Impact of Curing Methods on Curling of Concrete Pavements

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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?
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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.
Why do pavements curl/warp?
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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

![Sunset over a field](image_url)

temperature
moisture                    temperature

dry

wet
moisture

dry

wet

less dry

temperature
moisture

dry

- wet
less dry

wet

less wet

temperature
moisture

- dry
- wet
- less dry
- less wet

temperature

- cold
- hot
- less cold
- 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

![Diagram of cement grain](image)
Why is curing important?

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• Improve strength
• Improve water-tightness
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Proper curing will:

- **Reduce permeability**
- **Improve strength**
- **Improve water-tightness**
- **Improve abrasion resistance**
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• This additional curling will lead to cracking and premature failure.
• A wet cure is challenging to provide in the field.
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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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• The uncoated surface shrinks and causes the specimen to curl
Curing Methods for Rigid Pavements

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  - 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
• 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
maximum deflection
Day 3

Day 6

Day 11

Day 36

Deflection (in)

Beam Length (in)
Constant 40% RH

Moisture profile

Drying shrinkage

Curling UP

Maximum Curling

Curling DOWN

All sides coated, except the top
Wet cure vs. no curing
Weight loss (grams)

- No curing
- 1 day wet cure
- 3 day
- 7 day
- 14 day

Day
Max Def. (in)

Point of maximum curl

14 day
7 day
3 day
1 day wet cure
no curing

Day
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
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
100% of manufactured recommended dosage was used
100% of manufactured recommended dosage was used
How do curing compounds compare to other methods of curing?
no curing

7 day wet cure

C1

100% recommended coverage
Max Def. (in)

Age (day)

7 day wet cure

no curing

C1
100% recommended coverage

0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
4
8
12
16
20
24
28

0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
4
8
12
16
20
24
28
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.
Maximum curling height (in)

Gallon per square ft

C1, S (Poly-Alpha-methyl-styrene)

C2, S (Resin-Based)

C3, S (Wax-Based)

C3, D (Wax-Based)
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.

```
  Idealized specimen

  fixed edge

  free edge
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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

Relative Humidity

Free

Deflection Gages
Results

- Tip deflection
- Relative Humidity profiles
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
- There were calibrated at OSU according to ASTM E104
- These sensors are not accurate above 95% RH but very accurate below that.
6 days
Beam depth (in)

RH %

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?
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- 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???

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