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Rammed Earth and its Properties for Design of Construction

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Abstract. Two types of clays are compared in the article. The first type of clay is illitic, the second is ilitic - kaolinitic clay. Material properties such as compressive strength and flexural tensile strength are compared for different types of manufactured material mixtures. The test specimens were made of rammed earth, and that of defined mixtures. The dependence of material properties on the amount of clay, the type of clay and the amount of mixing water was monitored. The results of the comparison of properties were summarized in the conclusion.

Introduction

The design of building structures depends on the required shape of the structure, the type of use and the selected material design. Some constructions can be built only from suitable building materials, others can be built from any materials. If the above assumptions permit, rammed unfired earth can be used for building structures [1].

Material selection

Unfired clay is suitable for structures that are not exposed to direct water. In this case, the use of concrete is the most suitable solution. The rammed construction of clay allows to create a relatively free shape, which is limited in the case of using masonry elements. Like other building materials, rammed earth has its specific properties which make it suitable for use in selected building constructions. The paper presents the properties of unburnt earth, and it will be seen that the use of this material will be particularly suitable for vertical structures [2].

Rammed earth is a material consisting of three basic components, water, sand and clay, which has the function of a binder. The results of two types of clay are presented here. The first is Ilitic and the second is an Illitic-Kaolinitic clay. The mixtures labeled "KR" are prepared from Illitic- Kaolinitic clay [3]. On the other hand, "AGL" mixtures were prepared from Illitic clay. These two types of clays belong to the most frequently offered types of clays that are available in the Czech Republic. At the same time, these are mineralogically clearly defined types of clays.. The sand to clay weight ratio was the same for all mixtures. The difference was in the amount of water used in the prepared mixture. The amount of water is based on the weight of clay for all of the present compositions. This ratio is referred to as the water factor. This factor is called the water / clay ratio and is captured in the last column of Table1.

Preparation of specimens for testing

The specimens were manufactured by placing and ramming into moulds of 40 × 40 × 160 mm. Approximately 3 layers of material were compacted to produce of one specimen. The load direction of all specimens was perpendicular to the compaction direction. The ratio of base width to specimen height was 0.25.

Acquisition of the strength of the rammed earth is carried out by evaporating the mixing water from the body and drying it out. The drying process must be natural, as no cracks have formed since drying. Too fast drying of the material does not occur in the case of laboratory conditions. The clay itself is able to bind water, and gradually release it in the drying process. The specimens could dry out and gain strength for more than a month. Rammed earth is able to saturate the air humidity very well. All specimens were tempered to 20° C at 50% relative humidity before of testing. This was done to ensure that the saturation of the material was uniform [4]. The same method of compaction and the same procedure in the preparation of the bodies for testing gave very comparable bulk densities of the prepared mixtures, see Fig.6.

Composition of the all tested mixtures is described in Table 1. The water / clay ratio was between 0.25 and 0.45. A total of 12 specimens were prepared for each mixture. Of these, 3 were tested in a compression test and 3 bodies were intended for the bending tensile test. The remaining specimens were used for other experiments.

Table 1: Tested rammed earth in compression.

Description	Clay	Sand	Water / clay
AGL 3	20	80	0.4
KR 2	20	80	0.37
AGL 5	20	80	0,37
AGL 8	20	80	0.29
AGL 9	20	80	0,45
KR 7	20	80	0,25

Material tests

Compressive strength tests were performed by recording force and axial deformation using two extensometers and axial deformation of whole height of prism, see Fig.1. A typical working diagram in compression is presented in Fig. 2. The displayed deformation is recorded in the deformation of the entire height of the specimen.

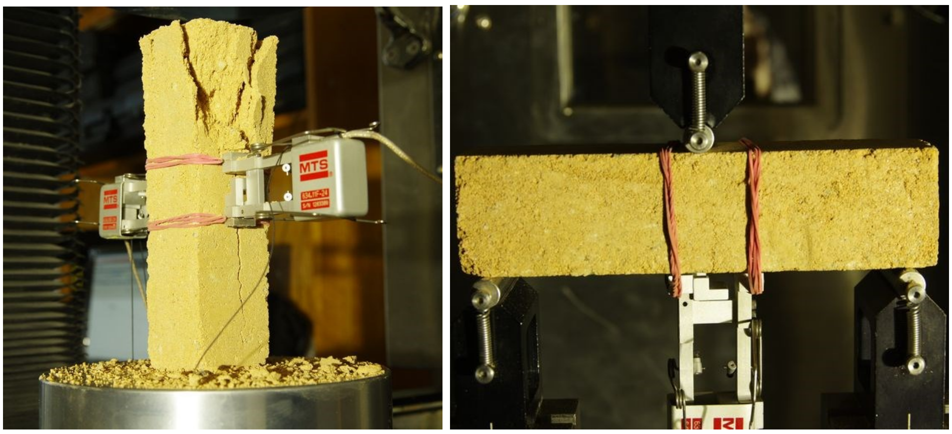

Fig. 1: Instrumentation of compression test (left) and bending test (right).

As can be seen from the working diagram, the ascending branch contains an elastic and later also a plastic area. The descending branch of the diagram is not steeply decreasing, as we would expect for more fragile materials.

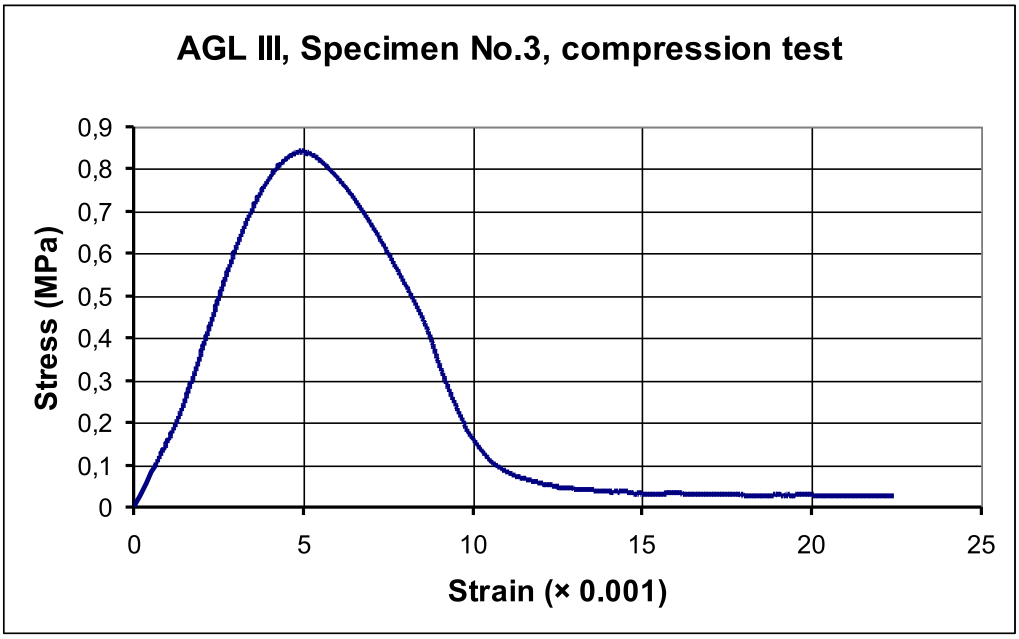

Fig. 2: Selected graph of compression test of mixture prepared from illitic clay.

The bending tensile test was instrumented by one extensometer on the lower surface of the bent specimen. It measured the opening of the tensile crack. Furthermore, the force and deflection of the prism in the middle of the span were recorded. The distance of the supports was 140 mm for all tested specimens. The test was performed in a three-point bend, as shown in Fig.1.

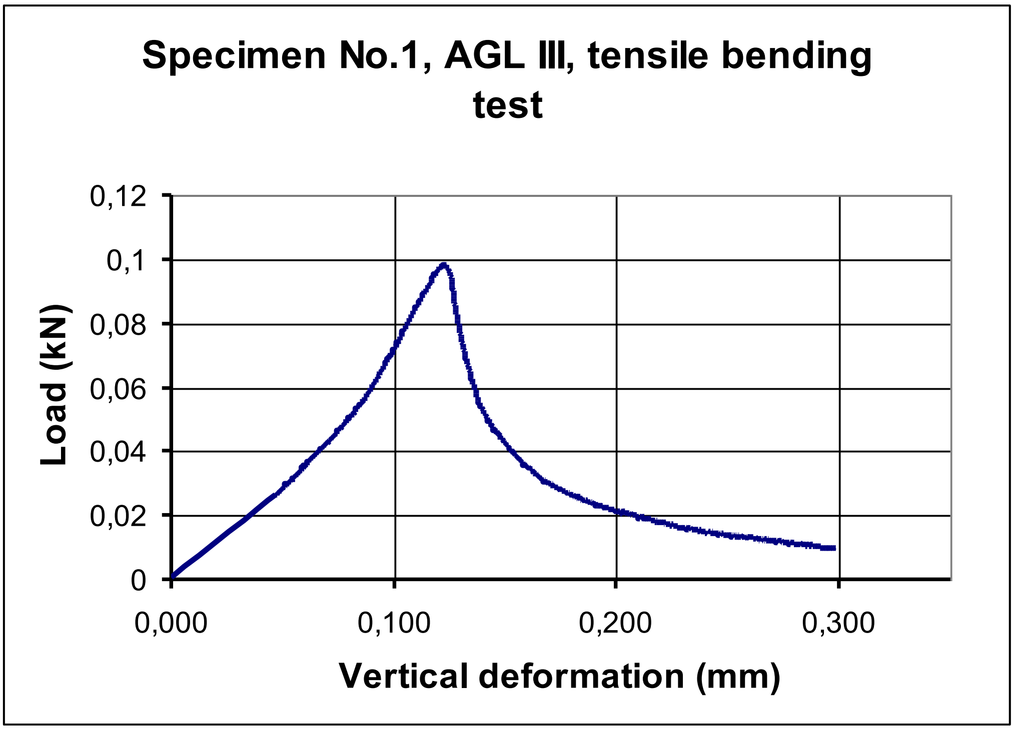

Fig. 3: Selected graph of bending test of mixture prepared from illitic clay.

The bending tensile behaviour of the material is interesting in that the descending branch of the working diagram is rapidly descending. The rapid decrease in force subsequently slows down and the deflection of the body increases considerably during the development of the main crack. The decrease in force slows down as the crack develops, as can be seem from Fig.3.

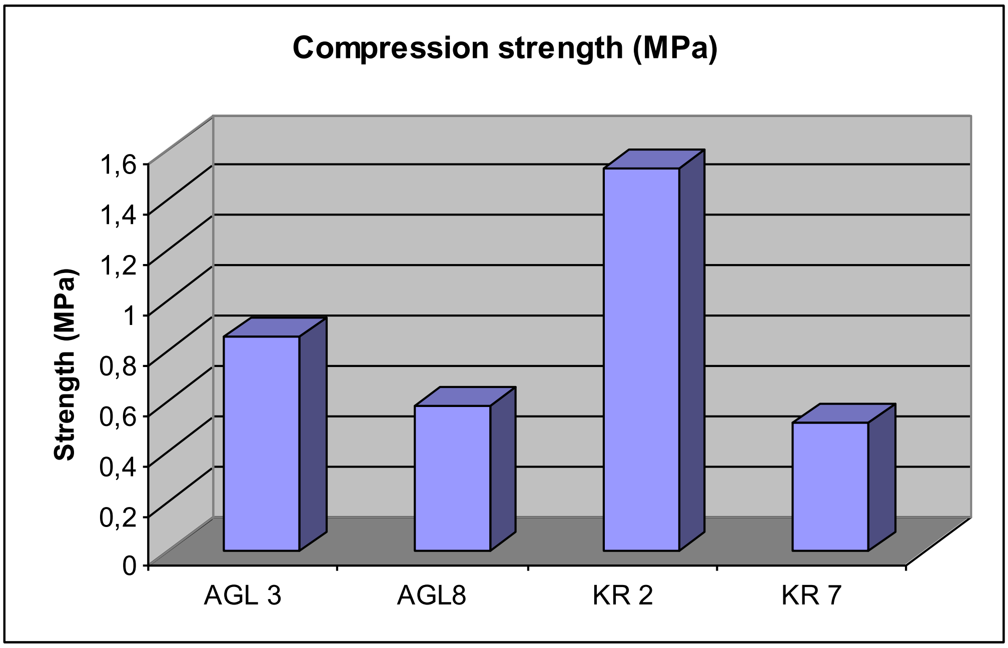

Fig. 4: Compression strength of specimens prepared from Illitic and Illitic-Kaolinitic clay.

Fig.4. provides an overview of the achieved compressive strengths. The achieved strengths of the material made of Illitic clay were 0.58 and 0.86 MPa. The specimens prepared from Illitic-Kaolinitic clay reached compressive strengths of 0.51 and 1.52 MPa. It should be noted that the KR7 mixture contained the least mixing water. This was clearly reflected in the lowest compressive strength achieved.

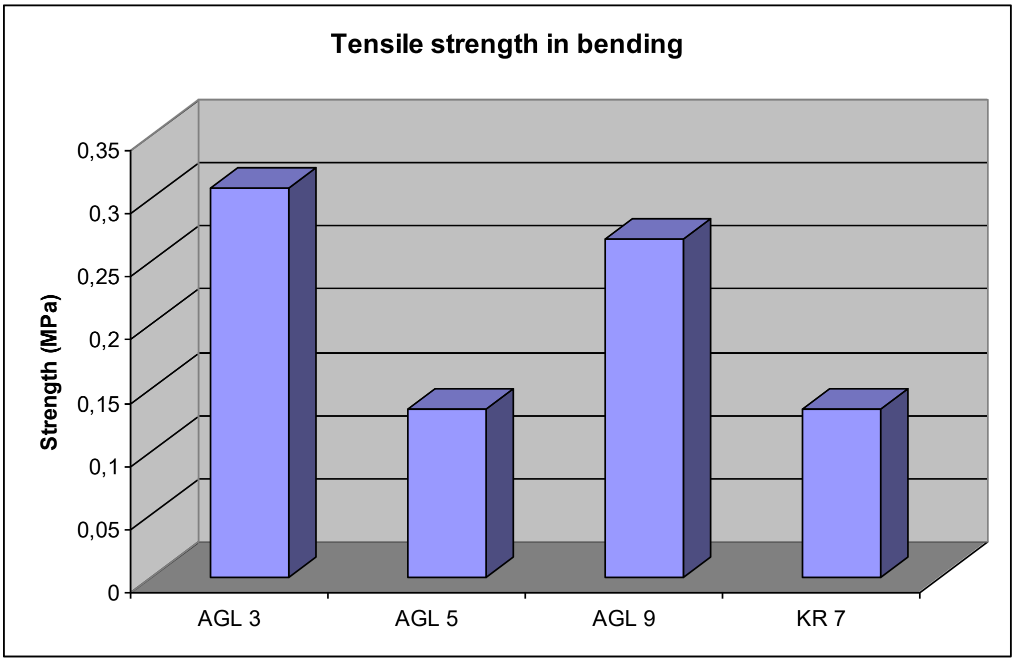

Fig. 5: Tensile strength in bending of specimens prepared from Illitic and Illitic-Kaolinitic clay.

On the contrary, the KR2 mixture did not contain the most mixing water, but its amount was given by a factor of 0.37. AGL 8 contained more mixing water than KR7. Its strength was higher. AGL3 also contained more water than KR2, but its strength was comparatively lower. It follows that for the compressive strength, the limit values of the water coefficient were 0.25 and 0.4. The most suitable water coefficient in terms of the highest compressive strength was a ratio of 0.37.

The lowest value of compressive strength is evident in connection with the lowest bulk density, as is possible see on Fig. 6. The density of the rammed clays was close to 2100 kg / m³. Only the KR7 set showed a lower strength value of 2020 kg / m³. For both types of used clays it is evident that with decreasing amount of mixing water the compressive strength decreases. The compressive strengths obtained, see Fig. 3, show that by means of an Ilitic-Kaolinitic clay a significantly higher strength can be achieved, while maintaining comparable proportions of water and clay than with an Illitic clay.

The graph in Fig. 5 shows a comparison of three materials prepared from Illitic clay with one material from Illitic-Kaolinitic clay. The comparison is made in flexural tensile strength. The range of water coefficient of Illitic clay materials was from 0.37 to 0.45. In this case, the highest flexural strength was achieved by a mixture with a water to clay ratio of 0.4. The AGL9 mixture, which was prepared with a water coefficient of 0.45, reached a flexural strength of 0.27 MPa. However, a single KR7 blend reached almost the same bending strength value of 0.13 MPa as the AGL 5 blend. The AGL5 blend had a water content of 0.37 and the KR7 blend was prepared with a water content of 0.25. The results show that the higher content of mixing water was favorable for achieving better values of flexural strength.

The volumetric density of all mixtures ranged between 2006 and 2098 kg / m³, see Fig.6. Two mixtures of AGL5 and KR7 had the lowest values. The two blends also had comparable flexural strength results. Other materials prepared from different blends had very similar bulk densities. These ranged from 2086 to 2098 kg / m³, although the amount of mixing water was between 0.29 and 0.45.

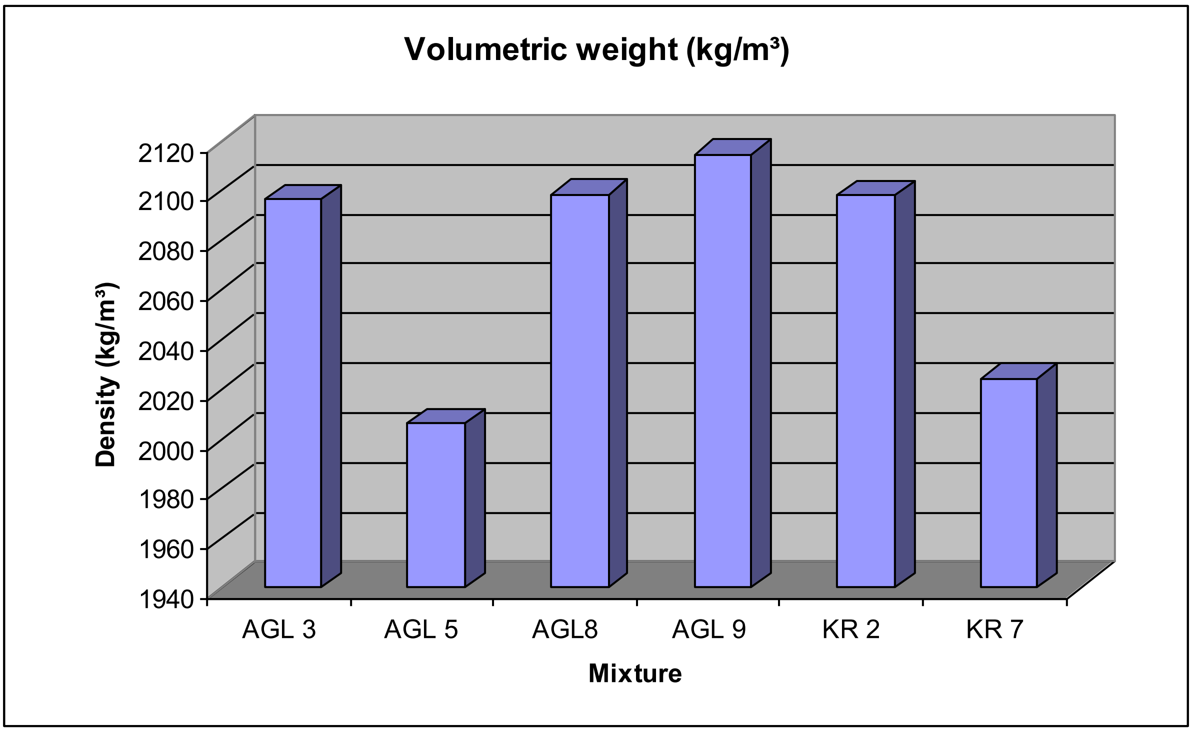

Fig. 6: Volumetric weight of all tested mixtures prepared from Illitic and Illitic-Kaolinitic clay.

Conclusions

Tests performed show that the compressive strength is affected by the amount of mixing water. In conclusion, it should be noted that the test specimens were tested after stabilization of their weight in a temperature-humidity chamber.. The optimal amount of mixing water was 0.37. A material prepared from Illitic kaolinitic clay (KR) seems to be more suitable. Since only one mixture of Illitic-Kaolinitic clay was tested in bending tensile strength, it cannot be confirmed with certainty that materials made of this clay are also more advantageous from the point of view of flexural strength.

As follows from the presented properties, unfired earth is suitable for structures loaded with pressure. Suitable applications can be found in vertical load-bearing and non-load-bearing structures. The results of compressive strength and their dependence on selected parameters differ from rheological properties [5]. Finding optimal properties will depend on comparing the results of multiple material properties.

Acknowledgement

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