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An experimental investigation on equilibrium moisture content of earth plaster with natural reinforcement fibres for straw bale buildings

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ABSTRACT

This work focuses on the determination of equilibrium moisture content (EMC) of natural plaster materials for straw bale buildings. Earth plasters of four different compositions of cohesive soil and sand combined with reinforcement of three different natural fibre types, wheat straw, barley straw and wood shavings, were investigated. The plaster materials were treated under different temperature (10–40 °C) and relative humidity (43–95%). The moisture content is in dynamic equilibrium with environmental condition. The effect of relative humidity is more pronounced than temperature. The test results are discussed with reference to the relevance of the earth plasters as rendering for straw bale buildings. Guggenheim-Anderson-de Boer (GAB) model is used to fit the experimental data.

1. Introduction

Earth plasters are experiencing a renaissance in sustainable building. Earth plasters may serve many functions in straw bale buildings, such as protecting the underlying surface, enhancing or preventing the migration of vapor or liquid moisture, mitigating the migration of air currents and carrying structural loads. When a hygroscopic material is placed in air, water molecules are constantly leaving and returning to its surface depending on the relative humidity of the air. If the same number of water molecules return to the surface as that leave it an equilibrium condition exists. Since the material is neither gaining nor losing water, it is said to have reached equilibrium moisture content (EMC). When air remains in contact with the material for sufficient time, the partial pressure of the water vapor in the air reaches equilibrium with the partial pressure of the water vapor in the material. The EMC is a dynamic equilibrium and changes with relative humidity and temperature of the surrounding air.

Recently, straw bale construction, either load-bearing or non-load-bearing is experiencing a renaissance. Usually, a straw bale wall consists of straw bales with skin of earth plaster for surface protection. The EMC of straw bale is of importance for the long term performance of straw bale buildings. High moisture content promotes microbial activities and gives rise to biological decomposition of straw fibre. However, the EMC of straw bale walls depends not only on the hygroscopic properties of straw but also on earth plaster. Whereas there are numerous studies on the EMC of straw bale, little is known of the hygroscopic properties of earth plaster.

Ashour [1] reported that the EMC of wheat straw increases with increasing relative humidity and decreases with rising temperature. The relative humidity has greater effect on the EMC of bales than temperature. For straw bale buildings EMC of about 15% seems to be safe and corresponds to the water activity level or equilibrium relative humidity [2]. The EMC of a biological material can be reliably measured after the material has exposed to an environment with constant temperature and relative humidity for an infinitely long period of time [3]. On the other hand, retted flax straw can be preserved for several years if the moisture content is kept below 15%. However, if the moisture content is above 16%, the

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Table 1
Mixing percentages for experimental recipes.

Earth plaster recipes	Wood shavings			Wheat straw			Barley straw		
	Soil (%)	Sand (%)	Reinforcement fibres (%)	Soil (%)	Sand (%)	Reinforcement fibres (%)	Soil (%)	Sand (%)	Reinforcement fibres (%)
A	25	0	75	25	0	75	25	0	75
B	25	25	50	25	25	50	25	25	50
C	25	50	25	25	50	25	25	50	25
D	25	75	0	25	75	0	25	75	0

Fig. 1. EMC test samples inside air-tight plastic bag.

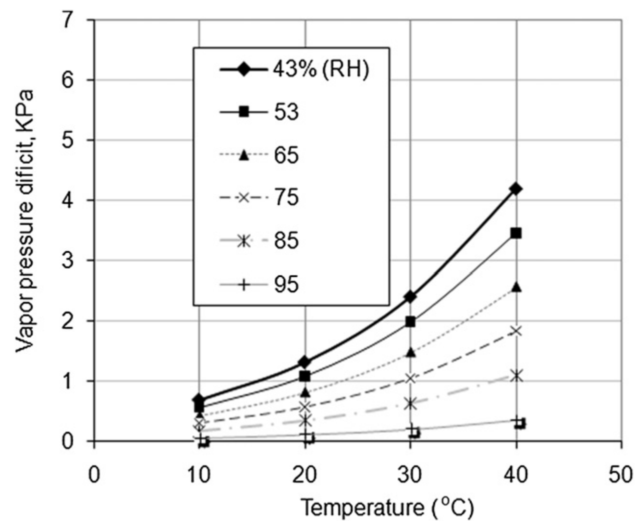

Fig. 3. Vapor pressure deficit at different environmental conditions.

Table 2
Chemical substances used for adjusting different relative humidity values.

Name	Materials	Relative humidity (%)
Sodium sulphate	$Na_2SO_4 \cdot 10H_2O$	95
Potassium chloride	KCl	85
Sodium chloride	NaCl	75
Sodium nitrite	$NaNO_2$	65
Magnesium nitrate	$(MgNO_3) \cdot 6H_2O$	53
Potassium carbonate	$K_2CO_3 \cdot 2H_2O$	43

retting process will continue during storage, resulting in fibre quality deterioration [4]. Damp crop stems are also more difficult to process due to higher friction [5]. Moreover, moisture content above 18% encourages fungi, which are present in wood and straw as spores, and may degenerate cellulose to create what we know as "dry rot". When the moisture content is below 18%, fungi become dormant. If the moisture content exceeds a certain level, fungi may grow exponentially [6].

Furthermore, the deterioration of straw can also be due to microbial activities, such as growth, survival, death, sporulation and toxin production of microorganisms. These activities are dependent on environmental variables such as temperature, pH, oxygen, radiation and moisture. Moisture for microbial activity is measured as water activity, which is numerically equal to the equilibrium relative humidity. When the equilibrium relative humidity is kept below 70%, the microbial activity is largely

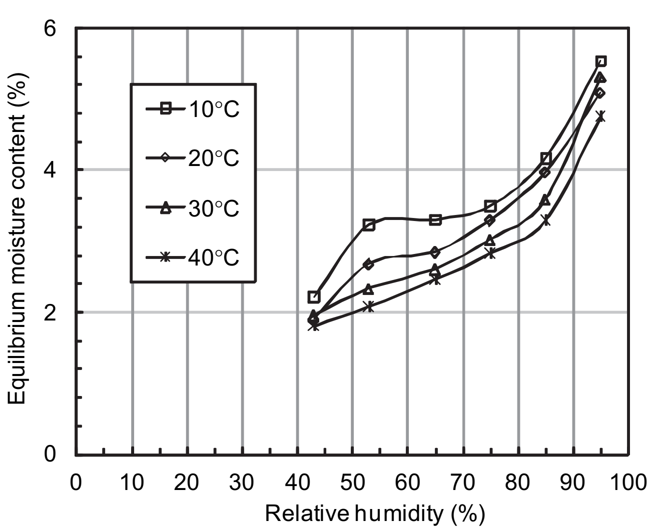

Fig. 2. EMC of recipe A for plaster reinforced by wheat straw fibre.

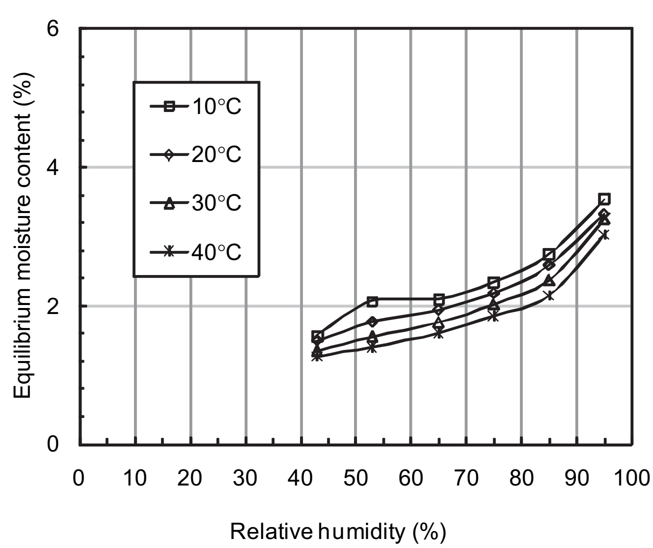

Fig. 4. EMC of recipe B for plaster reinforced by wheat straw fibre.

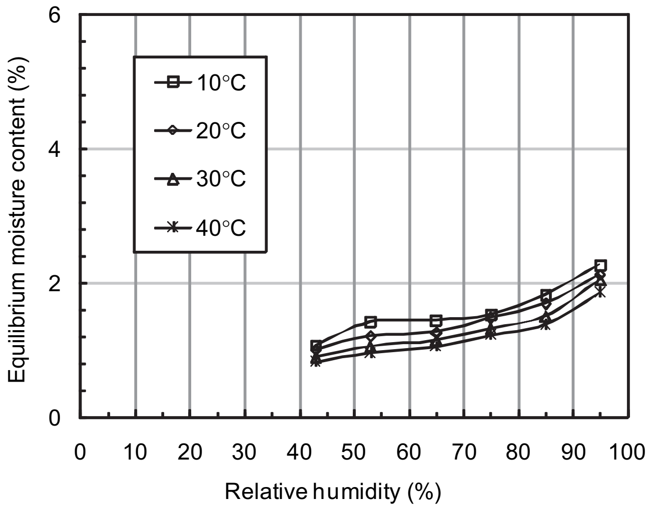

Fig. 5. EMC of recipe C for plaster reinforced by wheat straw fibre.

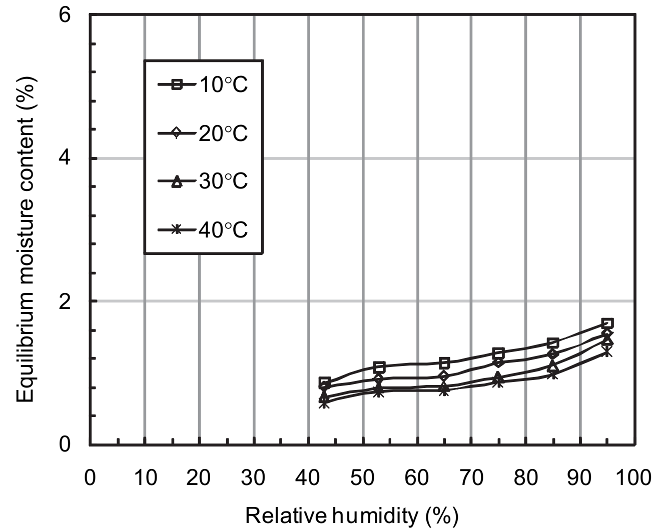

Fig. 6. EMC of plaster without reinforcement fibre.

harnessed and the straw remains stable [7]. Absorbent materials such as wood, paper and cotton stabilize the atmosphere against the changes in relative humidity by temperature variation and by exchange of air with the surrounding [8]. The influence of temperature and humidity on permeability is mainly dictated by the hygroscopic properties of the materials, the permeability to airflow and their capillary transfer ability [9]. The EMC of un-retted and dew-retted flax straw, un-retted and frost-retted hemp stalks and spring-harvested reed canary grass were determined and fitted to five commonly used three-parameter EMC equations [10]. All

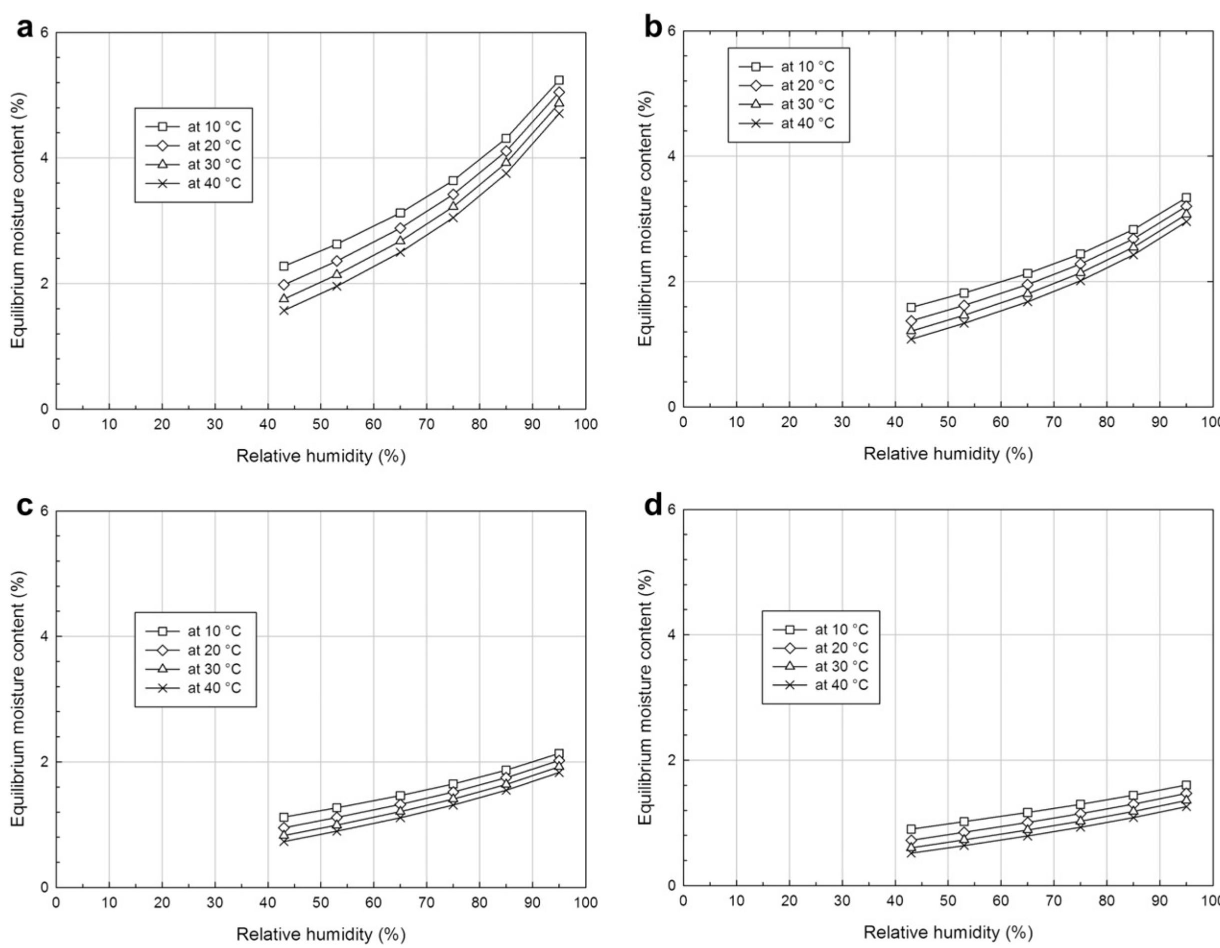

Fig. 7. EMC predicted with the GAB model, (a) Plasters reinforced with wheat straw for recipe A, (b) Plasters reinforced with wheat straw for recipe B, (c) Plasters reinforced with wheat straw for recipe C, and (d) Plasters without reinforcement of fibres.

building materials tested were susceptible to mold growth in humidities higher than 90% relative humidity at temperature above 15 °C [11]. In general the adsorption rate is dependent on both the temperature and the relative humidity [12,13], while successive adsorption–desorption cycles at a temperature of, e.g. 25 °C shift the isotherms downward for canola [14].

There are many methods for determining the EMC. The most commonly used methods are the static and the dynamic gravimetric methods [15]. In the static method, the sample reaches the EMC in still air moistened by various salt solutions, whereas in the dynamic method the air is mechanically moved and often moistened by air conditioning units [3,16].

Several isotherm models have been proposed to fit EMC data from Agricultural products [17]. The most commonly used model is Guggenheim-Anderson-de Boer (GAB) model. The modified GAB model gives a better fit of moisture contents [18–20].

1.1. Objective

Due to the lack of information about the relation between plasters and the outside conditions such as temperature and relative humidity especially these plasters will be used for straw bale buildings. Because of the moisture immigration from the outside condition to the straw bale walls through these plasters will effect on the walls, and makes its deterioration. The main aim of this work is to obtain the EMC curves of natural plaster materials reinforced by different natural fibres such as wheat straw, barley straw and wood shavings.

2. Experimental procedures

2.1. Materials tested

Three different materials are used cohesive soil, sand and reinforcement fibres. The composition of the cohesive soil texture is as follows: 31% clay (< 2 μm), 22% silt (20–63 μm) and 47% sand (63–2000 μm). Three different fibre types, barley straw, wheat straw and wood shavings are used. The wheat and barley straw were harvested in 2008 and wood shaving is usually used for animals as litter material. The length of straw is about 5 cm, while the length of wood shavings is about 2 cm.

2.2. Sample preparation

At first, the oversized gravels and organic matter (grass root) were removed from the natural cohesive soil. The soil was then oven dried at the temperature of 105 °C to obtain a constant mass. After the drying process, the hard soil lumps were broken up with a hammer. The natural fibres were also oven dried at 105 °C to constant mass.

Different recipes of earth plasters with different compositions of cohesive soil, sand and fibre were used for testing. The dosing of different materials was controlled by volume with given density. This was done by compressing the materials in a mold. The densities of wheat straw, barley straw and wood shavings are 103.6 kg/m^3, 106.9 kg/m^3 and 111.4 kg/m^3 respectively. The densities of soil and sand are 1666.8 kg/m^3 and 1974.4 kg/m^3 respectively. The soil and the fibre of a given recipe were placed in

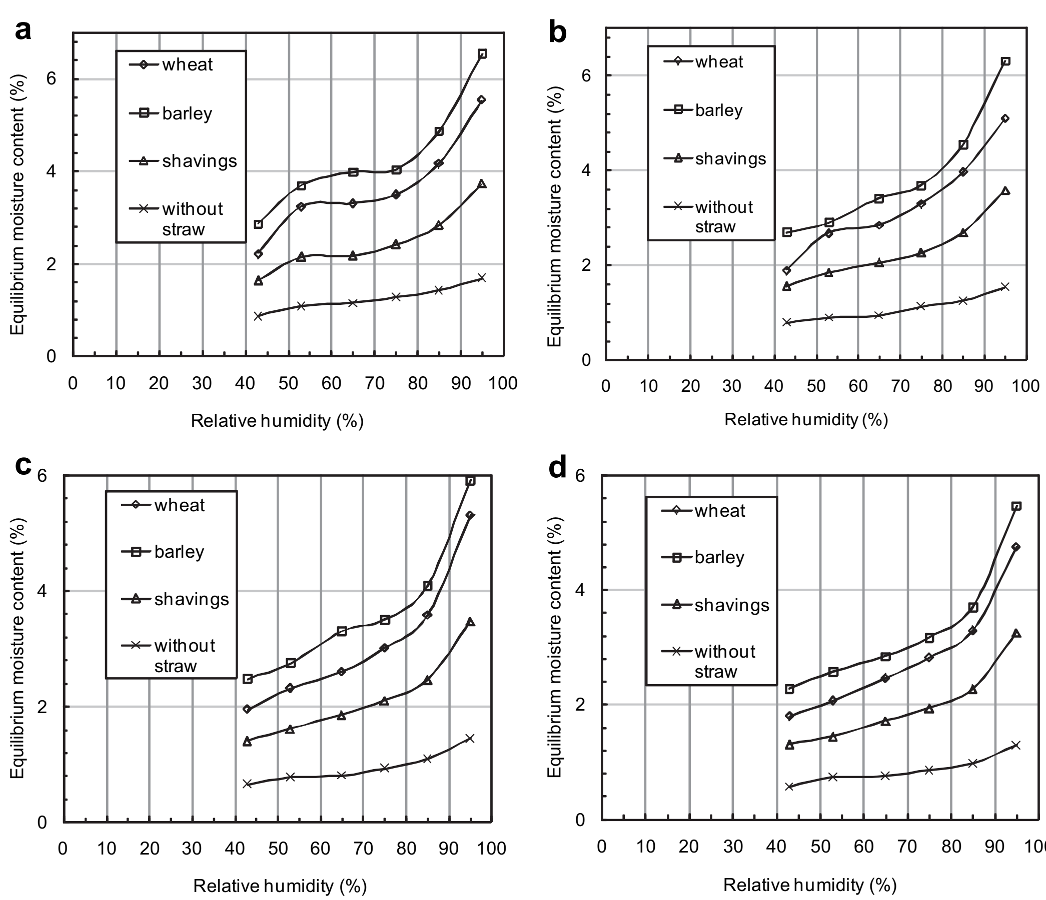

Fig. 8. EMC of recipe A for different plasters, (a) 10 °C, (b) 20 °C, (c) 30 °C and (d) 40 °C.

a container and mixed by hand without water until the different materials were homogeneously distributed. Afterwards, 2 L water was sprayed over the materials and the materials were mixed by hand for about 15 min until a homogenous mixture was obtained. The soil-fibre mixture was left to rest for about 30 min and then manually mixed for about 15 min. Earth plaster of four different recipes combined with three different natural fibres used in the EMC tests are given in Table 1. The compositions of the materials in Table 1 are given in volume percentage with the average material densities mentioned above.

The soil-fibre mixture was poured into a steel mold placed on a wood board. The steel mold has a side length of 5 cm, and a depth of 5 cm. The surface was leveled and compressed with a loading plate under a force of about 50 kg, which simulates the plaster preparation on site. Afterwards, the steel mold was lifted leaving an earth plaster sample on the wood board. The samples were further dried in an oven at a temperature of 105 °C to obtain a constant mass, which was controlled by weighing the samples every 24 h.

2.3. Test procedure

The EMC test was conducted according to [21]. The samples were placed on a wire mesh over a plastic box containing a saturated salt solution. The samples together with the wire mesh and box were in a basket. The basket was placed in an air-tight plastic bag as shown in Fig. 1.

These bags were placed inside a climate chamber at different temperatures (10, 20, 30 and 40 °C) and relative humidity levels (43, 53, 65, 75, 85 and 95%). For each relative humidity, straw type and treatment three samples of the same material were used as replicates. In all 54 samples of each material were used.

The climate inside the bags was monitored by combined T/RH sensors. After 2–3 weeks, when constant relative humidity inside the bag was achieved, the samples were weighed and the moisture content was calculated.

A climate chamber was used for the storage of the baskets under controlled temperature. The capacitive humidity sensors (Ahlborn FH 9646; maximum linearity deviation ± 2% for RH and 0.1 K for temperature accuracy) for climate control inside the bags contain a glass substrate with a humidity-sensitive polymer layer between two metal electrodes. By absorption of water, corresponding to the relative humidity, the dielectric constant and the capacity of the thin-film capacitor change. The measuring signal is directly proportional to the relative humidity and is independent of the atmospheric pressure.

2.4. Chemical substances

In order to obtain different relative humidity in the surrounding, some chemical substances were used (Table 2).

2.5. Moisture content equation

The materials were dried according to the German Norm DIN EN ISO, 12570 [22]. Moisture content (MC, %) is obtained according to

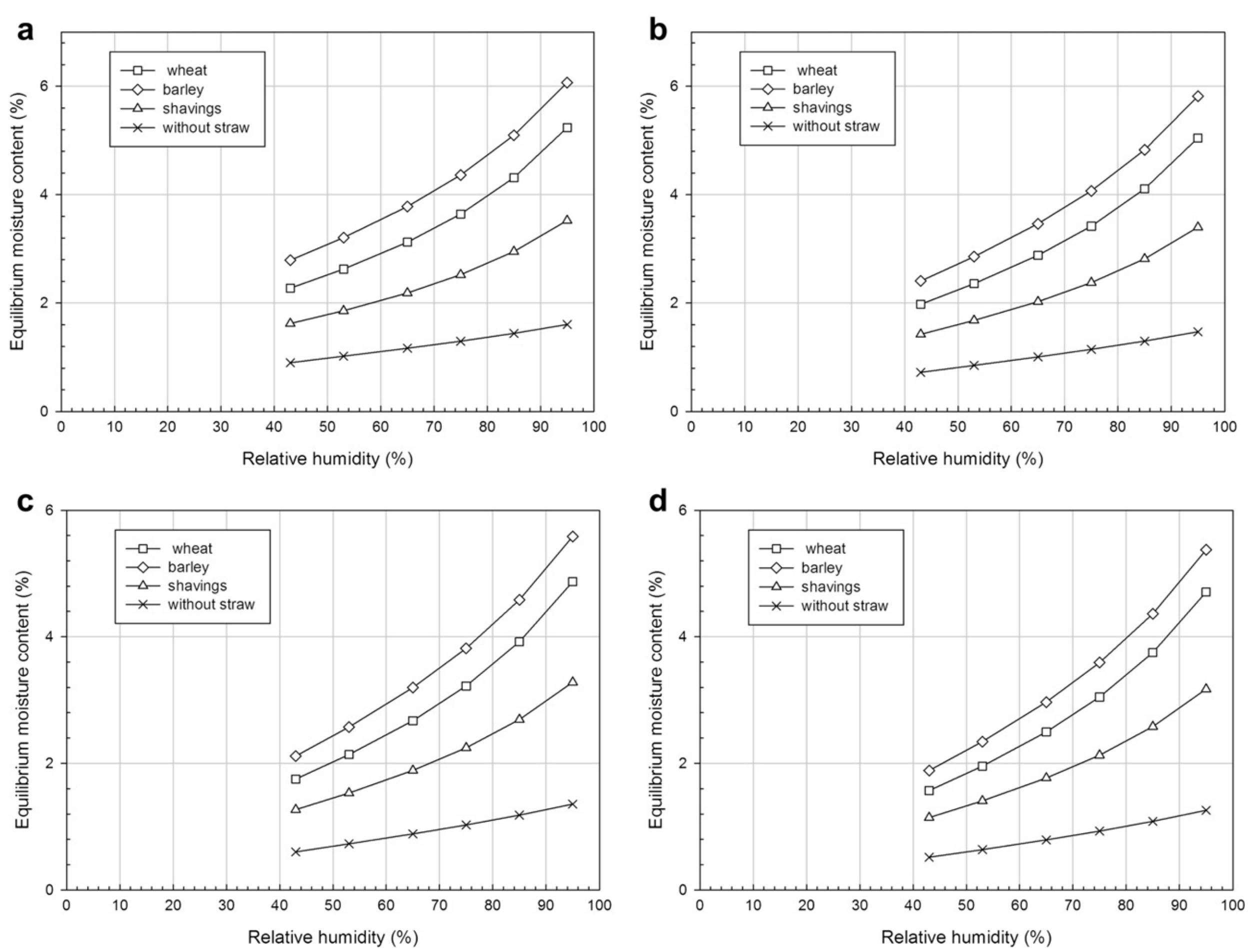

Fig. 9. EMC predicted with the GAB model of plasters reinforced with different fibres for recipe A, (a) 10 °C, (b) 20 °C, (c) 30 °C and (d) 40 °C.

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$$\mathrm{MC} = \frac{W_m - W_d}{W_d} \times 100 \quad (1)$$

where, W_m is the moist weight and W_d is the dry weight. The average of replicates is taken for further statistical analysis.

2.6. Data analysis by using GAB model equation

The average EMC of all replicates is calculated, and the constants A, B and C in the GAB model isotherm equation are determined using the nonlinear regression procedure NLIN in the SAS statistical package (SAS Institute Inc., Cary, NC, USA).

The following equation is the modified GAB model [10,17]:

$$M = \frac{\mathrm{abH_R}\left(\frac{c}{T}\right)}{\left(1 - \mathrm{bH_R}\right)\left(1 - \mathrm{bH_R} + \mathrm{bH_R}\left(\frac{c}{T}\right)\right)} \quad (2)$$

where M is the moisture content, % db, H_R is the relative humidity (decimal), T is the temperature, a, b and c are constants.

This procedure minimizes the sum of residual squares in an iterative process. The fit goodness of each model is assessed by the mean relative percentage deviation P and the root mean square of the residuals or the standard error of estimate E_S

$$P = \frac{100}{N}\sum\frac{|Y - \hat{Y}|}{Y} \quad (3)$$

$$E_S = \sqrt{\frac{\sum(Y - \hat{Y})^2}{d_f}} \quad (4)$$

where, Y and $\hat{Y}$ are the measured and predicted equilibrium moisture contents in % (db); N is the number of data points; and d_f is the degrees of freedom.

3. Results and discussion

3.1. Plaster material reinforced by wheat straw fibre

3.1.1. Recipe A

Fig. 2 presents the EMC equilibrium moisture content of recipe A at different relative humidities and temperatures. The samples were placed under conditions of relative humidity of 43–95% and temperature of 10–40 °C.

The results revealed that the EMC of plaster material reinforced with wheat straw fibre increases with increasing relative humidity but decreases with increasing temperature. It seems that the relative humidity has greater effect on the EMC than temperature. Changing the relative humidity from 43% to 95% leads to an increase of 3.3% in moisture content of the plaster at 10 °C. On the other hand, increasing the temperature from 10 to 40 °C caused a decrease of 0.4% in the equilibrium moisture content EMC of the material at 43% relative humidity. Increasing the relative humidity from 43% to 95% at 40 °C gave rise to an increase of 3.0%, compared

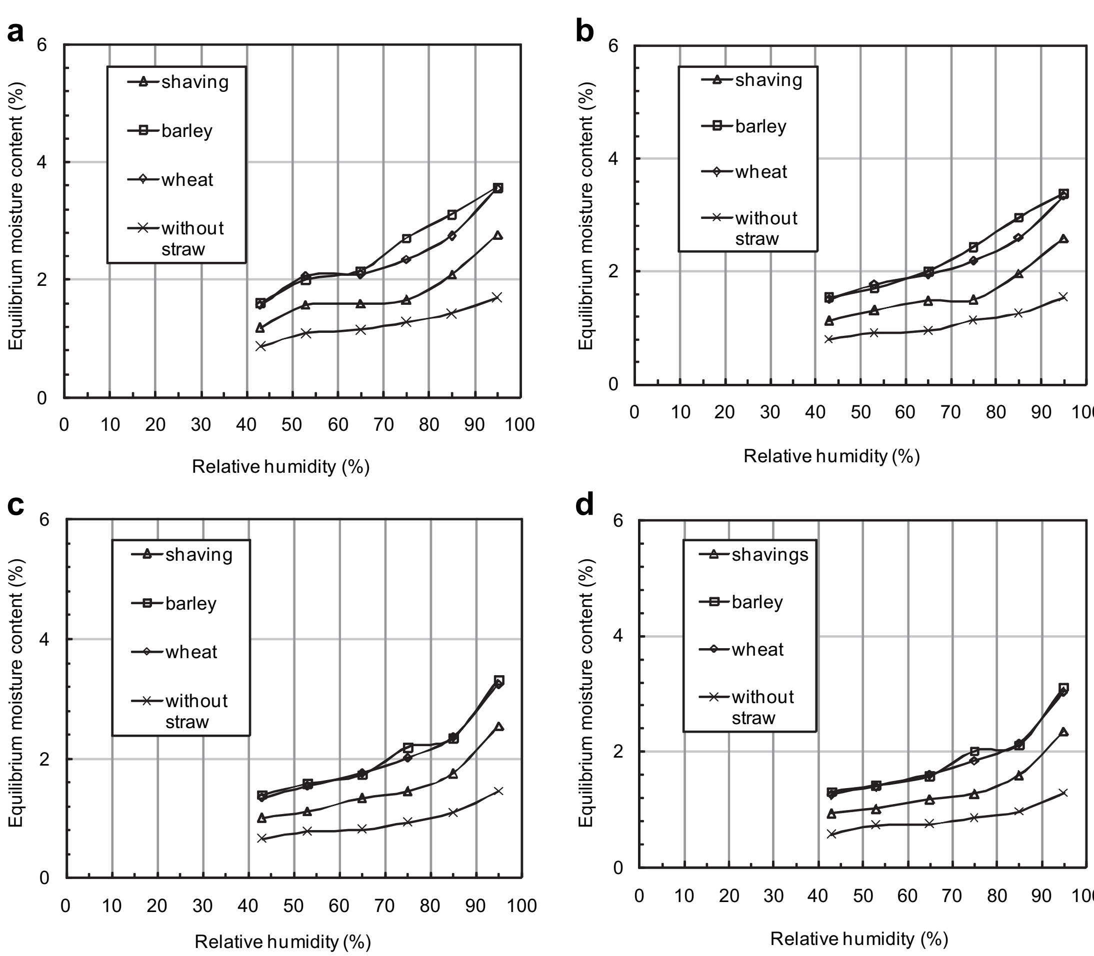

Fig. 10. EMC of recipe B for different plasters, (a) 10 °C, (b) 20 °C, (c) 30 °C and (d) 40 °C.

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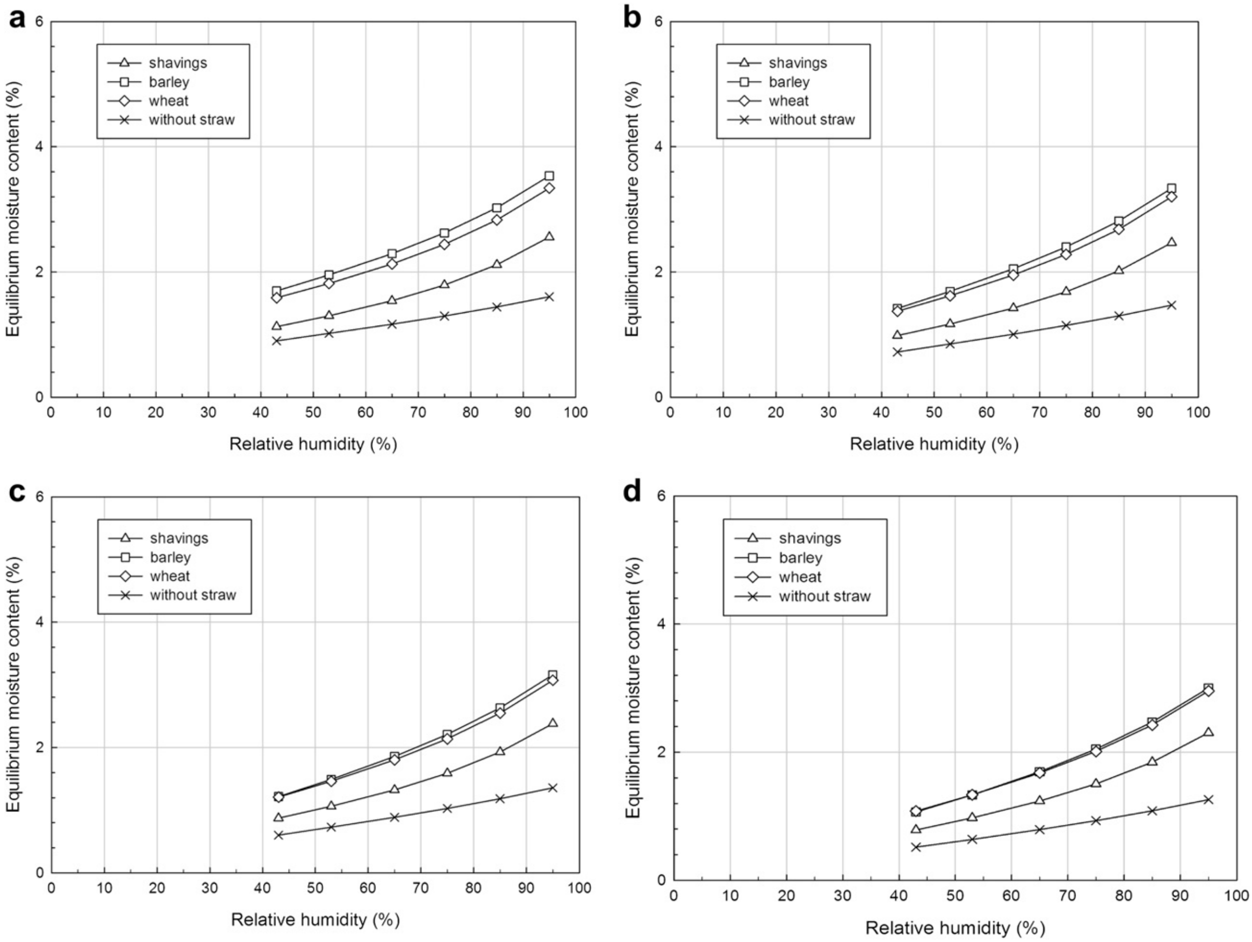

Fig. 11. EMC predicted with the GAB model of plasters reinforced with different fibres for recipe B, (a) 10 °C, (b) 20 °C, (c) 30 °C and (d) 40 °C.

to 0.7% when the temperature increased from 10 to 40 °C at 95% relative humidity.

The effect of temperature on EMC is less pronounced than the relative humidity. For example, a change of temperature from 10 °C to 40 °C gives decrease to change of the EMC from 3.6% to 2.9%. While a change of relative humidity from 43% to 95% gives rise to a change of the EMC from 2.0% to 5.2%.

The moisture content is in line with the sorption isotherms, where water is adsorbed from the vapor of the ambient air and the moisture content is in equilibrium with the ambient relative humidity. Two mechanisms are responsible for this sorption phenomenon. At low relative humidity, water molecules are attached to the pore walls forming a thin water film. As the relative humidity rises, this water film becomes thicker and capillary the condensation takes place in the narrow pores. The mechanisms overlap each other, but at high relative humidity the capillary condensation becomes dominant [15].

At low relative humidity (43%), the maximum EMC is about 2.2% at 10 °C while it is about 1.8% at 40 °C. As relative humidity rises, the EMC reached 5.5% at 10 °C and 4.8% at 40 °C.

EMC of plaster material increases with the rise of relative humidity at the same temperature. That is because the vapor pressure deficit (VPD) decreases with increasing relative humidity, which creates an atmosphere close to saturation and increases the ability of material to absorb more moisture from the ambient atmosphere. On the other hand, with increasing temperature from 10 to 40 °C, the EMC decreases from 2.2% to 1.8% at 43% relative humidity and from 5.5% to 4.8% at 95% relative humidity.

This is due to the fact that VPD increases with increasing temperature, which is thought to be the main factor of moisture movement from or to the wheat straw fibre.

Fig. 3 shows that the VPD increases by more than 6 times when temperature increases from 10 °C to 40 °C. The EMC decreases and reaches a level lower than the initial moisture content of the plaster material. Apparently, the material has lost some of its moisture to the ambient.

The VPD at lower temperature under different relative humidities shows little difference. This means that the relative humidity at lower temperature has only minor influence on the VPD. According to Refs. [23–25], the apparent increase in vapor diffusion at high relative humidity is due to liquid flow on the surface of the pore walls and the surface diffusion, which is controlled by the vapor pressure gradient.

3.1.2. Recipe B

Fig. 4 shows the EMC (%) of samples at different relative humidity and temperature. At low relative humidity (43%) the maximum EMC is about 1.6% at 10 °C while it is about 1.3% at 40 °C. As relative humidity rises, the EMC reached 3.5% at 10 °C and a low of 3.0% at 40 °C. Note that, changing the relative humidity from 43% to 95% leads to an increase of 2.0% in the moisture content of the material at 10 °C.

On the other hand, increasing the temperature from 10 °C to 40 °C causes a decline of 0.3% in the EMC of the plaster material. While increasing the relative humidity from 43% to 95% at 40 °C reduces the EMC by about 1.8%. An EMC of 0.5% is measured, when

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the temperature increased from 10 to 40 °C at 95% relative humidity.

3.1.3. Recipe C

Fig. 5 shows the relationship between EMC (%), relative humidity and temperature. For a relative humidity of 43% the maximum EMC is about 1.1% at 10 °C and 0.8% at 40 °C. As the relative humidity rises, the EMC reaches 2.3% at 10 °C and 1.9% at 40 °C.

For the temperature of 10 °C an increase of the relative humidity from 43 to 95% leads to an increase of 1.2% in the moisture content. Furthermore, increasing the temperature from 10 °C to 40 °C gave rise to decrease of 0.3% in the EMC.

The EMC curves for the plaster reinforced with barley straw and wood shavings fibres show similar trend, but differ in values. Therefore, these results are not shown here but will be summarized later.

3.2. Plaster material without reinforcement fibre

At low relative humidity (43%) the maximum EMC is about 0.9% at 10 °C and about 0.6% at 40 °C. As the relative humidity rises (95%), the EMC is about of 1.7% at 10 °C and 1.3% at 40 °C. Increasing the relative humidity from 43% to 95% leads to an increase of 0.8% in moisture content at 10 °C and 0.7% at 40 °C. Furthermore, increasing the temperature from 10 to 40 °C caused a decrease of 0.3% in the EMC at 43% and 0.4% at 95% relative humidity (Fig. 6).

Fig. 7a–c shows the predicted sorption isotherms curves for plasters reinforced with wheat straw fibres. Fig. 7d presents the predicted sorption isotherms for plaster without reinforcement fibres. It is widely accepted that an increase in temperature results in decrease in equilibrium moisture content.

3.3. Comparison between the different plaster materials

3.3.1. Recipe A

Fig. 8a illustrates the relationship between the EMC of different plaster materials and the relative humidity at 10 °C. It can be seen that the EMC increased gradually with increasing relative humidity up to 65% and this increase slowed down between 65 and 80% relative humidity and then increased gradually again at a relative humidity higher than 80% for all materials.

For temperatures below 10 °C the EMC values are 2.2%, 2.9%, 1.6% and 0.9% at 43% relative humidity and increases to 5.5%, 6.50%, 3.7% and 1.7% at 95% relative humidity for plaster reinforced with wheat, barley straw, wood shavings and without fibre respectively. Moreover the EMC of plaster reinforced with barley straw fibre is higher than the other materials. The lowest EMC is observed for plaster without fibre. This may be attributed to the fact that the reinforced fibres absorb more moisture than other materials.

The EMC at 20 °C are 1.9%, 2.7%, 1.6% and 0.8% at 43% relative humidity and increased to 5.1%, 6.3%, 3.6% and 1.5% at 95% relative humidity as shown in Fig. 8b. The results indicated that the EMC for plaster with barley straw is higher than that of other materials. At 30 °C the EMC values were 2.0%, 2.5%, 1.4% and 0.7% at 43% relative

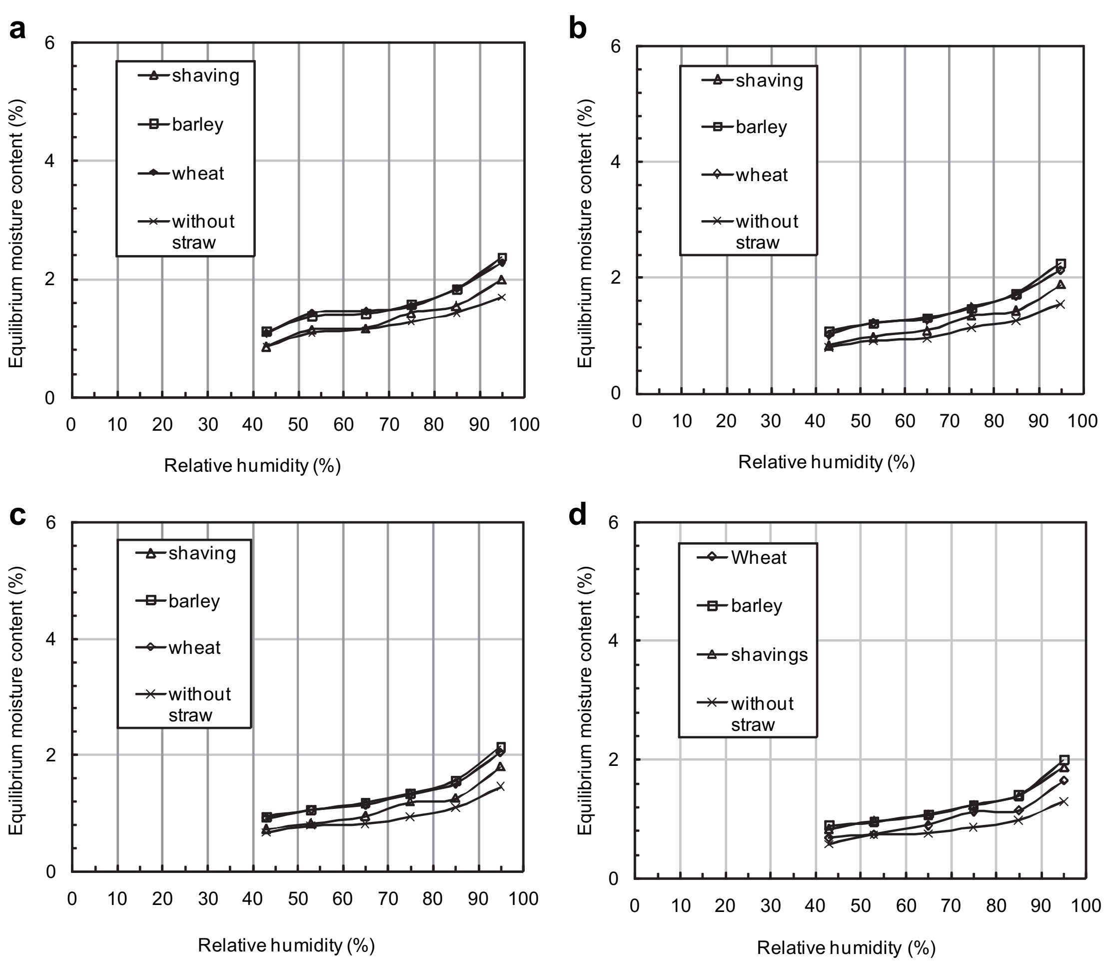

Fig. 12. EMC of recipe C for different plasters, (a) 10 °C, (b) 20 °C, (c) 30 °C and (d) 40 °C.

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humidity and increased to 5.3%, 5.9%, 3.5% and 1.5% at 95% relative humidity as shown in Fig. 8c.

At 40 °C the EMC values are 1.8%, 2.3%, 1.3% and 0.6% at 43% relative humidity and increased to 4.8%, 5.5%, 3.3% and 1.3% at 95% relative humidity as shown in Fig. 8d.

Fig. 9 illustrates the predicted sorption isotherms by using GAB model of recipe A for plasters reinforced with different natural fibres. The curves showed that predicted sorption isotherms are the same trend of the measured results.

3.3.2. Recipe B

At low temperature (10 °C) the EMC values are 1.6%, 1.6%, 1.2% and 0.9% at 43% relative humidity and increased to 3.5%, 3.6%, 2.8% and 1.7% at 95% relative humidity for wheat straw plaster, barley straw plaster, wood shavings and plaster without fibres, respectively as shown in Fig. 10a.

The results also showed that the EMC for plaster with barley straw is higher than the other materials. For temperature below 20 °C the EMC values are 1.5%, 1.5%, 1.1% and 0.8% at 43% relative humidity and increased to 3.3%, 3.4%, 2.6% and 1.54% at 95% relative humidity as shown in Fig. 10b.

At 30 °C the EMC values are 1.3%, 1.4%, 1.0% and 0.7% at 43% relative humidity and increased to 3.2%, 3.3%, 2.5% and 1.5% at 95% relative humidity (Fig. 10c).

At higher temperature (40 °C), the EMC values are 1.3%, 1.3%, 0.9% and 0.6% at 43% relative humidity and increased to 3.0%, 3.1%, 2.4% and 1.3% at 95% relative humidity (Fig. 10d).

The predicted sorption isotherms by using GAB model of recipe A for plasters reinforced with different natural fibres are presented in Fig. 11.

3.3.3. Recipe C

The EMC values at low temperature (10 °C) are 1.1%, 1.1%, 0.9% and 0.9% at 43% relative humidity and increases to 2.3%, 2.4%, 2.0% and 1.7% at 95% relative humidity for wheat straw plaster, barley straw plaster, wood shavings and plaster without fibres, respectively, as shown in Fig. 12a.

The results indicated that the EMC for plaster with barley straw is higher than the other materials. At 20 °C the EMC values are 1.0%, 1.1%, 0.8% and 0.8% at 43% relative humidity and increases to 2.1%, 2.2%, 1.9% and 1.5% at 95% relative humidity (Fig. 12b).

The EMC values at 30 °C are 0.9%, 0.9%, 0.7% and 0.7% at 43% relative humidity and increases to 2.0%, 2.1%, 1.8% and 1.5% at 95% as shown in Fig. 9c. The EMC values at high temperature (40 °C) are 0.8%, 0.9%, 0.7% and 0.6% at 43% relative humidity and increases to 1.9%, 2.0%, 1.6% and 1.3% at 95% (Fig. 12d).

Fig. 13 presents the predicted sorption isotherms by using GAB model of recipe A for plasters reinforced with different natural fibres.

The test results show that the adsorption rate is dependent on both the temperature and the relative humidity ([12,13]). The EMC increases gradually with increasing relative humidity up to 65% and this increase slows down between 65 and 80% relative humidity and then increases again at a relative humidity higher than 80% for the

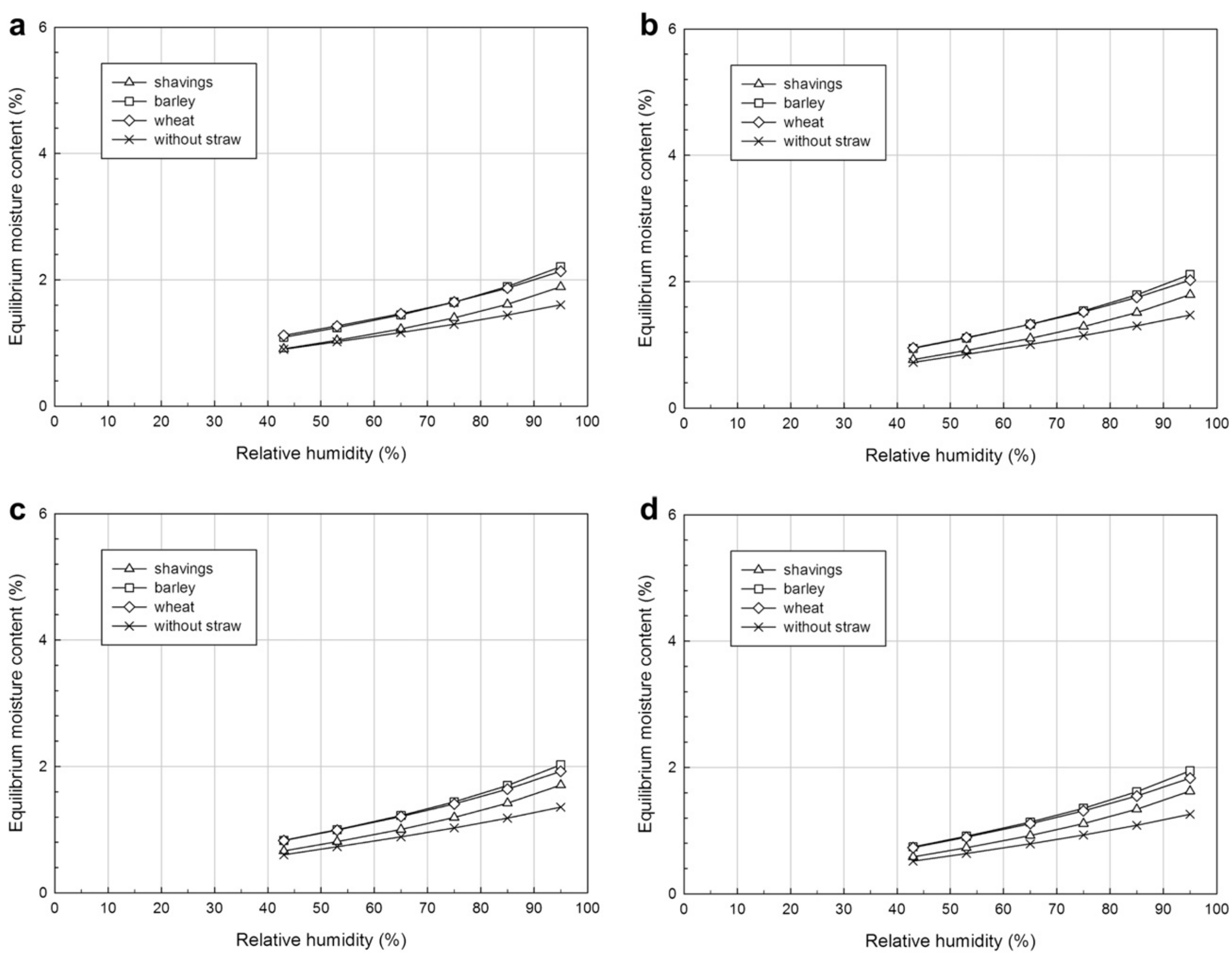

Fig. 13. EMC predicted with the GAB model of plasters reinforced with different fibres for recipe C, (a) 10 °C, (b) 20 °C, (c) 30 °C and (d) 40 °C.

Table 3
Parameters and goodness of fit measures for isotherm GAB model describing the equilibrium moisture content (EMC).

Plaster materials	Treatment	Constants			Mean relative deviation (P), %	Standard error of estimate(E_s)
		a	b	c		
Plaster material reinforced by wheat straw fibres	A 1:0:3	1.883	0.688	135.2	6.325	0.275
	B 1:1:2	1.362	0.641	141.5	5.978	0.156
	C 1:2:1	1.024	0.575	141.1	5.812	0.101
Plaster material reinforced by barley straw fibres	A 1:0:3	2.383	0.657	133.8	8.056	0.380
	B 1:1:2	1.556	0.617	112.4	5.741	0.160
	C 1:2:1	0.949	0.949	148.0	6.758	0.118
Plaster material reinforced by wood shavings fibres	A 1:0:3	1.349	0.665	153.6	6.073	0.174
	B 1:1:2	0.932	0.683	140.9	8.388	0.167
	C 1:2:1	0.824	0.619	118.1	5.299	0.083
Plaster materials without reinforcement fibres	D 1:3:0	0.944	0.490	114.0	5.953	0.073

different materials. Moreover, the EMC of plaster reinforced with barley straw is higher than of the other materials. This is due to the pores in the barley straw fibres, which take up more moisture.

3.4. Data analysis using GAB model

The relationship between water content versus relative humidity is not linear. Our literature study shows that the GAB model is suitable to describe the sorption curves at given temperature. The GAB model is used to fit the experimental data on plaster reinforced with barley straw, wheat straw, wood shavings and plaster without fibre as a function of both temperature and relative humidity. The GAB model can be used to predict the equilibrium moisture content under different conditions such as temperature and relative humidity. The model parameters for all plaster recipes are shown in Table 3. The maximum mean relative deviation is about 8.388% for the recipe of plaster reinforced with wood shavings fibre, while the minimum is about 5.299% for recipe C of the same plaster.

Furthermore, the maximum estimated standard error is about 0.380 for recipe A of plaster reinforced by barley straw fibre, while the minimum is about 0.073 for the plaster without reinforcement fibres. The results of standard error show that GAB model is suitable for predicting the equilibrium moisture content of earth plaster for straw bale constructions.

Figs. 7, 9, 11 and 13 present the sorption isotherms fitted with GAB model for the measured EMC.

4. Conclusions and recommendations

Our test results show that the EMC of plaster materials increases with increasing relative humidity and decreases with rising temperature. The EMC of plaster reinforced with barley straw is somewhat higher than the other materials examined. The relative humidity has greater effect on the change of moisture content than temperature. The moisture content changes from 1.9 to 5.7% when the temperature changes from 10 to 40 °C at 43% and 95% relative humidity. The EMC increases gradually with increasing relative humidity up to 65% and this increase slows down between 65 and 80% relative humidity and then increases again at relative humidity higher than 80%.

The EMC of barley straw fibre is in the range of 2.3–6.5%, 1.3–3.6% and 0.9–2.4% for recipe A, B and C, respectively. The EMC values of plaster with wheat straw fibre reinforcement are 1.8–5.5%, 1.3–3.5% and 0.8–2.3% for recipe A, B and C, respectively. The EMC values of plaster with wood shavings fibre are 1.3–3.7%, 0.9–2.8% and 0.7–2.0% for recipe A, B and C, respectively. The EMC of plaster material without any reinforcement fibre is in the range of 0.6–1.7%. The results indicate that the EMC is less than 7% for all materials, which shows why plaster materials are useful for straw bale buildings for its protection of the straw bale walls against the harsh external conditions. The results proved that the GAB model is suitable for predicting the equilibrium moisture content of earth plaster for straw bale constructions.

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