APPENDIX J.

CTLGROUP REPORTS

TESTING AND EVALUATION OF ECOMELT

EVALUATION OF ECOMELT IN CONCRETE TESTING

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May 5, 2007

Ken Partymiller
TetraTech EM Inc.
5326 Paris Pike
Georgetown, KY 40324

Testing and Evaluation of Ecomelt

Dear Ken:

The report on the Testing and Evaluation of Ecomelt from TetraTech EM Inc. is enclosed. If you have any questions regarding this report, please don't hesitate to contact me.

CTLGroup appreciates the opportunity to work with you on this project, and trusts that we will find additional opportunities to work together.

Sincerely:

Javed Bhatty, Ph.D
Senior Scientist, Material Science and Consulting
Tel: 847 972 3082, Fax (847) 965 6541
jbhatty@ctlgroup.com.

TESTING AND EVALUATION OF ECOMELT

Javed I. Bhatty[1]

SUMMARY

A sample of Ecomelt generated from Passaic River sediment at the Cement-Lock demonstration plant in Bayonne, NJ was received from Tetra Tech EMI (Tetra Tech) for evaluation as a pozzolan for use in cement blends. The as-received material was tested for its physical, chemical, microscopical, and mineralogical properties. Subsequently, the Ecomelt was finely ground and made into a 40:60 Ecomelt:cement blend to test for its engineering properties. The 40:60 Ecomelt:cement blend was evaluated in accordance with ASTM C 1157 and ASTM C 595 specifications for blended hydraulic cements. The material was evaluated as 1) Type GU, hydraulic cement for general construction, and 2) Type HE, high early strength – both under Designation ASTM C 1157, "Standard Performance Specification for Hydraulic Cement." The 40:60 Ecomelt:cement blend was also evaluated as 1) Type S, slag cement, 2) Type I(SM), slag-modified Portland cement, and 3) Type IP, Portland-pozzolan cements – all under Designation: ASTM C 595, "Standard Specification for Blended Hydraulic Cements."

Based on the preliminary data from chemical and physical testing, the Ecomelt appears to exhibit pozzolanic activity. Mortars made with a 40:60 blend of Ecomelt and portland cement complied with the performance requirements of both Type GU and Type HE hydraulic cements – which, according to ASTM C 1157 specifications, are designated as hydraulic cements for general construction and high early strength hydraulic cement, respectively.

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[1] Senior Scientist, Materials Science and Consulting, CTLGroup, 5400 Old Orchard Road, Skokie, Illinois 60077, Tel: 847 972 3082, Fax: 847 865 6541, Jbhatty@CTLGroup.com

INTRODUCTION

Two 5-gallon buckets of Ecomelt were received from Tetra Tech EMI for evaluation. After the characterization of the Ecomelt, the material was finely ground and a 40:60 blend of the Ecomelt and portland cement was produced for further testing. The following tests were conducted on the as-received Ecomelt as well as on the 40:60 Ecomelt:portland cement blend.

CHARACTERIZATION OF ECOMELT

The as-received Ecomelt sample was a granular mixture of fine, coarse, and flaky fractions as shown in (Figure 1).

Figure 1. As-received Ecomelt is a mixture of fine, coarse, and flaky fractions

Physical Characterization

Moisture Content - ASTM C 311: The as-received Ecomelt was placed in an oven at 105 to 110°C to dry the material to a constant weight in order to determine moisture content. The weight loss was recorded and the moisture content was determined to be 3.54 weight percent (wt. %).

Particle Size Analysis - ASTM C 136: The dried as-received Ecomelt sample was screened through a set of ASTM standard sieves to determine particle size distribution. Sieving was continued for sufficient time so that not more than 1% of the residue on the sieve passed during one minute of continuous sieving. The fractions retained on sieves and the distribution of particle size is shown in Figure 2a, b, and Table 1.

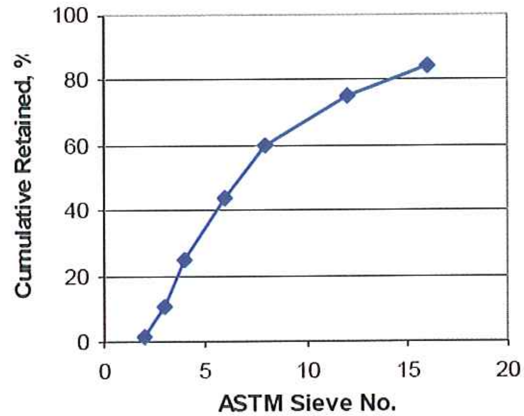
a)  b) 

Figure 2. a) Size fractions and b) size distribution of as-received dried Ecomelt

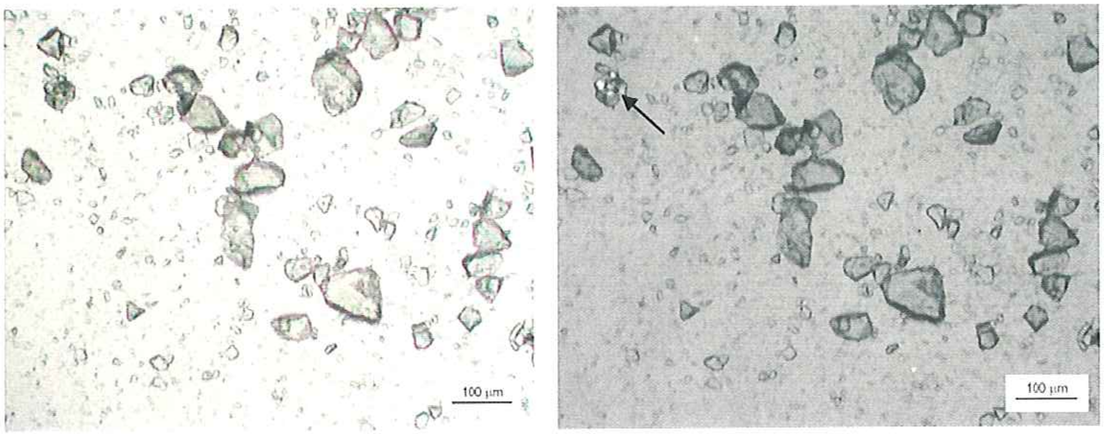
Table 1. Particle size distribution of as-received Ecomelt

ASTM Sieve No.	Sieve Size, microns	Amount Retained, g	Cumulative Retained, g	Cumulative, %
+ ½ "	12500	35	35	1.3
- ½ + ¼"	6300	258	293	10.6
- ¼" + 4	4750	392	685	24.8
- 4 + 6	3350	527	1212	43.8
- 6 + 8	2360	442	1654	59.8
- 8 +12	1700	425	2079	75.2
- 12 + 16	1180	250	2329	84.3
Passing 16	Passing 1180	435	2764	100.0
Total		2764	–	–

The median particle size of the as-received Ecomelt is between sieve No. 6 and 8; i.e. close to 3000 microns (3 mm).

Density Determination - ASTM C128: A representative sample of the as-received dried Ecomelt was tested for density in accordance with the ASTM C 128 procedure. The density was determined to be 2.67 g/cm^3.

Microscopical Examination: A ground sample of the as-received dried Ecomelt was subjected to microscopical examination using ordinary as well as cross-polarized transmission light in order to determine the glassy phase. The examination suggested that the material is predominantly glassy (Figure 3a and 3b). In Figure 3b, the glassy portion of the sample appears transparent. The bright speck (arrow) is the crystalline fraction.



a) b)

Figure 3. a) Ecomelt under plane polar light; b) Ecomelt under cross-polar light, small bright speck at the top left corner (arrow) is crystalline fraction, rest is all glassy

X-RAY Diffraction Analysis: A broad hump around the 2Θ angle of 28 (Figure 4) in the XRD pattern, confirms the presence of an abundance of glassy phase in the Ecomelt sample.

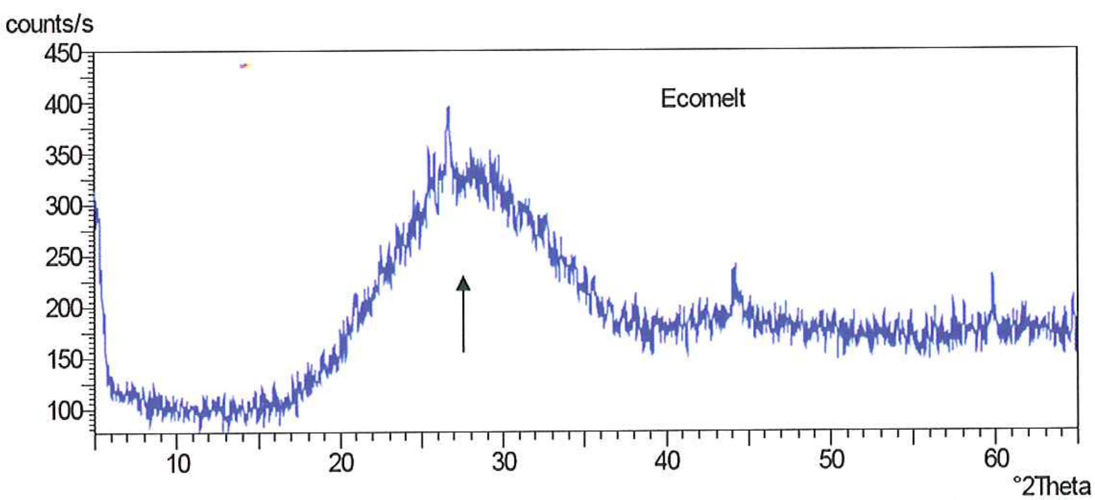


Figure 4. XRD pattern of Ecomelt; hump at the 2Θ angle of 28 confirms glassy phase

Chemical Characterization

Oxide Analysis: A representative sample of the dried Ecomelt was finely ground and analyzed for oxide composition using X-ray fluorescence (XRF) analytical technique. The analysis data are shown in Table 2.

Table 2. Major and minor oxides in Ecomelt

Oxide	Mass, %
SiO_2	52.43
Al_2O_3	16.98
Fe_2O_3	5.41
CaO	18.79
MgO	1.73
SO_3	0.14
Na_2O	1.25
K_2O	1.54
TiO_2	0.67
P_2O_5	0.56
Mn_2O_3	0.11
SrO	<0.01
Cr_2O_3	0.06
ZnO	0.05
L.O.I. (950°C)	– 0.13
$SiO_2 + Al_2O_3 + Fe_2O_3$	74.82
Alkalies as Na_2O equivalent	2.27

Preparation of 40:60 Ecomelt:Cement Blend

Crushing and Grinding of Ecomelt and Fineness Determination: A bulk portion of dried Ecomelt was crushed in a gyratory crusher to pass ASTM No. 6 sieve (Figure 5).

Figure 5. Ecomelt after crushing in a gyratory crusher

The material was then ground in a ball mill until 90% of the material passed the ASTM No. 325 (45μm) sieve. The ground Ecomelt was also tested to determine its Blaine fineness which is a measure of the relative surface area to mass of a sample. The Blaine fineness was 459 m^2/kg. For comparison, Portland cement is typically ground to a Blaine fineness of about 350 m^2/kg. The ground Ecomelt was used in a 40:60 Ecomelt:portland cement blend for the tests outlined in the next section. Samples of ground Ecomelt, 40:60 blend, and portland cement are shown in Figure 6.

Figure 6. (From left) 40:60 Ecomelt:portland cement blend, Ecomelt, and portland cement

TESTING AND EVALUATION OF 40:60 ECOMELT:CEMENT BLEND

Chemical Requirements

Several chemical tests were conducted on the 40:60 Ecomelt:portland cement blend to check for compliance with the ASTM C 595 chemical requirements. These included 1) determination of sulfur as sulfide (S), 2) sulfur as sulfate (SO_3), and 3) insoluble residue. The data and the corresponding standard limits are shown in Table 8.

Table 8. Chemical data on 40:60 Ecomelt:portland cement blend

Tests Conducted	Determined values, %
Sulfur as sulfide (S)	0.030
Sulfur as sulfate (SO_3)	1.65
Insoluble residue	10.03

Physical Testing

Time of Setting - ASTM C 191: The setting time of a neat paste made with 40:60 Ecomelt:portland cement blend was measured by Vicat needle apparatus. The initial time of setting was determined to be 195 minutes, which is well within the minimum and maximum limits of 45 and 420 minutes as allowed by ASTM C 595 and C 1157.

Heat of Hydration - ASTM C 186: The heat of hydration of fresh paste made with the 40:60 Ecomelt:portland cement blend was measured in accordance with the method outlined in ASTM C 186. The heat of hydration values obtained at 7 and 28 days are given in Table 3. The recorded heat of hydration is marginally higher than the ASTM C 595 limit.

Table 3. Heat of hydration of 40:60 Ecomelt:portland cement blend at 7 and 28 days

Test Time	Heat of Hydration, kJ/kg
7-day	293
28-day	408

Compressive Strength - ASTM C 109: Two-inch mortar cubes were prepared with the 40:60 Ecomelt:portland cement blend using a mixing procedure in ASTM C 109. Deionized water was used as the mix water keeping a constant water/cementitious material ratio (w/cm) of 0.484. Mortars cubes were cast in triplicate and left overnight in a moist room at ambient temperature. Thereafter, the cubes were demolded and cured in a moist room maintained at close to 100% relative humidity. Sample cubes before after testing are shown in Figure 7.

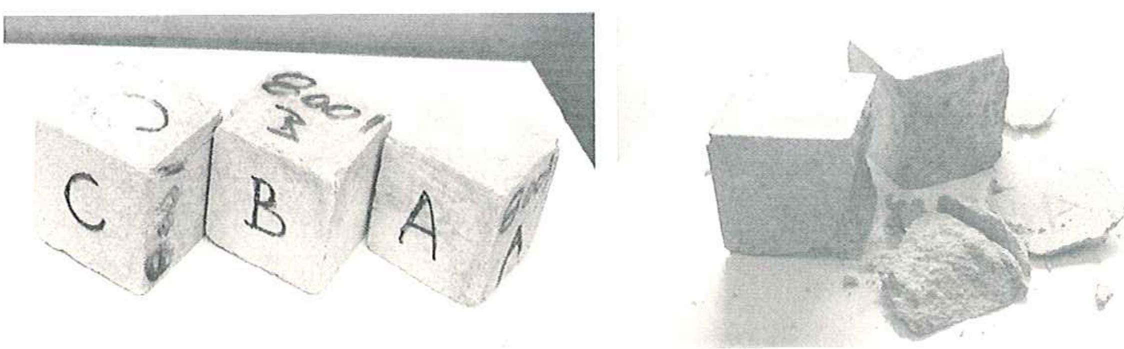


Figure 7. Test cubes before and after compressive strength testing

The cubes were tested for compressive strength after 1, 3, 7, and 28 days. Three cubes were tested at each age and the average value was recorded. Strength comparison of 40:60

Ecomelt:cement mortar was also drawn with mortar made with cement only (control), as shown by data in Table 4.

Table 4. Compressive strength of 40:60 Ecomelt:portland cement blend mortar and comparison with control

Test Periods	Compressive Strength, psi (MPa)				
	40:60 Ecomelt:portland cement mortar				Control mortar, Average
	Sample 1	Sample 2	Sample 3	Average	
1 Day	1803	1753	1843	1800 (12.4)	–
3 Day	3715	3698	3630	3680 (25.4)	3690 (25.5)
7 Day	5300	5233	5353	5300 (36.5)	4860 (33.6)
28 Day	7305	7610	7735	7550 (52.1)	6900 (47.8)

The data indicate that the average strength of mortar made with 40:60 Ecomelt:portland cement exceeded the strengths of the control mortar at 7 and 28 days. Mortars made with 40:60 Ecomelt:cement blend also conformed to both ASTM C 595 and ASTM C 1157 strength requirements. As expected, the compressive strength increased with curing time.

Air Content - ASTM C 185: The air content of fresh mortar made with the 40:60 Ecomelt:portland cement blend was measured in accordance with the procedure outlined in the ASTM C 185. The air content was determined to be 5% by volume (Table 5), which is well within the specified ASTM C 595 maximum limit of 12%.

Table 5. Air content of 40:60 Ecomelt:portland cement blend mortar

Sample tested	Air Content, volume %
40:60 Ecomelt:cement blend	5

Autoclave Expansion/Contraction - ASTM C 151: A test mortar bar was prepared with 40:60 Ecomelt:portland cement blend and tested according to ASTM C 151 method. The results were compared with a mortar bar made with portland cement (control). The mortars were cast as 1 x 1 x 10-inch bars and cured overnight. The bars were demolded, measured for length using a comparator and then placed in the autoclave (high pressure steam vessel) at a saturated steam pressure of 295 ± 10 psig (nominal temperature of 420°F) for 3 hours (Figure 8a). Thereafter, the bars were taken out of the autoclave (Figure 8b), cooled, and measured for any length change. The percent increase/decrease in length to the nearest 0.01% is reported as autoclave expansion/contraction. The results are shown in Table 6:

a) b)

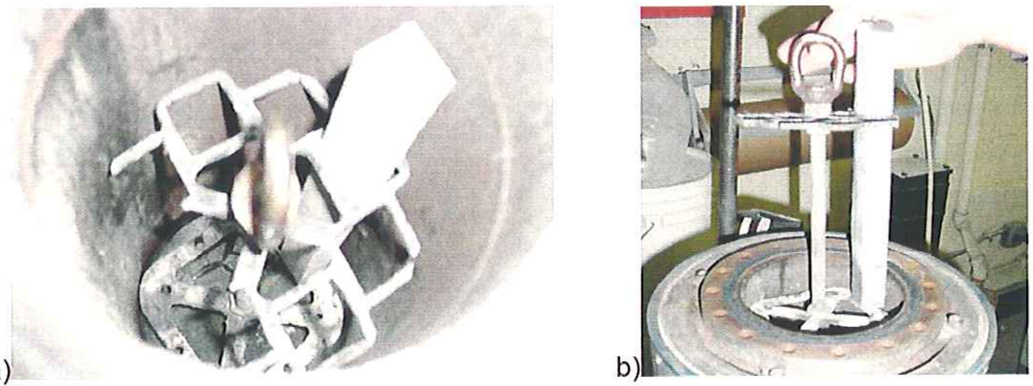


Figure 8 (a, b). Ecomelt:portland cement mortar bar in autoclave expansion test

Table 6. Autoclave expansion/contraction data on 40:60 Ecomelt:portland cement mortars

Sample tested	Expansion/contraction, %
40:60 Ecomelt: cement blend	– 0.047

There was no significant expansion or contraction of mortar bars made with the Ecomelt:portland cement blends. This is a favorable result of using a pozzolanic material.

Mortar Expansion (ASR) - ASTM C 227: Test mortar bars were prepared with 40:60 Ecomelt:portland cement blend as 1 x 1x 10-inch bars and cured overnight. The bars were demolded, measured for length, and then placed in a sealed container at 100°F. The bars were measured for length change after withdrawing from the container when 14 days old. Any change to the nearest 0.01% is reported. Test data is shown in Table 7.

Table 7. Mortar expansion (ASR) data on Ecomelt:portland cement mortars

Sample tested	Expansion, %
40:60 Ecomelt: cement blend	– 0.003

Again, there was no expansion in the mortar bars made with the Ecomelt:portland cement blends. Instead a contraction of 0.003% was noted. This suggests that the Ecomelt has a negligible tendency for ASR reactivity. ASR – the alkali-silica reaction – is expansive in nature, and occurs between the alkali in the pores of the concrete and reactive silica in some aggregates. Expansion caused by ASR can result in cracking of concrete.

A summary of the overall test results on the 40:60 Ecomelt:portland cement blend and its comparison with both ASTM C 595 and ASTM C 1157 requirements are shown in Table 9.

Table 9. Overall summary of 40:60 Ecomelt:cement blend data and ASTM requirements

Standard Tests Conducted	ASTM Requirements					Test Data	Comment
	ASTM C 595			ASTM C 1157			
	I(SM)	IP	S	GU	HE		
Chemical Tests							
Magnesium Oxide (MgO), max %	*–	6.0	–	–	–	1.73	#meets
Sulfur reported as SO_3, max %	3.0	4.0	4.0	–	–	1.65	meets
Sulfide Sulfur (S), max %	2.0	–	2.0	–	–	0.03	meets
Insoluble residue, max %	1.0	–	1.0	–	–	10.03	does not meet
Loss on ignition, max %	3.0	5.0	4.0	–	–	– 0.13	meets
Physical Tests							
Air content of mortar, max vol., %	12	12	12	–	–	5	meets
Autoclave expansion, max, % Autoclave contraction, max, %	0.80 0.20	0.80 0.20	0.80 0.20	0.80 –	0.80 –	– 0.047	meets
Heat of hydration 7 days, max kJ/kg 28 days, max kJ/kg	 290 330	 290 330	 – –	 – –	 – –	 294 408	does not meet
Initial time of set, min, minutes Initial time of set, max, minutes	45 420	45 420	45 420	45 420	45 420	195	meets
Strength, compression, min, psi 1 day 3 days 7 days 28 days	 – 1890 2900 3620	 – 1890 2900 3620	 – – 720 1600	 – 1450 2465 4060	 1450 2465 – –	 1800 3680 5300 7550	 meets meets meets meets
ASR Expansion,14 days, max %	0.02	0.02	0.02	0.02	0.02	– 0.003	meets

*– No specifications prescribed; #Meets required ASTM requirements

It is evident from the above data and comparison with the standard specifications, that the 40:60 Ecomelt:portland cement blend conforms to both Type GU and Type HE hydraulic cements designated by ASTM C 1157 performance specification. Type GU is designated as hydraulic cement for general construction, whereas Type HE is designated as high early strength hydraulic cement.

Except for heat of hydration and insoluble residue – for which the Ecomelt:portland cement blend exceeded the maximum limits – the 40:60 Ecomelt:portland cement blend conforms to Type I(SM) and Type IP hydraulic cement requirements as designated by ASTM C 595 specification.

CONCLUSIONS AND RECOMMENDATIONS

The mineralogical and microscopical examinations suggest that the Ecomelt is pozzolanic in nature. A blend of 40:60 Ecomelt:portland cement and mortars prepared with it complied with the requirements of Type GU and Type HE cements designated in ASTM C 1157 performance specification. The Ecomelt appears to be potentially suitable as a 40% replacement for portland cement in concrete for use in general construction and/or where high early strength is required. However, CTLGroup recommends that additional testing such as effects on durability including frost resistance, freeze-thaw, scaling, admixture compatibility be conducted on a larger batch of Ecomelt so that an appropriate concrete mix design can be developed for a specific application.

Gas Technology Institute

Project Number 054557

Evaluation of Ecomelt in Concrete Testing

Date:
May 1, 2008

Submitted by:
Javed I. Bhatty

CTLGroup
5400 Old Orchard Road
Skokie, Illinois 60077-1030
(847) 965-7500

9030 Red Branch Road, Suite 110
Columbia, Maryland 21045

www.CTLGroup.com

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EVALUATION OF ECOMELT IN CONCRETE TESTING

by

Javed I. Bhatty[1]

SUMMARY

A sample of Ecomelt was received from Gas Technology Institute for evaluation as partial replacement for portland cement in producing concrete for construction purposes. The material was finely ground so that more than 95% passed the # 325 sieve size. Concrete specimens were fabricated using a blend of 40% ground Ecomelt and 60% Type I/II portland cement. Concrete was tested for a number of ASTM standard test methods that included: ASTM C 403 setting time, ASTM C 39 compressive strength, ASTM C 78 flexural strength, air-content, ASTM C 157 drying shrinkage, ASTM C 666 freeze-thaw resistance, ASTM C 672 deicing-scaling, and ASTM C 1202 resistance to chloride permeability. The results were compared with control concrete samples made under identical conditions but using portland cement only. The objective of these tasks was to determine if the ground Ecomelt could be used as a partial cement supplement in concrete without impacting typical engineering properties.

The data indicate that 40% replacement of cement by ground Ecomelt could produce concrete with properties comparable to those of the control concrete. The setting times for portland blend were slightly longer and the initial strengths were lower. The 56-days compressive and flexural strengths were, however, comparable with those of the control. The results of drying shrinkage and freeze-thaw resistance tests were also comparable to those of the control. Resistance to chloride permeability was noticeably better for the Ecomelt/portland concrete specimen as compared to the control. However, concrete made with Ecomelt displayed more deterioration compared to the control when subjected to the deicer salt-scaling tests.

INTRODUCTION

This report consists of results obtained from the testing and evaluation of a sample of Ecomelt submitted to CTLGroup by Gas Technology Institute (GTI). The Ecomelt was produced from a sediment dredged from the Passaic River during a commercial-scale demonstration of the Cement-Lock® Technology. The Cement-Lock® Technology employs pyro-processing of

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1 Senior Scientist, CTLGroup, 5400 Old Orchard Road, Skokie, IL 60077

carefully proportioned blends of sediment with other ingredients to immobilize inorganic contaminants in the sediment while producing a marketable product usable in construction applications. Furthermore, the organic compounds in the sediments are reportedly destroyed and converted to innocuous carbon dioxide and water during the pyro-processing of the material (Rehmat et al, 1998).

ECOMELT GRINDING

The as-received Ecomelt sample was dry, free-flowing granular material. It contained coarse granules with presence of larger size glassy aggregates (Figure 1).

Figure 1 The As-Received Ecomelt Sample

The material was first crushed in a jaw crusher into a coarse-grained material followed by secondary crushing in a gyratory crusher to produce a feed for finish grinding (Figure 2).

Figure 2 The Crushed Ecomelt as Feed for Finish Grinding

Forty pounds (40 lbs) of the material was loaded into a ball mill for finish grinding. During the finish grinding process, the Ecomelt was repeatedly checked for its particle size until 95% passed the # 325 sieve. The ground material was stored in sealed bags for later testing in concrete.

BATCHING OF CONCRETE AND SPECIMEN PREPARATION

Concrete Mix Design: The ground Ecomelt was used as 40% by weight replacement of Type I/II portland cement. The mix designs used in the study are given in Table 1.

Table 1 Mix Design for Concrete Batching

Mixes	**Control**	**Test**
Type I Cement (%)	100	60
Ecomelt (%)	0	40
Surface Saturated Dry (SSD) Mix Design		
Cement, Continental (lbs.)	564	338.4
Ecomelt (lbs.)	0	225.6
1" Coarse Aggregate, Vulcan (lbs.)	1875	1875
Fine Agg., McHenry Sand (lbs.)	1256	1222
Water, City (lbs.)	255	255
Air entraining agent (AEA), Daravair (oz/cwt.)	1.00	2.25
Water reducer (WR), WRDA 64 (oz/cwt.)	4.25	5.00
Fresh Properties		
Fresh Density (pcf)	145.4	145.4
Slump (in.)	4.00	4.00
Air Content (%)	6.2	5.7
Yield (cf/cy)	27.2	26.9
w/cm ratio	0.45	0.45
Time of Set (hr:min):		
Initial	6:21	6:33
Final	7:37	8:19

The w/cm (water to cementitious material ratio) for both the control and test mix was 0.45. Their slumps (4 in. vs. 4 in.), fresh density (145.4 pcf vs. 145.4 pcf), air contents (6.2% for control vs. 5.7% for test mix), and yields (27.2 cf/cy for control vs. 26.9 cf/cy for test mix), were also kept close to each other by adjusting the addition of air entraining (AEA, Daravair) and water reducing (WRDA 64) admixtures; data on these parameters are also given in Table 1.

The ingredients used in concrete and batch preparation are shown in Figures 3 and 4.

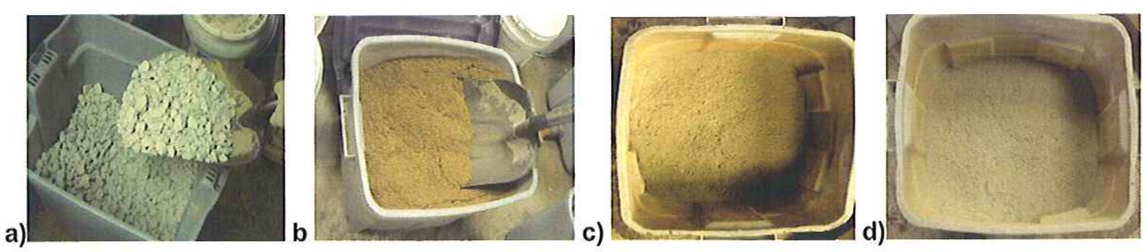

Figure 3 Ingredients Used in Making Concrete a) Coarse Aggregate, b) Fine Aggregate, c) Portland Cement, d) Ecomelt

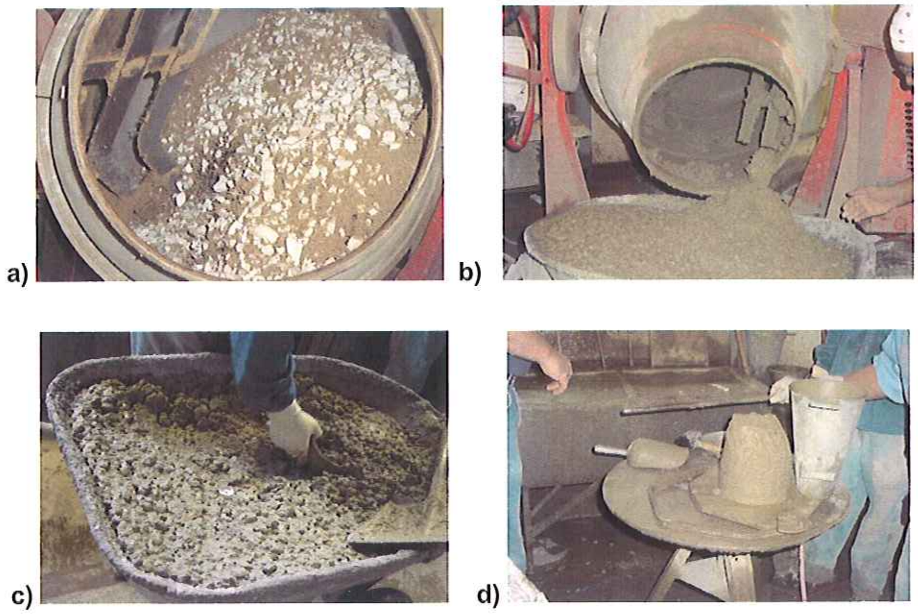

Figure 4 Concrete Batch Preparation

The concrete test specimens were prepared as per the specifications for the respective ASTM standard tests. The specimens were prepared for 1) compressive strength, 2) flexural strength, 3) deicer salt scaling, 4) drying shrinkage, 5) freeze-thaw testing, and 6) chloride-permeability (see Figure 5).

Figure 5 Concrete Specimen Preparation

TESTING AND EVALUATION

The fresh batch was used for making concrete specimens that were tested in accordance with the ASTM standard procedures as follows (Table 2):

Table 2 ASTM Tests Conducted on Concrete Specimens

Test	ASTM Designation	Test Specimen	Curing Regimens
Initial and Final Setting Times	**ASTM C 403/C 403M – 05**: Standard Test Method for Time of setting of concrete Mixtures by Penetration Resistance	Mortar fraction removed from fresh concrete by sieving over No. 4 sieve	Tested by penetration until reaching initial and final setting stages
Compressive Strength	**ASTM C 39/C 39M – 04a**: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	4 in. D x 8 in. L cylinders	Cured in 100% relative humidity (RH) until tested at 3*, 7, 28, and 56 days
Flexural Strength	**ASTM C 78 – 02**: Standard Test Method for Flexural Strength of (Using Simple Beam with Third – Point Loading)	3 in. x 3 in. x 11.25 in. prisms	Cured in 100% RH until tested at 3*, 7, and 28 days
Drying Shrinkage	**ASTM C 157M – 04**: Standard Test Method for Length Change of Hardened-Cement Mortars and Concrete	3 in. x 3 in. x 11.25 in. prisms cured at 100% RH in lime saturated water for 28 days then tested for drying shrinkage at 4, 7,14, and 28 days	Change in specimen length monitored
Freeze – Thaw Resistance	**ASTM C 666/C 666M – 03**: Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing	3 in. x 3 in. x 11.25 in. prisms cured at 100% RH for 14 days, then subjected to freezing/thawing for 301 cycles	Mass change (deterioration) in specimen monitored
Deicer – Scaling Resistance	**ASTM C 672/C 672M – 03**: Standard Test Method for Scaling Resistance of Concrete Surface Exposed to Deicing Chemicals	3 in x 12 in x 12 in. slabs cured at 100% RH for 14 days then at 45-55% RH for 14 days then exposed to deicing chemical for 50 cycles	Deicing salt 4% $CaCl_2$ used for testing, surface scaling (mass deterioration)) in specimen monitored
Rapid Chloride Permeability	**ASTM C 1202 – 97**: Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration	6 in. D x 12 in. L cylinders cured at 100% RH for 56 days and exposed to chloride ions	Charge (Coulombs) measure across the specimen - as a function of permeability

*4-day strength were reported instead as 3-day fell on weekends

The tests results are given in Tables 3 through 12, and Figures 6 through 15.

INITIAL AND FINAL SETTING TIMES (ASTM C 403/C 403M – 05)

Table 3 Setting Time of Concrete Mixes (Hrs:min)

Time of Set	Control Mix	Test Mix
Initial	6:21	6:33
Final	7:37	8:19
Difference	1:16	1:46

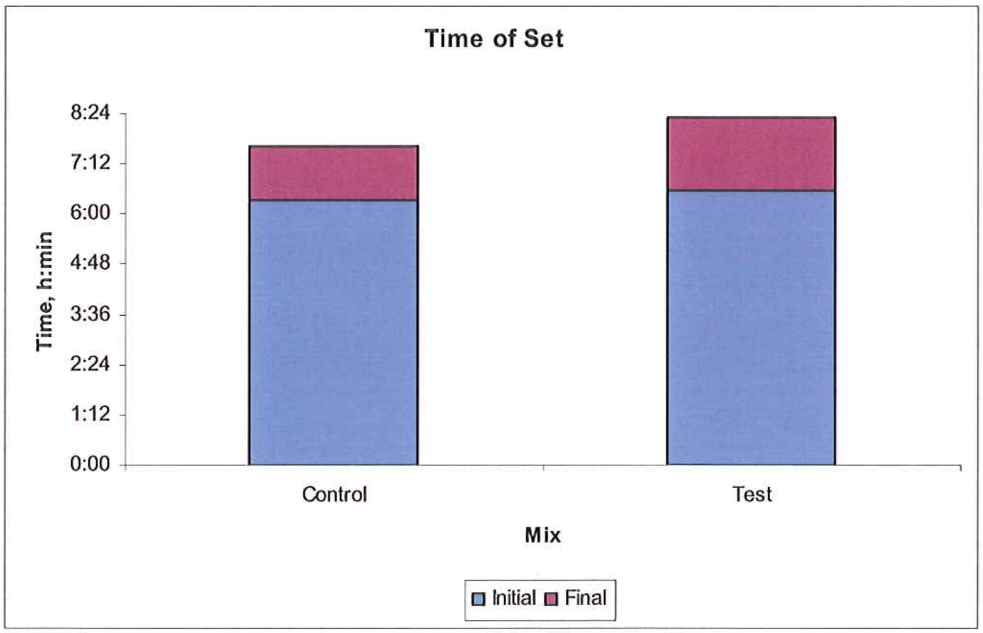

Figure 6 Initial and Final Times of Setting on Test Specimen and Control

COMPRESSIVE STRENGTH (ASTM C 39/C 39M – 04a)

Table 4 Compressive Strength (psi) of Test Specimens Compared with Control

Compressive Strength, 4"x8" Cylinders (psi) Ave. of 3 Specimens Each Age		
Test Age	**Control Mix**	**Test Mix**
4 Days*	4500	2850
7 Days	4800	3450
28 Days	5950	5700
56 Days	6650	6650

* 3rd day fell on a weekend

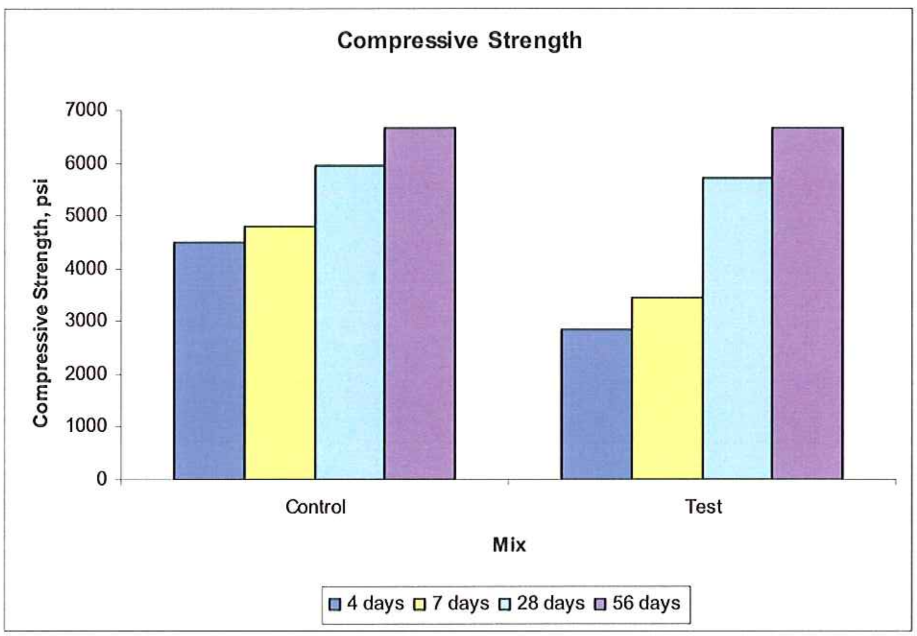

Figure 7 Compressive Strength (psi) of Test Specimen Compared with Control

FLEXURAL STRENGTH (ASTM C 78 – 02)

Table 5 Flexural Strength (psi) of Test Specimens Compared with Control

Flexural Strength, 4"x8" Cylinders (psi) Ave. of 3 Specimens Each Age		
Test Age	**Control Mix**	**Test Mix**
4 Days	690	510
7 Days	740	660
28 Days	920	910

DRYING SHRINKAGE (ASTM C 157M – 04)

Table 6 Drying Shrinkage

Length Change, %, Test Mix					
		Specimens			
Age, days	**Condition**	**A**	**B**	**C**	**Average**
1	*	0.000	0.000	0.000	0.000
28	**	0.004	0.004	0.002	0.003
31	dry***	-0.009	-0.011	-0.014	-0.013
34	dry	-0.013	-0.014	-0.017	-0.016
41	dry	-0.020	-0.020	-0.022	-0.021
55	dry	-0.030	-0.029	-0.032	-0.031

* Specimens demolded and initial measurement taken.

** Specimens stored at 73.4±3° F and immersed in lime-saturated water for 28 days, including the period in the molds.

*** Specimens tested in dry condition at room temperature.

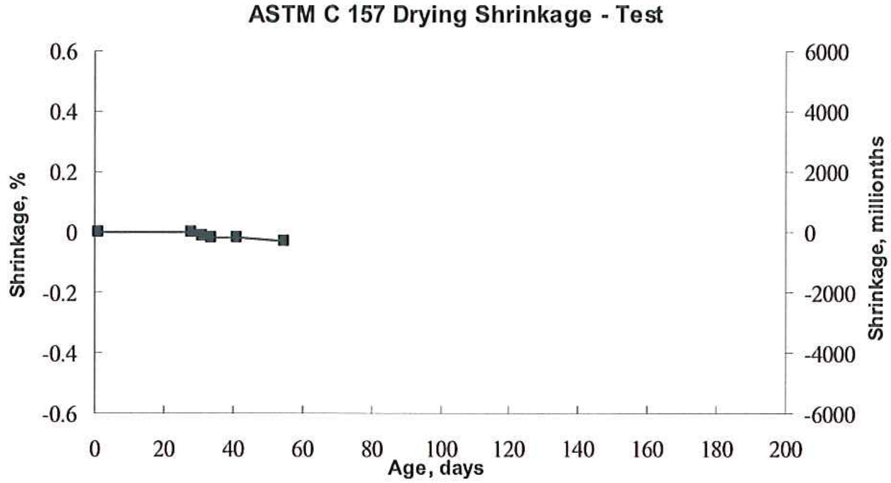

Figure 8 Length Change (%) of Test Specimens

Table 7 Drying Shrinkage

Length Change, %, Control Mix					
		Specimens			
Age, days	**Condition**	**A**	**B**	**C**	**Average**
1	*	0.000	0.000	0.000	0.000
28	**	0.005	0.002	0.002	0.002
32	dry***	-0.016	-0.016	-0.019	-0.017
35	dry	-0.019	-0.020	-0.022	-0.021
42	dry	-0.027	-0.027	-0.029	-0.028
56	dry	-0.037	-0.036	-0.039	-0.038

* Specimens demolded and initial measurement taken.

** Specimens stored at 73.4±3° F and immersed in lime-saturated water for 28 days, including the period in the molds.

*** Specimens tested in dry condition at room temperature.

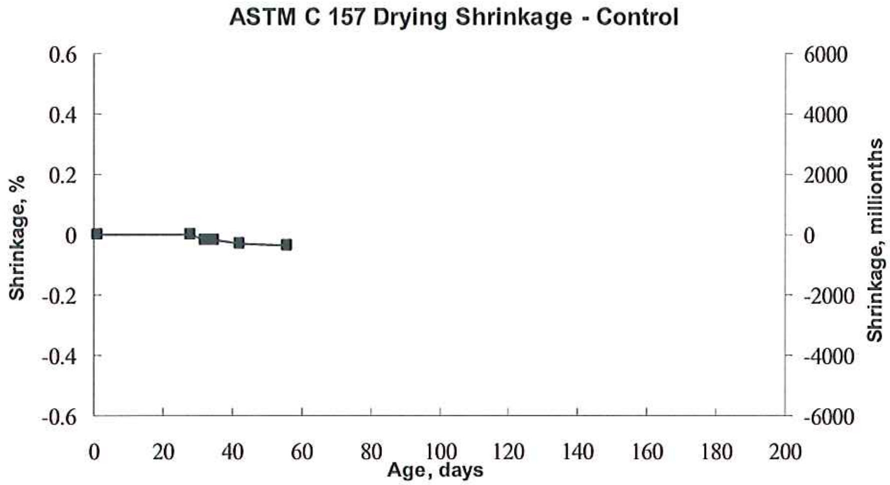

Figure 9 Length Change (%) of Control

FREEZING-THAWING (ASTM C 666)

Table 8 Freezing and Thawing (%) of Test Specimens

Test Results* of ASTM C 666 - Procedure A Freezing and Thawing in Water of Concrete Specimens Test Mix			
Cycles	Length change, %	Mass change, %	**RDM (1), %
0	0.000	0.00	100
33	0.000	- 0.16	91
65	0.001	- 0.62	91
98	0.000	- 0.55	91
132	0.000	- 1.32	90
162	0.000	- 1.42	90
201	0.000	- 2.10	89
245	0.000	- 2.52	89
288	0.000	- 3.10	89
301	0.000	- 3.27	91

* Values are an average of three specimens.
** RDM = Relative Dynamic Modulus
(1) Severe scaling observed for all specimens.

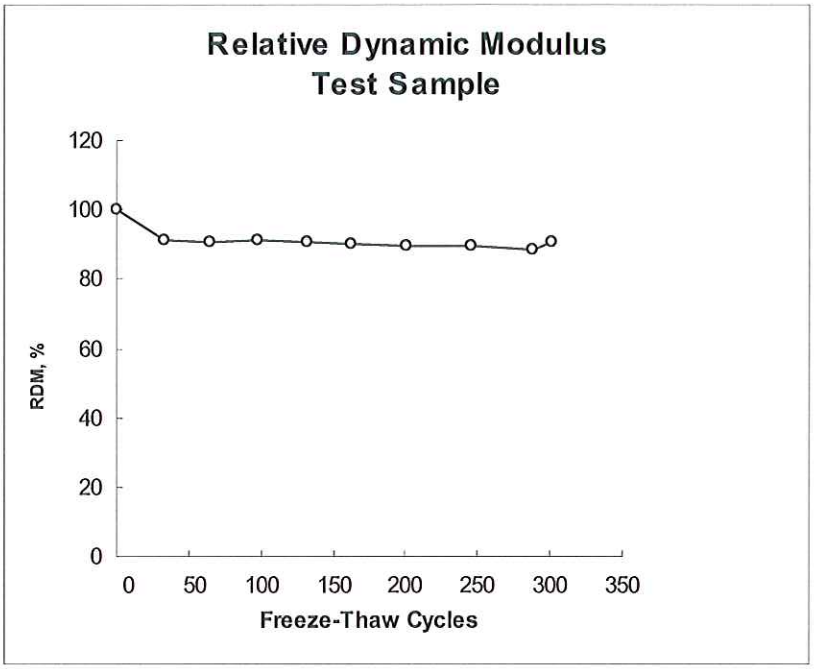

Figure 10 Freezing and Thawing (%) of Test Specimens

Table 9 Freezing and Thawing (%) of Control

Test Results* of ASTM C 666 - Procedure A Freezing and Thawing in Water of Concrete Specimens Control Mix			
	Length	Mass	
Cycles	change, %	change, %	**RDM(1), %
0	0.000	0.00	100
33	0.000	- 0.07	95
65	0.001	- 0.21	93
98	0.000	- 0.18	90
132	0.000	- 0.90	93
162	0.000	- 1.25	92
201	0.000	- 1.90	90
245	0.000	- 2.68	90
288	0.000	- 3.23	90
301	0.000	- 3.33	90

* Values are an average of three specimens.
** RDM = Relative Dynamic Modulus
(1) Severe scaling observed for all specimens.

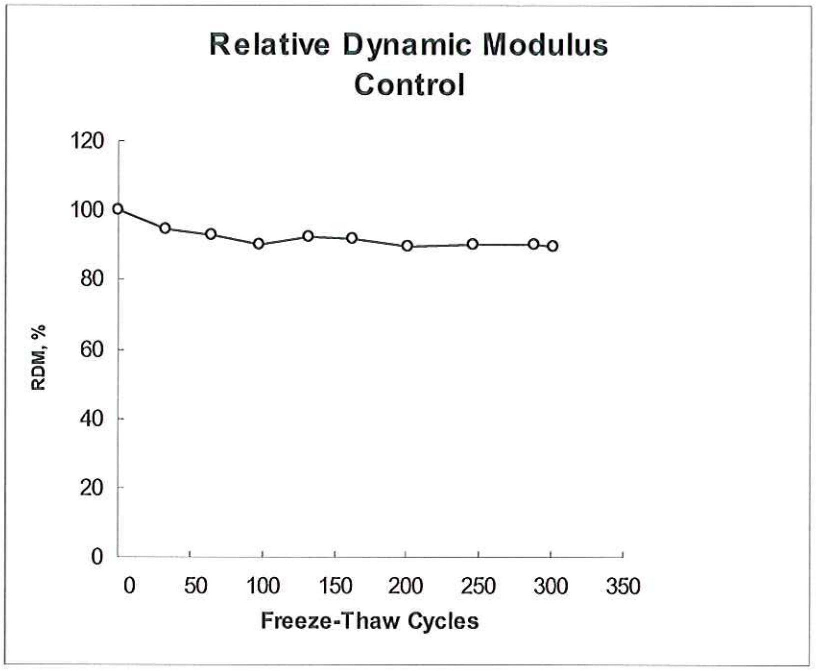

Figure 11 Freezing and Thawing (%) of Control

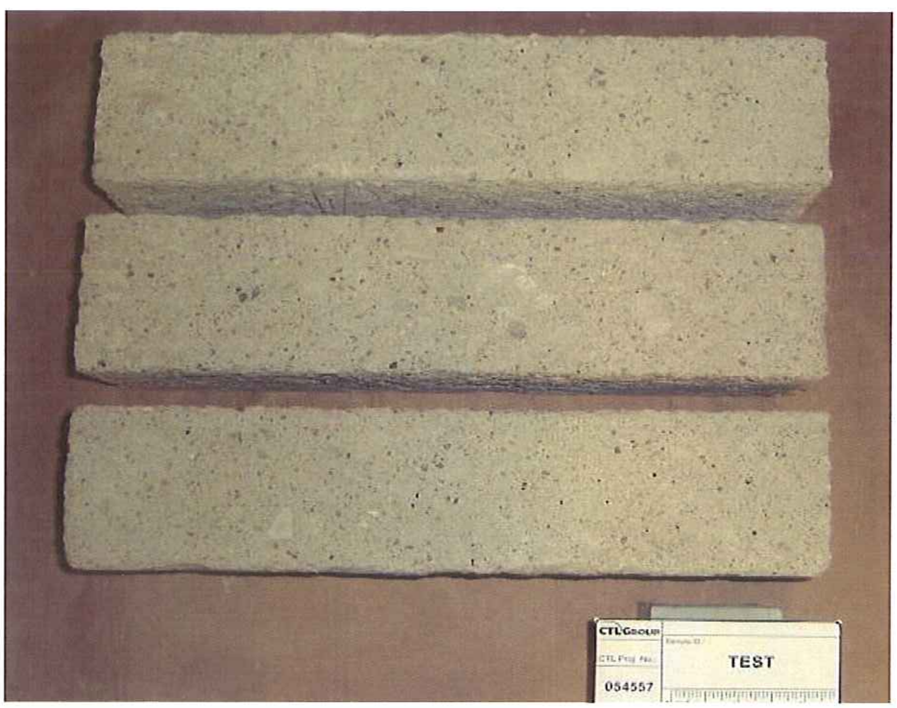

Figure 12a Freezing and Thawing (%) of Test Specimens

Figure 12b Freezing and Thawing (%) of Control Specimens

DEICER-SCALING RESISTANCE (ASTM C 672)

Table 10 Scaling Resistance of Test Specimen Surface Exposed to *Deicing Chemical

	Cumulative Mass Loss, lb/ft^2				Visual Scale Rating (ASTM C 672)**			
Cycle	1	2	3	Avg.	1	2	3	Avg.
5	0.01	0.01	0.01	0.01	0.5	0.5	0.5	0.5
10	0.01	0.01	0.01	0.01	0.5	0.5	0.5	0.5
15	0.01	0.01	0.01	0.01	ND***	ND	ND	ND
20	0.27	0.31	0.22	0.26	3.5	3.5	3.0	3.3
25	0.27	0.31	0.22	0.27	3.5	3.5	3.0	3.3
30	0.30	0.37	0.24	0.30	4.0	4.0	3.5	3.8
35	0.31	0.44	0.30	0.35	4.0	4.5	3.5	4.0
40	0.33	0.50	0.33	0.39	4.0	5.0	4.0	4.3
45	0.34	0.51	0.35	0.40	4.5	5.0	4.5	4.7
50	0.34	0.51	0.35	0.40	4.5	5.0	4.5	4.7

*Deicing chemical - 4% calcium chloride.
**Rating/Condition of Surface: 0 - no scaling; 1 - very slight scaling (1/8 in. depth max, no coarse aggregate visible)
2 - slight to moderate scaling; 3 - moderate scaling (some coarse aggregate visible); 4 - moderate to severe scaling; 5 - severe scaling (coarse aggregate visible over entire surface)
***ND: not determined

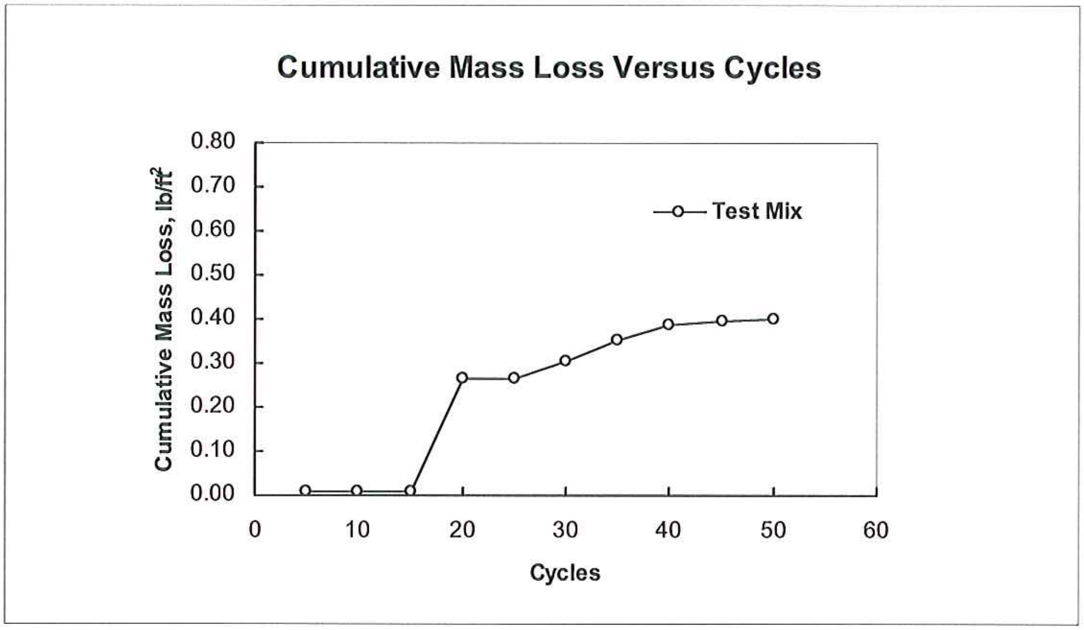

Figure 13 Scaling Resistance of Test Specimen Surface Exposed to Deicing Chemicals

Table 11 Scaling Resistance of Control Surface Exposed to *Deicing Chemical

	Cumulative Mass Loss, lb/ft²				Visual Scale Rating (ASTM C 672)**			
Cycle	1	2	3	Avg.	1	2	3	Avg.
5	0.00	0.00	0.00	0.00	0.0	0.0	0.5	0.2
10	0.00	0.00	0.00	0.00	0.0	0.0	0.5	0.2
15	0.00	0.00	0.00	0.00	ND***	ND	ND	ND
20	0.00	0.00	0.01	0.00	0.5	0.5	0.5	0.5
25	0.00	0.00	0.01	0.00	0.5	0.5	0.5	0.5
30	0.02	0.02	0.03	0.02	0.5	0.5	0.5	0.5
35	0.02	0.02	0.03	0.02	0.5	0.5	0.5	0.5
40	0.02	0.02	0.03	0.02	0.5	0.5	0.5	0.5
45	0.02	0.02	0.06	0.03	0.5	0.5	1.0	0.7
50	0.02	0.02	0.07	0.04	0.5	0.5	1.5	0.8

*Deicing solution - 4% calcium chloride.
**Rating / Condition of Surface:_0 - no scaling; 1 - very slight scaling (1/8 in. depth max, no coarse aggregate visible);
2 - slight to moderate scaling; 3 - moderate scaling (some coarse aggregate visible); 4 - moderate to severe scaling; 5 - severe scaling (coarse aggregate visible over entire surface)
***ND: not determined

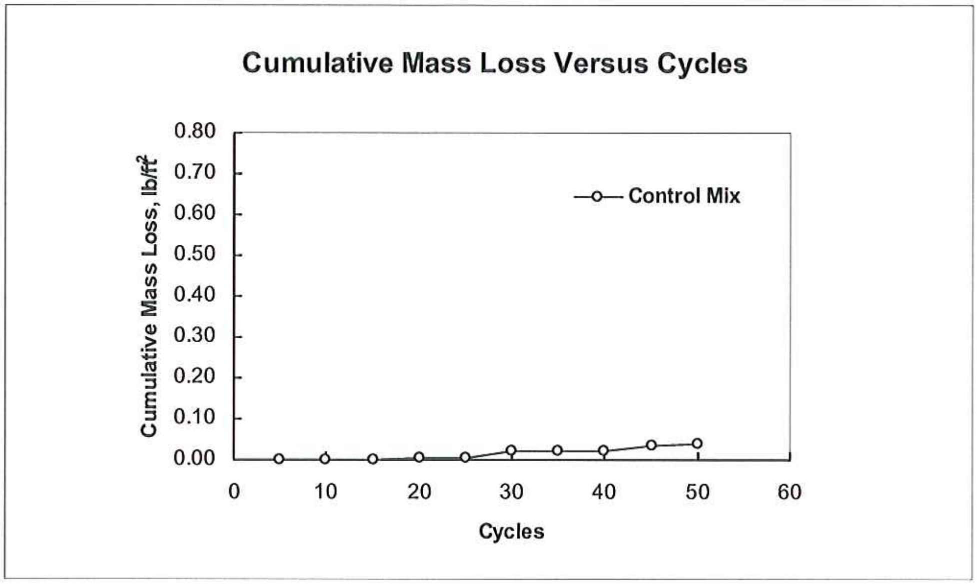

Figure 14 Scaling Resistance of Control Surface to Deicing Chemicals

Figure 15a Scaling Resistance of Concrete Test Specimen to Deicing Chemicals

Figure 15b Scaling Resistance of Control Specimen to Deicing Chemicals

RAPID CHLORIDE PERMEABILITY (ASTM C 1202–97)

Table 12 Modified Rapid Chloride Permeability: ASTM C 1202–97 (AASHTO T 277)*

Sample No.	Charge Passed	Relative
(Sample ID)	(Coulombs)	Chloride Permeability
# Control - A	3205	Moderate
# Control - B	3207	Moderate
# Control - C	3603	Moderate
# Test Specimen - A	658	Very low
# Test Specimen - B	658	Very low
# Test Specimen - C	653	Very low

Specimen age - 56 days. Specimens were prepared and then moist cured until tested.
*Interpretation of results per ASTM C 1202.

DATA ANALYSIS AND CONCLUSIONS

Test data summarized in Table 13 indicate that, when prepared under identical conditions, concrete made with 40% Ecomelt replacement of portland cement displayed comparable properties to that of the control. An exception seems to be the surface deterioration of the test specimen when exposed to deicing chemicals. However, the chloride permeability of the test specimen is significantly reduced with concrete made with Ecomelt/portland cement blend compared to that of the control.

Table 13 Summary of Data on ASTM Tests Conducted on Concrete Specimens

Tests	Data for Test Specimen	Comparison and Comments
ASTM C 403/C 403M – 05: Standard Test Method for Time of setting of concrete Mixtures by Penetration Resistance	Both Initial and final setting times longer than the control	Similar to control - Typical for pozzolans as they are slow to react and set but catch up later
ASTM C 39/C 39M – 04a: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	Early compressive strength lower than control, but late strength (56-day strength) same	Similar to control - Typical for pozzolans as they exhibit low early strength but catch up later
ASTM C 78 – 02: Standard Test Method for Flexural Strength of (Using Simple Beam with Third – Point Loading)	Early flexural strength lower than control, but late strength (56-day strength) similar	Similar to control - Typical for pozzolans
ASTM C 157M – 04: Standard Test Method for Length Change of Hardened-Cement Mortars and Concrete - Drying Shrinkage	Drying shrinkage over 56-days is similar to control	Similar to control
ASTM C 666/C 666M – 03: Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing	Freeze-Thaw resistance over 301 cycles is similar to control	Similar to control
ASTM C 672/C 672M – 03: Standard Test Method for Scaling Resistance of Concrete Surface Exposed to Deicing Chemicals	Test specimen showed lower scaling resistance over 50 cycles than control	Worse than control
ASTM C 1202 – 97: Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration	Test specimen showed *very low* permeability compared with *moderate* for control	Better than control

Based on the data obtained with the given mix designs, with the exception of deicing salt-scaling resistance, it appears the 40% replacement of portland cement by ground Ecomelt can produce concrete having comparable properties to those of control concrete made under identical conditions. Slightly longer setting times and lower early strengths indicate the presence of 40% Ecomelt which, like typical pozzolanic materials, is slower to react but gains strength as it ages.

With respect to deicing-scaling resistance, much greater deterioration occurred with the sample containing 40% Ecomelt. This could be due to bleed water accumulated on the surface that reacted with the deicing salt (4% $CaCl_2$ solution). On the other hand the resistance of the test concrete to chloride permeability exceeds that of the control; this could be because the fine Ecomelt particles resulted in a more compact matrix than the control.

One approach could be to conduct concrete testing using lower replacement of portland cement with Ecomelt (for example 25% instead of 40%) - with the anticipation that the scaling performance of concrete could further improve.

REFERENCE CITED

Rehmat, A.; Lee, A.; Goyal, A.; Mensinger, M.; and Bhatty, J. I., "Production of Construction-Grade Cement from Wastes Using Cement-Lock™ Technology," *Proceeding of the 4th Beijing International Symposium on Cement and Concrete*, Beijing, China, Vol. 3, pp 75-181, October 27-30, 1998.