European Journal of Scientific Research
ISSN 1450-216X / 1450-202X Vol. 150 No 2 September, 2018, pp. 152-158
http://www. europeanjournalofscientificresearch.com

Determination of Hydraulic Conductivity of Recycled Clay Bricks and Recycled Concrete Aggregate for base Course Materials

Mababa Diagne
Institut des Sciences de la Terre, Faculté des Sciences et Techniques
Université Cheikh Anta DIOP de Dakar, Laboratoire de des Géomatériaux
BP 5396 Dakar-Fann, Sénégal
E-mail: mababa.diagne@ucad.edu.sn
Tel: +(221) 33 825 25 30

Ibrahima Dia
Institut des Sciences de la Terre, Faculté des Sciences et Techniques
Université Cheikh Anta DIOP de Dakar, Laboratoire de des Géomatériaux
BP 5396 Dakar-Fann, Sénégal

Abstract

This work deals with the determination of hydraulic parameters of base course materials made by recycled clay brick (RCB), recycled concrete aggregates (RCA) and mixture of both of them. The specimens made, show that the saturated hydraulic conductivities are closely related to the grain size distribution according to Hazen's empirical equation. The experimental ksat values are very similar to the theoretical values obtained. Results from the soil water characteristic curves (SWCC) show that the desorption of water from the specimens increase when the percentage of bricks on the blend increase. The sol water characteristic curves (SWCC) from experimental data are compared to the values obtained from Genuchten model. They show a very good fitting curve and the pore size distribution parameter (n) from Genuchten model which is 1.70, 1.75, 1.76, 1.93, and 2.21 respectively for 100%RCA, 5%RCB + 95%RCA 15%RCB + 85%RCA, 30%RCB + 70%RCA, and 100%RCB show that the porosity of the material increase with the percentage of bricks in the mixture. In sum, recycled clay brick cannot be used alone as base course material due to its high porosity and low density.

Keywords: Recycled Clay Bricks, Base Course, Hydraulic Conductivity, Recycled Concrete Aggregates, Soil Water Characteristic Curves, Van Genuchten Model, Hazen's Equation

1. Introduction

The scarcity of building materials, the need for recycling through environmental standards requirements becoming increasingly stringent make the Recycled Clay Bricks (RCB) are used as an unbound road base material next to natural aggregates which are expensive. This use is also associated with a high consumption of natural aggregate resources decreasing that used high-energy consumption during their crushing and their screening. In this regard, many road works have been made using the RCB only or mixtures in varying proportions of naturals aggregate in RCA that are material composed by nearly 60% to 75% of high-quality well-graded aggregates that may include 10% to 30% of subbase soil material (**Kuo et al., 2007**). Cost reduction road building and environmental constraints are the primary objectives of recycling nowadays. RCB is used in almost all the countries. To achieve the objective of recycling, there are intensive efforts being made in the effective utilization of wastes and by-products, particularly from building materials industries.

In the developed countries, the demolition waste industry used large quantities of materials that come from road construction, building renovation, and demolition of buildings and other structures that once were delivered to landfills for disposal (**Poon, 2006**). RCB aggregate may come from over-burnt clay bricks in the customary burning process of clay bricks manufacturing. **Mazumder et al., (2006)** estimated this quantity to 13% due to uncontrolled distribution of temperature in the kiln. They found that aggregate from over-burnt clay bricks present LA value and water absorption lower than values obtained in normal clay bricks. The use of RCB in the developing countries is limited as an unbound road base material because masonry bricks are produced mostly manually or in non-automated factories without quality control. This type of brick, therefore, is not high quality in terms of mechanical strength and physical properties and may be thought of as inappropriate for concrete aggregate or road layer construction.

The use of RCB alone as an unbound base material is really not accepted. It's used when blend with RCA in concrete. And once blend; the materials are often used on subbase for pavement, or base for sidewalks or low traffic roads. The amount (% by dry mass) of RCB in RCA is variable. **Grab et al. (2012)** reported that some European specifications allow a maximum of 30% RCB (Recycled Clay Masonry) blended with RCA. In South Australia, the Department for Transport, Energy and Infrastructure allows 20%. In the USA, according to the Greenbook specification for construction, the amount of RCB cannot exceed 3% by weight (**Greenbook, 2009**). **Poon (2007)** shows that it is feasible to allow a higher level of contamination in the recycled concrete aggregates for making the concrete products.

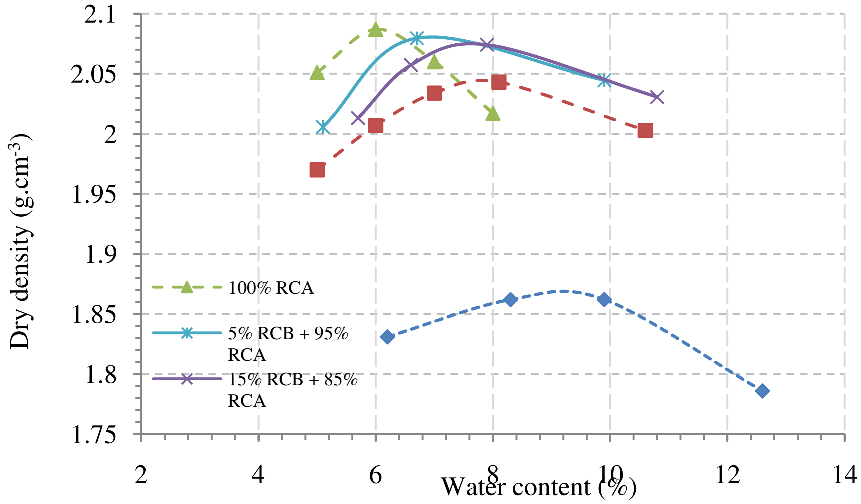
Based on the literature, water absorption content of RCB aggregates can vary between 6% and 30% depending on the nature of initial material used, the particles size, the clay bricks manufacturing way, the density etc. RCB aggregates present low particles density compared to natural aggregates. This low density is associated with a greater porosity subject of its higher water absorption content. **The Federal Highway Administration (1997)** reported that concrete made by recycled aggregates has lower density, higher water absorption, higher soundness mass loss, and higher content of foreign material compared to natural aggregates. This higher water absorption content of RCB combined to the seasonal variation of moisture and temperature may influence the characteristics of the unbound road base pavement made by RCB aggregates or material containing RCB by the actions of wet and dry or freeze and thaw cycles and repeated load (represented by action of standard wheels loading on the road). The durability of a pavement can be influenced by repeated freeze-thaw cycles, wet-dry cycles, or a combination of both (**Khoury and Zaman, 2005**).

This research focused on the determination of k_{sat} of 100% of RCB, 100%RCA, 5%RCB+95%RCA, 15%RCB+85%RCA, and 30%RCB+70%RCA. The Soil Water Characteristic Curve (SWCC) of each specimen was measured by using a hanging column test and was fitted using **van Genuchten (1980)** model. The saturated hydraulic conductivity ksat measured are compared to the theoretical hydraulic properties obtained with Hazen's relationship (**Hazen, 1911**).

2. Materials and Method

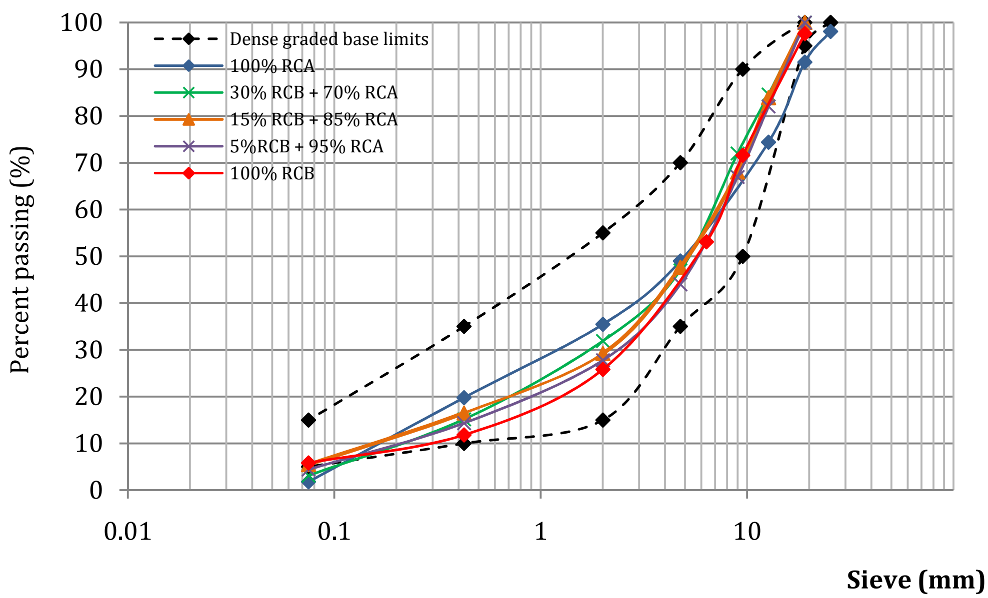
RCB and RCA, used in this research, were from a building demolition and a recycling concrete company. They were all crushed and the maximum size was 19 mm (3/4 in). Figure 1 gives the compaction curves of our specimen and shows the optimum Proctor water content increases with the percentage of clay bricks.

Figure 1: Modified Proctor compaction curves.



The grain size distribution according to **ASTM D 6836** of all materials used in this research is summarized in Figure 2. They are compared to upper and lower bound curves specified by the local state road authority.

Figure 2: Grain size distribution



Materials were obtained by combined various proportions of different size of crushed materials made with aggregates from a demolished building wall (Figure 3).

Figure 3: Red clay brick, a) Wall made with red clay brick, b) Crushed brick with 21% or mortar

a) b)

Table I gives the engineering properties of the blends. The experimental investigation included laboratory tests, such as particle size distribution, modified Proctor compaction, particle density, water absorption and hydraulic conductivity tests.

Table 1: Engineering Properties of Aggregates Used

MATERIALS	G_s	Water Abs. (%)	LA (%)	$\omega_{opt.}$ (%)	γ_d max (kN/m^3)	USCS Symbol	AASHTO Symbol
100% RCB	2.25	5.12	36.8	8.6	18.7	GW-GM	A-1-a
5% RCB+95% RCA	2.39	4.76	30.1	6.4	20.8	GW	A-1-a
15% RCB+85% RCA	2.36	4.86	31.9	6.8	20.6	GW-GM	A-1-a
30% RCB+70% RCA	2.33	4.95	33.7	6.8	20.4	GW	A-1-a
100% RCA	2.41	4.64	29.9	6.1	20.9	GW	A-1-a

2.1. Saturated Hydraulic Conductivities

The **ASTM D 5856** standard with a compaction-mold permeameter and a falling head was used to measure the saturated hydraulic conductivities of our samples. The sample was saturated overnight with water before starting the test, to make sure that the voids in the sample were fully saturated. For each test, the falling of the water level in the standpipe was recorded with time. The height and diameter of the sample were measured and the diameter of the standpipe was also recorded.

The permeameter cell consists of a rigid-wall compaction mold into which the material to be tested is compacted and in which the compacted material is permeated. The percentage of clay bricks and the particle size distribution influenced the saturated hydraulic parameters. Hydraulic gradients (i) of about 1 m were applied in order to avoid the material washing ($i > 1$) and very long testing times ($i < 1$).

2.2. Soil Water Characteristic Curve

The behavior of soils under completely dry or completely saturated conditions is more understood than the unsaturated one because of matric suction caused by water surface tension on the curved pore air/pore water interface (**Health et al., 2004**). When modelling unsaturated moisture flow beneath a road pavement, the hydraulic conductivity of the base course and subgrade materials, as a function of water content, must be known. This function can be estimated based on the SWCC. It expresses the relation between volumetric water content (θ) or gravimetric water content (ω) and soil suction (ψ) in unsaturated soils. SWCC can determine the engineering behavior of unsaturated soil since it permits to have soil functions such as hydraulic conductivity and volume change. A numerical model has been proposed to describe the SWCCs that relate matric suction to volumetric water content. A flexible analytical equation that relates the pressure head (h) to volumetric water content (θ) was developed by **van Genuchten (1980)** (Equation 1).

$$\theta = \theta_r + \left(\frac{\theta_s - \theta_r}{1 + (\alpha\psi)^n} \right)^m \quad (1)$$

where θ is the water content corresponding to matric suction ψ; θ_s is the saturated volumetric water content; θ_r is the residual water content, α, m, n are mathematical fitting parameters, n is related to the pore size distribution and m gives an indication of the asymmetry of the curve ($m = 1 - n^{-1}$).

3. Results

The saturated hydraulic conductivities were measured and compared to estimated values using empirical equations. Hazen (1892, 1911) developed an empirical formula (Equation 2) to predict the permeability or hydraulic conductivity of saturated sands. The formula's applicability is generally limited to 0,1 mm ≤ D10 ≤ 3 mm (**Hazen 1892, 1911**).

$$k_{sat.} = C_H \times D_{10}^2 \quad (2)$$

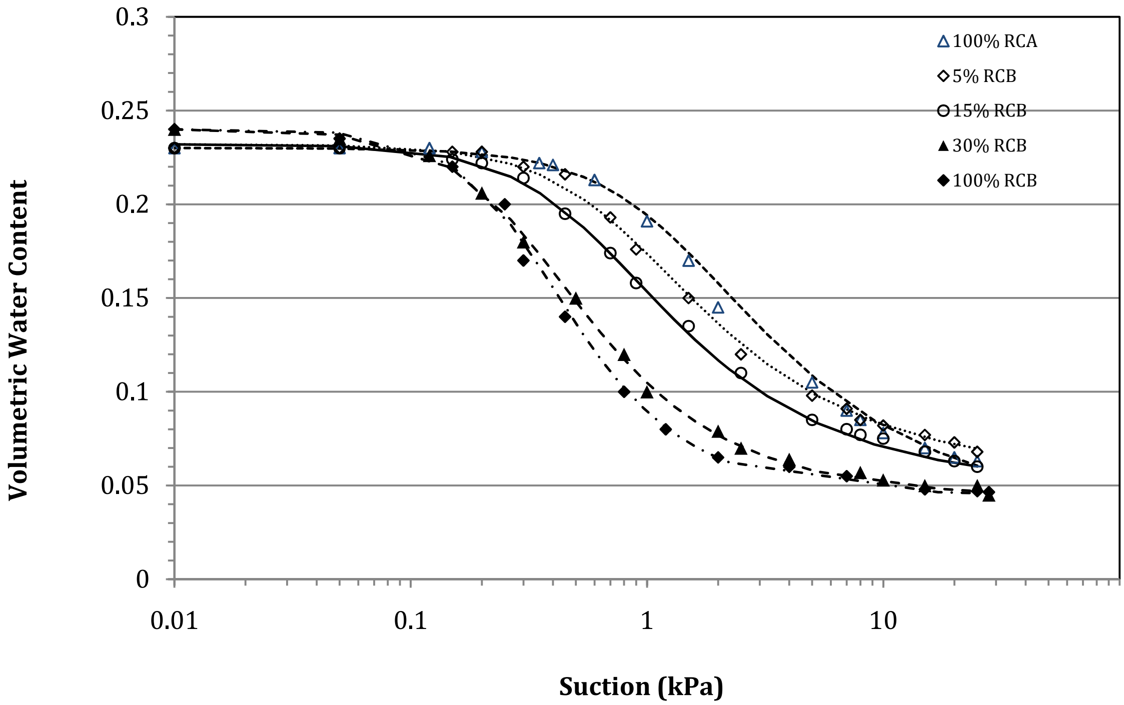
C_H: Hazen empirical coefficient and D_{10}: particle size for which 10% of the soil is finer. The results obtained by comparison of the measured and the predicted values are summarized in Table 2. They show that the k_{sat}, predicted by Hazen, are almost the same compared to the values of k_{sat} measured.

Table 2: Comparison of measured and predicted values of k_{sat}

Materials	**D_{10}**	**C_H**($\times 10^{-2}$)	**$k_{sat. Predicted}$ Hazen** ($\times 10^{-5}$)	**$k_{sat. Measured}$** ($\times 10^{-5}$)
100%RCA	0.17	0.113	3.28	3.00
30% RCB + 70%RCA	0.21	0.133	5.87	5.88
15% RCB + 85%RCA	0.16	0.180	4.61	5.07
5% RCB + 95%RCA	0.21	0.102	4.50	4.51
100% RCB	0.30	0.164	1.48	1.48

The data obtained from the SWCC were fitted to **van Genuchten (1980)** model as shown in Equation (1). Figure 4 showed the best fitting curves compared to the experimental data.

Figure 4: Soil-Water Characteristic Curves, measured WCC data fitted to van Genuchten (1980) model



The fitting parameters of the model are summarized in Table 3. Good fitting are obtained. In Figure 4, the points represented the experimental data and the line the Genuchten model data. The suction at which water content starts to decrease significantly on the specimen is defined as the air entry value (ψ_a). For higher values of suction the volumetric water content tends to be residual (θ_r). The air entry values range from 0.55 kPa (100% RCA) to 0.15 kPa (100% RCB). It decreases when the percentage of RCB in the blends increases. The slope desorption of all specimens have almost the same trend. The drainage of water is faster when the percentage of RCB increases due to higher porosity and lower density. This fact is confirmed by the modified Proctor tests.

Table 3: SWCCs fitting parameters in van Genuchten (1980) model

MATERIALS	100%RCA	5%RCB+95% RCA	15%RCB+85% RCA	30%RCB+70% RCA	100%RCB
ψ_a (kPa)	0.55	0.35	0.25	0.15	0.15
Van Genuchten (1980) fitting parameters					
θ_r (m^3/m^3)	0.036	0.057	0.045	0.044	0.045
θ_s	0.230	0.232	0.232	0.240	0.240
α (kPa^{-1})	0.770	1.30	1.760	3.350	3.290
n	1.710	1.75	1.760	1.930	2.210
m	0.410	0.43	0.410	0.480	0.550

4. Conclusion

Recycled materials, such as clay brick from demolished building, are used for road construction. Due to the manusfacturing way of bricks and their composition, recycled clay bricks presented high porosity and low dry density. For this reasons, only RCB cannot be used as material on base course. RCB can be mixed with recycled concrete aggregates for good mechanical and hydraulic behavior. The properties of the crushed brick could be enhanced further by blending it with other recycled aggregates to improve its performance in pavement subbase applications. The SWCC show a rapid desorption of the specimen when the percentage of brick increase and the van Genuchten model describe perfectly the relation with the volumetric water content and the suction applied to the soil. This paper gives evidence that the unsaturated and saturated hydraulic conductivities are linked to the grain size distribution of the soil. The theoritical saturated hydraulic conductivities obtained by Hazen's equation are almost the same than our experimental data.

Acknowledgements

This research paper is supported by the Office of Scholarship Program (OSP) of the Islamic Development Bank under its Merit Scholarship Program for High Technology (MSP), (Number: 66/SN/D33).

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