Earth plaster for durable straw-bale walls; a PhD research on natural stabilizers

by Matthieu Pedergnana
Earth plaster for durable straw-bale walls

Outline

Introduction

Earthen construction in Turkey
Advantages/disadvantages of earthen plasters

Specific properties of plasters for straw-bale construction
State of the research

Research on natural stabilizers

Objectives of the research
Materials for plasters
Research design

First results

Conclusion and further objectives
Introduction

Earth plaster and construction in Turkey

Long history of earthen (mud brick) construction


Reconstruction of the gate of Hattuşas with traditional techniques (2002-2005) (http://www.hattuscha.de/English/citywall.htm)
Introduction

Earth plaster and construction in Turkey

Harran – mudbrick houses  

Safranbolu – wooden framed mudbrick houses  

Main technique = Mud brick
Introduction

Earth plaster and construction in Turkey

Traditional plasters

Gypsum plasters (specific additives: lime, clay)

Lime plasters (specific additives: egg white, tragacanth gum, brick powder, clay)

Earth plasters (specific additives: lime, chaff, cow dung)
Introduction

Specific functions of plasters on straw-bale walls

Load carrying

Failure mode of load-bearing wall
(King, 2009, p.69)

Mechanical model of plastered straw-bale
load-bearing wall
(Lacinski & Bergeron, 2000, p.117)
Introduction

Specific functions of plasters on straw-bale walls

Bale protection (weather – moisture – animals – fire)

Wetting and drying mechanisms of straw-bale walls
(Straube, 2009, p.8)
Introduction

Specific functions of plasters on straw-bale walls

Internal comfort

IR image of straw-bale building
(https://naturalbuild.wordpress.com/2013/03/04/evaluating-the-success-of-an-eco-house/

Air tightness details
(http://endeavourcentre.org/2014/10/air-tightness-details-for-straw-bale-walls/)
Introduction

Specific functions of plasters on straw-bale walls

Aesthetic

3rd Ecological Architecture and Natural Building workshop – Bayramiç, Yeniköy farm (2013)
### Introduction

#### Advantages / Disadvantages of earth plasters

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low ecological impact material</td>
<td>Low mechanical strength</td>
</tr>
<tr>
<td>Large availability of material</td>
<td>Low water/weather resistance</td>
</tr>
<tr>
<td>Biodegradable</td>
<td>Need of regular maintenance</td>
</tr>
<tr>
<td>High moisture storage capacity and absorption/desorption speed</td>
<td>Social non-acceptance</td>
</tr>
<tr>
<td>High thermal capacity and low effusivity</td>
<td></td>
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<tr>
<td>Aesthetic and workability</td>
<td></td>
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</tbody>
</table>
Introduction

State of the research

Naturally stabilized plasters

- Improvement of mechanical strength
- Improvement of water/weather resistance
- Optimal grain size distribution
  
  *Monatana, Randazzo and Sabadinni, 2013*

- Optimal proportion of fibers
  
  *Ashour, Bahnasawey and Wu, 2010*

- Coating with oil
  
  *Minke, 2012*

- Additives (dung, eggs, mucilages)
  
  *Vargas Neumann, Heredia, Bariola and Mehta, 1987*

- Additives
  
  *Galán-Marín, Rivera-Gómez and Petric, 2010*
Introduction

State of the research

Main research topics

Chemically stabilized plasters

Weather resistant plasters

(Svoboda and Procházka 2012 – Eires, Camões and Ponte, 2014 – Faria and Santos, 2014)
Introduction

State of the research

Main research topics

Chemically stabilized plasters

Reproduction of historical plasters


Research on natural additives
Introduction

State of the research

Main research topics
Chemically stabilized plasters
Reproduction of historical plasters
Research on natural and traditional additives

(Vissac, Fontaine and Anger, 2013 – Beas, 1991)
**PhD research on natural stabilizer**

**Objectives of the research**

<table>
<thead>
<tr>
<th>Impact of different stabilizers on plasters</th>
<th>Impact of stabilized plasters on walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical strength</td>
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</tr>
<tr>
<td>Hygric behavior</td>
<td>Hygric behavior</td>
</tr>
<tr>
<td>Weather resistance</td>
<td>Weather resistance</td>
</tr>
<tr>
<td>Durability</td>
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</tbody>
</table>
PhD research on natural stabilizer

Materials for plasters

Earth (3 types)

Stabilizers

Sand (2 types)  Fibers (3 types)

Additives (6 types)

Workmanship

Setting time  Application method (layer thickness)

Drying conditions
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Materials for plasters

Earth

Metu
Kerkenes A
Kerkenes B
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Materials for plasters

Sand

- Non washed calcareous sand
- Silica sand (river sand)
- Washed calcareous sand
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Materials for plasters

Fibers

Tomatoes + sugar beetroots residues

Increase of compressive strength under dry and wet conditions (Achenza & Fenu, 2007)
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Materials for plasters

Fibers

Short straw / chaff

Traditional Middle-East fiber – reduce shrinkage (Eckart, 1972 – Fodde, 2009 and other)
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Materials for plasters

Fibers

- Short straw / chaff
- Cattail (reed) fibers

Increase resistance to water and humidity buffering (Georgiev, Theuerkorn, Krus and Kilian 2014 – Maddison, Mauring, Kirsimäe and Mander, 2009)
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Materials for plasters

Additives

Rotten straw/hay juice

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Materials for plasters

Additives

- Rotten straw/hay juice
- Egg white

Reduction of water capillarity – improve resistance to rain
(Bourges and Colas, 2013)
PhD research on natural stabilizer

Materials for plasters

<table>
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<th>Additives</th>
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<tr>
<td>Rotten straw/hay juice</td>
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<tr>
<td>Egg white</td>
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<tr>
<td>Oxen blood</td>
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Increase compressive strength – reduce water sensitivity  
(Kraus, Hirmas and Roberts, 2015)
**PhD research on natural stabilizer**

**Materials for plasters**

<table>
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<th>Additives</th>
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<tr>
<td>Molasses</td>
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<tr>
<td>Rotten straw/hay juice</td>
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<td>Egg white</td>
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Increase of compressive strength under dry and wet conditions (Vilane, 2010)
PhD research on natural stabilizer

Materials for plasters

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Traditional additives in Middle-East country – improve water resistance (Minke, 2012 + Hassan Fathy)
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Materials for plasters

Additives

- Molasses
- Donkey dung
- Cow dung
- Rotten straw/hay juice
- Egg white
- Oxen blood

Traditional additives in Africa and Middle-East – increase hardness and reduce shrinkage
PhD research on natural stabilizer

Research design and Experimental set-ups

- Survey of local resources and techniques
- Identification of raw materials
- Properties of local straw-bales

Impact of stabilizers on earth plasters

- Impact of plasters on the durability of straw-bale walls
- Impact of plasters on the mechanical strength of straw-bale walls
# PhD research on natural stabilizer

## Properties of straw-bales

<table>
<thead>
<tr>
<th>Straw-bale type</th>
<th>Mechanical properties of bales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of cereal + production</td>
<td>Initial settling and creep</td>
</tr>
<tr>
<td>Size – Density - Humidity</td>
<td>Compressive strength</td>
</tr>
<tr>
<td>Fiber length</td>
<td></td>
</tr>
<tr>
<td>Moisture sorption curves</td>
<td></td>
</tr>
</tbody>
</table>

- Fiber length
- Mechanical properties of bales
- Compressive strength
- Initial settling and creep
**PhD research on natural stabilizer**

### Preliminary research on earth plasters

<table>
<thead>
<tr>
<th><strong>Mechanical strength</strong></th>
<th><strong>Hygric behavior</strong></th>
<th><strong>Durability</strong></th>
</tr>
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<tbody>
<tr>
<td>Flexural strength</td>
<td>Humidity absorption rate</td>
<td>Surface water capillarity</td>
</tr>
<tr>
<td>Dry compressive strength</td>
<td></td>
<td>Shrinkage</td>
</tr>
<tr>
<td>Binding (shear) strength</td>
<td></td>
<td>Water resistance</td>
</tr>
<tr>
<td>Humid compressive strength</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Durability**
  - Surface water capillarity
  - Shrinkage
  - Water resistance
## PhD research on natural stabilizer

### Properties of selected earth plasters

<table>
<thead>
<tr>
<th>Mechanical strength</th>
<th>Hygric and hydric behavior</th>
<th>Durability</th>
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<tr>
<td>Flexural strength</td>
<td>Humidity absorption rate</td>
<td>Erosion rate</td>
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<tr>
<td>Dry compressive strength</td>
<td>Humidity absorption capacity</td>
<td>Shrinkage</td>
</tr>
<tr>
<td>Binding (shear) strength</td>
<td>Water capillarity absorption</td>
<td>Water resistance</td>
</tr>
<tr>
<td>Humid compressive strength</td>
<td></td>
<td>Humidity expansion</td>
</tr>
</tbody>
</table>

**Definitions:**
- **Mechanical strength**: Flexural strength, Dry compressive strength, Binding (shear) strength, Humid compressive strength
- **Hygric and hydric behavior**: Humidity absorption rate, Humidity absorption capacity, Sorption isotherms, Water capillarity absorption, Drying behavior
- **Durability**: Erosion rate, Shrinkage, Water resistance, Humidity expansion
PhD research on natural stabilizer

Impact of plasters on straw-bale walls

- Mechanical resistance of plastered walls
  - Vertical loading

- Hygro-thermal behavior of plastered walls
  - Moisture diffusion
  - Heat diffusion

- Durability of plastered walls
  - Erosion rate
  - Moisture level
  - Surface appearance
First results – mechanical strength

Production of plasters
First results – mechanical strength

Testing of plasters
First results – mechanical strength

Impact of fibers content / density

Impact of fibers

compressive strength (Mpa)
density (kg/m³)

KerkA - 1st set
KerkA - 2nd set
First results – mechanical strength

Impact of molasses

![Graph showing the impact of molasses on mechanical strength. The graph plots compressive strength (MPa) against the % of molasses (by weight). The data points are labeled KerkA.]
First results – mechanical strength

Impact of molasses

Impact of molasses and fibers

- KerkA + 10% molasses
- KerkA + 5% molasses
First results – mechanical strength

Impact of setting time

Evolution of compressive strength

- KerkA - 20% short straw
- KerkA - 40% short straw
- Metu - 20% short straw
Conclusion and further objectives

Straw-bale construction in Turkey

- Develop rules of thumbs and good practices for earthen plasters
- Develop low maintenance natural plasters
- Develop trust through tested examples and practices
- Increase the number of straw-bale buildings in Turkey
Conclusion and further objectives

Partnership for further research

- Partnership with other universities to assess the suitability of straw-bale in every climate
- Development of building rules and good practices for seismic areas
- 2016 – Ankara – Organization of an international builder and researcher workshop on Natural Building Materials
Conclusion and further objectives

Acknowledgment

The Kerkenes Eco-center for using its facilities for the in-situ research

http://www.kerkenes.metu.edu.tr/keco/index.html
https://www.facebook.com/KerkenesEcoCenter

Middle-East Technical University for its small research grants
Thank you – Merci a tous

http://riccardodepaoli.com/enduits-decoratifs/larbre-genealogique/
Conclusion and further objectives

Short bibliography on earthen plasters

Books on plasters:
Moréteau (2011) *Enduits de Terre Crue*, Terre Vivante
Conclusion and further objectives

Short bibliography on earthen plasters

Important scientific articles (1):

**Anger, Fontaine, Gandreau, Bourges, and Joffroy** (2012) “Earthen Surfaces Stabilization with Biopolymers: Traditional Recipes and Literature Review” In *Terra 2012*


**Bourges, Anger, Fontaine and Joffroy** (2012) “Monitoring Methods and Tools Adapted to Evaluate Properties of Earthen Surfaces.” In *Terra 2012*


**Faria, Paulina, Santos, and Aubert** (2015) “Experimental Characterization of an Earth Eco-Efficient Plastering Mortar” in *Journal of Materials in Civil Engineering*

**Faria, Paulina, Santos, and Silva** (2014) “Earth-Based Mortars for Masonry Plastering” In *9th International Masonry Conference*, 1–12, Guimares, Portugal

**Hamard, Morel, Salgado, Marcom, and Meunier** (2013) “A Procedure to Assess the Suitability of Plaster to Protect Vernacular Earthen Architecture” *Journal of Cultural Heritage* 14 (2)
Conclusion and further objectives

Short bibliography on earthen plasters

Important scientific articles (2):


Conclusion and further objectives

Short bibliography on earthen plasters

Other cited references:


Eckart (1972) “Lehmziegekhauser in der Altinova” in Keban Project 1970 Activities, METU


