Update on NCHRP Project 10-104: Recommendations for Revision of AASHTO M 296 Standard Specification to Include Marginal and Unconventional Source Coal Fly Ashes

NC^2 Conference

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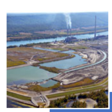
Alternative fly ashes

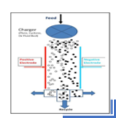
Marginal
- Lime injection ashes
- High alkali
- High ammonia
- Increased particle size
- High carbon content
- Trona

High lime, sulfate, ammonia, alkali, or carbon. Potential for AEA and durability issues.



Unconventional
- Ponded
- Landfilled
- Circulating fluidized bed
- Bottom

Increased carbon content & changes in particle size distribution. Potential for high variability.



Beneficiated
- Cyclone-collected
- Surfactant modification
- Thermally beneficiated
- Carbon burn out
- Stage turbulent reactor (STAR)
- Triboelectrostatic
- Sonicated
- Reground
- Blending

Treated to meet spec requirements, typically by reducing LOI and increasing fineness. Chemical additions possible.

Fly Ash Sources and Classifications

A total of <u>22 fly ash sources</u> will be used for testing of paste, mortar, and concrete specimens

<u>7 Conventional fly ash sources meeting AASHTO-M295 requirements</u>

3 Class C *(D, E, & H)*

4 Class F *(A, I, P, Q)*

<u>15 Marginal or unconventional fly ash sources</u>

7 beneficiated ashes *(B, K, O, M, N, R, & S)*

2 ponded sources/2 landfilled fly ash sources *(M, S, T, U)*

6 extreme properties sources (high SO_3, high LOI, off-spec fineness, high alkali) *(B, F, G, U, L, I)*

Other (CFB, cyclone collector ash, bottom ash blend) *(C, J,V)*

AASHTO M295 Sample Compliance

Close to limit (marginal)

Outside of limit

Samples	Beneficiated?	Class	Supplier Notes	SiO_2 + Al_2O_3 + Fe_2O_3, %	CaO, %	SO_3, %	Na_2O_{eq}, %	Moisture Content, %	Water Req, %	Fineness, %	Density	LOI, %
				50, min	N/A	5, max	4.5% max – R80	3, max	105, max	34, max	N/A	5, max
			Standard Ashes				Total alkalis:					
A	N	F	Class F, in-spec	83.4	5.4	0.41	2.87	0.23	92	29.3	2.37	0.64
I	N	F	Class F with CaO 12-18%	71.1	11.9	0.58	5.02	0.11	88	34.1	2.55	0.34
P	N	F	Class F moderate LOI	88.7	1.7	0.10	1.89	0.23	100	20.2	2.57	3.83
Q	N	F	Class F high LOI	82.2	5.0	0.65	1.71	0.18	100	30.3	2.38	4.62
E	N	C	Class C with elevated SO_3	50.1	25.3	2.75	1.94	0.18	94	14.2	2.78	0.79
D	N	C	Class C, in-spec	63.5	19.9	0.80	1.80	0.30	100	24.5	2.59	0.69
H	N	C	Class C	50.9	24.8	2.18	2.13	0.45	94	20.6	2.80	1.43
			Beneficiated Ashes									
N	Y	F	Blend of Class C and Class F	69.2	14.5	0.69	1.95	0.14	95	30.7	2.52	0.79
B	Y	F	Off-spec ash, beneficiated by sieving/ grinding	84.0	4.3	0.08	5.75	0.17	100	31.4	1.88	0.43
R	Y	F	HT Treatment	90.5	2.2	0.11	2.05	0.1	100	12.4	2.49	0.7
O	Y	F	LOI Electrostatic Beneficiation	82.4	4.7	1.27	2.23	0.77	104	24.1	2.43	2.57
K	Y	C	Surfactant Treated	51.2	24.8	2.05	1.85	0.15	88	21.9	2.83	0.95
M	Y	F	Harvested ash, dried and sieved	83.3	2.1	0.21	1.76	0.30	94	36.2	2.43	2.90
S	Y	F	Beneficiated harvested ash	92.0	1.5	0.11	1.85	0.1	102	22.1	2.38	0.3
			Marginal and Unconventional Ashes									
F	N	F	Fly ash with LOI > 5%	82.3	3.7	0.54	2.51	0.11	91	23.9	2.40	4.88
T	N	F	Ponded ash	90.8	2.8	1.01	2.39	5.19	110	23.1	2.56	5.00
C	N	C	CFB ash (not covered in spec)	65.7	18.5	4.11	1.00	0.22	107	31.6	2.59	0.69
J	N	F	Cyclone collector ash	61.5	15.3	2.28	2.92	0.28	94	15.7	2.79	3.10
G	N	C	High SO_3	37.8	25.5	17.45	3.94	1.05	94	15.5	2.55	2.08
L	N	F	Low Fineness	86.4	3.9	0.10	5.29	0.09	100	63.1	1.76	0.22

2 ashes did not meet 7- or 28-day SAI

Reference: Wang, Y., Acarturk, B. C., Burris, L., Hooton, R. D., Shearer, C. R., & Suraneni, P. (2022). Physicochemical characterization of unconventional fly ashes. *Fuel, 316*

Problematic Specification Items (AASHTO M295)

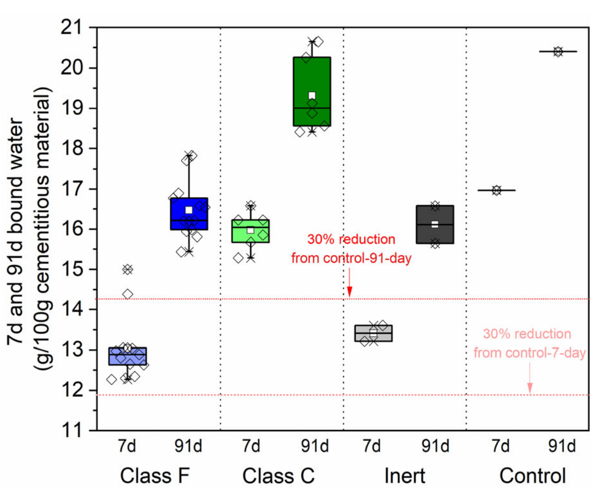
Item	Class F	Class C	Potential issues
LOI (%)	≤ 5		Does not correlate to adsorption. Different types of carbon, bound water, volatile organic compounds.
Fineness - Amount retained on 45 µm sieve (%)	≤ 34		Limit the % retained on a #100 mesh sieve to 5% or 10% to avoid coarse particles.
SAI, 7 days (% control)	≥ 75		SAI does not correlate with reactivity. Some future ashes may need to be better screened for reactivity.
SAI, 28/56 days (% control)	≥ 75		
Soundness – Autoclave expansion/contraction (%)	≤ 0.8		Soundness limit may not be meaningful for fly ash. MgO not an issue and free-CaO only an issue with some C-ashes.
Uniformity – Density variation from average (%)	≤ 5		Rationale for uniformity numbers not clear/based on literature. Link between density and fineness uniformity and performance not clear.
Uniformity – Amount retained on 45 µm sieve variation from average (%)	≤ 5		

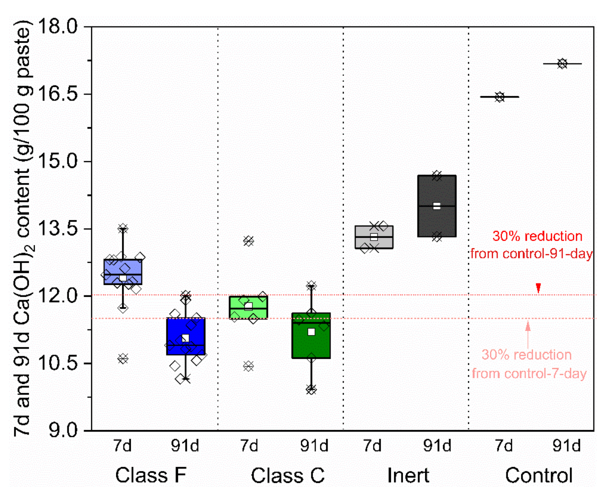
Reference: Suraneni, P., Burris, L., Shearer, C. R., & Hooton, R. D. (2021). ASTM C618 Fly Ash Specification: Comparison with Other Specifications, Shortcomings, and Solutions. *ACI Materials Journal*, 118(1), 157-167.

Bound Water and CH Content of Paste Samples at 7- and 91-days

30% Fly Ash Replacement of Type I/II Cement (w/cm = 0.4)

All ashes are reactive, with substantial differences observed between Class C and Class F





Reference: Wang, Y., Burris, L., Hooton, R. D., Shearer, C., & Suraneni, P. (2021). Effects of unconventional fly ashes on cementitious paste properties. *Cement and Concrete Composites*.

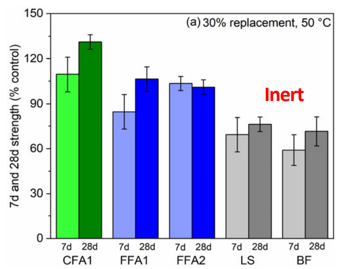
Modified SAI vs. Bulk Resistivity Index (BRI) (@50°C)

Instead of using SAI as an assessment of reactivity, it would be better to measure bulk resistivity at higher replacement levels and at an elevated temperature

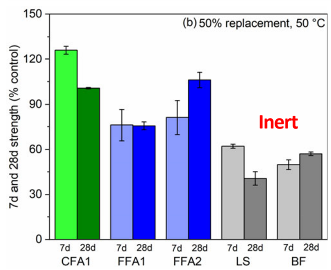
Modified SAI

30% Replacement

(w/cm=0.4)



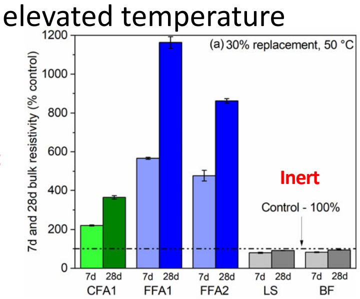
50% Replacement



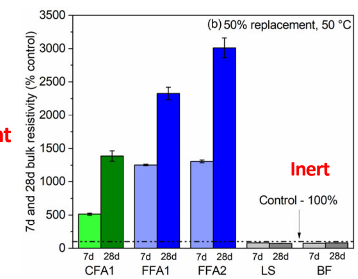
BRI

30% Replacement

(w/cm=0.4)



50% Replacement



Reference: Wang, Y., Burris, L., Shearer, C. R., Hooton, D., & Suraneni, P. (2021). Strength activity index and bulk resistivity index modifications that differentiate inert and reactive materials. *Cement and Concrete Composites*, 124, 104240.

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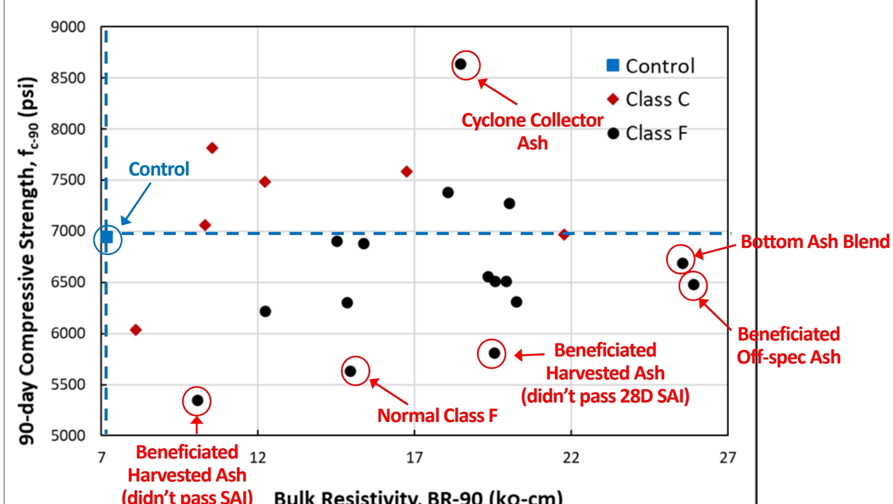
Correlation of Concrete Compressive Strength and Bulk Resistivity (90 Day)

All ashes contribute to strength gain to varying degrees in concrete, but strength is not correlated to bulk resistivity. Most marginal/unconventional ashes had similar strength to concrete and higher bulk resistivity.

Concrete Design

Material	W (lb/yd^3)
Water	270
Cement	420
Fly ash	180
Fine Agg	1333
Coarse Agg	1820
Air	0.0

30% Fly Ash Replacement
Type I/II Cement
w/cm = 0.45



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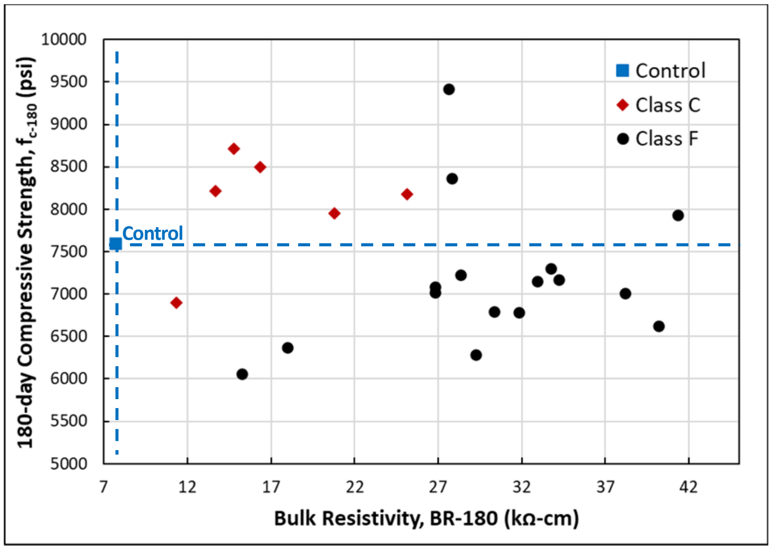
Correlation of Concrete Compressive Strength and Bulk Resistivity (180 Day)

30% Fly Ash Replacement of Type I/II Cement (w/cm = 0.45)

As curing time is increased, strength and especially the bulk resistivity for all ashes increase



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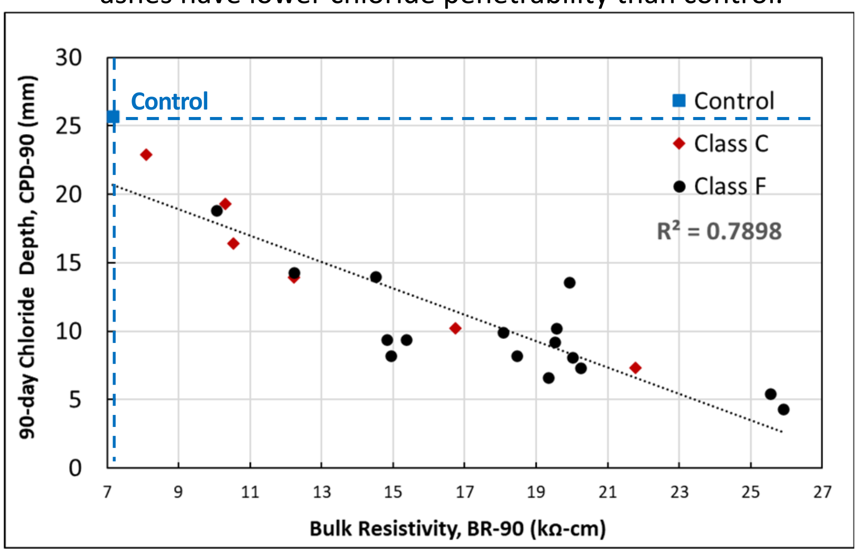
Correlation of Concrete Permeability and Bulk Resistivity (90 Day)

ASTM C1202, 30% Fly Ash Replacement of Type I/II Cement (w/cm = 0.45)

Concrete chloride penetrability is strongly correlated to bulk resistivity for all ashes. All ashes have lower chloride penetrability than control.



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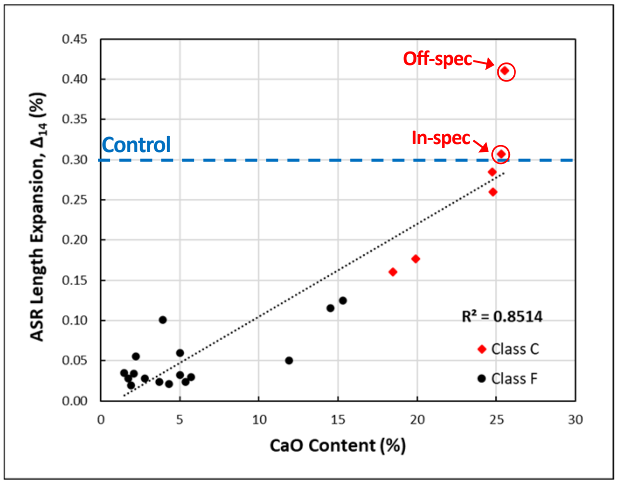
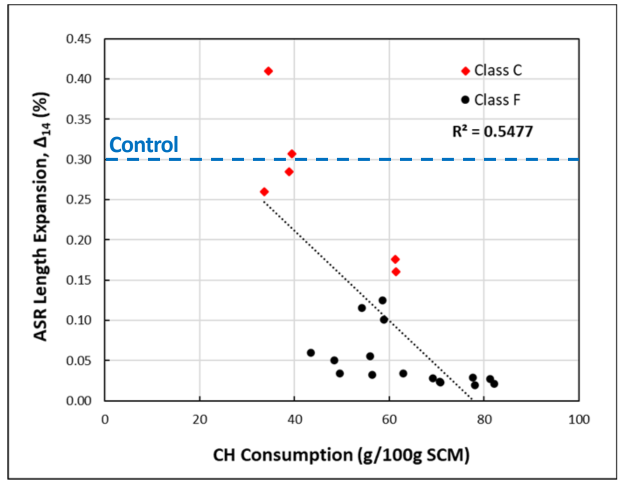
ASR Expansion (ASTM C1567)

30% Fly Ash Replacement of Type I/II Cement (Na_2O_{eq} = 0.5%)

ASR expansion was strongly correlated with CaO content, like relationships that have been established for standard fly ashes. Compared to control, expansion was reduced for most of the ashes.



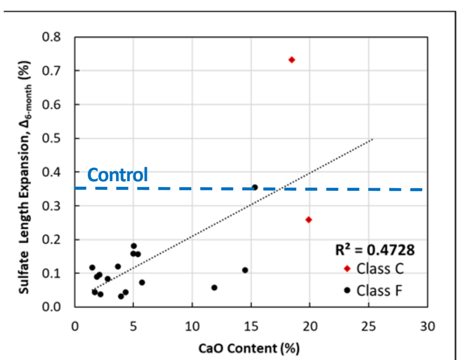


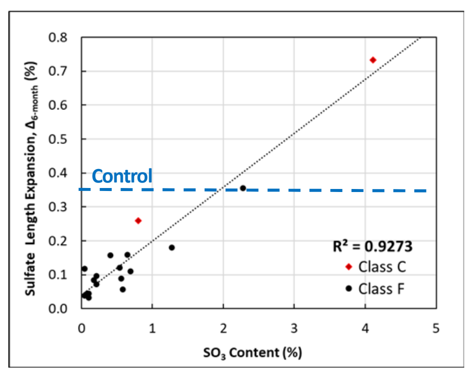
Measured by Modified R3 Method

Sulfate Attack (ASTM C1012)

30% Fly Ash Replacement of Type I/II Cement (C_3A = 6%)

Sulfate attack expansion was also significantly reduced for most ashes compared to the control. Ashes with high CaO and SO_3 contents did not perform well for both standard and unconventional ashes.





Outliers/Failed	Description	CaO (%)	C_3A (%)	SO_3 Content (%)	Sulfate Phases (XRD)
C	CFB ash (out of spec)	18.5	3%	4.1	Anhydrite (11%)
E	Class C (in spec)	25.3	8%	2.8	Anhydrite (3.2%)
G	High SO_3 (out of spec)	25.6	3%	17.5	Gypsum (2%), Bassanite (6%), Arcanite (1%)
H	Class C (in spec)	24.8	11%	2.1	Anhydrite (2%)
J	Cyclone Collector Ash (in spec)	15.3	0%	2.3	Anhydrite (5%)
K	Surfactant Treated (in spec)	24.8	7%	2.1	Anhydrite (2%)

Summary

- Many marginal and unconventional ashes will be able to be used in concrete. Standards should be updated to allow them.
- A modified bulk resistivity test would be a better indicator of reactivity compared to the standard SAI for these ashes.
- For durability, these fly ashes must be carefully used by assessing performance.
- Further analysis needs to be conducted on data with final report being released next year.

Acknowledgements

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 10-104

Contributing Fly Ash Producers

Thank you!
Questions?

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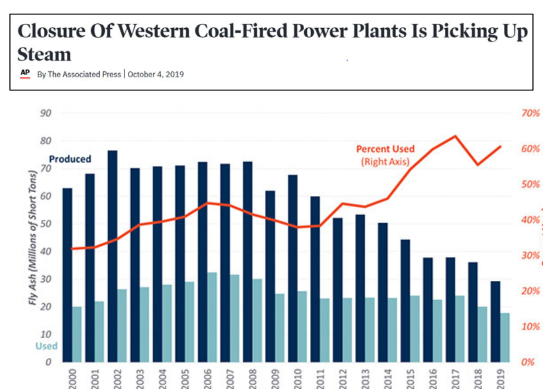
Project Need

NCHRP 10-104: *Recommendations for Revision of AASHTO M295 Standard Specification to Include Marginal and Unconventional Source Coal Fly Ashes*

- Reducing production of specification-meeting fly ash – consumption constant or increasing
- Solutions rapidly needed – Use of "alternative" fly ashes
- Definitions
  - Alternative fly ash: Marginal, unconventional source, or beneficiated
  - *Marginal source*: Lower quality fly ash (produced due to changes in manufacturing processes)
  - *Unconventional source (Reclaimed, Harvested)*: Ponded and landfilled fly ashes, and other types
  - *Off-specification*: Any fly ash that does not meet specs
- *Beneficiated*: Marginal and unconventional fly ashes treated to meet specs

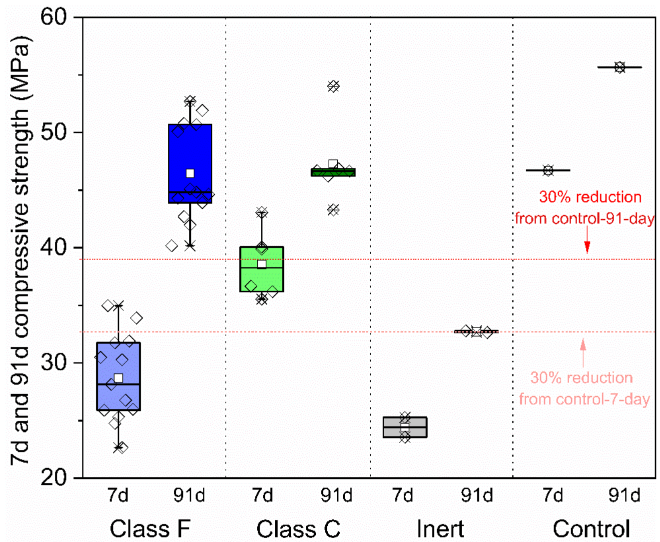


Source: ACAA

Somewhat confusing

Need for standardization

Compressive Strength of Paste Samples at 7- and 91-days



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Reference: Wang, Y., Burris, L., Hooton, R. D., Shearer, C., & Suraneni, P. (2021). Effects of unconventional fly ashes on cementitious paste properties. *Cement and Concrete Composites*, 104291.