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Moisture Buffer Value of Composite Material Made of Clay-Sand Plaster and Wastepaper

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The scope of the Nordtest method is to evaluate the moisture buffer value (MBV) for materials exposed to indoor air. The test is intended to simulate daily variations with relative humidity (RH) of 75% during 8 hours and 33% during 16 hours. The specimen made according to a recipe contains the following: waste paper, glue, clay plaster mixture and water. Eleven paper plaster mixtures with different percentages were used.
Test results showed that a large percentage of paper in the plaster increases the MBV. An impressive result, which needs to be studied further, was that the MBV was the highest in the mixture that consisted of 80% paper.

Keywords: composite material, clay-sand, moisture buffer value, Nordtest, wastepaper.

Introduction

Due to the deepening problems of environmental pollution and global warming, the interest in environmentally friendly building materials and technology has increased in many fields of production, including in the building materials industry. This article introduces the properties of composite material made of two environmentally friendly materials: clay (clay plaster mixture) and paper.

Unburnt clay has the most extensive stocks and is one of the most widespread and readily accessible building materials in Estonia. Clay is a traditional building material that has been used for the construction of buildings and interiors. The on-site supply of material and energy-efficient technology are following the principle of sustainable development.

In 2016 approximately 409 million tons of paper and cardboard products were manufactured in the world (Forest products statistics), and this number increases every year. The demand for finding new ways to reuse waste, including wastepaper increases as circular economy and recycling becomes more and more popular.

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The MBV has been studied by several authors (Vares et al. 2017, Zhang et al. 2017, Mazhoud et al. 2015, Svennberg 2006, Rode 2005). The results of previous laboratory studies of the MBV of interior finishing plaster made of wastepaper (Teearu 2018) portray that the paper plaster MBV is excellent (MBV>2.0 = „excellent") and the MBV of the composite material made of paper and clay (clay plaster mixture) is higher than the MBV of clay plaster (Nutt et al. 2020). Also, the effects of the technology used to make paper plaster (Soolepp 2019) and the ingredients' (glue mixture) effect on the MBV, and the environmental dangers of the wastewater which emerges when making paper plaster (Allikvee 2019) have been studied.

Our hypothesis is based on our research (Nutt et al. 2020) about the hygrothermal performance of clay-sand plaster and paper mixtures MBV. Our experiment showed that adding paper to clay plaster mixtures changes the hydrothermal properties of the clay plaster mixture. The research determined that adding paper plaster to clay plaster increased the MBV of the plaster.

Our hypotheses:

- MBV increases when adding paper plaster mixture to clay plaster mixture.
- Adding even a small amount of paper in the mixture has an impact on the MBV by increasing it.
- MBV depends on the amount of paper used. The more significant the proportion of paper in the mixture, the higher the moisture buffering value of plaster mixture.

Method and Equipment

In order to determine the moisture buffering characteristics of plaster, the Nordtest methodology was used, which established the MBV of composite systems open to the indoor environment (Rode 2005). At first, the specimen was kept at a temperature of 23 ± 5^0C with relative humidity (RH) of 50±5 % until a balance point was reached. Balance point was considered to be reached when the change in the mass of two specimens was under 1% during two weigh-ins with 24 hours in-between. When the balanced moisture was established, the specimen was initially kept in an environment with RH of 75% for 8 hours and then in an environment with RH of 33% for 16 hours. Throughout the whole experiment, the temperature was 23 ± 5^0C. The cycle was repeated until the average change in mass Δm (g) of three continuous cycles was within 5% and the difference in each cycle of moisture absorption and drying out is smaller than 5% of the average change in mass, Δm.

Nordtest protocol formula for $MBV_{practical}$ [g/(m^2·%RH)] calculations (Equation 1):

$$MVB_{8h} = \frac{m_{max} - m_{min}}{A\cdot(\varphi_{high} - \varphi_{low})} \tag{1}$$

where:

$m_{min/max}$ explain the moisture mass (min and max) in the final sample (g or kg);

A – explain the exposed area m^2;

$\varphi_{high/low}$ – explain the high/low RH (75-33) levels applied in the measurement.

Nordtest method says that the specimen needs to be weighed five times in one cycle. We altered the testing method and weighed the specimen two times in one cycle as according to the methodology, only the data from two weigh-ins is necessary to calculate the MBV (Equation 1).

Equipment included a climate chamber RUMED 4101 affording RH 20…95% with accuracy ±2-3% and temperature from 0 to +60°C with accuracy ±0.5°C; Memmert Incubator Oven INB200 with a temperature range from +30 °C (however, at least 5 °C above ambient) up to +70 °C and digital balance Kern PLT 1200-3A with an accuracy of 0.001 g. The climate chamber method was used at environment temperature 23±0.5 °C with three specimens of each type.

Plaster Mixtures and Specimens

The specimen was made according to the recipe that contains: wastepaper (newspaper paper), glue (methylcellulose), clay plaster mixture and water. The total number of specimens was 33 (3 x 11). Eleven different percentage plaster mixtures were used where paper plaster proportion were (g) 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90%, in addition there were two control groups, paper plaster mixture and clay plaster mixture (**Fig. 1**, **Table 1**). A product by Saviukumaja Ltd was used for clay plaster mixture, and it was a clay finishing plaster consisting of clay and sand with grain size 0-2 mm and had added fibre of the *Typha spadix*.

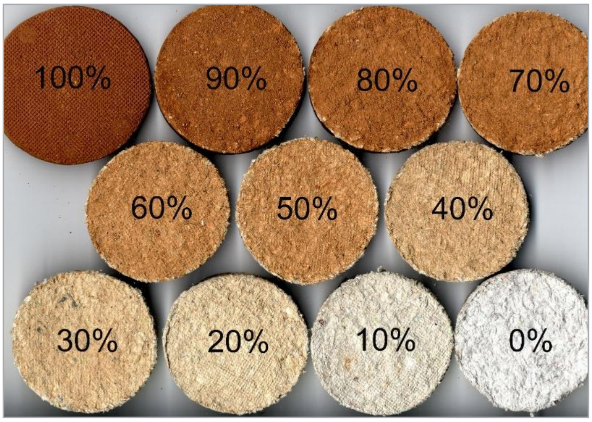


Fig. 1

Examples of specimen groups, proportion of clay (%)

X-ray diffraction analysis helped to determine the mineralogical composition (% of mass) of clay plaster mixture (< 0.2 mm) : quartz 45.6, k-feldspar 6.6, plagioclase 7.9, chlorite 1.5, illite/illite-smectite 20.9, kaolinite 4.1, calcite 8.5, dolomite 4.0, hematite 0.5 and amphibole 0.5 wt% (Altmäe et al. 2019).

Table 1

Composition of mixtures

Plaster group	Plaster composition	Grain size of clay plaster (mm)	Paper (g)	Glue (g) Glue/water	Clay (g)	Proportion (clay (%))	Proportion (paper (%))	Number of samples	Average area (cm2)	Average density (g/cm3)
1 control	paper	-	500	20/1000	0	0%	100%	3	75	0.3
2 control	clay	< 0.2 mm	-	-	-	100%	0%	3	83	2.0
3	clay + paper	< 0.2 mm	0	20/1000	55	10%	90%	3	71	0.3
4	clay + paper	< 0.2 mm	500	20/1000	125	20%	80%	3	70	0.4
5	clay + paper	< 0.2 mm	500	20/1000	214	30%	70%	3	72	0.4
6	clay + paper	< 0.2 mm	500	20/1000	333	40%	60%	3	70	0.5
7	clay + paper	< 0.2 mm	500	20/1000	500	50%	50%	3	67	0.6
8	clay + aper	< 0.2 mm	500	20/1000	750	60%	40%	3	69	0.7
9	clay + paper	< 0.2 mm	500	20/1000	1166	70%	30%	3	70	0.9
10	clay + paper	< 0.2 mm	500	20/1000	2000	80%	20%	3	72	1.1
11	clay + paper	< 0.2 mm	500	20/1000	4 500	90%	10%	3	74	1.4

Test Report

The method: Nordtest

Type of product: composite plaster

Produce name: clay + paper plaster, homemade

Production: made in a laboratory

Composition: paper + clay plaster + glue + water, material with homogenous structure

Description: specimen thickness 2.5 cm, the exposed surface area of a circle with a 9 cm diameter

Sealing: waterproof nitrile pouch with a thickness of 1.25 mm

Number of test specimens: 3

Test configuration: temperature 23°C, low RH 33% for 16 hours (±10 min), high RH 75% for 8 hours (±10 min)

Test 1. Dates of test 1: 23.06.2019 - 29.06.2019

Test 2. Dates of test 2: 02.08.2019 - 07.08.2019

Test 3. Dates of test 3: 17.08.2019 - 25.08.2019

The Results

Nordtest results describe the moisture absorption and separation of plaster mixtures, which is expressed by an index MBV. In actual living spaces, the change in relative humidity is described by $MBV_{practical}$ (Janssen and Roels 2009). As a result of the cyclic change of relative humidity, the weight of the specimens also changed in cycles (**Fig.** 2). Using the MBV [g/(m^2·%RH)@8/16h] materials can be classified as follows: negligible (0-0.2), limited (0.2-0.5), moderate (0.5-1.0), good (1.0-2.0), and excellent (2.0-) (Rode 2005).

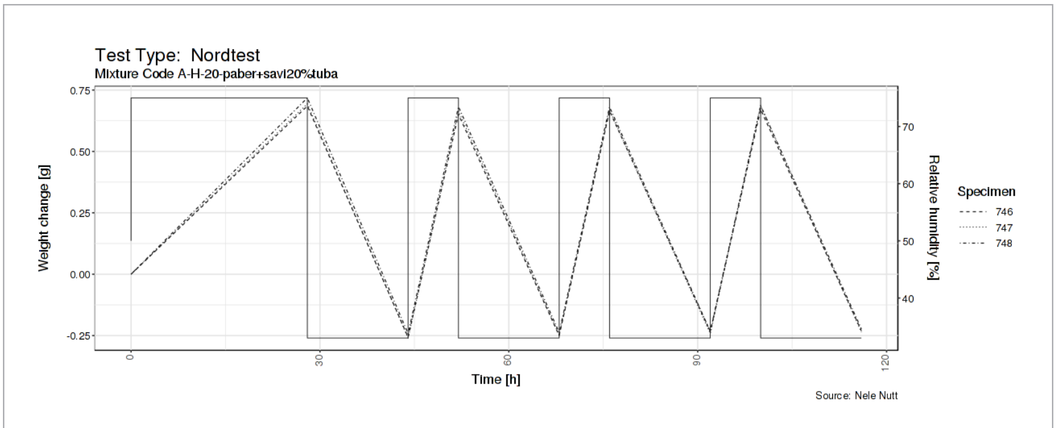


Fig. 2

Nordtest test no 1: change in specimens' mass

Plaster group 4 (clay 20% and paper 80%). The continuous line portrays the change in moisture cycles (RH 33% ja RH 75%) in the climate chamber.

Hypothesis (2): adding even a small amount of paper in the mixture has an impact on the increase of the MBV is correct. All specimens that had paper added to (10-90%) increased the value of their MBV. Clay plaster mixture (plaster group 2) has an MBV<2.0 g/(m2·%RH)@8/16h ("good") which stays in the range of 1.91-1.98 g/(m2·%RH)@8/16h. All the mixtures that had paper added to it (plaster groups 3-11) had an MBV>2.0 g/(m2·%RH)@8/16h which stayed in the range of 2.12- 3.17 g/(m2·%RH)@8/16h ("excellent") (**Table 2**).

Hypothesis (1): the MBV increases when adding paper plaster mixture to clay plaster mixture, and hypothesis (3): MBV depends on the amount of paper used. The more significant the proportion of paper in the mixture, the higher the MBV of plaster mixture was partially confirmed. When generally test results show that increasing the proportion of paper in the mixture increases the plaster mixture's MBV, then in specific ratios, this trend was not noted. All three test results portrayed that the MBV was the highest (accordingly 3.10, 3.17, 3.14 g/(m2·%RH)@8/16h)) when the specimens consisted of 80% paper (plaster group 4). The MBV was even higher than the MBV of specimens that were made only from paper (plaster group 1) (**Table 2, Fig. 3 (a)**).

Table 2

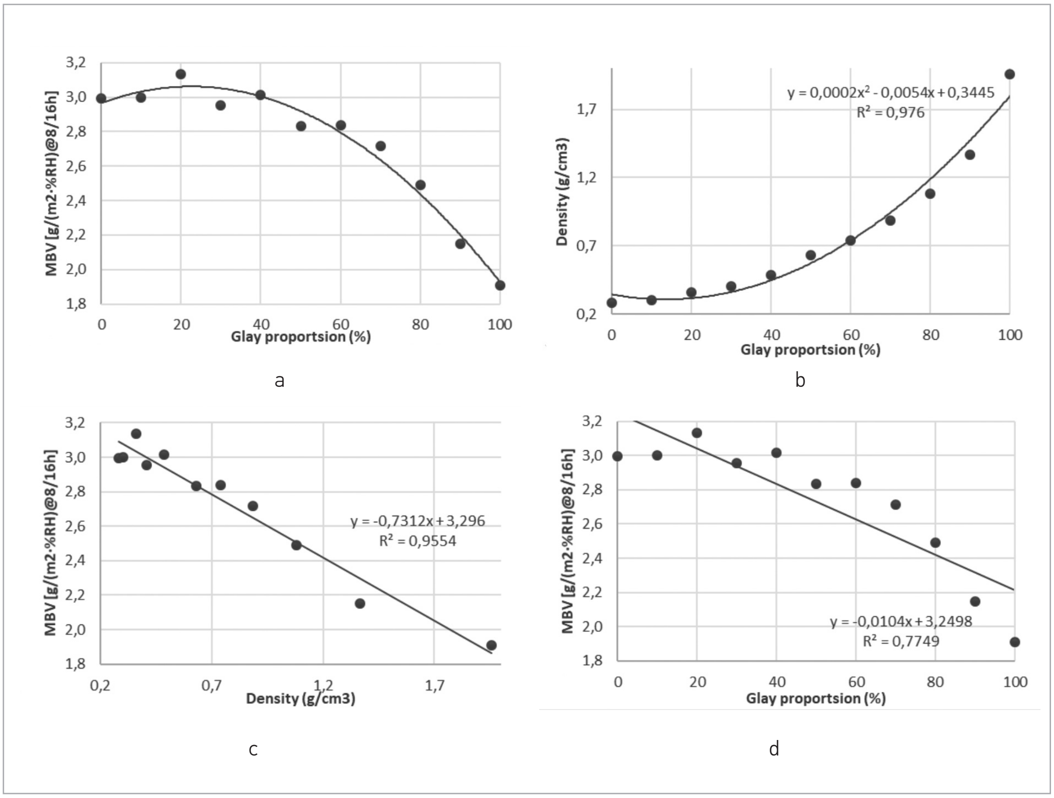
MBV of mixtures

Plaster group number	Paper %	Test 1 MBV [g/(m2·%RH)@8/16h]	MBV classification	Test 2 MBV [g/(m2·%RH)@8/16h]	MBV classification	Test 3 MBV [g/(m2·%RH)@8/16h	MBV classification
1	100	2.94	excellent*	3.05	excellent*	2.97	excellent*
3	90	2.99	excellent*	3.01	excellent*	3.10	excellent*
4	80	3.10	excellent*	3.17	excellent*	3.14	excellent*
5	70	2.91	excellent*	3.00	excellent*	3.01	excellent*
6	60	2.99	excellent*	3.04	excellent*	2.94	excellent*
7	50	2.78	excellent*	2.89	excellent*	3.01	excellent*
8	40	2.80	excellent*	2.88	excellent*	2.76	excellent*
9	30	2.65	excellent*	2.78	excellent*	2.68	excellent*
10	20	2.49	excellent*	2.49	excellent*	2.61	excellent*
11	10	2.18	excellent*	2.12	excellent*	2.31	excellent*
2	0	1.91	good*	1.91	good*	1.98	good*

*negligible (0-0.2), limited (0.2-0.5), moderate (0.5-1.0) good (1.0-2.0), excellent (2.0-).

Fig. 3

(a) MBV, (b) Density and clay proportion, (c) MBV and Density, (d) MBV and clay proportion



The ratio of clay and paper has a strong impact (R^2=0,976) on the density of the mixture (Fig. 3 (b)). The densities of mixtures (plaster groups 3 – 11) are in the range of ρ=0.3 - 1.4 (g/cm^3) (Table 2). The larger the proportion of paper in the mixture, the smaller the density of the mixture. Clay plaster mixture (plaster group 2) density is ρ=2.0 g/cm^3 and paper plaster (plaster group 1) mixture density is ρ=0.3 g/cm^3 (Table 2). The density, in turn, had a strong effect on (R^2=0,9554) the MBV of composite mixtures. The MBV increased as the density decreased (Fig. 3 (c)). The ratio of clay and paper (R^2=0,7749) also influenced the MBV. The higher the amount of paper was, the higher was the MBV (Fig. 3 (d)).

Conclusions

Our experiment portrayed that the hydrothermal properties of clay plaster mixture change when the paper is added to the mixture.

1. Adding paper to clay plaster mixtures enables the MBV's classification to change from "good" (1.0-2.0) to "excellent" (>2.0).
2. All the specimen tested in the experiment that had paper added to (10-90%) had a higher MBV (MBV= 2.12- 3.17 g/(m2·%RH)@8/16h)) then the specimen that was made of clay plaster only. Clay plasters MBV=1.91-1.98 g/(m2·%RH)@8/16h.
3. MBV is dependant on the amount of paper added to the plaster mixture. MBVs of plaster mixtures with different paper ratios differ from each other. Paper mixtures MBV=2.12 - 3.17g/(m^2·%RH)@8/16h.
4. The ratio of clay and paper and MBV were strongly connected (R^2=0,7749).
5. The proportion of paper in the mixture influenced the density of the mixture. The more significant the amount of paper in the mixture, the smaller the density of the mixture was. The density of paper mixtures ρ=0.3– 1.4 g/cm^3 and clay plaster ρ=2.0 g/cm^3.
6. There was a strong connection (R^2=0,976) between the components (clay and paper ratio) of the mixture and density.
7. The higher the density of the mixture, the lower the MBV.
8. There was a secure connection between density and MBV(R^2=0,9554).
9. Plaster mixture made of 80% paper had the highest MBV (accordingly 3.10, 3.17, 3.14 g/(m2·%RH)@8/16h)).

Discussion

The results of the study introduced in this article confirmed that by adding paper to clay plaster mixtures, the MBV of clay plaster is increased, which creates an opportunity to improve the properties of natural clay plaster and to improve the indoor climate of living spaces when using the created composite material.

Interior finishing materials have a significant effect on the indoor climate. The moisture buffering ability of materials is connected to the sorption and diffusion abilities. The materials used for interior finishing have an important role in the moisture stabilisation of indoor spaces. Household activities affect the humidity in living spaces and as a result relative humidity can become too high or too low. The experiment showed that using wastepaper as a plaster component affects the moisture buffering ability, thus, the plaster mixture passively regulates indoor climate, which in particular is important in the Nordic countries where people spend 70% of their time indoors.

Our hypothesis that adding paper to clay plaster increases the MBV was confirmed. The increase is caused by the difference in the technical properties of paper plaster and clay plaster moisture. Previous studies have shown that the technical properties of clay plaster moisture are not as good as the technical properties of paper plaster moisture (Altmäe et al. 2019) and the latter can be classified as a material with excellent moisture buffering abilities (Teearu 2018). Therefore, adding paper to the plaster mixture increases its MBV. To assess the effect of paper on the plaster's porosity more precisely it is necessary to study the sorption ability (absorption, desorption) of the plaster mixture. Before the results are put into practice in the construction industry it is necessary to study if the natural plasters intended to be used indoors can become suitable environments for microbes and mould to grow in due to their excellent moisture buffering ability. It is also necessary to study the long term effects on the indoor air quality to see if organic compounds are being separated into the air. The issues related to the fire resistance of plasters made of paper need to be studied as well.

Further research also starts to observe other moisture properties. The method described in the standard "EVS-EN ISO 12571:2013 Hygrothermal performance of building materials and products – Determination of hygroscopic sorption properties" is used to study the sorption of water vapour when determining the hygroscopicity of porous materials. In order to study the conductivity of water vapour, the method from "EVS-EN ISO 12572:2016 Hygrothermal performance of building materials and products - Determination of water vapour transmission properties - Cup method" was used.

Also, it is energy efficient to use local building material clay, and the use of wastepaper also supports the circular economy and environment-friendly principles. Before the results are put into practice in the construction industry it is necessary to study if the natural plasters intended to be used indoors can become suitable environments for microbes and mould to grow in due to their excellent moisture buffering ability. It is also necessary to study the long term effects on the indoor air quality to see if organic compounds are being separated into the air. The issues related to the fire resistance of plasters made of paper need to be studied as well.

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