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Determining Fracture Energy of unstabilised Rammed Earth by Using Three-Point Bending Test

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Abstract. The article is focused on measurement and evaluation of the fracture energy of unfired rammed earth. Fracture energy G_f is an important magnitude for understating of crack development in quasi-brittle materials as rammed earth. The fracture energy in mode I is observed for several types of prescriptions. It was found that adding clay and greater value of the water-clay ration increases the value of the fracture energy. It was also found that the mixture with montmorillonite clay have higher fracture energy than the mixture with illite-kaolinite clay. The maximum value is 20.57 ± 4.32 J/m^2 for *GEM II* and the minimum is 7.46 ± 0.43 J/m^2 for *S IV*.

Introduction

Nowadays utilization of the unfired earth as a building material is rising. The reason of the trend is mainly the fact that unfired earth is according to the principles of sustainable building development. It is environmentally friendly thanks to using of the final product, there is no need to produce any intermediate products. More over unfired earth building is a hundred per-cent recyclable. On the other hand, the mechanical behavior of the material is not described enough to use the data for designing in practical engineering [1, 2].

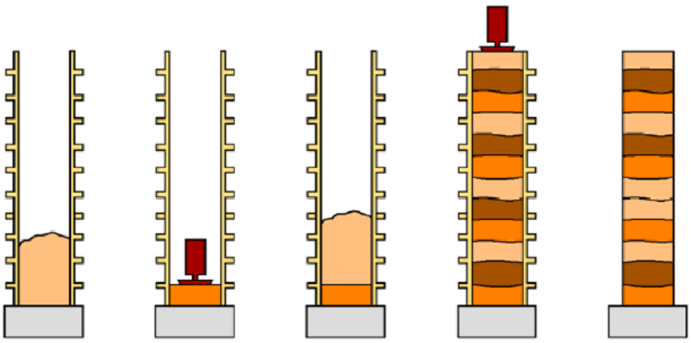

Fig.1 The principle of building with rammed earth.

Production of specimens

Building of rammed earth. The process of building rammed earth wall is as follows. First of all, the framework is built, then the first layer of rammed earth is filled in. Secondly the layer of moist earth is compressed by a tamper. Than next layers of moist earth are added and compressed up to the top of framework. Finally, the framework is removed and the result is a hard monolithic wall. The principle is shown in fig. 1.

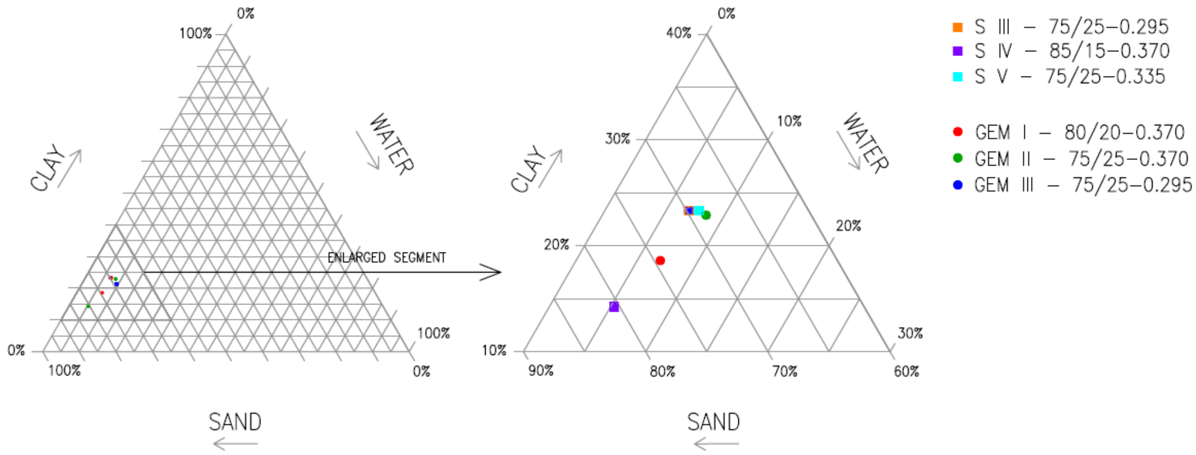

Fig.2 The used prescription in the triangular graph in the dependence on the relative procentual ratio.

Production of specimens. The material is a mixture of sand, clay and water. Six different prescriptions were tested for determining G_f. Sets *GEM* with montmorillonite clay and sets *S* with illite-kaolinite clay, sets differed in the ration of sand and clay and water-clay ration. In all there were six prescriptions of 34 specimens.

Fig.3 The produce of specimens in laboratory.

The laboratory produce of specimens is similar to building of real construction. Firstly the prescription is defined as a ration between sand (the filler) and clay (the binder) and the water-clay ratio is determined. The tested prescriptions are shown in the fig. 2, where the triangular graph illustrates the dependence on the relaive procentual ratio of each component.

Secondly the compounds were mechanically mixed together, then the moist earthen mixture was layer by layer pressed in to the mould by the drill or manually by a steel block. The specimens were removed from the mould and set in to the climatic chamber where the stable conditions were settled. The three point bending tests were made after a month after the produce. The produce and final specimens are shown in the fig. 3.

Testing of Specimens

Fracture energy. As it was written rammed earth is a quasi-brittle material. The fracture energy is the amount of energy which is needed for starting a crack growth. The methodology recommended by the RILEM – the model of fictional crack was used to determine the fracture energy. The P-δ curve from three point bending test was needed. Then the evaluation was as follows.

Firstly, the three point bending test was made and the P-δ curve was recorded. The fracture work *δW* could be determine as:

$$\delta W = G_f \cdot B \cdot \delta a \qquad (1)$$

Where *B* was the size of crack perpendicular to the direction of its growth and *δa* was growth of the crack length. The fracture energy could be calculated as an area A_F under the P-δ curve which was the work of the *P* force:

$$A_F = \int^{\delta max} P(\delta)\, d\delta \qquad (2)$$

Then the area was divided by the crack area and B was the width of the specimen [3, 4]:

$$G_f = A_f / (B \cdot W) \qquad (3)$$

Fig.4 Specimens of rammed earth in the climatic chamber and during the three point bending test.

The three point bending tests were made to observe the P-δ curve (fig. 5) on specimen of size 40×40×160 mm. Overall 34 specimens of six different prescriptions were tested. The fracture energy was settled from the measured data.

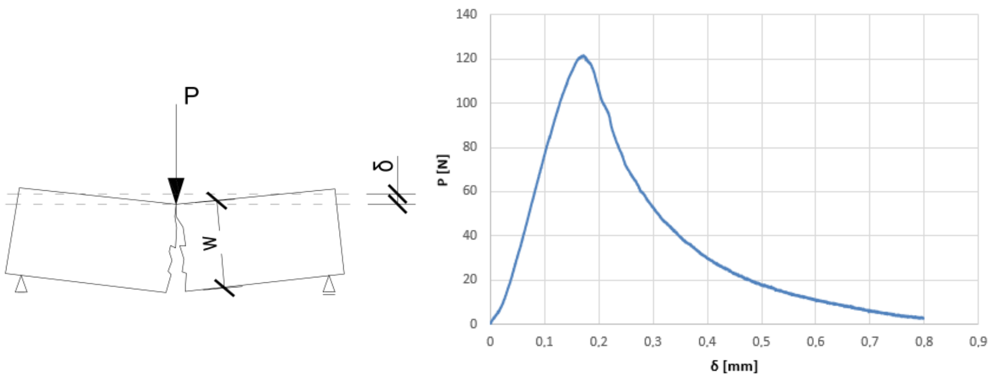

Fig.5 The three point bending test that was carried out and the P-δ curve from the test.

Evaluation of Measured Data

The evaluated data are shown in the table 1. The name of the tested set is in the first column, composition of the mixture is in the next one, then the value of fracture energy G_F, the standard deviation σ, the number of tested specimens, average bulk density of the set and type of used clay in the prescription.

Minimum content of clay. The set *S IV* (85/15 – 0.370) had the minimum content of clay (in percentage 14.2 %) and maximum content of sand (in percentage 80.5 %) and also the set *S IV* had the minimum value of G_f (7.46 ± 0.46 J/m^2).

Maximum content of clay and comparing of clay types. On the other hand the maximum content of clay (in percentage 23.3 %) and the minimum content of sand (in percentage 69.8 %) had sets *GEM III* (10.65 ± 1.85 J/m^2) nad *S III* (17.37 ± 3.75 J/m^2). For set GEM it was the minimum value but for the S set it was the maximum value. The prescriptions of these two sets were the same, they differed only in the type of used clay. As for the results the prescription with mormollionite clay had higher value of G_f than the one with illite-kaolinite clay.

Maximum water content. The maximum content of water was in the set *GEM II* (in percentage 8.2 %) and the set had the highest value of G_f of all sets (20.57 ± 4.32 J/m^2).

Tab.1 The values of evalueted fracture energy

Set	Sand/clay – water-clay ration	Gf [J/m^2]	σ [J/m^2]	Psc of tested specimens	Bulk density [kg/m^3]	Type of clay [-]
GEM I	80/20 – 0.370	18.30	1.54	6	2073	mormollionite
GEM II	75/25 – 0.370	20.57	4.32	6	2040	mormollionite
GEM III	75/25 – 0.295	10.65	1.85	4	1929	mormollionite
S III	75/25 – 0.295	17.37	3.75	6	2170	illite-kaolinite
S IV	85/15 – 0.370	7.46	0.43	6	2036	illite-kaolinite
S V	75/25 – 0.335	16.78	2.91	6	2179	illite-kaolinite

Conclusions

The article was focused on determining the fracture energy of rammed earth using the three point bending test. It has been found that adding clay and enlarging the value of the water-clay ration increased the fracture energy.

It has also been found that the mixture with montmorillonite clay had higher value of the fracture energy than the mixture with illite-kaolinite clay. The maximum value was 20.57 ± 4.32 J/m^2 for *GEM II* and the minimum is 7.46 ± 0.43 J/m^2 for *S IV*.

Acknowledgements

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