American Concrete Institute®
Advancing concrete knowledge

The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 1

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

ACI
WEB SESSIONS

Passarin Jongvisuttisun is a graduate research assistant in the School of Civil and Environmental Engineering at the Georgia Institute of Technology. Her research interests have included the early-age behaviors of cementitious materials, the mechanical behavior of fiber-cement composites, modeling in materials, microstructure of cement hydrates and characterization techniques.

ACI
WEB SESSIONS

Efficiency of Eucalyptus Pulps for Internal Curing

Passarin Jongvisuttisun[a], Camille Negrello[a,b], and Kimberly E. Kurtis[a]

[a]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia USA

[b]Civil Engineering Department, Ecole Normale Superieure de Cachan, Cachan Cedex, France

Georgia Institute of Technology

Content

- Background
- Motivation for research
- Studies and results
  - Fiber characterization
  - Internal curing capacity
- Conclusions
- Q&A

Georgia Tech

Background

- Not only HPC but also hot weather concrete that requires special care for placing and finishing.
- Cement-based plaster also subject to water loss.
- Cracking is the most frequent cause of complaint.

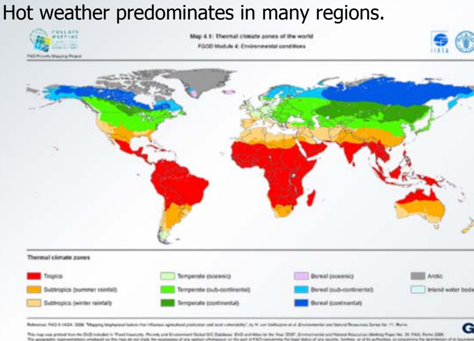
Georgia Tech

Image derived from www. walkersconcrete.com and www.dreamstime.com

---

Background

- Hot weather predominates in many regions.



Georgia Tech

Image derived from www.fao.org

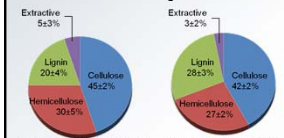
Why pulps?

- Natural fiber is "green."
  - Contributes to the sustainability of concrete
- Pulp has several additional advantages:
  - May substantially reduces autogenous shrinkage
  - Provides additional resistance to shrinkage-induced cracking
  - Provides post-cracking ductility
  - Is found all over the world (accessible and economical)

Georgia Tech

Motivation for research

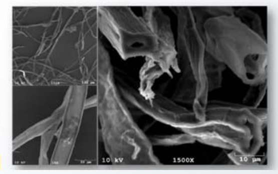
- Chemical and physical features have not been explored.
- The selection, dosing, and even the design of pulp fiber for internal curing in mortar and concrete is challenging.



Average composition of hardwoods — *Average composition of softwoods*

Average fiber length:

Hardwoods ~ 1-2 mm — Softwoods ~4-5 mm



Scanning Electron Microscopy (SEM) images of unbleached eucalyptus soda pulp

Georgia Tech

Motivation for research

Mohr et al. (2005):

- TMP softwood fiber was effective at reducing autogenous shrinkage.
- Kraft fiber (k=1) was less effective than TMP fiber (k=3.3).

Mezencevova et al. (2012):

- Compared the internal curing efficiency of untreated TMP softwood to chemical-treated TMP softwood fibers
- Lacked information about fiber morphology

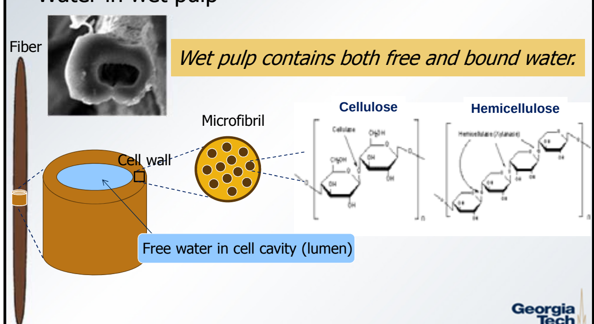
Prior efforts have focused on softwood fibers.
Hardwood fibers examined here have been relatively unexplored for internal curing.

Georgia Tech

Motivation for research

- Water in wet pulp

Wet pulp contains both free and bound water.

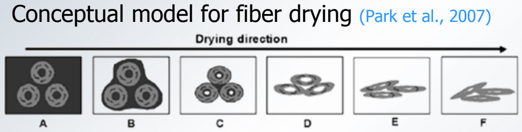


Georgia Tech

Image modified from www.sigmaaldrich.com and US patent 6806955

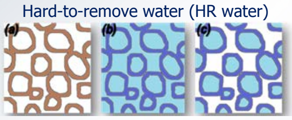
Motivation for research

- Conceptual model for fiber drying (Park et al., 2007)



*In picture A, B, and C, The fiber cell wall is saturated.

Hard-to-remove water (HR water)



a) Fiber at dry state
b) Fiber with free and bound water
c) Fiber with HR water

Internal diffusion is the key mechanism for removing HR water.

S. Park, R. A. Venditti, H. Jameel, and J. J. Pawlak, "Hard-to-remove water in cellulose fibers characterized by thermal analysis: A model for the drying of wood-based fibers," *TAPPI, vol. 6, pp. 10-16, 2007.*

Georgia Tech

Content

- Background
- Motivation for research
- Studies and results
  - Fiber characterization
  - Internal curing capacity
- Conclusions
- Q&A

Georgia Tech

Fiber characterization

As received fiber

Physical properties

Fiber quality analysis (by using FQA)
- Length
- Coarseness
- Percent fines

Fiber morphology (by using SEM)
- Cross-sectional dimensions (by image analysis)

Chemical properties

Chemical compositions
- Lignin content
- Cellulose-to-hemicellulose ratio (by using TGA)

Absorption capacity (by using calorimeter)

Hard-to-remove water content (by using TGA)

Georgia Tech

Fiber characterization

As received fiber

Physical properties

Fiber quality analysis (by using FQA)
- Length
- Coarseness
- Percent fines

Fiber morphology (by using SEM)
Cross-sectional dimensions (by image analysis)

Chemical properties

Chemical compositions
- Lignin content
- Cellulose-to-hemicellulose ratio (by using TGA)

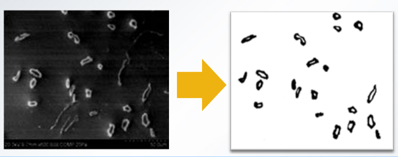
Absorption capacity (by using calorimeter)

Hard-to-remove water content (by using TGA)

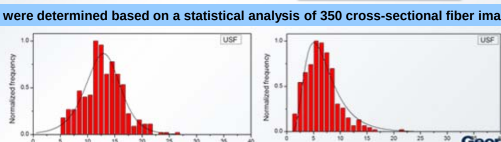
Georgia Tech

Fiber characterization

Fiber morphology: fiber diameter, lumen diameter, cell wall thickness



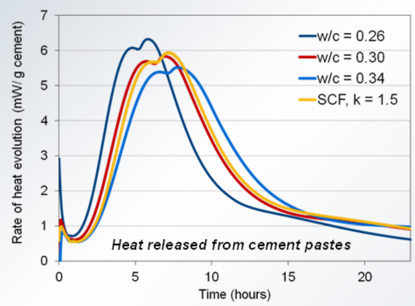
Data were determined based on a statistical analysis of 350 cross-sectional fiber images.



Georgia Tech

Fiber characterization

Absorption capacity, *k* : the amount of water absorbed by dry fiber



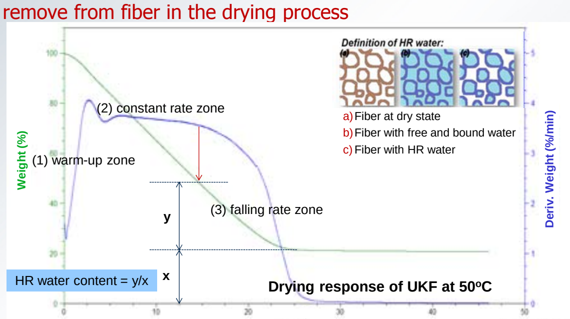
TAM air isothermal calorimeter

N. A. Johansen, M. J. Millard, A. Mezencevova, V. Y. Garas, and K. E. Kurtis, "New method for determination of absorption capacity of internal curing agents," *Cement and Concrete Research, vol. 39, pp. 65-68, Jan 2009.*

Georgia Tech

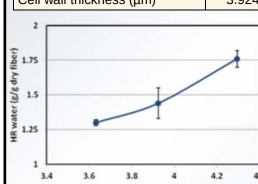
Fiber characterization

Hard-to-remove water content: the amount of water difficult to remove from fiber in the drying process



Fiber properties

Fiber Properties	Types of Fibers				
	USF	BSF	UKF	BKF	SCF
Absorption capacity, *k*	1	1	2	2	1.5
Cellulose-to-hemicellulose ratio	3.99	5.89	3.01	4.49	1.05
HR water content (g/g dry fiber)	1.44±0.11	1.45±0.01	1.30±0.02	1.37±0.09	1.76±0.06
Cell wall thickness (µm)	3.924	3.904	3.631	3.728	4.372

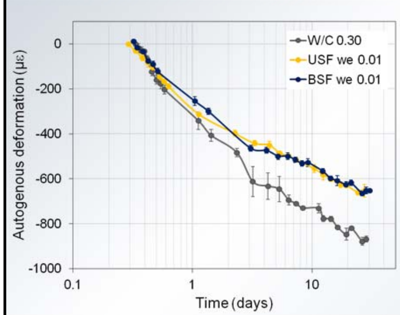


- High cellulose content was found in full chemically-treated fibers.
- No clear relationship was obtained between *k* and HR water content.
- A thicker cell wall corresponds to higher amount of HR water.

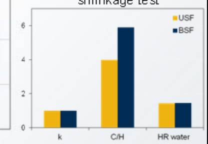
Georgia Tech

Properties of fiber-cement composites

Internal curing capacity: composition



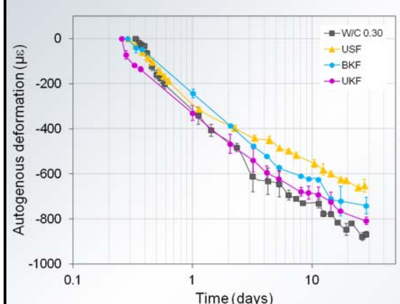
Corrugated polyethylene mold and measurement comparator for autogenous shrinkage test

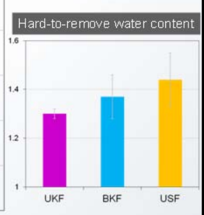


k: absorption capacity
C/H: cellulose-to-hemicellulose ratio
HR water: hard-to-remove water content

The cellulose-to-hemicellulose ratio did not significantly affect the internal curing capacity of the fibers.

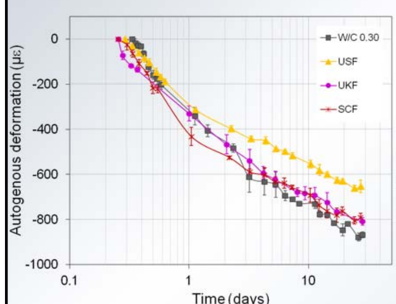
Internal curing capacity: HR water

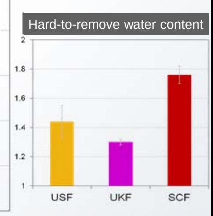




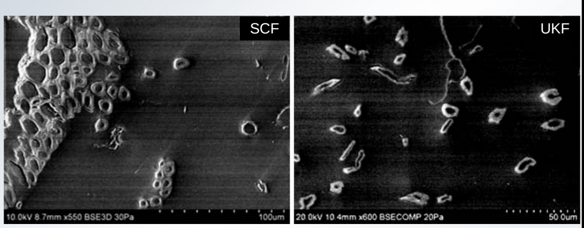
The higher the HR water content, the better internal curing capacity.

Internal curing capacity: morphology





Internal curing capacity: morphology



- Fiber bundling related to the method of fiber processing is found in SCF.
- SCF could not be adequately dispersed.

Content

- Background
- Motivation for research
- Studies and results
  - Fiber characterization
  - Internal curing capacity
- Conclusions
- Q&A

Conclusions

- The internal curing efficiency of pulp fiber relates more strongly to their physical morphology than to their variations in chemical composition.
- HR water content could be a meaningful parameter for the assessment of pulp fibers as internal curing agents.
- HR water content, appears to be related to increasing cell wall thickness.

Georgia Tech

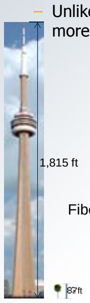
Conclusions

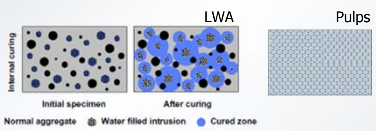
- Soda fibers with higher HR water content exhibited better autogenous mitigating efficiency.
- For hardwood pulp fibers, a slower moisture release rate appears to be more favorable for internal curing.
- Confirming observations in other research, the dispersability of the internal curing agent was found to affect the fiber capacity for mitigating autogenous shrinkage.

Georgia Tech

Conclusions

- Internal curing mechanism in pulp fibers.
  - Unlike LWA and SAPs, the slower rate of water release could be more favorable.





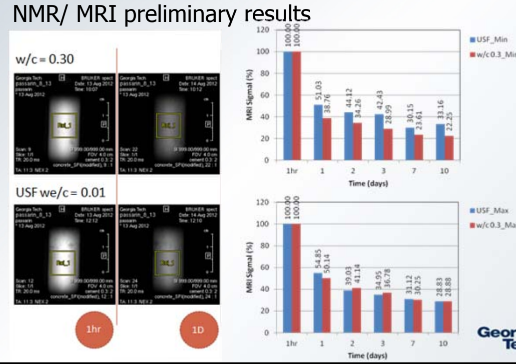
Fibers are smaller than LWA and are added at higher dosages than SAPs.

Georgia Tech

Image derived from I. De la Varga, J. Castro, D. Bentz, and J. Weiss, "Application of internal curing for mixtures containing high volumes of *Cement & Concrete Composites*, vol. 34, pp. 1001-1008, Oct 2012. and www.toptenz.net/top-10-canadian-landmarks.php/image003-4

Future research plan

- NMR/ MRI preliminary results



Georgia Tech

Acknowledgements

The author gratefully acknowledged SCG cement for the financial support and SCG paper for the donation of eucalyptus pulps

SCG CEMENT SCG PAPER