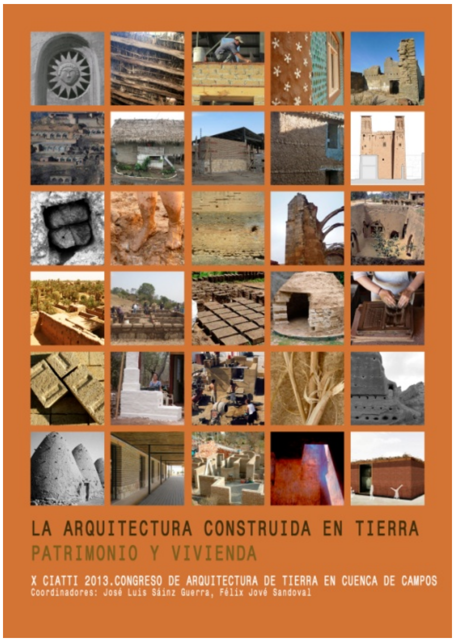

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ACCESSING THE INITIAL RATE OF SORPTION FOR RAMMED EARTH MADE WITH PALM KERNEL SHELL

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PALABRAS CLAVE: rammed earth, palm kernel shell, sustainable building, earth building.

1. Introduction

Rammed earth is a compacted aggregate-based material typically containing hygroscopic clay minerals and usually exhibiting a high density and a low void ratio[1]. It is formed when earth (usually graded and prepared for the purpose) is compacted between forms and shuttering to create a monolithic unit that is strong and durable. Soils used are usually moistened to optimum moisture content. Rammed earth construction is an ancient technique (practiced by ancient civilisations such as the Egyptians, Minoansand the Romans[1]) that is attracting renewed interest throughout the world today[2] it is possible that the rammed earth material is anisotropic. This paper presents the first study of this anisotropy, carried out on two scales. The first is the scale of Representative Volume Elements (RVEs, thanks to its 'green' characteristics in today's context. Hall reports that approximately one half of the world's population are said to live or work in an earth building[3].

Rammed earth can be formed from most soil combinations but strength usually differs depending on soil grading and addition of binders or stabilizers like lime, cement, fly ash, straw and even cow dungs.Stabilisation is the modern practice of improving rammed earth and is typically achieved by the addition

Figure 1. Palm Kernel Shell (PKS).

of up to 10% Portland Cement to soils used for rammed earth production[3]. Rammed earth is seen as being heterogenic and though the complexities of manufacturing a representative samples is discussed by Bui[4], most samples used in testing are usually 100mm[5] or 50mm cubes.

Soils differ from one location to the other. Differences are observed in the grading, colour, texture and chemical composition. One of the factors that influences rammed earth properties is grading. Rammed earth soils are composed of a mix of three different fractions. The inert aggregate fraction is represented by granular soils (sand and gravel), the binder fraction is represented by cohesive soil (clay) and water is used to activate the lot. Some soils are lacking in one or two fractions. Some soils are sandy and therefore contain very little proportion of clay and silt. Other soils also lack sufficient coarse aggregates. The missing fraction can be augmented by proactively sourcing it from another location and blending it properly with locally found soil to provide the material for rammed earth building. Where this would increase cost greatly, and where they are available locally, replacement materials should be considered.

Most of the materials that are considered for use are usually agricultural or industrial waste. Some of these wastes include sawdust, pulverized fuel ash, palm kernel shells, slag, etc which are produced from milling stations, thermal power station, waste treatment plants etc. The utility of fly ash as partial replacement in concrete mixes is on the rise[6]. The manufacture and use of lightweight aggregates from wastes such as expanded pelletized fly ash aggregates, sintered fly ash aggregates, expanded slag gravel, blast furnace slag etc., while demonstrating the effectiveness of waste utilization in industrially advanced countries, have been found to have a high processing cost. As the ultimate aim in using rammed earth as a construction material is cost reduction, use of naturally found aggregates should be encouraged. Palm kernel shell requires very little or no processing and can be used as gravel replacement in rammed earth construction.

Palm Kernel Shells (PKS) are organic waste materials obtained from palm oil producing factories in Africa and Asia[7]. PKS, as seen in Figure 1, is the hard stony endocarp of palm kernel fruit that surrounds the palm seed[6,8]. The sizes of PKS vary and can range from 2mm to 15mm. the shells are flaky, parabolic, angular and possess smooth concave and convex surfaces. The thickness of PKS vary in the range of 1.5-3mm[7]. Being hard and of organic origin, they will not contaminate or leach to produce toxic substances once they are bound in a rammed earth matrix.

Understanding moisture infiltration in dry or partially saturated media is important for forecasting moisture distribution in rammed earth. As the presence of moisture greatly retards the compressive strength of rammed earth, it is of paramount importance that the mechanism of moisture ingress, retention and egress be understood.

In rammed earth, the rate of moisture transport is influenced by pore size distribution. Porous materials are often permeable by air and moisture because they contain a network of open channels[9]. The driving force is surface tension. Capillary absorption takes place in fine pores (10nm - 10μm) and it occurs when forces arising from surface tension are in the same range as gravity forces present in the liquid. It is the prime mechanism when a material is only partially wetted[10]. Sorptivity is a measure of the capacity of a medium to absorb or desorb liquid by capillary action. Sorptivity is defined analytically as a function of soil water content and diffusivity[11]. In practice, however, Philip[11] showed that sorptivity can be measured relatively easy from horizontal infiltration where water flow is only controlled by capillary absorption.

The sorptivity for rammed earth has previously been determined by hall. However, for rammed earth that contain PKS, sorptivity needs to be reassessed due to the high absorption and moisture retention rate of PKS.

Many models have been developed to describe moisture ingress in a porous material[12–22]. These models predict the time-rate of infiltration and the cumulative volume of infiltration based on parameters like the sorptivity S, which quantifies the effect of capillarity on a liquid's movement in a material[23].

The governing partial differential equation for water absorption of a one-dimensional horizontal soil column, and its initial and boundary conditions are given as[12]

$$\frac{\partial \theta}{\partial t} = \nabla.\left(D(\theta)\nabla\theta\right) \quad (1)$$

$$\nabla = \frac{\partial}{\partial x} \quad (2)$$

$\theta(0, X) = \theta_i$
$\theta(t,0) = \theta_s$
$\theta(t,\infty) = \theta_i$

Here,
$D(\theta)$ is the unsaturated hydraulic diffusivity,
θ is the volumetric soil water content,
t is time (min),
x is the horizontal distance (cm),
θ_i is the initial water content, and
θ_s, is the saturated soil water content at the end of the soil column where water enters into the soil column ($cm^3\ cm^{-3}$).

For a rammed earth sample which is a one dimensional, semi-infinite system subject to boundary conditions $\theta=1$ at $x=0$ and an initial condition $\theta = 0$, $x > 0$, $t = 0$ (describing a condition of uniform initial water content within the sample) the equation may then be described by

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(D(\theta)\frac{\partial \theta}{\partial x}\right) 0 < x < \infty \quad (3)$$

Boltzmann transformation

$$\emptyset = x/\sqrt{t} \quad (4)$$

Reduces the equation to

$$-\frac{1}{2}\emptyset\left(\frac{d\theta}{d\emptyset}\right) = \frac{d}{d\theta}\left(D(\theta)\frac{d\theta}{d\emptyset}\right) \quad (5)$$

But because the functional relationship between D and θ is strongly non-linear and is not always feasible to be determined, for the purpose of predicting the water content profile by absorption, it is commonly approximated by the exponential-law

$$D(\theta) = D_o e^{n\theta} \quad (6)$$

Where D_o and n are empirically fitted constants.

But because moisture ingress in rammed earth, due to capillary suction, increases linearly per unit inflow surface area against the square root of elapsed time ($\sqrt{t}$)

Therefore, we can say that the volume of imbibed water i[24]

$$i = St^{0.5} \quad (7)$$

S is measured practically by finding the slope of the line produced when imbibed water i, is plotted against $t^{0.5}$.

2. Experimentation

The process of determining sorptivity was carried out through experimentation and by applying equation (7).

The test performed was the modified Initial Rate of Suction test. This test is an adaptation of the IRS test as described by British Standard 3921. The IRS test consists primarily of gravimetrically determining the quantity of water absorbed by a partially submerged porous building material through capillary action over a specified duration of time. The sample is dried to a constant weight before testing is carried out.

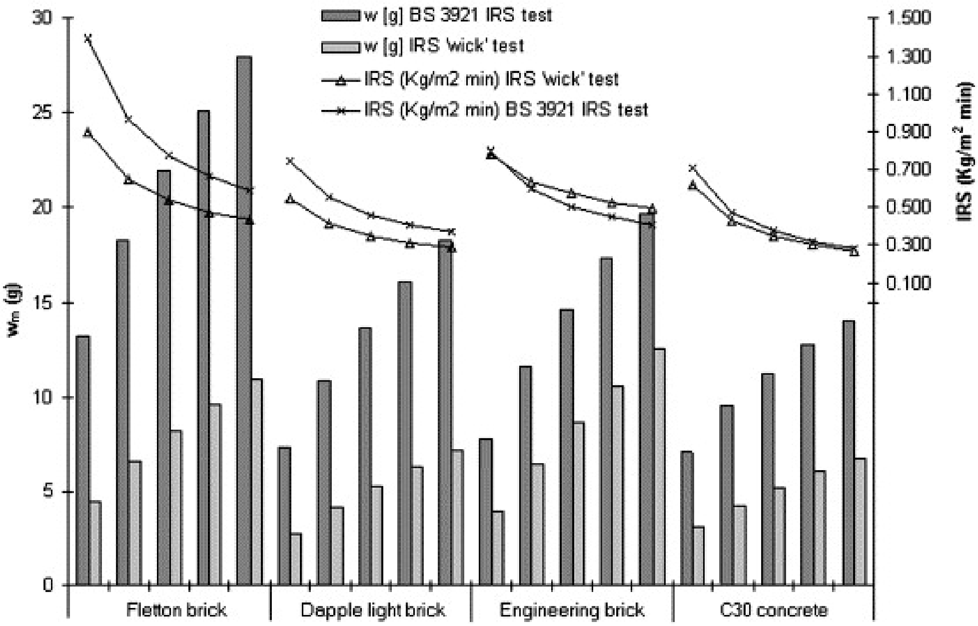

Figure 2. Comparison between BS 3921 IRS test and Modified IRS test results[9].

The modified IRS test was used here to solve the problem that would otherwise have meant that testing rammed earth would be impossible. Rammed earth slakes on contact with water and thus would not have been able to undergo testing using the IRS test. To determine the mass of water absorbed, the mass of the material being tested has to be kept constant. The Modified test was devised and described by hall[9]. It differs from the IRS test by virtue of the fact that the sample sits on a 30mm thick wick which in turn sits in a trough of water. The wick possesses very high hydraulic conductivity which allows maximum transmission of moisture from the wick to the sample. This results in negligible mass loss as the sample being tested does not disintegrate. Hall[9] reports that the sorptivity values obtainable from both the IRS and modified IRS procedures are in close agreement. This is seen in Figure 2.

Synthetically blended soils were used for the purpose of providing uniformity in material properties.The soil that was used in making rammed earth was derived from a blend of three soil fractions. Sand, fines and coarse aggregate was blended in the ratio 5:3:2. The sand fraction consisted of 0.25mm to 2mm diameter particles. It was oven dried to a constant weight at a temperature of 105^{o}C. The clay was obtained in blocks and had to be cut up in small pieces. It was then air dried and then crushed to 'fines' size. This represented the fine fraction which usually consists of clay and silt. The coarse aggregate was gravel. It was pea shaped and passed through the 7mm sieve. It was however retained on the 5mm sieve. 3 cubes measuring 50x50x50mm were made for each specimen. As shown in Table 1, the difference between the specimens was that there was a gradual replacement of gravel with PKS from 0% to 100%. The replacement was by volume.

The samples were made by packing the specimen in a mould and compacting uniformly. The samples were then demoulded the next day and testing was carried out after 90 days.

Testing commenced from the point the bottom part of the specimen made contact with the wick which was immersed in water. During the

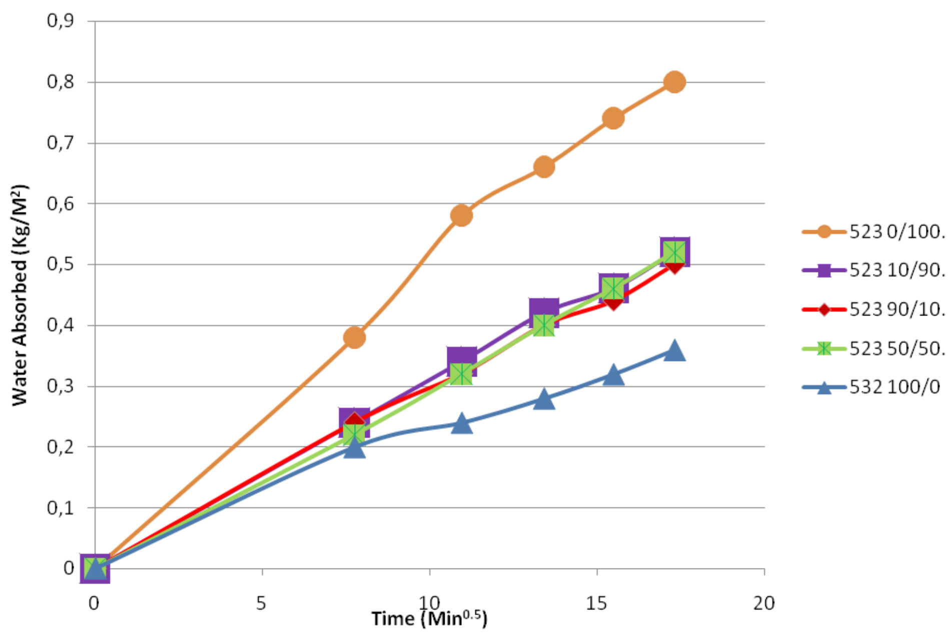

Figure 3. Initial Rate of Suction for Rammed Earth samples.

test, the samples had the testing surface dried and weighed at intervals. The entire process was completed quickly to avoid evaporation taking place at the surfaces.

Figure 3 shows the mass of absorbed water over time. This is governed by Equation (7) which predicts that results obtained should result in a straight line graph. The slope of the figures provide sorptivity values. It can be seen from Figure 3 that more water is absorbed over the same time period when PKS is increased. Lowest trend for mass of water absorbed is observed for sample 532 100/0 which represents zero PKS substitution.

There is a steeper initial absorption rate for specimen containing 10% PKS than for specimen containing 50% PKS. This trend however reverses after the first minute as the absorption rate for specimen containing 10% slows thereafter. The highest absorption rate is observed for specimen containing 100% PKS.

The capillarity coefficient otherwise known as sorptivity is presented in Table 2. It can be observed that sorptivity increases with PKS content. It is worth noting that none of the specimens are stabilised with cement. Cement stabilised specimen result in much greater absorption values.

The specimens show a much smaller sorptivity value than those reported by hall[24]surface receptiveness (o. This could be due to the nature of sand used and the particle size distribution. The replacement of coarse aggregate with PKS by 10% had significant effect in increasing sorptivity. Sorptivity surged by a massive 43%. Further increase to 50% further increased sorptivity by merely 6%. There was no further increase in sorptivity following a further replacement of PKS of 90%. However, when all the coarse aggregate was replaced by PKS, there was massive rise in sorptivity by 133%.

3. Conclusion

The application of IRS wick test on samples that slake easily on contact with water proves to be untenable. The adaptations that the

Sample Name	Gravel Content (%)	PKS Content (%)
532 100/0	100	0
541	90	10
533	50	50
532 1/9	10	90
532	0	100

Table 1. PKS content and sample name.

Sample Name	PKS Content (%)	Sorptivity Values
532 100/0	0	0.0202
541	10	0.0286
533	50	0.03
532 1/9	90	0.03
532	100	0.047

Table 2. Sorptivity values.

modified IRS test, as prescribed by Hall[9] affords ensures that the sorptivity of rammed earth can be determined accurately.

The waste product PKS can be used as replacement for coarse aggregates. This can be either a partial replacement or a complete replacement. Replacements starting from 10% up to 100% would result in increased sorptivity. Sorptivity values can rise by up to 43% for a 10% replacement, right up to 133% for a 100% replacement.

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