

AN EXPERIMENTAL STUDY ON SHRINKAGE BEHAVIOUR OF EARTH BRICKS REINFORCED WITH STRAW

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ABSTRACT

There is a growing interest in using earth as a building material which exhibits excellent physical properties with respect to ecological design, and fulfils all strength and serviceability requirements for thermal transmittance. In this paper a series of laboratory tests on shrinkage of earth bricks materials is presented. The brick materials consist of cohesive soil, cement, gypsum and different natural fibres. Two types of fibres, wheat and barley straw were used as reinforcement in the tests. Cement and gypsum was used as stabilized materials. The shrinkage behavior of bricks was studied by laboratory tests for different compositions. The specimens of brick material were dried under a constant temperature of 105°C respectively. The average shrinkage percentage of unfired earth bricks reinforced with wheat straw are 4.161, 2.615 and 0.573 % for the fibres contents of 0%, 1% and 3% respectively, while the shrinkage percentages for bricks reinforced with barley straw fibres are 4.161, 3.458 and 0.613 % for reinforcement fibres contents of 0%, 1% and 3% respectively. The percentages of shrinkage for bricks reinforced with barley straw fibres are 3.458, 3.51 and 3.60% for cement contents of 0%, 5% and 10 % respectively. additionally, the percentages of shrinkage for bricks reinforced with barley straw fibres are 3.458, 3.677 and 3.829% for gypsum contents of 0%, 5% and 10 % respectively. The results revealed that fibres content have greater effect on shrinkage behaviour than gypsum and cement content.

Key Words: earth bricks, shrinkage, soil, straw, cement, gypsum.

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INTRODUCTION

A sustainability building is one in which technology and practice meets the multiple requirements of the people and society in an optimal way during the life cycle of the building facility (**AIA, 2006**). There is a growing interest in using earth as a building material which exhibits excellent physical properties with respect to ecological design, and fulfils all strength and serviceability requirements for thermal transmittance. This development is also due to the present concerns for sustainable development that have arisen out of extensive environmental problems (such as climate change and impoverishment of resources) and also rapid pace of technological development within the building sector (**Ashour et al., 2010, Ashour et al., 2011**). Straw is a natural product, grown by photosynthesis during a half or one-year period, fueled by the sun. Straw is currently produced in surplus to requirements, so it is cheap and easily accessible in most countries. It is the end product of growing crops; so using it for building purposes present a sustainable and ecological way of recycling (**Ashour et al., 2011**). The use of natural fibres as reinforcing agents in composite materials offers many advantages such as low density and biodegradability (**Li et al., 2006, Mwaikambo and Ansell 2003, Joshi et al., 2004**). The natural fibres used in the tests are wheat straw, barley straw and wood shavings. Both the soil composition and the fibre content are varied in the tests. The fibre content and the fibre type are found to have remarkable effect on the erosion resistance of the plasters (**Ashour and Wu 2010**). The use of natural earth bricks is experiencing a renaissance in sustainable building practice. Earth plasters may serve multiple purposes, e.g. to protection the underlying surface, enhancing or preventing the migration of moisture and carrying structural load. An important issue for the performance of earth plasters is its shrinkage behavior. The excessive formation of drying cracks has negative impact on the durability of earth bricks. **Hossain et al. (2007)** studied the influence of stabilization of soils by using volcanic ash. drying shrinkage were investigated. He found that better shrinkage resistance of volcanic ash stabilized soil mixtures compared to cement/lime stabilized soils suggests the viability of using such stabilized soils. **Bouhicha et al. (2005)** investigated a composite soil reinforced with chopped barley straw with four different soils. The effect of fibre

length and fibre content on shrinkage was studied. Their tests showed the positive effect of straw in decreasing shrinkage-induced cracks. The effect of fibre and earth composition on shrinkage was also investigated by **Yetgin et al. (2006)**. **Campbell and Coutts (1980)** investigated the possibility of using the wood fibres as reinforcement for a structural composite material. Their results indicated that pulp is suitable for applications where slurry dewatering can be employed during the forming operation and that the thermo mechanical pulp is more suited for applications where low water-cement ratio slurry is used. **Bai et al. (2005)** measured the drying shrinkage of concrete with natural sand replaced with furnace bottom ash. Their tests showed that at fixed water-cement ratio the compressive strength and the drying shrinkage decreased with increasing sand content. **Al-Amoudi et al. (2006)** compared four types of super plasticizers and used them in conjunction with three types of silica fume to prepare cement concrete slab specimens that were utilized to measure plastic shrinkage strain and time to attain maximum strain. **Ashour et al. (2010)** mentioned that, the average shrinkage ratios ranged between 0.82–1.03, 1.15–1.85 and 2.60–5.40% for the curing temperatures of 30, 50 and 70 °C, respectively. The highest shrinkage was observed for plaster reinforced with wood shavings, while the lowest shrinkage was observed for plaster reinforced with barley straw fibres. **Montes-H. (2005)** mentioned that swelling and shrinkage potential is governed by the relative humidity and by the nature of the interlayer cation. The objective of this work is attempt to investigate the drying shrinkage of earth bricks reinforced by different fibres types and contents with different cement and gypsum content.

MATERIALS AND METHODS

2.1 Materials tested

Earth brick usually comprises four components such as cohesive soil, cement, gypsum and agro fibres. The composition of the cohesive soil texture is as follows: 28.7% clay, 63.3% silt, 3% gravel and 5% sand. Two different fibre types, wheat and barley straw, were applied for reinforcement. The length of straw particles is about 4 cm.

2.2 Sample preparation

At first, oversized gravel and organic matter (grass roots) were removed from the natural cohesive soil. The soil samples were put in an oven to

dry at a temperature of 105°C to obtain the dry constant weight. The natural fibres were also oven dried at 105°C to obtain a constant mass. A variety of earth bricks with different compositions of cohesive soil, cement, gypsum and fibre were used in the tests. The dosing of different materials was controlled by the dry weight. The amount of soil, cement, gypsum and fibre of a given mixture were placed in a mechanical mixer and dry blended for circa 30 minutes until the different materials were homogeneously combined. Afterwards, water was sprayed over the mixture until 24% moisture content level was achieved. The materials were again blended using an electric mixer for approximately 30 minutes until a homogenous mixture was obtained.

Earth bricks from different mixtures combined with different natural fibres that were used in the shrinkage test are given in Table 1.

Table(1): Recipes of earth bricks.

Recipes	clay (%)	barley (%)	Wheat (%)	cement (%)	Gypsum (%)
Clay	100	-	-	-	-
B ₁	99	1	-	-	-
W ₁	99	-	1	-	-
B ₃	97	3	-	-	-
W ₃	97	-	3	-	-
B ₁ C ₅	94	1	-	5	-
W ₁ C ₅	94	-	1	5	-
B ₁ C ₁₀	89	1	-	10	-
W ₁ C ₁₀	89	-	1	10	-
B ₃ C ₅	92	3	-	5	-
W ₃ C ₅	92	-	3	5	-
B ₃ C ₁₀	87	3	-	10	-
W ₃ C ₁₀	87	-	3	10	-
B ₁ G ₅	94	1	-	-	5
W ₁ G ₅	94	-	1	-	5
B ₁ G ₁₀	89	1	-	-	10
W ₁ G ₁₀	89	-	1	-	10
B ₃ G ₅	92	3	-	-	5
W ₃ G ₅	92	-	3	-	5
B ₃ G ₁₀	87	3	-	-	10
W ₃ G ₁₀	87	-	3	-	10

The material compositions in Table 1 are given as a percentage of earth material as dry weight. The soil-fibre mixture was then poured into a steel mould and compacted in a press. The inside dimensions of steel mould have a length of 15 cm, by width of 4 cm, and height of 4 cm (see Fig. 1). The surface was levelled and compressed using a loading plate under a force of about 50 kg. The samples were further dried in an oven under the temperature of 105 °C to obtain a constant mass, which was controlled by weighing the samples every 24 hours. Thirty samples of different bricks materials were used for shrinkage test.



Fig. (1): Frame for sample preparation

2.3 Scanning electron microscopy

To test the fibre/matrix adhesion and composite morphology, micrographs in scanning electron microscopy (SEM) were taken. The SEM fracture surface were prepared by using drying bricks . The brick was cutting to appear the inside surface of the bricks and show the fibres distribution. Five replicates were used for each recipe.

2.4 Shrinkage test procedure

Shrinkage tests were carried out according to (ASTM D4943, 1995). The soil-fibre mixture was poured into a steel mold. The inside dimensions of steel mold were length of 15 cm, 4 cm in width and 4 cm in depth (Fig. 1). The materials were poured into the mold and compressed. Afterwards the samples were placed in the oven and dried under constant temperature until the constant weight according to (DIN EN ISO 12570, 2000) was obtained.



Fig. (2): Vernier scale for measuring the shrinkage
The samples dimensions were measured with a vernier scale (Fig. 2).

RESULTS AND DISCUSSIONS

3.1. The influence of different components on bricks density

The effect of fibre content on bricks density was investigated. As expected, the dry density decreased when the fibre quantity increased. It is well demonstrated that, the new blocks manufactured with wheat straw fibre have a relatively high density varying between 1476 and 1277 kg/m³ for 1% and 3% fibre contents respectively. This corresponds to a decrease of about 8.8% to 21% in comparison with non-fibrous cohesive soil bricks.

For bricks reinforced with barley straw fibres, it can be seen that the average density ranged between 1445 to 1099 kg/m³. This means that the density decreased from 10.6 to 33% when the fibre content increased from 1% to 3%. It could be noticed that the brick densities reinforced with wheat straw are higher than bricks reinforced with barley straw. This may be due to wheat straw containing more solid material and lignin than barley straw. The average brick densities stabilized with cement are 1310 and 1229 kg/m³ for 5% and 10 % cement content at 1% fibre content. The bricks densities reinforced with barley straw are 1204 and 1112 kg/m³ at 5% and 10 % cement contents. The average brick densities stabilized with cement are 1004 and 1040 kg/m³ for 5 and 10 % cement at 3% fibres while bricks reinforced with barley straw are 1146 and 1025 kg/m³ at 5% and 10 % cement contents at the same fibre content. In

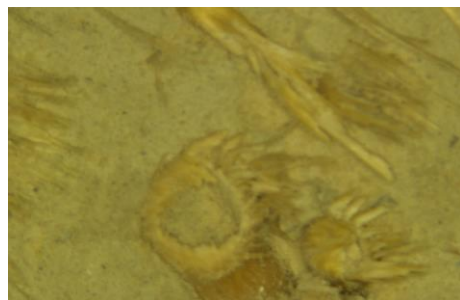
general, increasing the fibre content in the mixtures decreased the specimen weights. Replacing soil cement or soil gypsum (dense materials) with wheat or barley straw fibres (light materials) resulted in a total volume increase even after compaction. The compacted mix volume increases resulted in a decrease in specimen weights and densities (**Duke and Atchly 1984, TS, 1979**).

3.2 Microstructure of earth bricks.

The morphology and microstructure of the residues were examined by scanning electron microscopy (SEM). The distribution of fibers in the brick are shown in Fig. 3a and b Fig. 3a shows the cross section of fibres distribution. While Fig. 3b illustrate the typical SEM micrographs taken at the top surface of the blocks. It reveal a uniform distribution of fibers inside the brick samples. The micrographs clearly show that the straw fibers were randomly oriented within the samples. Additionally, the moisture equilibrium is mainly influenced by the pore size, with pore-specific surface and the percentage of micropores playing a fundamental role in promoting the structure/water interactions.



a)



b)

Fig. (3). Fibres distribution inside the bricks, a) cross section showed fibres distribution, b) SEM micrograph of fibres distribution inside the earth bricks.

3.3 Shrinkage behaviour

3.3.1 Bricks without additions

Earth bricks of the cohesive soil with neither reinforcement fibres nor cement or gypsum has the maximum shrinkage and shows extensive

crack formation. Figure 4 shows the pattern of cracks under the curing temperature, which gives rise to entirely disintegrated specimens.



Fig. (4): Shrinkage and crack formation for earth bricks.

3.3.2 The influence of fibre contents

The average shrinkage percentage of unfired earth bricks reinforced with wheat straw are 4.161, 2.615 and 0.573 % for the fibres contents of 0%, 1% and 3% respectively, while the shrinkage percentages for bricks reinforced with barley straw fibres are 4.161, 3.458 and 0.613 % for reinforcement fibres contents of 0%, 1% and 3% respectively. The mentioned results illustrated that increasing wheat straw fibre percentages from 0% to 1% caused a decrease of shrinkage percentages to 37.15% in comparison to bricks without reinforcement fibres. On the other hand, increasing wheat straw fibre percentages from 0% to 3% caused a decrease of shrinkage percentages to 86.23%. Also, the results illustrated that, increasing barley fibre percentages from 0% to 1% caused a decrease of shrinkage percentages to 16.89% in comparison to bricks without reinforcement fibres. While, increasing barley straw percentages from 0% to 3% caused a decrease of shrinkage percentages to 82.27%. The change in shrinkage by altering the fibre content is shown in Fig.5. As expected, shrinkage percent decreased with an increase in fibre content. Figure 5 also shows that the decrease in shrinkage was gradual with increasing fibre content. The results showed significance difference between bricks reinforced with wheat and barley straw fibres and bricks without fibres ($P < 0.05$).

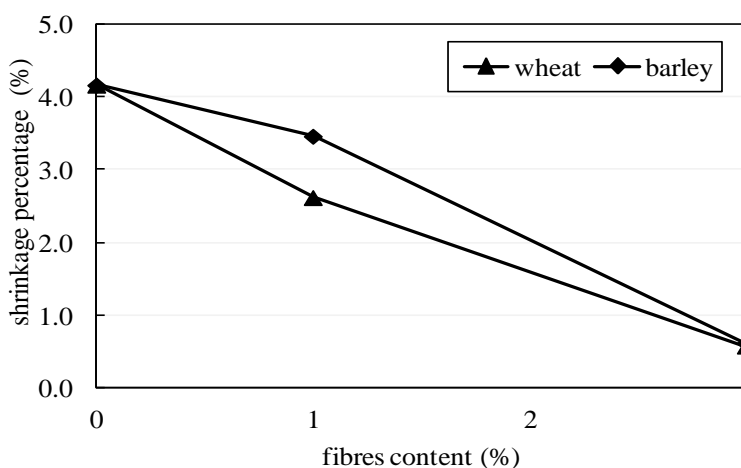


Fig. (5): The influence of reinforcement fibres.

3.3.3 The influence of cement content

3.3.3.1 Cement content with 1% fibre

Figure 6a shows the relationship between cement content and shrinkage percentages for bricks reinforced with 1% fibre. The figure shows that shrinkage increases slightly with increasing cement content. The results showed no significance difference between the performance of wheat and barley straw fibre reinforced bricks ($P > 0.05$). The average shrinkage percentages of wheat straw reinforced earth bricks are 2.615, 2.731 and 2.93% for cement contents of 0%, 5% and 10% respectively. The percentages of shrinkage for bricks reinforced with barley straw fibres are 3.458, 3.51 and 3.60% for cement contents of 0%, 5% and 10% respectively. The results showed also that increasing cement content from 0% to 5% caused an increase of shrinkage percentages to 4.44% for wheat straw in comparison to bricks without reinforcement fibres. On the other hand, increasing wheat straw fibre percentages from 0% to 10% caused an increase of shrinkage percentages to 12.05%.

Also, the results of bricks reinforced by barley straw fibres illustrated that, increasing cement content from 0% to 5% caused an increase of shrinkage percentages to 1.50%. This means that, increasing cement percentages from 0% to 10% caused an increase of shrinkage percentages to 4.11%. The figure also showed that the shrinkage percentages for barley straw fibre reinforced bricks is higher than wheat straw reinforced bricks.

3.3.3.2 Cement content with 3% fibre

The average shrinkage of bricks reinforced with wheat straw fibres are 0.573, 0.601 and 0.653% for the cement contents of 0%, 5% and 10 % respectively. The shrinkage percentages of barley straw reinforced bricks are 0.613, 0.710 and 0.82% for cement contents of 0%, 5% and 10 % respectively. Figure 6b shows the relationship between bricks cement content and shrinkage percentages with 3% fibre. The figure showed that shrinkage slightly increased with increasing cement content. The results showed no significance difference between wheat and barley reinforced bricks ($P > 0.05$).

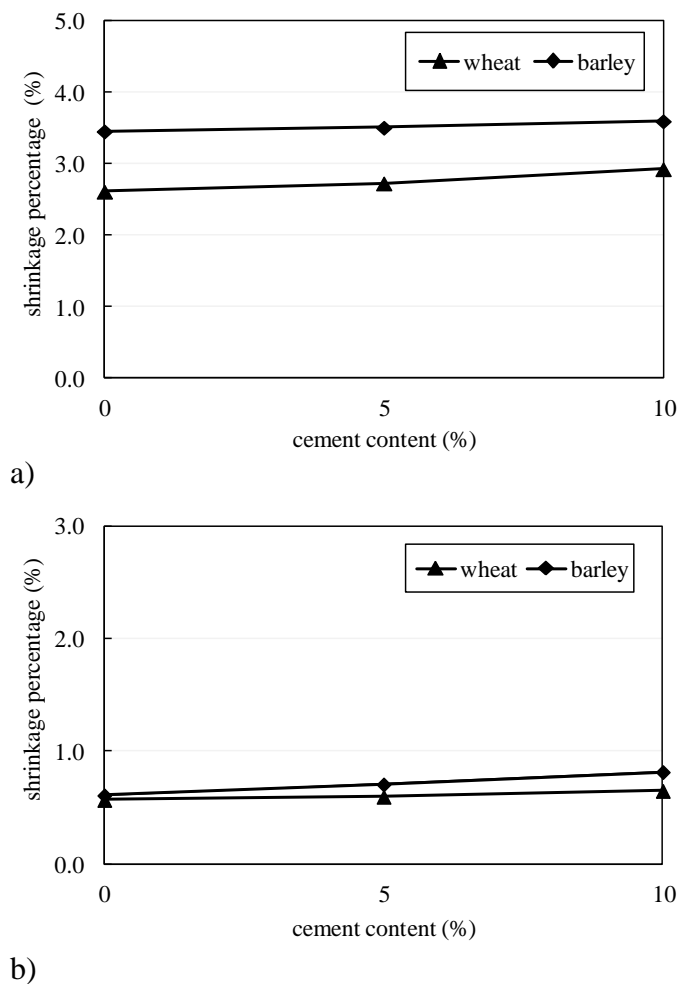


Fig. (6): The influence of cement content, a) 1% fibres, b) 3% fibres.

It could be noticed that, the results for wheat straw fibres showed that increasing cement content from 0% to 5% caused an increase of shrinkage percentages to 4.89%. While, increasing cement from 0% to 10% caused an increase of shrinkage percentages to 13.96%. Also for bricks reinforced by barley straw fibres, the results illustrated that, increasing cement content from 0% to 5% caused an increase of shrinkage percentages to 15.82%. While, increasing cement from 0% to 10% caused a decrease of shrinkage percentages to 33.77%. The figure also showed that the shrinkage percentages for barley straw fibre reinforced bricks is higher than wheat straw reinforced bricks.

3.3.4 The influence of gypsum content

3.3.4.1 Gypsum content at 1% fibre

Figure 7a shows the relationship between bricks gypsum content and shrinkage percentages reinforced with 1% and 3% fibre. The figure shows that shrinkage increases slightly with increasing gypsum content. The results showed no significance difference between the performance of wheat and barley straw fibre reinforced bricks ($P > 0.05$). The average shrinkage percentages of unfired wheat straw reinforced earth bricks are 2.615, 3.542 and 3.614% for gypsum contents of 0%, 5% and 10 % respectively. The percentages of shrinkage for bricks reinforced with barley straw fibres are 3.458, 3.677 and 3.829% for gypsum contents of 0%, 5% and 10 % respectively.

It could be seen that, obtained results for wheat straw fibres showed that increasing gypsum content from 0% to 5% caused an increase of shrinkage percentages to 35.45% in comparison to bricks without gypsum. While, increasing gypsum content from 0% to 10% caused an increase of shrinkage percentages to 38.20%.

Similarly, for barley straw, the results illustrated that, increasing gypsum content from 0% to 5% caused an increase of shrinkage percentages to 6.33% comparing to bricks without gypsum. While, increasing gypsum from 0% to 10% caused an increase of shrinkage percentages to 10.73%. The figure also showed that the shrinkage percentages for barley straw fibre reinforced bricks is higher than wheat straw reinforced bricks.

3.3.4.2 Gypsum content with 3% fibre

The average shrinkage of bricks reinforced with wheat straw fibres are 0.573, 0.702 and 0.850% for the gypsum contents of 0%, 5% and 10 %

respectively. The shrinkage percentages of barley straw reinforced bricks are 0.613, 0.824 and 1.021% for cement contents of 0%, 5% and 10 % respectively. Figure 7b shows the relationship between brick cement content and shrinkage percentages with 3% fibre. The figure showed that shrinkage slightly increased with increasing cement content. The results showed no significance difference between wheat and barley reinforced bricks ($P > 0.05$). The present results revealed that bricks reinforced with wheat straw fibres showed that rising gypsum percentages from 0% to 5% caused an increase of shrinkage percentages to 22.51% in comparison to bricks with no gypsum. Alternatively, the shrinkage percentages were elevated to 48.34% by increasing gypsum from 0% to 10%.

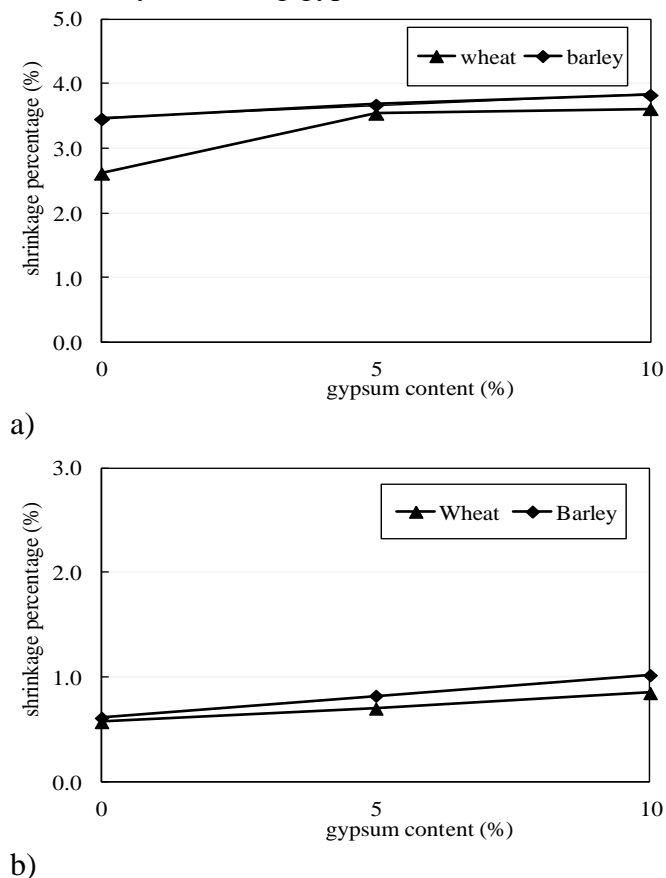


Fig. (7): The influence of gypsum content, a) 1% fibres, b) 3% fibres.

For bricks reinforced by barley straw fibres, the results illustrated that, increasing gypsum content from 0% to 5% caused an increase of

shrinkage percentages to 34.42% in similar to bricks with no gypsum content. While, increasing gypsum percentages from 0% to 10% caused increasing the shrinkage percentages to 66.56%. The figure also showed that the shrinkage percentages for barley straw fibre reinforced bricks stabilised gypsum is higher than wheat straw reinforced bricks.

A comparison of the earth bricks in Sections 3.1, 3.2 and 3.3 shows that the earth bricks of cohesive soil with neither reinforcement fibres nor cement or gypsum has the maximum shrinkage and shows extensive crack formation. Fibre properties, i.e. components, surface roughness and surface polarity have important contribution to fibre wettability and adhesion in composites. However surface chemistry of the fibres has influence on the mechanical properties of the composites (**Bledzki et al., 2010**).

3.4 Multiple regression analysis

Regression analysis generates an equation to describe the relationship between shrinkage of different brick materials and one or more variables such as cohesive soil, fibres content, cement content and gypsum content. The optimum equation for shrinkage percentage for all types of blocks is linear equation. The following equation was obtained:

$$y = a + bx$$

Where,

- y : shrinkage percentage (%)
- x : fibre or cement content or gypsum content
- a,b : Constants are listed in Table (2)

Regression coefficients represent the mean change in the response variable for one unit of change in the predictor variable. Table (2) show the constants of shrinkage percentage equation for different brick materials. The results presented in table (2) illustrated that the slopes of the equation are -1.171 and -1.217 for wheat and barley respectively. This means that increasing the fibres content lead to decrease the shrinkage percentage for both wheat and barley straw fibres. While the slopes for cement at 1% and 3% fibres were 0.032 and 0.021 respectively. On the other hand, the slopes for gypsum at 1% and 3% fibres were 0.099 and 0.028 respectively . These findings confirmed that increasing cement or

gypsum contents resulting in increasing the shrinkage percentages for different earth bricks.

Finally, to limit shrinkage, if it is excessive for our building needs, we can increase the amount of larger and inert soil particles such as fibres and cement or gypsum. The particles are massive in comparison to the soil particles, and do not swell and shrink with drying. So, if we get enough of fibres in a soil mix we can limit shrinkage. Fibres interrupt cracks if they should develop and prevent them from growing larger and cracking the material.

brick materials	wheat straw			barley straw		
	Constants		R ²	constants		R ²
	a	B		a	b	
Fibres	4.011	-1.171	0.987	4.367	-1.217	0.979
Cement (1% fibres)	2.601	0.032	0.977	3.452	0.014	0.977
cement (3% fibres)	0.612	0.021	0.998	0.569	0.008	0.971
Gypsum (1% fibres)	2.758	0.099	0.804	3.469	0.037	0.989
gypsum (3% fibres)	0.569	0.028	0.998	0.615	0.041	0.999

Table2: Equation constants and coefficient of determination of the relationship between shrinkage and fibres, cement and gypsum.

4. CONCLUSIONS

Our testing results show that the shrinkage of earth brick is influenced by several factors, e.g cohesive soil, fibre content and type, cement and gypsum. The earth brick without reinforcement fibre shows extensive crack formation, which leads to disintegration of the specimens. Both the reinforcement fibres, cement and gypsum have some positive

effect on shrinkage. However, reinforcement fiber has greater effect on shrinkage than cement and gypsum. The crack formation decreases with increasing fibre content and increases with increasing cohesive soil. The average shrinkage percentage of unfired earth bricks reinforced with wheat straw are 4.161, 2.615 and 0.573 % for the fibres contents of 0%, 1% and 3% respectively, while the shrinkage percentages for bricks reinforced with barley straw fibres are 4.161, 3.458 and 0.613 % for reinforcement fibres contents of 0%, 1% and 3% respectively. The percentages of shrinkage for bricks reinforced with barley straw fibres are 3.458, 3.51 and 3.60% for cement contents of 0%, 5% and 10 % respectively. additionally, the percentages of shrinkage for bricks reinforced with barley straw fibres are 3.458, 3.677 and 3.829% for gypsum contents of 0%, 5% and 10 % respectively.

In general, higher fibre content are to be preferred to improve the performance of earth bricks, i.e. to reduce shrinkage and crack formation.

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الملخص العربي

دراسة تجريبية على سلوك الإنكماش للطوب النى المسلح بالقش

طه عاشور*

تتجه أبحاث مواد البناء إلى المواد الطبيعية لما لها من خصائص طبيعية وحرارية ممتازة تؤدي إلى توفير الطاقة المستهلكة في المبنى , كما يمكن إنشاء المباني في الظروف المناخية الصعبة مثل المناطق الصحراوية أو المناطق الباردة. ولما كان لخاصية الإنكماش أهمية كبرى تؤثر على جودة الطوبة المنتجة. لذلك يهدف هذا البحث إلى تحسين خاصية الإنكماش للطوب النى من خلال تسليحة بالقش, وكذلك إضافة الجبس والأسمنت بنسب خلط مختلفة . ولذلك في هذا البحث تم تدعيم الطوبة بنسب تسليح مختلفة من الألياف الطبيعية المختلفة مثل قش القمح وقش الشعير بنسب خلط مختلفة (صفر، ١ و ٣%). تم إضافة الأسمنت والجبس للطوبة من أجل زيادة الصلادة والمتانة وبنسب مختلفة (صفر، ٥ و ١٠%).

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تم حساب نسب الخلط كنسبة وزنية من وزن التربة، وكانت جميع النسب السابقة كلها منسوبة للوزن الجاف، كما تم خلط المكونات على الجاف ثم إضافة الماء إليها حتى تصل نسبة الرطوبة الى ٢٤%، وتم كبس العينات طبقاً للأبعاد العالمية المثلى لإجراء اختبار الإنكماش وهي ٤X٤X١٥ سم (الطول X العرض X الارتفاع). كانت نسب الإنكماش للطوب المسلح بقش القمح ٤،١٦١، ٢،٦١٥ و ٠،٥٧٣ % عند استخدام محتوى قش صفر، ١، و ٣% على التوالي. كانت نسب الإنكماش للطوب المسلح بقش الشعير ٤،١٦١، ٣،٤٥٨، و ٠،٦١٣ % عند استخدام محتوى قش صفر، ١ و ٣ % على الترتيب.

أثبتت النتائج النهائية أن تأثير إضافة القش إلى خلطات صناعة الطوب أفضل من إضافة الجبس والأسمنت على خاصية الإنكماش للطوبة المنتجة.

الكلمات الدالة: الطوب اللبن - الإنكماش - قش القمح - قش الشعير - الأسمنت - الجبس.