DETERMINATION OF WATER ABSORPTION COEFFICIENT OF UNFIRED EARTH MATERIALS DIFFERENT IN USED CLAY AND RATIO OF COMPONENTS

Barbora Mužíková*, Tereza Plaček Otcovská, Pavel Padevět

Czech Technical University in Prague, Faculty of Civil Engineering, Thakurova 7, 166 29 Prague 6, Czech Republic

* corresponding author: `barbora.muzikova@fsv.cvut.cz`

Abstract. The paper is focused on unfired rammed earth and its water absorption properties. Increasing the utilization of raw natural materials can be one of the approaches towards sustainable development. Different prescriptions were designed and specimens were rammed. Then they were put in the covering of nylon and settled in the box with soft foam that was moistened. The level of moistening was constant. The specimens were regularly weighted. Specimens with montmorillonite clay have the highest values of the water absorption coefficient. Montmorillonite clay has a higher binding capacity. The values are compared to values that were found in the literature. Then the maximal capillary water capacity by area was determined.

Keywords: Rammed earth, unfired earth, water absorption coefficient, clay.

1. Introduction

Nowadays the price of building material is steeply rising and it begins to be lack of it. Stone quarries have stocks for the next seven years in the Czech republic and no new ones are opening. One way out of this problem is recycling and the second one is using natural local materials. This leads us to unfired earth that is local material, minimizing the cost for transportation. Increasing the utilization of raw natural materials can be one of the approaches towards sustainable development. Natural materials have a high potential of environmental quality for example in criteria: embodied CO_2 and SO_2 emissions, embodied energy, using renewable sources or easy recycling [1–3].

Of course, using this material is not without any problems. Since building with them was minimal in the last years, there are no sufficient data about its mechanical and physical data. These data are necessary for designing and building.
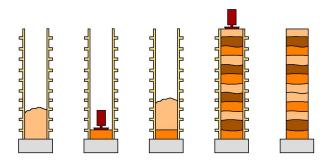

Figure 1. Process of making rammed earth specimen.

One of the problems for the unfired earth is water. The water inside or outside the earthen construction usually leads to problems. Any time earth is to deal
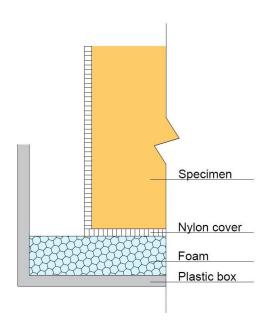

Figure 2. Schema of the water absorption test.

with water needs to be controlled thoroughly: water content in mixture, vapor condensation in construction, or effects of weather. These are widely recognized issues of civil engineering. Another big issue that is drawing unfired earth back from wide use is a strongly varying composition of raw material. The aim of this paper is to settle the water absorption coefficient for different clay mixtures and describe the influence of used clay and composition of the mixture on its water absorption characteristics [4–8].
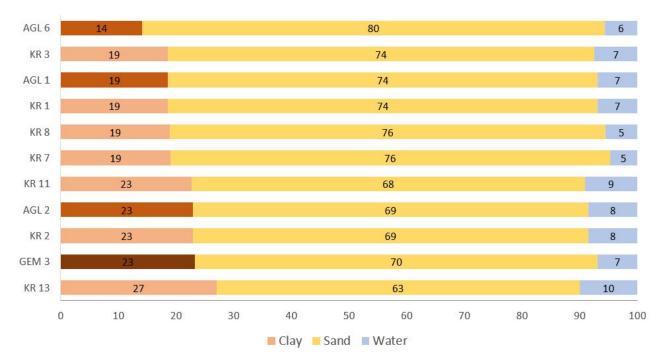
FIGURE 3. Prescription of used specimens – graph shows percent procuration of clay, sand and water in the mixture.

Mixture	sand/clay – w/c [%/%] – [-]	bulk density [kg/m³]
AGL 6	85/15 – 0.400	2063
KR 3	80/20 – 0.400	2180
AGL 1	80/20 – 0.370	2191
KR 1	80/20 – 0.370	2212
KR 8	80/20 – 0.290	2127
KR 7	80/20 – 0.250	2093
KR 11	75/25 – 0.400	2102
AGL 2	75/25 – 0.370	2159
KR 2	75/25 – 0.370	2138
GEM 3	75/25 – 0.295	1905
KR 13	70/30 – 0.370	2064

TABLE 1. Composition of mixtures and bulk density of specimens.

2. WATER IN UNFIRED EARTH

Water is very important for rammed earth it activates the binding properties of clay and thanks to it the material holds together. On the other hand, water is very dangerous to unfired earth. If loam becomes wet, it swells and changes from a solid to a plastic state [3]. Mechanical properties are firmly affected by the moisture of the material. The unfired rammed earth is very sensitive to moisture and its structures can even collapse if the volume of water is high and affect the construction for a longer time period.
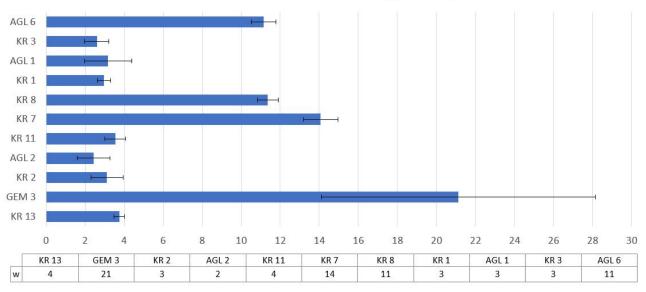
3. PREPARATION OF SPECIMENS

The earth material is very sensitive to moisture and water that is why it is an important characteristic that needs to be examined. The structure of the earth is widely un-homogeneous, porous, and open. It is capable to absorb water and transport it in the material itself.

Rammed earth is a mixture of sand, clay, and water. Clay works as a binder and water activate the binding forces of the clay. Sand is a filler. The mechanical properties are depending on the composition of these components and their ratio and type of used clay. There are three basic kinds of clay – illite, kaolinite, and montmorillonite. Eleven prescriptions were designed and made, they differ in the ratio of components and type of clay.

Prescriptions are shown in Tab. 1. The prescriptions are arrayed by a rising amount of clay. The prescriptions are described as a ratio of sand and clay and the water ratio in the table t. Water ratio is a relation between binder and water, in this case between clay and water. Bulk densities for each prescription are shown in the table.

The prescription are also shown in the Fig. 3. The compounds are expressed by the percent. Sand, clay, and water give together 100 %. In the Tab. 1 just sand and clay give 100 % (and water is expressed by the water-clay ratio). For prescription AGL the illite clay was used, for GEM the montmorillonite clay and for KR mix of illite-kaolinite clay. The reciprocal ratio between the components is in percent. The orange color represents the clay, the yellow color represents sand and the blue color represents water. The first prescription AGL 6 had the least amount of clay (14 %), the second group are specimens with clay containing around 19 % (KR 3, AGL 1, KR 1, KR 8, KR 7). The third group is specimens with clay containing around 23 % (KR 11, AGL 2, KR 2,

Water Absorption Coefficient w [kg/m².hod^{0,5}]

	KR 13	GEM 3	KR 2	AGL 2	KR 11	KR 7	KR 8	KR 1	AGL 1	KR 3	AGL 6
w	4	21	3	2	4	14	11	3	3	3	11

FIGURE 4. Water Absorption Coefficient.

FIGURE 5. Water Absorption Coefficient for earth mixture in literature [3].

FIGURE 6. Specimens in nylon cover during testing.

4. METHOD OF DETERMINING WATER ABSORPTION COEFFICIENT

Specimens of measurement $40{\times}40{\times}160$ mm were used for the test of water absorption. The absorbing area of specimens is $40{\times}40$ mm. Specimens were covered in nylon to protect them from eroding. Specimens were measured and weighted. A box with foam was filled with water until the foam was fully waterlogged.

Specimens were weighted up every hour, data were recorded and the condition of the specimen is judged. It means that a breakup of the specimen or magnitude of soaked up is observed.

Loam is a material with an open porous structure and it can transport water in capillaries. The water moves from the area with higher humidity to the area with lower humidity. Capillarity means the capacity of water that can move such as was described. The

GEM 3) and the prescription KR 13 with the highest amount of clay 27 %.

The production of specimens was as follows. Firstly, the sand was mixed with two-thirds of water and mixed up. Then the clay and the rest of the water were added. It was stomped by a drilling machine with a special ending. Specimens of size $40{\times}40{\times}160$ mm were prefabricated for the testing in the laboratory. The production was made by ramming into steel molds (shown Fig. 1) by hand and by the drilling machine. The molds were wiped by oil and the earth was rammed in four to five layers. The last one was always made by hand. Comprehensive strength and tensile strength in bending can be found in [9–11].
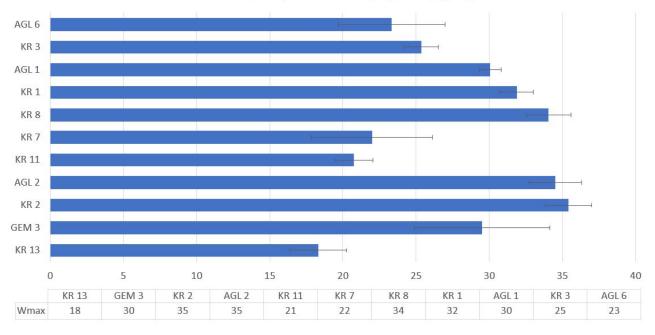
Maximal Capillary Water Capacity by Area [kg/m²]

	KR 13	GEM 3	KR 2	AGL 2	KR 11	KR 7	KR 8	KR 1	AGL 1	KR 3	AGL 6
Wmax	18	30	35	35	21	22	34	32	30	25	23

FIGURE 7. Maximal Capillary Water Capacity by Area.

FIGURE 8. Specimens after testing.

process is called capillary action. The coefficient w is calculated by the formula:

$$w = \frac{W}{\sqrt{t}} \quad \left[\frac{kg}{m^2 \cdot hod^{0.5}}\right], \tag{1}$$

where W is the increase in weight per unit surface area and t is the time of measurement. W is calculated:

$$W = \frac{m - m_d}{A} \quad \left[\frac{kg}{m^2}\right], \tag{2}$$

where m is the weight in the moment of measuring and m_d is the weight at the beginning of the test, the weight of the dry sample. The parameter W is also called the water movement and it represents the
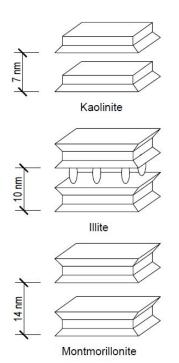

FIGURE 9. Type of clay – kaolinite, illite and montmorillonite.

quantity of water that can be absorbed by a time period [3].

Evaluated data of water absorption coefficient are shown in the Fig. 4. The averaged value and its standard deviation are shown.

5. Method of Determination Maximal Capillary Water Capacity Area

The specimens were settled in the water bath as was described above. They were in the water until they broke up. The maximal weight was recorded and then the maximal capillary water capacity was determined by the formula:

$$W_{\max} = \frac{m_{\max} - m_d}{A} \quad \left[\frac{kg}{m^2}\right], \qquad (3)$$

where $m_{\max}$ is the maximal weight until the specimen was broken. The maximal weights are not measured at the same time, the time differed for prescriptions.

6. Evaluation of the Results

6.1. Water Absorption Coefficient

Calculated values of water absorption coefficients are shown in the Fig. 4. The prescriptions are arrayed by a rising amount of clay. Water absorption coefficient w says how quickly can the material absorb the water. The evaluation is after one hour of testing and the absorbing area of specimens was $40{\times}40$ mm.

The highest value has the prescription GEM 3 with montmorillonite clay. This type of clay has the highest absorption capabilities. The value is 21 ± 7 kg/m^{2}hod$^{0.5}$. Similar value have solid brick 25.5 kg/m^{2}hod$^{0.5}$ according to [3]. The minimum value had prescriptions with a mixture of illite-kaolinite and illite clay.

Prescription AGL 6, KR 8 and KR 7 have higher values than others, they have less water just 5 % and 6 %. Other prescriptions had similar value around 3 kg/m^{2}hod$^{0.5}$. The value responds to the values that were found by G. Minke in [3] for his earth mixture. There were also values around 3 kg/m^{2}hod$^{0.5}$. These values were for different types of loams. These values are shown the Fig. 5 with bulk densities of specimens. They can be compared with measured values in the Tab. 4.

The main influence has the type of used clay, the amount is not so important as the type. Clay minerals are three basic ones – kaolinite, illite and montmorillonite. They differ in structure. Clays have hexagonal lamellar crystalline structures. These lamellas consist of different layers that are usually formed around silicon or aluminum cores [3]. This is shown in the Fig. 9. The difference between clays can be seen in this picture. Kaolinite is a two-layered mineral and has a lower ion-binding capacity. On the other hand, montmorillonite is a three-layered mineral and has a higher ion binding capacity [4].

6.2. Maximal Capillary Water Capacity by Area

Calculated values of maximal capillary water capacities by area are shown in the Fig. 7. The prescriptions are arrayed by a rising amount of clay again.

The maximal capillary water capacity by area is determined from the maximal weight at the end of testing before the specimens collapsed. The time is not the same at all prescriptions, some of them collapsed sooner than others.

The results were divided in three groups - the first one with values around 30–35 kg/m^2 (AGL 1, KR 1, KR 8, AGL 2, KR 2, GEM 3). The second group are prescriptions with value 20–25 kg/m^2 (AGL 6, KR 3, KR 7 and KR 11) and the minimal value had KR 13 108 kg/m^2.

GEM 3 with montmorillonite clay was specifed. The volume of the specimen extended a lot in the wet bottom and then it brooked. No other mixture had expansion like the mixture with montmorillonite clay.

7. Conclusions

The price of building material is steeply rising and it begins to be lack of it. One way out of this problem is recycling and the second one is using natural local materials. This leads us to unfired earth that is local material, minimizing the cost for transportation. Increasing the utilization of raw natural materials can be one of the approaches towards sustainable development.

The earth material is very sensitive to moisture and water that is why it is an important characteristic that needs to be examined. The structure of the earth is widely un-homogeneous, porous, and open. It is capable to absorb water and transport it in the material itself. It is important to search the properties connected with water.

Different prescriptions were designed and specimens were rammed. Then they were put in the covering of nylon and settled in the box with soft foam that was moistened. The level of moistening was constant. The specimens were regularly weighted. The highest values of water absorption coefficient have the specimens with montmorillonite clay that has the higher binding capacity. The values are compared to values found in the literature. Then the maximal capillary water capacity by are was determined.

The results of maximal capillary water capacity by area were divided into three groups - the first one with values around 30–35 kg/m^2 (AGL 1, KR 1, KR 8, AGL 2, KR 2, GEM 3). Second group are prescriptions with value 20–25 kg/m^2 (AGL 6, KR 3, KR 7 and KR 11) and the minimal value had KR 13 18 kg/m^2.

List of symbols

A Area [m^2]

m Weight of specimen in the moment of measuring [kg]

m_d Weight of specimen in the begging of the test (dry sample) [kg]

$m_{\max}$ Maximal weight of specimen [kg]

t Time of testing [hod]

w Water absorption coefficient [kg/m^{2}hod$^{0.5}$]

W Capillary water capacity $[\text{kg/m}^2]$

$W_{\max}$ Maximal capillary water capacity $[\text{kg/m}^2]$

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