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EXPERIMENTAL INVESTIGATION OF CLAY-STRAW BUILDING FINISHING LAYER UNDER DIFFERENT DRYING CONDITIONS

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Abstract. This manuscript represents investigation of six different clay mixtures under variable drying conditions, namely: bright yellow clay (typical for Lithuania), brown clay (Lithuania Sergėnai district), mixture of different clays, white Spanish clay, clay mass which is resistant for thermal coldness (with synthetic cardigan) and Lithuanian coarse clay with granite additives. Drying process was provided imitating natural drying process and fast drying in drying oven at 110 C°. The main idea of this study – imitate clay and clay-straw buildings drying process and to determine which of used clay types had smallest volumetric and linear deformations. Volumetric and linear deformations for clay-straw buildings is one of the most important factors evaluating cracking in this type of buildings. To reach this purpose six tiles of different clay types were used. Before drying stage water content, plasticity, and liquid limits index, respectively was determined for all types of clay. All clay tiles volumetric and linear deformations before and after drying process were measured with specialized view analysis program in order not to damage samples' form. According to the obtained results a clay type whith the smallest deforamations (volumetric and linear) was found. With the smallest volumetric and linear deformations clay-straw building is not only environmental friendly, sustainable and green, but it does not require a lot of maintenance during building life time.

Keywords: clay, clay-straw buildings, volumetric deformations, linear deformation, ecological buildings, CO_2 emision.

Introduction

Nowadays more and more people choose to live in the clay-straw buildings. These buildings are environmentally friendly, whith main construction materials – clay and straw (Minke 2006). These buildings characterize according to their qualities: high quality for indoor environment (Yokobayashi, Sato 2015), hygrothermal properties (Labat *et al.* 2016; Miljan M., Miljan J. 2015), low cost (Gupta 2015), air tightness (Brojan *et al.* 2015) and one of the most important factors – materials which are used for these buildings do not have high impact for CO_2 emissions increment. According to Gustavsson and Sathre (2006) analysis, the most aggressive materials for environment (highest CO_2 emissions) are concrete and steel (Fig. 1).

Buildings which may be called ecological should provide more energy than it is necessary to use for the building. This type of buildings can be also called zero emission buildings (Sartori *et al.* 2012). The main concept of a zero emission building is that the renewable energy sources produced or transformed at the building site have to compensate for CO_2 emissions (Gustavsson *et al.* 2010) from operation of the building and for production, transport and demolition of all the building materials and components during the life cycle of the building (Fig. 2.).

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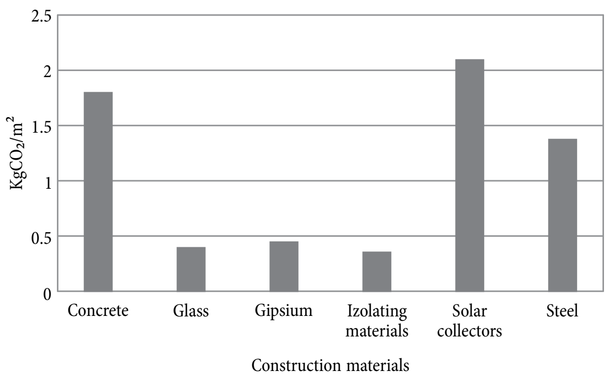

Fig. 1. CO_2 emissions of the most popular construction materials

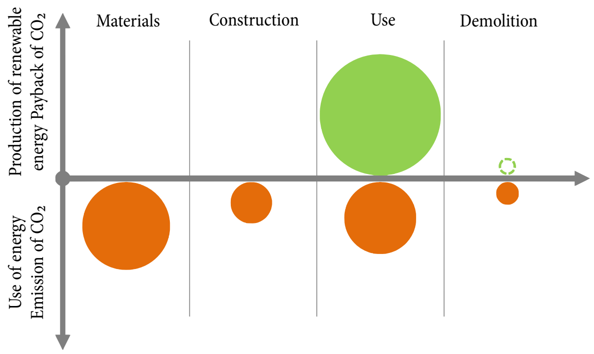

Fig. 2. Description of zero energy buildings

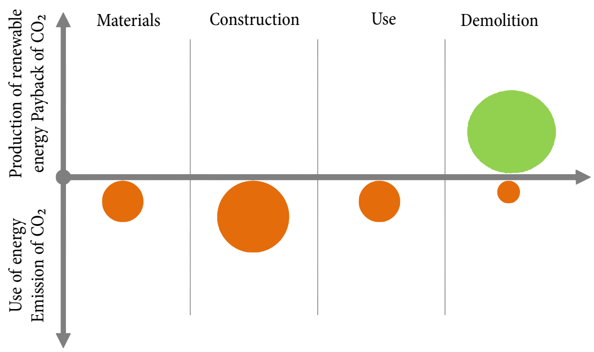

Fig. 3. Clay, clay-straw or straw buildings energy description

Fig. 4. Clay wall finish layer variance (Weismann, Bryce 2006)

For clay, clay-straw and straw buildings the highest payback of renewable energy production is obtained in demolition stage (Seyfang 2010; Bribian *et al.* 2011), because mostly all construction materials are organic and environmentally friendly (Fig. 3).

Architecture of such structures is rapidly improving because of increasing demand of these buildings (Mansour *et al.* 2007; Walker 2004; Ashour *et al.* 2010; Girkontas *et al.* 2014; Torgal, Jalali 2012). According to geological conditions in Lithuania, there is an opportunity to explore different clay types and colors (Weismann, Bryce 2015) for clay and clay-straw buildings finish (Fig. 4). Clay from different deposites has different deformation properties (Minke 2006). Due to this reason, purpose of this manuscript is to determine clays deformation affected by different drying temperatures and to compare obtained deformations. According to comparison results we strive to determine clay with smallest deformations.

1. Determination of physical clay parameters

In this study 6 different clays are used, namely: bright yellow clay (typical for Lithuania), brown clay (Lithuania Sergėnai district), mixture of different clays, white Spanish clay, clay mass which is resistant for thermal coldness (with synthetic cardigan), and Lithuanian coarse clay with granite additives (Fig. 5).

For examined clays (Fig. 5) Atterberg limits (Amšiejus *et al.* 2006; Medzvieckas *et al.* 2004), plasticity index and liquidity index (LST EN ISO 14688-1:2007) were determined and they are shown in Figures 6 and 7.

Fig. 5. Tested clays in the study: 1. Bright yellow clay (typical for Lithuania); 2. Brown clay (Lithuania Sergėnai district); 3. Mixture of different clays; 4. White Spanish clay; 5. Clay mass which is resistant for thermal coldness (with synthetic cardigan); 6. Lithuanian coarse clay with granite additives

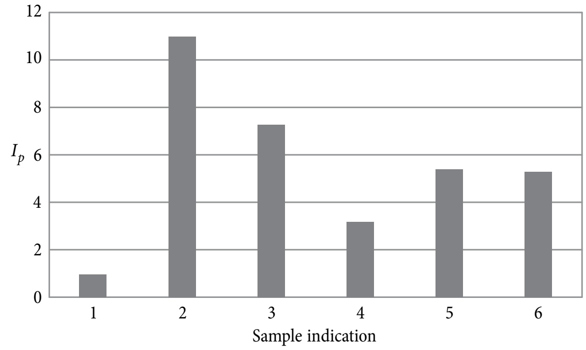

Fig. 6. Plasticity index of examined clays: 1 – bright yellow clay (typical for Lithuania); 2 – brown clay (Lithuania Sergėnai district); 3 – mixture of different clays; 4 – white Spanish clay; 5 – clay mass which is resistant for thermal coldness (with synthetic cardigan); 6 – Lithuanian coarse clay with granite additives

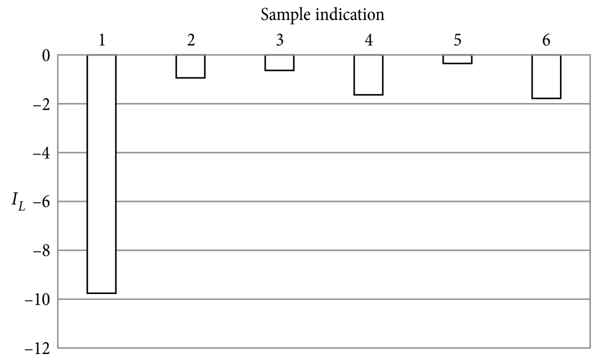

Fig. 7. Liquidity index of examined clays: 1 – bright yellow clay (typical for Lithuania); 2 – brown clay (Lithuania Sergėnai district); 3 – mixture of different clays; 4 – white Spanish clay; 5 – clay mass which is resistant for thermal coldness (with synthetic cardigan); 6 – Lithuanian coarse clay with granite additives

Analyzing Figure 6 it was obtained, that bright yellow clay has a very small difference between plastic and liquid limits. Brown clay plastic and liquid limits has the biggest difference between each other. Liquidity index, which is shown in Figure 7 has a negative values, because for all speciments it was obtained low water content values which are smaller than plastic limits water content. The biggest liquidity index was obtained for bright yellow clay, the smallest – clay mass which is resistant for thermal coldness (with synthetic cardigan).

2. Determination of volumetric deformations

All clay samples were examined under two drying conditions: 1) Natural drying conditions +15 °C, drying time equals to 168 h, after this drying stage each sample was dried in drying oven (+110 °C 4 h), in order to reach 0% water content; 2) Prepared samples dried in the oven at +110 °C for 4 hours. All in different drying conditions obtained results are given in Table 1. Clay number given in this table is the same clay indication as in Figures 6 and 7.

Analyzing obtained volumetric deformations results it can be concluded that volumetric deformations of examined clays tiles are related with drying conditions. Obtained differences of volumetric deformations according to two different drying conditions are not the same for each examined clay tile. Most sensitive tiles with largest volumetric deformations according to volumetric deformations difference (see Table 1) are made from mixture of different clays (clay no. 3).

Table 1. Volumetric deformations of examined clay tiles

Clay No.	Drying conditions	Tile with natural water content				Dry tile				$V_w – V_d$, %
		L_w, mm	B_w, mm	t_w, mm	V_w, mm^3	L_d, mm	B_d, mm	t_d, mm	V_d, mm^3	
1	1	147.50	80.00	11.00	129800.00	140.69	75.66	8.72	92820.96	28.49
	2	148.00	83.50	11.50	142117.00	142.81	77.72	9.20	102112.58	28.15
2	1	147.50	79.00	11.00	128177.50	143.36	76.14	10.25	111883.16	12.71
	2	149.00	78.00	10.50	122031.00	148.04	76.70	8.36	94925.02	22.21
3	1	149.00	77.00	10.00	114730.00	143.31	76.84	8.94	98446.75	14.19
	2	152.00	78.50	10.50	125286.00	144.12	76.81	8.08	89444.45	28.61
4	1	149.00	80.00	10.50	125160.00	143.99	78.39	10.32	116485.72	6.93
	2	147.00	81.50	11.50	137775.75	144.61	78.28	10.31	116709.93	15.29
5	1	147.50	78.50	11.00	127366.25	139.98	77.76	10.35	112658.14	11.55
	2	152.00	80.00	9.50	115520.00	146.93	77.21	7.93	89961.61	22.12
6	1	148.00	77.50	10.50	120435.00	144.56	73.21	9.31	98529.94	18.19
	2	145.00	74.50	13.00	140432.50	139.92	72.32	9.90	100178.24	28.66

Lowest sensitivity for drying conditions is obtained for bright yellow clay (typical for Lithuania, see Table 1 clay no. 1).

3. Determination of linear deformations

In order not to damage clay tiles with measuring equipment, linear deformations were determined with optical microscope view analysis program (Skuodis, Šlečkuvienė 2014). In this case it is necessary to make a photo of investigated clay tile with measuring scale (Fig. 8). Obtained linear deformations results are given in Table 2. In all tested clay tiles any cracks or crushes did not happen as for Qiang *et al.* 2014 and Burst 1965.

The biggest obtained linear deformation was for clay tiles made of white Spanish clay and the smallest linear deformations was for clay tiles made of bright yellow clay (typical for Lithuania) and Lithuanian coarse clay with granite additives.

Conclusions

A series of different clay tiles volumetric and linear deformations tests were conducted according to different drying conditions. Analysis of deformations differences revealed clay types which had smallest and largest volumetric and linear deformations. Following findings were drawn from this study:

1. For clay tiles, which had higher I_p difference under different drying conditions (per all drying period), volumetric and linear deformations is increasing.
2. Drying conditions had more influence on the volumetric deformations than on the linear ones.
3. Clay tiles which were made from Lithuanian clay had 54–79% smaller deformations than those made of Spanish clay.
4. It is suggested to use Lithuanian clay for clay house wall finish because in this case smaller volumetric and linear deformations happen and due to a short transportation distance CO_2 emissions are reduced.

Table 2. Linear deformations of examined clay tiles

Clay tile	Linear deformation, %	
	Natural drying conditions	Drying in the oven
Bright yellow clay (typical for Lithuania)	2.86	2.49
Brown clay (Lithuania Sergėnai district)	1.72	3.72
Mixture of different clays	4.7	2.98
White Spanish clay	3.14	5.16
Clay mass which is resistant for thermal coldness (with synthetic cardigan)	4.7	3.47
Lithuanian coarse clay with granite additives	2.17	2.97

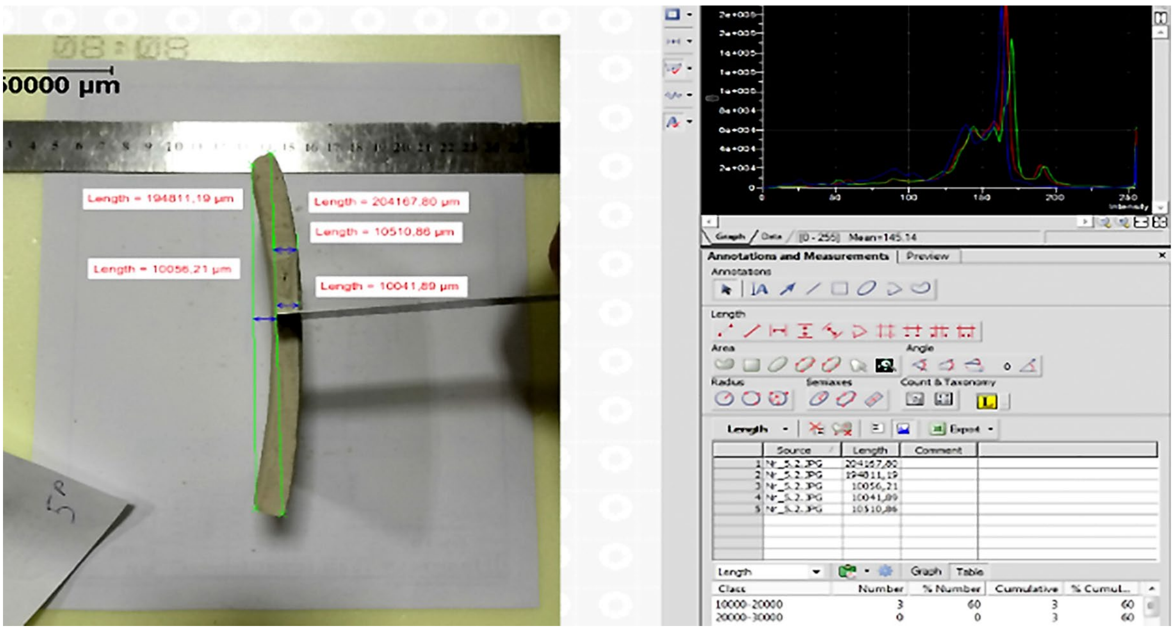

Fig. 8. Determination of linear deformations with view analysis program

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