

Shrinkage of natural plaster materials for straw bale buildings affected by reinforcement fibers and drying

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Abstract: This study was carried out to determine the shrinkage percentage of natural plaster materials consisted of soil, sand and different fibers. Straw was used as a reinforcement fiber for plaster and three types of fibers. The plaster materials were put under drying temperatures of 30°C, 50°C and 70°C. The results revealed that the highest shrinkage was for plaster reinforced by wood shavings fibers, while the lowest shrinkage was for plaster reinforced by barley straw fibers for treatments A, B and C. Also, the plaster without reinforcement fibers had a lot of cracks and problems that destroyed plaster. The reinforcement fiber had a greater effect on the drying shrinkage than sand. The study indicates that drying the plaster at 30°C with a lot of straw can decrease the shrinkage and cracks.

Keywords: shrinkage percentage, drying temperature, earth plaster, sand, straw, straw bale buildings

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1 Introduction

Drying shrinkage is one of the main causes of cracks of plaster materials, and so many studies have been made to prevent cracks. Profitable knowledge have been obtained on drying earth plaster. It is very important to study such a traditional problem as crack prevention in view of the drying shrinkage mechanism. Therefore, examinations on behavior of properties due to drying are required, when structural application of such materials is considered.

Campbell and Coutts (1980) investigated the possibility of using the wood fibers as reinforcement for a structural composite material. Although wood fibers had relatively poor mechanical properties compared with synthetic fibers, they had the advantages of low density, low cost and low energy demand during manufacture. They indicated that the kraft pulp was suitable for applications where slurry dewatering could be employed

during the forming operation and that the thermo mechanical pulp was more suitable for applications where low water-cement ratio slurry was used.

Bai, Darcy and basheer (2005) measured the drying shrinkage of concretes with the natural sand replaced with furnace bottom ash (FBA) at 0%, 30%, 50%, 70% and 100% by mass. They mentioned that at fixed water-cement ratios, the compressive strength and the drying shrinkage decreased with the increase of the FBA sand content.

Eve et al. (2006) studied the setting of binary blends such as latex-filled plaster and polyamide fibre-reinforced plaster materials. They showed that the choice of the proper latex to be associated with the plaster was made looking upon its influences on the setting time and the mechanical properties of the blend. Also, the ternary blends were characterized by a drastic increase of the setting time correlated with a reduction of the total swelling.

Omar et al. (2006) compared four types of super plasticizers and used it 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. They indicated that the plastic shrinkage strain varied with the type of super plasticizer and the type of silica fume.

Andrea and Harmuth (2008) investigated the mechanisms of crack formation of interior plasters applied on permanent shuttering panels which are used for the erection of concrete in walls. They mentioned that the composition of traditional mud plasters varies from place to place. The clay content is particularly significant, because if it is too low the plaster will lack strength and cohesion, and if it is too high there will be a risk of cracking due to shrinkage, which will weaken the bond to the wall.

Traditionally, clay plasters were often applied in one coat both internally and externally. If applied in two coats, the first coat contains more clay, even if cracks develop, while the second, containing more sand is applied in a thinner layer. The second coat will help to close the micro-cracks in the first, provided the surface has been lightly dampened before plastering. Finally, lime distemper or whitewash can be applied to give some additional weatherproofing (Hashmi, 2008).

So, the objective of this work was an attempt to examine fundamentally and physically the drying shrinkage of earth plaster reinforced by different fibers under 30°C, 50°C and 70°C thermal condition drying.

2 Materials and methods

The experimental site was located at the institute of production engineering and buildings research, federal agricultural research center (FAL), Braunschweig Germany. Three different plaster materials were selected such as soil, sand and reinforcement fiber. Three fibers types such as barley straw, wheat straw and wood shavings were used. Plaster materials were done by mixing the materials with different percentages (25%:0:75%), (25%:25%:50%), (25%:50%:25%), (25%:75%:0) and (100%:0:0) [soil: sand: reinforcement fiber] for treatments A, B, C, D and E, respectively. Mixing parts were calculated by dry volume. Soil texture was consisted of clay (<2 μm) 31%, silt (20-

63 μm) 22% and sand (63-2,000 μm) 47%.

2.1 Density

Density values of samples were calculated by using the following equation:

$$\rho = \frac{W}{V} \quad (1)$$

Where: ρ : density, kg/m³; W : weight of sample, kg; V : sample volume, m³.

2.2 Shrinkage test

Shrinkage test was measured according to ASTM D4943-95, but with different length and specialized equipment. The earth plaster was packed in a steel frame box with interior dimensions of 20 cm×5 cm×5 cm [length×width×height]. The box had sides, but no top or bottom and the inside surfaces of the box were smooth to avoid bonding between the steel and the plaster (Figure 1). The samples were put in the back oven and dried under different temperatures 30°C, 50°C and 70°C, until the constant weight according to DIN EN ISO 12570: 2000. The shrinkage was measured by pushing the complete sample (including separated lumps) tightly up to one end of the box and measuring the gap created by the shrinkage. The shrinkage values were measured by using vernier scale (Figure 2).

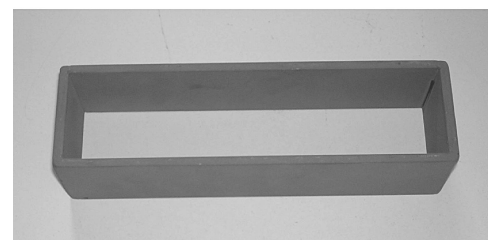


Figure 1 Frame for sample preparation

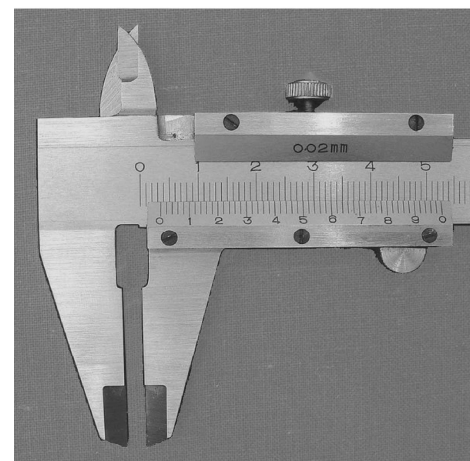


Figure 2 Vernier scale for measuring the shrinkage

2.3 Moisture content

Moisture contents of the materials were measured according to Ashrae’s method (1997) as follows:

$$MC. (\%) = \frac{(W_m - W_d)}{W_d} \times 100\% \quad (2)$$

Where: *MC*: moisture content (d.b), %; *W_m*: moisture weight, kg; *W_d*: dry weight, kg.

2.4 Shrinkage percentage

The shrinkage percentage is the deformation in sample length with the original length. The shrinkage percentage was calculated according to the method of Lerner and Donahue (2003) as follows:

$$\text{Shrinkage } (\%) = (\Delta L/L) \times 100\% \quad (3)$$

Where: ΔL : change in length, cm; *L* : original length, cm.

3 Results and discussion

3.1 Effect of drying temperature on shrinkage for wood shavings plaster

The density values of plaster material reinforced by wood shavings fibers were 681 kg/m³, 1,110 kg/m³ and 1,435 kg/m³ for treatments A, B and C, respectively. The relationship between different treatments and the shrinkage values was indicated in Figure 3. The average drying shrinkage values of treatment A were 1.75 mm, 2.64 mm and 3.20 mm at drying temperatures of 30°C, 50°C and 70°C, respectively. While the average drying shrinkage values of treatment B were 1.88 mm, 3.00 mm and 3.60 mm at drying temperatures of 30°C, 50°C and 70°C, respectively. On the other hand, the shrinkage values of treatment C were 2.06 mm, 3.70 mm and 5.40 mm at drying temperatures of 30°C, 50°C and 70°C, respectively.

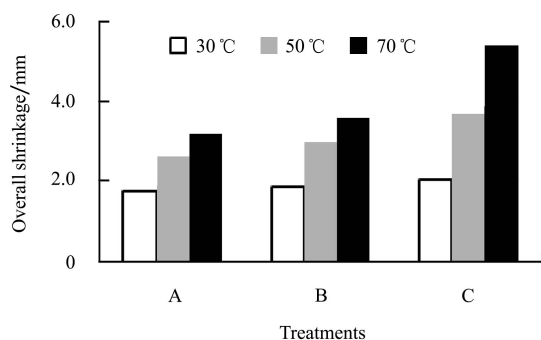


Figure 3 Overall shrinkage of plaster reinforced by wood shavings fibers

The average shrinkage percentages of treatment A were 0.88%, 1.32% and 1.60% at drying temperatures of 30°C, 50°C and 70°C, respectively. At treatment B, shrinkage percentages were 0.94%, 1.50% and 1.80% at different drying temperatures of 30°C, 50°C and 70°C, respectively. While, the shrinkage percentages of treatment C were 1.03%, 1.85% and 2.70% at drying temperatures of 30°C, 50°C and 70°C, respectively as shown in Figure 4.

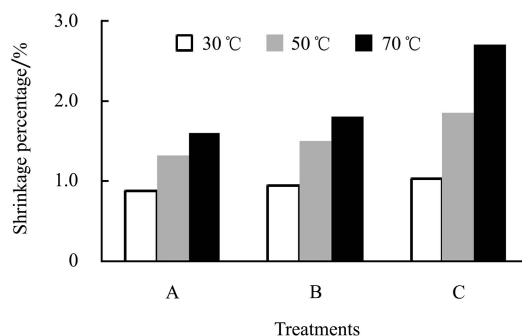


Figure 4 Shrinkage percentages of plaster reinforced by wood shavings fibers

The results indicated that increasing drying temperature from 30°C to 70°C led to an increase of 0.72% shrinkage percentage. Furthermore, increasing wood shavings fibers from 25% to 75% caused a decrease of shrinkage percentage of 0.15%, 0.53% and 1.1% at drying temperatures of 30°C, 50°C and 70°C, respectively. The results showed that drying temperature had a great effect on shrinkage of plaster reinforced by wood shavings fibers.

3.2 Effect of drying temperature on shrinkage of wheat straw plaster

The density values of plaster materials were 594 kg/m³, 1,099 kg/m³ and 1,400 kg/m³ for treatments A, B and C, respectively. For plaster reinforced by wheat straw fiber, the overall shrinkage values of treatment A were 1.70 mm, 2.53 mm and 3.10 mm at drying temperatures of 30°C, 50°C and 70°C, respectively. While for treatment B, they were 1.80 mm, 2.70 mm and 3.30 mm at different drying temperatures of 30°C, 50°C and 70°C, respectively. Furthermore, the shrinkage values of treatment C were 2.05 mm, 3.60 mm and 4.80 mm at drying temperatures of 30°C, 50°C and 70°C, respectively (Figure 5).

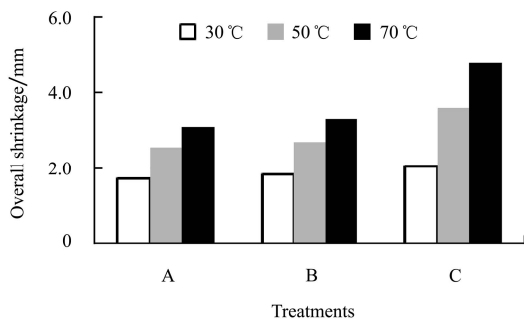


Figure 5 Overall shrinkage of plaster reinforced by wheat straw fibers

At treatment A, the shrinkage percentages were 0.85%, 1.27% and 1.55% at drying temperatures of 30°C, 50°C and 70°C, respectively. At treatment B, Shrinkage percentages were 0.90%, 1.35% and 1.65% for different drying temperatures of 30°C, 50°C and 70°C, respectively. Moreover, the shrinkage percentages of treatment C were 1.03%, 1.80% and 2.40% at drying temperatures of 30°C, 50°C and 70°C, respectively as shown in Figure 6.

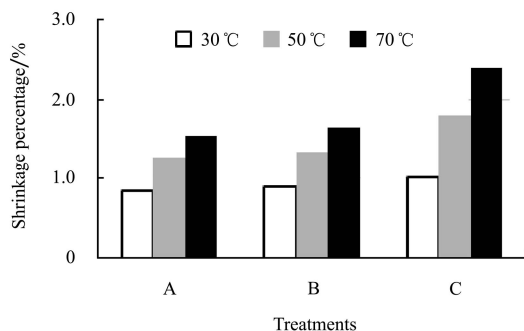


Figure 6 Shrinkage percentages of plaster reinforced by wheat straw fibers

The results indicated that increasing drying temperature from 30°C to 70°C led to an increase of shrinkage percentages of 0.70%, 0.75% and 1.37% for treatments A, B and C, respectively. Furthermore, increasing wheat straw fibres from 25% to 75% caused a decrease of shrinkage percentages 0.18%, 0.53% and 0.85% at drying temperatures 30°C, 50°C and 70°C, respectively.

3.3 Effect of drying temperature on shrinkage for barley straw plaster

Density values for plaster materials reinforced by barley straw were 584 kg/m³, 1,078 kg/m³ and 1,391 kg/m³ for treatments A, B and C, respectively. The overall shrinkages for plaster reinforced by barley straw

fibers of treatment A were 1.64 mm, 2.30 mm and 2.60 mm at drying temperatures of 30°C, 50°C and 70°C, respectively. While for treatment B, they were 1.75 mm, 2.60 mm and 3.10 mm for different drying temperatures of 30°C, 50°C and 70°C, respectively. On the other hand, shrinkage values of treatment C were 1.90 mm, 3.33 mm and 4.60 mm at drying temperatures of 30°C, 50°C and 70°C, respectively (Figure 7).

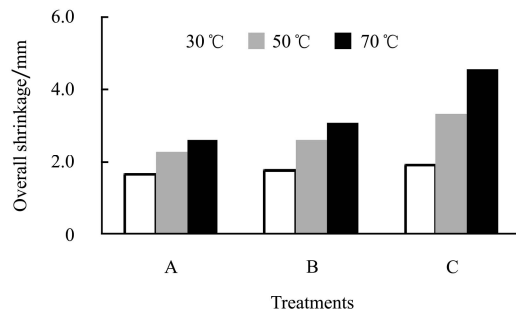


Figure 7 Overall shrinkage of plaster reinforced by barley straw fibers

The average shrinkage percentages of treatment A were 0.82%, 1.15% and 1.30% at drying temperatures of 30°C, 50°C and 70°C, respectively. At treatment B shrinkage percentages were 0.86%, 1.30% and 1.55% for different drying temperatures of 30°C, 50°C and 70°C, respectively. On the other hand, shrinkage percentages of treatment C were 0.95%, 1.67% and 2.30% at drying temperatures of 30°C, 50°C and 70°C, respectively as shown in Figure 8.

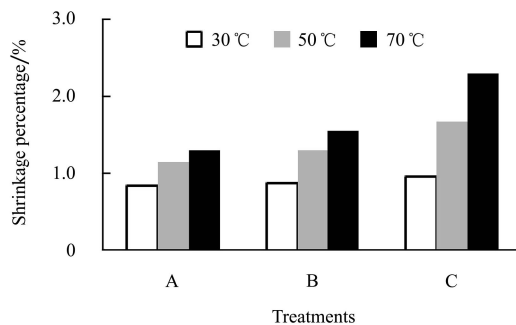


Figure 8 Shrinkage percentages of plaster reinforced by barley straw fibers

The results indicated that increasing drying temperature from 30°C to 70°C lead to an increase of shrinkage percentages of 0.48%, 0.69% and 1.35% for treatments A, B and C, respectively. Furthermore, increasing wheat straw fibers from 25% to 75% cause a decreasing of

shrinkage percentages 0.13%, 0.52% and 1.00% at drying temperatures of 30°C, 50°C and 70°C, respectively.

3.4 Effect of drying temperature on shrinkage for plaster without reinforcement fibers

The density of plaster without reinforcement fibers was 1,642 kg/m³. The relationships between different treatments and the shrinkage rate for sand plaster without reinforcement fibers were illustrated in Figure 9. The average drying shrinkage values were 3.72 mm, 4.12 mm and 5.61 mm at drying temperatures of 30°C, 50°C and 70°C, respectively. The results revealed that shrinkage increased with increasing drying temperature while increasing temperature from 30°C to 70°C caused an increase of shrinkage value by 1.89 mm.

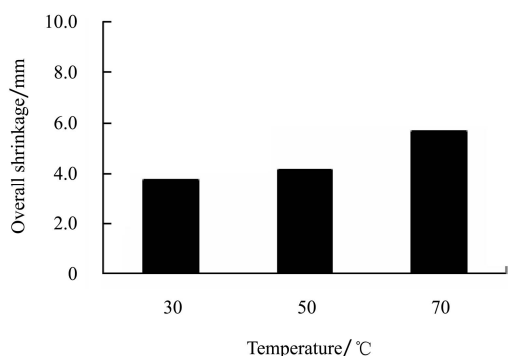


Figure 9 Overall shrinkage of sand plaster without reinforcement fibers

The average values of shrinkage percentage for plaster material without reinforcement fibers were 1.86%, 2.06% and 2.81% at drying temperatures of 30°C, 50°C and 70°C, respectively. Also, the shrinkage percentage increased as drying temperature increased while increasing temperature from 30°C to 70°C caused a drying shrinkage increase of 0.95% (Figure 10).

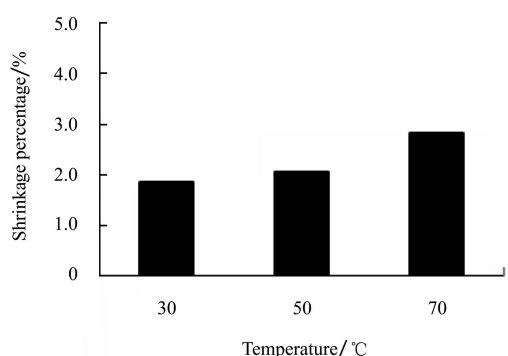


Figure 10 Shrinkage percentages of sand plaster without reinforcement fibers

3.5 Effect of drying temperature on shrinkage for clay plaster

The density of plaster without reinforcement fibers and without sand was 1,481 kg/m³. Figure 11 shows the relationship between different treatments and the drying shrinkage values for clay plaster. The average drying shrinkage values were 6.90 mm, 7.01 mm and 9.13 mm at drying temperatures of 30°C, 50°C and 70°C, respectively. The results revealed that shrinkage increased as drying temperature increased while increasing temperature from 30°C to 70°C caused a drying shrinkage increase of 2.23 mm.

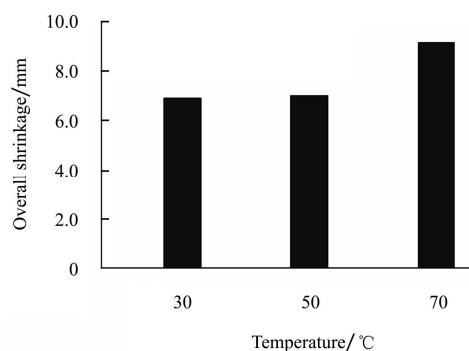


Figure 11 Overall shrinkage of clay plaster without sand and reinforcement fibers

The average values of shrinkage percentage for plaster material without reinforcement fibers were 3.45%, 3.51% and 4.57% at drying temperatures of 30°C, 50°C and 70°C, respectively. Also, the shrinkage percentage increased as drying temperature increased while increasing temperature from 30°C to 70°C caused a drying shrinkage increase of 1.12% as shown in Figure 12.

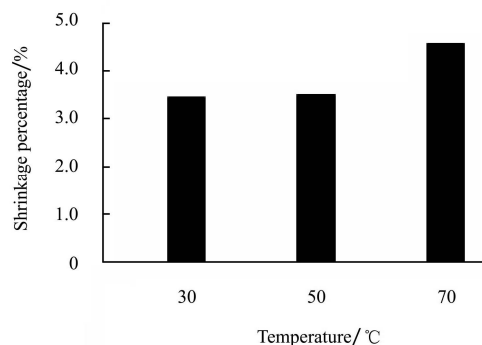


Figure 12 Shrinkage percentages of clay plaster without sand and reinforcement fibers

Also, high cracks were showed under drying

temperatures of 50°C and 70°C and the samples full destroyed (Figure 13).



Figure 13 Shrinkage and cracks for clay samples

3.6 Comparisons of the different plaster materials under the study

At treatment A, overall shrinkage values were 1.75, 1.70, 1.64, 3.72 and 6.90 mm at 30°C for plaster reinforced by wood shavings, wheat, barley, without fibers (sand plaster) and clay, respectively. While at 50°C, overall shrinkage values were 2.64, 2.53, 2.30 4.12 and 7.01 mm for wood shavings, wheat, barley, sand and clay plaster, respectively. On the other hand, overall shrinkage values at 70°C were 3.20, 3.10, 2.60, 5.61 and 9.13 mm of plaster reinforced by wood shavings, wheat, barley, sand and clay, respectively (Figure 14).

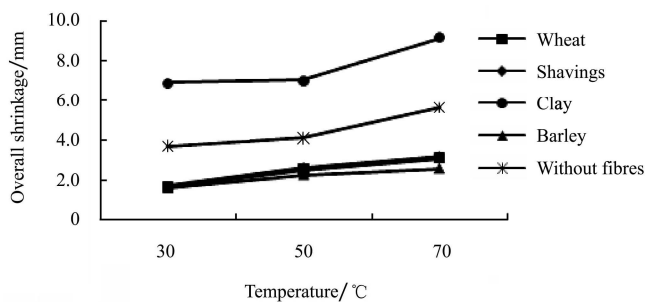


Figure 14 Overall shrinkage of different plaster materials for treatment A

Furthermore, shrinkage percentages were 0.88%, 0.85%, 0.82%, 1.86% and 3.45% at 30°C for plaster reinforced by wood shavings, wheat, barley, without fibers (sand plaster) and clay, respectively. While at 50°C, shrinkage values were 1.32%, 1.27%, 1.15%, 2.06% and 3.51% for wood shavings, wheat, barley, sand and clay plaster, respectively. On the other hand, overall shrinkage percentages at 70°C were 1.60%, 1.55%, 1.30%,

2.81% and 4.57% of plaster reinforced by wood shavings, wheat, barley, sand and clay, respectively as shown in Figure 15.

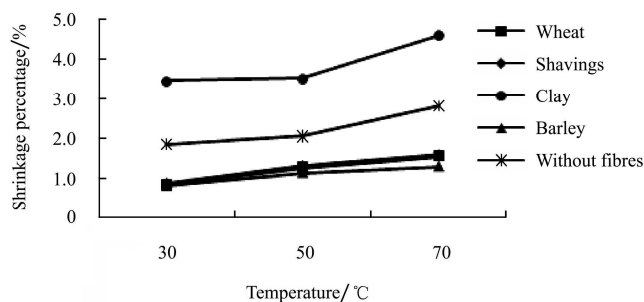


Figure 15 Shrinkage percentage of different plaster materials for treatment A

The results revealed that clay plaster without reinforcement fibers and straw had high shrinkage values with high cracks in the plaster samples. Also, sand plasters without fibers had high shrinkage but lower than only clay. For the reinforcement fibers plasters, the highest shrinkage was for plaster reinforced by wood shavings fibers, while the lowest shrinkage was plaster reinforced by barley straw fibers.

For treatment B, overall shrinkage values were 1.88, 1.80, 1.75, 3.72 and 6.90 mm at 30°C for plaster reinforced by wood shavings, wheat, barley, without fibers (sand plaster) and clay, respectively. While at 50°C, overall shrinkage values were 3.00, 2.70, 2.60, 4.12 and 7.01 mm for wood shavings, wheat, barley, sand and clay plaster, respectively. On the other hand, overall shrinkage values at 70°C were 3.60, 3.30, 3.10, 5.61 and 9.13 mm of plaster reinforced by wood shavings, wheat, barley, sand and clay, respectively (Figure 16).

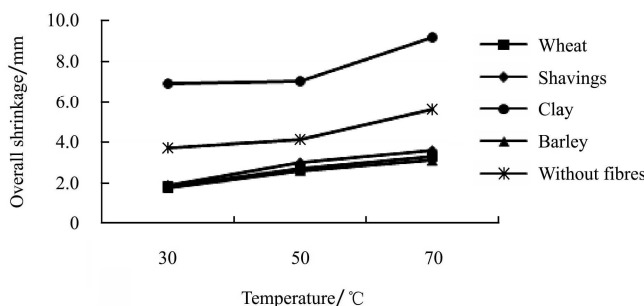


Figure 16 Overall shrinkage of different plaster materials for treatment B

Furthermore, shrinkage percentages were 0.94%,

0.90%, 0.86%, 1.86% and 3.45% at 30°C for plaster reinforced by wood shavings, wheat, barley, without fibers (sand plaster) and clay, respectively. While at 50°C, shrinkage percentages were 1.50%, 1.35%, 1.30%, 2.06% and 3.51% for wood shavings, wheat, barley, sand and clay plaster, respectively. On the other hand, overall shrinkage percentages at 70°C were 1.80%, 1.65%, 1.55%, 2.81% and 4.57% of plaster reinforced by wood shavings, wheat, barley, sand and clay, respectively as shown in Figure 17.

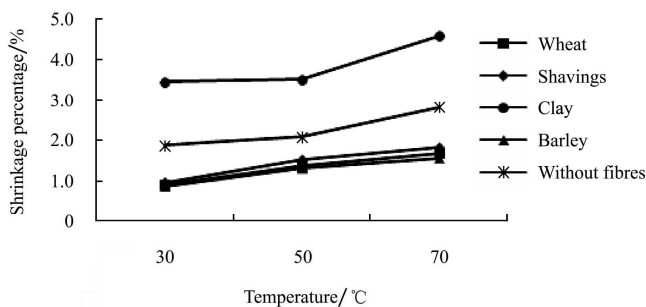


Figure 17 Shrinkage percentage of different plaster materials for treatment B

At treatment C, overall shrinkage values were 2.06, 2.05, 1.90, 3.72 and 6.90 mm at 30°C for plaster reinforced by wood shavings, wheat, barley, without fibers (sand plaster) and clay, respectively. While at 50°C, overall shrinkage were 3.70, 3.60, 3.33, 4.12 and 7.01 mm for wood shavings, wheat, barley, sand and clay plaster, respectively. On the other hand, overall shrinkage at 70°C were 5.40, 4.80, 4.60, 5.61 and 9.13 mm of plaster reinforced by wood shavings, wheat, barley, sand and clay, respectively (Figure 18).

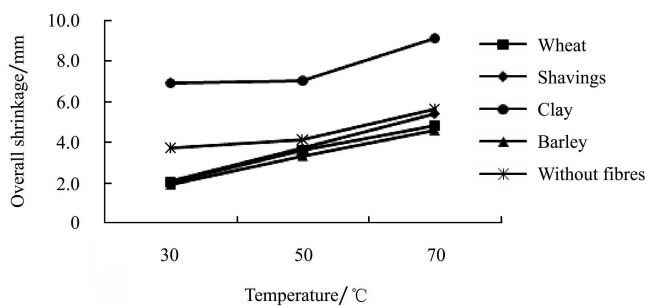


Figure 18 Overall shrinkage of different plaster materials for treatment C

Furthermore, shrinkage percentages were 1.03%, 1.03%, 0.95%, 1.86% and 3.45% at 30°C for plaster

reinforced by wood shavings, wheat, barley, without fibers (sand plaster) and clay, respectively. While at 50°C, shrinkage percentages were 1.85%, 1.80%, 1.67%, 2.06% and 3.51% for wood shavings, wheat, barley, sand and clay plaster, respectively. On the other hand, overall shrinkage at 70°C were 2.70%, 2.40%, 2.30%, 2.81% and 4.57% of plaster reinforced by wood shavings, wheat, barley, sand and clay, respectively (Figure 19).

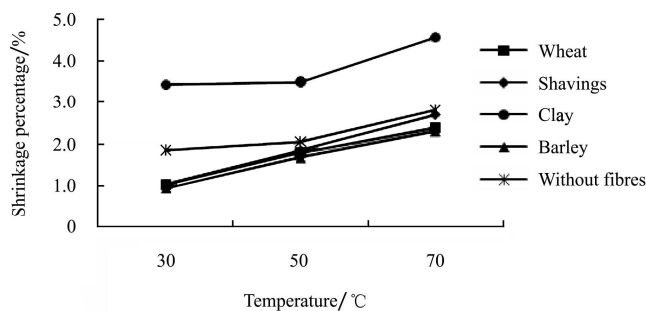


Figure 19 Shrinkage percentage of different plaster materials for treatment C

The average of shrinkage percentages for treatments A, B and C were ranged between 0.82%–1.03%, 1.15% – 1.85% and 2.60%–5.40% at 30°C, 50°C, and 70°C, respectively.

The results confirmed that, the highest shrinkage was for plaster reinforced by wood shavings fibres, while the lowest shrinkage was for plaster reinforced by barley straw fibers for treatments A, B and C. The results also revealed that the plaster without reinforcement fibers had a lot of cracks and problems that caused plaster destroyed.

4 Conclusions

The results confirmed that the average of shrinkage percentages for treatments A, B and C were ranged between 0.82%–1.03%, 1.15%–1.85% and 2.60%–5.40% at 30°C, 50°C and 70°C, respectively. The highest shrinkage was for plaster reinforced by wood shavings fibers, while the lowest shrinkage was for plaster reinforced by barley straw fibers for treatments A, B and C. The plaster without reinforcement fibers had a lot of cracks and problems that caused plaster destroyed. Also, the reinforcement fiber had greater effect on the drying shrinkage than sand. The drying temperature had a high effect on shrinkage values as a result of forced desorption

from the plaster surfaces. The cracks decreased as reinforcement fibers increased and it increased as clay and sand content increased. Also, the cracks increased as drying temperatures increased and vice versa. It will

be better when the plaster is setted at low temperature condition (30°C) and used a lot of quantity of straw amounts for improving the plaster materials to decrease the shrinkage and cracks.

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