Intrinsic Hydrophobicity of Rammed Earth

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Intrinsic Hydrophobicity of Rammed Earth

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Abstract. Rammed earth is well known for its vapour diffusion properties, its ability to regulate humidity within the built environment. Rammed earth is also an aesthetically iconic material such as marble or granite and therefore is preferably left exposed. However exposed rammed earth is often coated with silane/siloxane water repellents or the structure is modified architecturally (large roof overhangs) to accommodate for the hydrophilic nature of the material. This paper sets out to find out optimal hydrophobicity for rammed earth based on natural composite fibres and surface coating without adversely affecting the vapour diffusivity of the material. The material is not required to be waterproof, but should resist at least driving rain. In order to evaluate different approaches to increase hydrophobicity of rammed earth surface, peat fibres and four types of repellents were used.

1. Introduction

Rammed earth, also known as taipa [1] (Portuguese), tapial (Spanish), and pisé (de terre) (French), is a technique for building walls using natural raw materials such as earth, chalk, lime or gravel.

It is an old building method that is coming to the fore in the recent years as people seek more sustainable natural building materials and economic building methods.

Rammed earth walls are simple to construct, non combustible, strong, durable and exhibit good thermal properties.

By 2000 BCE, rammed earth building techniques were commonly used for walls and foundations in China [2] (some can be observed even now, figure 1), but the evidence of early using can be seen on Neolithic archaeological sites dating back to 5000 BCE. Rammed earth buildings are found all over

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the world, in a range of environments that include temperate and wet regions of northern Europe [3], semiarid deserts, mountain areas and the tropics. The availability of useful soil and a building design appropriate for local climatic conditions are the factors that favour its use.

Rammed earth constructions also exhibit negative properties resulting from the material used. Rammed earth is well known for its vapour diffusion properties, its ability to regulate humidity, which is a positive factor for the internal building environment, but only to a certain extent. Due to the permeable and hydrophilic nature of rammed earth building materials, water can easily penetrate through the construction. For this reason water penetration becomes an important factor which affects the durability of rammed earth based construction. Modern approach focused to improve the durability of rammed earth structures includes usage of small amount of cement as a stabiliser. Taking into consideration the fact that cement is also a hydrophilic material, it cannot solve the problems associated with water penetration that damages thermal insulation properties of rammed earth buildings.

Figure 1. The ruins of a Han Dynasty (202 BCE – 220 CE) Chinese watchtower made of rammed earth at Dunhuang, Gansu province.

At present, there exist two approaches that can improve the durability against natural weathering. In the first stage of building the rammed earth construction it is possible to use *internal admixtures*, mainly silicon water-repellent admixtures that effectively minimise water movement within the capillaries. Another benefit is that vapour permeability and surface appearance of the construction are not affected.

In the case when the construction is built, a post-*surface treatment* can be applied. Silicone water-repellents are useful sealers for rammed earth constructions. This approach is based on the penetration of the sealer into the capillary system and reaction with the substrate via strong siloxane bonding providing a long-term protection against natural weathering [4]. Silicone is a highly reactive material which forms a polysiloxane molecular lining within the capillary walls of the masonry substrate. Commonly used silicone sealers include siliconate, alkyalkoxysilane and siloxane (see figure 2) [4].

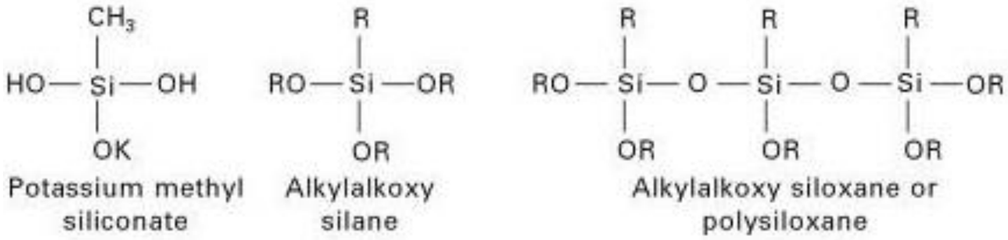

Figure 2. Silicone water-repellent sealers for masonry substrate.

The presented article is focused on the second approach mentioned. Four types of repellent were used to study the hydrophobic/hydrophilic properties of rammed earth. One sample with hydrophobic peat fibres (as internal admixture) was also tested. Samples were studied by goniometric surface hydrophobicity measurements of water drop on the rammed earth surface.

1.1. Theoretical background

Regarding the decision on surface hydrophobicity measurements used in this article, brief foundations have to be presented. There are three types of forces acting upon a liquid drop on a surface (see figure 3).

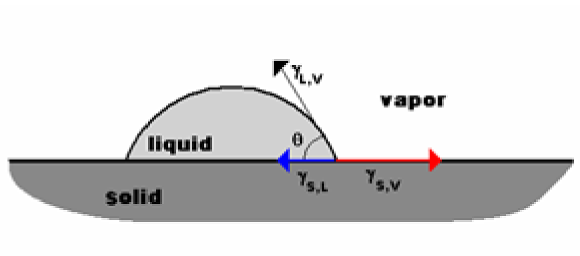

Figure 3. Forces acting on a liquid droplet on a solid.

Following simple goniometric rules, Young [5] derived that the contact angle θ_Y is given by relation (1):

$$\cos \Theta_Y = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}} \quad (1)$$

where γ_{IJ} denotes surface tension (energy per unit surface) of the interface IJ and where *S*, *L* and *V* designate solid, liquid and vapor phases.

Different approaches can be used for measuring contact angles of non-porous solids, a goniometric approach and a tensiometric approach, with both having their advantages and their drawbacks. Another approach is used when measuring the angles of porous substrates, involving the use of a tensiometer and the Washburn method [6].

The results presented in this contribution are achieved by applying a goniometric method, which is based on the analysis of the shape of the liquid drop. The contact angle can be found directly by measuring the angle formed between the solid and the tangent of the drop of an image made of the drop.

The large advantage of goniometry comes from its relative simplicity. It can be used for almost any solid, as long as it has a relatively flat portion or a regular curvature and can be fitted on the stage of the instrument. The main disadvantage of this approach is the subjectivity of the researcher in assigning the tangent line. This problem was eliminated by computer analysis of the droplet shape, which will be described later.

2. Materials and methods

2.1. Samples preparation

For the application of surface treatment, a reference samples consisting of components listed in table 1 were prepared.

Table 1. Percentage composition of basic components of rammed earth samples.

Component	Content (%)
Dredged sand (fraction 0/2 mm)	50
Lime gravel (fraction 0/4 mm)	20
Clay	15
Silt	15

Variable speed mixer was used to ensure homogeneity and mixing of the above listed components with water and Portland cement (type III, 32.5 R) in the ratio 82:10:8.

The mixture was placed in a steel cylinder of 101.3 mm diameter and height of 80 mm and subsequently compressed with powered tamper. Once removed from the molds, samples were dried at laboratory temperature for two weeks before application of the surface treatment.

Another type of sample (P1) was also prepared adding of 5% hydrophobic peat fibers to the mixture and processed under the same conditions.

After hardening of the rammed earth material, the surface of the samples was treated with different types of sealers and dried once again to ensure the homogeneity of the surface. For better clarity the samples are marked according to different types of sealers (see table 2).

Table 2. Different types of repellent sealers used in surface treatment.

Label	Repellent type
Ref.	Reference sample without repellent
S703	Sikagard – 703 W (silane/siloxane based repellent)
G1	Geolak – transparent varnish (mixed with water in ratio 2:1)
G2	Geolak – transparent varnish (not mixed with water)
A1	Aqua lackspray
S1	GrandX Silicon oil spray

2.2. Measurements set-up and method

Measuring contact angles with a high level of precision usually requires high-tech contact angle goniometers that can perform a great number of automated measurements (N=50-100) per drop, thus reducing the error on each returned average value [7].

In this article, simplified experimental apparatus according to [8] was used. The simple experimental apparatus provides a convenient alternative to commercial goniometers because the method allows measurements with sufficient precision to be obtained while being accessible in terms of cost and ease of construction. A schematic view of the set-up is given in figure 4.

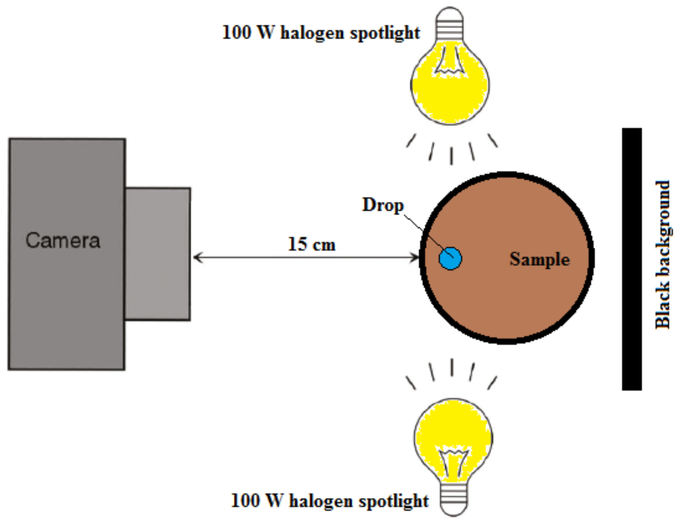

Figure 4. Sketch of experimental set-up used to measure contact angles.

The optical part includes 21.1 megapixels full-frame CMOS digital camera (Canon EOS 5D Mark II) with EF 24 – 105 mm f/4.0L IS USM wide-to-telephoto zoom lens. A highly absorptive background located behind the sample and a couple of halogen spotlights (100 W) positioned on the sides of the sample were used to make the drop shape sharp, which is necessary for measurement precision as well as for image processing.

Every measurement was performed duplicate applying 50 μL deionized water by laboratory pipette on the sample surface to create an equal droplet. After applying of the water and stabilization of the drop (10s), the picture was made. The pictures were processed and exported twice (original and optically zoomed, see figures 5 and 6).

The profiles of the drops were automatically fitted using ImageJ software using the contact angle plug-in.

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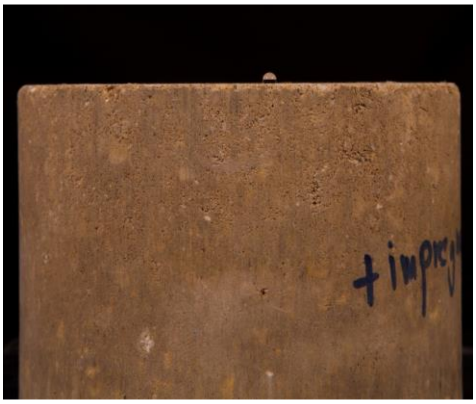

Figure 5. Original picture of the drop on the silane/siloxane treated rammed earth surface.

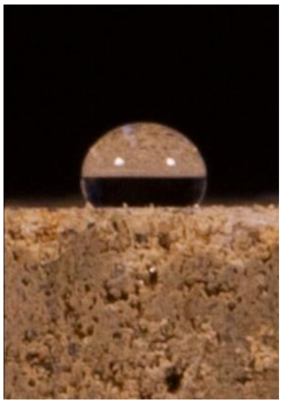

Figure 6. Optically zoomed drop on the silane/siloxane treated surface.

3. Results

On a hydrophobic surface, water forms distinct droplets. As the hydrophobicity increases, the contact angle of the droplets with the surface increases. Surfaces with contact angles greater than 90° are designated as hydrophobic. The theoretical maximum contact angle for water on a smooth surface is 120° – 130°. Micro-textured or micro-patterned surfaces with hydrophobic asperities can exhibit apparent contact angle exceeding 150° and are associated with super hydrophobicity and the "lotus effect".

The fitted contact angles using ImageJ software are presented in table 3 and also depicted in figures 7 – 12. From the results it is evident that the reference sample represents ordinary surface with "typical wetting". During the measurement procedure (wetting the surface), different shapes of drop on different parts of the sample were observed. This fact was caused by heterogeneity of the surface (different smoothness, presence of the cracks). It can be said that the working procedure has an impact on the hydrophilicity/hydrophobicity of the sample. This negative factor should be eliminated by the treatment of the surface, where whole surface is impregnated by equal layer of the repellent. The same contact angle was also calculated for G2 sample and thus was proved that it is necessary to mix the Geolak with the water. After the recommended mixing of Geolak with water and surface treatment, sample (G1) exhibited hydrophobic properties (see figure 10). Similar properties were achieved applying Aqua lackspray (contact angle of 93°).

Table 3. Calculated contact angles.

Label	Calculated contact angle and deviation (°)	
Ref.	61.3°	(+/- 2.5°)
S703	123.8°	(+/- 1.0°)
G1	93.2°	(+/- 1.5°)
G2	61.8°	(+/- 1.7°)
A1	91.7°	(+/- 0.9°)
S1	132.5°	(+/- 0.5°)
P1	0°	-

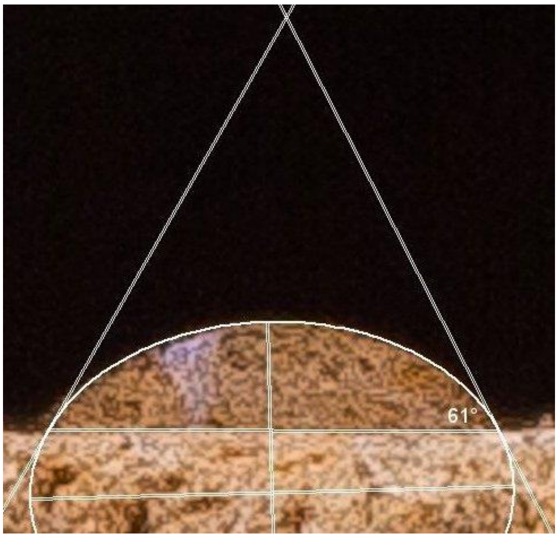

Figure 7. The shape of the drop and calculated contact angle (Ref. sample).

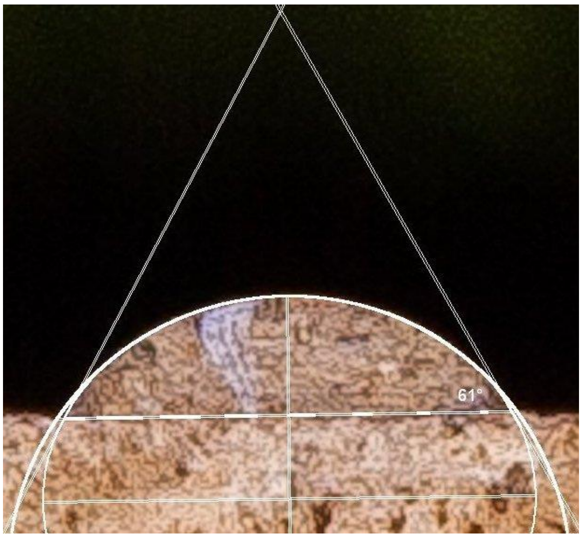

Figure 8. The shape of the drop and calculated contact angle (G2 sample).

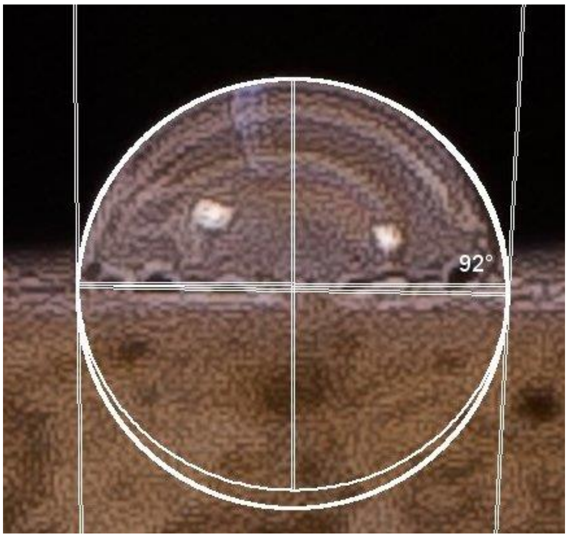

Figure 9. The shape of the drop and calculated contact angle (A1 sample).

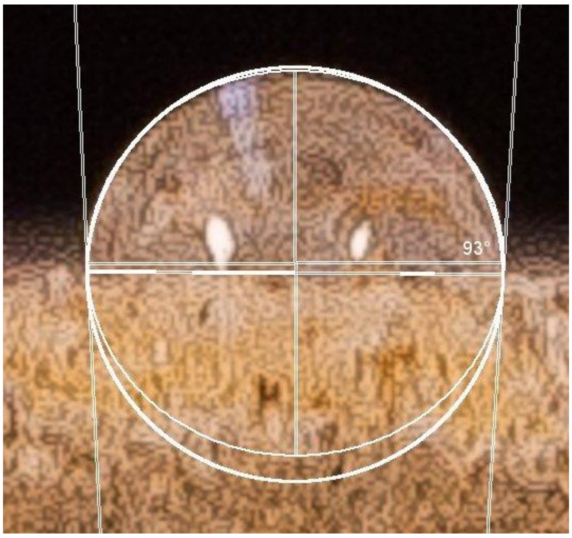

Figure 10. The shape of the drop and calculated contact angle (G1 sample).

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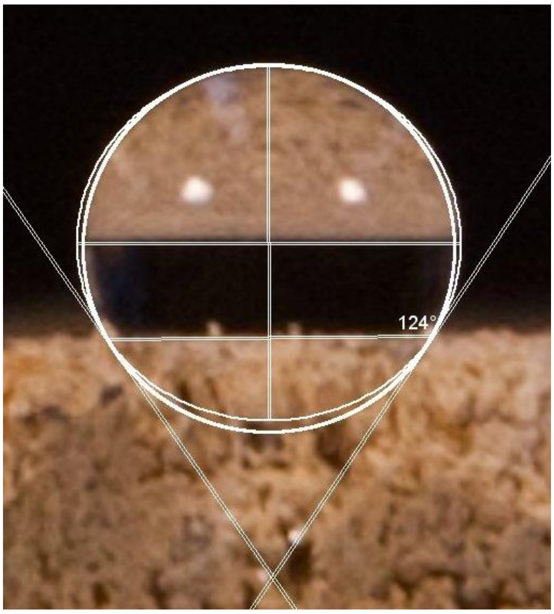

Figure 11. The shape of the drop and calculated contact angle (S703 sample).

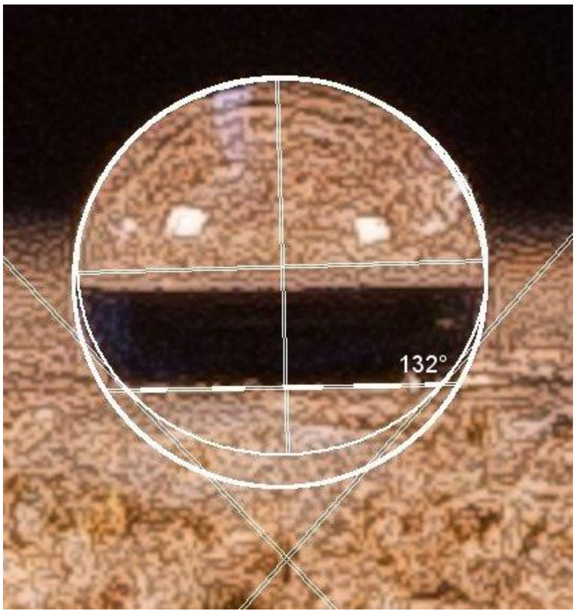

Figure 12. The shape of the drop and calculated contact angle (S1 sample).

Higher contact angles (up to 130°) were achieved by commercial silane/siloxane and silicone repellents (figures 11 and 12) designed for building construction materials. The cost of these repellents is a negative aspect of this approach. Usage of hydrophobic peat fibres proved to be an inappropriate way to increase the hydrophobicity of rammed earth, it was not possible to measure the contact angles due to high hydrophilic nature of the sample.

4. Conclusions

We used a simple, efficient, and inexpensive method for contact angle measurements of the rammed earth samples that proved to be adequate. The experimental results, summarized in table 3, were obtained with ImageJ software (with contact angle plug-in), which returned precise and stable values of the contact angles.

From the results it is evident that pure rammed earth represents ordinary surface with “typical wetting”, which can be improved by different types of repellents. Application of commercial silane/siloxane and silicone repellents can sufficiently protect the rammed earth constructions for a long period. In this case, we can observe 100 % increases in contact angle values, from 61.3° of original sample to 123.8° and 132.5° after silicone and silane/siloxane treatment, respectively. Treatment by Geolak (G1 sample) was also successful and surface exhibited hydrophobic properties (contact angle of 92°). Similar properties were achieved applying Aqua lackspray (contact angle of 93°). Hydrophobic peat fibres proved to be an inappropriate internal admixture to increase the hydrophobicity of rammed earth.

5. References

[1] Fleming J, Honour H and Pevsner N 1991 *The Penguin Dictionary of Architecture* (London: England Penguin Books)
[2] Fu X, Guo D, Liu X, Pan G, Qiau Y and Sun D 2002 *Chinese Architecture* (ed. Steinhardt, Nancy Shatzman) The Culture and Civilization of China (New Haven: Yale University Press)
[3] Keable R 2012 *Rammed Earth Lecture Theatre, CAT* (London: Rammed Earth Consulting)
[4] Hall M R, Lindsay R and Krayenhoff M 2012 *Modern Earth Buildings: Materials, Engineering, Construction and Applications* (Cambridge: Woodhead Publishing Limited)
[5] Young T 1805 An Essay on the Cohesion of Fluids *Philosophical Transactions of the Royal Society of London* **95** 65 – 67
[6] Lai S C S 2003 *Mimicking Nature: Physical Basis and Aartificial Synthesis of the Lotus – Effect* (Leiden: Universiteit Leiden)
[7] Barankin M D, Gonzalez E, Habib S B, Gao L, Guschl P C and Hicks R F 2009 *Langmuir* **25** 2495 – 2500
[8] Buvailo A, Xing Y, Keuleyan S, Prakash V, Eftekhari – Bafrooei A and Borguet E 2012 Contact Angle Measurements Using a Simplified Experimental Setup *J. of Chem. Educ.* **87** 1403 – 07

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