EAN 2018
56th conference on experimental stress analysis

Drying Rate of Rammed Earth with Illite-kaolinitic Clay

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Keywords: Rammed earth, clay, water coefficient, draying speed, form coefficient

Abstract. This submission concerns with unfired clay as a construction material. Its main goal is to determine rammed earth drying speed. The speed of drying is crucial because it is only process with which unfired clay obtains its strength. A main part of the submission is dedicated to description of carried out experiments and their evaluation. There were two earth mixtures tested with four testing body sizes manufactured by technology of ramming.

Introduction

Scientific research of unfired earth mechanical properties was not accomplished sufficiently because the unfired earth had become minority building material in 2nd half of 20th century. But history of unfired earth is rich and long. Probably the most famous unfired clay building is The Great Wall of China [1–5].

Nowadays, there is a growing interest in unfired earth for its properties that fit into principles of a sustainable building, positive effects on human health, good adaptability of relative humidity in interior and attractive visual aspect [1, 6, 8].

The growing interest is evident from a number of scientific papers or quantity of sales of unfired bricks by HELUZ cihlářský průmysl v.o.s [9].

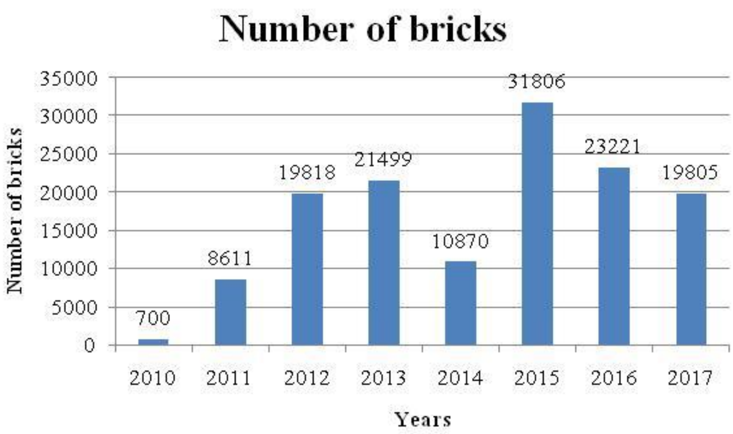

Fig. 1 Sales of unfired bricks by HELUZ cihlářský průmysl v.o.s

There is a few types of unfired earth. One of the primary types of unfired earth is rammed earth which is a topic of this paper. A final appearance of rammed earth is similar like monolithic concrete. A principle of rammed earth production is press down of earth mixture layers to formwork (see Fig. 2).

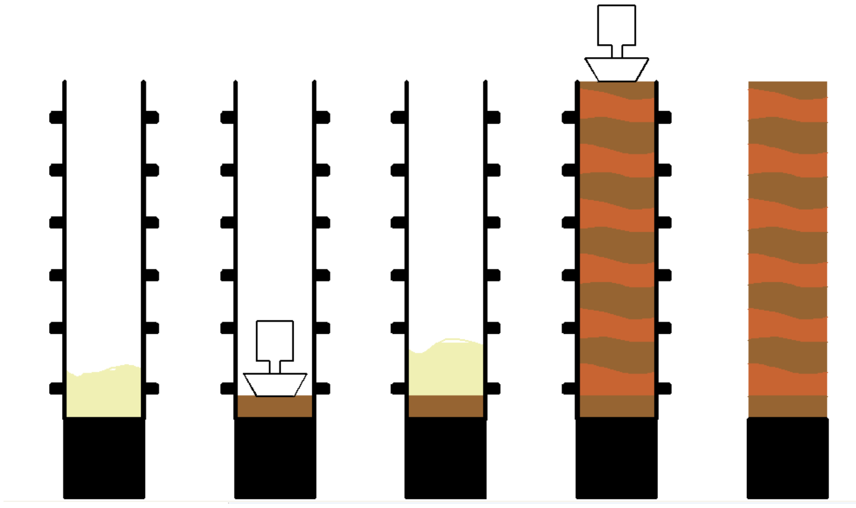

Fig. 2 Production of rammed earth

The essential topic about unfired earth is its moisture characteristics and its water resistance. There are a few parts of research about unfired earth moisture characteristics. Absorption of water, capillary storage capacity, resistance of unfired earth in standing water, weather resistance and drying rate are some of the fields of the research [1, 6].

In general, increasing moisture content in unfired earth construction could have an adverse effect on its mechanical properties.This low water resistance is the most common argument why the unfired earth is not suitable material for building construction. And that's why inorganic binders like cement or lime are added to the clay mixture often [1, 6, 7,10].

However, there are reasons why it is a good way to use of earth mixture without inorganic binder. Firstly, rammed earth with inorganic binder loses some of its good properties. Secondly, there are researches that indicate that the rammed earth can have satisfactory water resistance. And thirdly, there are a lot of unfired clay historic buildings which are in good condition by centuries. That is why we decided to investigate the rammed earth without the addition of inorganic binder [1, 5, 11].

This article is focused on drying speed of rammed earth without addition of inorganic binder. The drying speed is important because drying is the only process with witch unfired clay receives its strength. The rammed earth is usually load bearing construction. It is thus necessary to know drying speed to be able to estimate the time that must pass from a manufacture to a full construction load [1, 6].

Earth appropriate for building constructions consists from three elementary components: sand, clay and water. The clay fulfils a function of binder, the sand a function of filling agent and the water serves for activation of bonding properties of the clay and for good earth mixture processing [1, 2, 12].

However, the earth in nature is usually composed of several kinds of clay and contains another components like stones, gravel, etc. The natural earth composition varies and its composition is unique for each locality. The properties of unfired earth are dependent on composition of the earth mixture. These two fact are the reason why it is very difficult to describe the properties of the final unfired earth construction [1, 2, 12].

Knowledge of mechanical properties of rammed earth dependence on earth mixture composition is necessary for creation of such methodology. That is why we have decided to produce our own clay mixtures from the basic components.

Manufacturing Method

The earth mixtures for testing bodies manufacture were proposed and produced in our laboratory. The earth mixture was prepared from sand, illite-kaolinite clay and mixture water.A grain curve of the used sand can be seen in the Figure 3. The clay was used in powdery form (see Fig. 4). The amount of mixture water was determined by water coefficient. The water coefficient is defined by Equation 1.

$$W = m_w/m_c \quad (1)$$

W - water coefficient [-]
m_w - weight of water [g]
m_w - weight of clay [g]

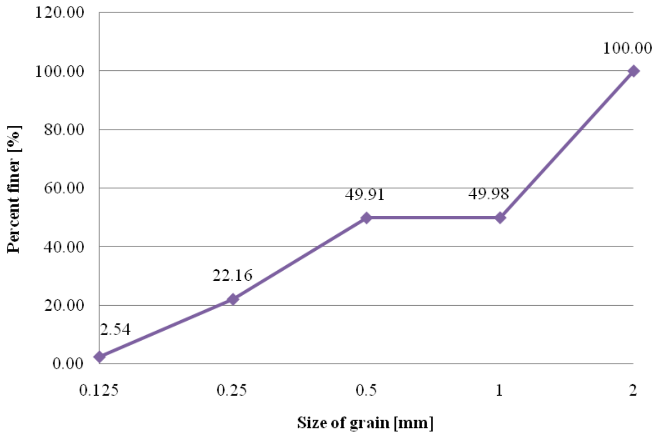

Fig. 3 Grain curve of used sand

Fig. 4Illite-kaolinite clay

There were produced two sets of clay mixtures (sets KRVII and KRIX).The sand to clay ratio was 80/20 for both of the sets and water to clay coefficient (water coefficient) was 0.25 (set KRVII) and 0.45 (set KRIX). The components were mixed and mechanically and manually kneaded until homogenous clay mixture was obtained.

Fig. 5 Ramming of the earth mixture to the steel moulds

The clay mixture was rammed to steel moulds and the testing bodies were created (see Fig. 5). It was manufactured for both of the sets 4 test bodies of size 4/4/16 cm, 4 testing bodies of size 2/2/10 cm, 4 testing bodies of size 2/2/5 cm and 4 testing bodies of size 4/4/8 cm. Ready-made testing bodies were right after unmolding inserted into air-conditioned chamber.

The environment properties in air-conditioned chamber were set to 20 °C and 50 % relative air humidity. The composition of the earth mixtures and number of the test bodies can be seen in the Table 1.

Tab.1 Composition and number of the test bodies

Set	Sand/clay ratio [-]	Water coefficient [-]	Number of the test bodies			
			2×2×10 cm	2×2×5 cm	4×4×16 cm	4×4×8 cm
KRVII	80/20	0.25		4		4
KRIX	80/20	0.45		4		4

Principle of measurement

The test bodies were inserted into air-conditioned chamber and were regularly weighed.The decrease of test bodies mass due to water drying in air-conditioned chamber was measured. Moisture content was calculated from value of measured weight (see Equation 2).

$$w = m_{wet} - m_{dry}/m_{dry} \, . \, 100 \ \% \qquad (2)$$

w - moisture content [%]
m_{wet} - weight of wet material [g]
m_{dry} - weight of dry material [g]

A form coefficient was determined from shape and size of tested bodies. The form coefficient was defined like volume to surface ratio (see Equation 3). There is a hypothesis that the smaller value of the form coefficient means quicker decrease of the moisture content. The question is what dependence between shape and drying rate is.

$$F_{coeff} = V/S \qquad (3)$$

F_{coeff} - form coefficient [m^3/m^2]
V - volume [m^3]
S - surface [m^2]

Results

The moisture contents of the sets KRVII and KRIX in time are showed in the Table 2 and 3. The experiments show drying speed dependence on the form coefficient (see Fig. 6, 7).

Tab.2 Moisturecontentofset KRIX over time

Size [cm]	**Form coefficient [-]**	**Moisture content over time [%]**						
		0 h	**0.5 h**	**3.25 h**	**4.25 h**	**5.5 h**	**22.25 h**	**47.25 h**
4x4x16	0.89	9	8.2	6.6	5.9	5.1	1.4	0.9
2x2x10	0.45	9	7.6	5	3.9	2.9	1.3	1.2
4x4x8	0.80	9	7.4	4.5	3.6	2.8	1.1	0.8
2x2x5	0.42	9	6.5	1.8	1.2	1	0.2	0.2

Tab.3 Moisturecontentofset KRVIIover time

Size [cm]	**Form coefficient [-]**	**Moisture content over time [%]**					
		0 h	**0.75 h**	**2 h**	**3 h**	**5 h**	**23 h**
4x4x16	0.89	5	4.3	3.4	2.7	1.9	0.6
2x2x10	0.45	5	2.8	0.9	0.8	0.1	-
4x4x8	0.80	5	4	3.4	3.1	2.6	1.6
2x2x5	0.42	5	2.4	1	0.3	-	-

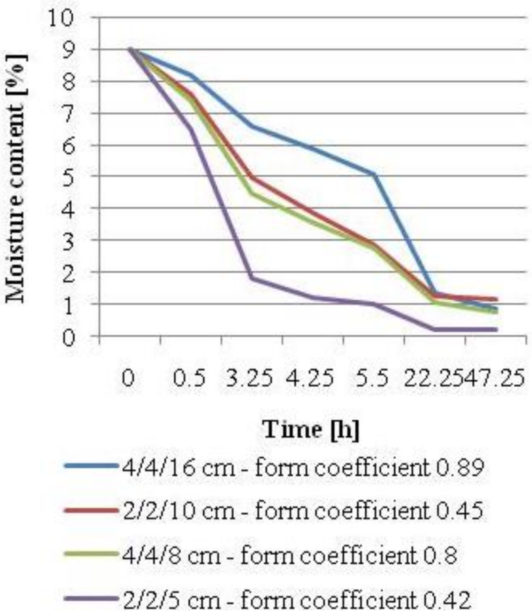

Fig. 6 Moisture content of set KRIX in time

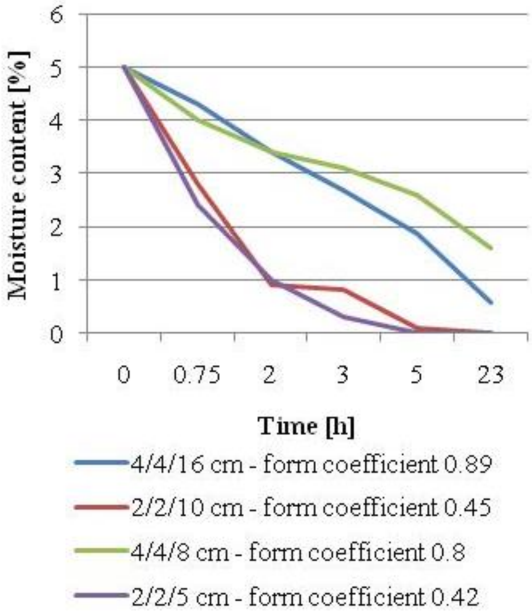

Fig. 7 Moisture content of set KRVII in time

One day after the production of the test bodies equilibrium humidity occurred (state of constant moisture content of the test bodies).

The slowest drying rate had the test bodies with the highest value of the form coefficient and the fastest drying rate had the test bodies with the lowest value of the form coefficient.It corresponds to our hypothesis. But, shape of the curves of graphs are not sufficiently convincing about our hypotheses (see Fig. 6, 7).

In particular Figure 6 shows that drying rate of the test bodies with different form coefficient (form coefficient 0.45 and 0.8) were very similar.This discrepancy could have been caused by induced deviation in geometry of the test bodies.

If we focus on the extreme values of the form coefficient we can see that the moisture content was determined approximately 4-9 times lower after three hours from the production of the test bodies (see Fig. 8).

Because of the inaccuracy of measurement it is not possible to determine the dependence the drying speed on the form coefficient from a narrow interval.

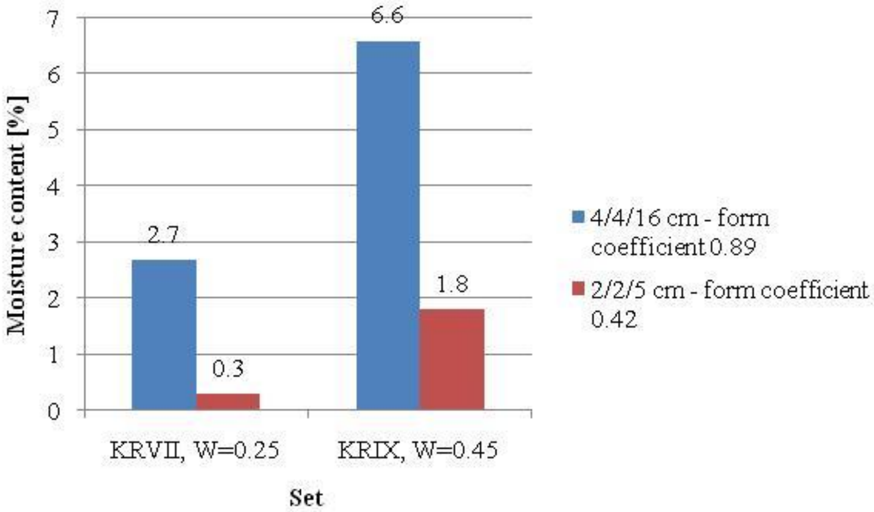

Fig. 8 Moisture content of set KRVII in time

Conclusions

The conclusions from this part of research are not satisfactory. The method for determination of the drying speed was not suitable, because the form coefficient of the test bodies were selected on the narrow interval. The next fault was to produce too small test bodies. The grains of sand that crumbled from the test bodies had significant proportion in the weight of a test body. After these experiences we found a good solution to produce special moulds for it. The rammed earth would be in these moulds whole drying time and it would be weight with these moulds. The grains of sand would not fall off and we will be able to obtain more exact value of the form coefficient.

Acknowledgement

The financial support of this experiment by the Czech Science Foundation (GAČR project NO. 18-10884S) and Faculty of Civil Engineering, Czech Technical University in Prague (SGS project No. SGS16/201/OHK1/3T/11) is gratefully acknowledged.

We would like to express our thanks to LB MINERALS, s.r.o. company for free supply of material necessary for experimental measurement and we would also like to express thanks to HELUZ cihlářský průmysl v.o.s. for giving statistical data and information.

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