Mechanical and Abrasion Resistance of Recycled Aggregates Concrete in Relation to the Cement Content

Athanas Konin (Corresponding author)
Institut National Polytechnique Félix HOUPHOUET-BOIGNY,
BP 1093 Yamoussoukro, Côte d'Ivoire
Tel: 225-30-643-632 E-mail: kathanas@yahoo.fr

David Mangoua Kouadio
Laboratoire du Bâtiment et des Travaux Publics
04 BP 03 Abidjan 04, Côte d'Ivoire
Tel: 225-21-212-335 E-mail: madok83@yahoo.fr

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Abstract

This paper presents the results of an experimental investigation carried out to study the effects of cement content on the mechanical and abrasion resistance of recycled aggregates concrete. Four series of mixtures with cement content 300, 350, 400 and 450 kg/m^3 were formulated. In each series, natural coarse aggregate were totally replaced with recycled aggregate that allows obtaining two types of concrete: natural aggregates concrete and recycled aggregates concrete. Compressive strength, splitting tensile strength, modulus of elasticity and abrasion thickness loss were determined for both recycled aggregates concrete and natural aggregate concrete. The results show that as cement content increased, mechanical properties of recycled aggregates concrete also increased. It was observed that for cement content upper than 300 kg/m^3, the difference between mechanical properties of natural aggregates concrete and recycled aggregates concrete was lower than 7%. Furthermore, for the same water-cement ratio, this difference is not significant. Correlation between mechanical properties of recycled aggregates concrete and abrasion resistance were proposed.

Keywords: Cement content, Recycled aggregates concrete, Abrasion resistance, Modulus of elasticity, Splitting tensile strength

1. Introduction

Sustainable development was defined as "an economic activity that is in harmony with the earth's ecosystem" (Mehta, 1997). The concept of sustainable development includes the judicious use of natural resources, which in some areas are rapidly depleting, achieved by using industrial by-products and thereby reducing materials waste. Koffi (2000) indicated that the amount of demolition waste dumped at landfill sites in Côte d'Ivoire is in excess of 100000 tons per annum. The bulk of this material is concrete (40 – 50%) and masonry (30 – 40%) with small percentage of other materials such as metal, glass and timber (Sane, 1999; Koffi, 2000). Recovery of these waste materials can reduce the use rate of landfill areas and preserve natural gravel resources. The influence of using recycled aggregate as a replacement of natural aggregate has been widely investigated by others researchers (Hansen, 1996; Poon, et al., 2002; Park, et al., 2004; Evangelista and De Brito, 2007; Ismaïl, et al., 2007; Binici, et al., 2008; Kou, et al., 2008; Corinaldesi and Moroconi, 2009; Ismaïl and Al-Hashimi, 2009; Yüksel, et al., 2009; Omingo, et al., 2010). But, these studies were mainly based on the comparison of workability, compressive strength and long-term properties such as shrinkage, creep of concrete prepared with natural and recycled aggregates. The properties of concrete made with recycled aggregate generally inferior to those of natural aggregate. Nevertheless, Evangelista and Brito (2007) have shown that the use of fine recycled concrete aggregates does not jeopardize the mechanical properties (such as compressive strength, splitting tensile strength and abrasion resistance) of concrete for replacement ratio up to 30%. However, the shortcomings of using recycled aggregate could be ameliorated by employing a lower water-to-cement ratio (w/c) and increasing the cement content (Hansen, 1996; Konin and Kouadio, 2011).

Although, it is environmentally beneficial to use recycled aggregates, the Ivorian current legislation and experience are not sufficient to encourage recycling of demolished concrete waste. This paper forms part of a continuous study on the influence of cement content on the properties of recycled aggregates concrete. In previous study (Konin and Kouadio, 2011), the effects of cement content on the porosity to water, nitrogen permeability and compressive strength of recycled aggregate concrete were reported. The results indicated that an increase in cement content (beyond 300 kg/m^3) reduced significantly porosity to water, gas permeability and enhanced the compressive strength of recycled aggregates concrete. Correlations between recycled aggregate concrete compressive strength and that of natural aggregate concrete were presented.

This paper presents the results of an experimental study concerning splitting tensile strength, static modulus of elasticity and abrasion resistance and draws some conclusions on the viability of using recycled aggregate concrete in structural concretes, namely by comparing them with natural aggregates concrete.

The final objective of this work is to establish correlation between abrasion resistances of recycled aggregate concrete and cement content.

2. Experimental Program

2.1 Materials

A Portland cement type CPA CEM II 32.5 is used in the concrete mixtures. The properties of cement are given in Table 1.

Natural and recycled aggregates were used as the coarse aggregate in the concrete mixtures. For this study, crushed granite was used as the natural aggregate and recycled aggregate sourced from old concrete waste was used. These two types of aggregates are the same maximal granular size and recycled aggregate is composed of crushed granite (from the same quarry of natural aggregate used in this study) coated with mortar. It is so possible to compare mechanical properties of concrete manufactured with these two coarse aggregate. Natural siliceous sand was used as fine aggregate in the concrete mix. The physical and mechanical characteristics of sand and coarse aggregates are shown in Table 2.

2.2 Mix Compositions

The concrete mixtures were formulated with four different cement contents (300, 350, 400 and 450 kg/m^3). Full replacement of natural coarse aggregate (N) by recycled aggregate (R) was adopted, keeping constant the coarse aggregate volume. Water proportioning was adjusted to obtain concrete having a value with the slump test of 8 cm. The absolute volume method was adopted to design the mix proportions of the concrete compositions as shown in Table 3.

2.3 Specimens Casting and Curing

For each concrete mix, 65 x 65 x 60 mm prisms and 320 x 160 mm diameter cylinders were cast. The prisms specimens were used to test abrasion thickness loss. The cylinders were used to determine splitting tensile strength and elastic modulus of concrete. After casting, the samples were led in the molds for 24 hours, stripped and cured in water at 27±1°C until the age of testing.

2.4 Testing

The testing program introduced the determination of the splitting tensile strength, elastic modulus and abrasion resistance. Tests carried out are:

2.4.1 Splitting tensile Strength Test

The splitting tensile strength was determined after 7 and 28 days (three specimens were tested at each age). Test was carried out according to the relevant NF EN 12390-6 standard. The sample is placed between both trays of the press. The contact between trays and specimen is realized through two wooden holds. The speed of loading is maintained constant and is about 0.5 MPa/s. The splitting tensile strength is calculated using the following equation:

$$f_{ct} = \frac{2 \cdot F}{\pi \cdot \emptyset \cdot L}$$

Where, F (N) is the maximum load, L (mm) is the length (mm) and ϕ (mm) is the diameter of the specimen.

2.4.2 Testing the Modulus of Elasticity

The procedure for measuring the static modulus of elasticity in compression is described in DIN 1048. In this procedure, molded concrete cylinders are subjected to a slowly increasing longitudinal compressive stress.

Longitudinal strains are determined using a bonded sensing device that measures the average deformation of two diametrically opposite locations to the nearest 5 millionths of strain. The applied load and longitudinal strain are recorded when the longitudinal strain is 50 millionths and when the applied load is equal to 30% of the cylinder compressive strength. The modulus of elasticity can be calculated by the difference of the measure stresses and strains on an upper level (i.e 40% of the value of compressive strength) and a lower level (i.e 0.5 MPa). The modulus of elasticity then is given by the equation:

$$E_b = \frac{(\sigma_0 - \sigma_u)}{(\varepsilon_0 - \varepsilon_u)}$$

With: ε_0, σ_0, stress and strain at the upper loading level,

ε_u, σ_u, stress and strain at the lower loading level,

In accordance to that standard, the measurement takes place at the samples age of 28 days.

2.4.3 Abrasion Resistance Test

Initially, the specimens were secured on the rotary platform and a 300 N vertical load is applied. 20 g standard abrasive dust is placed into the rotating table. After 30 revolutions, the path and the specimens were cleaned then, new 20 g standard abrasive is placed and the specimens were rotated (90°) in the horizontal axis. The specimens were weighed initially and every 4 x 20 revolutions. The specimens were submitted to 16 x 20 revolutions. Thickness measurements of the specimens also have been done from three points. The abrasion thickness loss can be controlled from:

$$A = \frac{(W_1 - W_2)}{W_1} \cdot \frac{V}{S}$$

Where, A (mm) is the average abrasion thickness loss, M_1 (g) and M_2 (g) are the initial and final weigh of sample, V (mm^3) is the volume and S (mm^2) surface of the specimen.

3. Results and Discussion

3.1 Splitting Tensile Strength

The results are presented in Table 4. All samples show similar trend in splitting tensile strength values with respect to the cement content and aggregates types. The best values are obtained for concrete with high cement content and containing natural aggregate. An increase in cement content about 30% gives an increase in tensile strength about respectively 20% for recycle aggregates concrete and 24% for natural aggregates concrete. However, the results indicate that by taking into account the age of concrete, the difference between tensile strengths of these two types of concrete decrease. So, at 7 days the increase of strength varies from 7% to 15 %, while it is only from 1% to 7 % at 28 days respectively. Furthermore, for a same water-cement ratio (values in bold in Table 4), concretes with recycled aggregates have similar tensile strength values otherwise higher than those of natural aggregates concrete. It seems that the cement content plays more important role than the type of aggregates.

3.2 Modulus of Elasticity

The results obtained for the modulus of elasticity are presented in Table 5. As shown, there is a slight reduction of the modulus of elasticity for recycled aggregate concrete (less than 6%). It was observed that with the increase of cement content, this reduction wasn't significant (less than 4%). It is known that the concrete's modulus of elasticity is related to the stiffness of the aggregate and the mortar, their porosity and bond (Limbachiya, et al., 2007). Therefore, the use of high cement content reduces significantly concrete porosity and increase paste-aggregate bond (Poon, et al., 2004; Tam, et al., 2008), so it is possible that the overall stiffness is not influenced and the concrete's modulus of elasticity is fairly affected.

3.3 Abrasion Resistance

According to Table 6, it is obvious that recycled aggregates concrete have greater abrasion resistance than natural aggregates concrete. The gain is about 8% to 12% respectively while cement content is increased from 300 kg/m^3 to 450 kg/m^3. That may have to do with the fact that abrasion resistance is deeply connected with the bond of cement paste with the fine aggregates.

3.4 Relation Between Mechanical Properties of Recycled Aggregate Concrete and Abrasion Resistance

Figures 1 to 3 present the relations between mechanical properties of recycled aggregates concrete and abrasion resistance. On each figure, an equation and a correlation coefficient are presented corresponding to the studied mix. It can be seen that the relationships obtained for natural aggregate concrete and those of recycled aggregate are of the same shape and it is presented as:

$$A_L = \alpha_i \cdot X^{-\beta_i}$$

Where, A_L is abrasion thickness loss (mm), X is the mechanical properties studied and (α_i, β_i) are coefficients depending on aggregate type and mechanical properties studied. The results obtained for the studied concrete are presented on Figure 1 to 3.

Figure 1 presents the relation between the compressive strength of recycled aggregates concrete and abrasion resistance. The compressive strength of recycled aggregates concrete is strictly linked to abrasion resistance. The coefficient of correlation is respectively 0.962 for natural aggregates concrete and 0.990 for recycled aggregates concrete.

Figure 2 presents the relation between the splitting tensile strength of recycled aggregates concrete and abrasion resistance. The splitting tensile strength of recycled aggregates concrete is strictly linked to abrasion resistance. The coefficient of correlation is respectively 0.995 for natural aggregates concrete and 0.953 for recycled aggregates concrete.

Figure 3 presents the relation between the modulus of elasticity of recycled aggregates concrete and abrasion resistance. The modulus of elasticity of recycled aggregates concrete is strictly linked to abrasion resistance. The coefficient of correlation is respectively 0.985 for natural aggregates concrete and 0.981 for recycled aggregates concrete. It was observed that the two correlation curves are homothetic.

These results confirm those obtained in the previous paper (Konin and Kouadio, 2011) and show that it is possible to estimate the mechanical properties of recycled aggregates concrete when those of natural aggregates concrete are known for the same proportion of concrete. These relationships can also be used to adapt the formulation method of natural aggregates concrete to recycled aggregates concrete.

4. Conclusion

The presented study concerns the possibility of using recycled aggregates in the formulation of concrete as a replacement of natural aggregates. At the end of this experimental study, the following conclusions can be drawn:

- The mechanical properties of recycled aggregates concrete can be increased by using high cement content (over 350 kg/m^3) and low water-cement ratio.
- The variation between the mechanical properties of recycled aggregates concrete and those of natural aggregates concrete are lower than 15 % independently to cement content.
- The abrasion resistances of recycled aggregates concrete are better than that of natural aggregates concrete.
- The correlations are presented between the mechanical properties of recycled aggregates concrete and abrasion resistance.

The results confirm the possibility of a large use of recycled aggregates in the manufacturing of concretes. The use of these aggregates constitutes an undeniable ecological contribution.

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Table 1. Chemical and physical properties of cement

Chemical composition (%)						Density (g/cm^3)	Specific surface (cm^2/g)
Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	SiO_2		
6.94	54.50	3.30	1.68	2.05	17.49	2.98	3214

Table 2. Properties of natural and recycled aggregates

	Granular	Density (g/cm^3)	Porosity to water (%)	L.A coefficient
Natural sand	0/2	2.43	-	-
Natural aggregate 1	5/15	2.70	1.46	16.20
Natural aggregate 2	15/25	2.70	1.46	16.00
Recycled aggregate	8/25	2.61	6.39	26.00

Table 3. Concrete mixture proportion

Notation	Constituents (kg/m^3)					f_{cm28} (1) (MPa)
	Cement	Sand	Natural aggregates	Recycled aggregates	Water	
N300	300	572	1310	0	176	21.6
N350	350	557	1283	0	178	23.5
N400	400	542	1249	0	180	27.7
N450	450	526	1212	0	183	29.9
R300	300	568	0	1267	181	20.2
R350	350	546	0	1218	192	21.6
R400	400	530	0	1180	196	25
R450	450	511	0	1139	202	27.1

(1) f_{cm28} correspond to the average compressive strength obtained at 28 days

Table 4. Splitting tensile strength of studied concrete (MPa)

Notation	Cement content (kg/m^3)	W/C	Splitting tensile strength (MPa)	
			7-days	28-days
N300	300	0.59	1.76	2.35
N350	350	**0.5**	**1.98**	**2.56**
N400	400	**0.45**	**2.14**	**2.81**
N450	450	0.4	2.42	3.11
R300	300	0.6	1.62	2.32
R350	350	0.55	1.81	2.43
R400	**400**	**0.49**	**1.94**	**2.58**
R450	**450**	**0.45**	**2.05**	**2.87**

Table 5. Static elastic modulus of studied concrete (GPa)

Notation	Cement content (kg/m^3)	W/C	Modulus of elasticity (GPa)	
			28-days	Δ (%)
N300	300	0.59	18.7	4.7
N350	350	0.5	19.4	3.3
N400	400	0.45	20.15	4.2
N450	450	0.4	20.85	4.8
R300	300	0.6	17.55	3.8
R350	350	0.55	18.5	3.8
R400	400	0.49	19.1	4.2
R450	450	0.45	19.85	4.5

Table 6. Abrasion resistance of studied concrete

Notation	Cement content (kg/m^3)	W/C	Abrasion thickness loss (mm)	
			28-days	Δ (%)
N300	300	0.59	2.2	3.1
N350	350	0.5	2.04	2.8
N400	400	0.45	1.86	3.3
N450	450	0.4	1.65	2.8
R300	300	0.6	2.01	2.9
R350	350	0.55	1.8	4.1
R400	400	0.49	1.57	3.2
R450	450	0.45	1.41	3.6

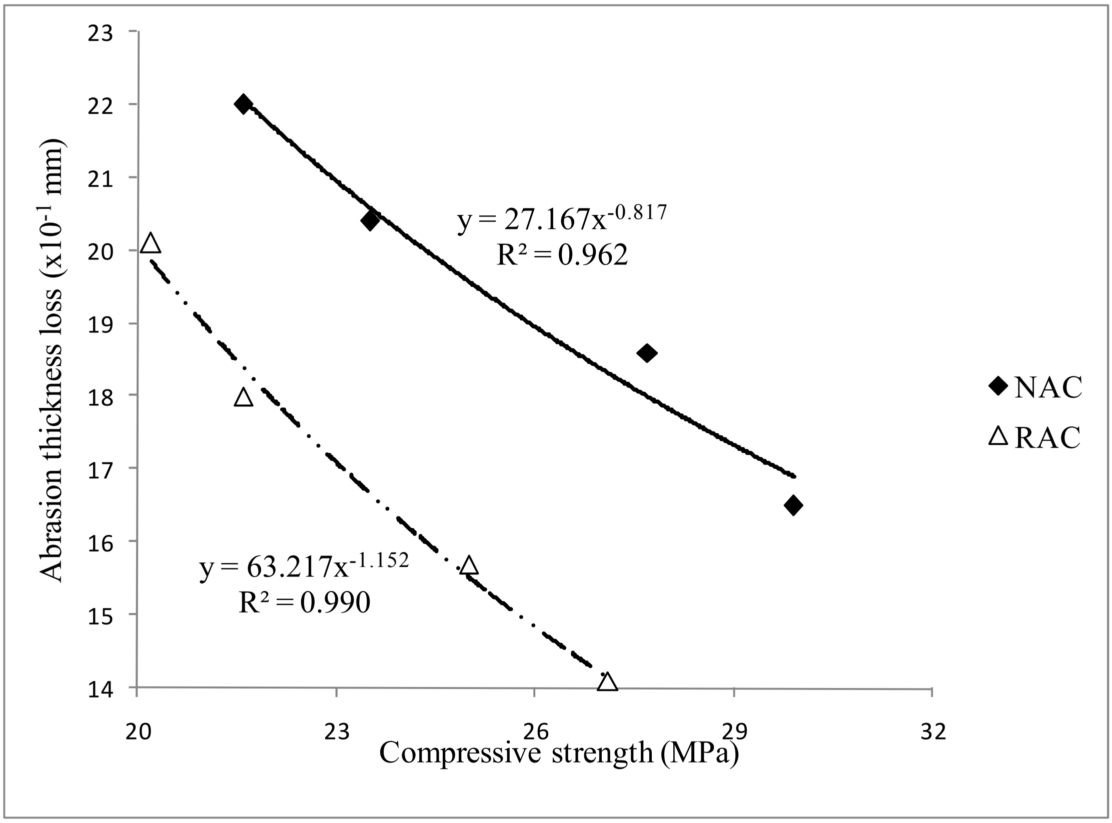

Figure 1. Correlation between compressive strength and abrasion thickness loss

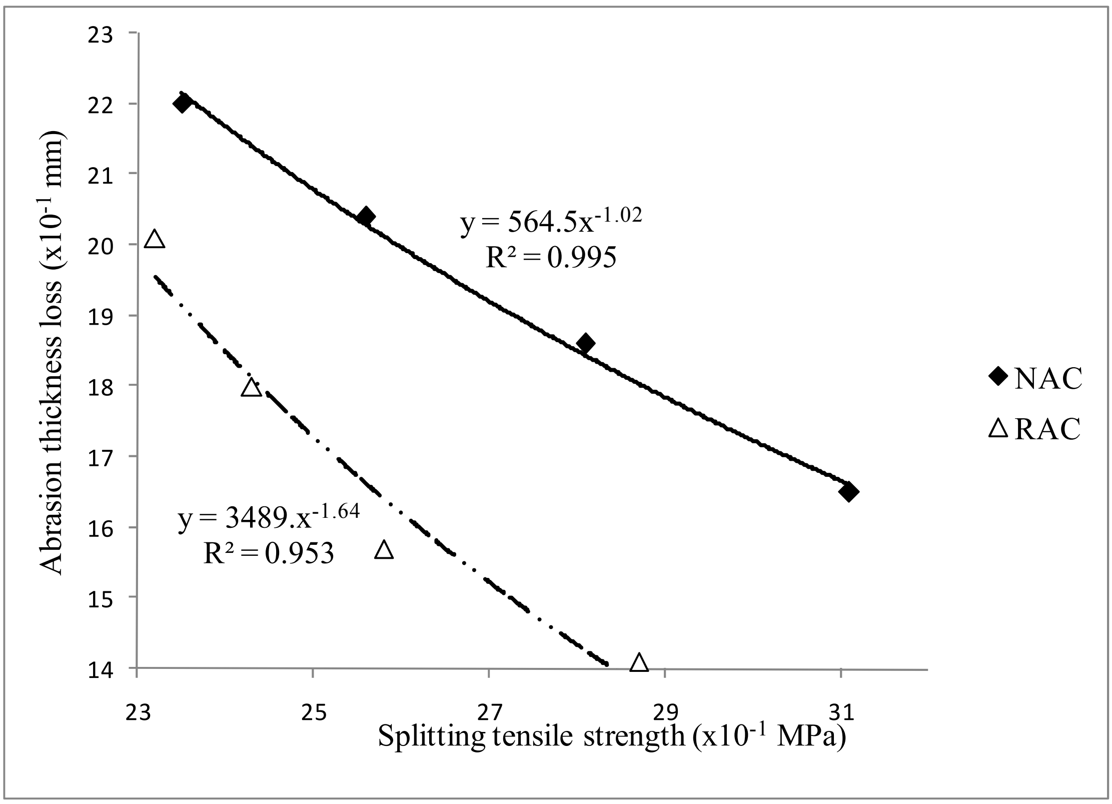

Figure 2. Correlation between splitting tensile strength and abrasion thickness loss

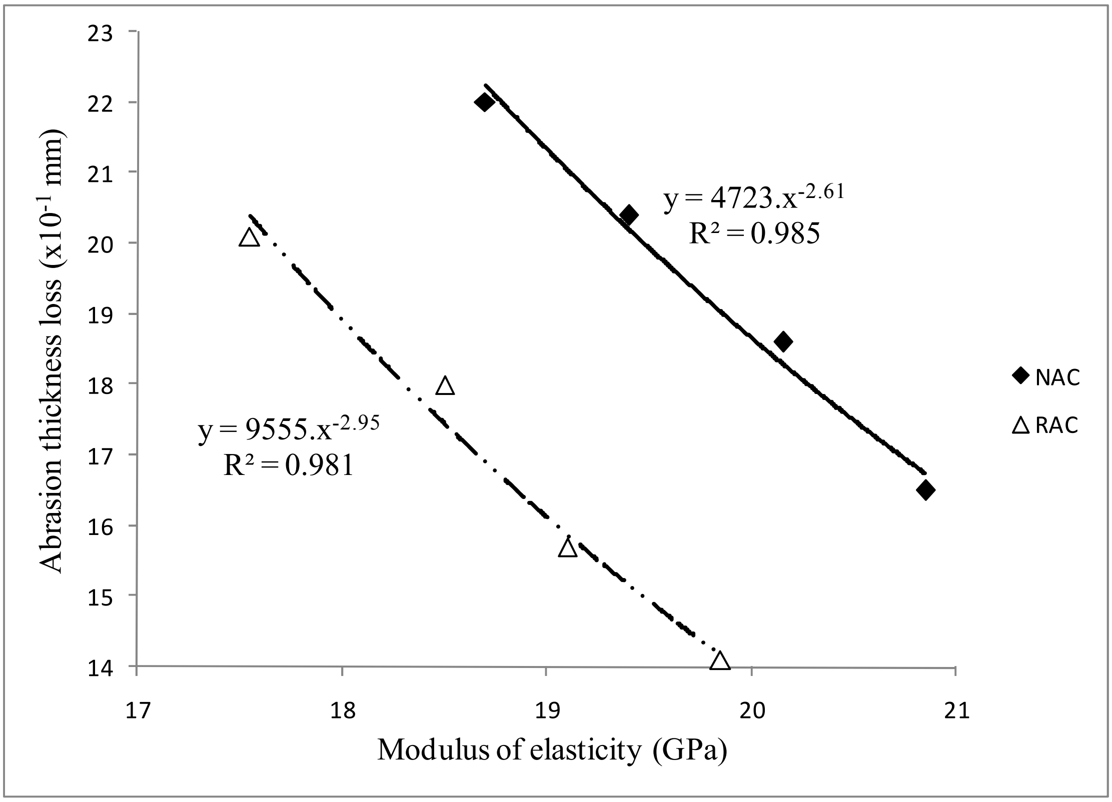

Figure 3. Correlation between modulus of elasticity and abrasion thickness loss