

# Impact of Curing Methods on Curling of Concrete Pavements



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# Acknowledgements

- ODOT
  - Jeff Dean
  - Kenny Seward
  - Chris Westlund
  - Bryan Hurst
- Oklahoma Transportation Center
- Jerry Thomason, Maxwell Supply
- Brent Burwell, ACPA

# Summary

- Introduction
- Laboratory Testing
- Conclusions



# Introduction

- What is Curling?
- Why does it happen?
- Why is it important?
- Why is curing important?
- What is the goal of this project?

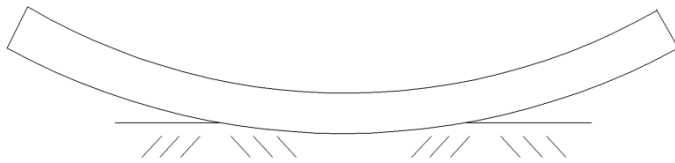
# What is Curling?



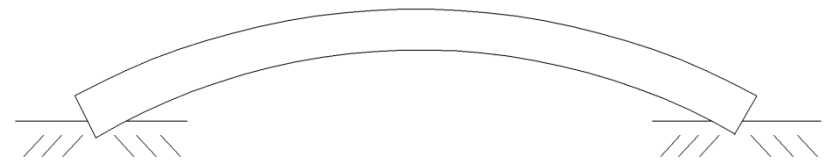
# What is Curling?

Curling is when the edges of a concrete pavement (or slab) deflect up compared to the middle.

Warping is the same thing only the edges deflect downward.



curling



warping



Why do pavements curl/warp?



# Why do pavements curl/warp?

Curling/Warping occur when there is a differential volume change between the top and bottom of the slab.

Typically these occur when there is a difference in either temperature or moisture between the top and bottom of the slab.



moisture



temperature



# moisture



# temperature



# moisture

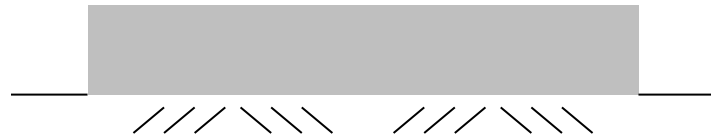


dry

wet



# temperature





# moisture

# temperature



dry

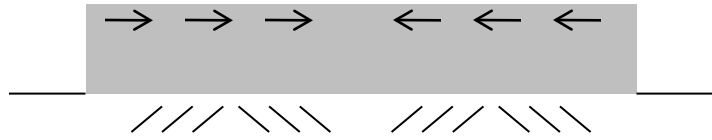


~~wet~~  
less dry



# moisture

# temperature



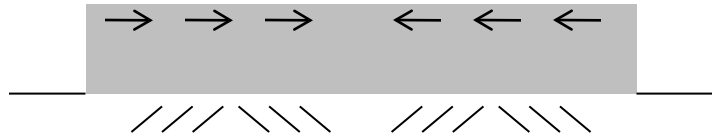
dry

~~wet~~  
less dry



# moisture

# temperature



dry

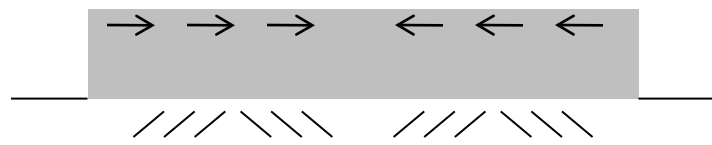
~~wet~~  
less dry





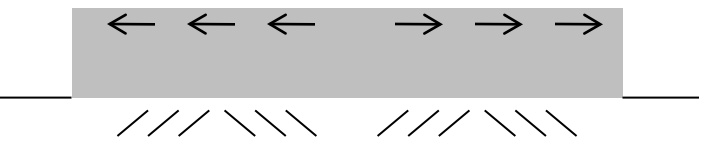
# moisture

# temperature



dry

~~wet~~  
less dry



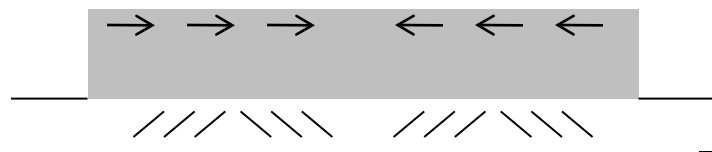
wet

less wet

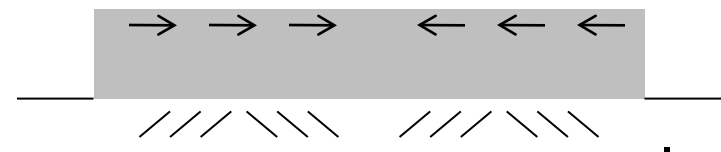


# moisture

# temperature



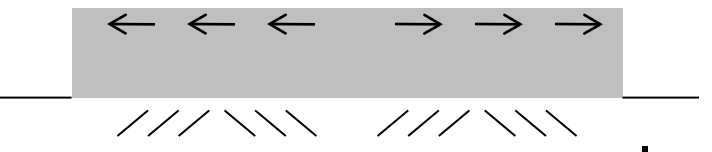
dry



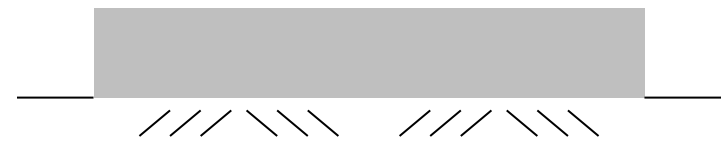
cold

~~wet~~  
less dry

less cold



wet



less wet

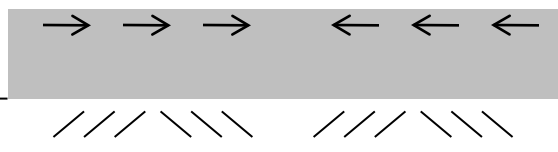
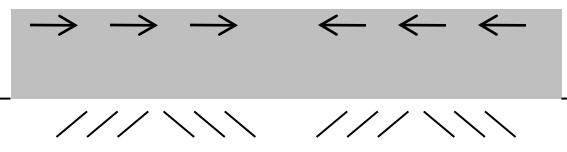
# moisture

# temperature



dry

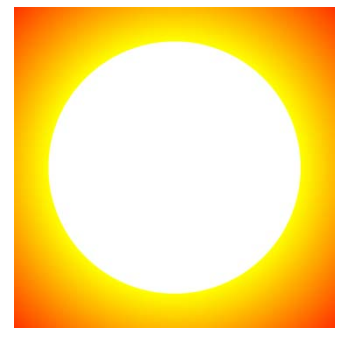
cold



~~wet~~

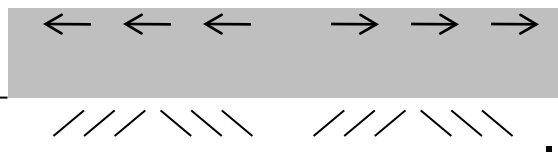
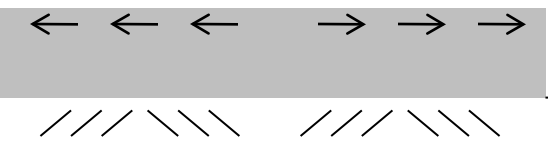
less cold

less dry



wet

hot



less wet

less hot



# moisture



dry



~~wet~~  
less dry



wet



less wet

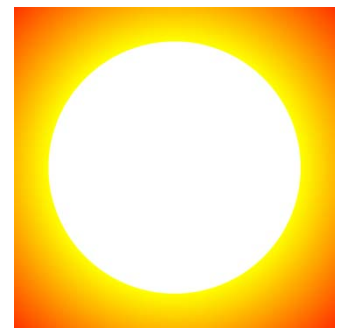
# temperature



cold



less cold

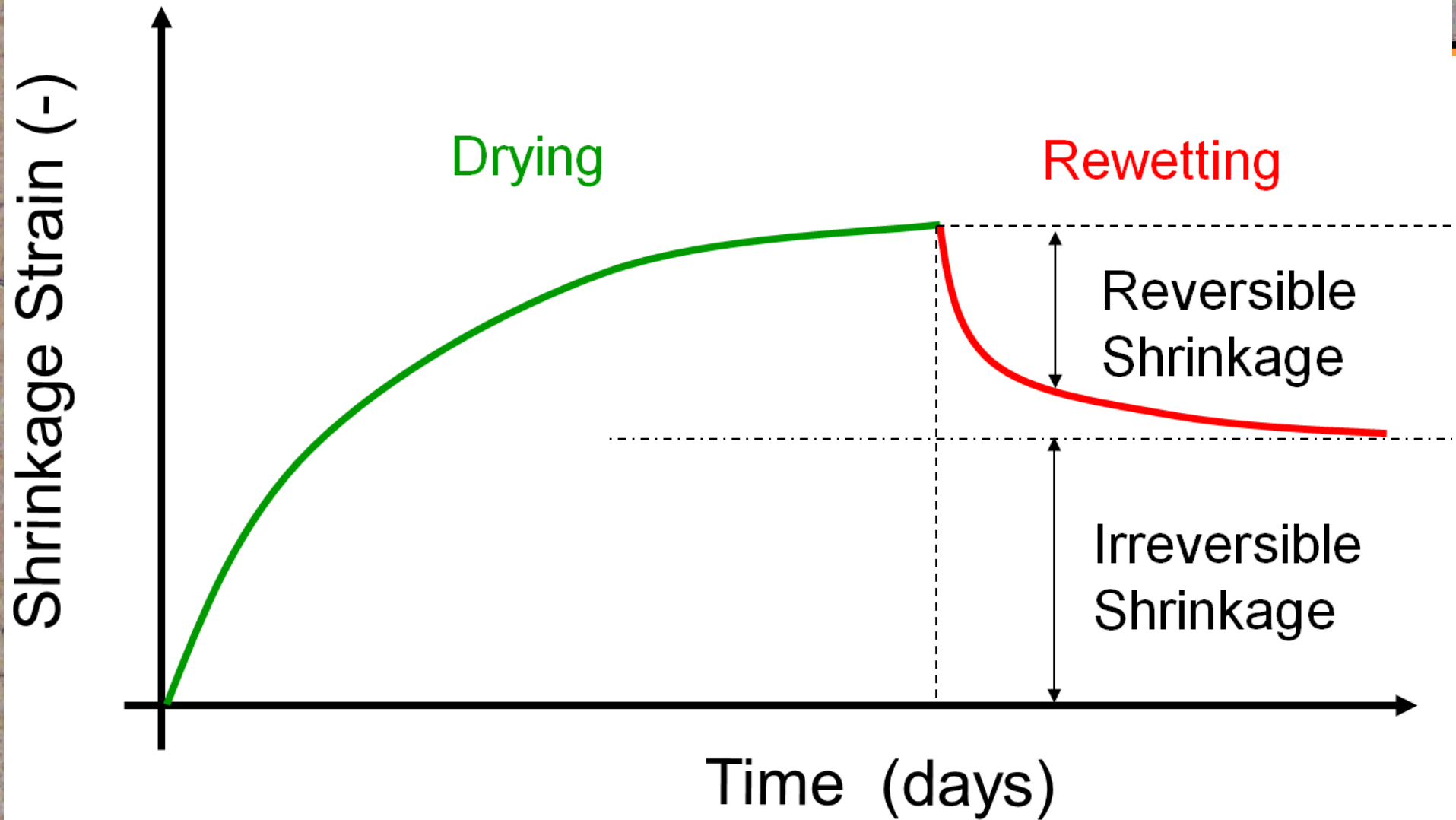


hot



less hot

*The focus of this talk*



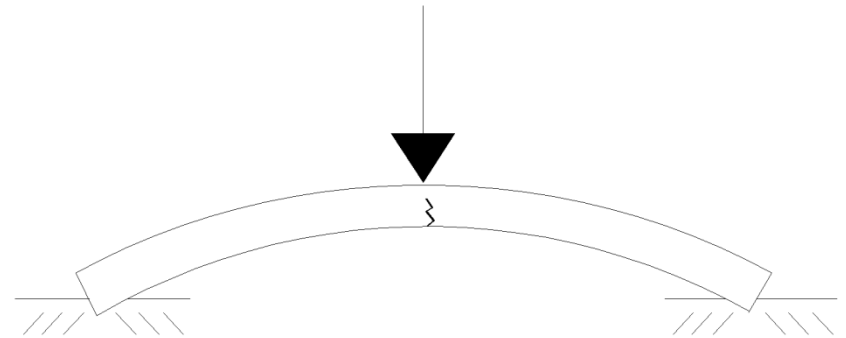
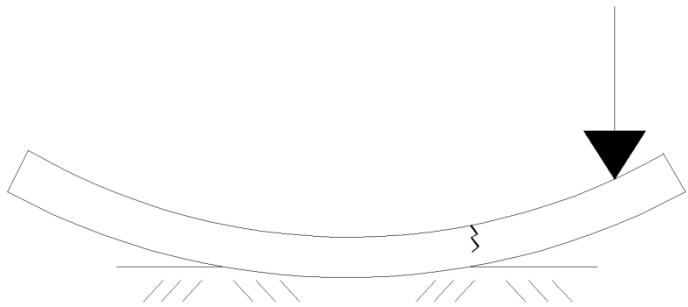
After Weiss (2009)

Why is this important?



# Why is this important?

Once the slabs curl traffic loadings can cause cracking.

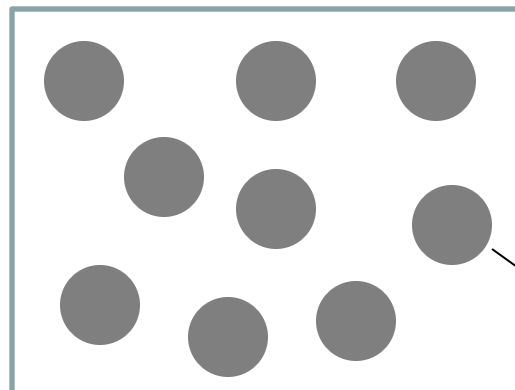




# Why is curing important?

## Proper curing will:

- **Reduce permeability**
- Improve strength
- Improve water-tightness
- Improve abrasion resistance



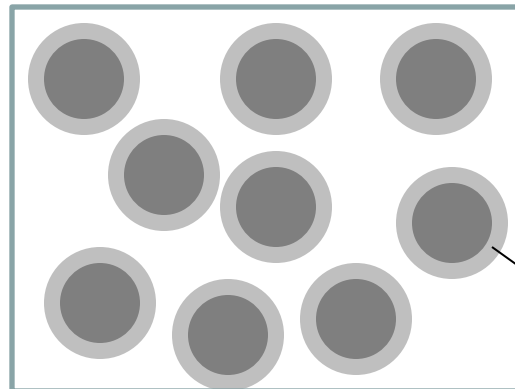
cement grain



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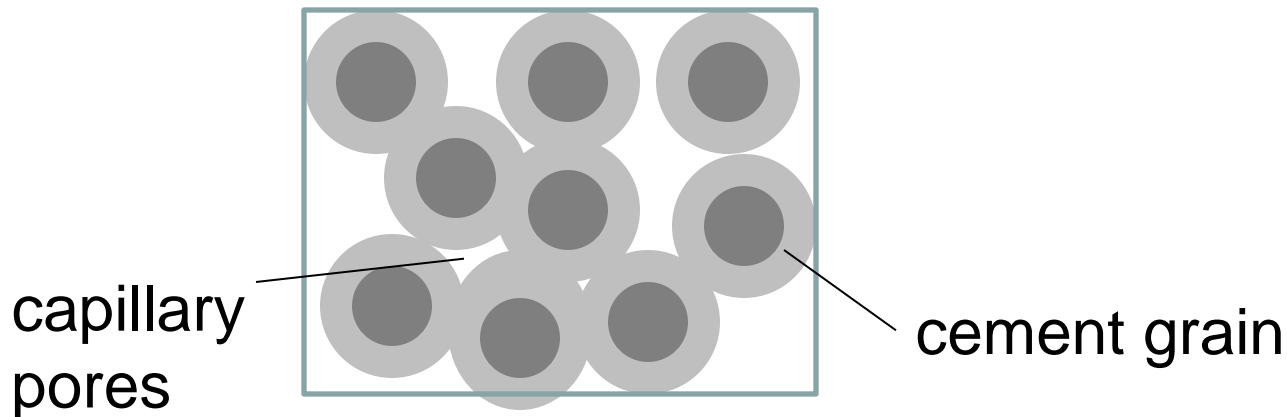


cement grain

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- The current version of the MEPDG indicates that a concrete pavement will curl less if a “wet cure” is used instead of curing compounds.
- This additional curling will lead to cracking and premature failure.
- A wet cure is challenging to provide in the field
- If an economical method of effective curing could be developed then this would extend the service life of the pavement

# Curing Methods for Rigid Pavements





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# Curing Methods for Rigid Pavements

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- A specimen is created that only allows moisture loss from the finished surface
  - 5 of the 6 faces are coated
- The specimen is stored in 73°F and 40% RH
- The uncoated surface shrinks and causes the specimen to curl
- This is the same mechanism that causes concrete pavements to curl due to drying



# Laboratory Tests

- Paste Beams
- Concrete Beams

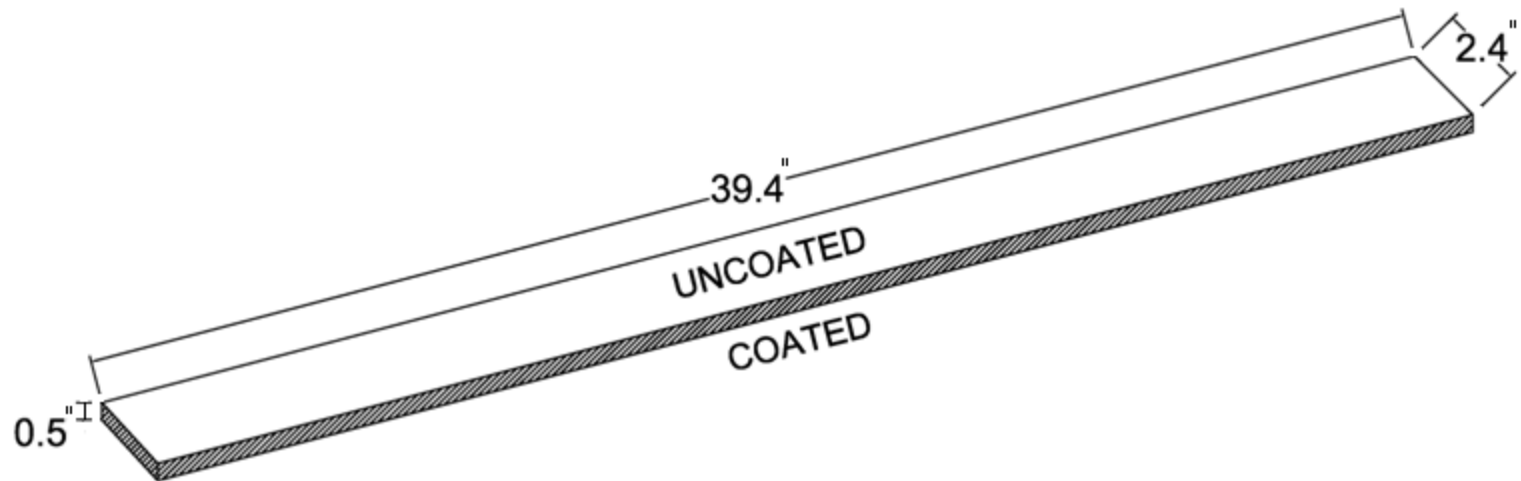
# Paste beams





# Paste beams

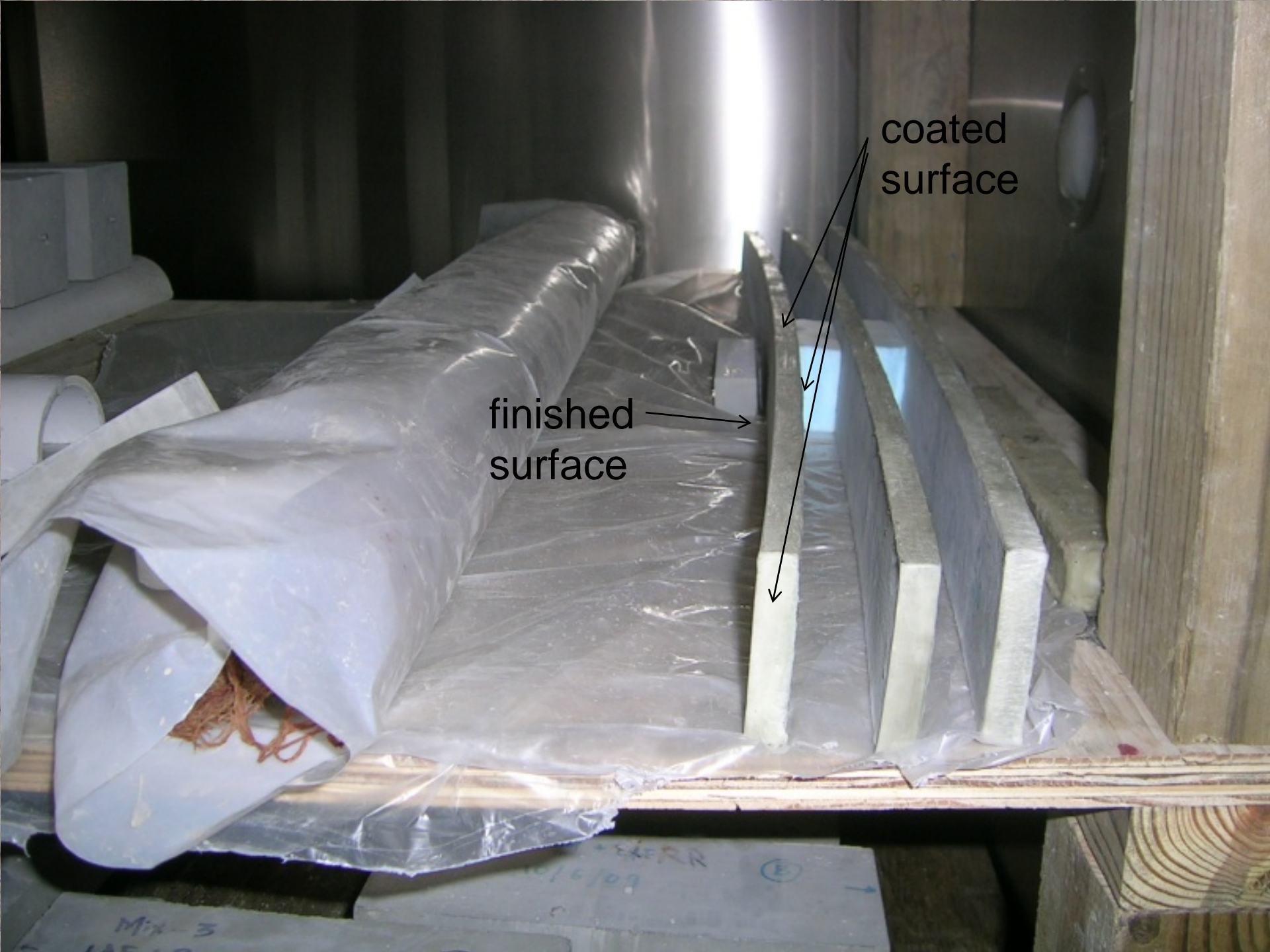
- A test was used based on work previously done by Berke et al. for investigation of effectiveness of Shrinkage Reducing Admixtures to reduce curling
- This testing was chosen as it was rapid, inexpensive, and easy to look at a number of variables



# Paste beams

- Paste mixtures were made with a 0.42 w/cm
- Specimens were cured at 73°F covered in one of the following ways:
  - wet burlap (wet cure)
  - sealed with plastic (sealed cure)
  - curing compounds
- Different durations and combinations were investigated
- Specimens were then stored in a 73°F and 40% RH drying environment





coated  
surface

finished  
surface



Mix-3

EXPER  
10/6/09

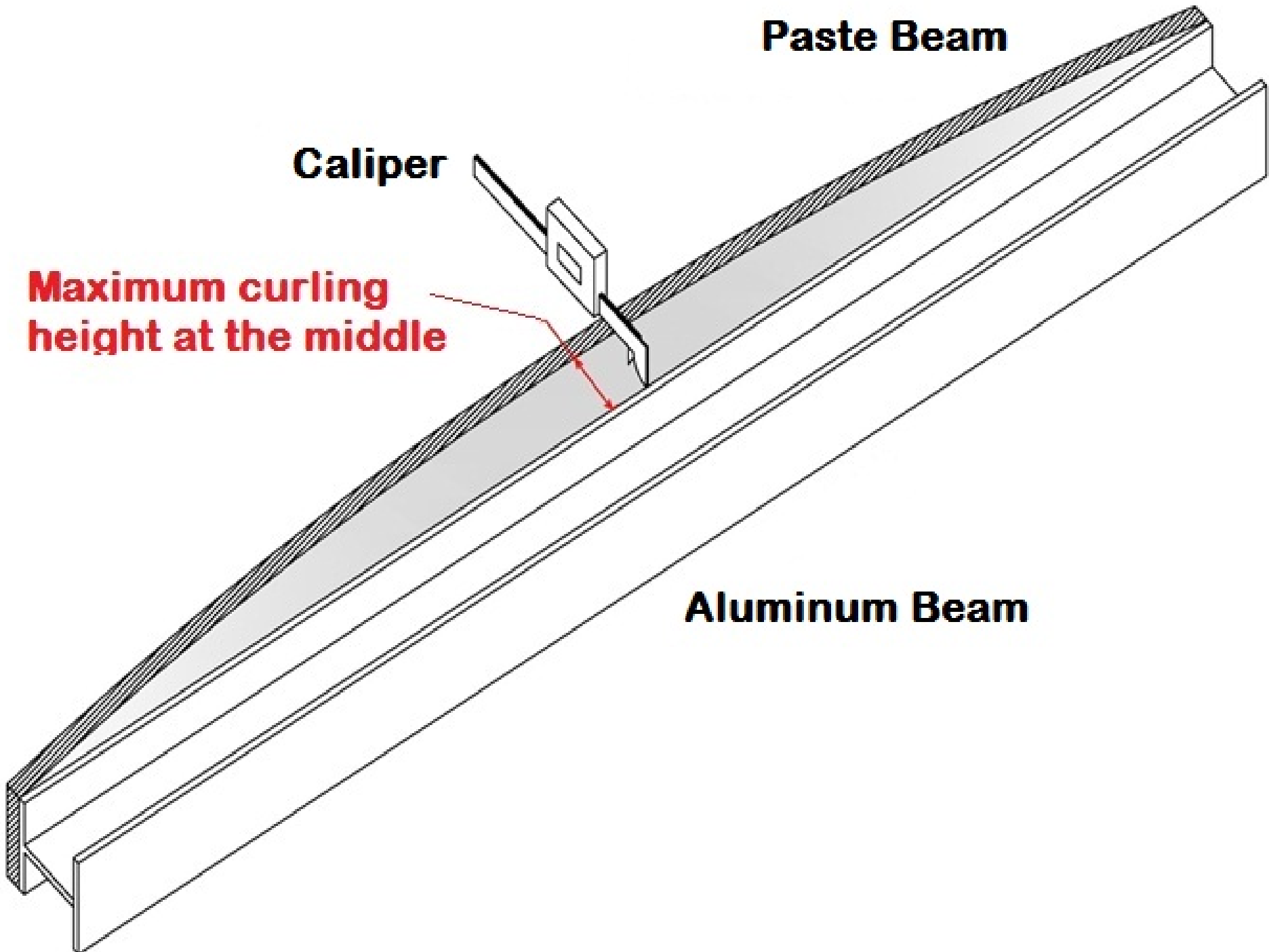


**Paste Beam**

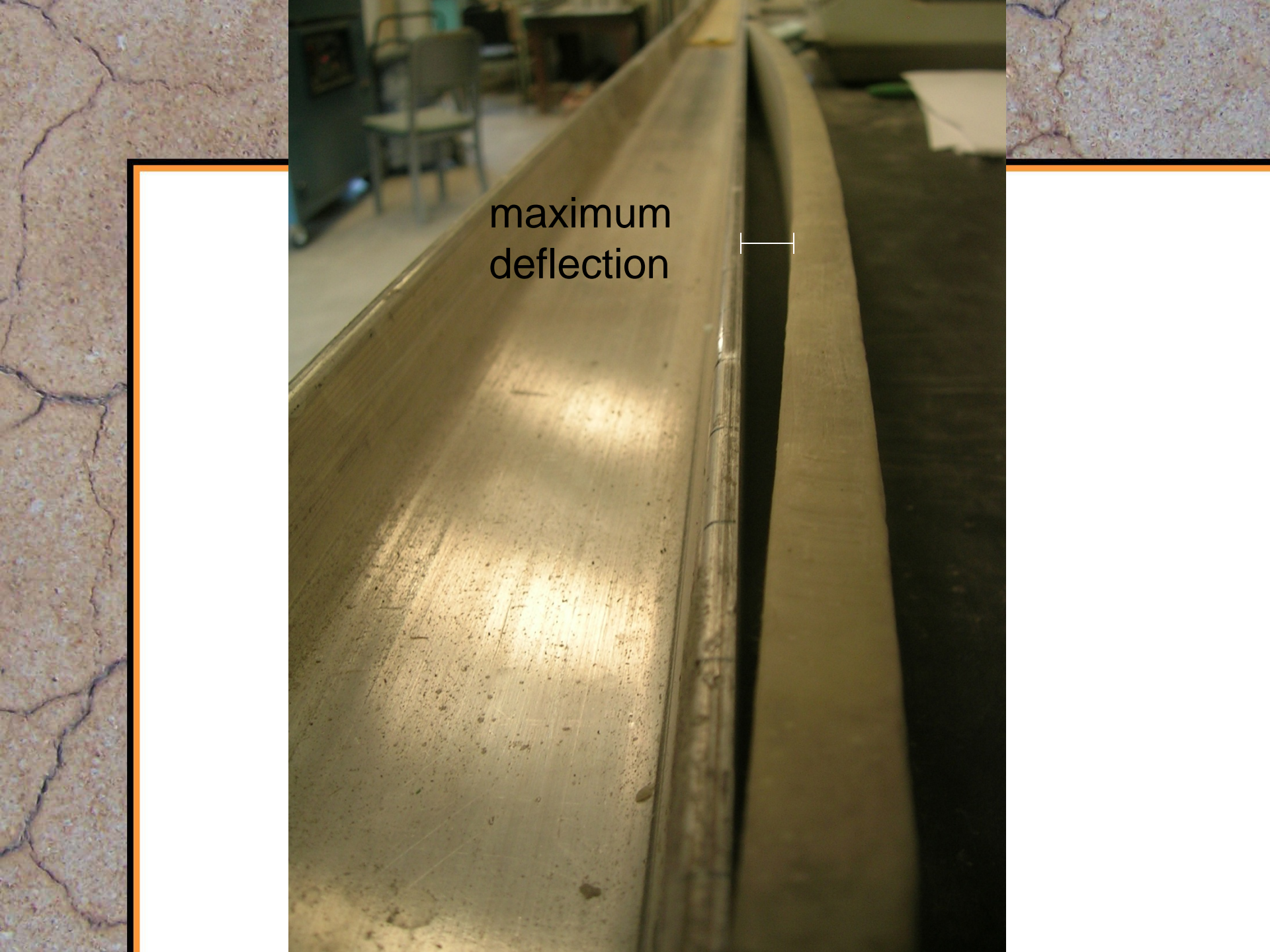
**Caliper**

**Maximum curling  
height at the middle**

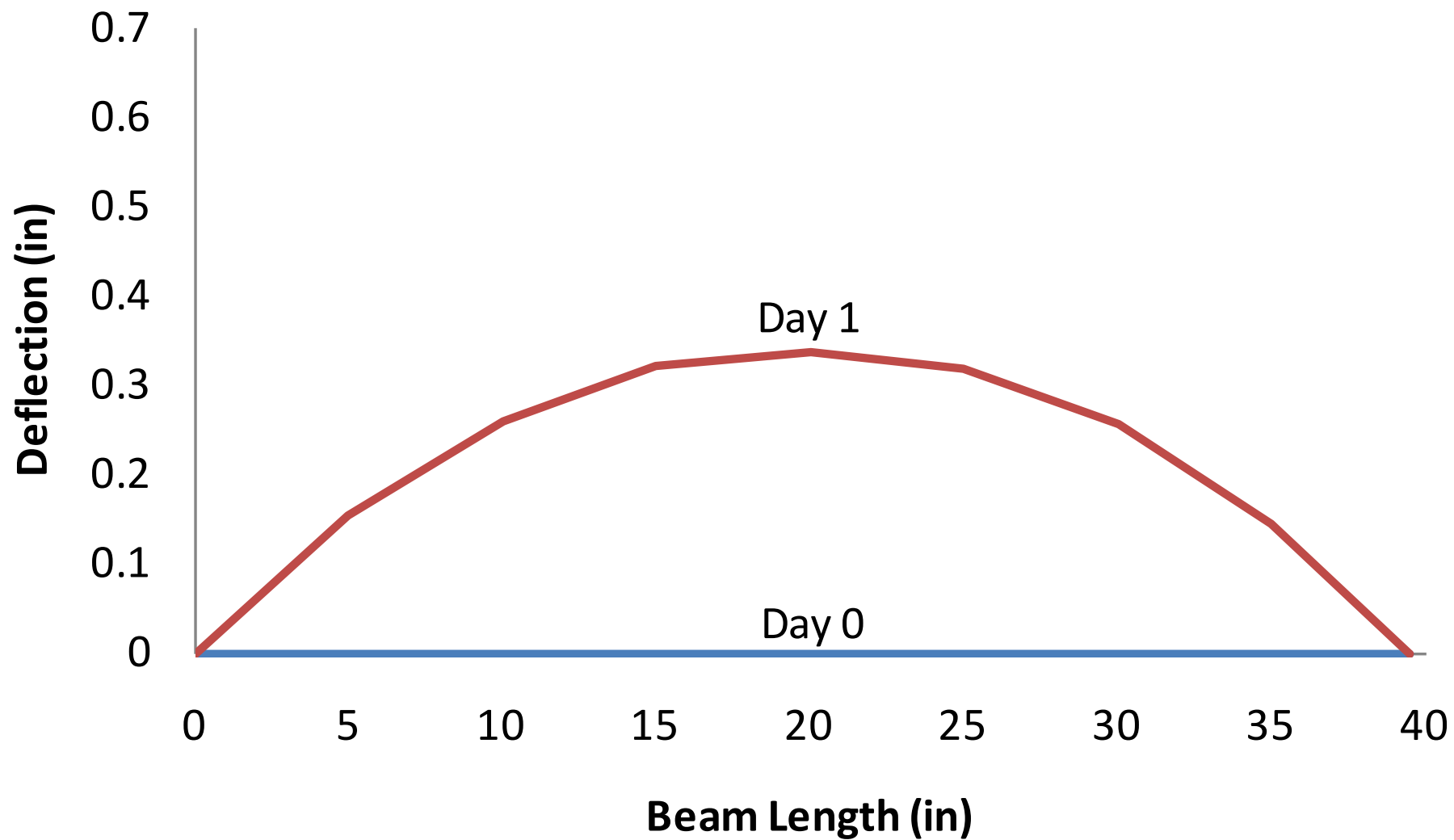
**Aluminum Beam**

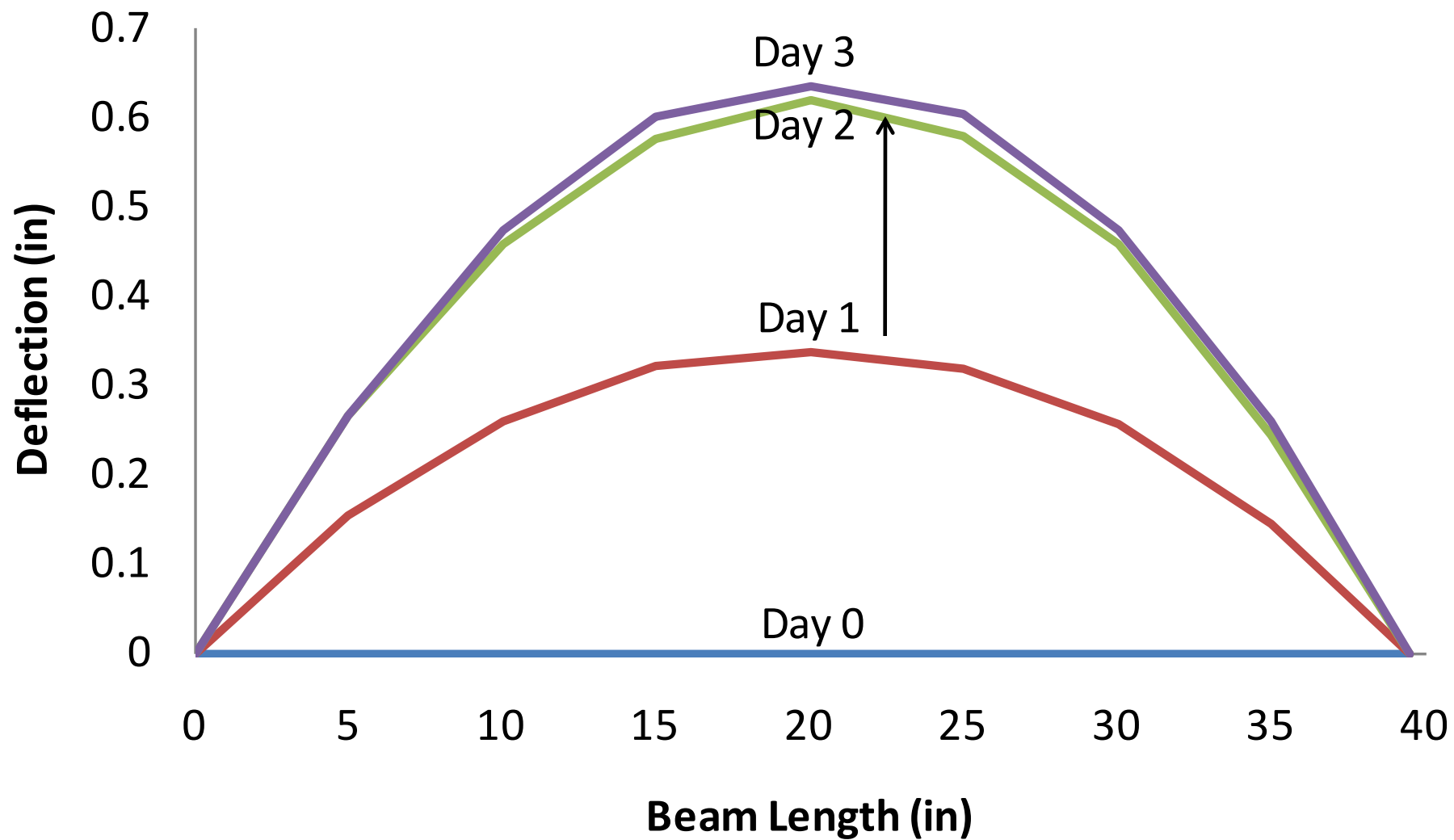


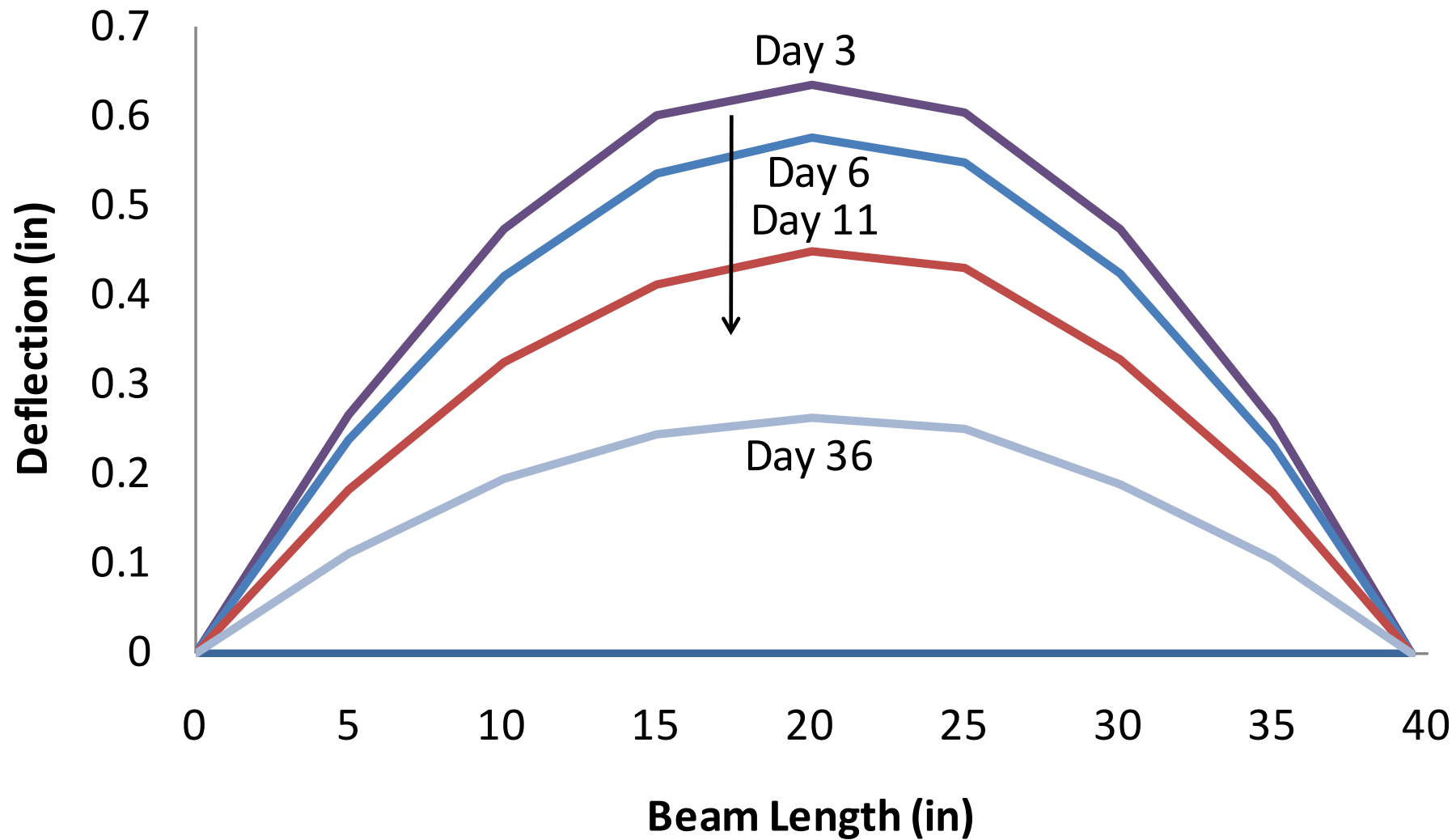




maximum  
deflection





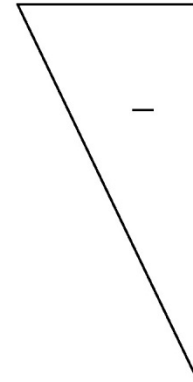
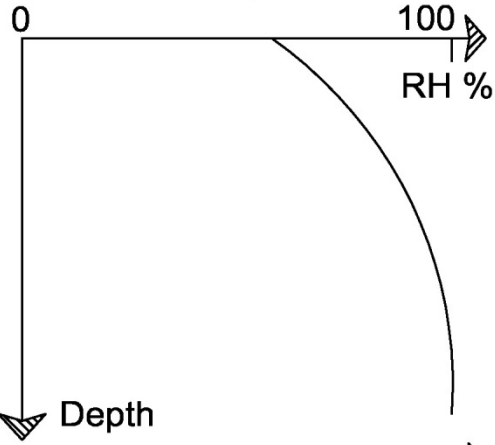




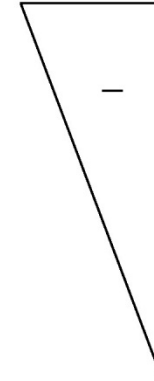
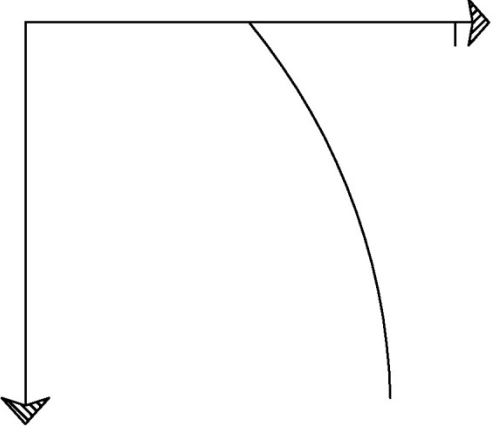
Constant 40% RH

Moisture profile

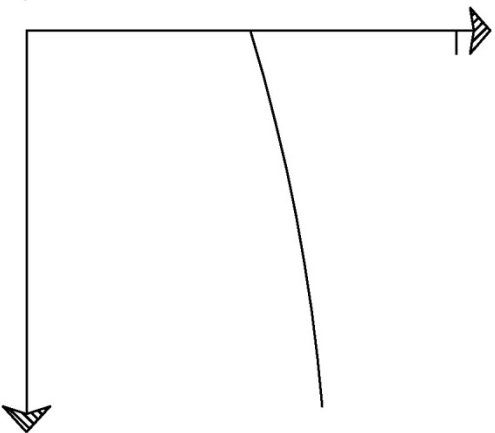
Drying shrinkage



Curling UP



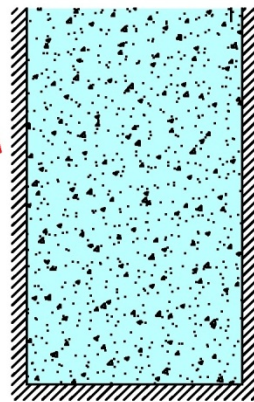
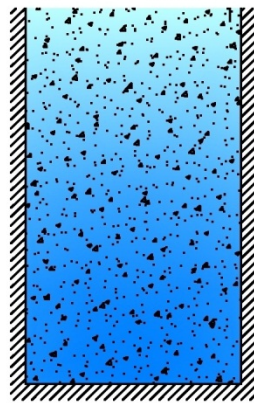
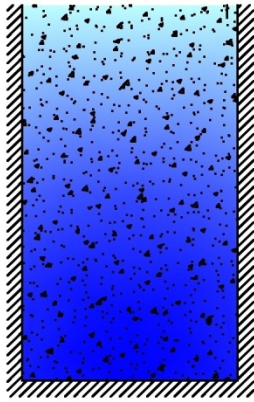
Maximum Curling



Curling DOWN

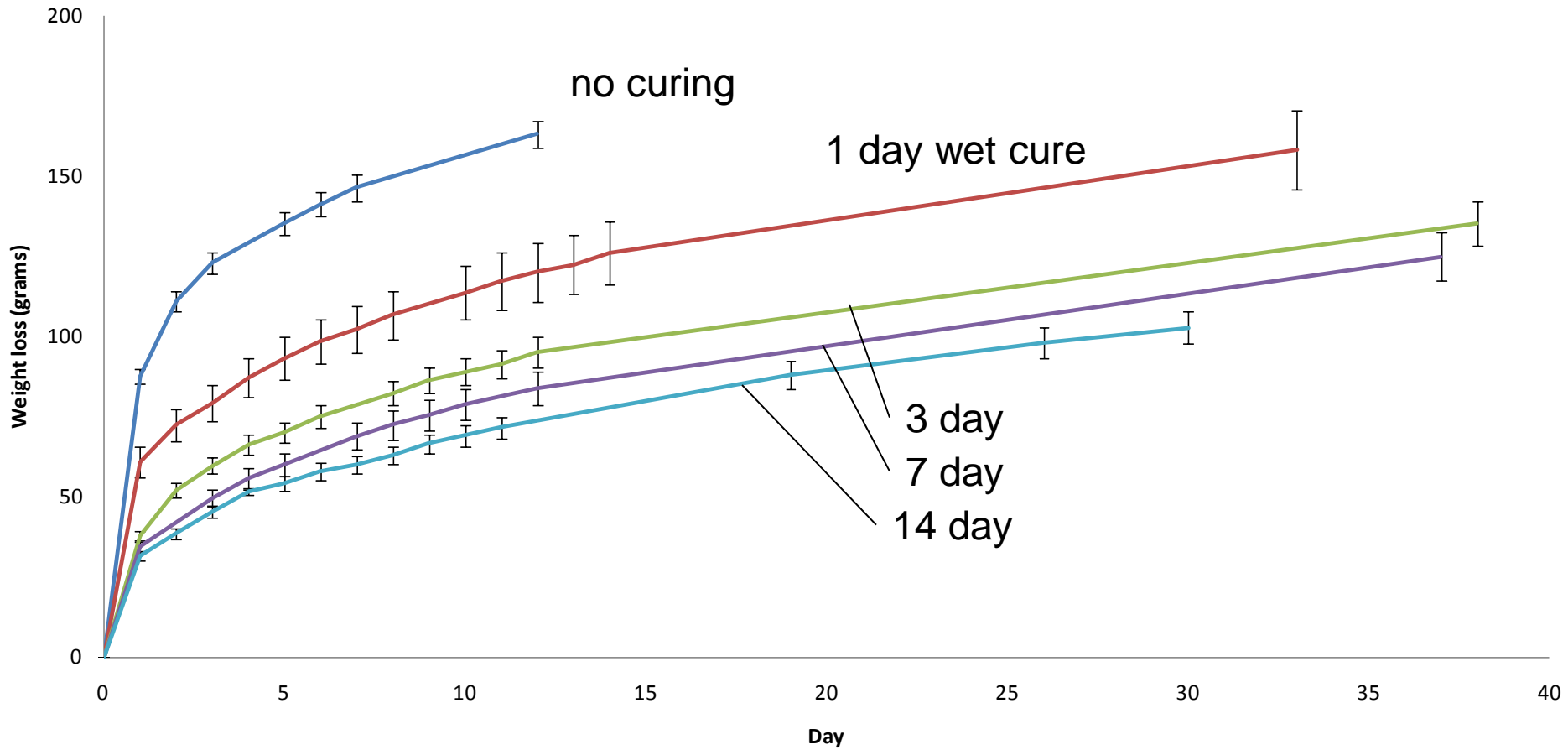


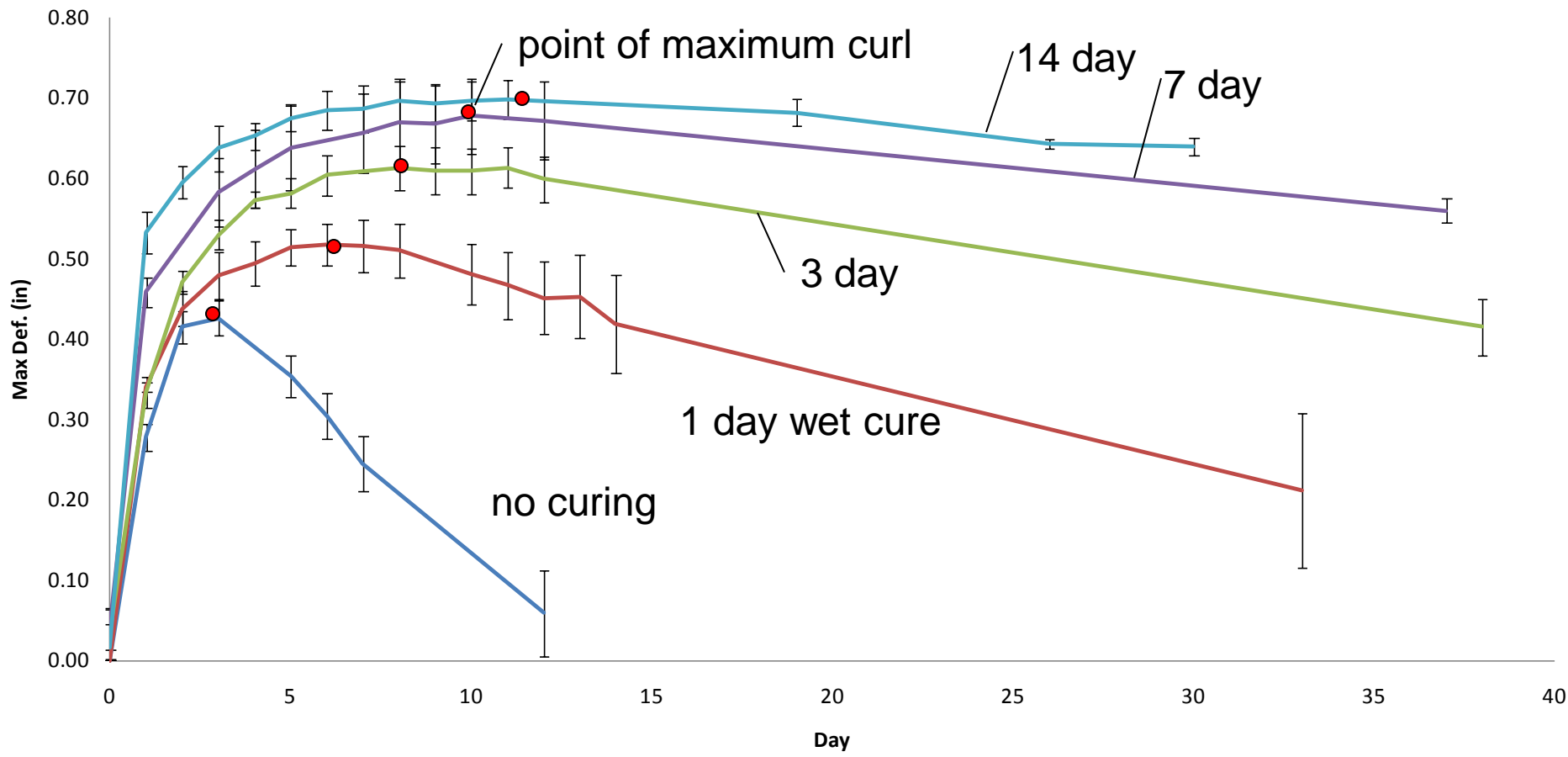
All sides coated, except the top



# Wet cure vs. no curing









# Observations

- The specimens that were wet cured loss less mass but curled more
- The specimens with a longer curing period took longer to reach the maximum curling height
- This suggests that the longer a pavement is wet cured then the long term curling will increase!

# Why does this happen?

- Concrete is like a sponge
- The longer you cure the smaller the pores will be at the surface of the concrete (Hedenblad 1997)
- These smaller pores make it harder to lose/gain water
  - This is why it takes longer to dry

# Why does this happen?

- The loss of water in small pores is the primary mechanism for drying shrinkage in concrete (Lane, Scott, and Weyers 1997).
- Since the pores are smaller then the negative pressure upon drying will be higher (Mackenzie 1950; Adamson and Gast 1997; Bentz et al.1998)



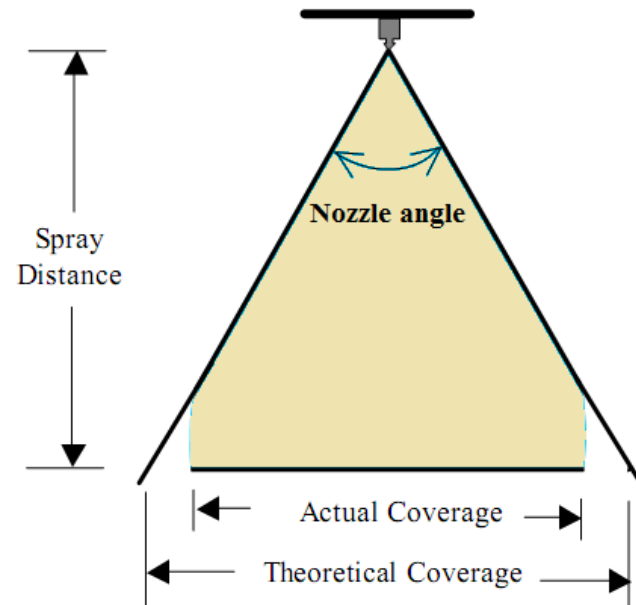
# Curing Compounds

- Three different curing compounds were investigated:
  - C1 : Poly-Alpha-methyl-styrene
  - C2 : Resin-Based
  - C3 : Wax-Based



# Curing Compounds

- A systematic approach was used to apply the curing compounds
  - Curing compound was applied at a constant pressure with a specified nozzle
  - The curing cart was moved at a constant rate over the specimens
  - The height of the spray nozzle was modified to change the coverage thickness

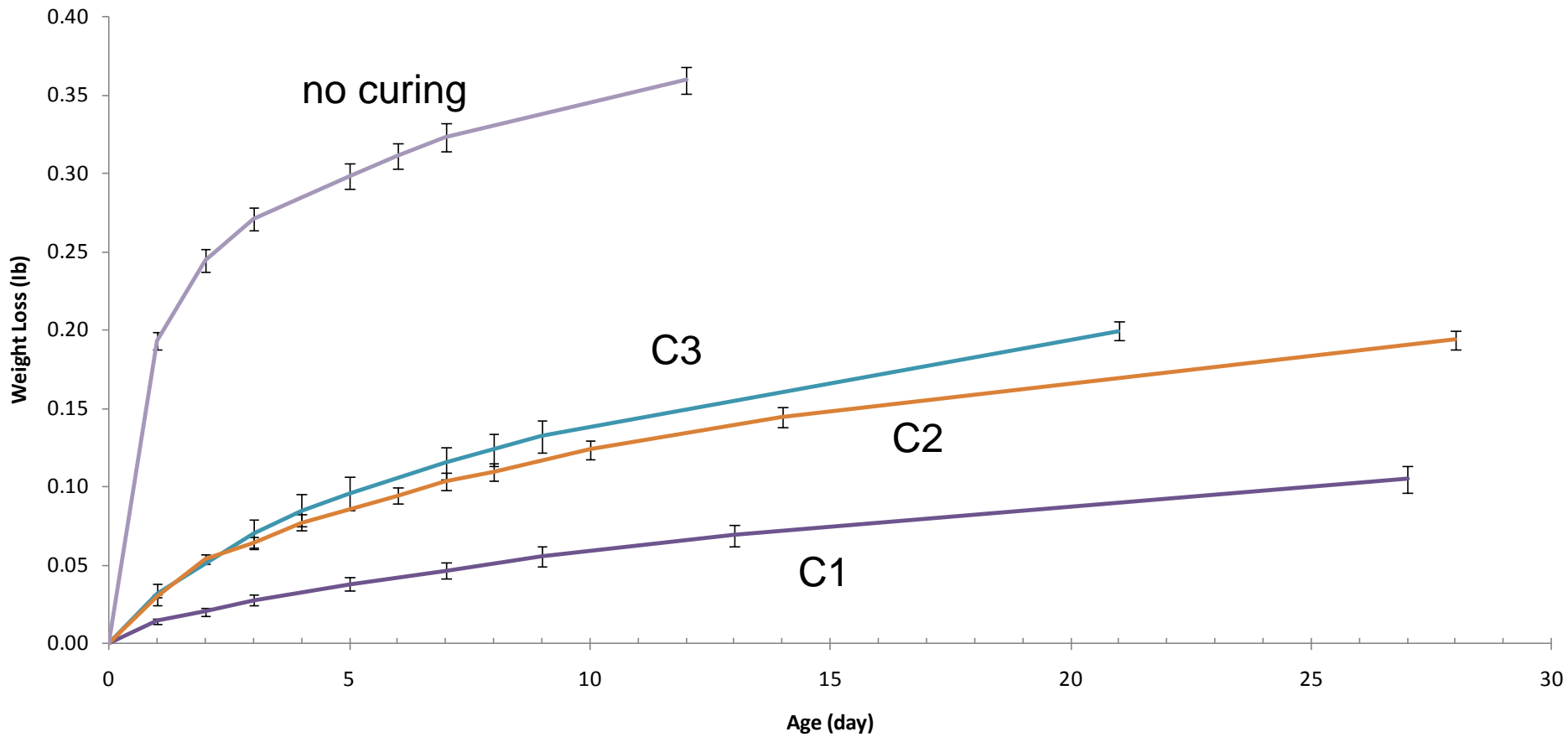


Vandenbossche 1999

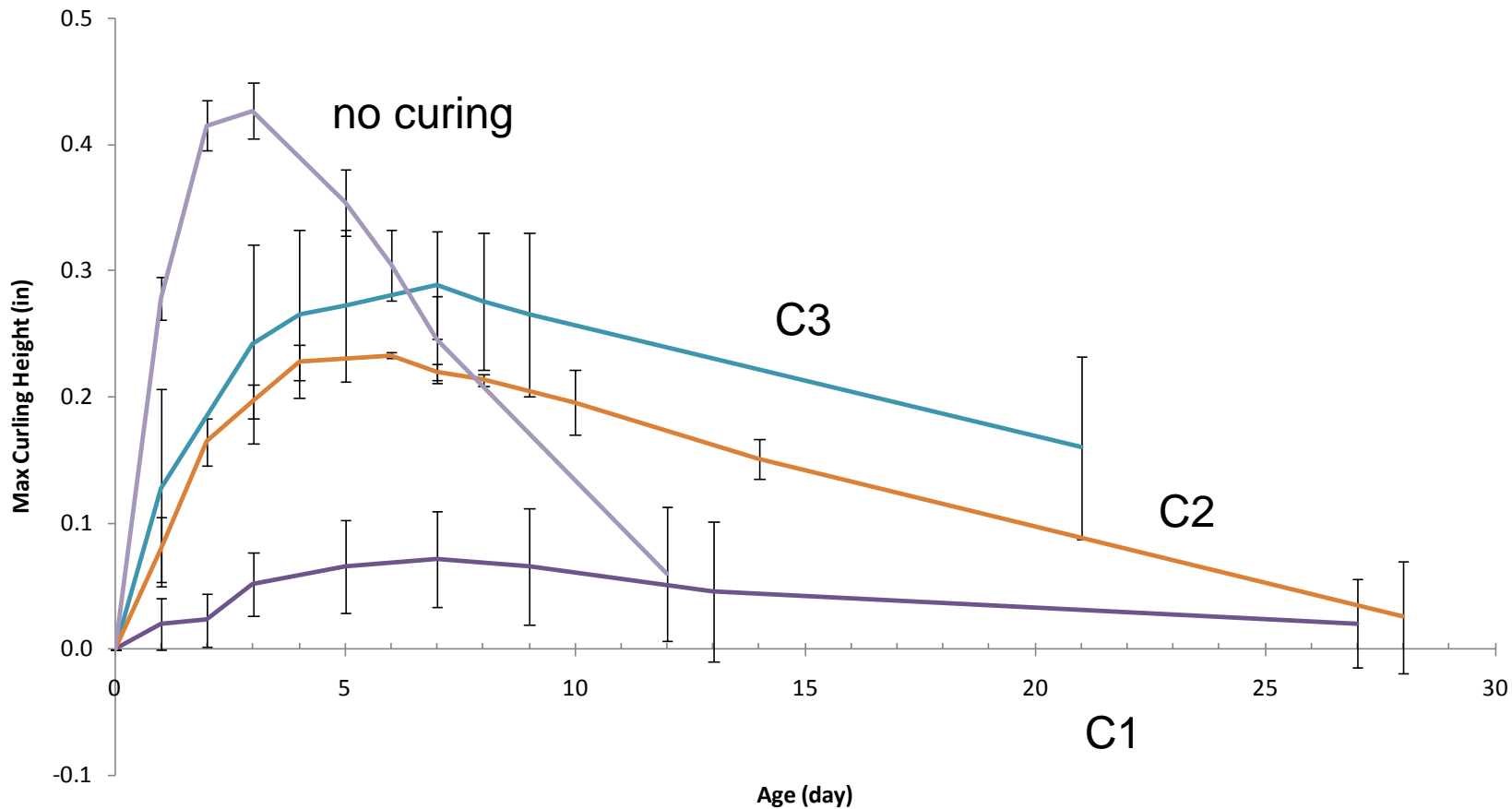
PARTS



BUY  
OVER



100% of manufactured recommended dosage was used

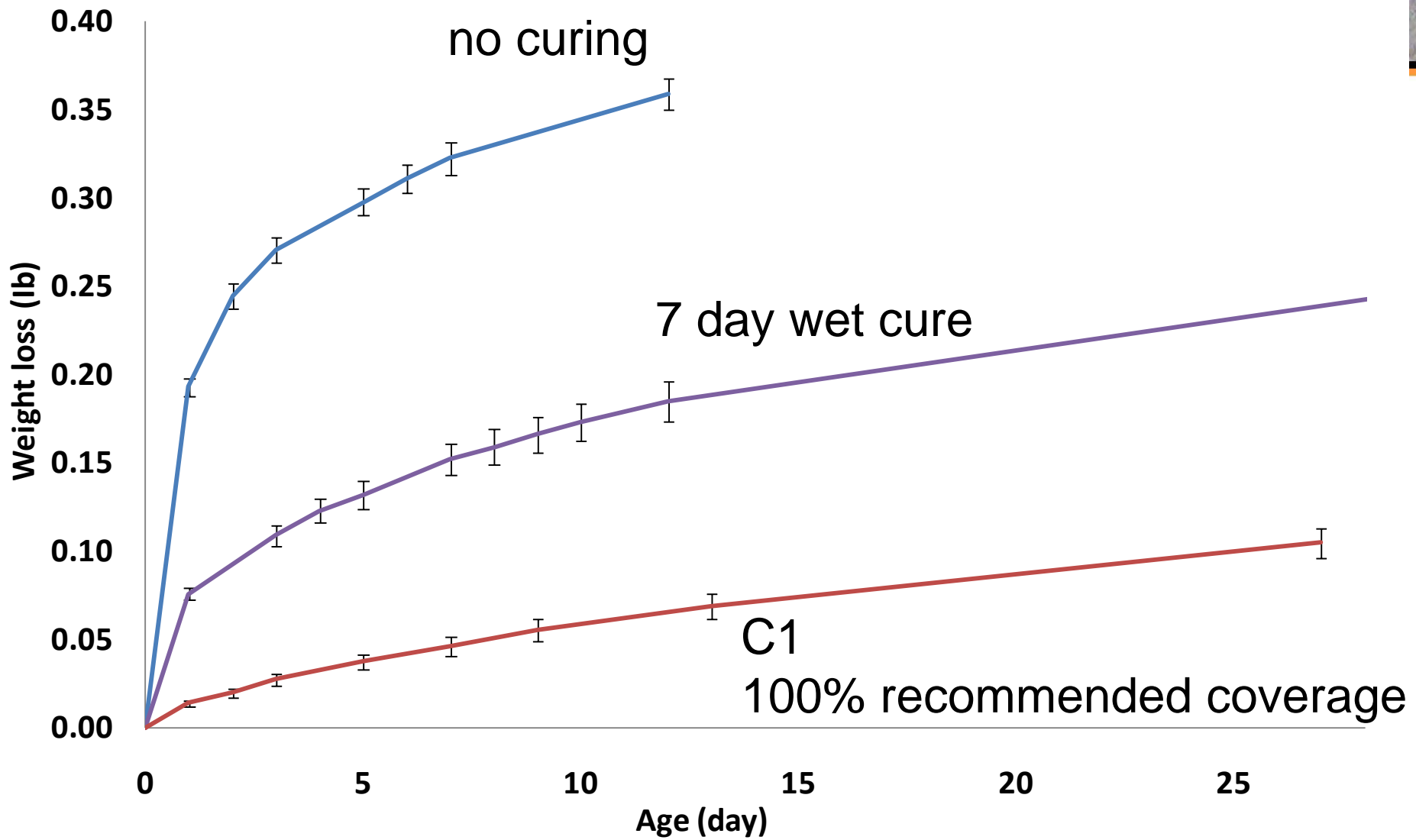


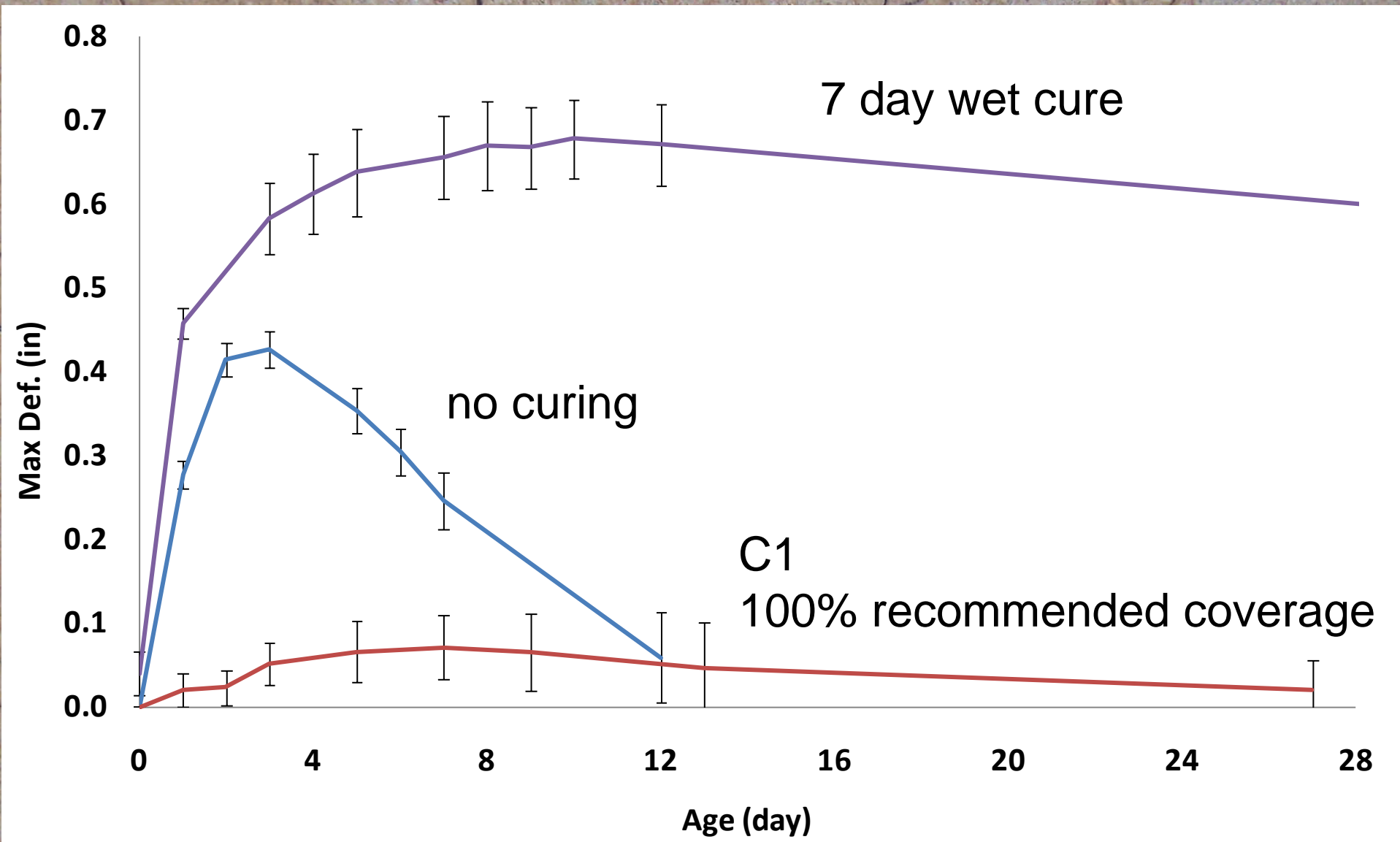
100% of manufactured recommended dosage was used



How do curing compounds compare to other methods of curing?







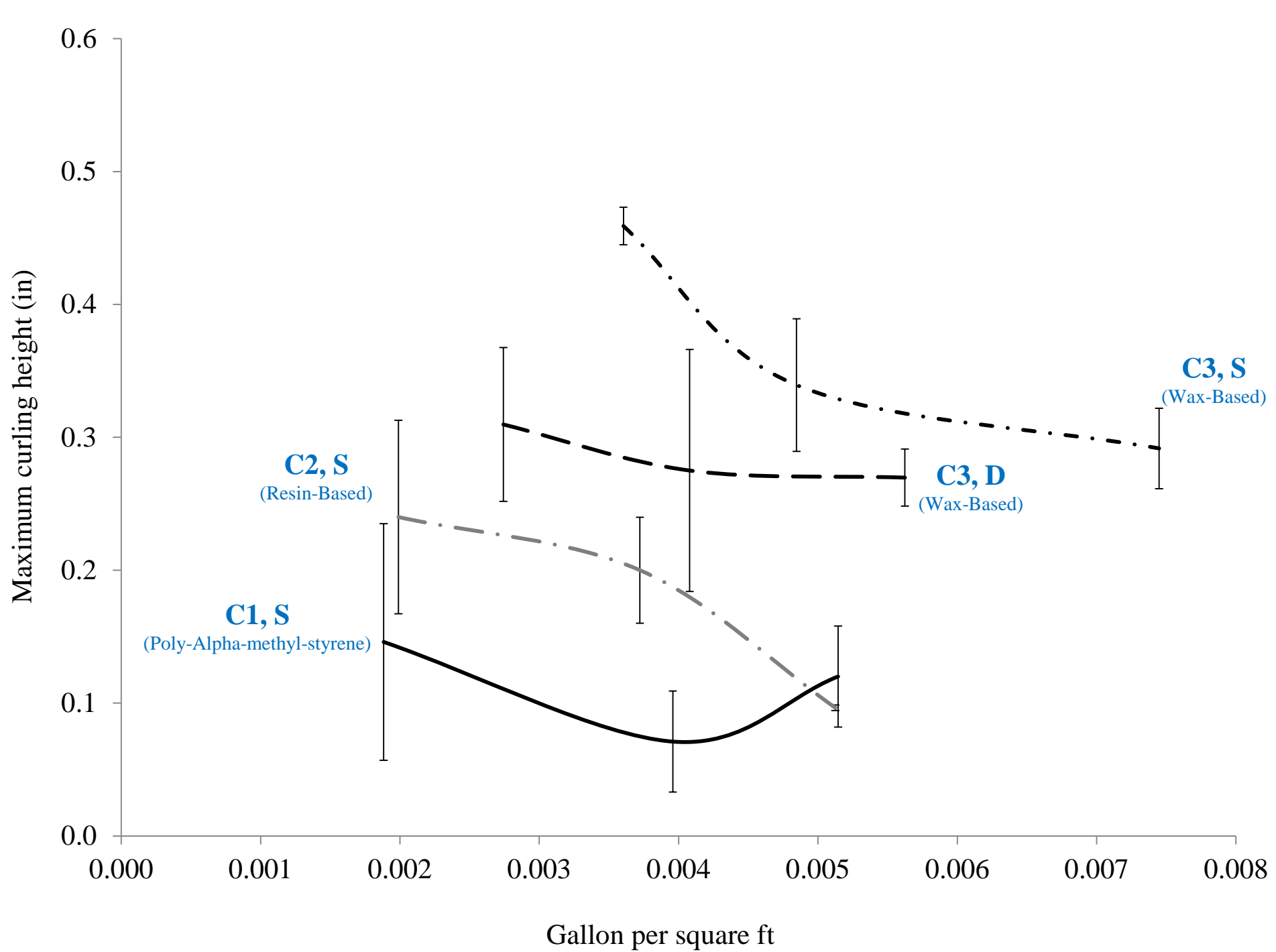
# Observations

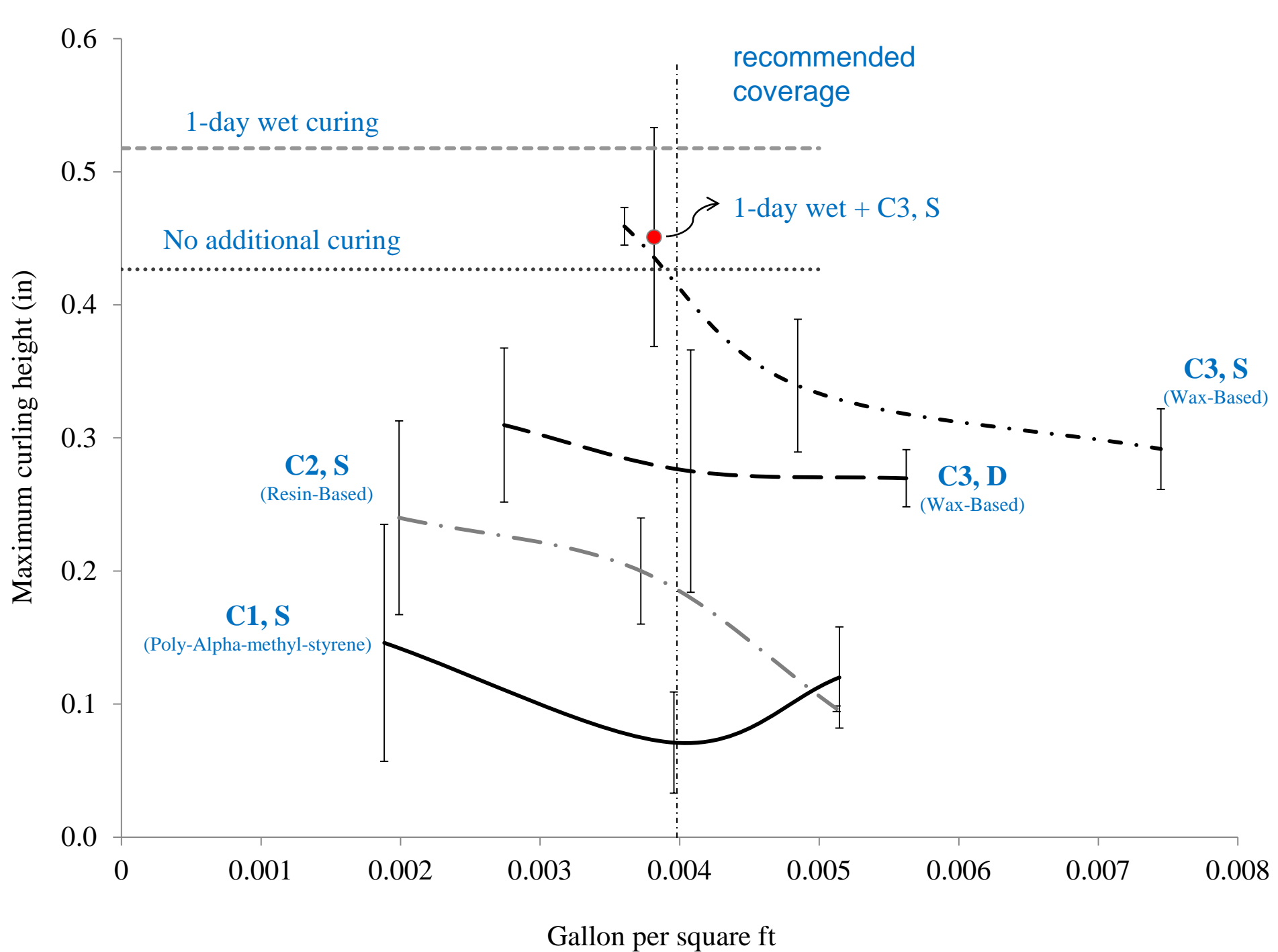
- Specimens with curing compound showed less water loss and less curling from shrinkage than with no curing or a wet cure.
- The Poly-Alpha-methyl-styrene curing compounds showed the best performance of the curing compounds investigated



# Why does this happen?

- The curing compounds help keep the moisture from being lost and therefore minimize differential curling from shrinkage
- If the voids don't lose the water then you won't have the shrinkage.
- This allows hydration to proceed and to minimize shrinkage.





# Observations

- There was some benefit from using a double layer of curing compound with curing compound C3
- When the coverage rate was below the manufacturer recommended dosage then the curling was similar to a specimen with no curing for compound C3
- As the coverage rate was increased all of the curing compounds showed an improvement in performance up to a point

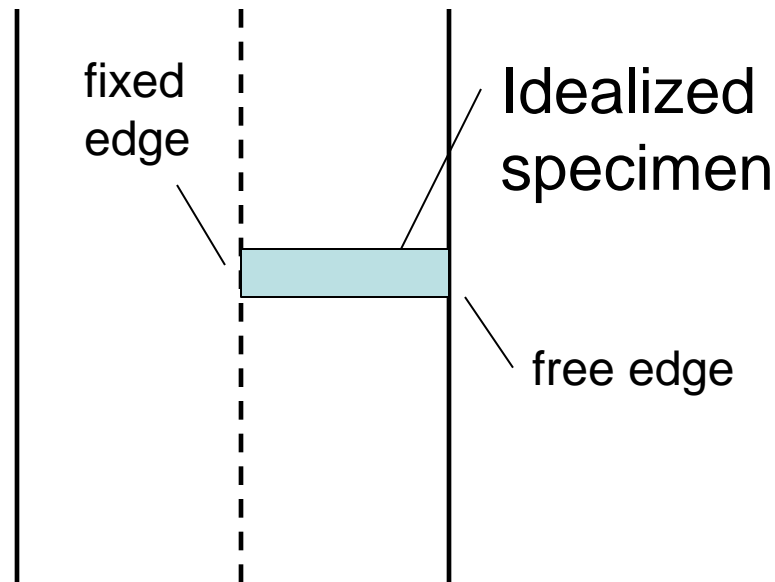


# Conclusions based on Paste Beams

- Curing compounds performed the best
- Wet curing performed the worst
- The longer you wet cure the worse the curling
- A double layer of curing compound seems to be more effective than a single layer when compared with the same amount of coverage
- As the coverage of the curing compound increased the curling decreased
- The Poly-Alpha-methyl-styrene showed the best performance of the curing compounds investigated.

# Concrete Beam

- While investigations with the paste beams are helpful it was decided to choose a specimen that is closer to mimic the performance of a concrete pavement



# Concrete Beam

- Concrete mixtures were made with a 0.42 w/cm
- Specimens were cured with either wet burlap or curing compounds and then stored at 73°F and 40% RH
- Curling, surface strain, and internal relative humidity were measured
- Surface of the beams were tined





Fixed

8'

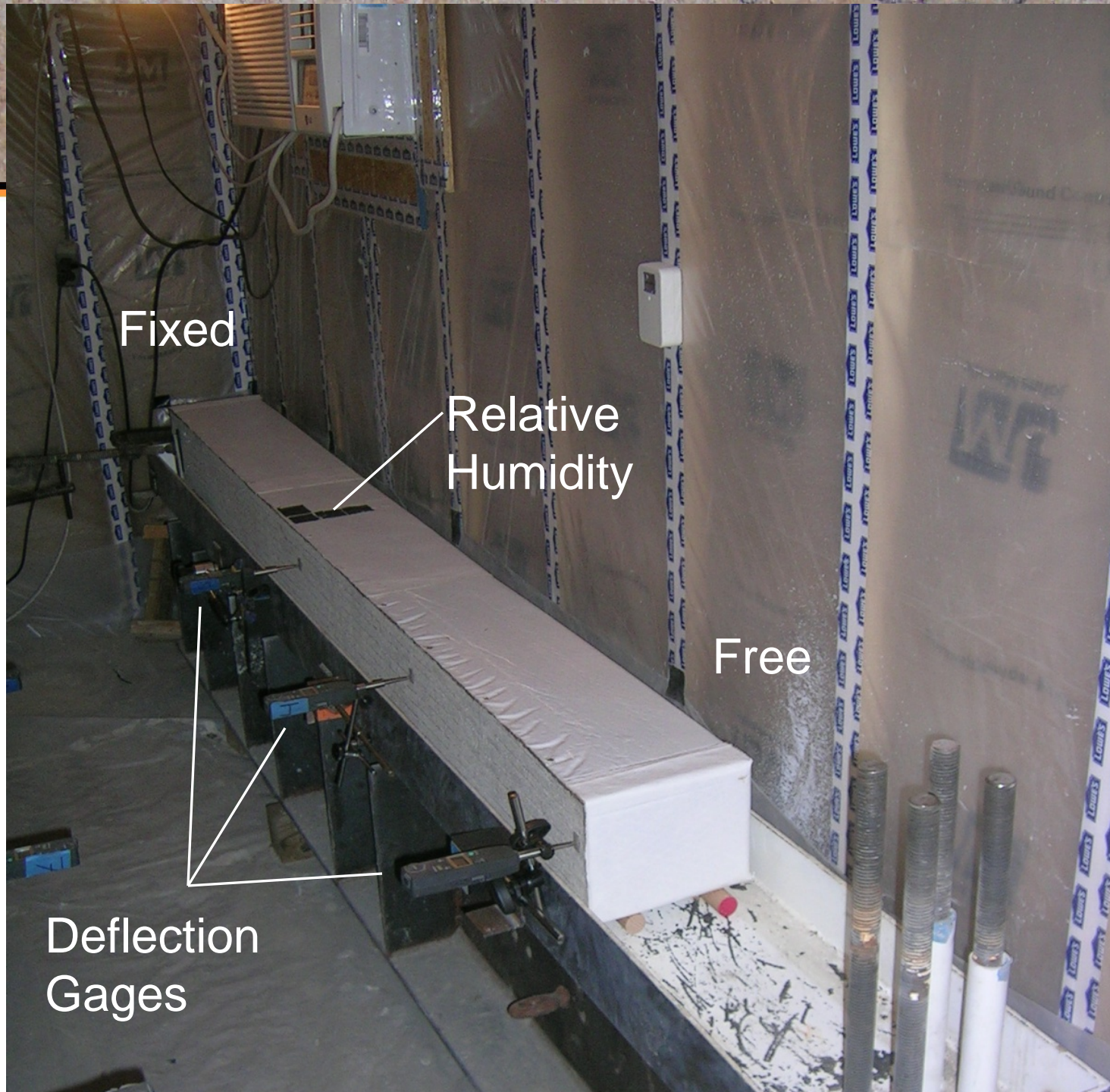
Free

8"

6"

Wood dowels





Fixed

Relative  
Humidity

Free

Deflection  
Gages

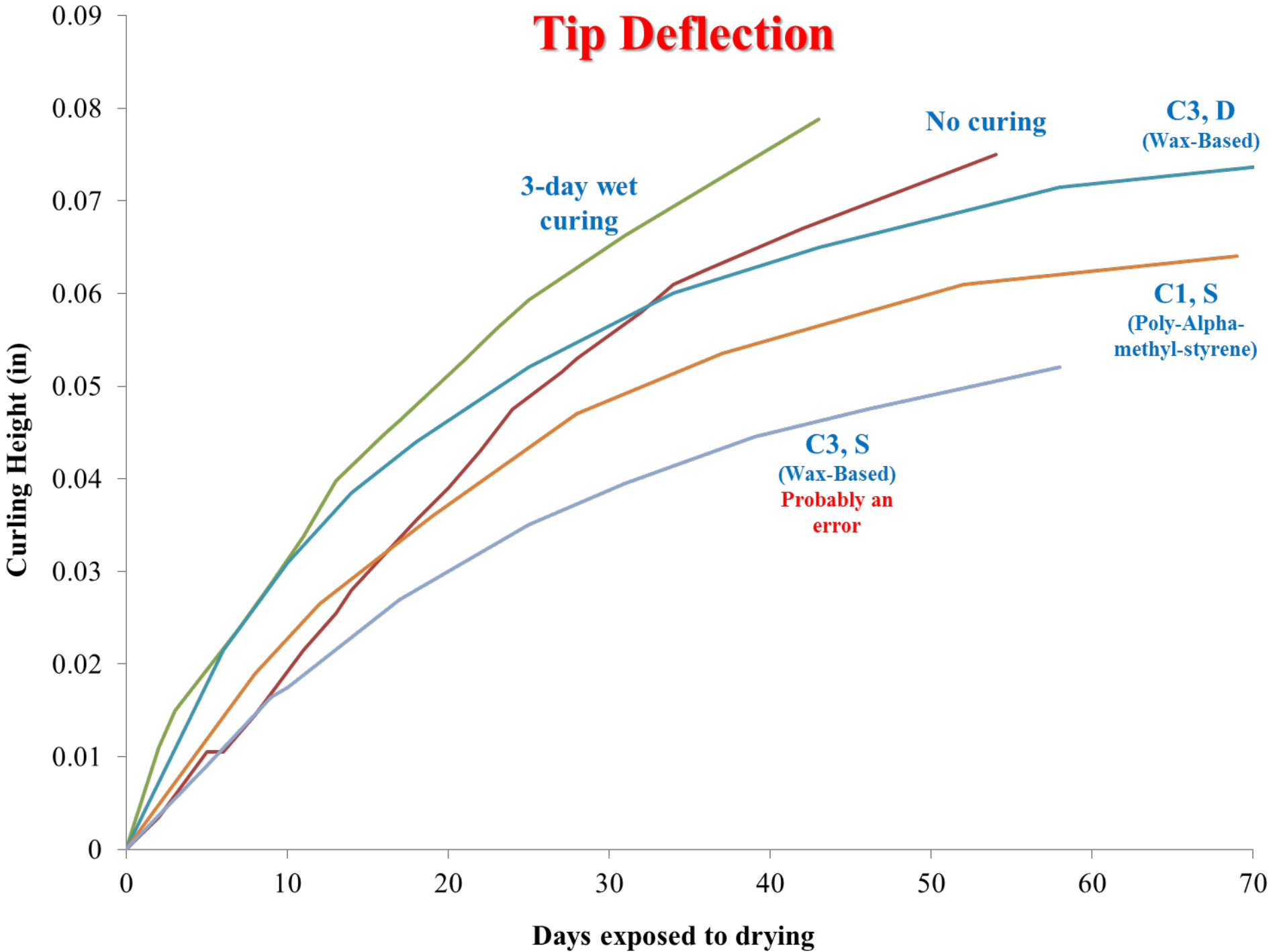




# Results

- Tip deflection
- Relative Humidity profiles

# Tip Deflection



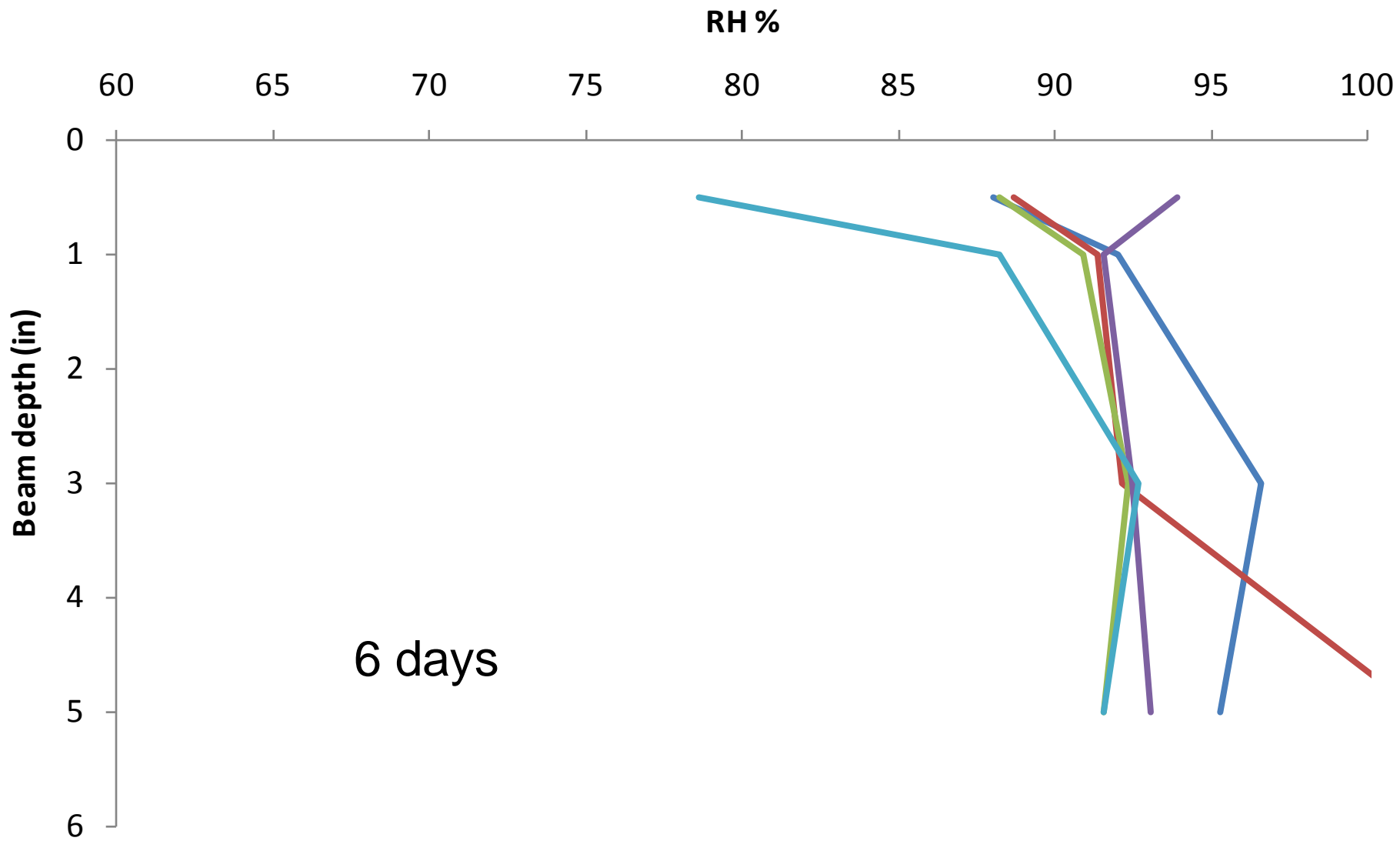


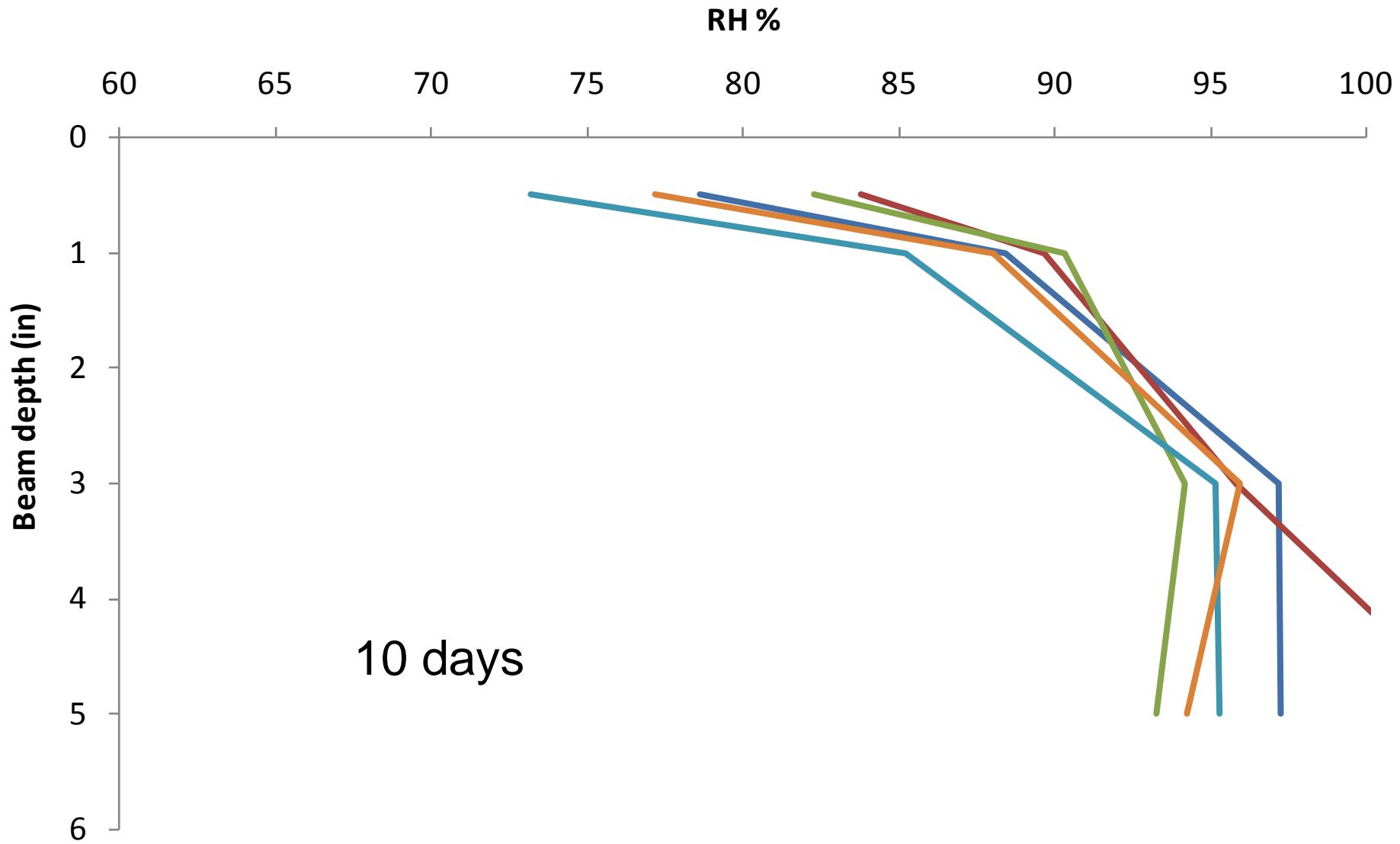
# Observations

- The concrete beams behavior is similar to the paste beams!
- The wet cured sample curled the most
- The curing compounds curled the least

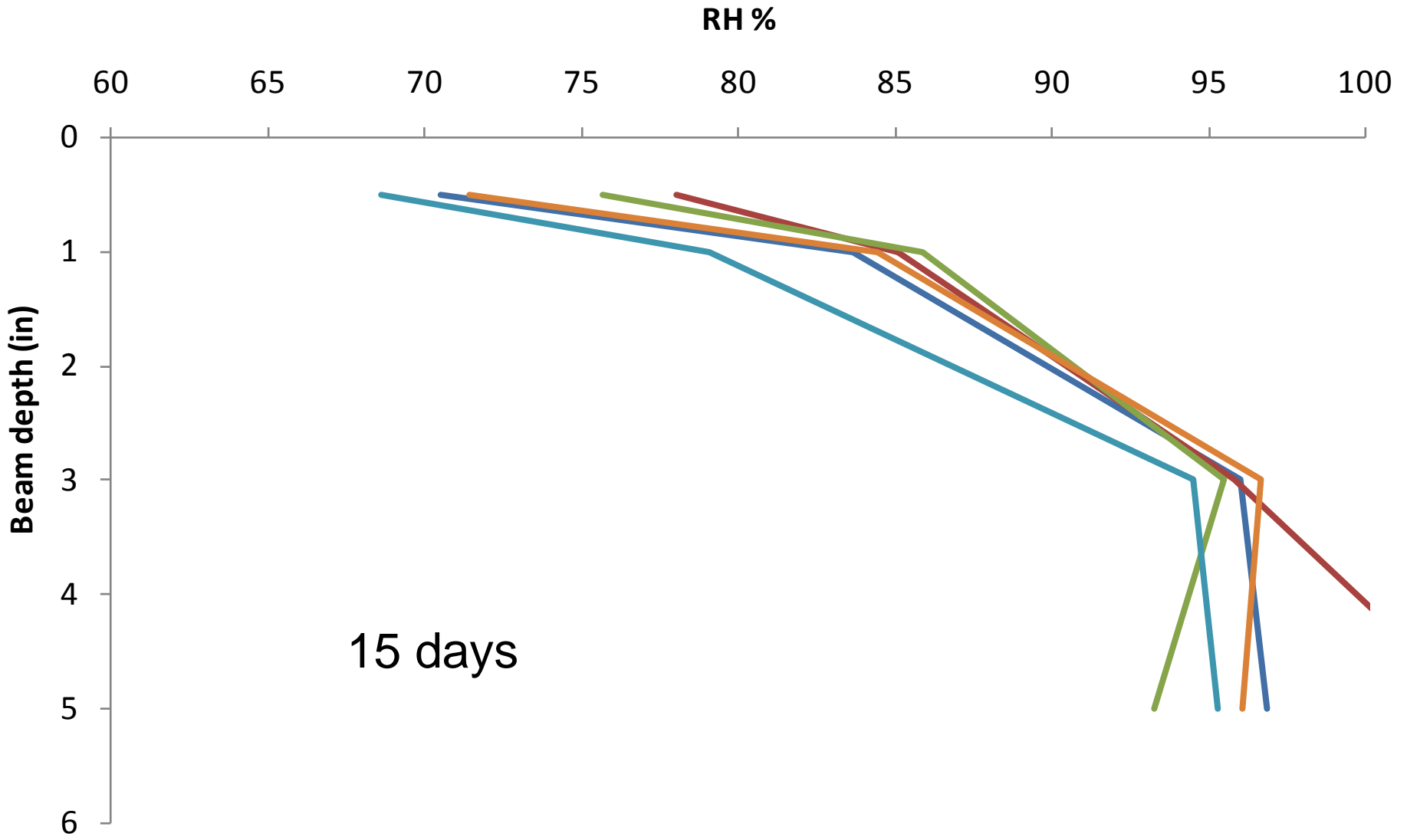
# Relative Humidity Profile

- I-button RH sensors were used
- They were calibrated at OSU according to ASTM E104
- These sensors are not accurate above 95% RH but very accurate below that.

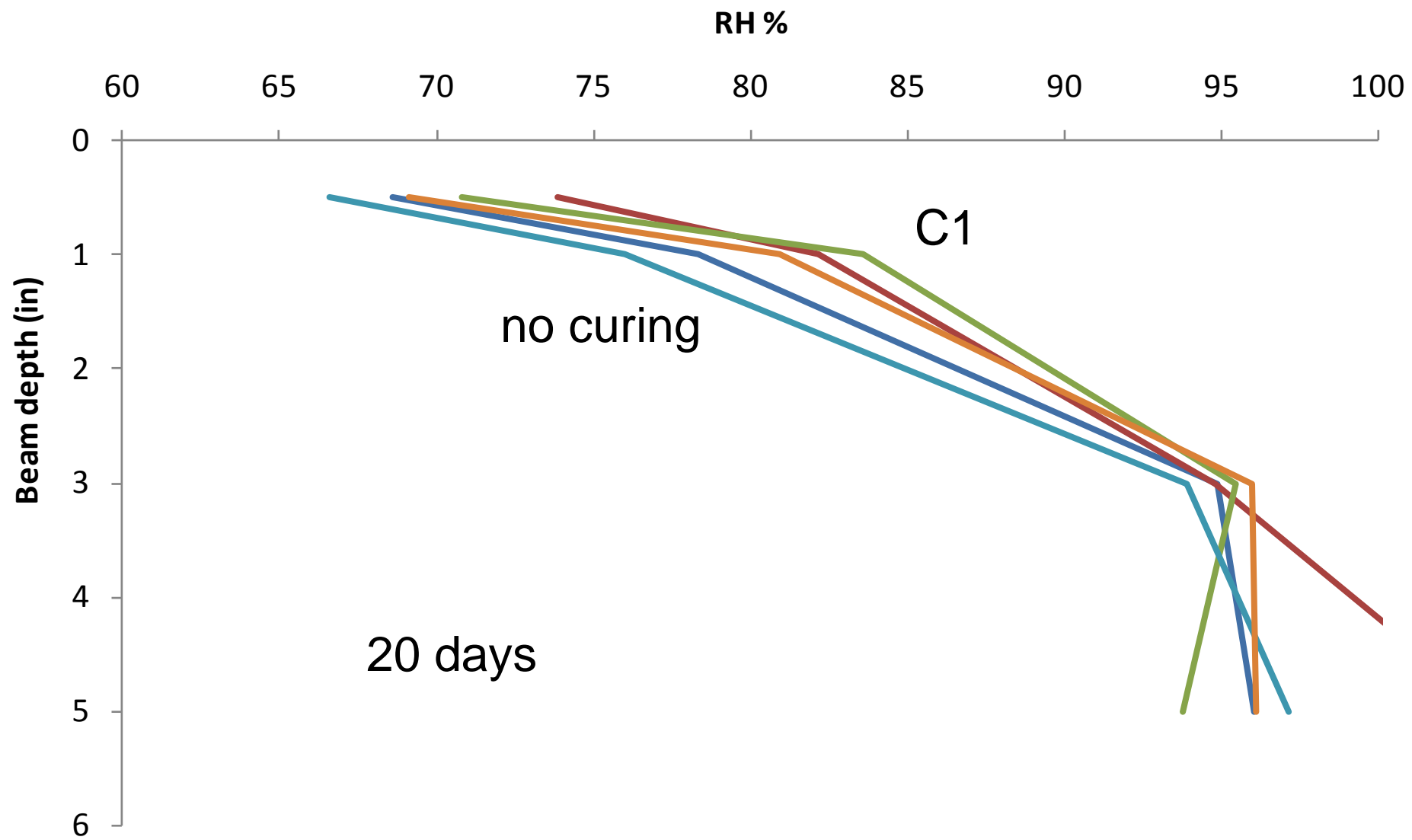








15 days



# In Summary

- We get similar results as the paste beams!

With wet curing the pore radius at the surface ↓

This makes the capillary tension ↑ upon drying

This makes the shrinkage of paste ↑

In turn the shrinkage of the concrete ↑

# Conclusions

- The laboratory tests produce curling!
- The results show that more curling from differential drying shrinkage can be best reduced by using curing compounds
- The Poly-Alpha-methyl-styrene curing compounds performed the best while the wax based curing compounds performed the worst
- A double layer of curing compound was found to perform better than a single for an equivalent amount of coverage in the paste beam tests



# Conclusions

- All of the work presented in this presentation was for curling due to differential drying shrinkage
- They do not include any impact from differential temperatures

Are the results applicable to the field?



# Are the results applicable to the field?

- All of the specimens were stored in environmental chambers at 73°F and 40% RH. This is not representative of the cyclic wetting and drying that is observed in the field
- However when concrete loses moisture and shrinks not all of it is reversible. This means over time as it dries it will keep shrinking/curling
- If one is in a very tropical environment then the data here may not apply as the concrete may not dry.



# Are the results applicable to the field?

- Much of the US and especially in Oklahoma would not be considered tropical.
- Therefore given enough time the field results should be similar to what has been observed in this study.



# Questions???



**Greetings Concrete Fans and Welcome to HydrationTheater.com!**