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***Journal of Scientific and Engineering Research*, 2024, 11(9):121-129**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Geotechnical Characterization of Recycled Concrete Aggregates (RCA)

Oustasse Abdoulaye Sall[1*], Déthié SARR[2], Diogoye DIOUF[1], Cheikh Ibrahima Tine[1]

[1]Département of Civil Engineering, UFR-SI Iba Der Thiam University of Thies, Thies, Senegal
[2]Département of Geotechnics, UFR-SI Iba Der Thiam University of Thies, Thies, Senegal
[*]Email: oustaz.sall@univ-thies.sn

Abstract: This work studies the project for the production of Recycled Concrete Aggregates (RCA) applied to the RN1 rehabilitation project, Tamba-Goudiry-Kidira section. A survey of the concrete waste deposits on this stretch of road estimated the concrete waste at 1,083.048 m3. This waste consists of basalt, laterite and limestone. The transformation of this concrete waste into RCA goes through the crushing-screening-washing circuit. This can be done either mechanically using a crushing station, or manually by local people. Identification tests on RCA and strength tests on concrete incorporating RCA were carried out. The results of these geotechnical.

Keywords: Geotechnical characterization, Mechanical resistance, Recycled concrete aggregates.

1. Introduction

Concrete is the building material most commonly used in the construction of civil engineering structures. These civil engineering structures have a limited lifespan, and disposing of demolition and repair waste represents a considerable challenge. In Senegal, the civil engineering sector consumes 5,100,000 tons of aggregates and dumps 340,000,000 tons of concrete waste every year. Another major challenge facing the construction industry is the dwindling sources of natural aggregates near major urban centers. Aggregates generally account for 60-80% of the composition of concrete, so very large quantities are needed for the construction of civil engineering structures. The current situation means that the aggregates used to prepare concrete in large urban centers are often transported over longer distances, resulting in high costs. In this context, the use of recycled aggregates is becoming an unavoidable alternative, both economically and environmentally. The main aim of this project is to assess the potential use of recycled aggregates in medium-strength concrete for construction applications. In this article, the mechanical characteristics of RCA are determined by geotechnical tests carried out in accordance with AFNOR standards. First, tests are carried out on recycled aggregates to establish their identification sheet. These tests are: particle size analysis, determination of flattening coefficient, specific weight, apparent density and absorptivity coefficient. Concretes are then formulated by substituting a fraction of natural aggregates with RCA, with substitution rates of 10%, 20%, 30% and 40%, and a formulation will be made with 100% RCA using the Dreux-Gorisse method. The Abrams cone slump test is measured on these fresh concretes. Compression and tensile tests are carried out on hardened concrete, with crushing at 7 and 28 days. The aim is to compare the behavior of these fresh and hardened concretes with that of a control concrete made from 100% natural aggregates.

2. Materials And Methods

Before considering the use of RCA in any project, they must first be characterized to gain an idea of their performance as concrete aggregates. For test results to be reliable, it is first necessary to ensure that the sample is representative of the entire deposit.

Sampling

At the time of the study, twenty-six (26) structures had been demolished. The total volume of the sample is estimated by the number of molds to be made and the corresponding volume of concrete. For each type of concrete, nine (9) cylindrical molds measuring 3215.36 cm^3 will be made. Table 1 summarizes the sample volume calculation.

Table 1: Summary of sample volume calculation

N°	Volume of concrete (cm^3)	Aggregate volume (cm^3)	Percentage of RCA	Corresponding volume of RCA (cm^3)
C1			10 %	12 298,75
C2			20 %	24 597,50
C3	144 691,20	122 987,52	30 %	36 896,26
C4			40 %	49 195,01
C5			100 %	122 987,52
Total	**245,975.04 cm^3 of RCA**			

In order to avoid a stock-out, three hundred (300) dm^3 of concrete blocks were taken. To ensure a representative sample, samples of different types were taken from ten (10) structures. Samples were taken in equal volumes from seven (7) basalt hydraulic structures and three (3) laterite structures, with the addition of limestone concrete blocks equivalent to 10% of the total. Table 2 lists the structures from which the RCA samples were taken and tested.

Table 2: Sampling location

N°	1	2	3	4	5	6	7	8	9	10
OH	72	73	91	92	99	100	101	102A	104	105
PK	53+630	53+686	59+273	59+321	61+753	63+698	63+861	63+890	65+381	65+400
Nature	Basalt	Basalt	Basalt	Laterite	Basalt	Basalt	Laterite	Laterite	Basalt	Basalt

A process of manual crushing of the samples followed by screening and washing yielded the RCA stock on which all the analyses required for this study were carried out. Figures 1 shows the 3/8 and 8/16 fraction RCA samples.

***Figure 1:** Sample of RCA fraction 3/8 and 8/16*

Particle size analysis and determination of the RCA flattening coefficient

The particle size analysis of RCAs and the determination of the flattening coefficient were carried out at the same time, in accordance with standards NF P 18 - 560 / NF P 18 - 561. The minimum sample mass on which the tests were carried out is given by the following formula:

$$m_{min} = 0,2 \text{ x } D_{max}$$

With:

$$m_{min} \text{ in kg}$$
$$D_{max} \text{ in mm}$$

Samples of 3000g for fraction 3/8 and 3500g for fraction 8/16 were used. For both fractions, the particle size distribution is continuous and the flattening coefficient measured on fraction 8/16 is 8.51%.

Determination of specific gravity and bulk density

The specific weight of RCA is determined by hydrostatic weighing in accordance with NF EN 1097-6 P 18-650-6. The results give specific weights of 2.588 g/cm^3 and 2.611 g/cm^3 for fractions 3/8 and 8/16 respectively. The equipment used to determine bulk density consisted of a mold with a volume of 2103 cm^3 and a tare weight of 5069 g, a 30 kg capacity balance and a hand. The material's drop height is set at 15 cm. Bulk densities of 1.218 and 1.174 were found for the 3/8 and 8/16 fractions respectively. Test sheets are attached in appendices 3.6 and 3.7.

Determining the absorption coefficient

This test was carried out in accordance with standard NF EN 1097-6 P 18-650-6, appendix B. Absorbency coefficients of 8.25% and 6.91% were obtained for the 3/8 and 8/16 fractions respectively.

Composition and formulation

The rate of replacement of natural aggregate by recycled aggregate has a very significant impact on the properties of recycled concrete. Although the impact of a 100% replacement rate varies greatly according to mix design and studies, it is clear that the impact on concrete properties is a function of the replacement rate. The value of this replacement rate varies, however, according to the mix formulas and parameters analyzed. Replacement values generally proposed in the literature range from 20 to 50% [1] [2] [3] [4] [5]. Four (4) types of concrete incorporating RCA fractions were produced. Their composition was determined on the basis of that of the control concrete. A Dreux-Gorisse formulation was made with 100% recycled aggregates. Batch sizes of 35 kg of cement were adopted in order to minimize the amount of concrete left over after mold making. The control concrete consisted of CEM II 42.5 R cement from Dangote, sand from the Falémé quarry near the town of Kidira and basalt from Diack. Table 3 shows the composition of this control concrete.

Table 3: Composition of control concrete containing 100% of basalt

Experimental wastage per 50 kg of cement				
Materials	**Volumetric percentage**	**Volume in liters**	**Density**	**Mass in kg**
Agnam Civol Sand	30 %	53,82	2,65	81,00
Crushed gravel 3/8	22 %	43,30	2,97	66,47
Crushed gravel 8/16	48 %	90,97	2,99	146,00
Cement CEM II 42.5	-	-	3,1	50,00
Efficient water	-	28	1	28
TOTAL	100 %			358,2

The compositions of concrete incorporating RCA are determined on the basis of this formulation. Concrete with recycled aggregate is obtained by substituting part of the basalt with RCA. RCA volumes are obtained by applying the following formulas:

$$v_{RCA\frac{3}{8}} = v_{basalte\frac{3}{8}} \text{ x Pourcentage de substitution}$$

$$v_{RCA\frac{8}{16}} = v_{basalte\frac{8}{6}} \text{ x Pourcentage de substitution}$$

$$v'_{basalte\frac{3}{8}} = v_{basalte\frac{3}{8}} - v_{RCA\frac{3}{8}}$$

$$v'_{basalte\frac{8}{6}} = v_{basalte\frac{8}{6}} - v_{RCA\frac{8}{16}}$$

With:

^{v}(RCA 3/8) and ^{v}(RCA 8/16) the volumes of RCA contained in the concrete,

^{v}(basalte 3/8) and ^{v}(basalte 8/6) the volumes of basalt contained in the control concrete,

$^{v'}$(basalte 3/8) and $^{v'}$basalte 8/6) the volumes of basalt contained in concrete incorporating RCA

Mass compositions are then obtained by multiplying the volume of each material by its absolute density. The results are given in Table 5, which lists the composition of all the concretes produced. For a formulation with 100% RCA using the Dreux-Gorisse method, the basic assumptions are: a target concrete strength class of C25/30, a cement dosage of 350 kg/m^3 of concrete, an Abrams cone slump of 6 cm, and a granular skeleton with a compactness of c = 0.825. Table 4 summarizes the composition of this concrete.

Table 4: Composition of recycled concrete containing 100% of RCA

Experimental wastage per 50 kg of cement				
Materials	**Volumetric percentage**	**Volume in liters**	**Bulk density (kg/l)**	**Mass in kg**
Local sand	29 %	51,0	1,536	78,3
Crushed gravel 3/8	9 %	20,8	1,215	25,2
Crushed gravel 8/16	62 %	140,0	1,260	176,4
Cement CEM II 42.5	-			50,0
Efficient water	-	28	1,000	28,3
TOTAL	100 %			358,2

Table 5 summarizes the composition, corresponding W/C ratio, slump and density of the different concretes produced.

Table 5: Composition of the different concretes for 35kg of cement

Components	**Absolute density kg/m ^{3}**	**CC (0%RCA)**	**C1 (10%RCA)**	**C2 (20%RCA)**	**C3 (30%RCA)**	**C4 (40%RCA)**	**C5 (100%RCA)**
CEM II/B 42.5	3,1	35	35	35	35	35	35
Local sand	2,654	56,70	56,69	56,69	56,69	56,69	54,81
Crushed gravel 3/8	2,970	46,53	41,87	37,22	32,57	27,91	17,66
Crushed gravel 8/16	2,990	102,20	91,97	81,75	71,53	61,31	123,47
RCA 3/8	2,588	0,00	4,05	8,11	12,16	16,22	35,00
RCA 8/16	2,611	0,00	8,92	17,85	26,77	35,69	19,83
Gravel/Sand (G/S)		2,62	2,59	2,56	2,52	2,49	3,58
	Calculated	19,90	19,90	19,90	19,90	19,90	20,00
Water	Added	0,72	1,22	1,54	1,97	2,60	2,75
	Total	20,63	21,125	21,4	21,9	22,5	22,75
E/C		0,589	0,589	0,604	0,613	0,625	0,643
Slump (cm)		6	7	6,4	6,8	7	7
Density	Real	2589,34	2551,67	2504,77	2483,75	2445,20	2356,77
(kg/m^3)	Calculated	2603,26	2584,04	2565,11	2546,17	2527,23	2507,61

Concrete testing

Tests on fresh concrete: Abrams cone slump

On fresh concrete, Abrams cone slump was measured in accordance with standard NF P 18-451. Test results are given in Table 3-5.

Tests on hardened concrete

Compression test

The compressive strength of concrete is one of the fundamental parameters used to assess concrete quality. Compressive strength is often considered the most important property of concrete for a number of reasons [6]. Nine (9) molds were made for each type of concrete. Crushing was carried out at 7 and 28 days to define compressive strength in accordance with NF EN 13286-41 P 98-846-41. Figure 2 shows the manufactured specimens, the crushings of these specimens and the internal aspect of the specimens.

Figure 2-a: *Ready-mix concrete specimens*

Figure 2-b: *Crushing of concrete specimens*

Figure 2*-c: Interior appearance of crushed specimens*

The results of the compression test are shown in Table 6.

Table 6: Uni-axial compression test results

Type of concrete	Percentage of substitution	Age (days)	Average compressive strength (MPa)
C0	0 %	7	28,00
		28	35,00
C1	10 %	7	25,30
		28	33,00
C2	20 %	7	23,89
		28	31,35
C3	30 %	7	23,80
		28	31,10
C4	40 %	7	22,48
		28	27,53
C5	100 %	7	21,40
		28	27,02

Tensile test

Concrete tensile strength is another important property for assessing concrete quality. This is measured by the indirect tensile strength test, also known as the Brazilian or splitting test. Although concretes are generally not designed to withstand direct tension, knowing the tensile strength enables us to estimate the load under which cracking develops [6]. It generally appears that the reduction in strength associated with the replacement of natural aggregate by recycled aggregate in concrete is 10% [6] [7]. The splitting tensile test was carried out at 28 days in accordance with standard NF 12390-6. The results of this test are given in Table 7.

Table 7: Results of split tensile test

Concrete type	Percentage of substitution	Age (Days)	Average tensile strength in MPa
C0	0 %	28	3,1
C1	10 %	28	2,73
C2	20 %	28	2,42
C3	30 %	28	2,54
C4	40 %	28	2,46
C5	100 %	28	2,36

3. Results And Discussion

The characteristics of RCA are given in Table 8. The specific weight of RCA is lower than that of basalt. This is because RCAs are loose materials due to the presence of cement mortar. The bulk density of RCA is lower than that of basalt due to the presence of other materials such as laterite, limestone and cement mortar, which are lighter than basalt. The flattening coefficient of RCA shows that the material is not flat. The very high coefficient of absorptivity is also explained by the cement paste, which is porous and absorbent. Figure 3 shows the E/C ratio variation curve as a function of the substitution rate.

Table 8: Comparison of RCA and basalt characteristics

Features	RCA		Basalt Diakk	
	3/8	8/16	3/8	8/16
Specific weight	2,588	2,661	2,97	2,99
Apparent density	1,218	1,174	1,54	1,61
Flattening coefficient	9,52%	8,51 %	69,55%	70,70%
Absorptivity coefficient	8,25 %	6,91 %	0,10 %	0,10 %

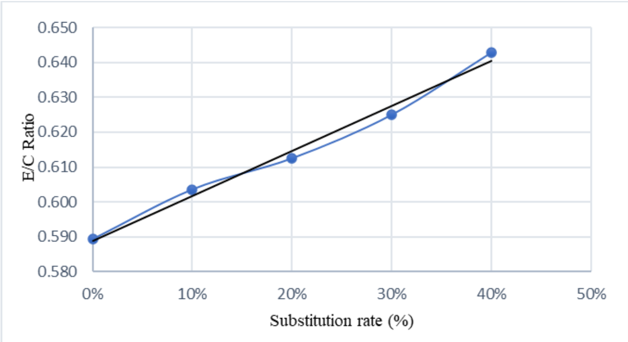

Figure 3: *E/C Ratio depending on substitution percentage*

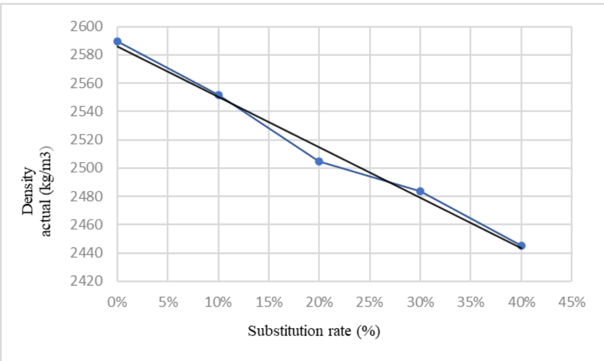

Figure 4: *Density depending on substitution rate*

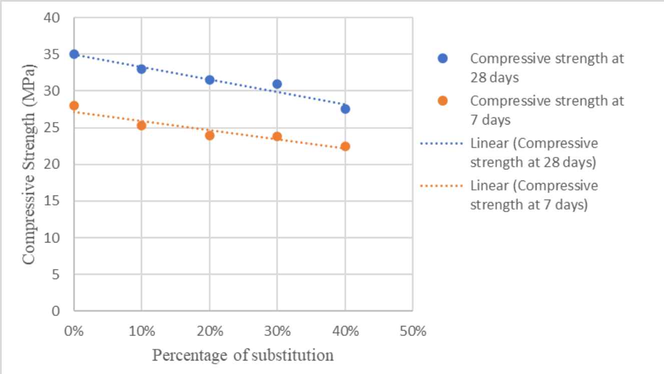

Figure 5: *Compressive strength depending on substitution rate*

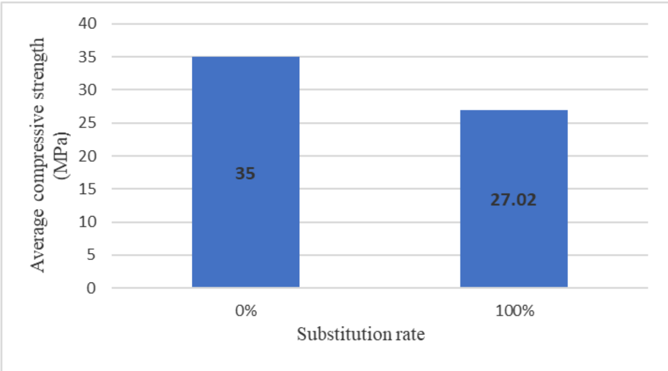

Figure 6: *Compressive strength of control concrete and concrete with 100% of RCA*

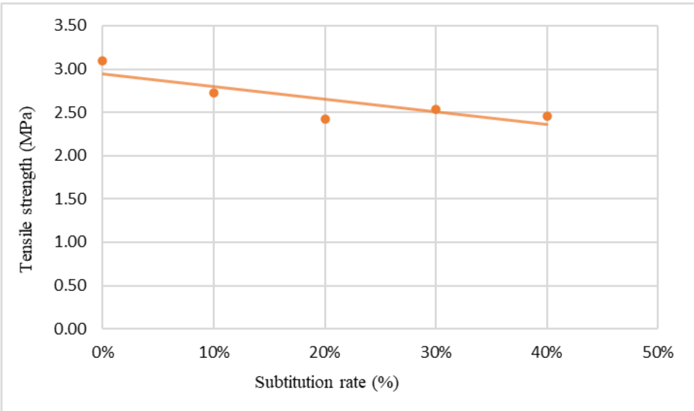

Figure 7: *Tensile strength depending on substitution rate*

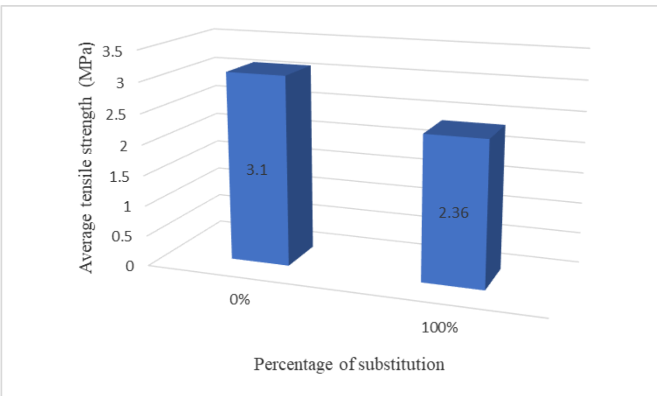

Figure 8: *Tensile strength of control concrete and concrete with 100% of RCA*

Figure 3 shows that the W/C ratio increases linearly with the substitution rate. This is explained by the fact that RCAs have a much higher absorptivity than basalt, due to the presence of cement mortar. The density of the various concretes produced is measured to see the influence of RCA use on the latter. Figure 4 shows the variation in density as a function of the substitution rate: concrete density decreases linearly with the substitution rate. This is due to the fact that, for the same volume, RCAs are lighter than basalt. Above 25% substitution, the density is below the 2500 kg/m^3 imposed by the market. Because of this requirement, it will not be possible to use RCA in structures with a substitution rate of over 25%. The 7-day and 28-day compressive strengths of the various concretes produced were used to draw the curve shown in figure 5. The 28-day compressive strength is higher than the 25 MPa required by the market. This is due to the quality of the RCAs, most of which come from structures formulated with basalt. Calculation of the correlation coefficient of the straight-line variation in 28-day strength as a function of the substitution rate gave a correlation of -0.82. The variation in 28-day strength and the substitution rate are therefore correlated. Figure 6 is a histogram representing the 28-day strengths of control concrete and concrete formulated with 100% recycled aggregates. In the case of the formulation with 100% RCA, the 28-day compressive strength is 27.02 MPa. This result exceeds market requirements. This shows that RCAs perform well in terms of compressive strength, despite a 22.8% drop compared with control concrete. Tensile strength was measured at 28 days, and the results were used to draw the curve shown in Figure 7. There is a good correlation between the variation in tensile strength and the substitution rate, with a correlation coefficient of -0.70. Tensile strength at 28 days decreases with the substitution rate. The tensile strength requested in the market is 2.3 MPa. Up to 40% substitution, the tensile strength exceeds this limit. Figure 8 shows the tensile strength of control concrete and concrete with 100% recycled aggregates. Similarly, for the formulation with 100% RCA, the strength is 2.36 MPa. Despite a reduction of 23.87%, RCA therefore have a satisfactory tensile strength to meet market requirements. These varied results can be explained by the fact that the rate of replacement of natural aggregate by recycled aggregate is just one of the many factors affecting the compressive strength of recycled aggregate concretes.

4. Conclusion

The characteristics of RCA were determined by means of identification tests (particle size analysis with determination of the flattening coefficient, determination of the specific weight, bulk density and absorptivity coefficient). Then, on concretes incorporating RCA with substitution rates of 10%, 20%, 30% and 40% and a complete Dreux-Gorisse formulation, Abrams cone slump was measured and compression and tensile tests were carried out with crushing at 7 and 28 days. RCA grading is continuous, with a flattening coefficient of 8.51% for the 8/16 fraction. Specific weights of 2.588 g/cm^3 and 2.6112.588 g/cm^3, bulk densities of 1.2182.588 g/cm^3 and 1.1742.588 g/cm^3 and absorption coefficients of 8.25% and 6.91% were obtained for fractions 3/8 and 8/16 respectively. When making concrete, the W/C ratio increases with the substitution rate. Measuring the density of fresh concrete shows that it is lower than 2500 kg/m^3 from a substitution rate of 25%. Compressive and tensile strength tests exceed market requirements up to 40% substitution rate. These results show that RCAs can be used in structures with a substitution rate of up to 25%. A W/C ratio of 0.62 is recommended to achieve the required slump. Further tests are required to gain a better understanding of the long-term behavior of recycled concrete.

References

[1]. Chakradhara Rao, M., Bhattacharyya, S. K. and Barai, S. V. (2011). Influence of field recycled coarse aggregate on properties of concrete. Materials and Structures/Materiaux et Constructions, volume 44, issue 1, pp. 205-220.

[2]. Corinaldesi, V. (2010). Mechanical and elastic behaviour of concretes made of recycledconcrete coarse aggregates. Construction and Building Materials, volume 24, number 9, pp. 1616-1620.

[3]. Etxeberria, M., Vazquez, E., Mari, A. and Barra, M. (2007). Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. Cement and Concrete Research, volume 37, number 5, pp. 735-742.

[4]. Rao, A., Jha, K. N. and Misra, S. (2007). Use of aggregates from recycled construction and demolition waste in concrete. Resources, Conservation and Recycling, volume 50, number 1, pp. 71-81.

[5]. Tam, V. W. -., Gao, X. -. and Tam, C. M. (2006). Comparing performance of modified twostage mixing approach for producing recycled aggregate concrete. Magazine of Concrete Research, volume 58, number 7, pp. 477-84.

[6]. Fathifazl, G. (2007). Structural performance of Steel Reinforced Recycled Concrete. Doctor of Philosophy in Civil Engineering, Carleton University,

[7]. Kou, S., Poon, C. and Etxeberria, M. (2011). Influence of recycled aggregates on long term mechanical properties and pore size distribution of concrete. Cement and Concrete Composites, volume 33, number 2, pp. 286-291.

[8]. Tabsh, S. W. and Abdelfatah, A. S. (2009). Influence of recycled concrete aggregates on strength properties of concrete. Construction & Building Materials, volume 23, number 2, pp. 1163-7.