Material Properties of Rammed Earth Prepared from Illitic-Kaolinitic Clay

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Abstract: The rammed unfired earth is one of the most eco-friendly materials, because the energy requirement for design is lower than the energy required for masonry brick structures. This paper is devoted to the characteristics of the rammed earth that is very much needed to design structures from this material. First, attention is paid to the preparation of test specimens from clay, sand and water. Dimensions of prism specimens for material testing are $40 \times 40 \times 160$ mm. Creep measurement is performed on specimens of 70 mm length and octagonal cross-sectional area with distance of oposite sides of 20 mm. Secondly, the measurement procedures and the results of material tests of compressive strength and tensile strength in bending are presented. Third, determination of shrinkage and shrinkage is described and reported for a particular mixture. Material properties such as strength and modulus of elasticity are closely related to creep and are also listed. At the end, the advantages and disadvantages of the rammed unfired earth are discussed in terms of acquired material properties.

Key–Words: Illitic – Kaolinitic Clay, Shrinkage, Compression Strength, Tensile Strength in Bending, Rammed Earth

1 Introduction

Global estimates indicate that roughly a third of humanity lives in dwellings where the main supporting structure is from unfired earth. This type of dwelling is used by nearly half of the population in developing countries. Clay buildings are found in different natural conditions. Still, these are traditional buildings with a historical context, but also modern buildings. Modern buildings from unfired earth give rise to a lot of questions about the properties of material and its mechanical properties [1].

The clay construction is consistent with the idea of sustainable growth [2]. A very favorable aspect of non-fired clay structures is low carbon emissions. A very positive astects of unfired clay construction are:

- Low carbon emission,
- efficient use of renewable resources,
- minimisation of pollution,
- minimization of wate generation,
- use harmless materials,
- use local resources and
- biodegradation.

Other positive features include:

- Locality,
- availability of clay as a builging material,
- very good formability and workability,
- absorption of harmful and unpleasant smells and allergens from environment,
- absorption and deabsorption of water wapor.

The Fig.1 shows the primary energy impact value (PEI), which is a bound energy indicating the total consumption of natural resources during the life cycle of a product. The value of unburnt clay is around 30 kWh / m^3, for PEI the indicator has a value of 475 kWh / m^3, which is approximately 16 times more [3]. For example, steel achieves PEI values of 63000 kWh / m^3.

Still, unfired earth has not only positive aspects. Clay constructions should be designed where they are not exposed to the direct effect of flowing water [4]. The designers are able respect thist important aspects. A very significant drawback is the absence of standards for the design of unburnt clay constructions. The properties of unfired earth depends on:

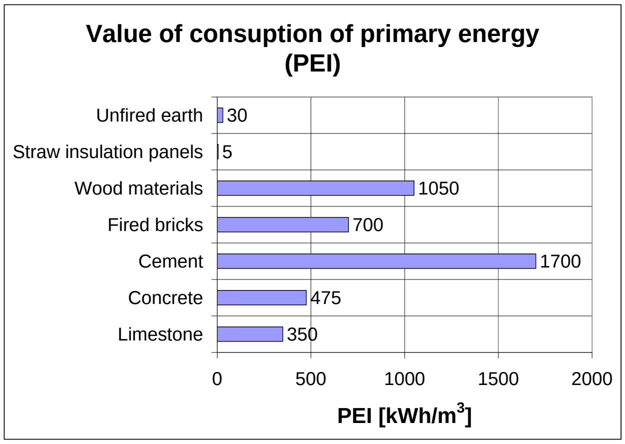

Figure 1: Values of PEI for another building materials.

- Place of location of the clay,
- relation between content of clay and sand.

So the properties of the clay will vary according to the place of construction and the particular type of mixture.

Still, there are places on Earth where the precise clay is mined. The clay type thus defined can be used as a binder for the formation of a mixture for rammed earth. If we know the effect of precisely defined types of clay on material properties, then it is easier to use this material as a binder in the mix and expect the corresponding material behavior.Knowledge of the use of clay as a binder and its effect on material properties would facilitate the design of the clay structures, the more frequent use of the clay-bearing structures, and thus the use of the positive properties that this unfired material has.

2 Tested material

A fundamental role for the use of unburnt clay will be the knowledge of material properties. This will allow its use in structures, as indicated in Fig.1. The attention of the research is concentrated on the use of illitic– kaolinitic clay. [5]. This is one of basic types of clay in the Czech republic. There are aviable the basic clays, illitic, kaolinitic and montmorillite. The illitic – kaolinitic clay used in the study is combination of first two kinds of clay. The earth material was prepared from three components, clay, sand and water. The binding component is the clay described above, manufactured by LB Minerals. Water has a binding function. The so-called water ratio, the water / clay weight ratio was 0.37. Sand is the last component of the blend and plays the role of filler. The production was realized with natural sand, which had a smooth grain line. The largest grain of sand was 2 mm in size.

The variability of the mixture consists in a change of the water coefficient and the mutual ratio of sand and clay.The mixture had a sand / clay ratio of 85 / 15. The mixture was poorer to the amount of clay, but the amount of mixing water was higher. The usual quantity of mixing water is close to the water coefficient of 0.3.

The preparation of the mixture consists of mixing clay and muddy sand. Finally, it is added to the mixture and the remaining amount of water is mechanically mixed by use of a mixing attachment on the drill. Then the mixture is ready for placement into the molds. Form filling is in two types:

- $40 \times 40 \times 160$ mm and
- $20 \times 20 \times 100$ mm.

The specimens from first one type of mold are used for testing of mechanical properties of rammed eatrh. The second one type of specimens are used for creep and shrinkage tests.

The filling of molds takes place in approximately three layers of materials. First, the mold is completely filled with the prepared mixture and compacted by threshing. Subsequently, the form is supplemented with a new addition and re-compacted. This is done until the mold is fully filled with the rammed mixture.

The rammed earth is not formed by adding any amount of cement or lime. The hydration process is eliminated in the mixture. Maturing of the material consists of water drying. Therefore, immediately after production of the specimens, they are removed from the molds and allowed to air drying. Only the specimens for creep measurement are inserted into the creep and shrinkage device immediately afte demolding.

3 Test procedure

The material properties are basic information that is relevant to designing structures. The compressive strength, flexural tensile strength and modulus of elasticity are basic material properties. Equally important is the ability of the material to resist shrinkage and the size of creep under loading.

Because the clay is not an isotropic material, it is necessary to distinguish the way of testing the material properties. Load methods include:

- Stress perpendicular to the direction of compaction and
- stress parallel to the compacted layers.

Figure 2: Specimen used for three poin bending test in direction perpendiculat to layers of compaction.

The effect of the stress direction is reflected in both bending strength and compressive strength. Specimens used in the bending test in the direction perpendicular to the compacted layers must be arranged in a thin layer of plaster bearing surface of the test device, see Fig. 2.

Thin layer of plaster has not influence on the bending strength. Crack propagation begins on the tension side of the body that is not provided with a layer of plaster, as is possible see on Fig. 2.

Compression test was realized in derection parallel with the compacted layers. There was measured Modulus of elasticity. The Modulus of elasticity was measured by extensometer with basic measuring length 100 mm, see Fig. 3. The specimen fragments from bending tests were used to compare the influence of the compressive stress direction. The layer of gypsum has been removed from bodies loaded parallel to the direction of the compacted layers, as is possible see on Fig. 4. These specimens were not fitted with measuring extensometer deformation, but deformation of the body was measured by the total deformation of height.

Relationships for the calculation of the tensile strength of the three point test and determination of the compressive strength can be defined by means of equations 1 and 2.

$$\frac{6Fl}{4bh^2} = R_t, \qquad (1)$$

where:
F is maximal achieved load,
l is distance of supports (140 mm),
b is width of specimen,
h is height of specimen
R_t is tensile strength in bending of specimen.

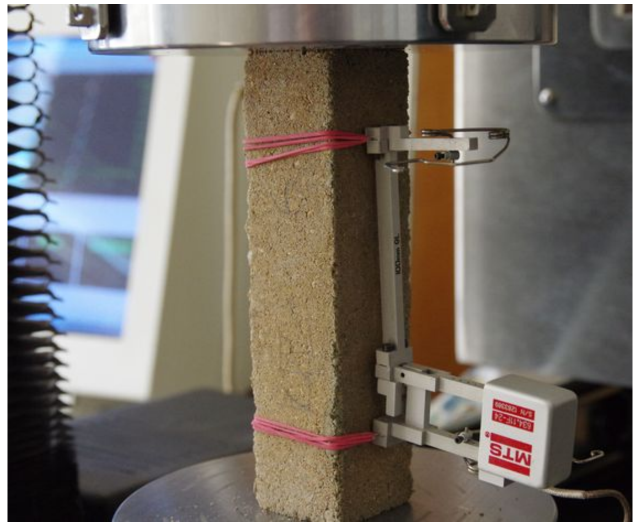

Figure 3: Instrumentation of the extensometer on the specimens for compression test.

$$\frac{F}{A} = R_d, \qquad (2)$$

where:
F is maximal achieved load,
A is compresed area and
R_d is compression strength of specimen.

The creep and shrinkage test was performed on a total of 6 bodies. 3 specimens were used to measure creep and 3 specimens for measuring of shrinkage. The instrumentation of test is possible see on Fig. 5. The specimens used for creep test were loaded by load 53 N during whole time of testing. Length of testing was 15 days. The body of the test specimens was 70 mm and the full length deformation was recorded using 3 optoelectronic sensors. The specimens for creep were not loaded during the test.

4 Results

The specimens were first tested in the bending test. The results of three tested specimens are presented in Table 1. Typical working diagram is possible see on Fig. 6. The softening phase is very well seen in the picture. The material behaves in bending linearly elastically until failure. The rammed clay in the bend relatively quickly softens, but in the working diagram the soil behaves quite ductilely. The average value of bending strength was 0.384 MPa.

The results of compression loading are presented in Table 2. The representative working diagram is possible see on Fig. 7. The picture shows that even in the case of pressure the material behavior is not

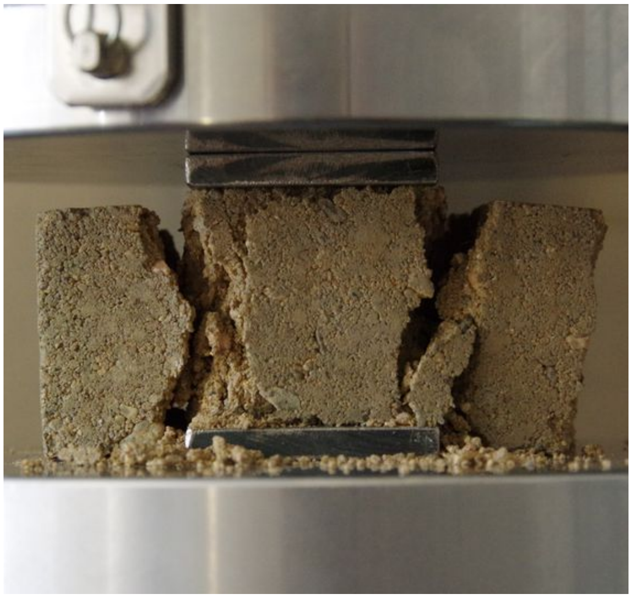

Figure 4: The compression test on fragments of specimens.

Figure 5: The istrumentation of the shrinkage test.

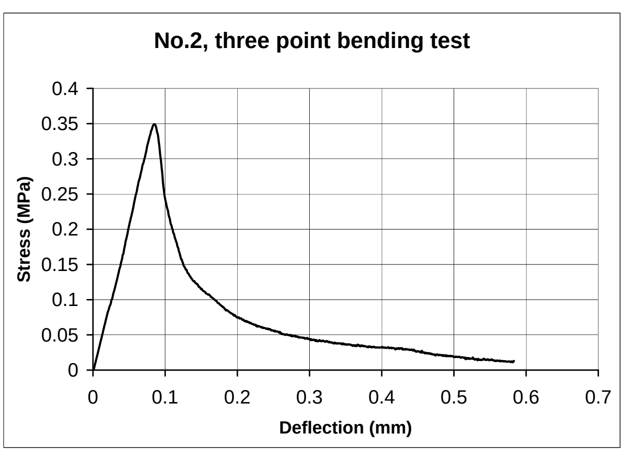

Figure 6: The working graph of specimen No.2 in bending test.

No.1	No.2	No.3
0.368	0.345	0.440

Table 1: The tensile strength of bending test in MPa.

Loading	No.1	No.2	No.3
Big	0.830	0.861	1.032
Small $\parallel$	1.842	1.635	1.449
Small $\perp$	1.952	2.034	1.530

Table 2: The compression strength of rammed earth in MPa.

fragile. The working diagram has a ductile phase. The behavior of the material on the upward branch is again almost linearly flexible. Plastic deformations begin at about 80 % of the maximum load. Small specimens were tested in compression after bending experiments. The average compressive strength of the rammed earth loaded on the layers direction was 1.642 MPa. On the other hand, the compressiom strenght of small specimens in perpenicullar direction was 1.838 MPa. This value is 1.119 times higher than strength in parallel direrection.

Very interesting are results from creep and shrinkage tests. Graph at Fig. 8 represents creep curve. Table 3 presents values of creep and shrinkage on end of testig in age of 15 days. The average value of creep is $1.05\ 10^{-3}$. Fig. 9 displays shrinkage curve of third specimens.The average value of shinkage was very close to 0. This means that the material almost did not shrink. Shrink and creep charts are accompanied by a graph of temperature development during the measurement, see Fig. 10. Temperature is usually of great importance for shrinkage [6]. Even in this case, the material's reaction to temperature changes is noticeable during the day when the laboratory temperature experienced a ± 1 degree deviation.

5 Conclusion

The results obtained show that the damp clay has relatively favorable material and rheological properties. The tensile strength after bending is approximately 2.36 times less than the compressive strength. The compressive strength is greatly influenced by the size of the test specimens. The smaller specimens achieved higher value of compression strength. Average compression strength of bigger specimens was 0.907 MPa. Average Modulus of elasticity achieved a value 0.905 GPa. The material can be characterized by mild orthopropy, which is evident from the differ-

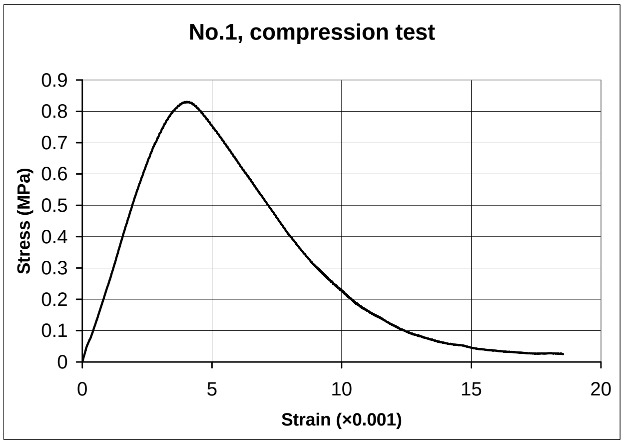

Figure 7: The working graph of specimen No.1 in compression.

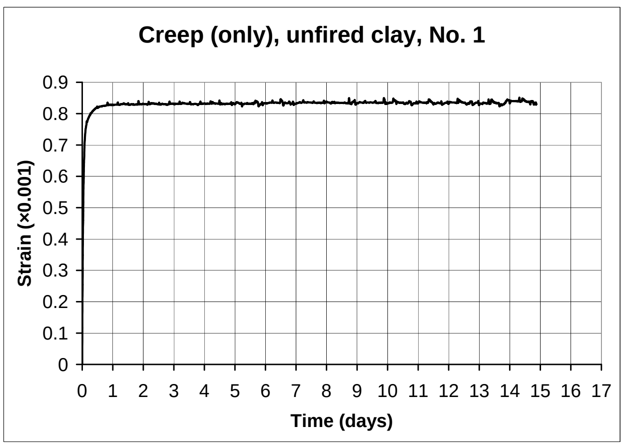

Figure 8: Creep curve of specimen No.1.

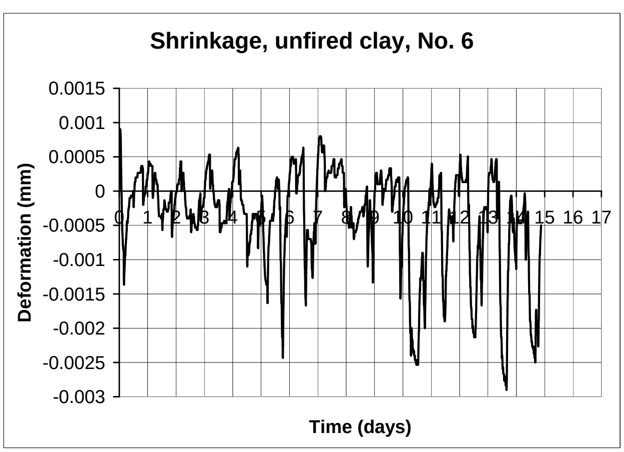

Figure 9: Shrinkage curve of specimen No.6.

	No.1	No.2	No.3
Creep	0.83	1.35	0.98
Shrinkage	-0.035	0.02	-0.0005

Table 3: Size of creep and shrinkage after 15 days.

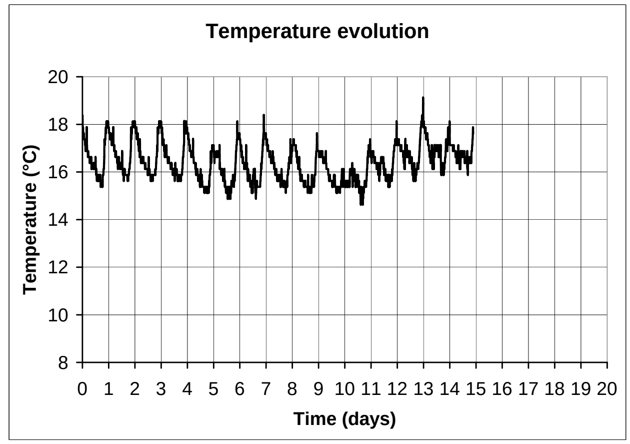

Figure 10: Temperature evolution duting creep test.

ence in the strength of the material according to the direction of loading.

Very good results were achieved by the material in the creep test. The material creeps especially during the drying period, which is seen from the presented graph. Approximately from the second day, the creep size does not change.Shrinkage is mainly affected by the composition of a mixture containing less clay. Therefore, during the shrinkage measuring the deformation of the material almost was near to zero.The tested material has comparable properties as similar materials [7].

The material properties of the rammed earth will depend on the amount and type of clay used. Clays are distinguished in the structure, which is directly related to the ability to bind water and resize structures at the time. For example, pure illitic clay used in a comparable experiment exhibits a different creep than the experiment described here [8]. However, illitic - kaoliinitic clay has properties close to illitic clay. This is due to the fact that the illite clay is part of the ilitic kaolinitic clay. Different results will be provided by montmorilonitic clay.

This study has shown that it is important to analyze the material properties of an unfired rammed clay that changes due to the type of clay used and the amount of components in the mixture. The significant contribution of the article is the search for the connection between shrinkage of material and material properties, which are influenced by the ratio of mixing components.

Future work will focus on finding the optimal ratio of clay components. This will make it possible to determine which clay is most suitable for a specific application. At the same time, the results of the future work will provide a solid foundation for the safe design of the rammed earthed construction. A very beneficial knowledge of future work will be the Poisson coefficient and material behavior, which contains different amounts of initial water in terms of shrinkage.

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