Boral Resources

Fly Ash Utilization, Applications & Supply Logistics

www.flyash.com

BORAL RESOURCES

Boral / Lab Introduction

Ash Definitions & Durability

Concrete Performance & Durability

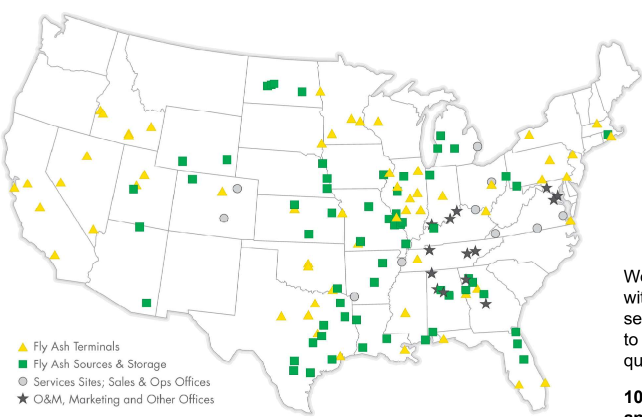
Micron 3 UFFA

CLSM (Controlled Low Strength Material)

Supply Update & Alternate SCM

National Footprint

BORAL RESOURCES



We partner with utilities to service their needs and to supply customers with quality products.

105 power plant sources and service in 45 states

Material Testing and Research Facility

Boral's Central Laboratory

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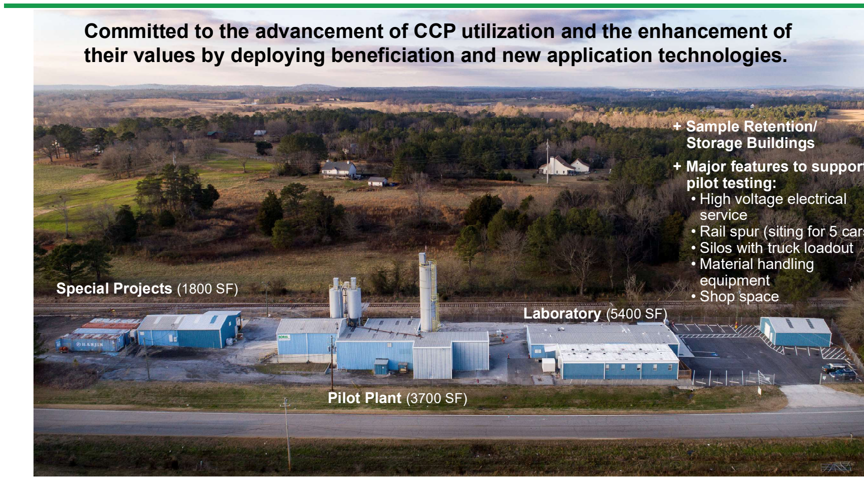

Boral's Central Laboratory

MTRF is a CCRL Inspected & AASHTO R18 Approved Laboratory

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QUALITY ASSURANCE, TECHNICAL SERVICES AND R&D

Advanced Material Science Testing

- X-ray fluorescence
- X-ray diffraction
- SEM Scanning Electron Microscope (EDAX)
- Atomic adsorption
- Thermo-gravimetric analyzer
- Pore size/surface area analyzer
- Particle size analyzer
- Calorimetry
- Carbon + sulfur analyzer
- Petrography
- Microscopy

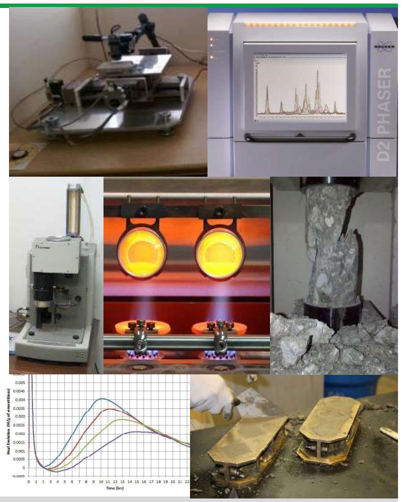
Strength and Durability of Materials

ASTM C-441, ASTM C-1567, ASTM C-1293, ASTM C-1012, ASTM C-192

- Compression machines
- Full ASR capabilities
- Chemical resistance
- Freeze/thaw, etc.

Mineral Processing Capabilities

- Pan + mixer pelletizers
- Milling + classification



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Ash Definition & Characteristics

General Description of Coal Fired Power Plant

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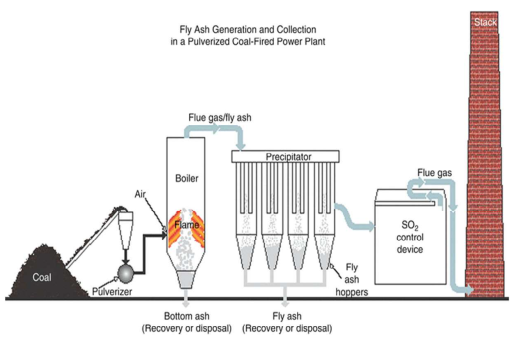
- A pulverizer grinds coal into fine powder
- Coal mixes with hot air and the mixture moves to the furnace
- Burning coal heats water in a boiler, creating steam
- Steam released from the boiler powers the turbine, transforming heat energy into mechanical energy that spins the turbine engine
- The turbine powers the generator turning mechanical energy into electric energy. This happens when magnets inside of a copper coil spin.
- Condensers cool the steam that converts back to water
- The water is returned to the boiler and the cycle begins again



What is a Pozzolan (Fly Ash)

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pozzolan, *n*—a finely-divided siliceous or siliceous and aluminous material that will not react chemically with water, but will react with calcium hydroxide and water at ordinary temperatures to form compounds possessing cementitious properties.

DISCUSSION—Some supplementary cementitious materials are weak hydraulic cements but their cementitious properties are enhanced in the presences of calcium hydroxide and water. Such materials possess the characteristics of a hydraulic cement and a pozzolan.

What makes Fly Ash Work?
Pozzolanic Reaction

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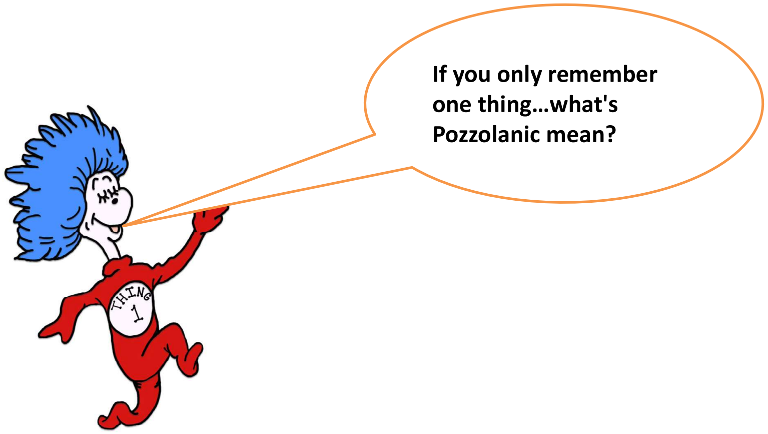

Why should Fly Ash be used?
Pozzolanic Reaction

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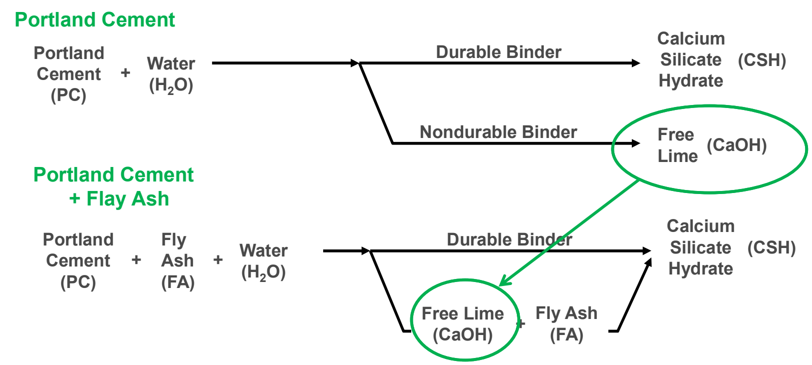
Through Pozzolanic Activity, Fly Ash combines with Free Lime to Produce the Same Cementitious Compounds Formed by the Hydration of Portland Cement



C-618 Results
Class F Ash

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	SiO_2+ Al_2O_3+ Fe_2O3	SO_3 %	Available Alkali %	Moisture Content %	LOI %	Fineness %	Density gm/cm³	SAI 7 d %	SAI 28 d %	Water Req' %	Foam Index*
Sample F Ash	85.3	0.9	0.9	0.03	0.7	16.9	2.46	87	99	97	4
ASTM C618 Class F	70% min	5% max	**	3% max	6% max	34% max	**	75% min	75% min	105% max	HW SOP
Pending Designation	<>18% CaO										

*Foam Index Conducted with Boral SOP 40g ash / 200 g water / MBVR concentrate
** No specification under ASTM C-618

Particle Size Distribution
(Horiba Particle Size Analyzer)

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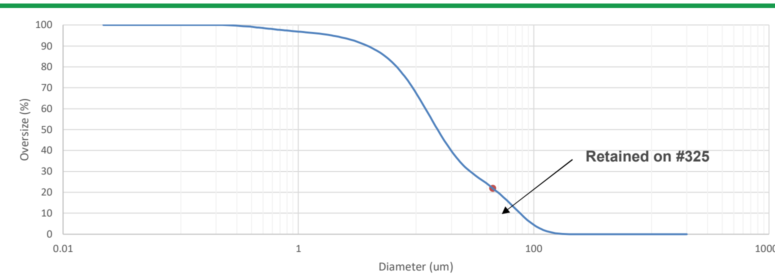

Particle Size Analysis conducted with Horiba LA 920

Color	Light Brown (Munsell)
S.P. Area	9521.4(cm2/cm3)
Median	15.2537(μm)
Mean	28.5605(μm)

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Ash in Concrete

Performance & Durability

BORAL RESOURCES

Effects of fly ash on fresh and hardened concrete

STRENGTH

ASR

By US Department of Transportation – Federal Highway Administration: Dr. P.E. Grattan-Bellew.

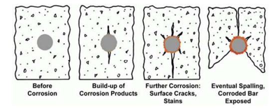
TEMPERATURE RISE

http://www.cement.org/designaids/mass-concrete

Water Demand / RHEOLOGY

https://www.galvanizeit.org

PERMEABILITY



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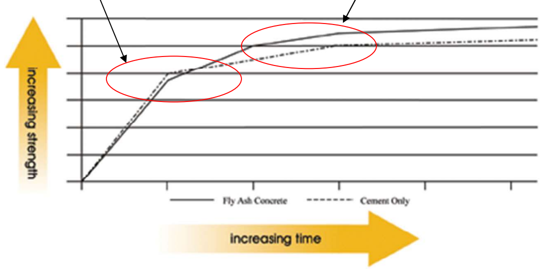
Why should Fly Ash be used?

Compressive Strength Improvement



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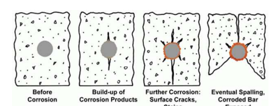

Flyash.com

Why should Fly Ash be used?
ASR Mitigation

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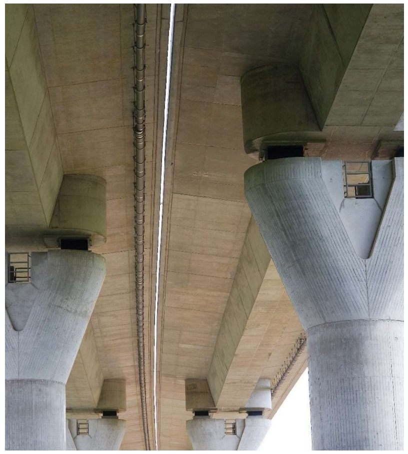
- The alkali–silica reaction (ASR), is a deleterious reaction that can cause expansion and eventually cracking in concrete.
- The reaction is between alkalis in cement paste and the reactive amorphous (*i.e.*, non crystalline) silica found in many aggregates, given sufficient moisture
- Use of pozzolan like Fly Ash provide confidence and reliability for ASR Mitigation



ASTM C441
ASR Testing (Pyrex Glass)

BORAL RESOURCES

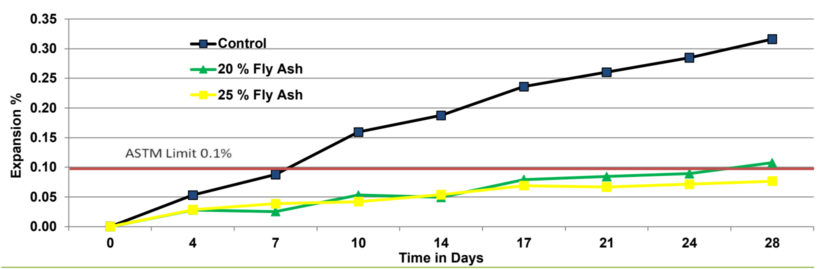
TEST DATA	Cement Control			Class F ash 20%		
Set Date						
	Bar 1	Bar 2	Bar 3	Bar 1	Bar 2	Bar 3
Initial	0.0049	0.1711	0.1516	0.0377	0.0432	0.0381
14d read	0.038	0.2026	0.1847	0.0531	0.0586	0.0548
diff.	0.0331	0.0315	0.0331	0.0154	0.0154	0.0167
Avg.		0.0326			0.0158	
% Reduction of Mortar Expansion					51.38	

The specimens were prepared in accordance with the procedures described in ASTM C441. Three mortar bars were prepared for both the control mix and the test mix using the modified proportions specified by ASTM C-441.

The specimens were cured in the moist room for 24 hours and then stored in the moist container specified in ASTM C227-10 *Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)* at 38° C ± 2° C for 14 days. Results of the testing are reported in Table above.

ASTM C-1567
Accelerated Mortar Bar (ASR)

BORAL RESOURCES



Age	Control	20 % Class F Fly Ash	25 % Class F Fly Ash
0	0.00	0.00	0.00
4	0.05	0.03	0.03
7	0.09	0.03	0.04
10	0.16	0.05	0.04
14	0.19	0.05	0.05
17	0.24	0.08	0.07
21	0.26	0.08	0.07
24	0.28	0.09	0.07
28	0.32	0.11	0.08

Control Aggregate Expansion 0.19% @ 14 days
Test mixtures at 20 and 25% replacement of cement

Effects of fly ash on fresh and hardened concrete

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STRENGTH

ASR

By US Department of Transportation – Federal Highway Administration: Dr. P.E. Grattan-Bellew.

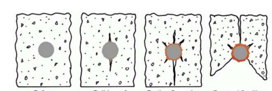
TEMPERATURE RISE

http://www.cement.org/designaids/mass-concrete

Water Demand / RHEOLOGY

https://www.galvanizeit.org

PERMEABILITY



Flyash.com

Why should Fly Ash be used?
Reduction in Heat of Hydration

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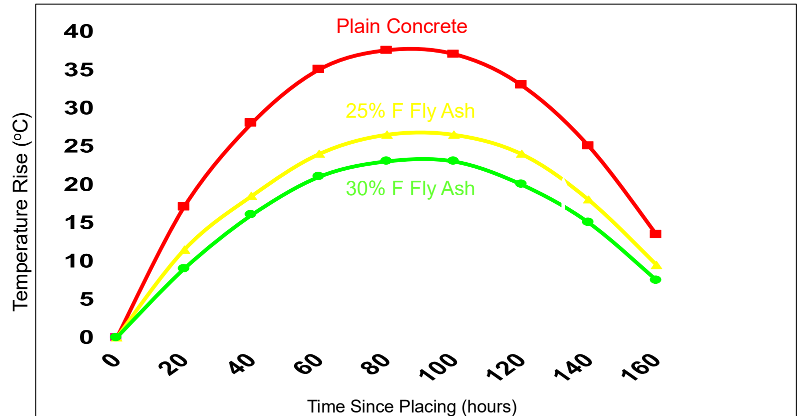

Variation of temperature with time at the center of 15 cubic meter concrete blocks(Samarin,Munn,and Ashby,1983)

Effects of fly ash on fresh and hardened concrete

BORAL RESOURCES

STRENGTH

ASR

By US Department of Transportation – Federal Highway Administration: Dr. P.E. Grattan-Bellew.

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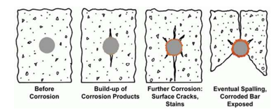
PERMEABILITY



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Why should Fly Ash be used?
Water Reduction

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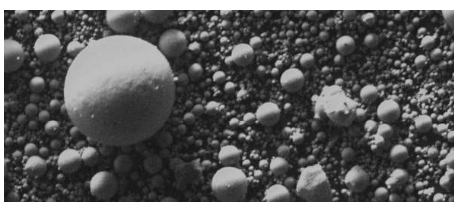
The ball bearing effect



RHEOLOGY

Flyash.com

- Fly ash reduces water demand by approx. 4% for every 10% replacement according to ACI 232
- Similar effect by C and F fly ash

Why should Fly Ash be used?
Water Reduction

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- The spherical nature of Fly Ash produces a ball bearing effect in concrete making it easier to place
- Provides slump reduction without additional water reducing admixtures
- Improves rheology for ease of pumpability and finish
- Reduction in water decreases drying shrinkage

Effects of fly ash on fresh and hardened concrete

BORAL RESOURCES

STRENGTH

ASR

By US Department of Transportation – Federal Highway Administration: Dr. P.E. Grattan-Bellew.

TEMPERATURE RISE

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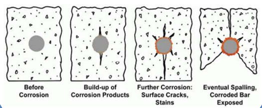
PERMEABILITY

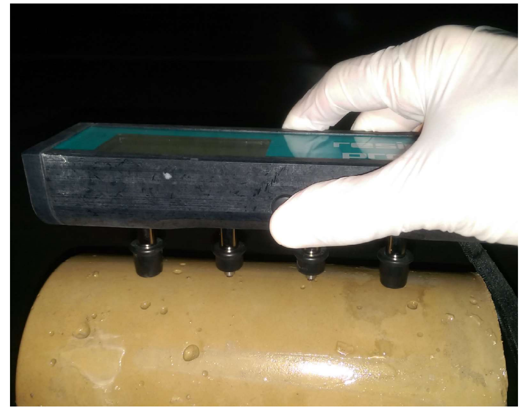


Flyash.com

Fly Ash Performance

Decreased Permeability

BORAL RESOURCES



- A resistivity probe measures the concrete's interference in the transmission of an electric field
  - Higher resistivity relates to decreased permeability
- This test is often used to estimate resistance to chloride ion penetration

ASTM C1012

Sulfate Expansion Testing

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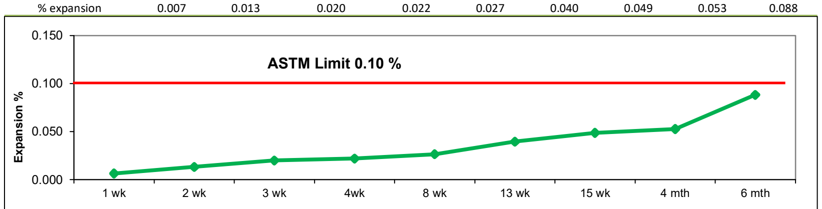
Average Expansion of Bars

Age	1 wk	2 wk	3 wk	4wk	8 wk	13 wk	15 wk	4 mth	6 mth
% expansion	0.007	0.013	0.020	0.022	0.027	0.040	0.049	0.053	0.088



Conducted at 20% replacement

The specimens were prepared in accordance with the procedures described in ASTM C1012 as modified by ASTM C311 / Procedure A. Prairie States ash was substituted for 20% of the cement. A complete chemical analysis of the fly ash is provided in Table 1.

The specimens were cured according to C1012 until the strength of the cubes reached a minimum of 2,850 psi. The specimens were then stored in sulfate solution at 72oF for six months.

BORAL RESOURCES

Kirkland Mine

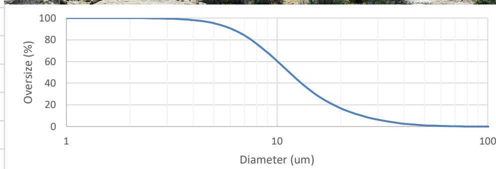
Natural Pozzolan

Kirkland Natural Pozzolan (KNP)

ASTM C618 Summary

BORAL RESOURCES

Characteristic	KNP	ASTM C618 Class N Limit
SiO_2 (%)	72 - 75	-
Al_2O_3 (%)	13 – 15	-
Fe_2O_3 (%)	1 – 3	-
Sum of Oxides (SiO_2+Al_2O_3+Fe_2O_3 %)	88 – 90	50% Min
SO_3 (%)	<1	5% Max
CaO (%)	1 – 3	-
Na_2O (%)	2 – 3	-
MgO (%)	1 – 2	-
K_2O (%)	2 – 4	-
Sodium Oxide Equivalent (Na_2O+0.658K_2O)	4 – 6	-
LOI (%)	3 – 5	10% Max
Fineness (% retained on 45 micron sieve)	<5	34% Max
7-day SAI (% of control)	85 – 95	75% Min
28-day SAI (% of control)	90 – 105	75% Min
Water Requirement (% of control)	105 -107	115% Max
Specific Gravity	2.3 – 2.5	-



Kirkland Natural Pozzolan (KNP)

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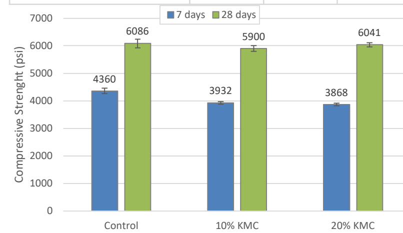
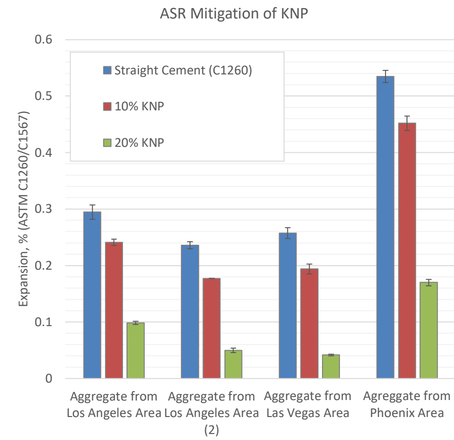
Concrete Mix Design

	Control	10% KNP	20% KNP
Cement (lb/yd³)	550	495	440
KNP (lb/yd³)	0	55	110
Fine Agg (lb/yd³)	1353	1338	1323
Coarse Agg (lb/yd³)	1809	1809	1809
Water (lb/yd³)	330	330	330
Mid-Range Water Reducer (oz/cwt)	0	2.8	6.4
Slump (in)	2.5	2.75	2
Air (%)	1.0	0.9	0.9





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Micron 3

Ultrafine Fly Ash

Background Micron³

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- How is Micron³ produced?
  - Micron³ is made by air classifying an ordinary production fly ash and separating a portion of the fines
- What is Micron³ ?
  - Ultrafine fly ash that has a median particle size between 2 and 4 µm
- What is the goal for the final product?
  - To provide a high-performance pozzolan for use in concrete

Background – What is Micron³ UFFA

How is it produced?

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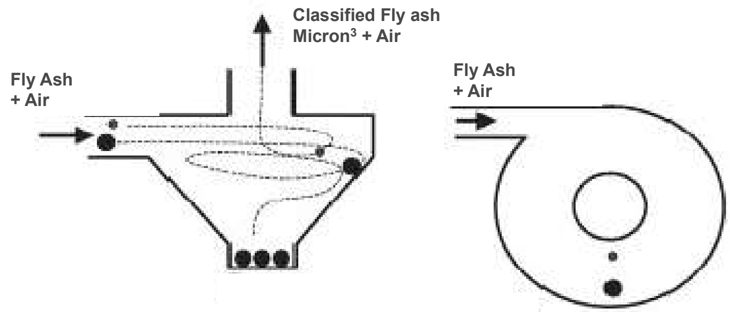
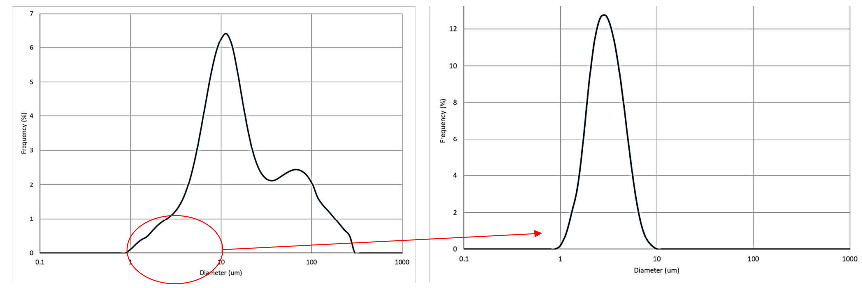


- Air classification?
  - **Air** classifier is an industrial machine which separates materials by a combination of size, shape, and density. It works by injecting the material stream to be sorted into a chamber which contains a column of rising **air**.

Background – Particle distribution of Micron³

BORAL RESOURCES



- Run of Plant ash has 44% passing 10µm
- Micron 3 Product has 100% passing 10µm

Performance – Micron³

ASTM C-618 Comparison

BORAL RESOURCES

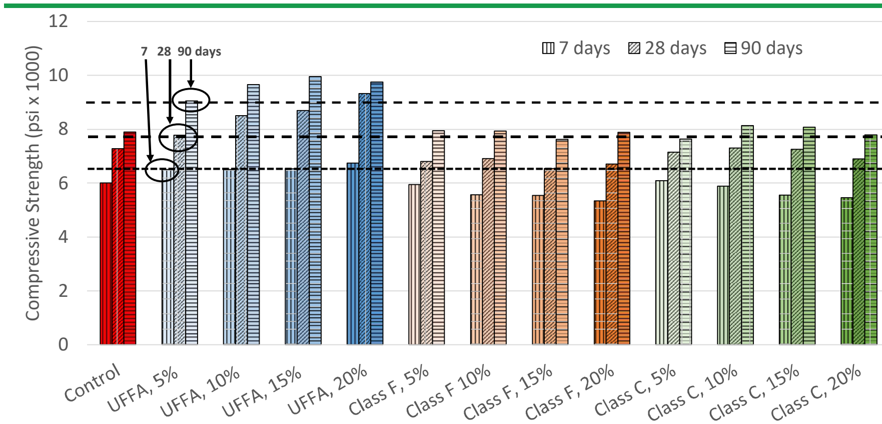
	Micron³	As-Produced Fly Ash	ASTM Limit
Sum of the Oxides ($SiO_2+Al_2O_3+Fe_2O_3$ %)	74.91	73.13	50% Min
CaO (%)	9.65	13.72	18% Max
SO_3 (%)	1.59	0.76	5% Max
Moisture (%)	0.09	0.05	3% Max
LOI (%)	0.52	0.27	6% Max
Fineness (% retained on 45 micron sieve)	0	21.32	34% Max
7 Day SAI (% of control)	111	84	75% Min
28 Day SAI (% of control)	125	91	75% Min
Water Requirements (% of control)	91	94	105% Max
Specific Gravity	2.69	2.59	-

Note Increase in Strength activity Index and reduction in water demand

Micron³ Performance

Strength Development Comparison to class F and C fly ash

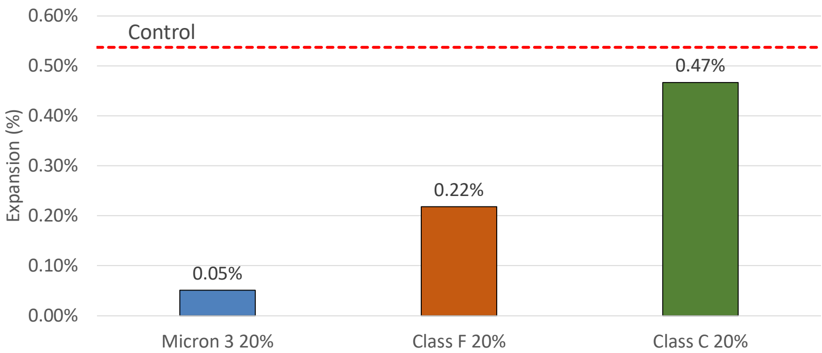
BORAL RESOURCES



- **5% replacement values of PC with UFFA exceed ash mixes at 7, 28 and 90 day**
- UFFA improves concrete strength at all testing ages

Micron[3] Performance

ASR Mitigation, C1567 Comparison to class F and C fly ash



- Expansion due to ASR is greatly reduced by Micron3

CLSM

Controlled Low Strength Material

CLSM / Controlled Low Strength Material

a.k.a Flowable Fill

A self compacting low to moderate strength material with flowable consistency which cures and hardens over time. It is used as backfill material instead of compacted granular material.

CLSM can also include sand or fine aggregates.

Primary Ingredients

Fly Ash

\+

Portland Cement

\+

Water


Fly Ash

Residual material after the combustion of coal. Primarily composed of silica, alumina, iron oxide and calcium oxide.


Portland Cement

Primarily composed of calcium oxide, silica and alumina.

Compared to compacted soil, CLSM:

- Provides more versatility and durability
- Fills voids or empty spaces more effectively
- Consistently achieves 100% compaction
- Reduces total project expenditures
- Provides a safer working environment

Flowability

BORAL RESOURCES

- Flowability is a significant advantage of using CLSM instead of granular or native fill material.
- Free flowing thus self-leveling. It's also easy to pump.
- It fills small voids, so no compaction required.
- Fast and inexpensive to place.

*ASTM D6103

Density & Thermal Insulation

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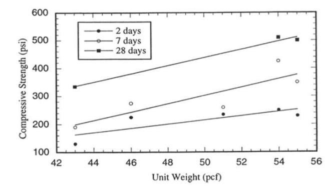
- **CLSM mixtures can be designed to provide insulating performance. The thermal insulation can be enhanced with foaming agents**
- **The in-situ unit weight of CLSM may range from 40 to 145 lb/ft³**
- **The use of air entraining admixtures can typically reduce the unit weight to 90 ~ 100 lb/ft³**
- **Foamed cell systems can reduce the unit weight to as low as 40 lb/ft³**

Foaming agent added to flowable fill mixture to reduce unit weight and improve flow



Decreasing compressive strength of foamed flowable fill mix designs as density decreases. (Vipulanandan, 2000)

You need it. We get it.™

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Supply and Alternate SCM

Initiatives and Technologies to Supply the Concrete Market

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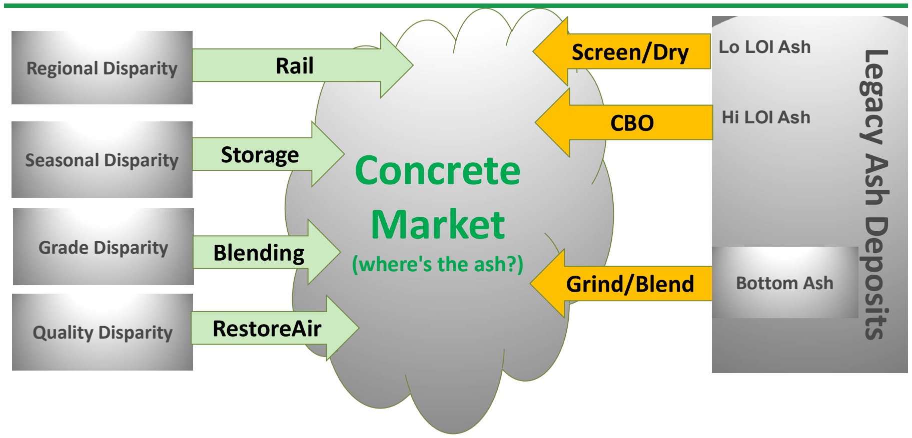

You need it. We get it.™

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Logistics

Rail Movement & Storage Options

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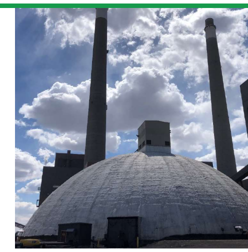
Logistics
Rail and Storge options



Coal Creek Station 80k

Denver Terminal 10K

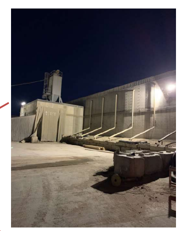
Typical Load out

- ✓ Rail large volumes of ash to manage supply deficits
- ✓ Use of high-volume domes and flat storage
- ✓ Versatility in transfer options
  - ✓ Conveyed pneumatically or auger
  - ✓ Portable Baghouse

Rail to Truck Offload

BORAL RESOURCES

Logistics
Iowa Locations

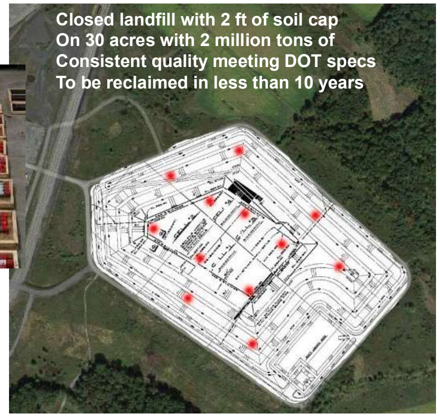


- ✓ Examples of some of the storage location in Iowa
- ✓ Storage during low demand winter to offset higher demand season

BORAL RESOURCES

Harvesting Ash

Harvesting Ash for Pozzolan Use
Driven by regional shortage of quality ash



A technology solution for harvesting pre-Lo-NOx burners fly ash from a utility owned deposit.

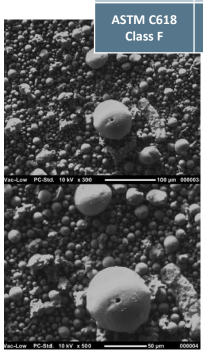
Harvesting Operation
Started in August 2018

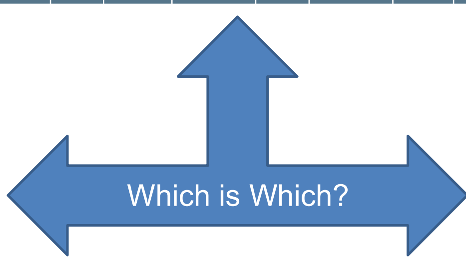
Drying System

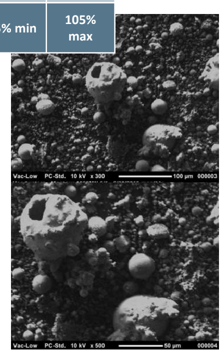
Site Photo

Reclaimed vs Current Generation Ash

	SiO_2+ Al_2O_3+ Fe_2O_3	SO_3	CaO	Moisture	LOI	Fineness	SAI 7 d	SAI 28 d	Water Req'
Current Generation	81.99	2.55	9.38	0.21	8.80	28.65	79	80	101
Reclaimed	90.84	0.19	2.21	0.16	3.05	11.90	79	83	100
ASTM C618 Class F	70% min	5% max	**	3% max	6% max	34% max	75% min	75% min	105% max



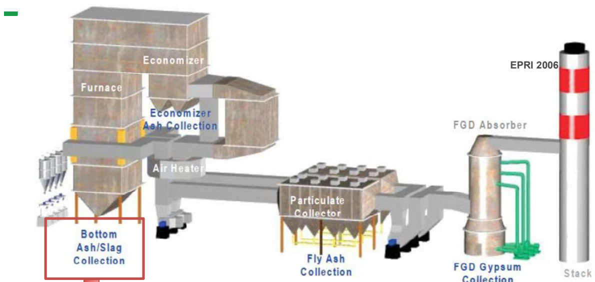




Ground Bottom Ash

Ground Bottom Ash (GBA)

BORAL RESOURCES

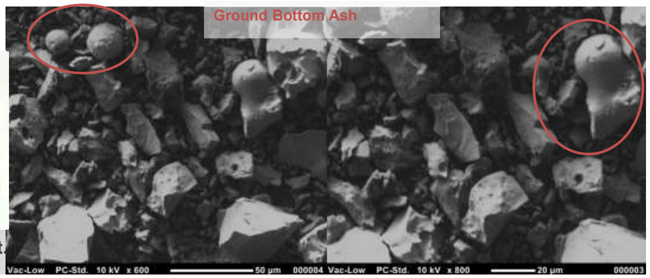


Commonalities

- Same source as fly ash

Differences

- Slower cooling
- Lower amorphous content
- Angular and spherical
- Requires milling



You need it. We get it.

C 618 Testing of Ground Bottom Ash

BORAL RESOURCES

Class F

	Sum of Main Oxides	SO_3 (%)	LOI (%)	Fineness (% retained on 325 mesh)	SAI 7D (% of cement control)	SAI 28D (% of cement control)	Water Req. (% of cement control)
Fly ash	87.58	0.43	0.66	17.67	87	91	95
Ground Bottom Ash	89.98	0.39	3.12	17.97	82	84	101
C 618 Criteria	70% min for F	3% Max.	6% Max.	34% Max.	75% Min.	75% Min.	105% Max.

Class C

	Sum of Main Oxides	SO_3 (%)	LOI (%)	Fineness (% retained on 325 mesh)	SAI 7D (% of cement control)	SAI 28D (% of cement control)	Water Req. (% of cement control)
Fly Ash	63.76	1.66	0.48	13.63	96	104	94
Ground Bottom Ash	72.08	0.32	2.2	3.03	83	87	101
C 618 Criteria	50% min for class C	3% Max.	6% Max.	34% Max.	75% Min.	75% Min.	105% Max.

Higher LOI

Lower SAI

Water Req. Closer to Control

You need it. We get it.™

BORAL RESOURCES

Blended Pozzolans

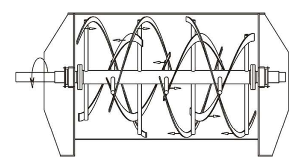
Regional Options

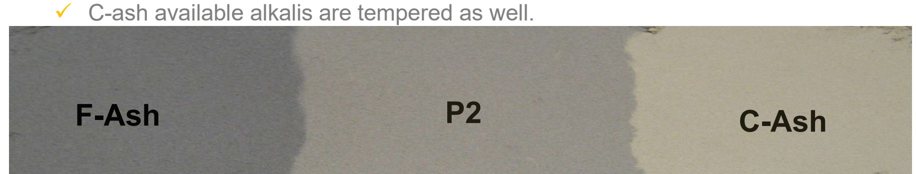
Performance Pozzolan (P^2)

Driven by DOT durability specs and demand for F-ash

BORAL RESOURCES

- ✓ Sum of oxides optimized between 72% and 75%.
- ✓ Sulfate resistance (F-ash)
- ✓ Mitigates ASR (F-ash)
- ✓ Early strength development (C-ash).
- ✓ Conforms to ASTM C1697 uniformity of ±5.0%.
- ✓ F-ash LOI is typically lowered (<2.0%).
- ✓ C-ash available alkalis are tempered as well.





P^2 (Gaston/ Miller) approved in 7 states

Other P^2 supplies/markets are being used Midwest, TX and GA

You need it. We get it.™

Ash Beneficiation

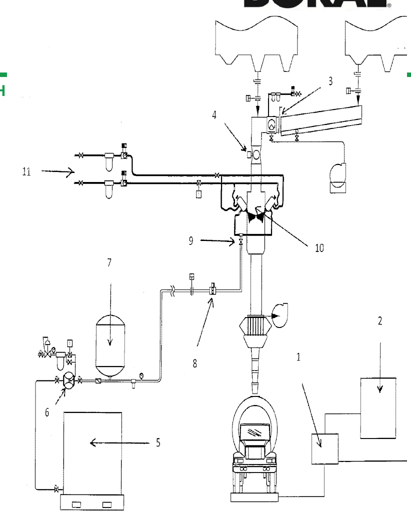
RestoreAir®

Carbon Treatment

A COST EFFECTIVE OPTION FOR PAC AND LOW LOI ASH

RestoreAir® Technology Highlights

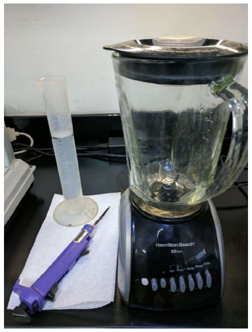
- New formulated reagent for improved dispersion
- Accurate PLC controlled reagent delivery system
- Robust QA/QC program
- 20 systems installed
- Combined capacity of 2 million tpy
- **Very suitable for reclaimed ash that meets DOT LOI specifications**

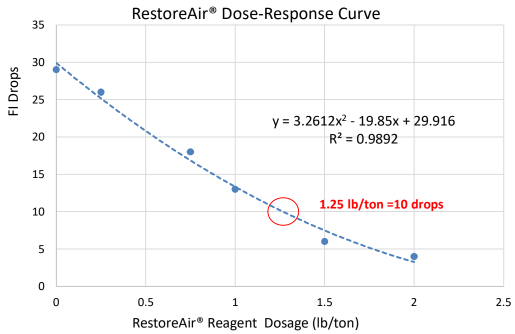


RestoreAir®

DOSAGE IS DETERMINED WITH FOAM INDEX TEST AND TREATABILITY INDEX

FOAM INDEX CAN BE TAILORED WITH VARIABLE DOSAGE RATE TO MEET MARKET DEMANDS

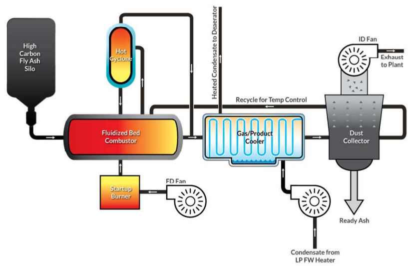




Carbon Burn Out (CBO)

Technology to beneficiate high carbon ash

- Developed by Progress Energy with support from EPRI and other utility partners.
- The technology was spun off through PMI to deploy at other utilities.
- Boral acquired all patents and know-how related to the CBO from PMI.
- 4 CBO plants were built at powerplant sites with a combined operating history of more than 40 years processing more than 7 mm tons of ash.
- Improvements and other design features have been developed to allow its operation without power plant support to reclaim ash from landfills and ponds.



Technical solutions to meet supply challenges

BORAL RESOURCES

Fly Ash

- Blending to augment supply
- Beneficiation for utilization
  - Chemical Treatment
  - CBO
- Seasonal Storage

Harvesting

- Excavation / Dredging
- Drying
- Crushing
- Sieving or Classifying

Ground Bottom Ash

- Milling to fly ash fineness
- Meet C-618 Requirements
- Durability
  - Effective mitigating ASR
  - Reduces Sulphate Expansion

Additional Resources

BORAL RESOURCES

Bill Sutton / Doug Rhodes

Boral Resources

Federal Highway Administration

Fly Ash Facts for Highway Engineers

https://www.fhwa.dot.gov/pavement/recycling/fafacts.pdf

BORAL®