix. Bourmate Nadjoua in 2017 achieved a compressive strength of 17 MPa at 28 days with the same dosage of 350 kg/m^3 and with the recycled gravel[16]. The same is true of Trucanu Vasile also in 2017, who obtained the resistance at 28 days of 17 Mpa of the recycled gravel concrete[17]. Guerzou Tourkia in 2019 obtained 8 Mpa, 18 Mpa and 25 Mpa at 3, 7 and 28 days respectively. Pierre Matar in his publication in 2012 obtained 15.2 Mpa at 28 days with the 30% recycled gravel concrete[18].

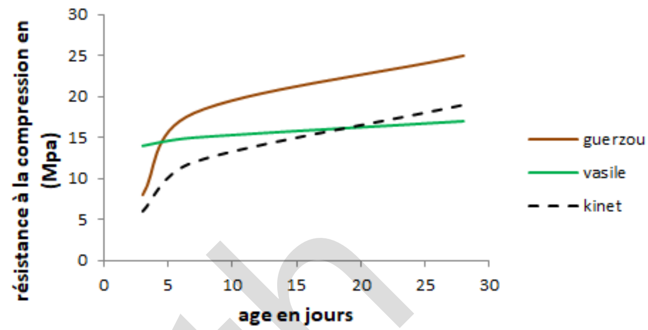

Figure-13: Resistance versus age curves.

Tensile strength: Antoine Tixier indicates that the tensile strength is about 1/10th of the compressive strength[19].

As for the tensile strength by splitting, the recycled gravel gives strength of 1.08 Mpa while the ordinary crushed gravel gives 1.43 Mpa. Considering the values obtained in compression, these values are less than one tenth of the compressive strengths.

Conclusion

Finally, the results both on recycled gravels and on concrete based on these gravels show that recycled gravels meet the conditions of use in the building and public works sector, in particular small-scale works for the development of spaces, the repair of structures, and blocks for pavement edges. Nevertheless, it is necessary to make an industrialized exploitation of solid waste because it is an activity which can constitute a sector which contributes to the preservation of natural resources and thus the protection of the environment.

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