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Characterising the moisture buffering potential of clay plasters

The beneficial moisture buffering characteristics of clay plasters have been well known for some time, and now this characteristic for passive moisture regulation is also increasingly recognised by the wider construction industry. Moisture Buffering Values (MBVs) quantify the response of materials to changes in the Relative Humidity (RH) of the surrounding environment. MBV is expressed as the mass of water vapour adsorbed by the material per unit area (m^2) for a defined change in RH%. Test procedures requires an environmental chamber within which specimens are initially conditioned at a lower RH (e.g. 30-50% RH). Once the mass of the specimen has stabilised for a defined period, the RH is increased step-change by some 20-50% RH for between 8 and 24 hours, and then reduced and held to the original RH to complete either a 24 hour or 48 hour cycle. The changes in specimen mass during the adsorption cycle, and sometimes the desorption cycle, are measured either continuously or incrementally. Cycles are repeated, typically 4–6 times, until the adsorption and desorption cycles have stabilised.

Presently there is no universally accepted methodology for measuring the MBV, with specimen details, moisture cycles and other test details varying. Recognised methods to measure MBV include JIS A 1470-1 (2002), the NORDTEST [Rode et al., 2005], ISO-24353 (2008) and DIN 18947 (2013). The experimental methods are similar, but they use different time-steps and RH levels. There also is an increasing recognition that measured MBVs are also influenced by the air flow and temperature within the environmental chamber [Gómez et al. (2011), Allinson and Hall (2012), Holcroft, 2016, and Zu et al. (2020)].

This paper presents results from an experimental programme to characterise the moisture buffering values of clay plaster specimens. The overall aim of this study has been to evaluate further the influence of clay plaster thickness on MBV but has been extended to study the significance of chamber temperature and RH variation, as well as test repeatability. The specific objectives of this study were to:

- Complete MBV testing of two proprietary clay plasters in accordance with DIN 18947 (2013) using specimens varying in thickness between 5 mm and 15 mm
- Evaluate the repeatability of MBV testing using DIN 18947, JIS A 1470-1 (2002), and NORDTEST [Rode et al., 2005] procedures.
- Explore the influence of test chamber temperature on MBV.

Research methodology

Two samples of clay plaster specimens were prepared for MBV testing. Each sample series comprised 15 specimens, made up of 3 × 5 specimens of nominal thickness 5, 8, 10, 12 and 15 mm depth. Two proprietary clay plasters were used in the study. The first was a natural clay plaster 'topcoat' containing chopped straw particles. The second plaster series were manufactured using a 'lime (stabilised) clay' plaster product. Both products were supplied as dry powder and were mixed with water to the appropriate consistency for plastering.

The 150 × 150 mm plaster specimens were cast into acrylic (plexiglass) moulds with vertical sides 5, 8, 10, 12 and 15 mm deep to control the plaster depth. These specimen dimensions and plaster depths were chosen following previous work [Maskell et al, 2018] had shown 'optimised' plaster thicknesses to be 8-12 mm. After casting the specimens were allowed to dry naturally in the laboratory environment for 14 days. Slight shrinkage cracking was noticed around the edges of

Table 1 MBV Tests

Plaster Type	MBV test standard	RH range	Cycle times	Temp. °C	Time increments hours	Specimens	Env. chamber model
Topcoat	DIN 18947	50-80%	12h/12h	23	½, 1, 3, 6, 12	3 × (5, 8, 10, 12, 15 mm)	VC3 0018*
Topcoat	DIN 18947 Repeat	50-80%	12h/12h	23	½, 1, 3, 6, 12	3 × (5, 8, 10, 12, 15 mm)	DY110***
Topcoat	NORDTEST	33-75%	16h/8h	23	½, 1, 2, 4, 8	3 × (5, 8, 10, 12, 15 mm)	DY110***
Topcoat	NORDTEST Repeat	33-75%	16h/8h	23	½, 1, 2, 4, 8	3 × (5, 10, 15 mm)	DY110***
Topcoat	NORDTEST Variation	40-60%	16h/8h	23	½, 1, 2, 4, 8	3 × (5, 8, 10, 12, 15 mm)	DY110***
Topcoat	NORDTEST Variation	33-75%	16h/8h	15	½, 1, 2, 4, 8	3 × (5, 8, 10, 12, 15 mm)	DY110***
Topcoat	JIS A 1470-1	53-75%	24h/24h	23	1, 2, 4, 8, 24	3 × (5, 8, 10, 12, 15 mm)	DY110***
Lime–clay	DIN 18947	50-80%	12h/12h	23	½, 1, 3, 6, 12	3 × (5, 8, 10, 12, 15 mm)	VC4034*

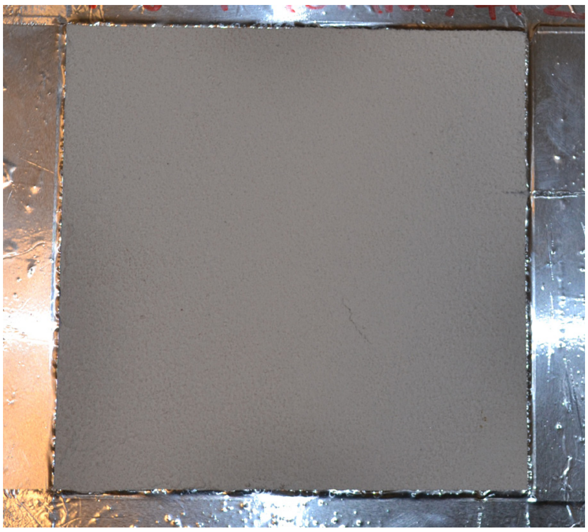
** Vötsch Environmental test chamber, model VC³ 0018*
*** ACS Compact Environmental test chamber, model DY110*
**** Vötsch Environmental test chamber, model VC4034*

the specimens. This gap was sealed using aluminium foil sealant tape wrapped carefully around the edges of the specimens (Figure 1).

The specimens were subject to a range of standard and modified MBV test regimes; these are outlined in Table 1. Prior to commencing each test series, the specimens were conditioned at the initial steady state conditions, for up to 7 days, in the environmental test chamber until they reached steady mass. The same natural clay topcoat specimens were used in all repeat tests.

The change in mass of each specimen was determined at a minimum of five time increments during the adsorption phase. The time increments for each series are listed in Table 1. The specimens were initially randomly located on the shelves of the chamber, but throughout each test series the same shelf location was maintained. At each time increment the specimens were removed from the chamber for a brief period to measure their mass (± 0.01 g). No measurements were taken during the desorption phase. In each test mass changes were determined for a minimum of four step-change RH cycles. The MBV value for each specimen was determined from the mass of water, expressed per unit area, adsorbed in the final cycle divided by the RH range over which the adsorption phase occurred; the units for MBV are $g/m^2.RH\%$.

01 MBV test specimen



Three different environmental chambers were used for the test programme. A Vötsch VC4034, at the Technical University of Berlin, was used for the lime clay plaster tests. A Vötsch VC³ 0018 was used for the first series on the natural clay topcoat series, located in the laboratory at ZRS Architekten Ingenieure, Berlin. All subsequent tests on the natural clay topcoat specimens were undertaken using the laboratory facilities at the University of Bath; an ACS Compact Test Chamber (DY110) was used for these tests (Table 1).

Experimental Results

In response to the stepped changes in chamber RH all specimens tested here developed a characteristic saw tooth non-linear curve response to increasing

Table 2 MBV test results

Plaster type	MBV test standard	RH range/ temperature	Average MBV (Coeff. of Variation (%) in brackets) g/m².RH%				
			5 mm	8 mm	10 mm	12 mm	15 mm
Topcoat	DIN 18947	50-80% 23°C	1.32 (1%)	1.87 (2%)	2.01 (2%)	2.18 (6%)	2.55 (5%)
Topcoat	DIN 18947 Repeat	50-80% 23°C	1.63 (2%)	2.02 (22%)	2.07 (19%)	2.44 (12%)	2.98 (11%)
Topcoat	NORDTEST	33-75% 23°C	0.93 (13%)	1.22 (13%)	1.31 (8%)	1.48 (10%)	1.68 (13%)
Topcoat	NORDTEST Variation	40-60% 23°C	0.84 (3%)	1.09 (6%)	1.07 (5%)	1.18 (5%)	1.32 (5%)
Topcoat	NORDTEST Variation	33-75% 15°C	0.86 (8%)	1.05 (16%)	1.11 (17%)	1.10 (2%)	1.14 (7%)
Topcoat	JIS A 1470-1	53-75% 23°C	1.33 (4%)	1.52 (10%)	1.66 (7%)	2.20 (6%)	2.45 (8%)
Lime–clay	DIN 18947	50-80% 23°C	0.36 (5%)	0.52 (4%)	0.58 (4%)	0.70 (5%)	0.84 (10%)

mass with time. Typical response curves, from the DIN 18947 series of tests, are shown in Figure 2 below; only the 5, 10 and 15 mm results are shown for clarity. As mass changes were only measured during the adsorption phase the non-linear responses during desorption phases are not shown.

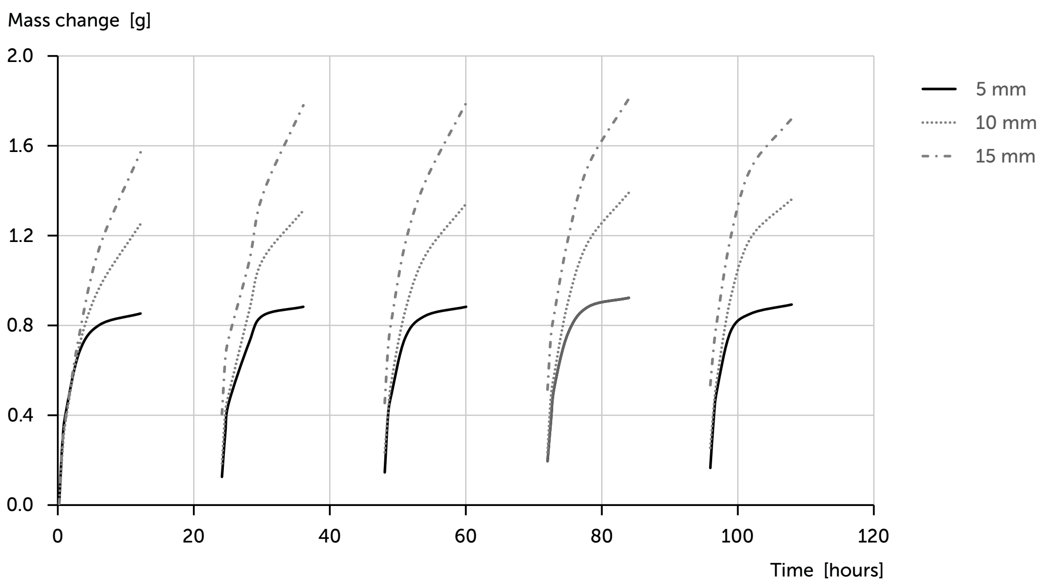
The calculated MBVs for the various test specimens and test regimes are presented in Table 2.

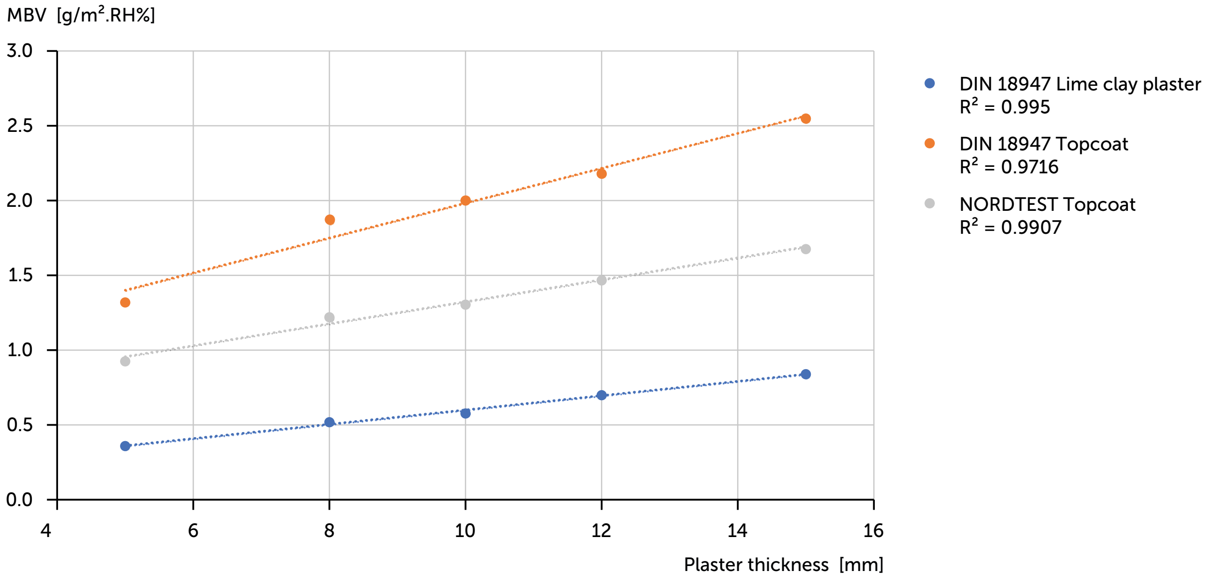
Discussion

The experimental MBVs for the topcoat plaster specimens varied with thickness, test procedure and environmental conditions. With one exception all tests were undertaken at a constant temperature of 23°C. The DIN 18947 procedure, varying between 50 and 80% RH, yielded the highest MBVs over a 12 hour adsorption cycle. In contrast the standard NORDTEST, with an 8 hour adsorption cycle, with RH changing between 33% and 75%, yielded the lowest MBVs. Interestingly the Japanese Standard procedure, with RH changing between 53% and 75%, over 24 hour adsorption and 24 hour desorption cycles, yielded MBVs most similar those recorded using the DIN 18947 test. A repeat of the DIN 18947 test yielded MBVs on average around 12% higher than measured initially. Variations in environmental chamber air velocity are known to influence MBV and could explain this change.

Previous tests have also shown the relationship between MBV and plaster thickness [Maskell et al, 2018].

02 Adsorption curves for topcoat plaster (DIN 18947 test)





03 Relationships between MBV and plaster thickness

Here a strong linear correlation was shown in performance using DIN 18947, the standard NORDTEST and the JIS test protocols; Figure 3. MBV increases with plaster thickness. However, the previous work has also shown that once plaster thickness exceeds 8-12 mm the MBV no longer increases, showing that additional plaster depth has no impact on water vapour exchange with the surrounding environment. For both, the natural clay topcoat plaster and the lime stabilised plaster, the plaster thickness at which MBV remained unchanged was greater than or equal to 15 mm. The MBVs for the lime stabilized plaster was around 2.5 times lower than the natural topcoat plaster for all thicknesses.

The NORDTESTs were intentionally altered to explore, independently, the influence of RH range and temperature on performance. In the first variation, maintaining a 8 hour adsorption cycle, the RH range was limited to 40-60%. This range is often seen as the ideal range to improve indoor environmental quality. Even though MBVs are expressed as per unit RH% the measured MBVs are 10-14% lower for the reduced RH tests. The lower peak RH reduces the total water vapour content in the chamber and as such explains the lower MBVs.

Reducing chamber temperature to 15°C had a more significant influence on MBV performance, with both lower MBVs but also results are in line with previous tests [Maskell et al, 2018] showing MBVs not increasing for plaster thickness greater than 8-10 mm. Although in the standard and modified tests the RH levels were maintained at 33% and 75%, lowering environmental temperature will significantly decrease the amount of water vapour in the atmosphere and hence the lower MBVs. It is open to question whether 23°C, the standard temperature for all MBV tests, is representative of many internal environments.

Conclusions

- The MBVs for earth plaster specimens were measured using a variety of tests. The MBVs increased linearly with plaster thickness over range 5-15 mm. Only when the environmental chamber temperature was reduced to 15°C did the MBVs stabilise with plaster thicknesses above 8-10 mm. So called optimal plaster thickness is evidently dependent on environmental conditions.
- MBVs for earth plasters are not fixed values, but vary depending on many factors including specimen thickness, environmental test conditions, and testing regime. For wider acceptance of moisture buffering materials in construction further standardisation of test procedures and recognition of these influences is required.
- The DIN 18947 test procedure recorded the highest MBVs, whilst the NORDTEST recorded the least. The Japanese Standard test with 53-75% RH showed greatest similarity to the DIN test results.
- The lime stabilised plaster showed significantly lower MBVs than the natural topcoat with straw. The 5 mm thick topcoat plaster exhibited a MBV

more than 50% higher than the 15 mm thick lime clay plaster specimen.
- Although there was some variation in the repeat testing of specimens the measurements were broadly consistent.

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