Portland Composite Cements: AASHTO M240 & ASTM C595

Eddie Deaver . Holcim Technical Services
NCDOT- PCI Joint Committee Meeting . 11.21.2013

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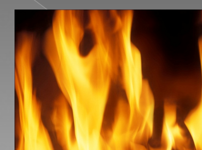
Sustainability of a Cement Can Be Enhanced

- Portland cement production is energy intensive but the intensity can be reduced by:
  - Reducing the amount of clinker in cement without compromising the fresh and hardened properties of concrete
  - Maintaining required performance and potential durability of a reduced energy cement for the intended purpose



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CO_2 Emissions: Other Source than Fossil Fuels

- Limestone = Calcium Carbonate ($CaCO_3$)
- Cement manufacturers need CaO
- Therefore: through heat exchange ->

  $CaCO_3$ + Heat -> CaO + CO_2

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So................What is a Composite?

- A complex material in which two or more distinct, structurally complementary substances, combine to produce structural or functional properties not present in any individual component.
- *Mathematics* The application of one function to another. For example, if $(x) = x^2$ and $g(x) = x + 1$, then the composite $(g(x)) = (x + 1)^2$ and the composite $g((x)) = x^2 + 1$.

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Hydration of Composite Cements

- Clinker + gypsum + H_2O → CSH + $Ca(OH)_2$ + other hydrates
- Fly ash, slag, pozzolan + $Ca(OH)_2$ → CSH

- Replacement of clinker by MIC reduces the content of C_3A of the cement
  - Lower C_3A and lower $Ca(OH)_2$ ⇒ higher durability

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Nomenclature : AASHTO M240/ ASTM C595

- Now: IP(xx) In the past: IP
- IS(xx) In the past: I(SM) & IS
- IL(xx)

Where (xx) is the target value of slag, pozzolan, limestone

  - Example: Type IL(10) = 10% limestone
- Limestone content 5% to 15%

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Type IT(AX)(BY)

Where A and B are SCM types and X and Y are amounts
- S=slag or P=pozzolan
- Primary (highest content) SCM listed first
- If X=Y requirements of Type IT(P>S) apply (Type IP)

- Example: Type IT(S25)(P15) contains 25% slag and 15% pozzolan

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Composite cement vs. Direct addition of MIC in concrete

Composite cement
- Intergrinding or blending at cement plant → Better homogeneity
- Optimized particle size distribution of constituents
- Optimized chemical composition of the system (clinker composition, use of chemical improvers, CKD, gypsum optimization, etc) → Reactivity of the system is enhanced; Improvement of: early strength; water demand (lower)
- Better resources in terms of staff and equipment
- Quality control able to detect problems before the cement is used → Better quality control

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Composite cement vs. Direct addition of MIC in concrete

MIC addition on site
- Gives flexibility → Different mixes for different applications/ requirements; Might lead to savings
- Optimization of particle size distribution and chemical composition of the system not possible → Best reactivity not achieved; Possibly lower early strength and higher water demand
- Need of additional silos, handling equipment (conveyors, for example)
- Need of relatively big mixers able to take 2 bags (one of cement; one of MIC). Otherwise bags must be split. → CAPEX
- Quality control must be rigorous → Investment in staff and equipment
- Performance tests (e.g. durability test) have to be done for each mix → Mistakes (overdosing of MIC, for ex.) only detected after concrete placed. Difficult to remediate

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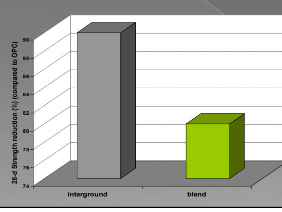
IP(xx) cement vs. Direct addition of fly ash in concrete

- In a composite cement fly ash is activated by intergrinding, increasing the performance of the product (agglomerates are broken). According to Monk (1983):
  - The strength of the interground cement was 10% higher at all ages
  - In general, for a constant slump, the water demand of concrete prepared with fly ash cement was lower than of concrete with added fly ash



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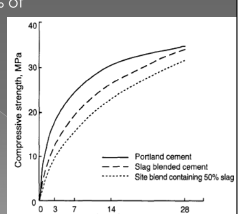
Composite cement vs. Direct addition of MIC in concrete

- Comparison of cements produced by intergrinding with site blends with 50% of slag in South Africa (Addis 1986)
- When compared to "composite concrete", composite cement had:
  - Shorter setting times
  - No significant differences in placeability, but easier to vibrate
  - Higher compressive strength



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IS(xx) In the Carolinas

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Uses IS(20) in the Carolinas

- Due to LEED requirements producer needed a product that contained SCMs and would not impede the release times of the prestressed panels.
- IS(20) that was on this project was an interground material.

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Rockefeller Tire Center Prestressed Panels

- IS(20) was used on the prestressed panels of this 1.1 million cubic foot warehouse west of Charleston, SC

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Rockefeller Tire Center Prestressed Panels

- During the duration of this project, producer also constructed AASHTO girders, hollow core decks, and barrier rail for both SCDOT and NCDOT.
- Other users in the Carolinas use the IS(20) in applications such as:
  - high strength military vaults where the required strength is 10,000 psi
  - Above and below ground precast storage tanks
  - As well as a multitude of drainage items

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University of South Carolina's Concrete Canoe

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Portland Limestone Cements

Sustainable
Reliable
Versatile

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What are Portland-Limestone Cements?

Portland cement clinker that is interground with 5% to 15% limestone
Designed to perform equivalent to or improved over the predominant cement available
Reduced CO2 emissions…
- less direct release of CO2 from clinker production
- research on Life Cycle Inventory indicates reduced overall energy to produce over predominant cement

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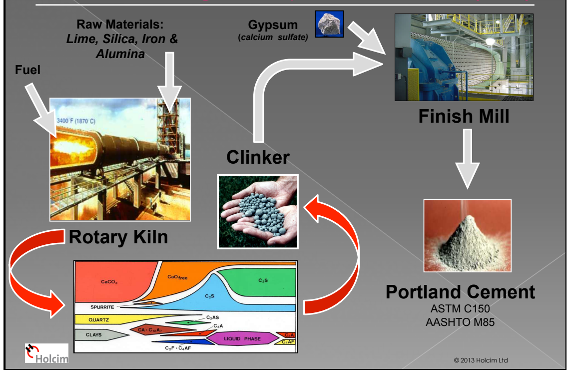
Manufacturing Ordinary Portland Cement (OPC)



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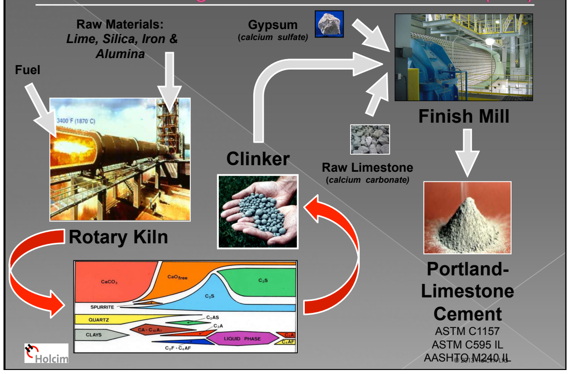
Manufacturing Portland-Limestone Cement (PLC)



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What Specifications cover Portland-Limestone cements?

- In 2011, ASTM developed a provision for having a portland cement that contained 5% to 15% limestone which would adhere to ASTM C595 *[Standard Specification for Blended Hydraulic Cements]* . AASHTO recognition of PLC was also aligned with ASTM in the August 2012 print in AASHTO M240.

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History of Use

- Currently the most commonly used cement in Europe
  - Decades of use
  - Up to 20 percent limestone allowed in EN197-1 CEM II/A and 35 percent in CEM II/B
- Allowed in Canada since 2008
  - Up to 15 percent limestone
- ASTM C595 and AASHTO M 240 adopted Portland Limestone Cement classification 2012

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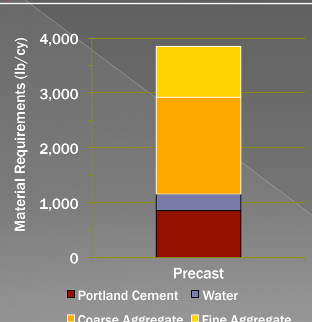
Typical Precast Concrete Mixture



Typical Precast Mixture (7500 psi)

850 pcy OPC
300 pcy Water
1770 pcy Coarse Agg.
935 pcy Fine Agg.

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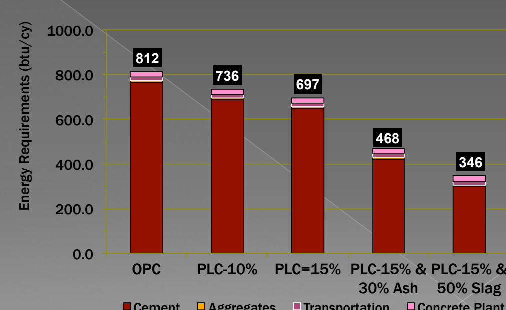
Energy Consumption per cubic yard of Concrete



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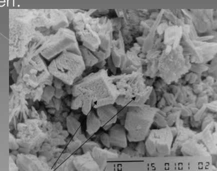
Interactions of Limestone with Other Cement Constituents

- Limestone acts as filler? - The fine particles:
  - Improve packing, leading to denser paste
  - Optimize water demand
  - Reduce bleeding

- Limestone is not completely inert.
  - It reacts with C_3A from the clinker and produces monocarbonaluminate
  - Because it reacts with C_3A, limestone decreases gypsum requirements



$CaCO_3$ crystal in a 1-d cement paste

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Equivalent or Improved

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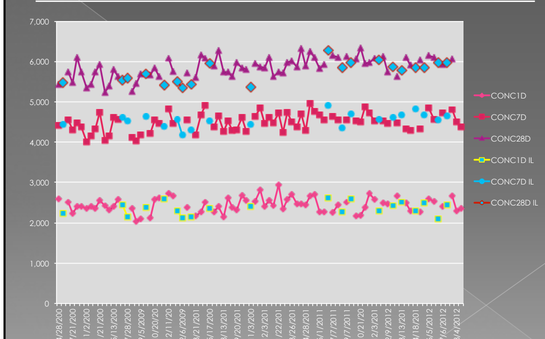
HH Concrete Testing 564 lb. cement at a 0.51 w/c)



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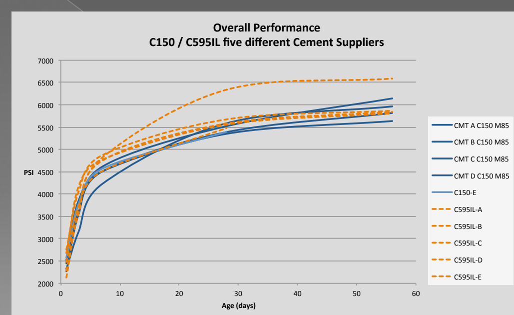
Georgia IL Study



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Georgia Testing Program

Lab Data Summary	Cement Company "A"							
	1	2	3	4	5	6	7	8
Mix Date	**08/13/12**	**08/13/12**	**08/13/12**	**08/13/12**	**08/13/12**	**08/13/12**	**08/13/12**	**08/13/12**
Mix Code	**C150 M85**	**C595IL M240**	**C150 M85** Fash	**C595IL M240** Fash	**C150 M85** Cash	**C595IL M240** Cash	**C150 M85** GGBFS	**C595IL M240** GGBFS
Cement	**611**	**611**	**458**	**458**	**458**	**458**	**367**	**367**
GGBFS							**244**	**244**
Boral Bowen F Ash			**153**	**153**				
Miller C Ash					**153**	**153**		
Total Cementitious	**611**	**611**	**611**	**611**	**611**	**611**	**611**	**611**
Aggregate								
Hanson Tyrone Coarse	1851	1851	1851	1851	1851	1851	1851	1851
Brown Brothers Sand	1098	1098	1176	1176	1112	1112	1118	1118
Design Air (%)	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Design Water (lbs)	306	306	290	290	290	290	290	290
Total wt	3866	3866	3928	3928	3864	3864	3870	3870
Design (W/Cm)	0.501	0.501	0.475	0.475	0.475	0.475	0.475	0.475
Admixture								
Euclid A+ (oz/cwt)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
uclid AEA 92S (oz/yard)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50

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Chemical Data

	ASTM C150					ASTM C595 IL					
	C150 "A" 12-08-1266	C150 "B" 12-08-1267	C150 "C" 12-08-1268	C150 "D" 12-08-1269	C150 "E" 12-08-1270	C595 "A" 12-08-1271	C595 "B" 12-08-1272	C595 "C" 12-08-1273	C595 "D" 12-08-1274	C595 "E" 12-08-1275	
Density (SG)	3.1669	3.1780	3.1653	3.1527	3.1685	3.1151	3.1474	3.1534	3.0975	3.1540	
Blaine	397	349	414	413	416	671	481	501	511	446	
(air Jet) 45mm Retain %	4.044	3.912	1.500	8.602	2.808	1.548	1.092	1.924	8.052	2.218	
(air Jet) 45mm Passing %	95.956	96.088	98.500	91.398	97.192	98.452	98.908	98.076	91.948	97.782	
SiO2	19.38	18.91	19.92	19.21	19.75	16.91	17.75	18.59	17.98	19.18	%
Al2O3	4.76	4.89	5.00	5.62	4.58	4.10	4.66	4.63	5.38	4.40	%
Fe2O3	3.16	3.62	3.83	3.52	3.31	2.79	3.34	3.34	3.30	3.27	%
CaO	62.53	63.21	63.34	63.99	62.71	61.11	61.83	62.27	62.50	62.09	%
MgO	3.19	2.87	1.56	0.76	2.78	3.23	2.88	1.38	0.75	2.84	%
SO3	3.22	2.65	3.16	3.16	3.36	3.19	2.73	2.84	3.69	3.15	%
Na2O	0.081	0.184	0.203	0.121	0.102	0.071	0.157	0.175	0.124	0.085	%
K2O	0.503	0.572	0.502	0.604	0.629	0.418	0.495	0.411	0.588	0.617	%
P2O5	0.055	0.064	0.220	0.211	0.085	0.070	0.064	0.198	0.204	0.085	%
TiO2	0.261	0.268	0.272	0.322	0.236	0.239	0.251	0.257	0.316	0.229	%
SrO	0.033	0.072	0.079	0.201	0.054	0.035	0.072	0.075	0.198	0.053	%
Mn2O3	0.058	0.202	0.132	0.048	0.065	0.064	0.194	0.102	0.045	0.065	%
Cr2O3	0.009	0.025	0.023	0.013	0.011	0.009	0.025	0.018	0.013	0.009	%
ZnO	0.008	0.114	0.137	0.028	0.014	0.009	0.107	0.097	0.023	0.014	%
L.O.I.	2.75	2.34	1.61	2.19	2.33	7.76	5.44	5.62	4.89	3.92	%
Sum Of Conc.	100	100	100	100	100	100	100	100	100	100	%
C3S	51.3	60.0	56.2	56.8	54.2	Not required under C595					%
C2S	16.8	9.0	14.7	12.2	15.7						%
C3A	7.3	6.8	6.8	9.0	6.5						%
C4AF	9.6	11.0	11.7	10.7	10.1						%
Total Alkali	0.412	0.560	0.533	0.518	0.515	0.347	0.483	0.445	0.511	0.490	%
CO2	1.98	1.55	0.43	1.14	1.14	6.83	4.88	5.00	3.41	2.65	wt%
CaCO3 in Limestone (Purity)**	97	95.3	90.1	75.9	97.5	97	95.3	90.1	75.9	97.5	%
Limestone In Cement	**4.6**	**3.7**	**1.1**	**3.4**	**2.7**	**16.0**	**11.6**	**12.6**	**10.2**	**6.2**	%

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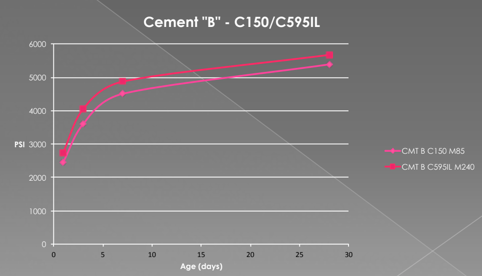
Limestone Content at 10.57%



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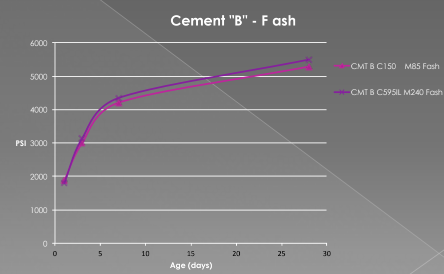
Limestone Content at 10.57%



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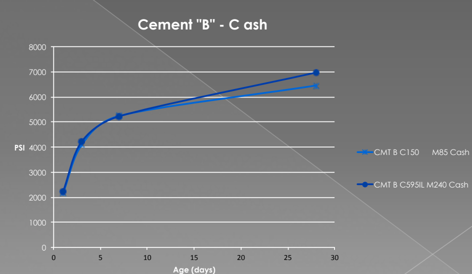
Limestone Content at 10.57%



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Limestone Content at 10.57%

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Rapid Chloride Ion Permeability Testing (ASTM 1202)

Georgia PCA Group	Rapid Chloride Ion Permeability Testing (ASTM 1202)								
	Cement E		Cement B		Cement C		Cement D		
Mix Date	08/13/12	08/13/12	08/13/12	08/13/12	08/13/12	08/13/12	08/13/12	08/13/12	
	CMT E	CMT E	CMT B	CMT B	CMT C	CMT C	CMT D	CMT D	
Mix Code	C150 M85	C595IL M240	C150 M85	C595IL M240	C150 M85	C595IL M240	C150 M85	C595IL M240	
			F_ash	F_ash	C_ash	C_ash	GGBFS	GGBFS	
Cement	611	611	458	458	458	458	367	367	
GGBFS							244	244	
Boral Bowen F Ash			153	153					
Miller C Ash					153	153			
Total Cementitious	611	611	611	611	611	611	611	611	
C1202 Rapid Chloride									
56 day RCP (avg of 2 specimens)	3598	3842	2262	1978	4566	1650	1115	738	> 4000 "High"
Reading 1			2226	2036	4483	1703	1133	738	2000-4000 "Moderate"
Reading 2			2297	1920	4648	1597	1096	738	1000-2000 "Low"

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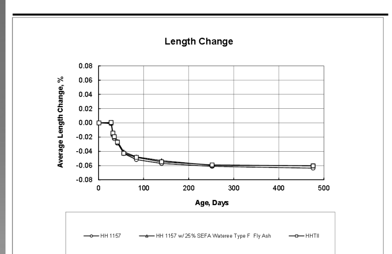
Test Results - ASTM C 157
Length Change of Hardened Concrete
Summary for 500 lb Concrete Mixes



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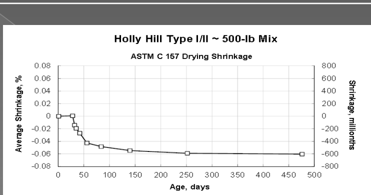

Specimen Measurements

Date	Age, days	Condition	A	B	C
07/29/2009	1	(3)	-563	-856	-174
08/25/2009	28	(3)	-563	-853	-175
08/29/2009	32	dry	-578	-868	-190
09/01/2009	35	dry	-584	-872	-195
09/08/2009	42	dry	-592	-880	-202
09/22/2009	56	dry	-610	-895	-216
10/20/2009	84	dry	-618	-900	-220
12/15/2009	140	dry	-623	-907	-227
04/06/2010	252	dry	-627	-912	-231
11/16/2010	476	dry	-628	-914	-232

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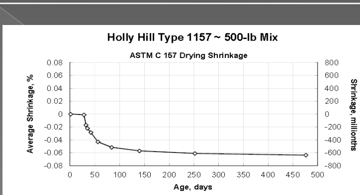

Specimen Measurements

Date	Age, days	Condition	A	B	C
07/29/2009	1	(3)	-1063	-626	(4)
08/25/2009	28	(3)	-1068	-623	(4)
08/29/2009	32	dry	-1085	-638	(4)
09/01/2009	35	dry	-1089	-644	(4)
09/08/2009	42	dry	-1097	-649	(4)
09/22/2009	56	dry	-1110	-665	(4)
10/20/2009	84	dry	-1119	-673	(4)
12/15/2009	140	dry	-1124	-679	(4)
04/06/2010	252	dry	-1129	-682	(4)
11/16/2010	476	dry	-1131	-685	(4)

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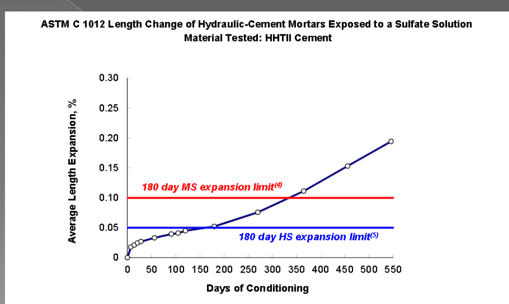

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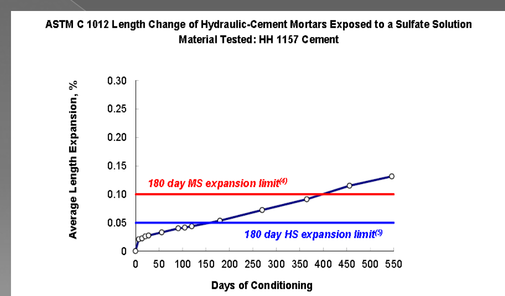

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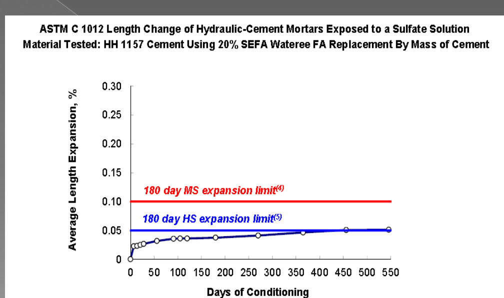

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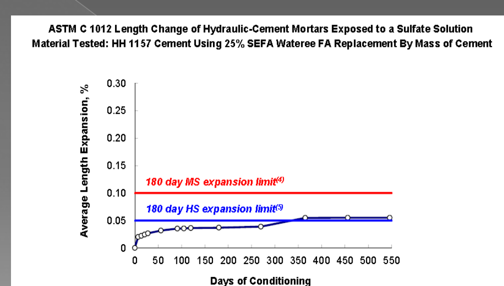

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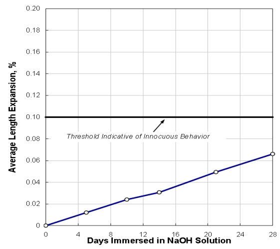
ASTM C 1567 Length Change Due to Alkali-Silica Expansion Testing For a Coarse Aggregate Identified as Vulcan/Gold Hill Quarry and the Submitted HH 1157 Cement with 20% SEFA Wateree Class F Fly Ash Replacement by Weight of Cementitious Materials



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RAPID CHLORIDE PERMEABILITY RESULTS
ASTM C 1202 (AASHTO T 277)

HH 1157 Cement ~ 564-lb Mix

Sample No. (Client ID)	Test Date	Charge Passed (Coulombs)	Relative Chloride Permeability
HH 1157 Cement Sample A	08-27-09	2423	Moderate
HH 1157 Cement Sample B	08-27-09	2516	Moderate

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RAPID CHLORIDE PERMEABILITY RESULTS
ASTM C 1202 (AASHTO T 277)

HH 1157 Cement with 20% SEFA Wateree Class F Fly Ash ~ 564-lb Mix

Sample No. (Client ID)	Test Date	Charge Passed (Coulombs)	Relative Chloride Permeability
HH 1157 Cement w 20% SEFA Wateree Class F FA Sample A	08-27-09	1274	Low
HH 1157 Cement w 20% SEFA Wateree Class F FA Sample B	08-27-09	1245	Low

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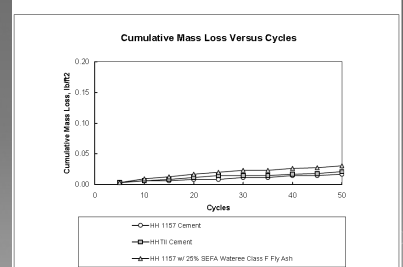
Test Results - ASTM C 672
Scaling Resistance of Concrete Surface Exposed to Deicing Chemicals
Summary of Cumulative Mass Loss Versus Cycles
for 500 lb Concrete Mixes



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Summary PLC

- perform equivalent to or improved over OPC in strength and durability
- lower environmental impact
- performs equally with fly ashes and slag cements

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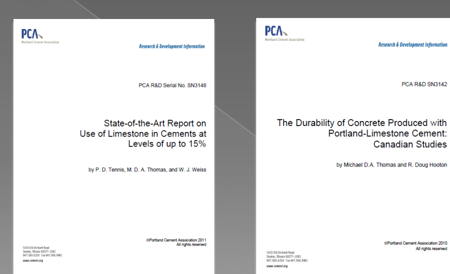
Additional information



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Thoughts?

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Requirements for *Limestone* for Use in Blended Cements

	Test Method	Limit
$CaCO_3$ content	C114/T105	Min. 70%
Methylene blue index	See Annex A2	Max. 1.2 g/100g
Total organic carbon	See Annex A3	Max.0.5%

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How do Portland-Limestone cements perform in the field?

- Equal or improved to C150 cements
  - Strength
  - Set time
  - Water demand
  - Compatibility with fly ash
  - Compatibility with admixtures
- Improved finishability
- Lower environmental impact

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Permeability Binary vs. Ternary

Permeability is a function of:

- WCR
- Cementitious factor
- Use of SCM's

Material	Typical Coulomb Values
Portland Cement	3500 coulombs +
Slag Cement	800 – 1800 coulombs
Fly Ash	1600 – 2300 coulombs
Slag / Fly Ash	900 – 1800 coulombs
Silica Fume	400 – 900 coulombs
Slag / Silica Fume	400 – 800 coulombs

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Influence of Slag on concrete properties

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