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DEVELOPMENT OF A BIO-BASED PLASTERBOARD

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Abstract

The use of gypsum plasterboard is ubiquitous within the construction industry and equates to an approximate 3.5% of the UK's green house gas emissions. Production alone accounts for 67% of gypsum plasterboard's life cycle global warming potential. Developing alternative boards, using materials with lower life-cycle impacts, offers significant scope to reduce current environmental impacts of plasterboard use. There has been an increase in research that demonstrates the potential of plasters with bio-aggregates to enhance indoor environmental quality. Board solutions that contain bio-aggregates within the core will help to further develop this potential. Such boards can be used in a conventional manner reducing on-site barriers to adoption, while offering a value added product with improved hygrothermal performance. This paper presents the development of an alternative plasterboard composed of hemp shiv which is bound by mineralogical aggregate composition. Different boards were developed using the binding properties of clay to ensure a low embodied environmental impact. The results of the different binding mechanisms of the clay based plasterboards were experimentally investigated and compared to conventional gypsum plasterboard. A range of mechanical and hygrothermal properties were investigated to establish the potential of a bio-based plasterboard. Standard test methods developed for gypsum plasterboard were used to establish the flexural, shear and impact resistance of the boards, while the investigation of hygrothermal properties considered the thermal conductivity, moisture buffering performance and isotherms. The alternative plasterboard had up to five times better moisture buffering properties compared to a gypsum plasterboard and a significantly lower thermal conductivity. While significant improvement of the hygrothermal properties have been observed, there has been a reduction in the mechanical performance of the alternative boards. However, rationale is presented indicating that the alternative plasterboards developed could be adopted in a comparable manner to conventional plasterboards, resulting in an improved indoor environmental quality with a reduced environmental impact.

Keywords:

Dry lining, moisture buffering, hygrothermal performance

1 INTRODUCTION

The use of gypsum plasterboard is ubiquitous within the construction industry accounting with 3.5 million tonnes being used within the UK every year (DEFRA, 2009). This is equates to an approximate global warming potential of up to 20MtCO2$_e$ representing 3.5% of all of UK's emissions in 2009. DEFRA (2010) addressed its high environmental impact with the Gypsum Products Development Association, resulting in zero waste to landfill and improvement in manufacturing processes. However, as the production of the gypsum plasterboard accounts for 67% of the global warming potential. There has been an increase in Gypsum plasterboard alternatives including magnesium oxide boards, magnesium silicate boards, with development considering the use of fibres within the gypsum plasterboard (Singh & Garg, 1994). This paper presents the development of an alternative low embodied environmental impact plasterboard with improved performance for the indoor environmental quality.

Gypsum plasterboard is typically used as part of a lightweight dry lining construction with a gypsum plaster skim that can form an airtight construction. A potential unintended consequence of the air-tight approach can be deterioration in the Indoor Environmental Quality (Crump *et al.*, 2009). A significant factor that affects the indoor environmental is the relative humidity of the air (RH), which influences the comfort of occupants and the Indoor Air Quality (IAQ).

Sterling et al., (1985) presented health and discomfort risks associated with the relative humidity, demonstrating that the optimum for both building fabric and occupants is between 40% and 60%. Relative humidity levels above 60% can lead to condensation within a building, resulting in the growth of micro-organisms whilst relative humidity levels below 40% are associated with discomfort and respiratory conditions (Fang et al., 1998, Toftum et al., 1998 and Luca et al., 2002). Interior moisture buffering by the building fabric can beneficially affect energy consumption, component durability, thermal comfort and air quality. Padfield (1998) demonstrated the enhanced moisture buffering potential of clay based materials compared to many other conventional materials. However, there is still a need for wider recognition of these effects and scientific characterisation of materials. Additionally, there is a growing interest in using aggregates to improve the humidity buffering properties of coating plasters (Maskell et al., 2017, Maskell et al., 2015b, Thomson et al, 2016).

While the effectiveness of subsurface layers on the ability to regulate the indoor environment has been questioned (Maskell et al., 2015a), plasterboard would typically be used for a carrier of a thin (approximately 3mm thick) layer of plaster. Under this construction, the effective depth of moisture buffering (Maskell at al., 2016) could be sufficient to mobilise the moisture buffering properties of the underlying plasterboard. Therefore, there is clear scope for the development of a plasterboard for regulation of moisture through the use of clay and bio-based aggregates.

The aim of the study presented in this paper was the characterisation of an alternative to gypsum plasterboard that has a lower embodied environmental impact as well as passive moisture management and thermal benefits with a reduced cost of disposal. The alternative board is based on clay and hemp shiv and is available from Adaptavate, and branded as “Breathaboard”. Objectives include material characterisation including mechanical and moisture buffering properties. This will be compared to gypsum plasterboard as a conventional and market-leading material. Additionally a conventional gypsum plaster skim was applied to both substrates to investigate the impact on moisture buffering of both plasterboards.

2 MATERIALS AND METHODS

2.1 Materials

The Breathaboard is at a prototype level of development, with samples used for the testing taken from small scale production runs. The Breathaboard is available at a thickness of 15mm; gypsum plasterboard is available in a range of thicknesses, with industry standard 12.5mm thickness selected here for purposes of comparison.

Figure 32 Breathaboard

Breathaboard is composed of hemp shiv bound with a mineralogical aggregate composition utilising the binding properties of clay. The resulting composite is referred to as a “biscuit”. This biscuit is sandwiched, with adhesive layers, between two pieces of building paper, which, when combined, make up the Breathaboard. The paper liners are comparable to those used to manufacture gypsum plasterboards. While the motive for the development of the Breathaboard is a lower embodied environmental impact compared to Gypsum plasterboard, a life cycle analysis is outside the scope of this paper. However, focussing on the embodied impact of the materials only, indicates that the Breathaboard composition will give significant reduction compared to gypsum (Hammond et al., 2008).

2.2 Methods

As there are as yet no standard test methods for clay-hemp boards, tests generally followed procedures developed for gypsum board products. (EN 520, 2004).

Flexural Strength

The flexural strength test method was carried out according to EN 520 §5.7. The flexural strength of plasterboards is characterised by the flexural breaking load. Specimens (400 x 300) mm cut from full size boards were subjected to a load rate of 250 N/min until failure. The deflection was also continuously measured. As a result of the manufacturing processes of both products, the flexural breaking loads are dependent on the direction of applied load, so results are expressed for both longitudinal and transverse spanning directions.

Shear Strength

The tests to determine shear strength (of the board/substructure connection) were conducted in accordance with BS EN 520 §5.8. Two identical plasterboard samples are fixed either side of two timber members. To load the connectors the timber members are pulled apart at a rate of 10mm/min, with the load continuously measured until the connection fails. The breaking load per faster is subsequently calculated from the experimental peak load.

Thermal performance

Thermal conductivity of the Breathaboard samples was determined using using a heat flow meter apparatus following ISO 8301:1991 and ISOMET surface probe. The specimens for the heat flow meter measured 600 mm x 600 mm x 15 mm thick. The mean temperature was set at 10°C with a temperature differential of 20°C. The ISOMET probe was used under ambient conditions.

Moisture Buffering

Moisture buffering properties were determined in accordance with ISO 24353:2008, that calculates the total absorption and desorption of water vapour by a step change. The cyclic test method for middle humidity level was adopted. This method required specimens to be pre-conditioned at a relative humidity of 63% and a temperature of 23°C before testing commenced. Four cycles of the following conditions were run, during which the specimen mass was recorded:

- Step 1: 12h, Relative Humidity of 75% and temperature of 23C;
- Step 2: 12 h, Relative Humidity of 50% and temperature of 23C.

The test specimens, measuring 150 mm x 150mm, were tested using environmental chambers programmed to subject the specimens to the standard humidity cycles set out by ISO 24353:2008. Balances installed inside the chambers were used to record individual specimen masses at 5 minute intervals. An open topped screen was placed around the mass balance to minimize the influence of air movement over the surface of the specimens during testing. An anemometer was used to measure wind speed at the specimen surface and was found to be on average 0.1 m/s.

3 RESULTS AND DISSCUSION

3.1 Physical properties

The density of both the Breathaboard and the gypsum plasterboards were measured for specimens of various sizes at 23C and 50% RH. Density of the Breathaboard was measured at 650kg/m^3 with a Coefficient of Variation (CoV) of 5.4%. This is similar to the gypsum plasterboard, which had a measured density of 658kg/m^3 with a CoV of 1.1%.

A particle size distribution, based on mass, of the hemp shiv used in the Breathaboard was established using sieves ranging from 8mm to 0.063mm, and presented in Figure 2. Hemp shiv is anisotropic, being flat and longitudinal, resulting in difficulties in measuring particle size by sieving alone. In addition to the shiv, a small amount of hemp fibre within the sample was retained by the 8mm and 4mm sieves, however, this was insignificant with respect to the total mass. Almost all of the particles were in range of 4mm to 0.25mm, with the majority of these being in the range of 4mm to 0.5mm.

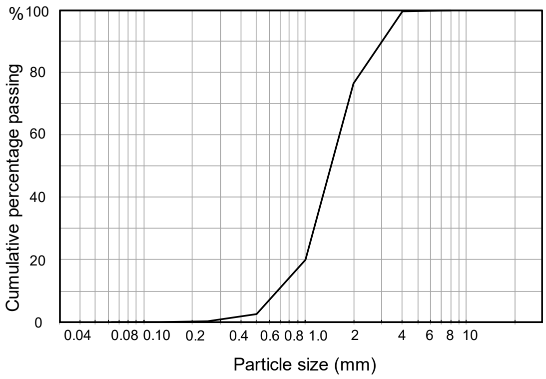

Figure 33 Particle Size Distribution of Hemp Shiv

3.2 Flexural resistance

The mean average flexural resistance of three Breathaboard specimens and three gypsum plasterboard specimens, in both the longitudinal and transverse direction of the boards, are presented with the CoV in Table 9.

BS EN 520 states in §4.1.2.1. that the flexural breaking load of gypsum plasterboard should not be less than 650N in the longitudinal direction and 250N in the transverse direction, based on a comparable 15mm thickness. For gypsum plasterboard with a 12.5mm thickness the flexural breaking loads should be 550N and 210N for the longitudinal and transverse directions respectively. Table 9 shows that the mean values for the gypsum plasterboard tested are below standard and actually equate to a thickness of 10.5mm in the longitudinal direction and 10mm transversely.

The failure modes of the Breathaboard samples varied depending on load direction. The longitudinal loading resulted in a sudden and brittle failure, however, those specimens tested in transverse flexure were less brittle. When loading in the longitudinal direction the paper readily de-bonded from the clay-hemp substrate, whereas this did not occur during the transverse loading. It is expected that this variation of the de-bonding of the paper is the cause for the different flexural behaviour.

Table 9 Flexural Results

	Max. Load (N)	Central deflection at Max. Load (mm)
Breathaboard Longitudinal direction	215	12.6
CoV	15%	21%
Breathaboard Transverse direction	155	20.0
CoV	27%	32%
Gypsum. Longitudinal direction	451	10.5
CoV	1.3%	1.6%
Gypsum. Transverse direction	168	13.2
CoV	0.9%	3.9%

Both of the two gypsum plasterboard samples behaved in a less brittle manner. Failure was observed to occur more suddenly in the longitudinal specimens than the transverse. Visual inspection showed that mid-span cracks in the transverse samples did not propagate through the full width, whereas this did occur in the longitudinal samples.

3.3 Shear Strength

Results for the shear strength of the two plasterboard types are presented in Table 3. The average maximum load, for the three specimens tested for each type of plasterboard, are presented with the CoV.

Table 10 Shear results

	Maximum Load/ per fastener (N)
Breathaboard Shear	90
CoV	23%
Gypsum. Shear	443
CoV	2.8%

Failure of the Breathaboard specimens was localised around the screw (Figure 3), resulting in global rotation of the test set-up (Figure 4). Shear strength is typically not measured for standard gypsum plasterboard, with No Performance Data "NPD" listed under the declaration of performance for plasterboard by British Gypsum (2016) and Knauf (2016). However, Table 10 shows that the tested gypsum plasterboard had nearly five times higher shear resistance compared to the Breathaboard samples. The failure modes for the two materials also differed. In the gypsum tests the plasterboard was seen to crush around the screws, whereas a splitting failure mode was observed in the Breathaboard.

Although the shear strength is significantly lower for the Breathaboard specimen compared to the gypsum plasterboard, it is sufficient for the intended purpose. The mass of a Breathaboard is 9.3kg, which is only slightly greater than the maximum load for a single fastener. Therefore only two fasteners are required to support each board.

3.4 Thermal Properties

The average thermal conductivity of three specimens was measured as 0.085 W/mK and 0.106 W/mK by the Heat Flow Meter and ISOMET Probe respectively. The measured thermal conductivity is a significant improvement compared to the design thermal conductivity for gypsum plasterboard, taken as 0.25 W/mK (BS EN12524).

Figure 34 Breathaboard Localised Splitting Failure

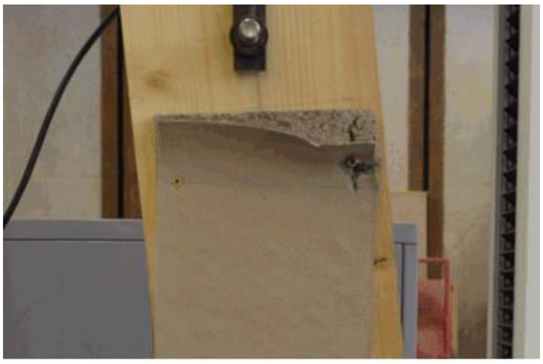

Figure 35 Global Splitting failure

3.5 Moisture Buffering

The average moisture buffering properties of four Breathaboard specimens and four gypsum plasterboard specimens were determined. The measured mass change is presented in Figure 5 with the moving average (taken over 5 minute periods) rate of moisture sorption across the samples presented in Figure 6.

The moisture buffering properties are not considered in BS EN 12524:2000, but are being increasingly investigated throughout the literature (McGregor et al., 2016). The moisture buffering properties of the Breathaboard are significantly higher than 15mm gypsum plasterboard from a statistical perspective. The Breathaboard has a similar moisture buffering performance to a commercial 20mm wet-applied base coat of clay plaster (Thomson et al., 2015).

The capacity of gypsum plasterboard to buffer humidity is lower and reaches this capacity within 1.5 hours. This is observed by a plateau in mass gain as seen in Figure 5. However, it can also be seen in Figure 5 and 6 that the gypsum has a higher rate of change compared to the Breathaboard. This indicates that the gypsum plasterboard could change an internal environment more quickly, but due to its limited moisture sorption capacity would have less overall effect than the Breathaboard for a similar quantity of material exposed (Figure 5).

3.6 The effect of a gypsum skim on performance

Three specimens of Breathaboard with a gypsum skim and three specimens of gypsum plasterboard with a gypsum skim have been tested. Figure 38 shows the change in mass against time for the 4th cycles of the Breathaboard and gypsum plasterboard respectively.

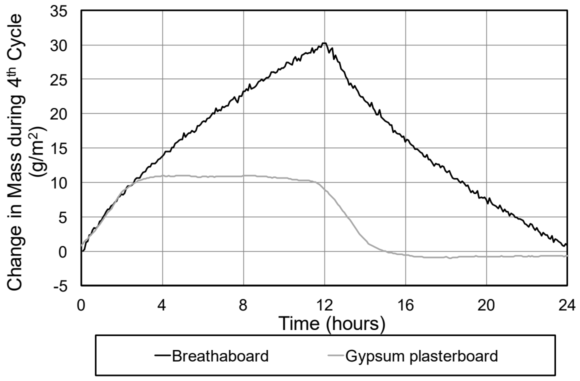

Figure 36 Mass change during 4th cyclic humidity change

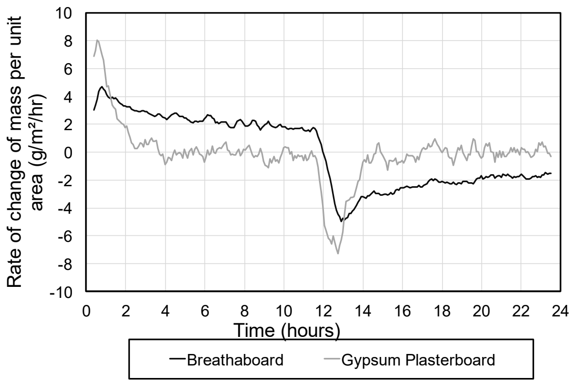

Figure 37 Rate of change during fourth cycle

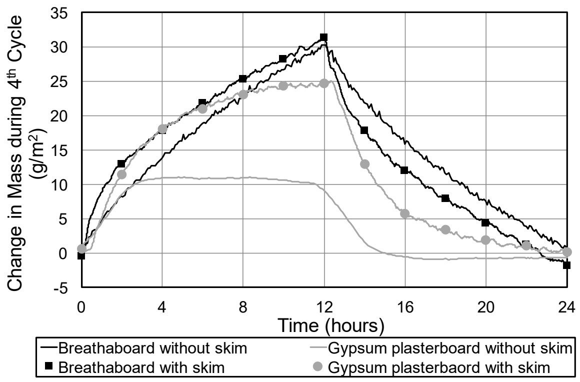

Figure 38 4th Cycle of boards with and without a gypsum skim

The moisture buffering content of the Breathaboard was not significantly enhanced by the application of a 3 mm thick gypsum skim, but importantly there was no significant detriment. However, the peak rate of change, measured within the first two hours of humidity change, significantly increased (Table 4). This is in contrast to the addition of a gypsum skim on the the gypsum plasterboard where the moisture buffering content increased, with minor improvement in the rate (Table 3). At the end of the 12 hour cycles the rate of change in gypsum plasterboard with a skim coating was almost zero, as opposed to the rate of change of both Breathaboard samples, which still had a significant change in mass occurring. Under longer periods of high humidity, more than 12 hours, the Breathaboard is likely to see further absorption whereas the plasterboard with a gypsum skim will not.

Table 11 Peak Adsorption and Desorption Rates of gypsum Plasterboard

	Adsorption Rate ($g/m^2/hr$)	Desorption Rate ($g/m^2/hr$)
Plasterboard without skim	6.7	6.5
Plasterboard with skim	7.5	7.9
Percentage Improvement	11.9%	21.5%

Table 12 Peak Adsorption and Desorption Values of Breathaboard

	Adsorption rate ($g/m^2/hr$)	Desorption rate ($g/m^2/hr$)
Breathaboard without skim	4.2	4.6
Breathaboard with skim	9.1	8.6
Percentage change with application of skim	117%	87%

4 SUMMARY

The Breathaboard has demonstrated favourable hygrothermal properties compared to gypsum plasterboard. Future development of the materials would focus on improvement of the flexural strength of the Breathaboard. This has been the only criteria where performance has been notably lower than the gypsum product although this is not expected to limit the general application of the board. Development of the flexural strength to meet the minimum required from the standard would potentially allow for certification and greater uptake.

The Breathaboard has three times the humidity buffering capacity of gypsum plasterboard when tested under the ISO 24353:2008 middle-humidity profile. The moisture buffering properties are not negatively effected by the addition of a gypsum skim. The addition of a gypsum skim improves the initial response of the Breathaboard to a change of humidity.

Further development of the board will focus on the adhesion of the outer paper coating and the mineral binder. This will improve the mechanical properties of the board. This paper has demonstrated the feasibility of producing a bio based, low environmental impact plasterboard that can have a significant impact within construction due to its similar form factor of existing products.

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