Reactivity analysis of high calcium fly ash as raw material for non-traditional, fly ash-based binders

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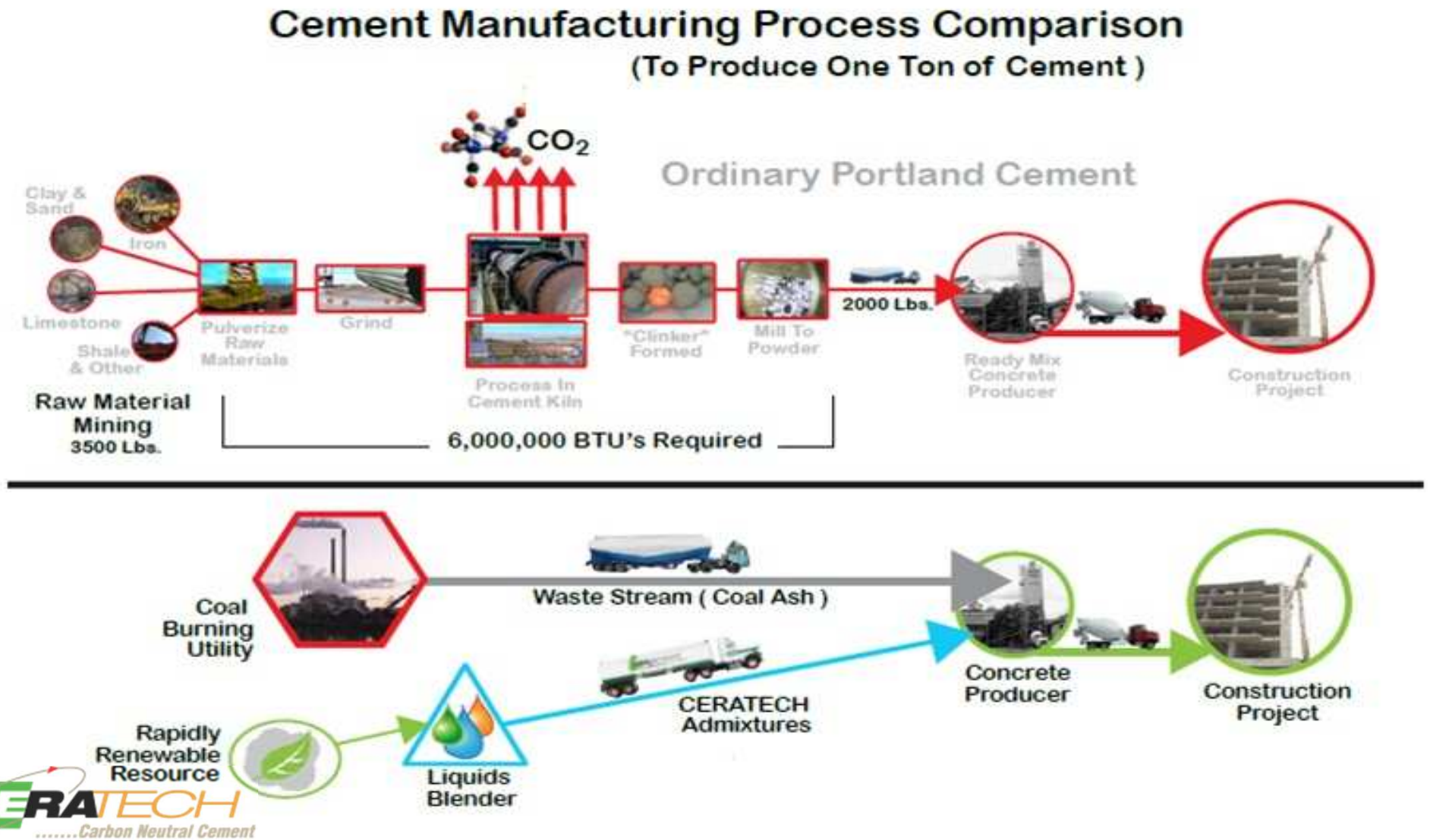
CeraTech, Inc.

Technology overview



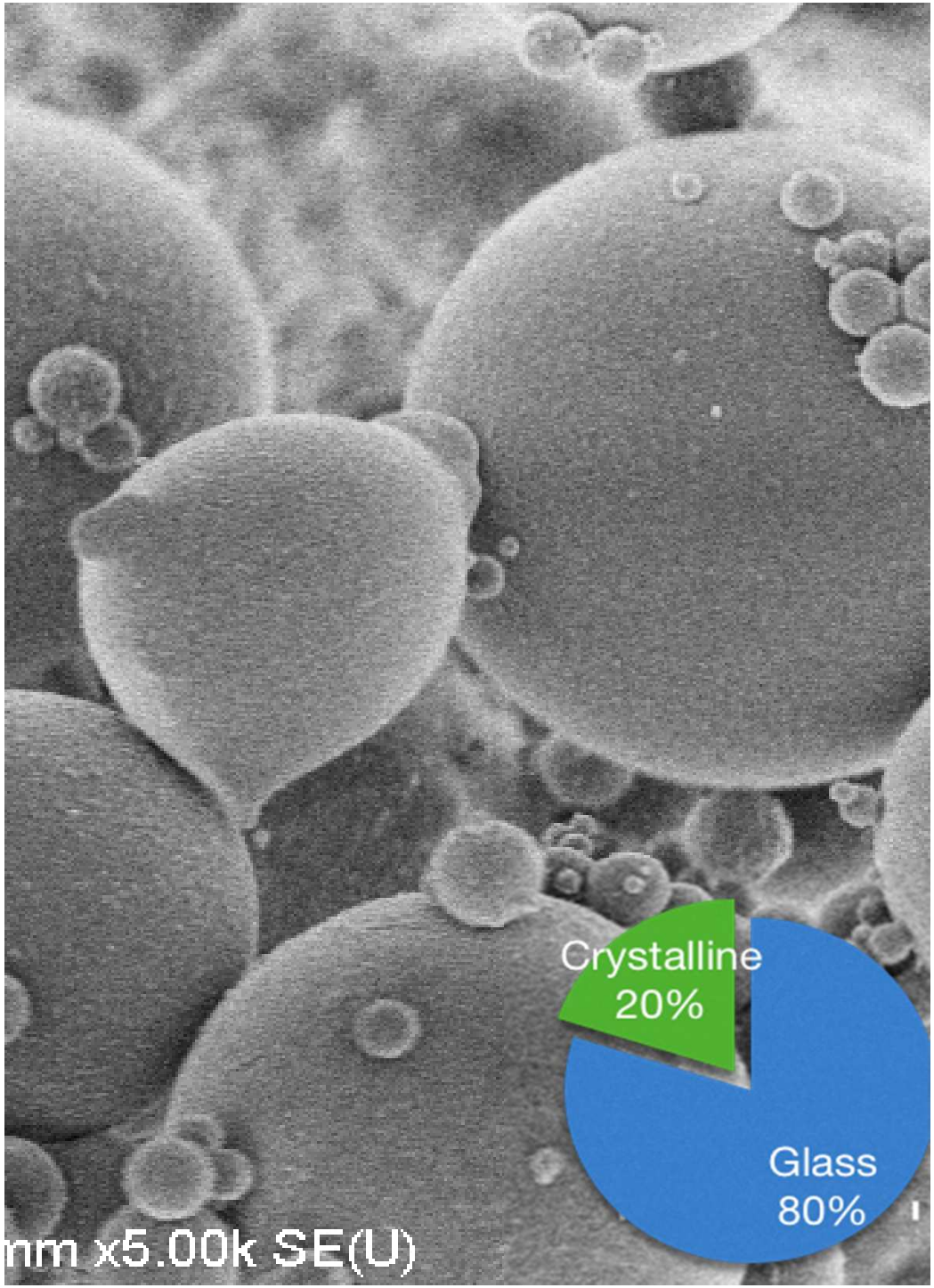
Quality control

QC Tools

- Beyond pass-fail
- Deliver concrete with consistent set time and strength
- Quantify reactivity and relate to the effect in the concrete mix. Quantify reactivity-quantify adjustments
- Deliver green concrete, quality and consistency

HC Fly ash

- Silica, calcium oxide, alumina and iron oxide
- Mostly amorphous
- Crystalline components can be considered relatively inert
- MPS: 20 microns on avg
- Reactivity depends on glassy phase content and composition



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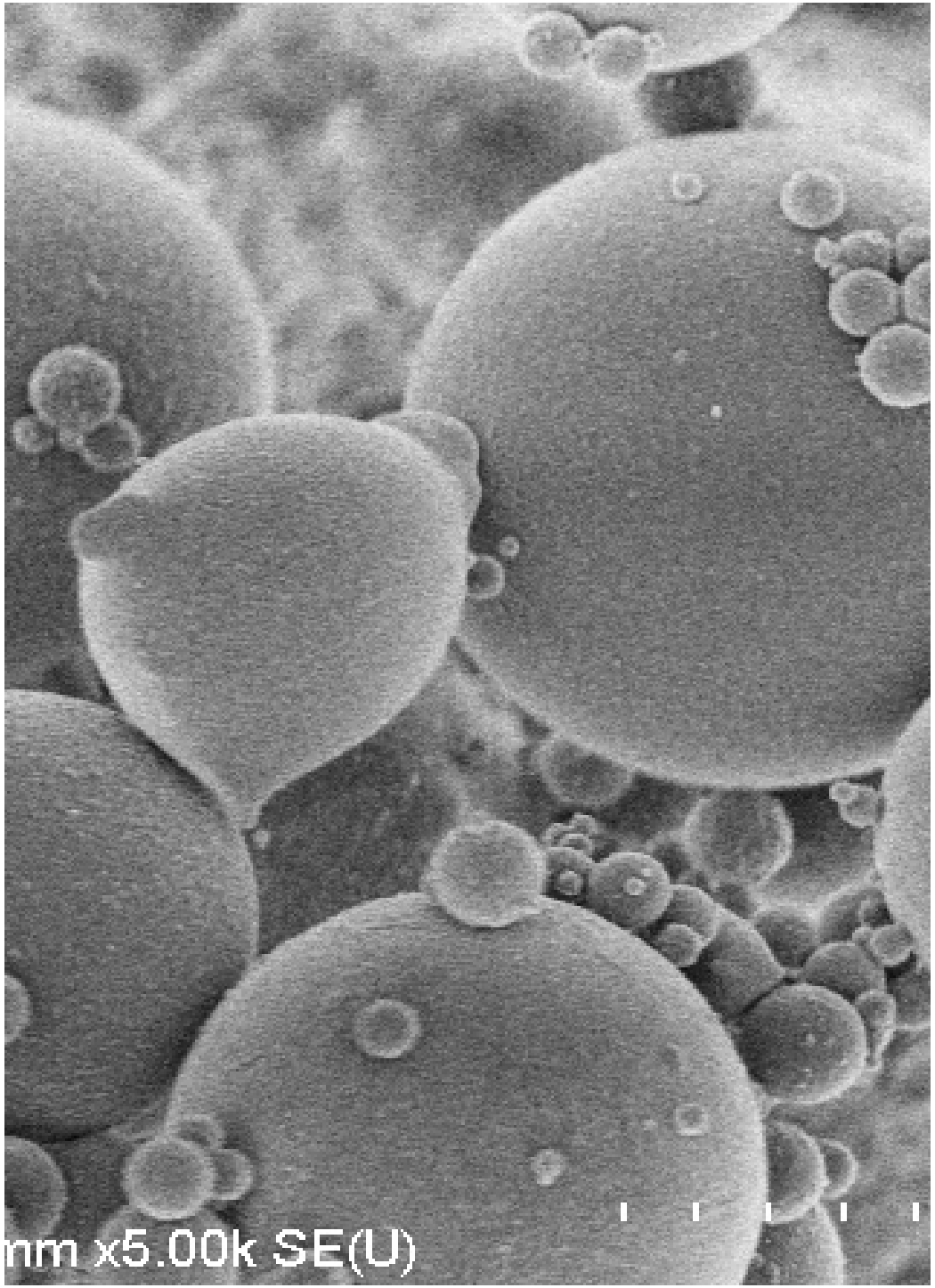
Reactivity study

- 20 Fly ash samples
- Fly ash variables: XRF, XRD, PSD
- ASI and NBO/T calculated from the total oxide content as measured by XRF
- Response: Compressive strength @ 1 day



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Chemical analyses

fly ash	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	Fe2O3	CuO	SrO	ZrO2	BaO	LOI
1	1.49	5.22	17.5	37.2	0.64	1.18	0.49	25.7	1.51	7.06	0.06	0.36	0.05	0.67	0.5
2	2.37	6.14	17.8	33.3	0.98	1.88	0.38	28.2	1.41	5.38	0.06	0.37	0.05	0.74	0.4
3	2.25	6.66	17.1	33.8	1.05	1.73	0.44	27.5	1.36	6.13	0.05	0.41	0.04	0.73	0.4
4	2.11	6.79	16	32.9	0.68	2.4	0.36	28.6	1.15	6.98	0.06	0.46	0.04	0.79	0.7
5	1.98	5.09	19.6	36.2	1.12	1.1	0.44	25.7	1.44	5.48	0.05	0.41	0.04	0.68	0.4
6	1.77	4.85	20	35.8	1.14	1.13	0.46	26.2	1.49	5.22	0.06	0.45	0.04	0.68	0.3
7	1.79	4.68	20.1	35.3	1.07	1.12	0.47	26.7	1.53	5.35	0.06	0.45	0.04	0.69	0.3
8	3.49	6.1	17.2	33.5	1.14	1.57	0.38	27.5	1.38	5.74	0.05	0.35	0.04	0.71	0.7
9	2.43	9.29	16.2	29.3	0.87	2.94	0.27	29.3	1.19	5.73	*	0.54	0.04	0.92	0.5
10	1.53	4.92	17	34.4	1.08	1.21	0.53	30.1	1.22	5.93	0.05	0.35	0.04	0.62	0.6
11	2.14	7.49	15.5	31.9	0.66	2.79	0.34	29.4	1.13	6.17	*	0.47	0.04	0.74	0.8
12	2	4.89	19.7	34.3	1.12	1.59	0.47	27.4	1.57	5.25	0.07	0.47	0.04	0.74	0.3
13	1.96	4.69	18	33.8	1.15	1.26	0.52	29.5	1.25	5.85	0.06	0.34	0.04	0.63	0.8
14	2.01	6.08	17	36.8	0.73	1.83	0.45	25.3	1.19	6.47	*	0.42	0.04	0.67	0.6
15	2.12	6.74	16.1	33.7	0.7	2.52	0.38	27.6	1.12	7.68	*	0.45	0.04	0.66	0.6
16	2.36	6.31	17.9	32.9	0.92	2.03	0.4	28.4	1.5	5.3	*	0.37	0.04	0.74	0.7
17	1.91	5.46	19.3	37.4	0.98	1.33	0.48	23.9	1.35	5.74	*	0.33	0.04	0.67	0.7
18	1.89	5.17	18.8	34.1	0.79	2.55	0.42	26.3	1.42	6	*	0.37	0.04	0.67	0.9
19	4.43	5.25	17.5	33.4	0.77	2.53	0.4	25.5	1.39	4.84	*	0.34	0.04	0.61	2.5
20	3.52	6.13	17.5	32.8	1.18	1.73	0.35	27.8	1.36	5.84	*	0.36	0.04	0.75	0.5
min	1.49	4.68	15.5	29.3	0.64	1.1	0.27	23.9	1.12	4.84	0.05	0.33	0.04	0.61	0.3
max	4.43	9.29	20.1	37.4	1.18	2.94	0.53	30.1	1.57	7.68	0.07	0.54	0.05	0.92	2.5
Avg	2.28	5.90	17.79	34.14	0.94	1.82	0.42	27.33	1.35	5.91	0.06	0.40	0.04	0.71	0.66

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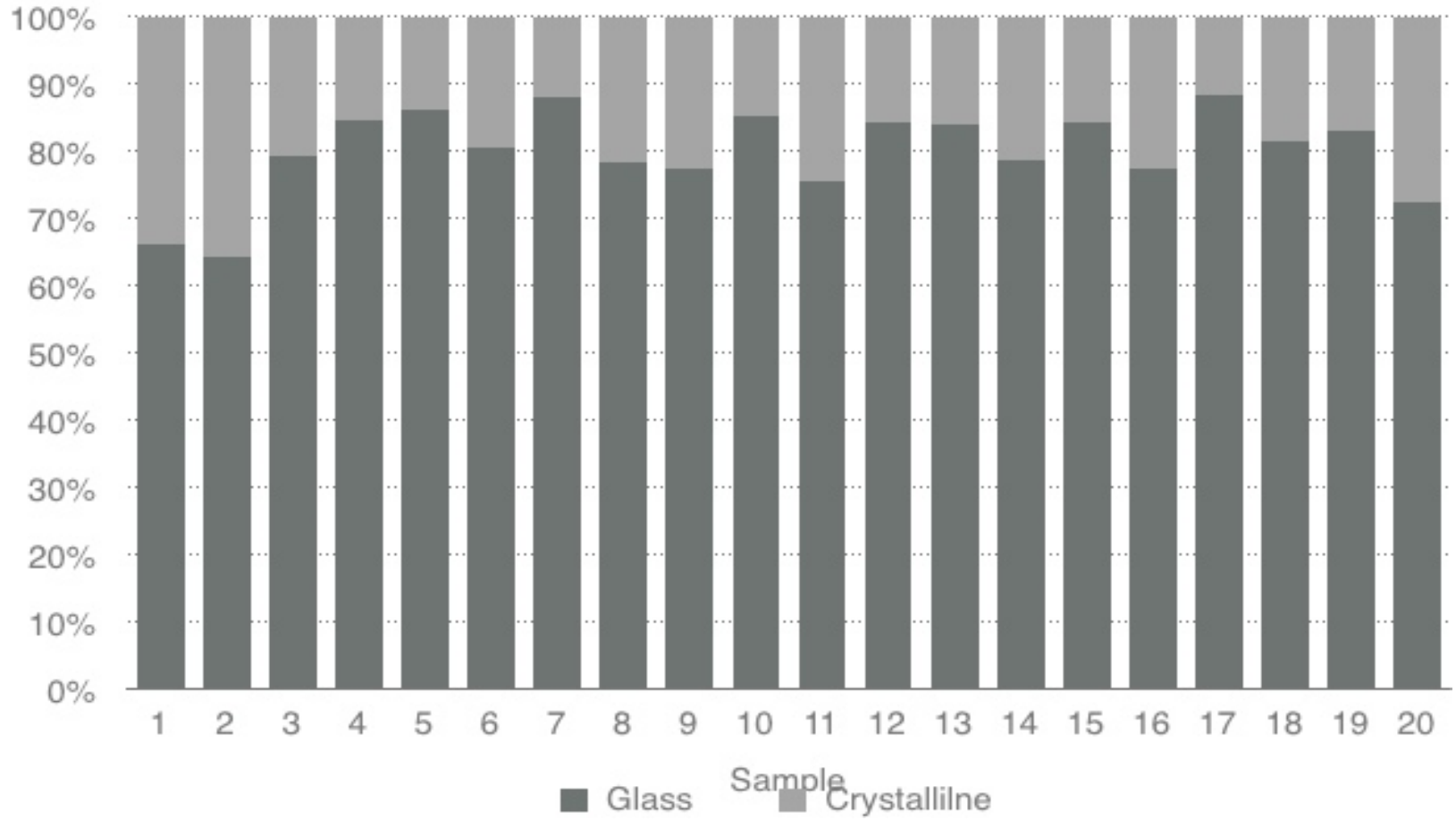
XRD



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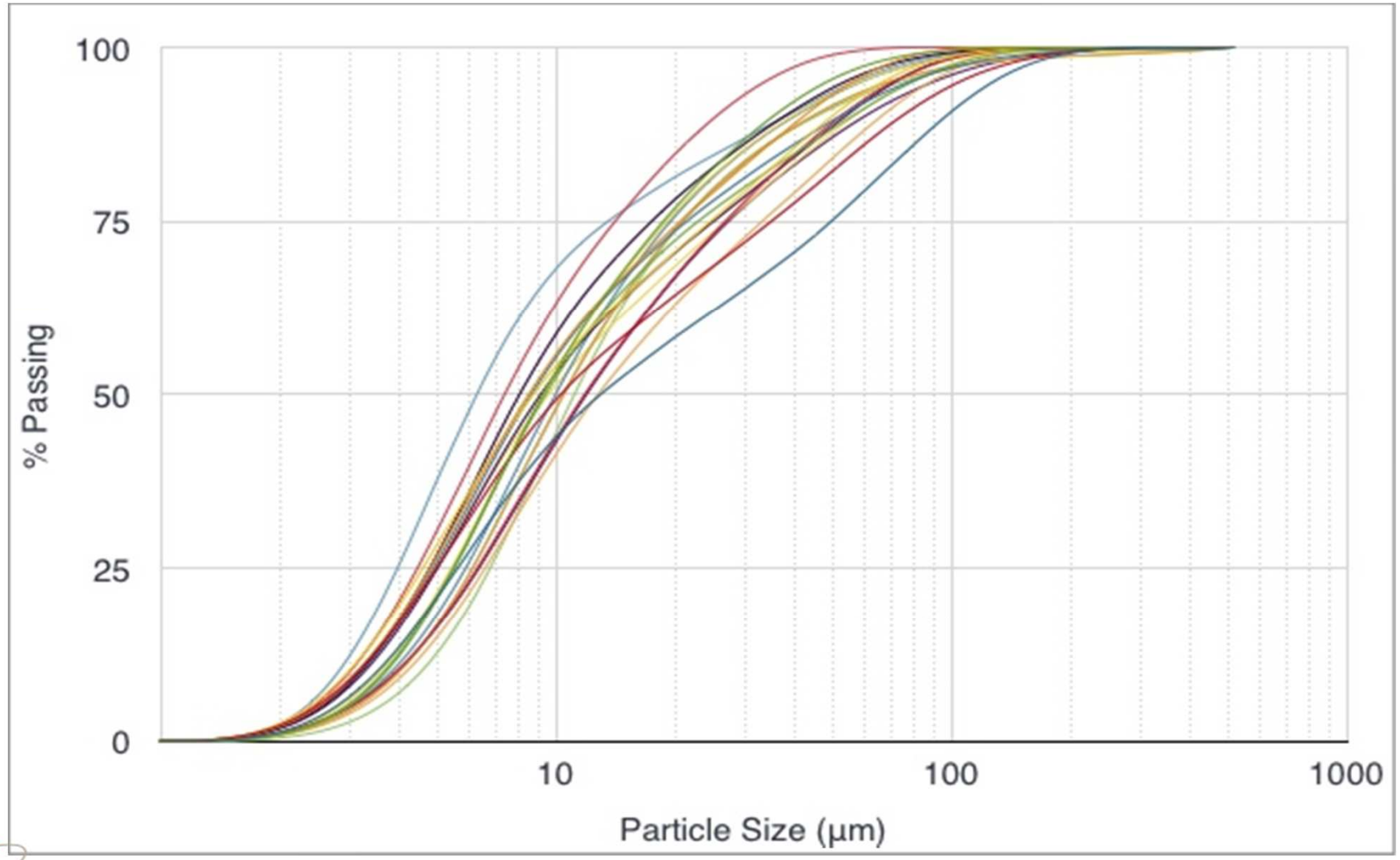
PSD



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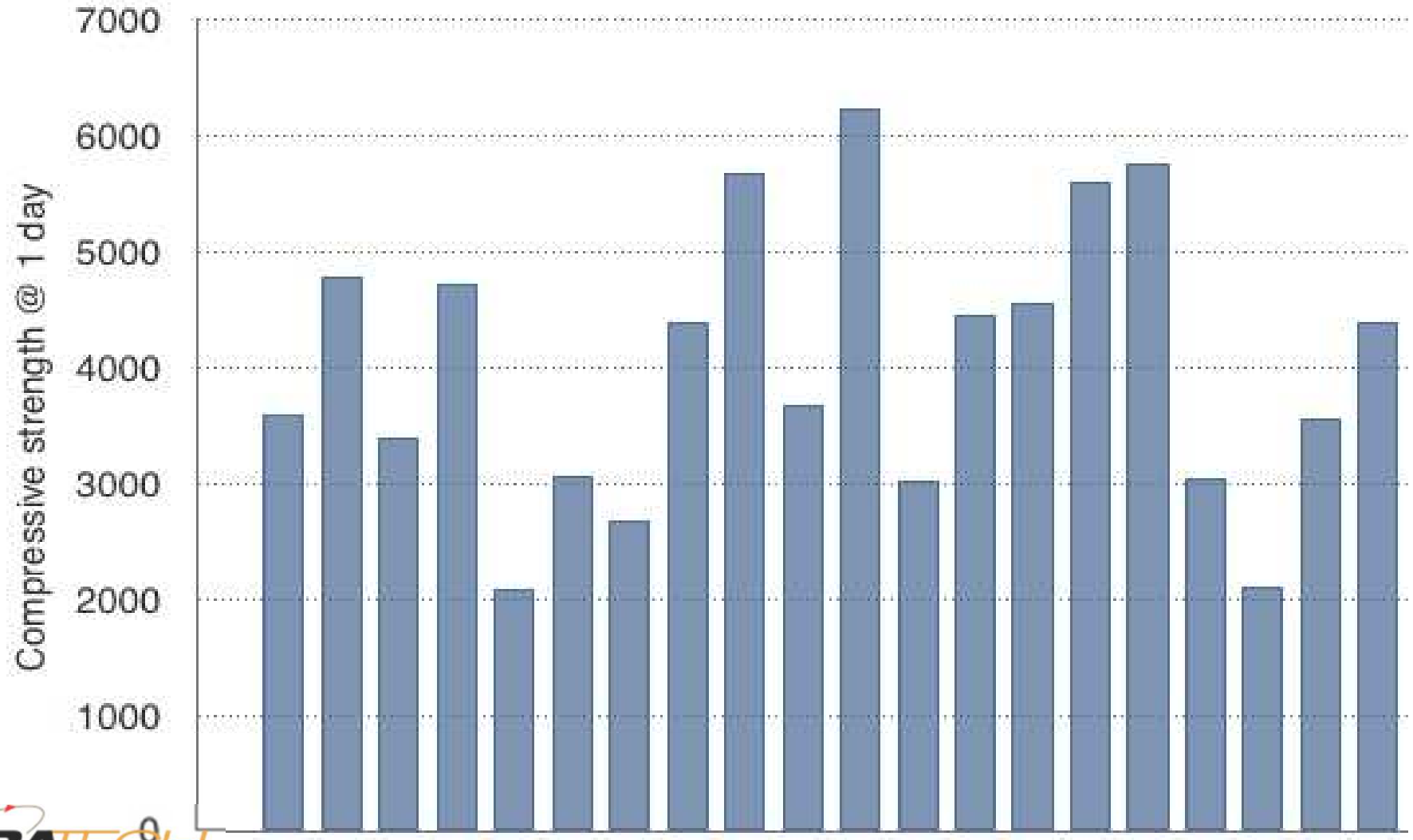
Compressive strength



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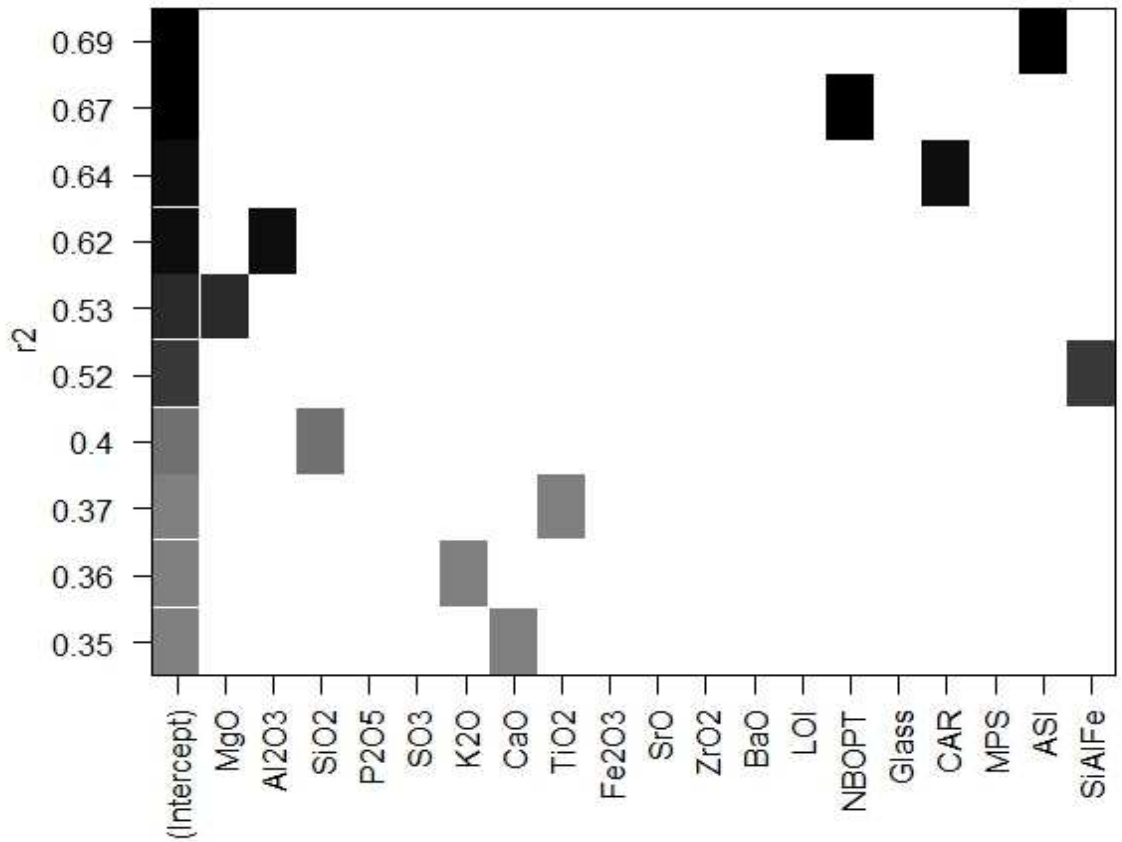
Stepwise regression



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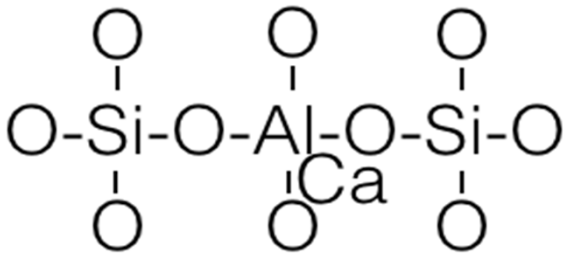
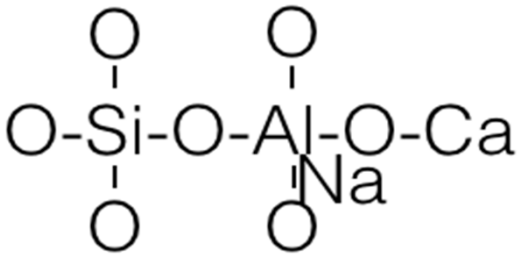
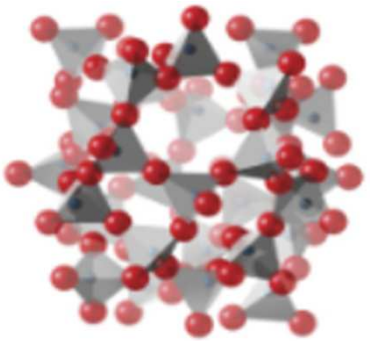
Glass science basics

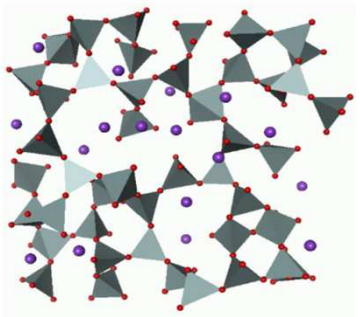
Network Formers
Si, Al, Fe





Network Modifiers
K, Na, Ca, Mg





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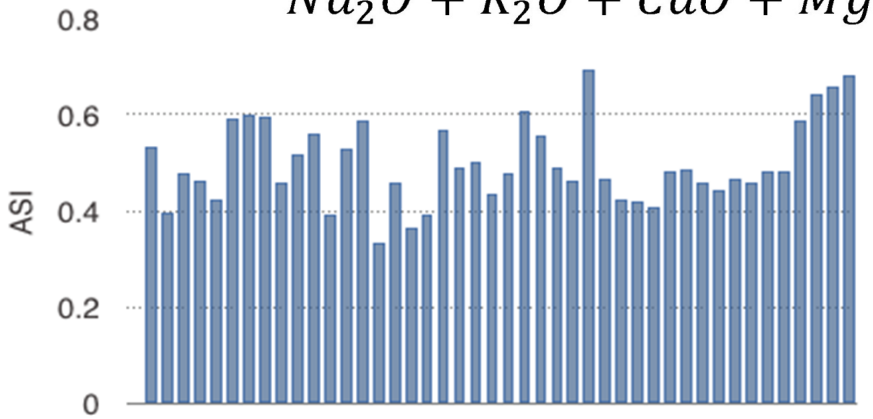
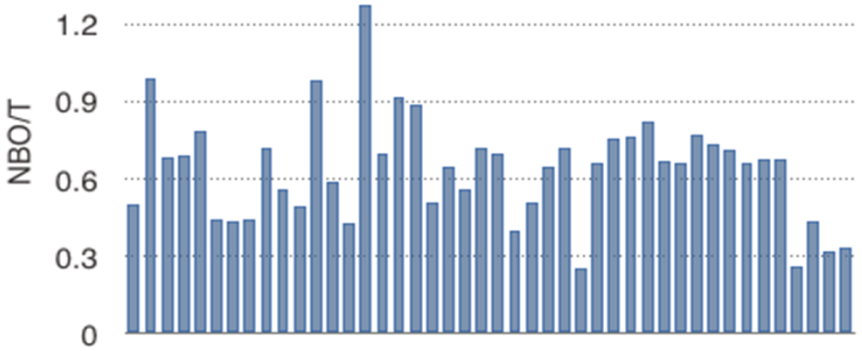
ASI and NBO/T

$$ASI = \frac{Al_2O_3}{Na_2O + K_2O + CaO + MgO}$$



$$\frac{NBO}{T} = \frac{2(Na_2O+K_2O+CaO+MgO-Al_2O_3)}{SiO_2+Al_2O_3+Fe_2O_3}$$



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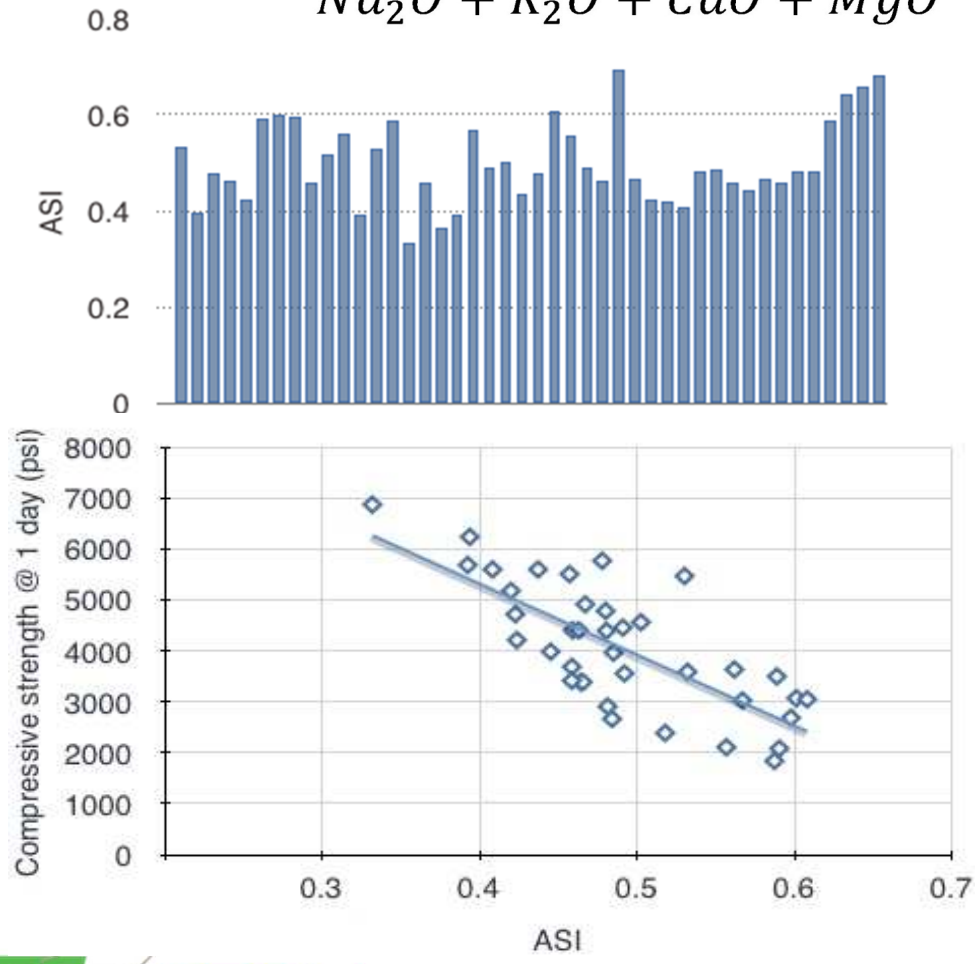

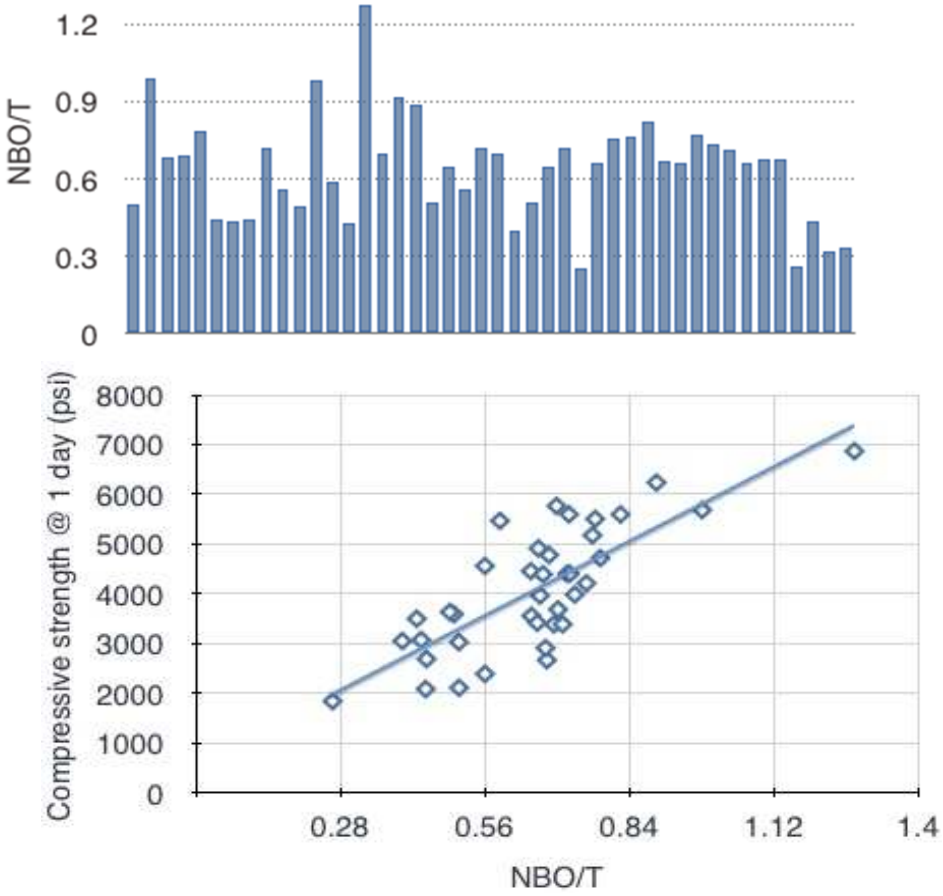

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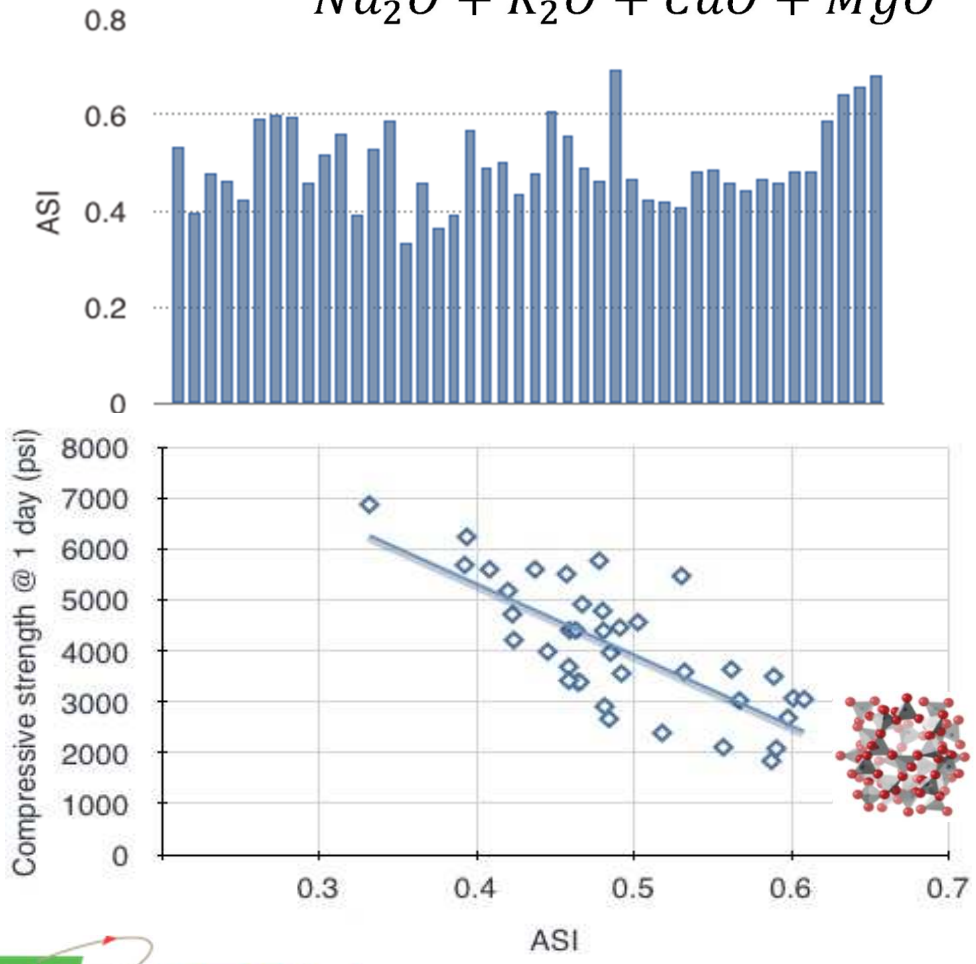

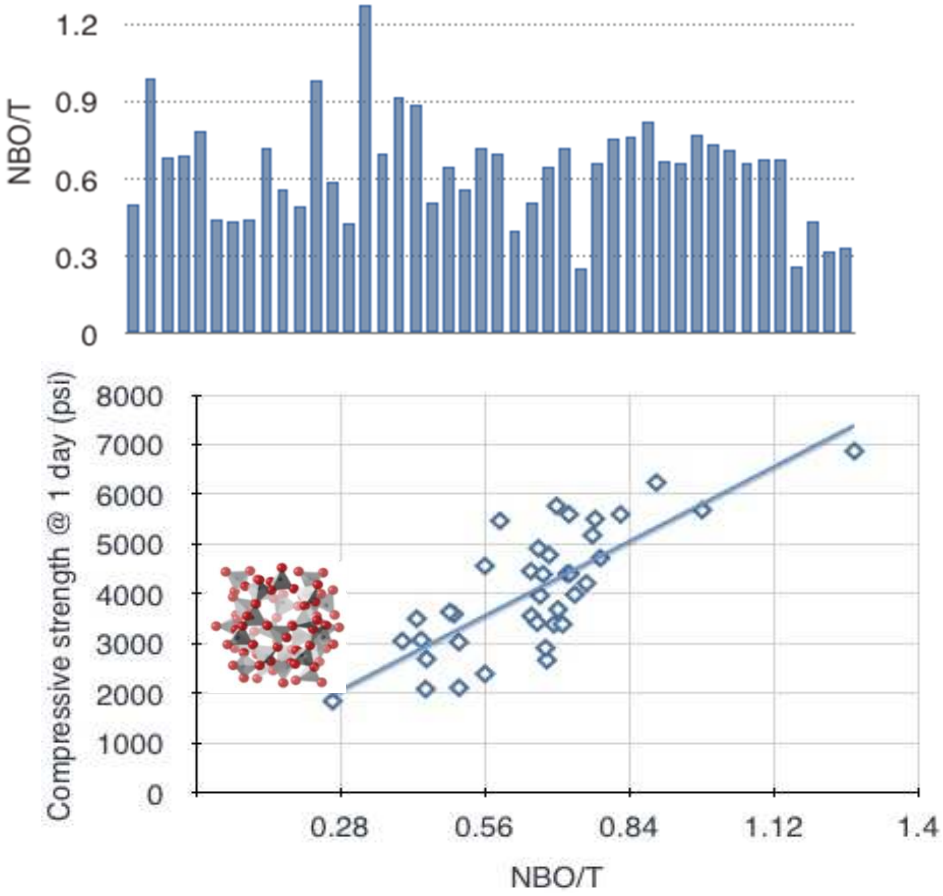

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ASI and NBO/T

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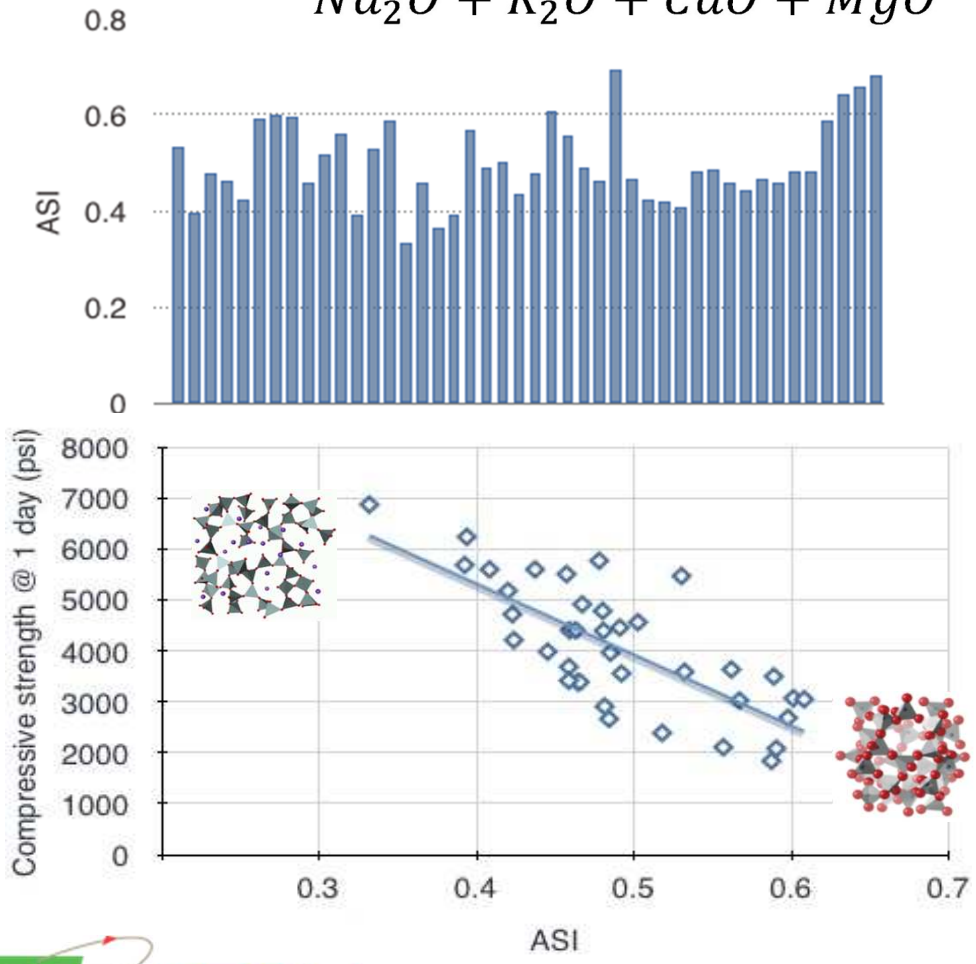

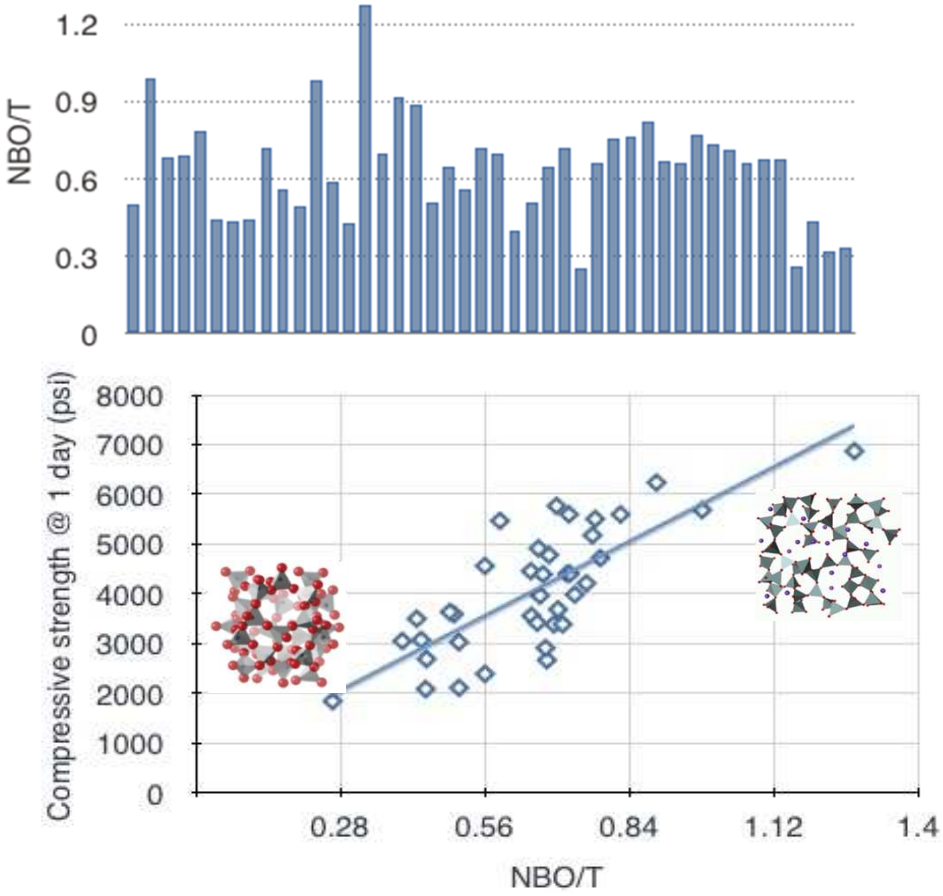

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Assumptions and restrictions

- No Crystalline phases (100% Glass)
- Free energy of hydration not considered
- Constant physical characteristics
- Homogeneity
- Compositional range
- Fe is always acting as a network former

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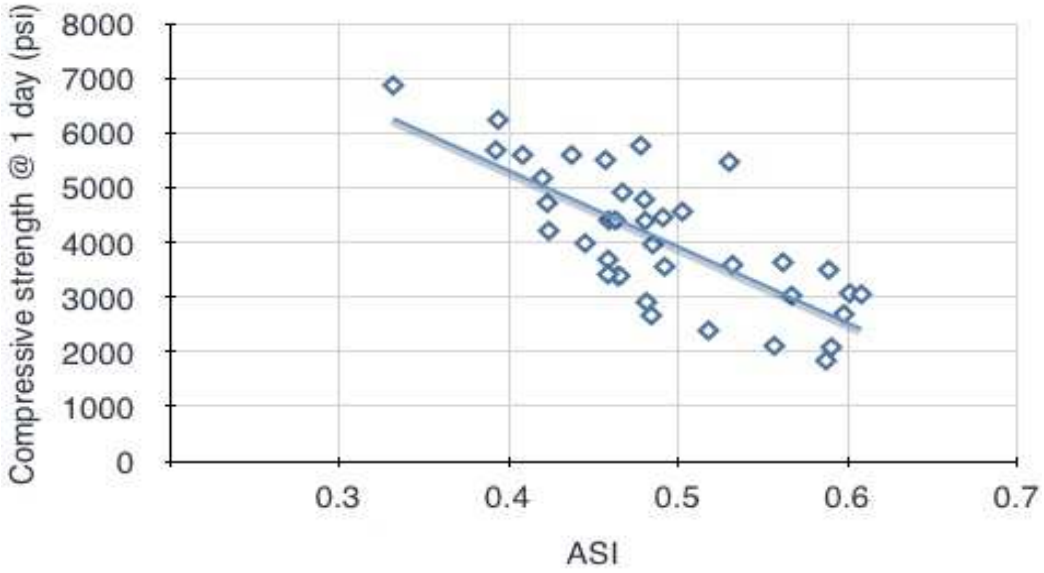
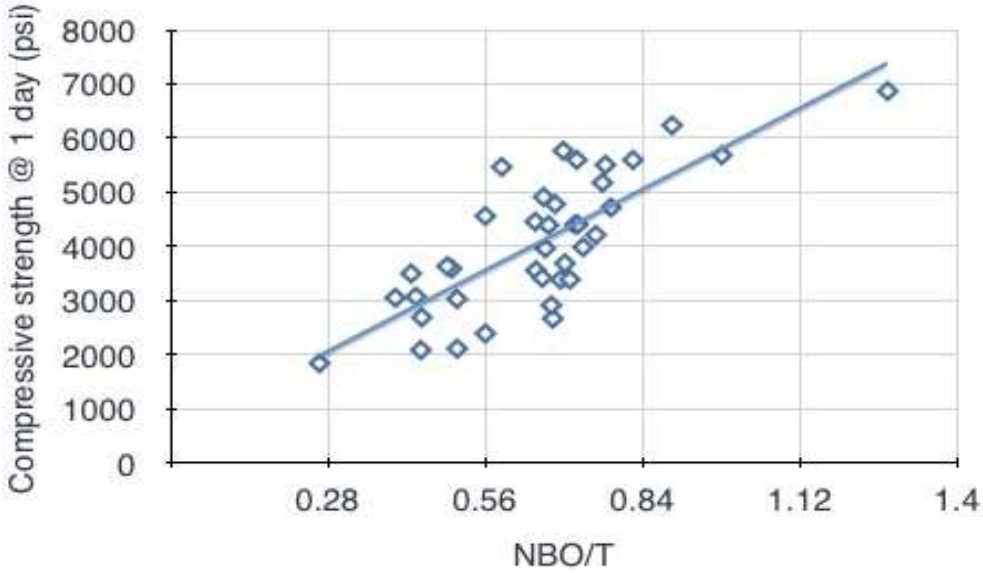
Other sources of variability

- Redox state or Fe — Fe (II) has much lower FEH than Fe (III)
- P2O5 in concentrations near as low as 1% can have profound effects on liquidus phase relations and transport properties [Willie an Tuttle, 1964; Toplis et al., 1994; Wolf and London, 1994]
- TiO2 can occur in a 4-fold coordination and substitute Si to act as a network former, it can also be coordinated with more than 4 oxygens and act as a network modifier
- S(-2) interactions

Despite the assumptions





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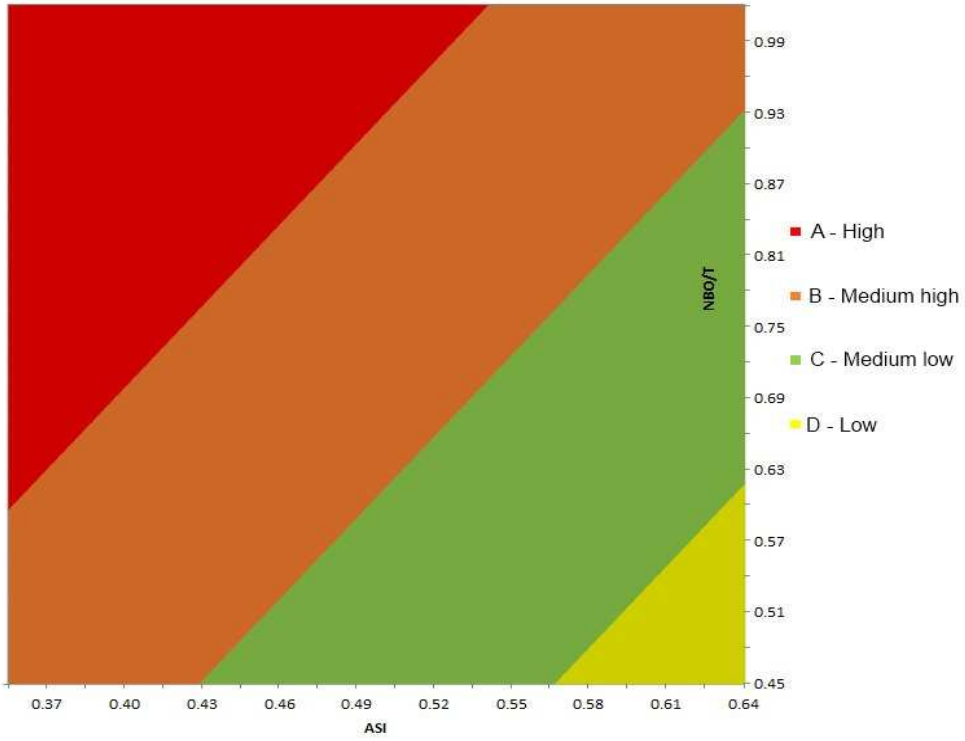
In practical terms



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Fly Ash Quality Control Report

Fly Ash Source	Welsh PP		Date	10/20/2010
Unit			ASTM C 618 date	
Silo				

Tests		Rating A	B	C	D
Chemical Tests					
	%				
Silicon Dioxide (SiO2)	33.30				
Aluminum Oxide (Al2O3)	17.80				
Iron Oxide (Fe2O3)	5.38				
Calcium Oxide (CaO)	28.20				
Magnesium Oxide (MgO)	6.14				
Sulfur Trioxide (SO3)	1.85				
Sodium Oxide (Na2O)	2.37				
Potassium (K2O)	0.38				
Alumina Saturation Index (ASI)	0.4799	0.3985 max.	0.5017 max.	0.5706 max.	0.6394 max.
Non-Bridging Oxygens per Tetrahedron	0.6831	0.8637 min.	0.6281 min.	0.4711 min.	0.3141 min.
Physical Tests					
Moisture Content, %	0.00	3.0 max.	3.0 max.	3.0 max.	3.0 max.
LOI, %**	0.13				
Amount Retained on No. 325 Sieve, %	8.11	30 max.	30 max.	30 max.	30 max.
Specific Gravity	2.69				
Performance					
Estimated ASHVC 1 day Compressive Strength (psi)*	4334	5500 min.	4000 min.	3000 min.	2000 min.
ASHVC 1 day Compressive Strength (psi)	4779	5500 min.	4000 min.	3000 min.	2000 min.
Estimated Ash Grade	B				
Ash Grade	B				

* These predictions are made based on a study performed in 44 fly ashes and using ASI as predictor. The correlation factor on this study was 169 and the average error was 570 psi

** LOI values as low as 4.0 % may have a negative effect on the performance of the fly ash. However, fly ash samples with LOI values as high as 6.0 % have been found to perform as expected. These observations are based on analysis performed in 44 fly ash samples

Aproved by: _____

3501 Brehms Ln., Baltimore, MD 21213 Quality Control CeraTech, Inc.

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Questions??

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