Use of an insulation-dispersion adobe composite in green building construction

Category: Delivering Sustainable Infrastructure

Associate Professor Douglas M. Matson
Mr. Aniruddha S. Nene

Department of Mechanical Engineering
School of Engineering
Tufts University
Medford, Massachusetts

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Overview

- Motivation
- Test procedure
- Results
- Delivering sustainable infrastructure
- Conclusions



Cinva ram brick fabrication on-site in Te Toke NZ – photos courtesy of Bryan Innes

Motivation

- Nga Whare Oranga Trust of Taupo is studying the use of adobe bricks made from locally available raw materials as wall insulation / thermal mass
  - Ohaaki clay
  - pumice
- Need test results to determine local building code compliance
- Desire modeling capability to extend use with variations in material properties

Warkworth

New Zealand Earth Builders Limited

Florian Primbs architect
Christopher Bean building/plastering
http://www.nzearthbuilders.co.nz/index.htm
Wellsford NZ

Nga Whare Oranga Trust

Sean Harris architect
Bryan Innes building/plastering
http://www.ecoshow.co.nz/
Taupo NZ

Te Toke

Why introduce a dispersed phase to adobe?

- Composite materials show significant improvements in
  - Increased strength in applications as a load bearing wall (compared to no adobe)
    Failure mechanism shifts from catastrophic cracking to incremental crumble mode

$$\sigma = \varepsilon\,\tilde{E}$$

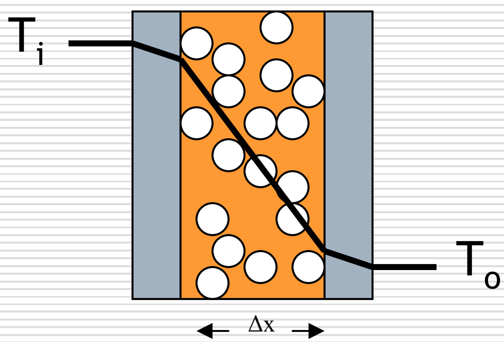
Voigt isostrain (ROM)

$$\tilde{E}_{\max} = \left(f_m\,E_m + f_d\,E_d\right)$$

Reuss isostress

$$\tilde{E}_{\min} = \left(\frac{E_m}{f_m} + \frac{E_d}{f_d}\right)^{-1}$$

  - Heat transfer resistance as an insulating surface



$$R = \frac{\Delta x}{\tilde{k}}$$

$$Q = -\tilde{k}\,A\,\frac{dT}{dx}$$

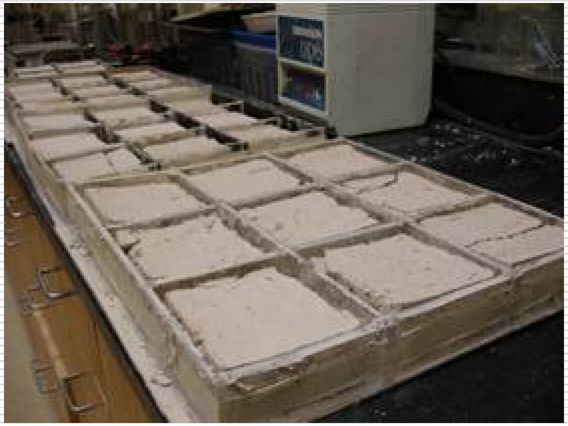
$$\tilde{k}_{\max} = \left(f_m\,k_m + f_d\,k_d\right)$$

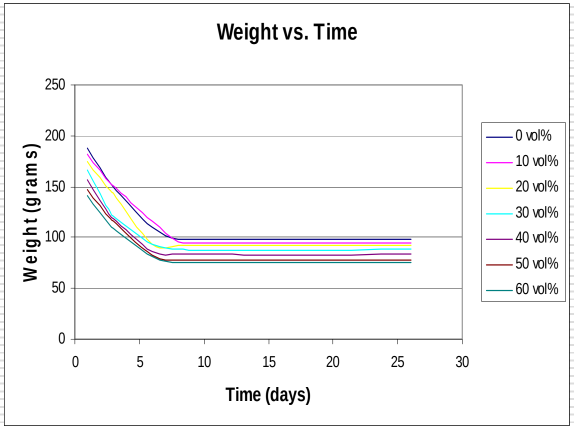
$$\tilde{k}_{\min} = \left(\frac{k_m}{f_m} + \frac{k_d}{f_d}\right)^{-1}$$

- Two phases: soft polystyrene beads
  hard local pumice pebbles

Brick and wall fabrication

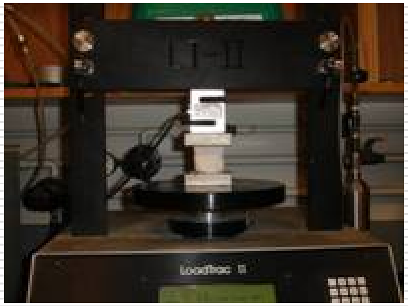
- On-site production / limited capital investment
- Local labor / local materials / sun dry
- Adobe brick fabrication steps
  - Mixing
  - Packing
  - Drying
- Wall assembly steps
  - Conventional stud wall
  - Brick laying between studs
  - Wall stucco as plaster
- Performance calculations needed
  - Drying shrinkage
  - Adobe strength (as function of dispersion content)
  - Wall R-value (as function of dispersion content)
  - Building code compliance

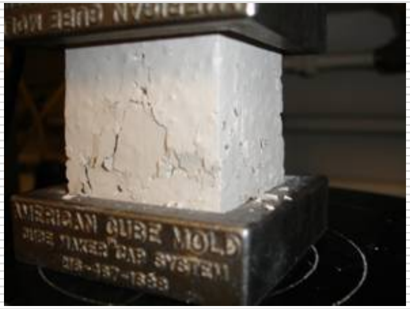




Compression testing

- 2'' x 2'' cubical molds used with greased inner surfaces
- Three series at different initial water contents (50%, 45%, 40%)
- Geocomp LoadTrac II compression test machine $\dot{\varepsilon} = 0.7$ in/min





Elastic modulus	E [MPa]
Ohaaki clay	6.45
Pumice	13.0
Kaolin clay	25.1
Polystyrene	0.77

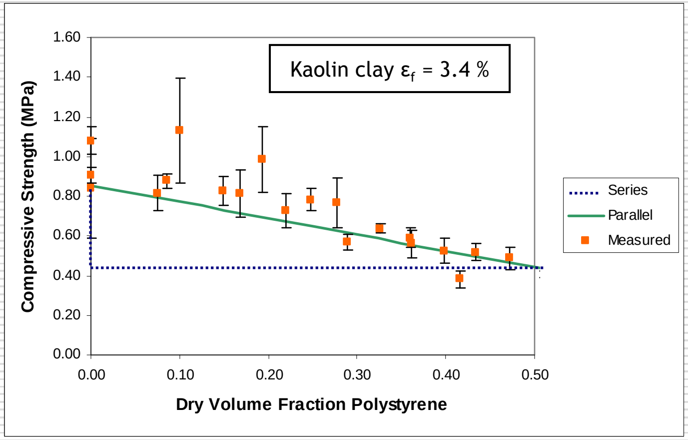
Yield strength	Sy [MPa]
Traditional adobe	1.20*
Ohaaki clay	1.07
Pumice	0.51
Kaolin clay	0.94
Polystyrene	0.5*

$$\sigma_d = \varepsilon\, E_d = 0.037\,(13.01) = 0.481\ MPa$$

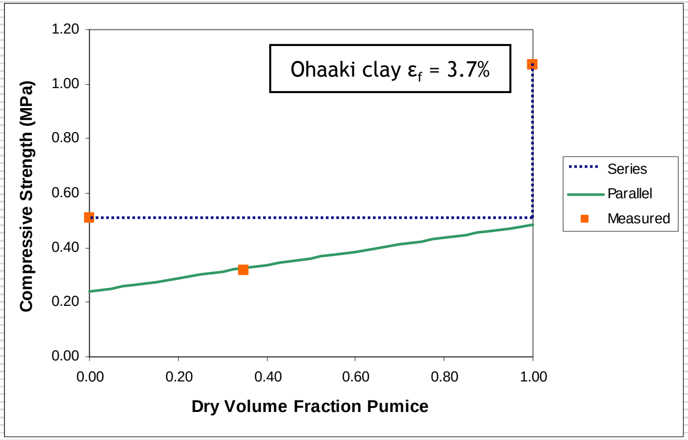
$$\sigma_m = \varepsilon\, E_m = 0.037\,(6.45) = 0.239\ MPa$$

$$\sigma = \sigma_d\ f_d + \sigma_m\ f_m = 0.481\,(0.349) + 0.239\,(0.651)$$

$$= 0.323\ MPa \qquad [0.32\ MPa\ observed]$$



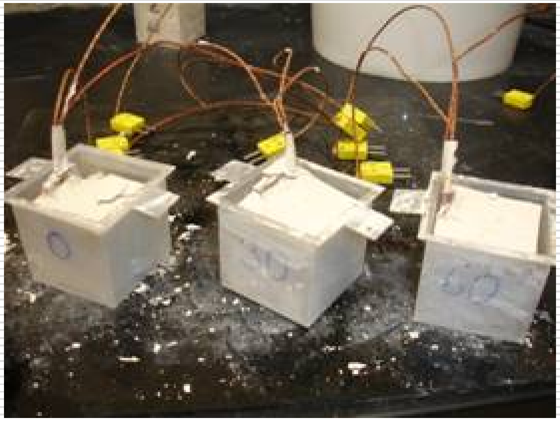
Soft dispersant shares strain with matrix

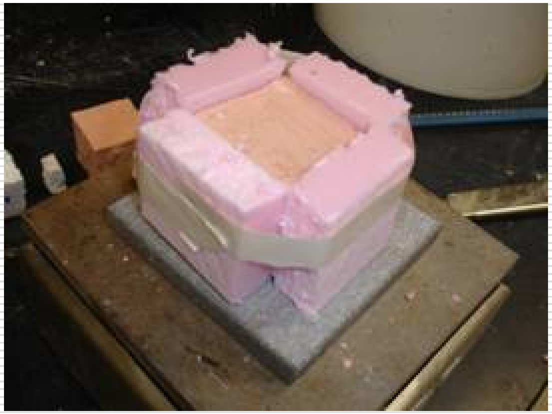


Hard dispersant concentrates strain in matrix

Thermal testing

- Indirectly measure heat flux generated by a common hot-plate by measuring the heat transfer through a standardized material with know conductivity – a granite block – using type-K thermocouples
- Use this flux calculation with knowledge of the temperature drop through the adobe brick to evaluate thermal conductivity
- Extrapolate behavior to wall thickness and evaluate R-value
- Simplicity of test makes it easy for on-site evaluation of local materials in the event of local variation in feedstock



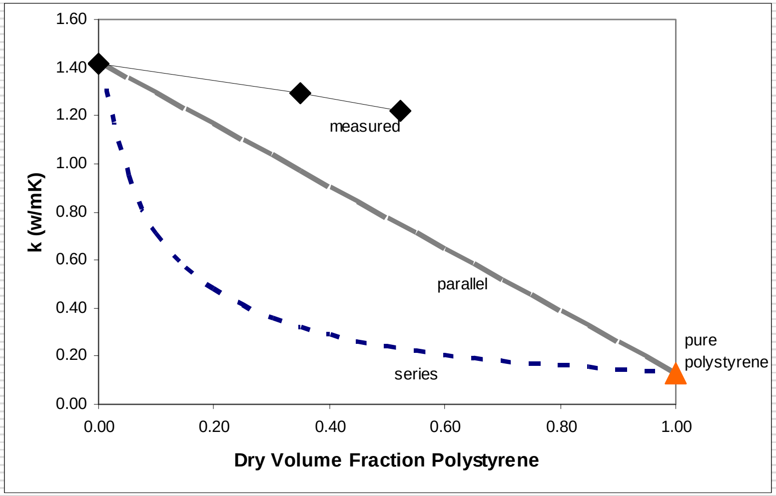


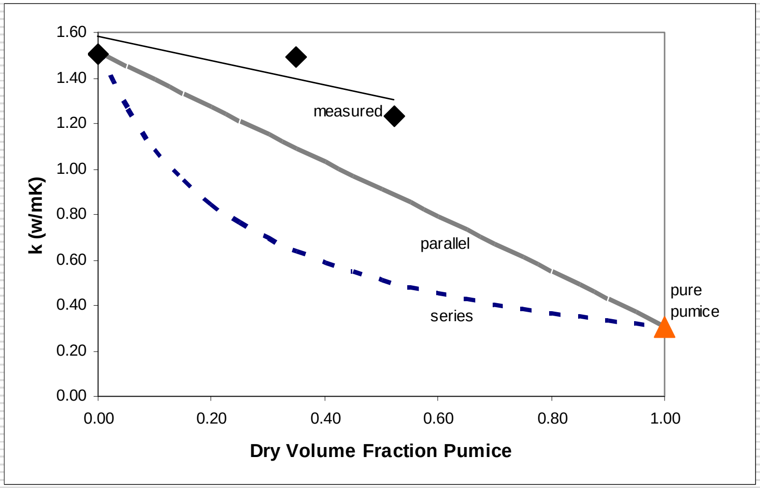
$$Q = -\tilde{k}\ A\ \frac{\Delta T_{granite}}{\Delta x_{granite}} = -\tilde{k}\ A\ \frac{\Delta T_{adobe}}{\Delta x_{adobe}}$$

Thermal conductivity measurement results

- Conductivity is dominated by the properties of the clay matrix
- Neither model adequately describes behavior limiting predictive capability except on an empirical basis (possibly due to fragmentation or matrix intrusion during the aggressive mixing process)

conductivity	k [W/mK]
Traditional adobe	1.5*
Ohaaki clay	1.51
Kaolin clay	1.42
Polystyrene	0.13*
Pumice	0.31





Sustainable Value

- Taupo Building Code specifies for "cold region" (with 128 mm walls typical)

Ceiling	R_C = 2.5 K m²/W
Floor	R_F = 1.2 K m²/W
Walls	R_W = 2.2 K m²/W

- Earthen Building Code requires R = 0.6 K m^2/W (with 350 mm walls required)
- Annual Loss Factor (ALF) calculations include balance over entire building
  with passive solar contributions obtain overall performance
  R = 2.1 K m^2/W based on measured adobe conductivities

- Technique is easy to teach
- No expensive equipment is required
- Raw materials are available on-site
- Finished product is readily exportable locally

- True value added is in application as a thermal mass when used on exterior walls of building
  NOT as a substitute for external insulation

Conclusions

- Adobe formed from local deposits of clay and pumice on the NZ north island can be made into bricks to fill wall space in standard wood frame construction.
- Initial water content has little effect on final properties and thus mixing procedures can be optimized to fit the equipment availability on-site.
- Properties of adobe made from polystyrene and pumice are readily measured using simple and sustainable techniques to promote quality assurance and predict performance.
- Measurements over a wide range of compositions shows that structural properties can be predicted using ROM estimation of modulus while thermal properties are dominated by the performance of the clay matrix.
- A soft dispersed phase is preferred over a hard dispersed phase.
- The structural performance is comparable to traditional adobe and addition of the insulating dispersed phase changes the fracture mode favourably.
- The thermal performance is superior to traditional adobe but not to an extent that warrants its application as an insulating material.
- Application of adobe as a thermal mass needs further investigation

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