# MnDOT Approach to Accepting Coal Combustion Ash

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## Acknowledgments

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2

## Acknowledgements

FHWA Exploratory Advanced Research
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## Overview

We have a lot of SCMs
Going to the Doctor
Buying breakfast cereal
The Future!

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Did you know?

The US only uses 40% of the fly ash produced every year.

The remaining fly ash and bottom ash end up in landfills.

5

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## CCA can be…

Traditional fly ash
Bottom ash
Off spec fly ash
Any combination of the above

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## Did you know?

+2.5 B tons of usable CCA are buried or in holding ponds in the US (ACAA, 2019)

**This is enough reserve to satisfy the US concrete industry for +170 y at current usage levels.**

9

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When we learn how to process and approve these materials, then our SCM problems will be over!

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What do I have to do differently?

Will it work?

Who will buy it?

What specification will be used?

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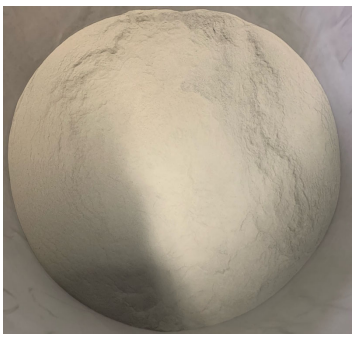
## EAR Research

- 23 sources of reclaimed fly ashes
- 14 sources for concrete testing.
- Four are unprocessed.

Unprocessed



Processed

14

## What are we doing with them?

Characterization
Strength
Resistivity
Diffusion Coefficient
ASR
Heat of hydration
Air Entrainment

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## Performance of CCA

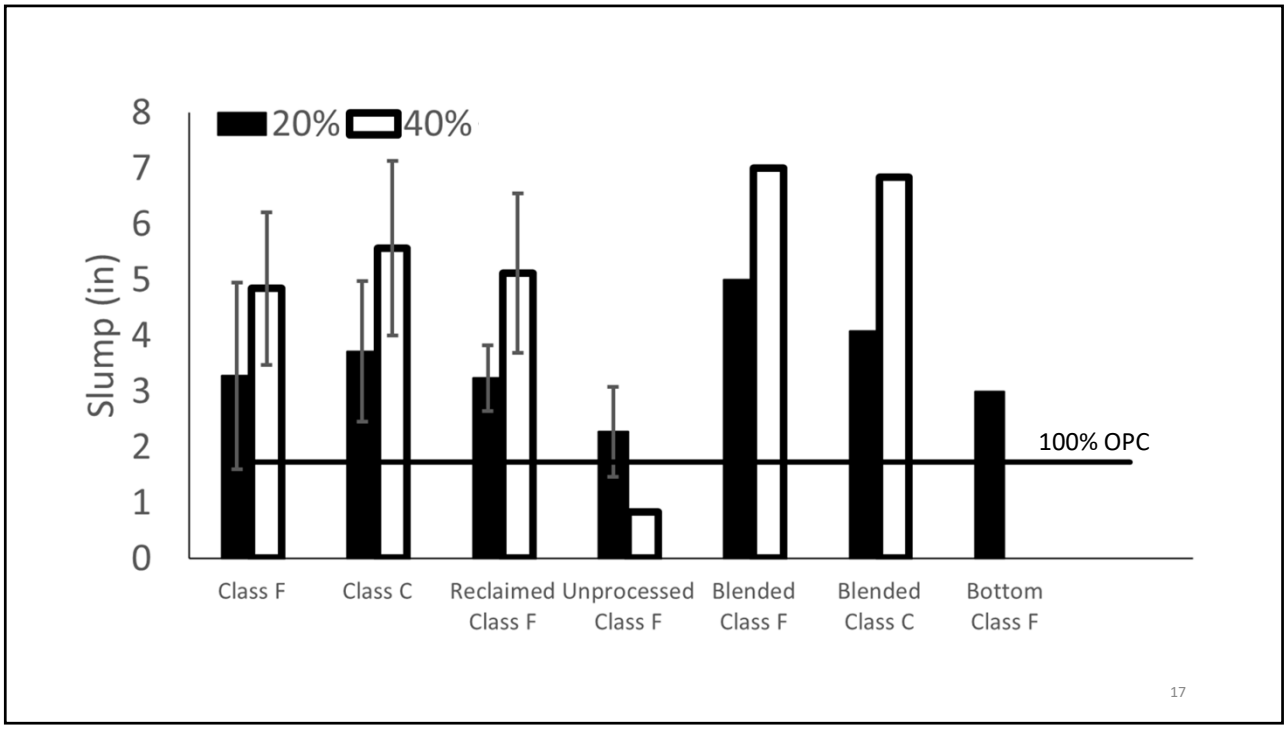
Let's compare performance with a standard concrete mixture

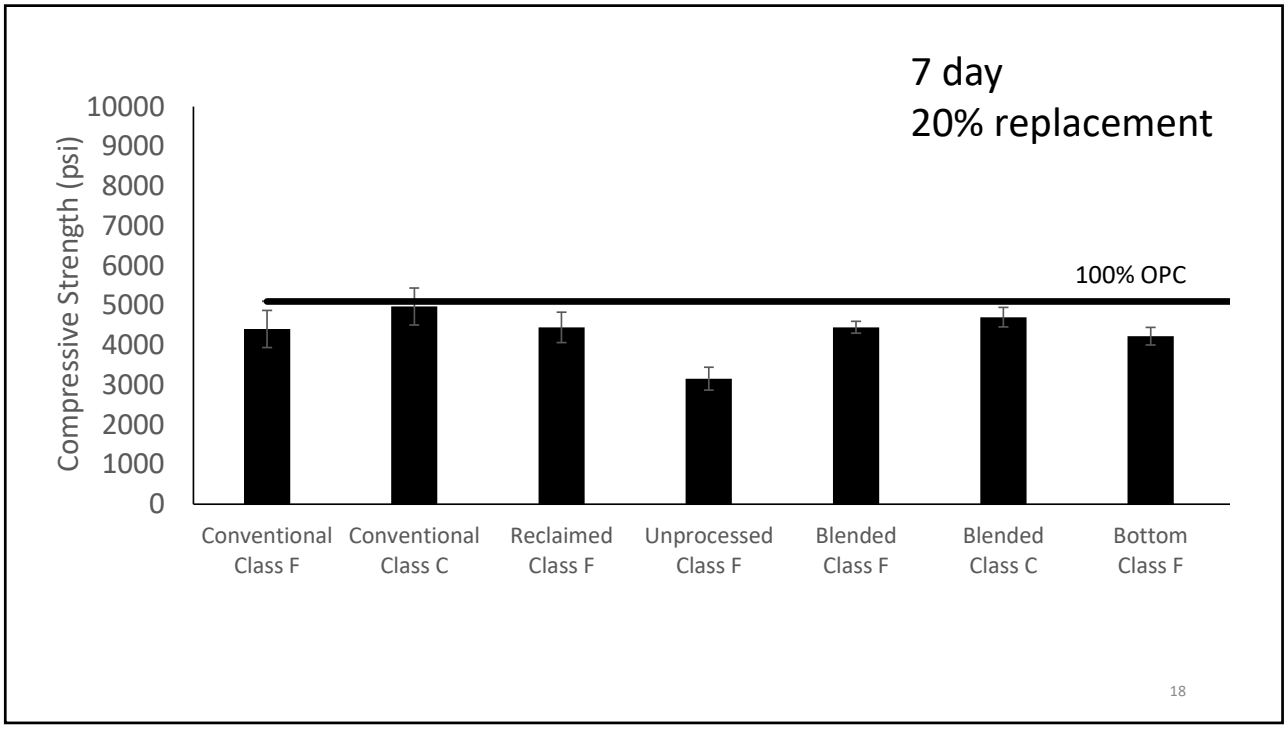
0.45 w.cm, 6 sacks of binder, Type I cement, one coarse and fine aggregate source.

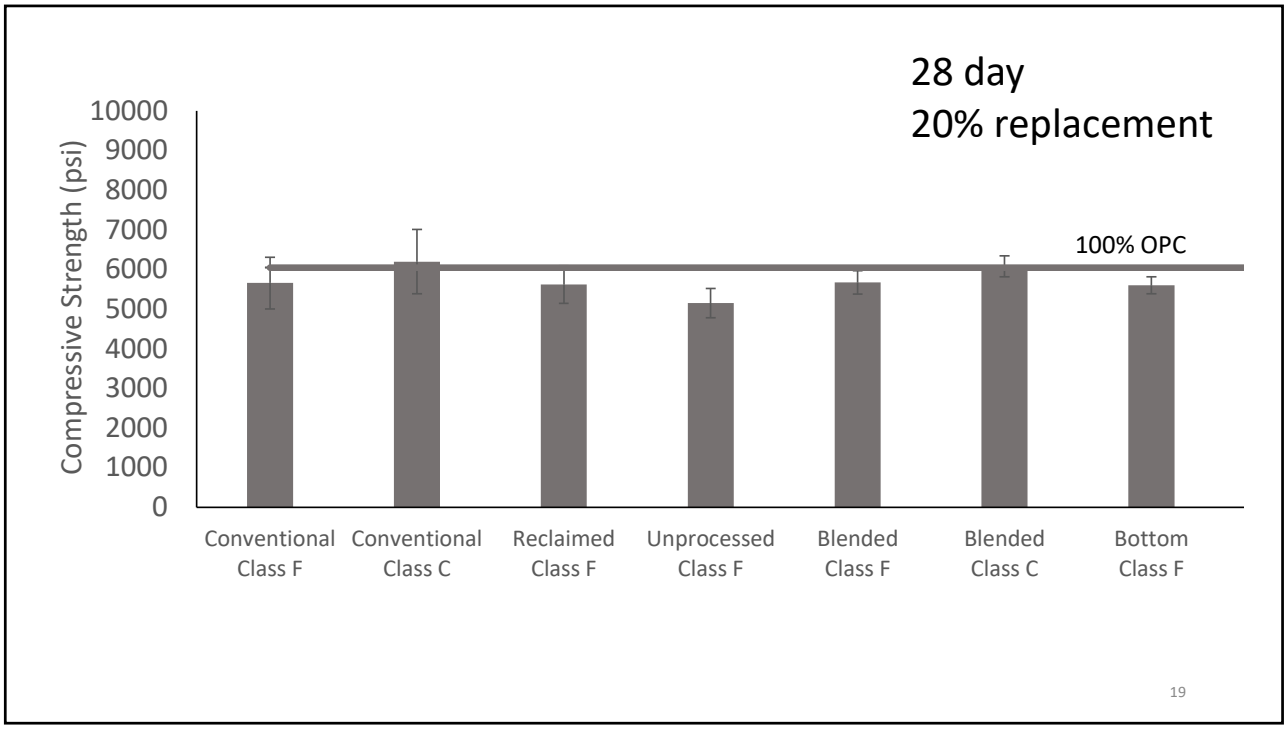
Use fly ash at 20% replacement and 40% replacement

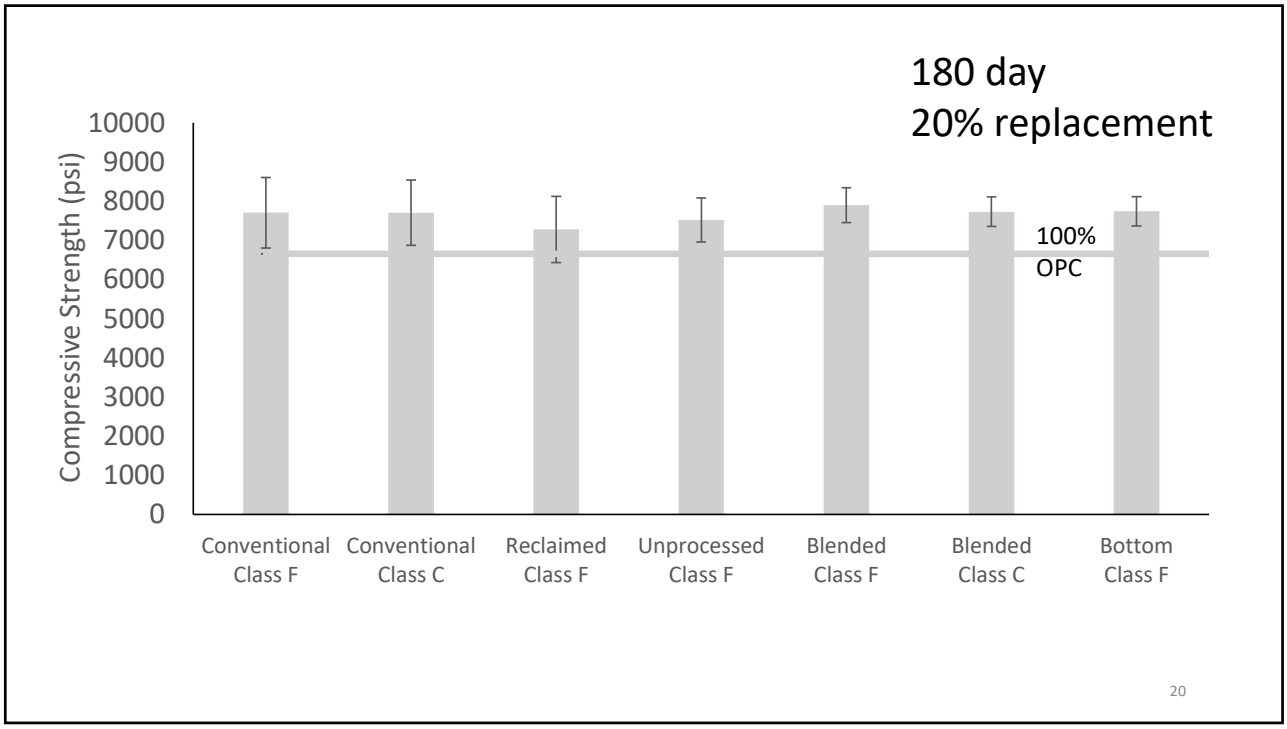
Slump
Compression Strength
Resistivity

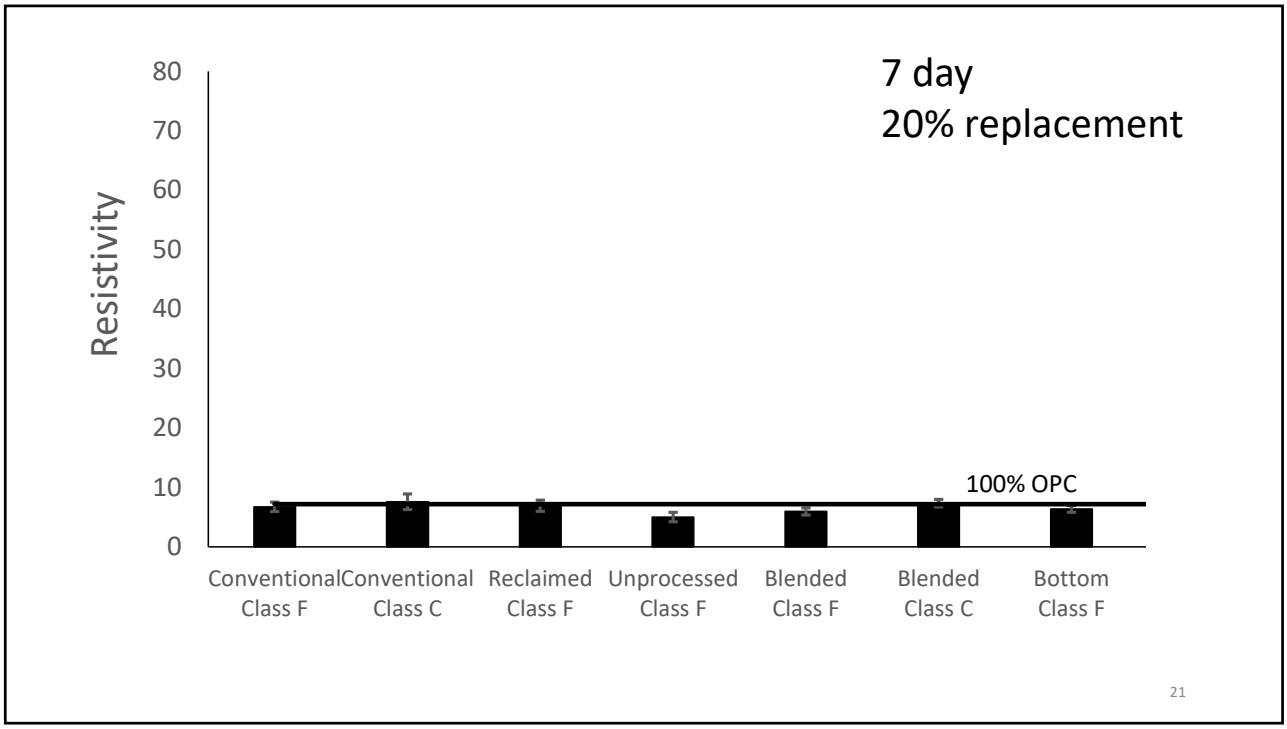
16

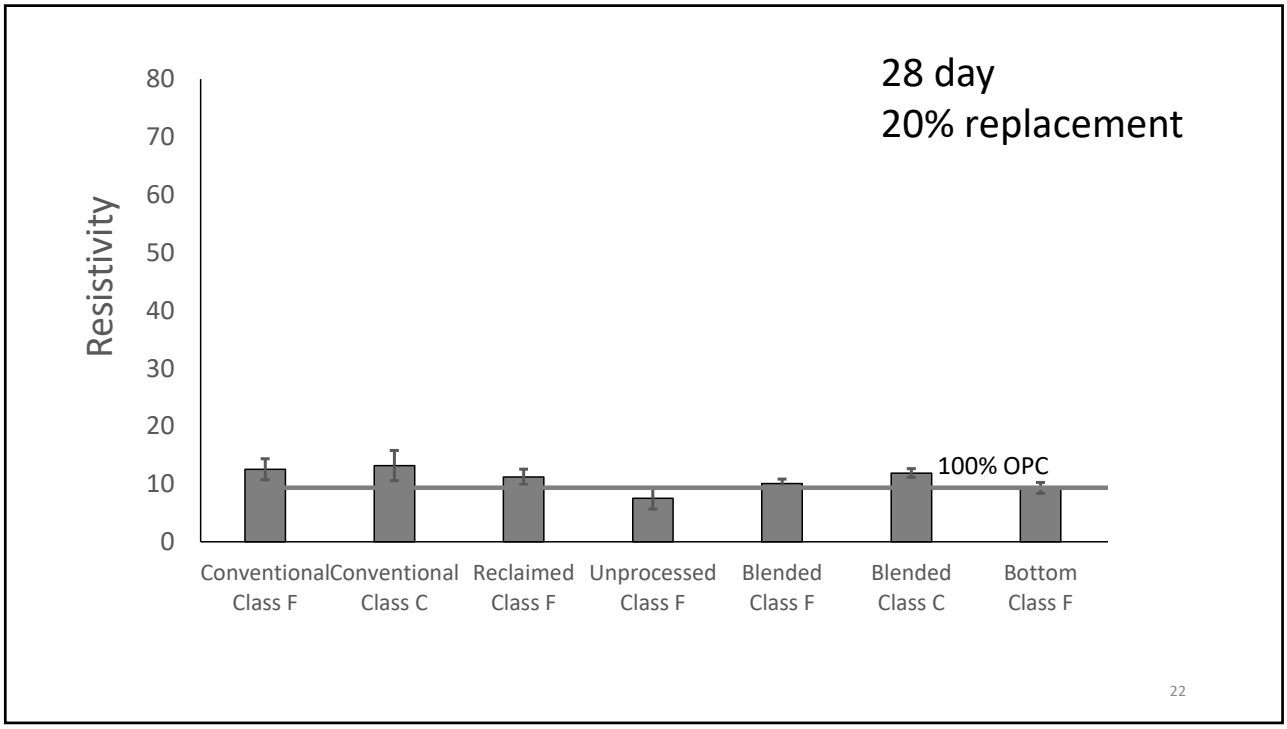

20%
40%
Slump (in)
8
7
6
5
4
3
2
1
0
100% OPC
Class F
Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
17

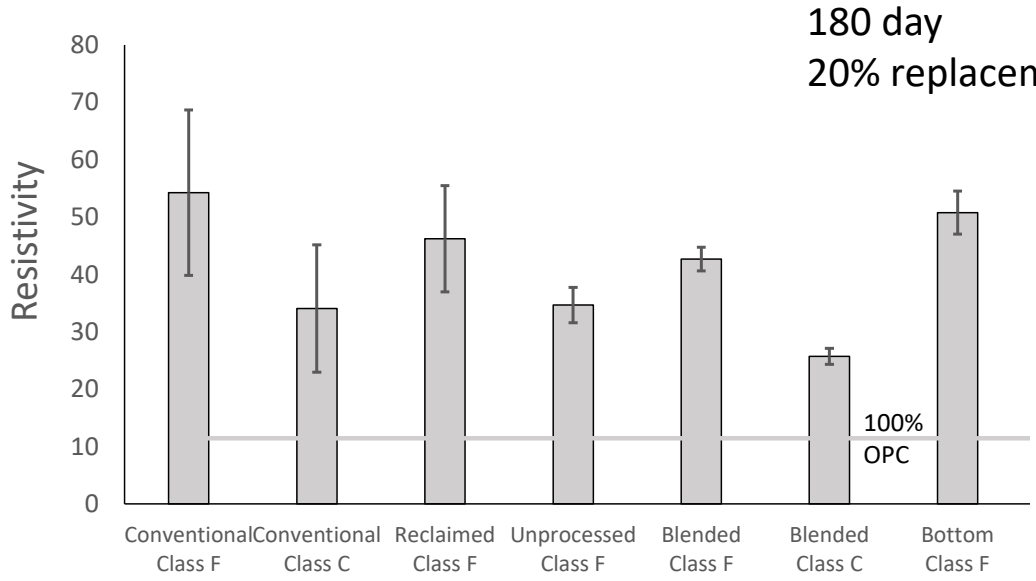

7 day
20% replacement
Compressive Strength (psi)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
100% OPC
Conventional Class F
Conventional Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
18


28 day
20% replacement
Compressive Strength (psi)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
100% OPC
Conventional Class F
Conventional Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
19


180 day
20% replacement
Compressive Strength (psi)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
100% OPC
Conventional Class F
Conventional Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
20


7 day
20% replacement
Resistivity
80
70
60
50
40
30
20
10
0
100% OPC
Conventional Class F
Conventional Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
21


28 day
20% replacement
Resistivity
80
70
60
50
40
30
20
10
0
100% OPC
Conventional Class F
Conventional Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
22




23

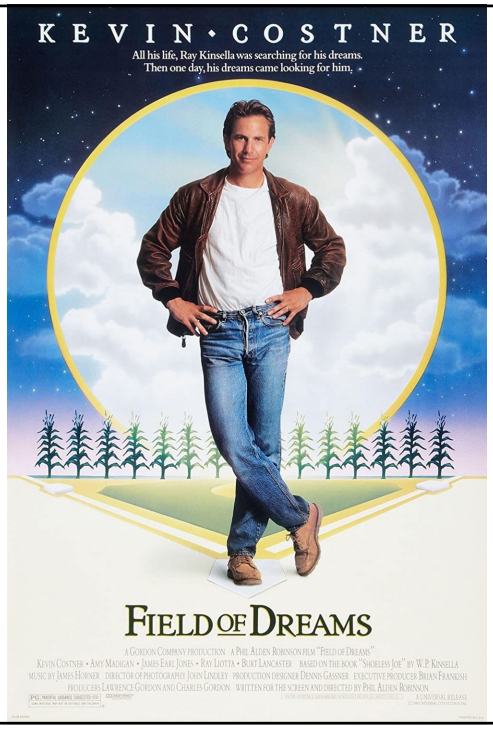
What do I have to do differently?

Will it work?

Who will buy it?

<u>What specification will be used?</u>

24

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If you spec it, they will come!!!!
Minnesota DOT!

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Did you know CCAs are being used in:

North Carolina
South Carolina
Georgia
Pennsylvania
New York

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"We are using CCAs everyday and not having any issues. The CCAs have similar performance to traditional fly ash."

TJ Harris – Concrete Supply Co.

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## For CCAs we need:

1. Consistent materials
2. A minimum level of performance
3. To know how the mixture with CCA compares to a mixture with only OPC or another known fly ash.

This is how admixtures are classified in ASTM C494.

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## How does my CCA compare to what I am used to using?

- Workability
- Rate of reaction (Set time)
- Total heat
- AEA dosage
- Strength
- Microstructure development
- ASR

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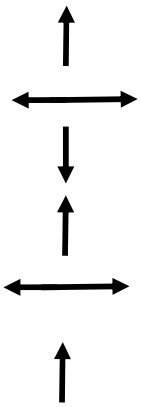

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## Important Concepts!!!

**Complexity is the enemy of execution.**

Use established test methods that build confidence

We don’t need to know the details if the end product is satisfactory.

Some details may change!

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## How does this work?

Concrete/mortar Tests

Material Tests

33

## How does this work?

Concrete/mortar Tests

Material Tests

Full Physical

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## How does this work?

Concrete/mortar Tests

Full Physical

Material Tests

Simple Health Measures

## Concrete/mortar tests

Slump

Compression Strength - 1, 3, 7, 28, 56d

Set time
Calorimetry
> Only choose one

ASR Accelerated Mortar bar – ASTM C1567

## Discussion

These tests are run with 0%, 20%, and 40% CCA replacement in a standard concrete mixture.

This allows the CCA to be compared to a straight cement mixture that is run with the same aggregate.

This is done when the CCA is approved and then must be repeated once every three years.

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| Mixture | OPC $lbs/yd^3$ | CCA $lbs/yd^3$ | Water $lbs/yd^3$ | Coarse $ft^3/yd^3$ | Fine $ft^3/yd^3$ |
|---|---|---|---|---|---|
| 0% CCA | 625 | 0 | 281 | 11.40 | 7.40 |
| 20% CCA | 500 | 125 | 281 | 11.34 | 7.33 |
| 40% CCA | 375 | 250 | 281 | 11.28 | 7.27 |

The mass of the coarse and fine aggregate is found by the following:

Mass ($lb/yd^3$) = SSD aggregate specific gravity x 62.4 $lb/ft^3$ x Volume from the table.

0.45 w/cm
6.65 sack mix
No admixtures!

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## Material Tests

Chemical Composition
Moisture Content
Fineness #325 retained
Density

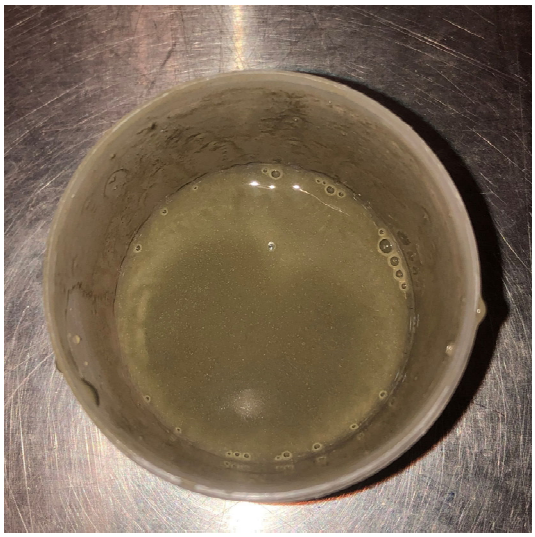
} ASTM C 311

Foam Index — ASTM C 1827 MnDOT Modified

## Foam Index Test

- 2g of CCA and 8 g cement with 25ml of water is combined in a 120ml jar
- Fixed dosages of dilute air entraining agent is added slowly to the solution

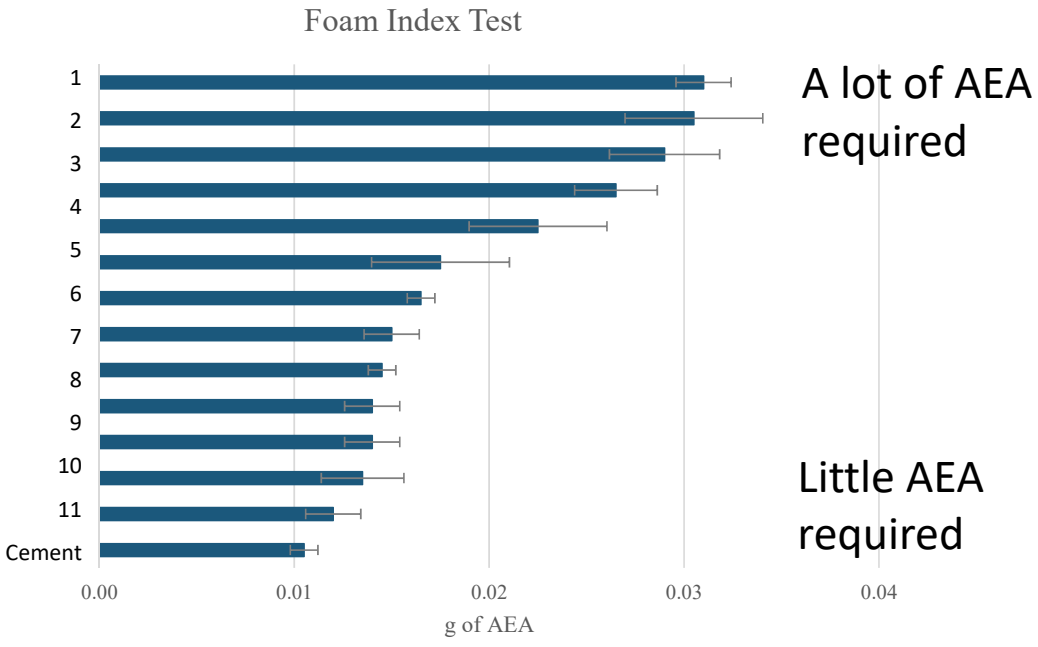
40



Beginning

End

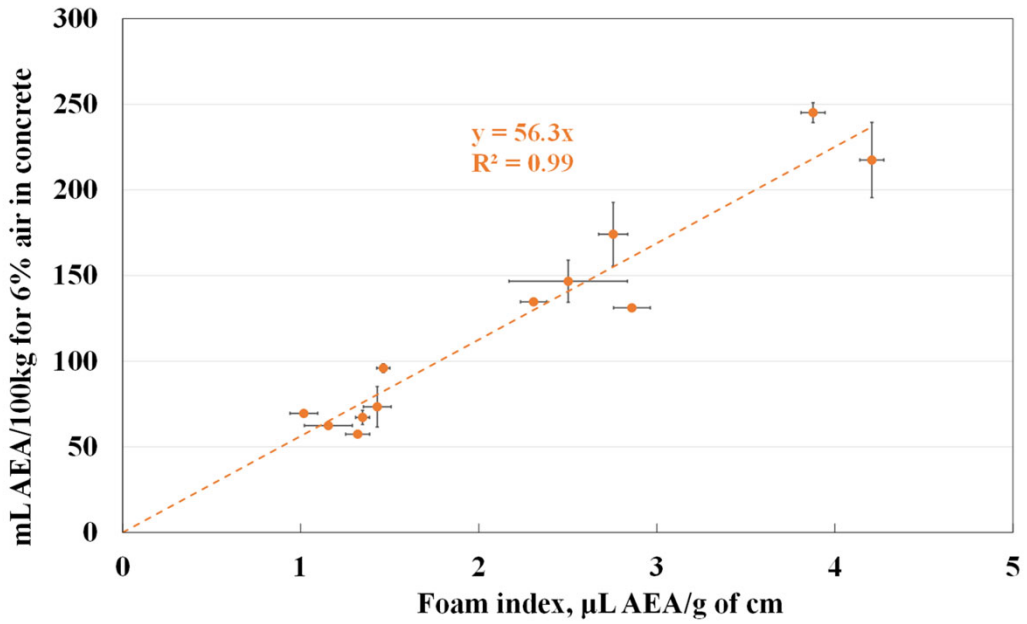
41




A lot of AEA required

Little AEA required

42

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## Discussion

- The MnDOT specific version of the foam index test shows a good correlation to AEA dosage in a standard concrete mixture.
- On to the Spec!!!!

44

Is the CCA currently used by another state agency with 1y of field performance?

45

Is the CCA currently used by another state agency with 1y of field performance?

YES!

Concrete Test x 1

Material Tests x 10

46

## Is the CCA currently used by another state agency with 1y of field performance?

YES!

Concrete Test x 1

Material Tests x 10

We will use the variation in these tests later!

47

## This is used for acceptance or rejection.

| Parameter | Calculation | Limit |
|---|---|---|
| Fineness* | Report value | < 34% |
| Moisture Content | Report value | < 3% |
| Foam Index | $\frac{\text{CCA foam index}}{\text{cement foam index}}$ | < 2.0 |
| Set time 20% CCA | $\frac{\text{20\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |
| Set time 40% CCA | $\frac{\text{40\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |

*Amount retained on 45 micron (No. 325) sieve

** Set time or time at max heat.

ASR requirements are coming.

48

Is the CCA currently used by another state agency with 1y of field performance?

NO!

For 3 days production

Concrete Test x 1 per day

Material Tests x 10 per day

49

This is used for acceptance or rejection.

| Parameter | Calculation | Limit |
|---|---|---|
| Fineness* | Report value | < 34% |
| Moisture Content | Report value | < 3% |
| Foam Index | $\frac{\text{CCA foam index}}{\text{cement foam index}}$ | < 2.0 |
| Set time 20% CCA | $\frac{\text{20\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |
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*Amount retained on 45 micron (No. 325) sieve

** Set time or time at max heat.

ASR requirements are coming.

50

## Is it too variable?

The allowable variability is being determined.

If it is too variable then it is not acceptable.

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Slump | A | ASTM C143 |
| Strength | B | ASTM C39 |
| Set time | C | ASTM C403 |
| Calorimetry | D | Emerson, 2021 |
| Foam index | E | Emerson, 2021 |
| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

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## Now that it is approved what do we do?

Sample the CCA at the same intervals established by ASTM C311 with the Material Tests

If the Material Tests are close to the values established in the approval process, then accept the material.

If the values are more variable, then do more testing!

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# Is it too variable?

The allowable variability is being determined.

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Slump | A | ASTM C143 |
| Strength | B | ASTM C39 |
| Set time | C | ASTM C403 |
| Calorimetry | D | Emerson, 2021 |
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| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

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If repeated Material Tests show that the material has “changed”.

Then we need to do repeat the Concrete/mortar testing to check the performance.

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Use the Material Tests to "check" the sample.

Material Tests

Simple Health Measures

Use the Material Tests to "check" the sample.

Material Tests

Simple Health Measures

Run the concrete tests if things look off.

Concrete/mortar

Full Physical

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## Why do we need concrete tests?

I think owners and producers are more comfortable making and testing concrete.

This could change as other tests improve.

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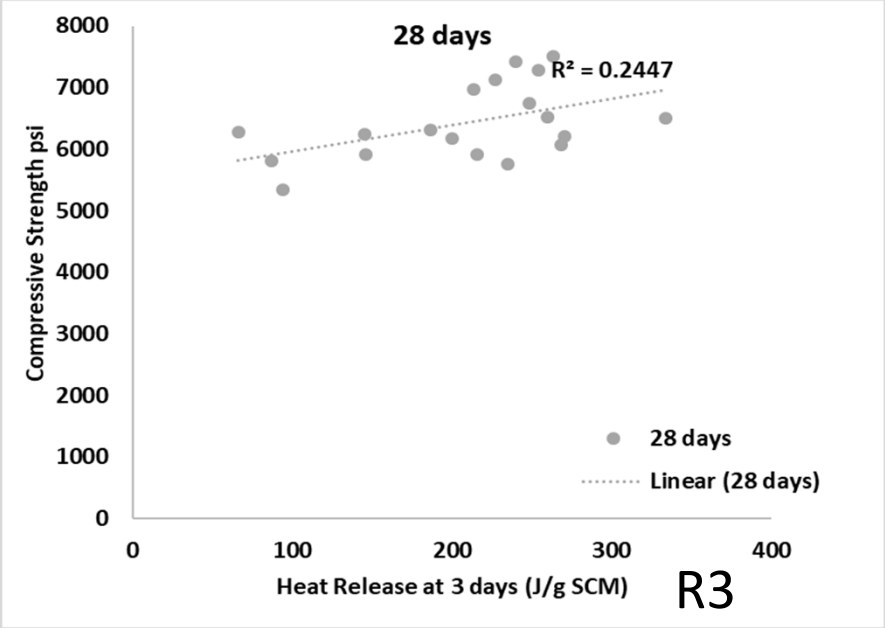
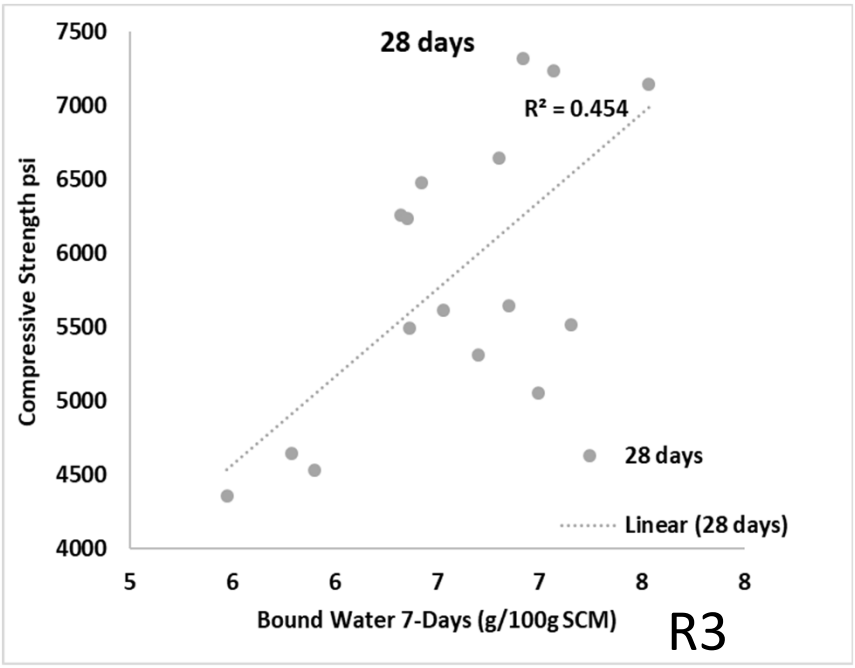
## Concrete




R3

58

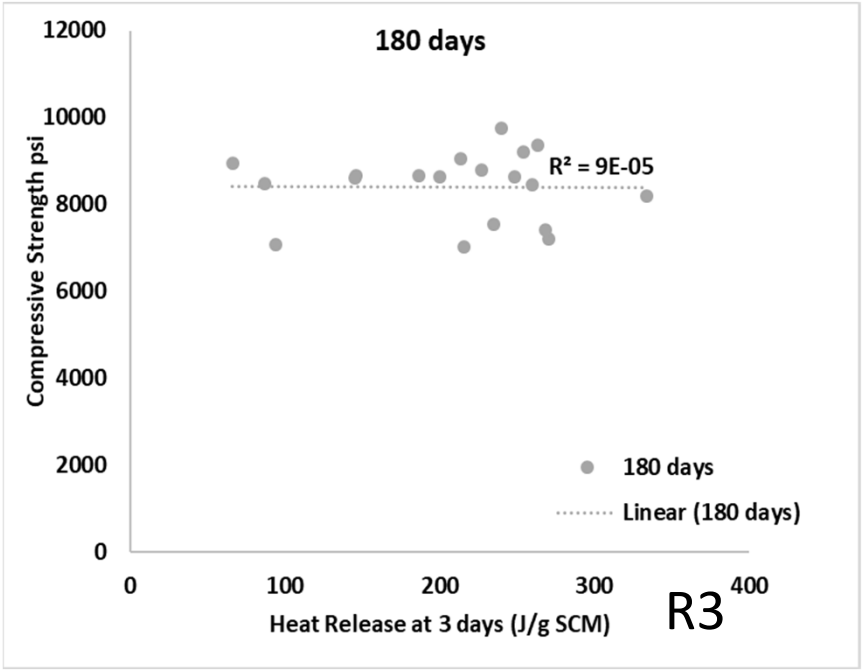
# Concrete




R3

59

# Concrete




R3

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## How can we use this info to make producers more comfortable with CCAs?

Compare the CCA performance to the mixture with just straight cement.

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CCA Facts

| | |
|---|---|
| Strength | xx |
| Workability | yy |
| Permeability | zz |
| ASR | aa |
| ….. | |

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| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| | | No Change in Slump | Improved Slump | High Slump |
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |

63

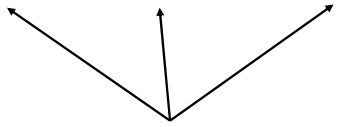
| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| | | No Change in Slump | Improved Slump | High Slump |
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |

Sump with 20% CCA = 7”
Slump with 0% CCA = 3”

$\frac{\text{20\% CCA Slump}}{\text{0\% CCA Slump}} = \frac{7”}{3”} = 2.3$ High slump!

64

| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| | | No Change in Slump | Improved Slump | High Slump |
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |



Sump with 20% CCA = 7”
Slump with 0% CCA = 3”

20% CCA Slump = 7” = 2.3 High slump!
0% CCA Slump 3”

These numbers are the 33% and 66% performance levels for > 40 fly ashes and CCAs

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| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| | | No Change in Slump | Improved Slump | High Slump |
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |
| | | Decrease in Strength | Same Strength | Increase in Strength |
| 20% CCA Compressive Strength 1d 3d 7d 28d 56d | 20% CCA Compressive Strength / 0% CCA Compressive Strength (This is done at each age.) | < 0.90 | 0.90 - 1.1 | > 1.1 |

66

| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| | | No Change in Slump | Improved Slump | High Slump |
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |
| | | Decrease in Strength | Same Strength | Increase in Strength |
| 20% CCA Compressive Strength<br>1d<br>3d<br>7d<br>28d<br>56d | 20% CCA Compressive Strength / 0% CCA Compressive Strength<br>(This is done at each age.) | < 0.90 | 0.90 - 1.1 | > 1.1 |
| | | Low AEA Demand | Moderate AEA Demand | High AEA Demand |
| Foam Index | CCA Foam Index / Cement Foam Index | < 1.25 | between 1.25 and 2 | > 2 |

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| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| | | No Change in Slump | Improved Slump | High Slump |
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |
| | | Decrease in Strength | Same Strength | Increase in Strength |
| 20% CCA Compressive Strength<br>1d<br>3d<br>7d<br>28d<br>56d | 20% CCA Compressive Strength / 0% CCA Compressive Strength<br>(This is done at each age.) | < 0.90 | 0.90 - 1.1 | > 1.1 |
| | | Low AEA Demand | Moderate AEA Demand | High AEA Demand |
| Foam Index | CCA Foam Index / Cement Foam Index | < 1.25 | between 1.25 and 2 | > 2 |


We also have this for set time and total heat.

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# How can we use this info to make producers more comfortable with CCAs?

This is not used to accept or reject materials!

This is used for informational purposes and to help guide changes in a mixture design and let the producers know about the capabilities of the CCA.

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# What is used for acceptance and rejection?

If it has 1y of field performance:

| Parameter | Calculation | Limit |
|---|---|---|
| Fineness* | Report value | < 34% |
| Moisture Content | Report value | < 3% |
| Foam Index | $\frac{\text{CCA foam index}}{\text{cement foam index}}$ | < 2.0 |
| Set time 20% CCA | $\frac{\text{20\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |
| Set time 40% CCA | $\frac{\text{40\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |

*Amount retained on 45 micron (No. 325) sieve

** Set time or time at max heat.

ASR requirements are coming.

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# What is used for acceptance and rejection?

If it does not have 1y of field performance:

| Parameter | Calculation | Limit |
|---|---|---|
| Fineness* | Report value | < 34% |
| Moisture Content | Report value | < 3% |
| Foam Index | $\frac{\text{CCA foam index}}{\text{cement foam index}}$ | < 2.0 |
| Set time 20% CCA | $\frac{\text{20\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |
| Set time 40% CCA | $\frac{\text{40\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |

*Amount retained on 45 micron (No. 325) sieve

** Set time or time at max heat.

ASR requirements are coming.

+

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Slump | A | ASTM C143 |
| Strength | B | ASTM C39 |
| Set time | C | ASTM C403 |
| Calorimetry | D | Emerson, 2021 |
| Foam index | E | Emerson, 2021 |
| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

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# RECAP!!!!

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# CCA Approval

Concrete/mortar

Material Tests

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# CCA Approval

Concrete/mortar

Material Tests

## Accept or Reject

### Minimum Performance

| Parameter | Calculation | Limit |
|---|---|---|
| Fineness* | Report value | < 34% |
| Moisture Content | Report value | < 3% |
| Foam Index | $\frac{\text{CCA foam index}}{\text{cement foam index}}$ | < 2.0 |
| Set time 20% CCA | $\frac{\text{20\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |
| Set time 40% CCA | $\frac{\text{40\% CCA Set Time}}{\text{0\% CCA Set Time}}$ ** | between 0.5 and 2.0 |

*Amount retained on 45 micron (No. 325) sieve
** Set time or time at max heat.

### Variability

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Slump | A | ASTM C143 |
| Strength | B | ASTM C39 |
| Set time | C | ASTM C403 |
| Calorimetry | D | Emerson, 2021 |
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| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

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# Daily and Monthly QC testing

## Material Tests

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# Daily and Monthly QC testing

## Material Tests

## Does variation match CCA approval?

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Foam index | E | Emerson, 2021 |
| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

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# Daily and Monthly QC testing

## Material Tests

Does variation match CCA approval?

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Foam index | E | Emerson, 2021 |
| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

Yes!

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# Daily and Monthly QC testing

## Material Tests

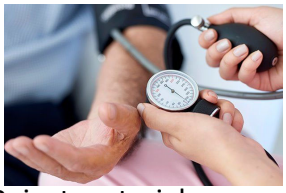
Does variation match CCA approval?

| Measurement | Allowable variation during acceptance* | Reference |
|---|---|---|
| Foam index | E | Emerson, 2021 |
| Moisture | F | ASTM C311 |
| Fineness | G | ASTM C430 |
| Density Le Chatelier Flask | H | ASTM C188 |
| Density pycnometer | I | ASTM C604 |
| $SiO_2$ | J | ASTM C311 |
| $Al_2O_3$ | K | ASTM C311 |
| $Fe_2O_3$ | L | ASTM C311 |
| CaO | M | ASTM C311 |
| MgO | N | ASTM C311 |
| $SO_3$ | O | ASTM C311 |

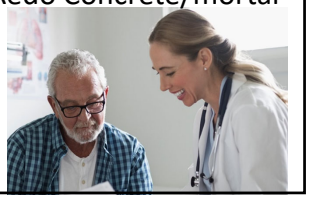
Yes!

No!

Redo Material Tests



Reject material or Redo Concrete/mortar



## Use approval testing to categorize CCA performance

Concrete/mortar

Material Tests

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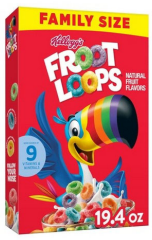
## Use approval testing to categorize CCA performance

Concrete/mortar

Material Tests

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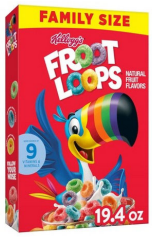
## Use approval testing to categorize CCA performance

Concrete/mortar

Material Tests




This is for information only.

| Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|
| 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | No Change in Slump < 1.1 | Improved Slump 1.1 - 2.0 | High Slump > 2.0 |
| | | Decrease in Strength | Same Strength | Increase in Strength |
| 20% CCA Compressive Strength 1d 3d 7d 28d 56d | 20% CCA Compressive Strength / 0% CCA Compressive Strength (This is done at each age.) | < 0.90 | 0.90 - 1.1 | > 1.1 |

## The Future!

There will be many new SCMs in the future and we need ways to understand their:

1. Consistency
2. A minimum level of performance
3. To know how the mixture with CCA compares to a known mixture

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## The Future!

I think standard concrete mixtures are a very powerful way to show the performance of SCMs. This is already done with ASTM C 494 for admixtures.

By combining more involved and simple tests we can help ensure performance of SCMs

CCAs will be widely used as an SCM in concrete.

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## Conclusion

This is a simple performance based specification that Minnesota DOT is proposing to evaluate CCAs for use in concrete.

It uses established test methods to benchmark and then compare the CCA performance to this benchmark.

The procedure and values are evolving but this establishes a rational path forward that could be used for any new SCM.

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www.tylerley.com
www.youtube.com/tylerley
tyler.ley@okstate.edu

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www.tylerley.com/Minnesota

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| | Does not meet ASTM C 618 or < 1y state agency performance (Choose whichever happens first.) | Meets ASTM C 618 or > 1y state agency performance |
|---|---|---|
| Production Sample* | Daily or 100 Tons (90 Mg) | Daily or 400 Tons (360 Mg) |
| Composite Sample** | Monthly or 2000 Tons (1800 Mg) | Monthly or 3200 Tons (2900 Mg) |

* Samples taken from a single lot of material this is the same as a "Regular Sample" as defined by ASTM C 311.
** Sample created from equal portions of production samples

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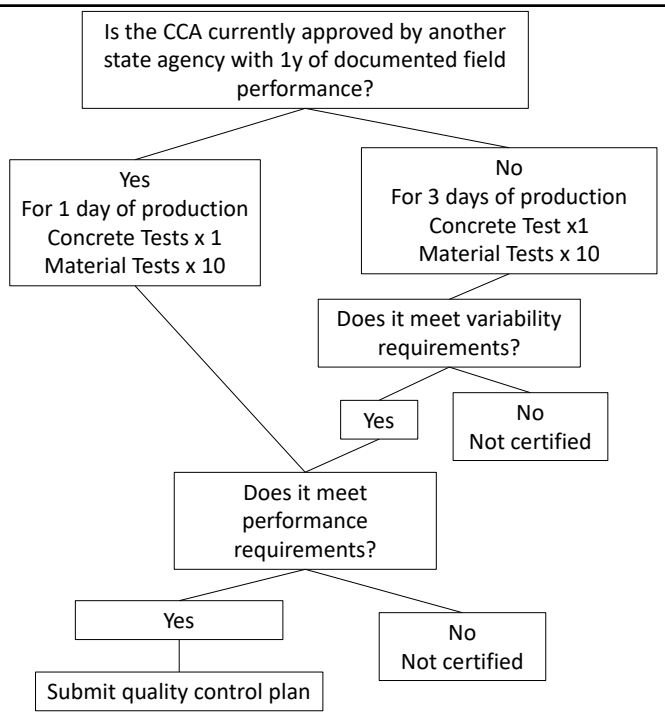


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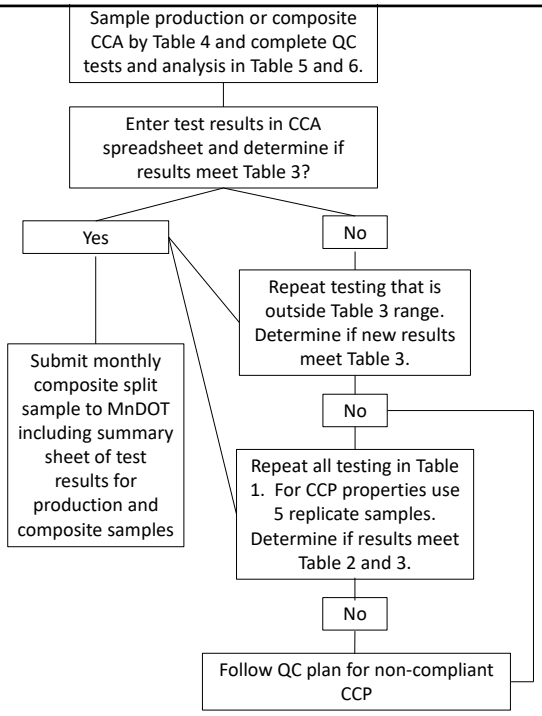


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| | Parameter | Calculation | Performance Classification | | |
|---|---|---|---|---|---|
| Measured Performance | 20% CCA Slump | 20% CCA Slump / 0% CCA Slump | No Change in Slump<br>< 1.1 | Improved Slump<br>1.1 - 2.0 | High Slump<br>> 2.0 |
| | 40% CCA Slump | 40% CCA Slump / 0% CCA Slump | < 1.1 | 1.1 - 2.0 | > 2.0 |
| | 20% CCA Compressive Strength<br>1d<br>3d<br>7d<br>28d<br>56d | 20% CCA Compressive Strength / 0% CCA Compressive Strength<br>(This is done at each age.) | Decrease in Strength<br>< 0.90 | Same Strength<br>0.90 - 1.1 | Increase in Strength<br>> 1.1 |
| | 40% CCA Compressive Strength<br>1d<br>3d<br>7d<br>28d<br>56d | 40% CCA Compressive Strength / 0% CCA Compressive Strength<br>(This is done at each age.) | < 0.90 | 0.90 - 1.1 | > 1.1 |
| | 20% CCA Set Time or Time at Max Heat | 20% CCA Set Time / 0% CCA Set Time | Accelerated Set<br>< 0.66 | No Change in Set<br>0.66 - 1.5 | Delayed Set<br>> 1.5 |
| | 40% CCA Set Time or Time at Max Heat | 40% CCA Set Time / 0% CCA Set Time | < 0.66 | 0.66 - 1.5 | > 1.5 |
| | Foam Index | CCA Foam Index / Cement Foam Index | Low AEA Demand<br>< 1.25 | Moderate AEA Demand<br>between 1.25 and 2 | High AEA Demand<br>> 2 |
| | Total Heat at 48h from isothermal calorimetry | CCA Heat at 48h / OPC Heat at 48h | Decrease in Heat<br>< 0.90 | Same Heat<br>between 0.90 and 1.1 | Increase in Heat<br>> 1.1 |

| | Parameter | Calculation | Notes |
|---|---|---|---|
| Predicted Performance | Compressive Strength | Values are predicted based on performance calculator at www.tylerley.com/flyash | 3, 7, 28, 56, 90, 180 d |
| | Diffusion Coefficient | | 45, 90, 135, 700 d |
| | Total Heat | | 48 h |

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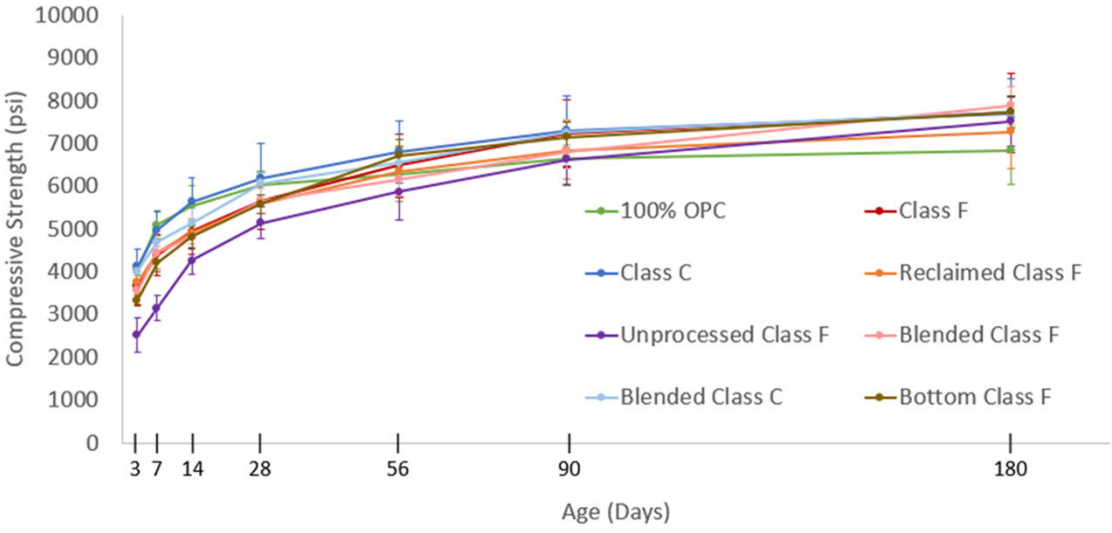
Compressive Strength (psi)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
3 7 14 28 56 90 180
Age (Days)
100% OPC
Class F
Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F

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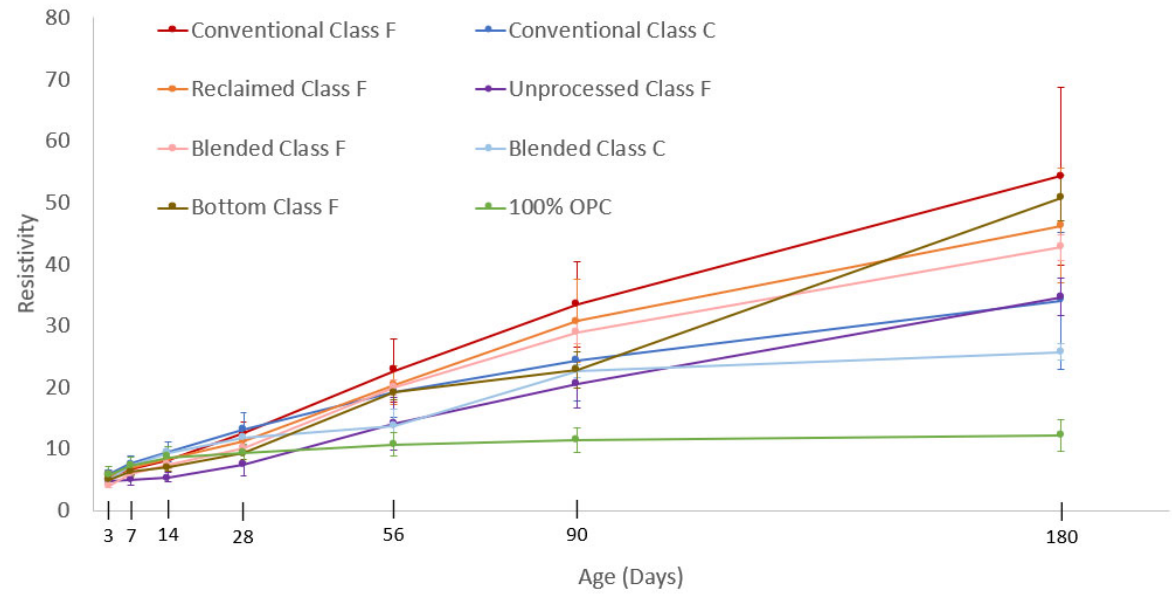
Resistivity
80
70
60
50
40
30
20
10
0
3 7 14 28 56 90 180
Age (Days)
Conventional Class F
Conventional Class C
Reclaimed Class F
Unprocessed Class F
Blended Class F
Blended Class C
Bottom Class F
100% OPC

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