ECOMATERIAL TECHNOLOGIES

Characterization, Reactivity, and Performance of Ground Bottom Ash and Fly Ash from the Same Sources in Cementitious Systems

Cole Spencer

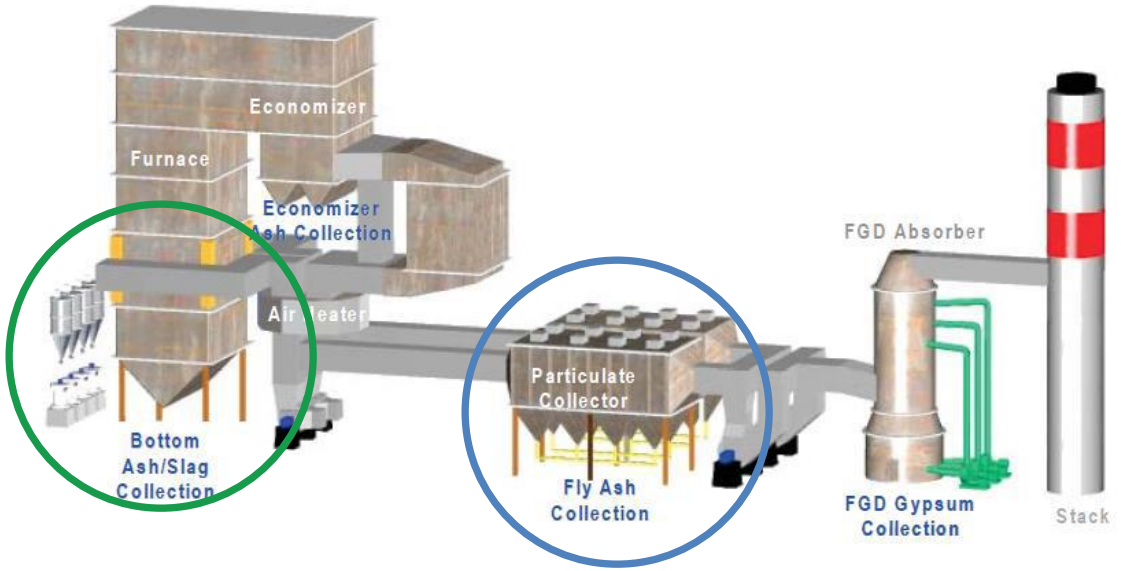
cole.spencer@ecomaterial.com

Material Information

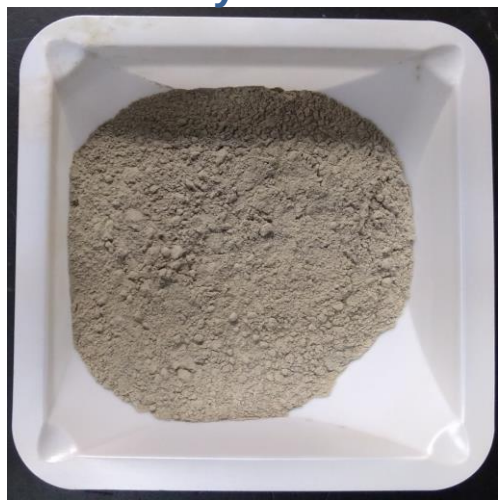
- Bottom Ash and Fly Ash
- Ash Sample Selection and Collection

Bottom Ash and Fly Ash

Bottom Ash



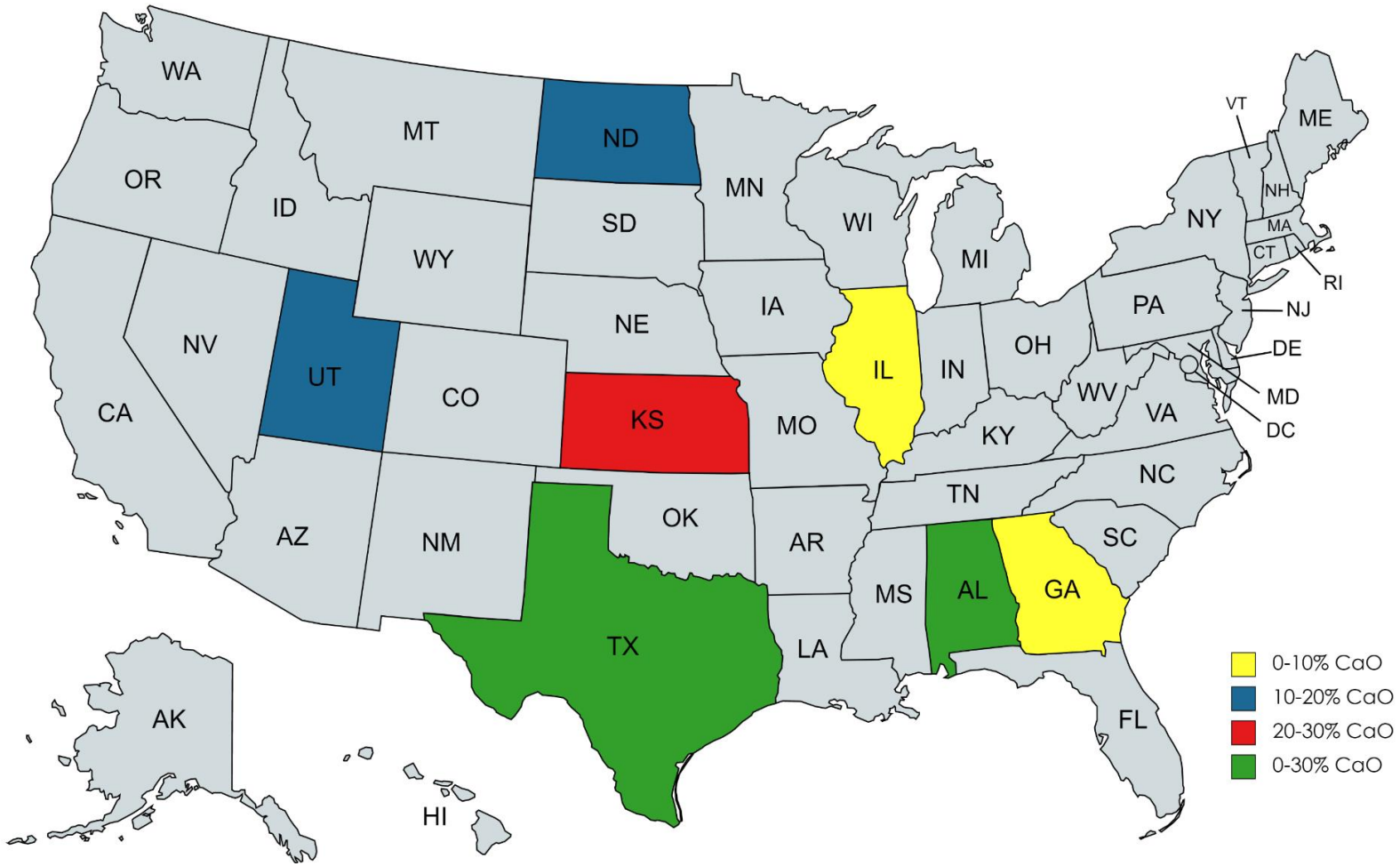
Fly Ash



Challenges and Questions

1. How can bottom ash be made into a useable SCM?
2. Is bottom ash a reactive material in cementitious systems?
3. Does bottom ash behave and react in the same way as fly ash?

Ash Sample and Collection



- Bottom Ash and Fly Ash were sourced from 9 different power generating facilities
- Sources were selected to ensure a wide range of calcium content was represented

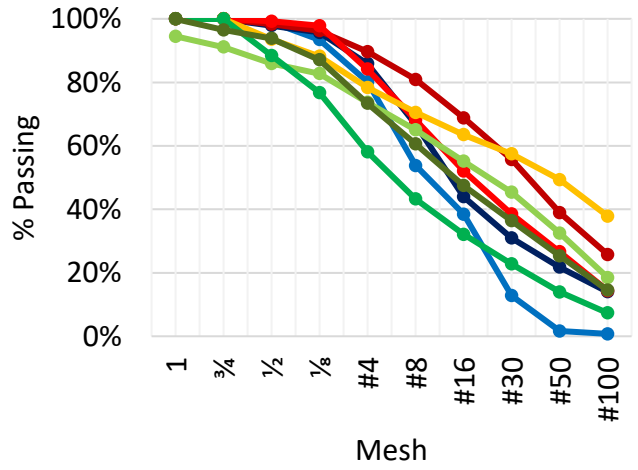
Material Characterization

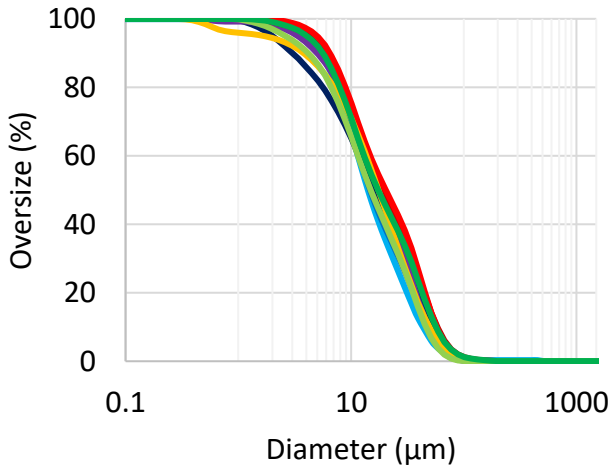
- Physical Characterization
- Chemical Characterization
- ASTM C618 Characterization

Physical Characterization - Processing

Processed via ball mill

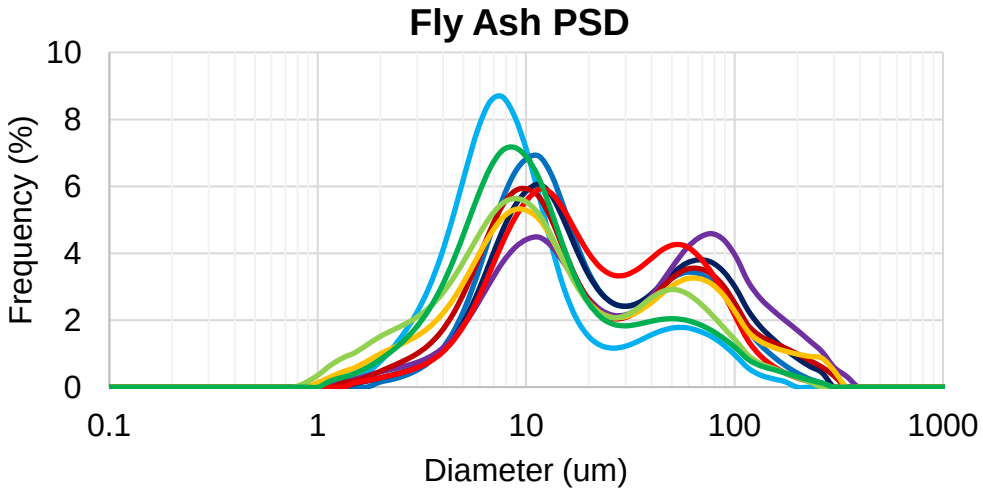
Milled to ASTM C311 Fineness of 10 +/- 1%

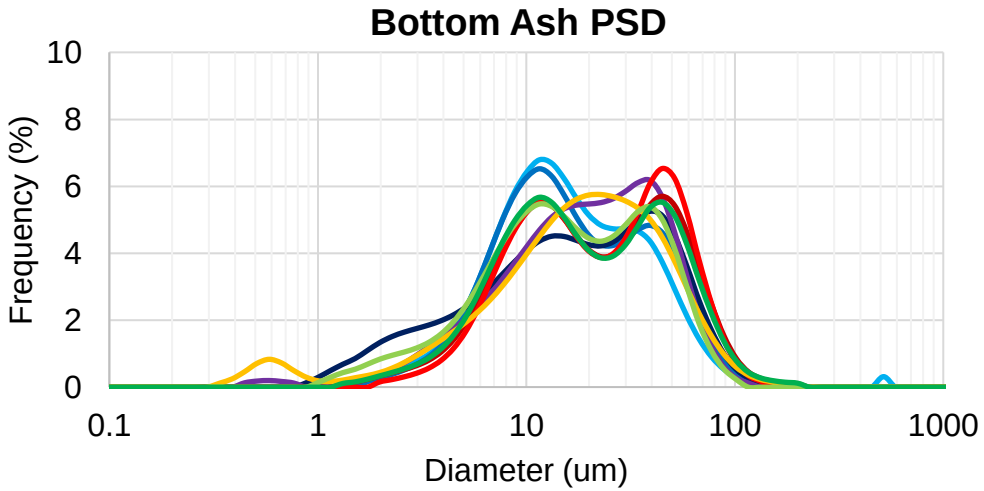


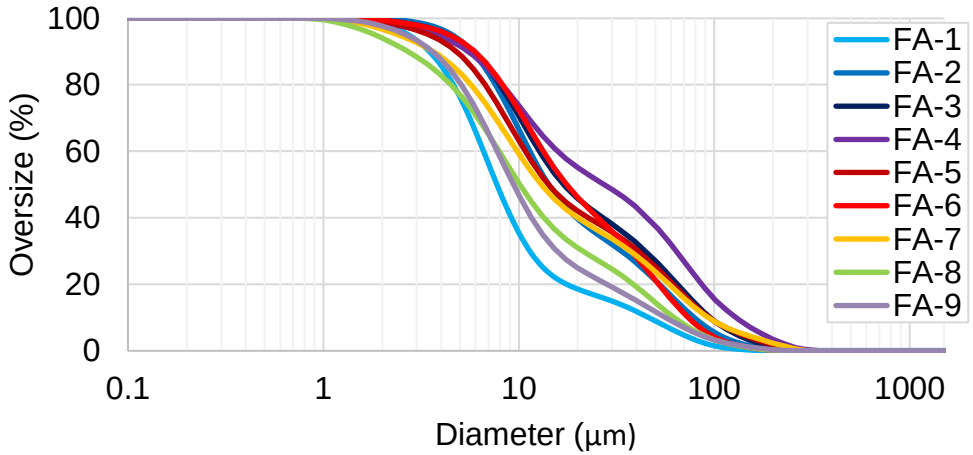


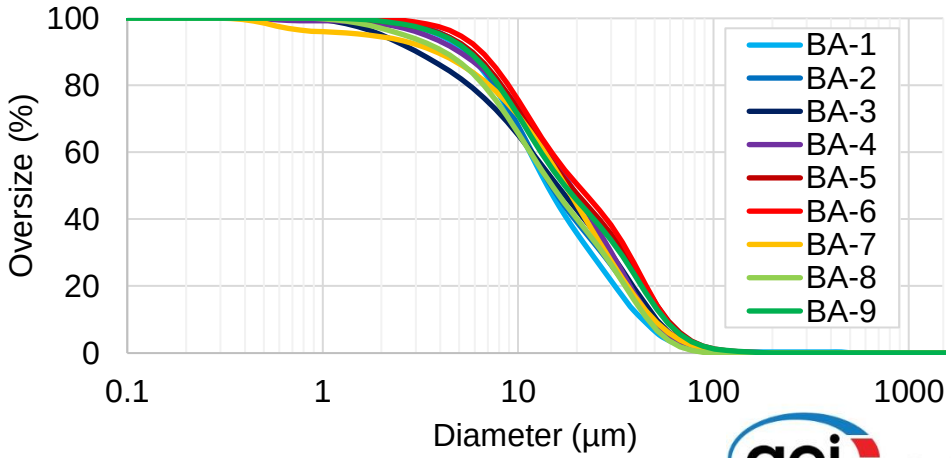
globalgilson.com

Physical Characterization – Particle Size Distribution





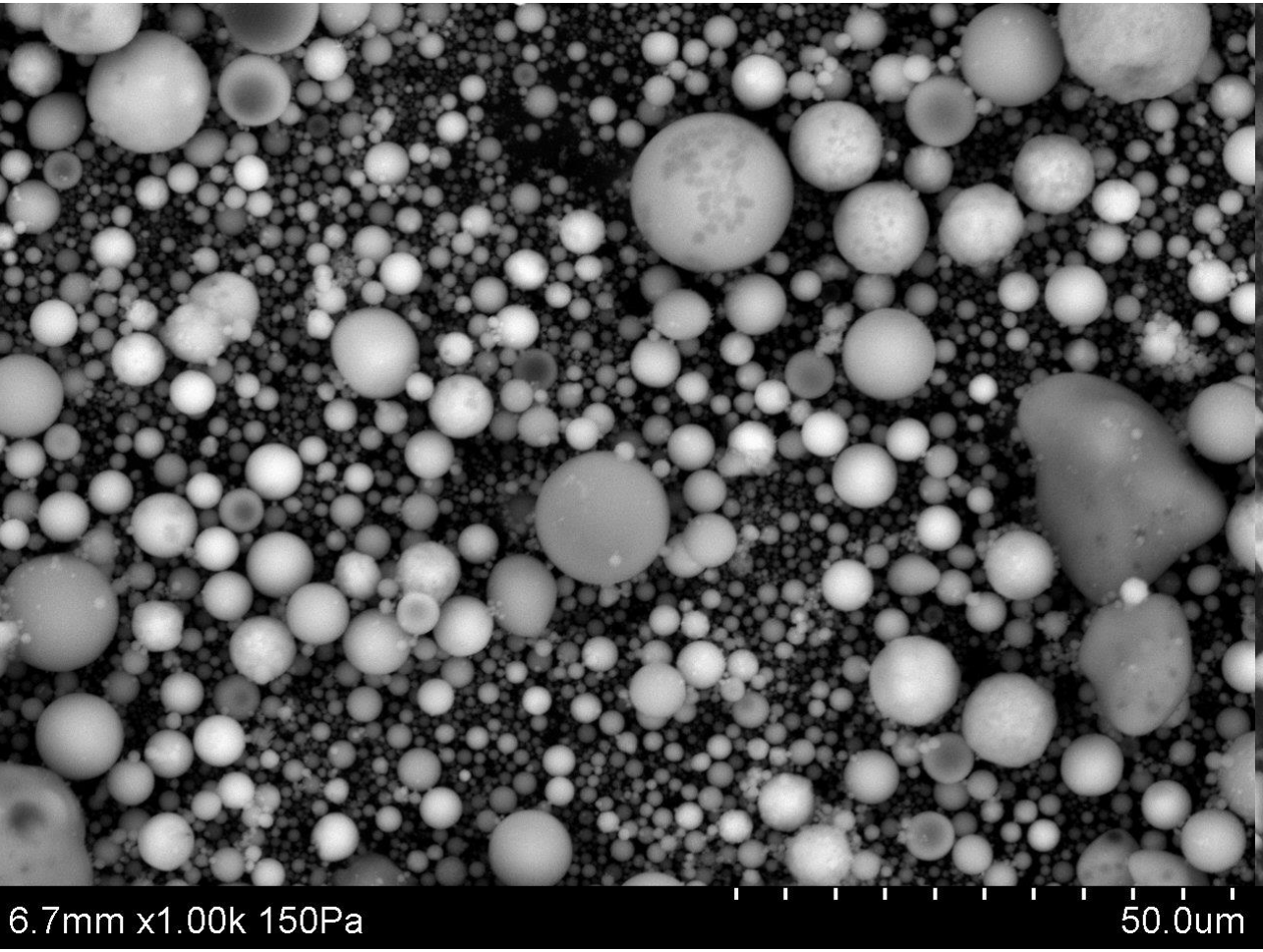




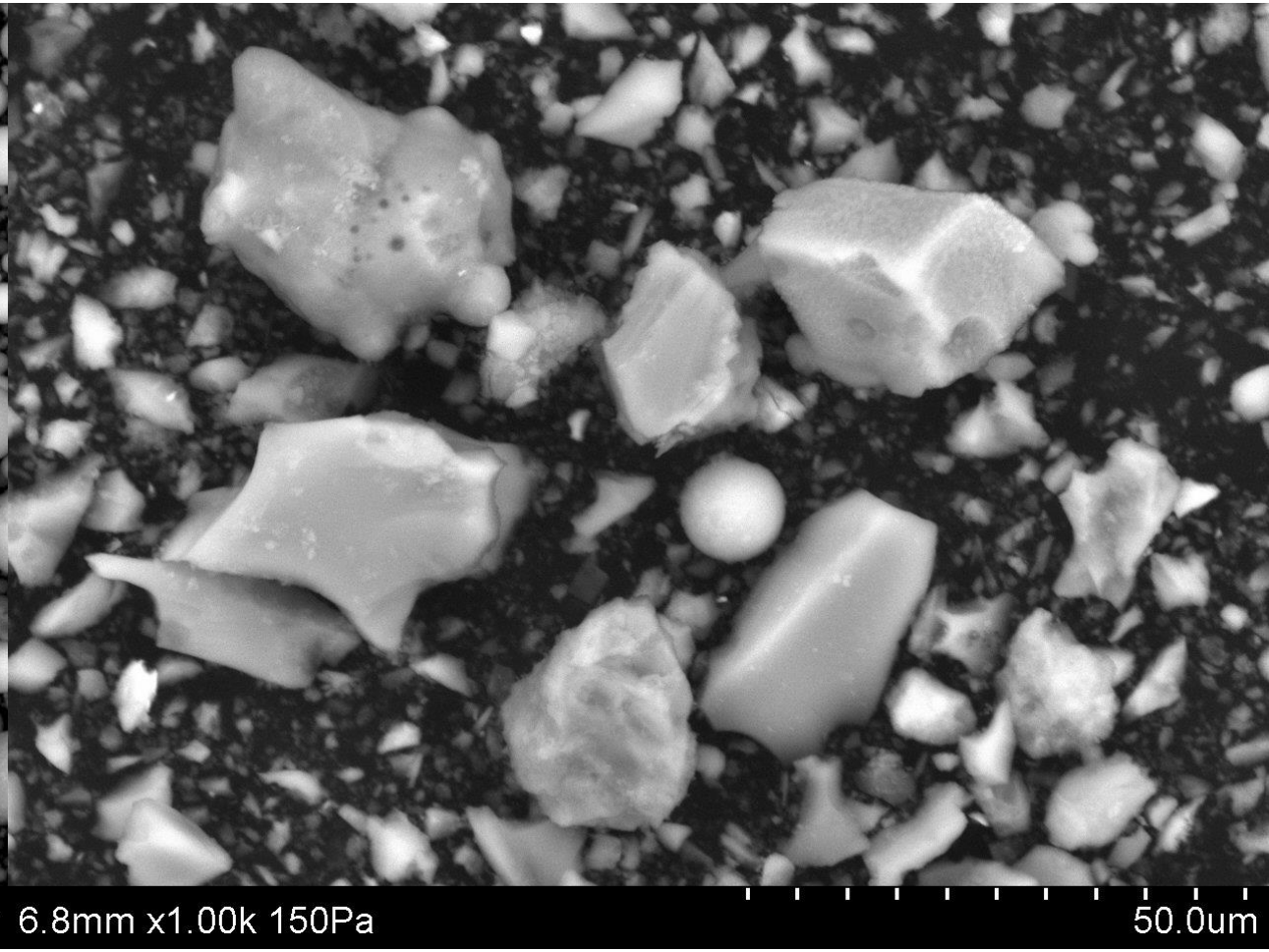
- Prescribed fineness for Bottom Ash creates similar PSDs between samples
- Fly Ash naturally has wide range in PSD

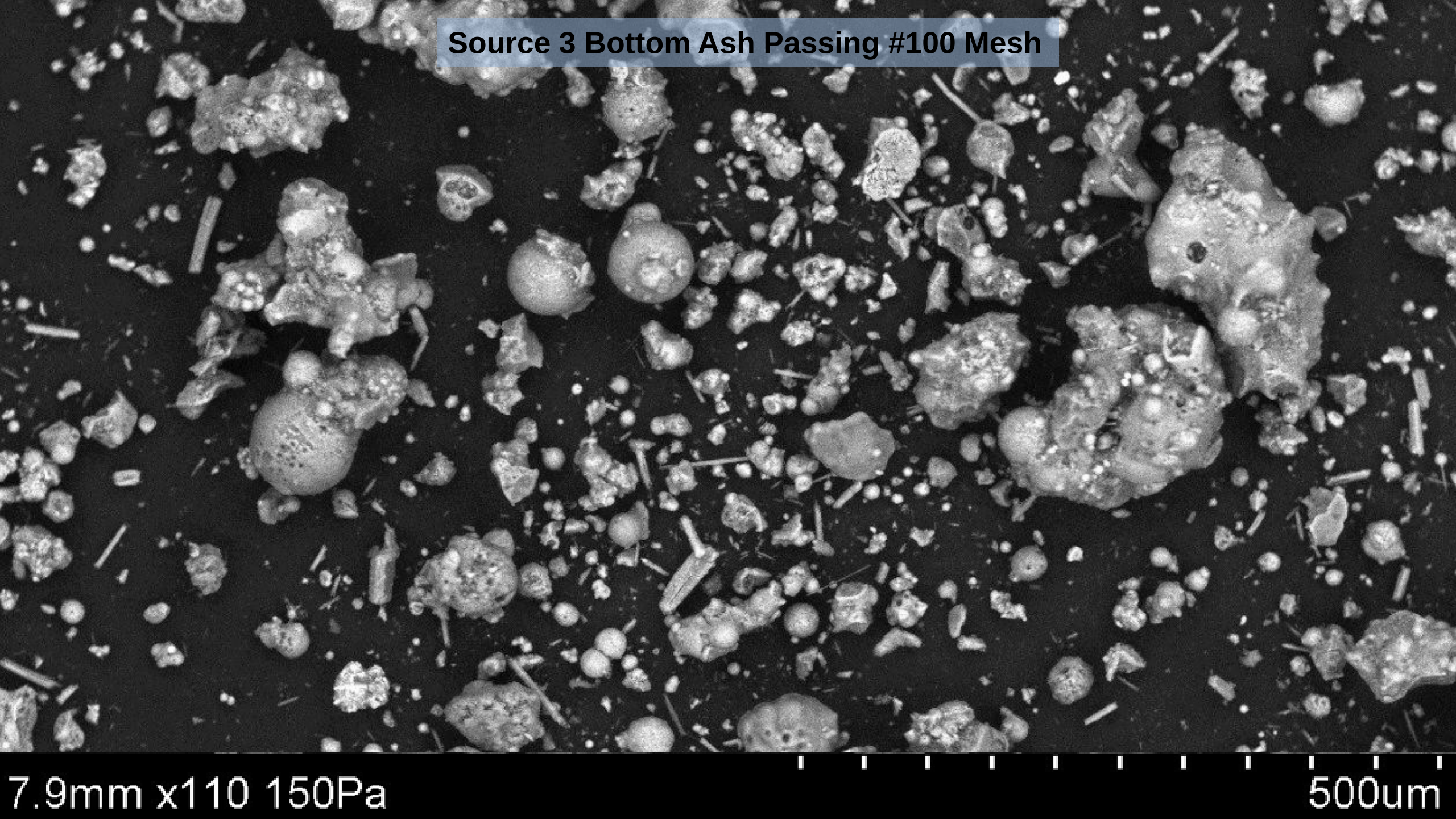
Physical Characterization – Morphology

Fly Ash from Source 3



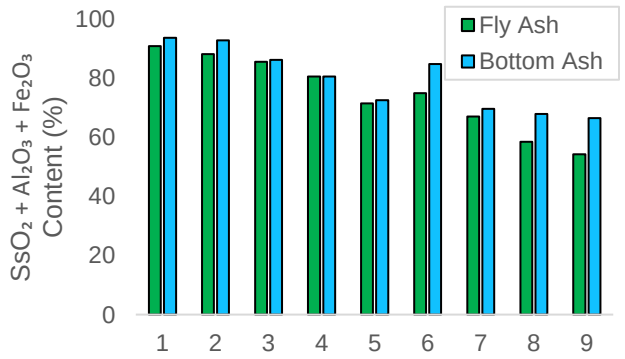
Pulverized Bottom Ash from Source 3

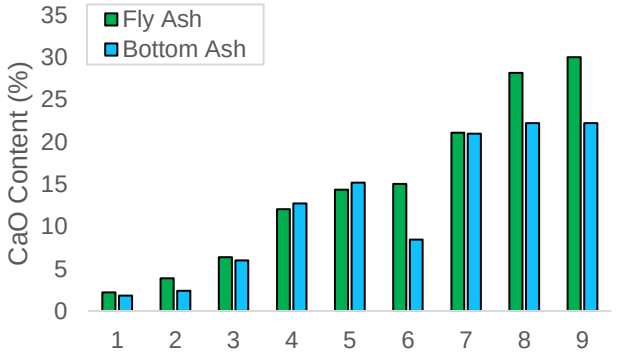


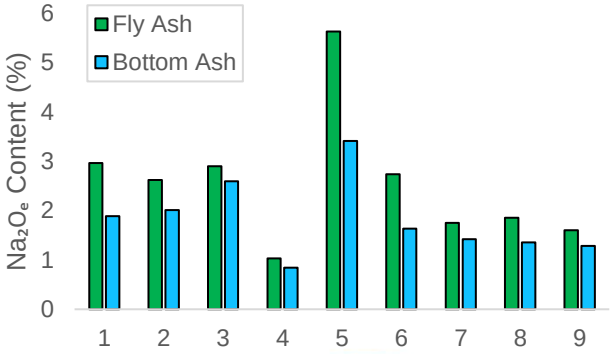

Source 3 Bottom Ash Passing #100 Mesh
7.9mm x110 150Pa
500um

Chemical Characterization – Bulk Oxide Composition (XRF)

	FA-1	BA-1	FA-2	BA-2	FA-3	BA-3	FA-4	BA-4	FA-5	BA-5	FA-6	BA-6	FA-7	BA-7	FA-8	BA-8	FA-9	BA-9	BA Generally Higher or Lower?
SiO_2	63.2	69.8	49.5	47.4	55.5	53.1	56.0	57.4	50.2	51.5	57.2	67.1	39.8	44.6	34.9	44.1	31.8	40.5	Higher
Al_2O_3	21.6	16.6	21.6	20.3	18.6	17.5	20.0	17.2	15.3	14.4	13.2	13.9	20.9	18.4	17.6	16.7	17.6	15.9	Lower
Fe_2O_3	6.0	7.2	16.9	25.0	11.3	15.4	4.4	5.8	6.0	6.6	4.5	3.7	6.2	6.6	5.9	7.0	4.8	10.0	Higher
Sum	90.7	93.5	88.0	92.7	85.4	86.1	80.5	80.4	71.4	72.5	74.9	84.6	66.9	69.5	58.4	67.8	54.2	66.4	Higher
SO_3	0.3	0.1	1.5	0.1	1.0	1.0	0.6	1.5	0.8	1.3	1.5	0.7	1.5	0.4	2.0	0.6	2.4	0.7	Inconclusive
CaO	2.2	1.8	3.9	2.4	6.4	6.0	12.0	12.7	14.4	15.2	15.0	8.5	21.1	21.0	28.1	22.2	30.0	22.2	Lower
Na_2O	1.5	0.9	1.0	0.7	1.2	1.0	0.4	0.3	4.2	2.2	2.1	1.0	1.3	1.1	1.6	1.1	1.4	1.1	Lower
MgO	1.4	1.0	1.2	0.9	1.4	1.4	2.5	2.4	4.5	4.9	3.7	2.7	4.5	4.1	6.0	4.5	7.6	6.1	Lower
K_2O	2.2	1.5	2.5	2.0	2.6	2.4	1.0	0.9	2.2	1.8	0.9	1.0	0.6	0.5	0.5	0.4	0.3	0.3	Lower
P_2O_5	0.1	0.1	0.2	0.1	0.5	0.6	0.1	0.1	0.1	0.2	0.2	0.2	1.1	0.8	0.9	0.7	0.9	0.5	Inconclusive
TiO_2	1.0	0.8	1.1	1.0	0.9	0.9	1.3	1.3	0.7	0.7	0.9	0.7	1.5	1.4	1.3	1.4	1.3	1.3	Inconclusive
SrO	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.1	0.1	0.3	0.3	0.4	0.4	0.5	0.4	Inconclusive
BaO	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.6	0.4	0.1	0.1	0.6	0.5	0.6	0.5	0.7	0.5	Inconclusive
Na_2O_e	3.0	1.9	2.6	2.0	2.9	2.6	1.0	0.8	5.6	3.4	2.7	1.6	1.7	1.4	1.9	1.4	1.6	1.3	Lower







Material Characterization – Fly Ash

ASTM C618 – Requirements for Coal Fly Ash

	ASTM C618 Chemical Requirements					ASTM C618 Physical Requirements				
Measurement	$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	CaO (%)	SO_3 (%)	Moisture (%)	LOI (%)	Fineness (% ret. #325)	7 Day SAI (% of Control)	28 Day SAI (% of Control)	Water Reqt. (% of Control)	Specific Gravity
Class F Ash ASTM Limit	50.0	18.0	5.0	3.0	6.0	34	75	75	105	-
FA-1	90.7	2.2	0.3	0.1	0.4	14	103	104	95	2.37
FA-2	88.0	3.9	1.5	3.0	3.1	29	87	81	100	2.41
FA-3	85.4	6.4	1.0	0.0	0.5	26	88	78	95	2.40
FA-4	80.5	12.0	0.6	0.0	0.0	26	86	84	96	2.56
FA-5	71.4	14.4	0.8	0.0	0.0	26	85	87	94	2.56
FA-6	74.9	15.0	1.5	0.0	0.4	17	88	84	95	2.53
FA-7	66.9	21.1	1.5	0.1	0.5	22	106	114	96	2.61
FA-8	58.4	28.1	2.0	0.0	0.1	11	113	108	94	2.79
FA-9	54.2	30.0	2.4	0.0	0.6	10	122	113	97	2.82

- All samples acquired for testing pass ASTM C618, and are representative of ashes currently sold in the market

Material Characterization – Bottom Ash

ASTM C618 – Requirements for Coal Fly Ash

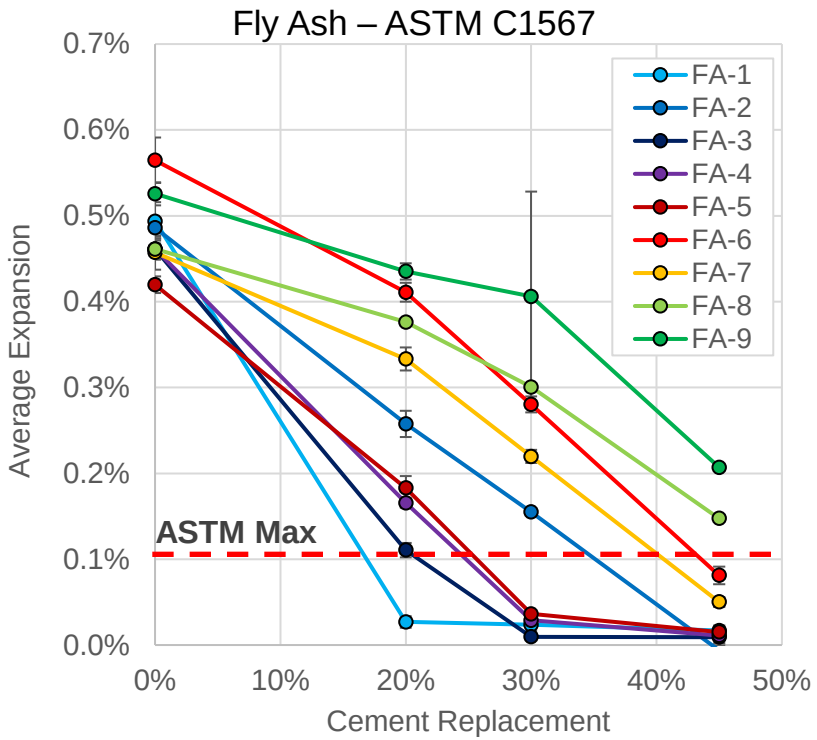
	ASTM C618 Chemical Requirements					ASTM C618 Physical Requirements				
Measurement	**$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)**	**CaO (%)**	**SO_3 (%)**	**Moisture (%)**	**LOI (%)**	**Fineness** (% ret. #325)	**7 Day SAI** (% of Control)	**28 Day SAI** (% of Control)	**Water Reqt. (% of Control)**	**Specific** Gravity
Class F Ash ASTM Limit	50.0	18.0	5.0	3.0	6.0	34	75	75	105	-
BA-1	93.5	1.8	0.1	0.1	0.2	11	81	74	101	2.67
BA-2	92.7	2.4	0.1	0.1	0.4	9	78	76	100	2.94
BA-3	86.1	6.0	1.0	0.4	0.2	9	77	82	99	2.80
BA-4	80.4	12.7	1.5	0.5	0.8	11	76	81	99	2.75
BA-5	72.5	15.2	1.3	1.2	13.6	10	84	89	98	2.50
BA-6	84.6	8.5	0.7	0.3	10.5	10	87	82	100	2.49
BA-7	69.5	21.0	0.4	0.0	0.1	10	90	84	98	2.94
BA-8	67.8	22.2	0.6	0.4	1.8	11	81	78	100	2.88
BA-9	66.4	22.2	0.7	0.0	3.5	11	88	87	100	-

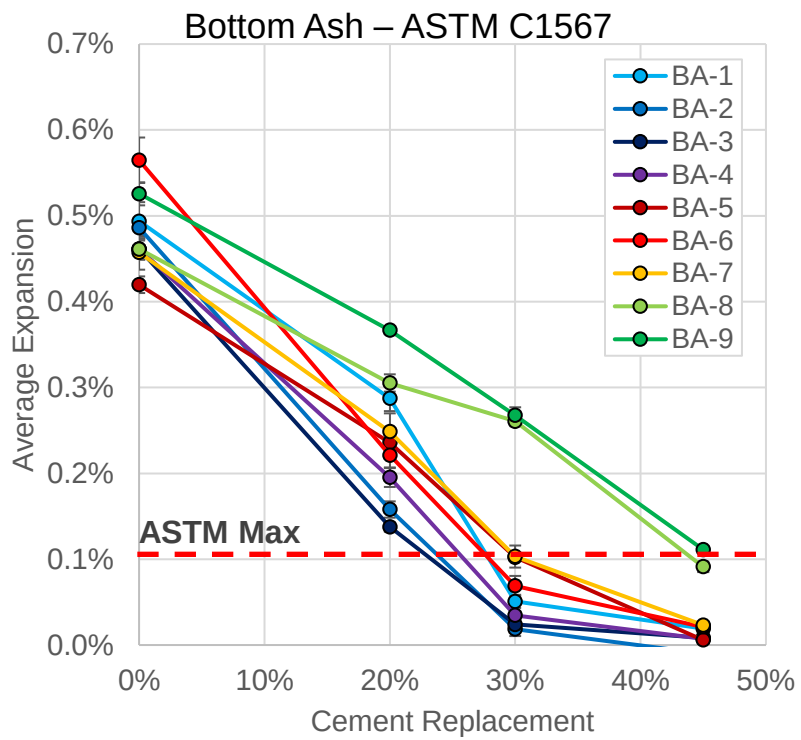
- Materials tested do not all cleanly pass ASTM C618
- SAI results of bottom ashes are less obviously influenced by parameters measured by ASTM C618

Material Performance

- Alkali-Silica Reaction Mitigation via ASTM C1567
- Concrete – Compressive Strength and Resistivity

Alkali-Silica Reaction Mitigation via ASTM C1567





How does Bottom Ash Compare to Fly Ash?			
Source	20% Rep.	30% Rep.	45% Rep.
1 – Class F	-	-	-
2 – Class F	**Better**	**Better**	**Better**
3 – Class F	-	-	**Better**
4 – Class F	-	-	**Better**
5 – Class F	-	-	**Better**
6 – Class F	**Better**	**Better**	**Better**
7 – Class C	**Better**	**Better**	**Better**
8 – Class C	**Better**	**Better**	**Better**
9 – Class C	**Better**	**Better**	**Better**

1. Bottom ash, when properly processed, can mitigate ASR more effectively than fly ash from the same source
2. Fly ash performance is more varied – likely due to differences in particle size
3. The ASR mitigation performance of processed bottom ash is, on the whole, similar to that of fly ash

Concrete – Ash Selection

- 3 Ashes were chosen for concrete based on CaO content of the Fly Ash
- Concrete cylinders were set for compressive strength and resistivity via Wenner Probe

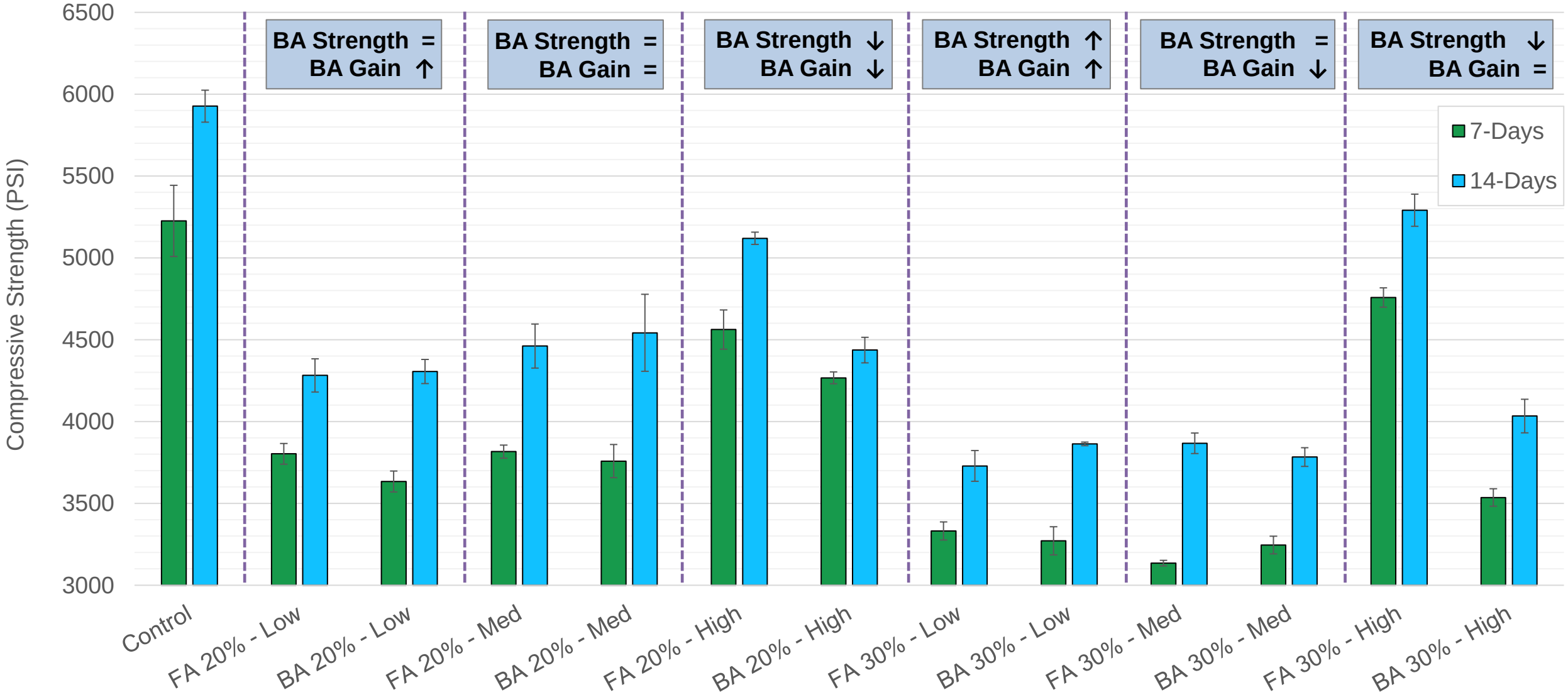
	Source	Label	CaO Content (%)	Fineness (%)	7-Day SAI (%)	28-Day SAI (%)
Fly Ash	Source 3	Low CaO	6.35	26.32	88	77.6
	Source 6	Mid CaO	15.01	16.58	88.1	83.9
	Source 8	High CaO	28.14	10.66	113.3	108
Bottom Ash	Source 3	Low CaO	5.98	9.49	77.4	82
	Source 6	Mid CaO	8.45	9.9	86.9	81.7
	Source 8	High CaO	22.21	10.7	80.5	78.2

Concrete Mix Design

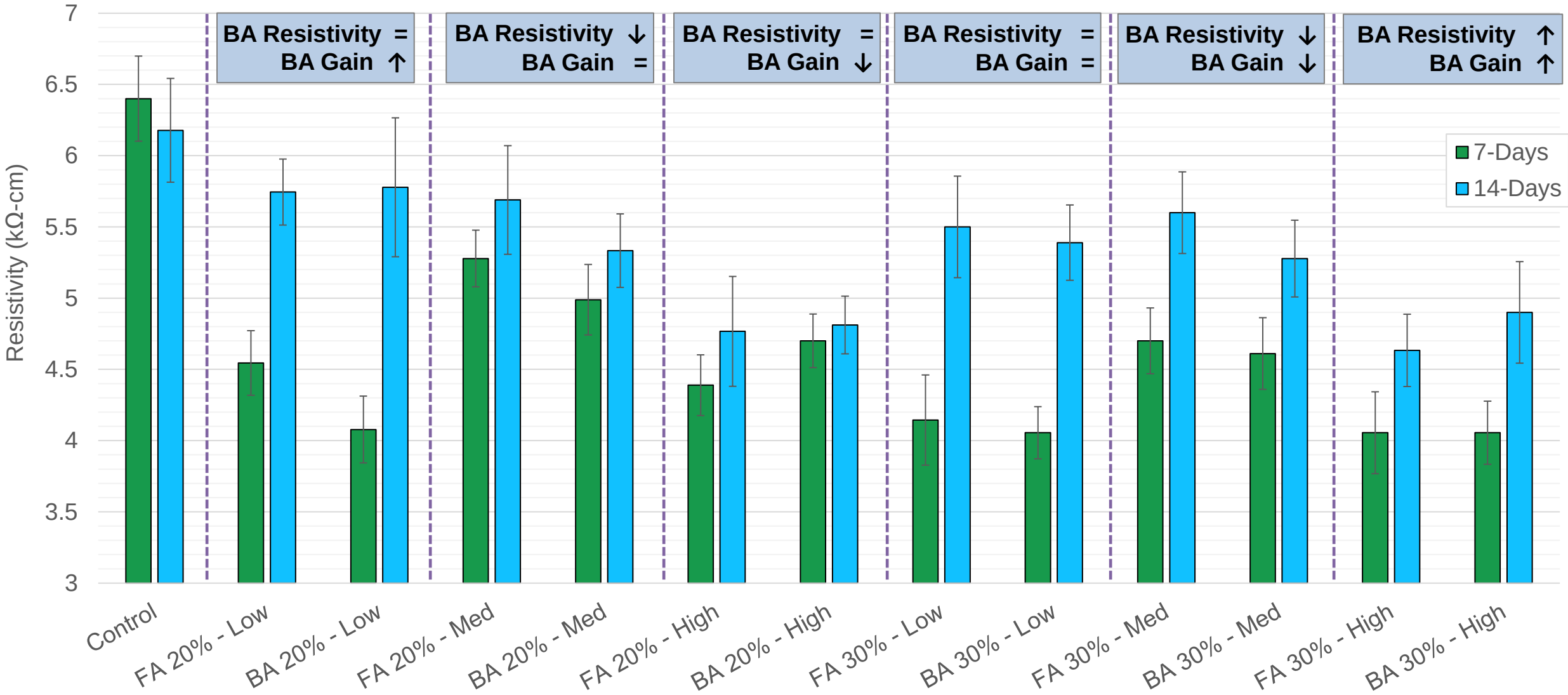
	GDoT Class A	Control	Fly Ash - Low CaO (20% / 30%)	Fly Ash - Mid CaO (20% / 30%)	Fly Ash - High CaO (20% / 30%)	Bottom Ash - Low CaO (20% / 30%)	Bottom Ash - Mid CaO (20% / 30%)	Bottom Ash - High CaO (20% / 30%)
Cement (lbs)	611 min	620	496 / 434	496 / 434	496 / 434	496 / 434	496 / 434	496 / 434
Ash (lbs)		-	124 / 186	124 / 186	124 / 186	124 / 186	124 / 186	124 / 186
Water Content (lbs)	-	304	304	304	304	304	304	304
W/C Ratio	0.49 max	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Coarse Agg (#57 stone lbs)	56, 57, 67 stone	1741	1741	1741	1741	1741	1741	1741
Fine Agg	-	1433	1399 / 1382	1406 / 1393	1419 / 1412	1420 / 1413	1405 / 1390	1423 / 1418
Water Reducer (oz/cwt)	-	10.5	5.9 / 5.0	6.7 / 5.9	5.9 / 5.1	6.7 / 6.7	8.4 / 8.8	7.6 / 6.7
Slump (inches)	2 - 4	4	3.25 / 2.25	3.5 / 2.25	3.25 / 3.25	3.5 / 2.75	3 / 2.25	4 / 2.5
Air Content (%)	6 max	1.6	1.6 / 2.0	2.0 / 2.3	1.6 / 1.9	1.9 / 1.9	1.7 / 1.8	1.4 / 1.6

- Concrete mix was designed to satisfy Georgia DoT's Class A General Use Concrete
- Bottom ash imparted a water reducing effect, although less so than fly ash

Concrete Performance – Compressive Strength



Concrete Performance - Resistivity



Conclusions and Future Work

Conclusions

1. Ground bottom ash is a reactive material that is suitable for use as a supplementary cementitious material when properly processed
2. The performance of bottom ash and fly ash is of a similar enough range as to not cause concern over potential blending or comingling

Future Work

1. Later age concrete data
2. Additional testing to better understand the role of calcium oxide in bottom ash
3. Investigation into the relationship between grinding/processing and performance

Thank You