Determination of Transport Properties of Lightweight Aggregate Concrete for Service Life Modeling

Expanded Shale, Clay, and Slate Institute (ESCSI)

TCG Project Number: 16059
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Mr. Ken Harmon
Stalite

Re: Determination of Transport Properties of Lightweight Aggregate Concrete for Service Life Modeling
TCG Project Number: 16059

Dear Mr. Harmon

TCG has completed its study for the Expanded Shale, Clay, and Slate Institute (ESCSI) to determine the effects of lightweight (LW) coarse and fine aggregates on the transport properties of concrete. The transport properties are used in several service life programs including STADUIM®, Life 365™ and analysis according to fib Bulletin 34. Specified required design service lives of 75 years or more is becoming very common, and the use of lightweight aggregates can offer several benefits. Determining how they affect the service life for typical mixtures utilized in these structures will lead to early consideration of lightweight aggregates in the design process.

Modeling the performance of a bridge deck in the Detroit area, with the transport properties determined for use in Life 365™ or STADIUM®, was performed. The STADIUM results showed that that the time to corrosion will be increased for lightweight mixtures compared to the control mixture with normal weight aggregates by approximately 22%. The replacement of normal weight sand with lightweight fines resulted in approximately a 34% to 88% increase in time to corrosion.

The Life 365 analysis showed equivalent performance between lightweight coarse aggregate mixes and the control mix. As with STADIUM, improvements were shown with the lightweight fines, up to a three times improvement with LW fines replacing NW fines.

An internal curing mix with a small quantity of LW fines had improved time to restrained shrinkage cracking, had higher strength, and a longer service life than the control concrete in both STADIUM and Life 365.

Supplementary cementitious materials (SCMs), corrosion inhibitors, or corrosion resistant reinforcing bars were not considered so that the pure effect of lightweight aggregates could be demonstrated. In combination with any of these, it is anticipated that the lightweight aggregates would show even a better performance enhancement.

Experimental Program:

Ten lightweight aggregate (LWA) plants' coarse aggregates were compared to a normal weight (NW) concrete with respect to transport properties (used in various service life models). In addition, one mixture with the normal weight aggregate and lightweight sand, and one mixture with all LWA were evaluated. A mixture with NW aggregate with a partial sand replacement of LW sand was evaluated for internal curing (IC) and transport properties.

The program is based on comparing the different aggregates for a specific mixture design frequently used in structures, which need to meet a service life greater than or equal to 75 years. It was decided to use only ordinary portland cement (OPC) for the cementitious component so that changes in properties are only related to the change in aggregates. The concretes were air-entrained to be representative of applications where freezing and thawing are a concern.

Table 1 shows the testing conducted for the fourteen mixes plus one control (C). Restrained shrinkage testing was only conducted on the C and IC mixtures. The results are being reported as average values for the 10 LW aggregate mixes, the C, IC, NW aggregate all LW sand, and LW sand plus LW aggregate. Individual reports for the specific coarse LW aggregate performance will be provided to each manufacturer.

Table 1 Test Program per Mixture Design

Tests	Per Mix	Notes
Plastic Properties (slump, air setting time)	1	For each Mix
Compressive Strength	3	1, 28, 90 days
STADIUM Transp. (IDC, MTC, ASTM C642 porosity)	2	28 and 90 days
ASTM C1760 Bulk Conductivity	2	28, 90 days
NT Build 492 Non Steady State Diffusion Coefficient	1	28 days
ASTM C1556 Bulk Diffusion	1	28 days
ASTM C1585 Capillary Absorption	1	28 and 90 days LWA
ASTM C1581 Restrained Shrinkage	1	Only for IC mix and Control

Description of Transport Tests

STADIUM® modeling software utilizes two transport properties; the first is the Ionic Diffusion Coefficient (IDC), which represents the movement of chloride and other ions through the capillaries. The second is the Moisture Transfer Coefficient (MTC), which models chloride ingress when the concrete is not 100% saturated, which is unique to STADIUM and highly relevant when conducting service life analysis. Note that the STADIUM modeling program is the only one that accounts for the movements of multiple species in the concrete as well as for chemical reactions and binding reactions. This allows for a prediction of the chloride-to-hydroxide levels, which is important for comparing mixtures with SCMs.

The ASTM C1760 Bulk Conductivity test is directly related to the ASTM C1202 Rapid Chloride Permeability, but is non-destructive, as it is conducted for a short time, and does not subject the specimens to heating. The bulk conductivity is used to monitor the change in permeability over time as it is directly related to the diffusion coefficients.

The NT Build 492 provides a relatively rapid (1 to 2 days) indication of chloride ingress. It adjusts for increases in conductivity that is not related to chloride ingress. The results are used in the fib service-life analysis.

The ASTM C1556 Bulk Diffusion is used to calculate the apparent diffusion coefficient for chloride ingress and can be used in Life 365 or the fib service-life analysis.

ASTM C1585 Capillary Absorption is used to predict the surface concentration of chloride when the concrete is not water-saturated. It can be used in Life 365 and the fib service-life analysis. This is of primary use when there is wetting and drying of the surface. In Life 365, the time to reaching the maximum surface concentration is decreased or increased compared to a control concrete based upon the ratio of the absorption values.

Concrete Plastic and Mechanical Properties

Fourteen concrete batches were produced. Table 2 shows the designations used for the various mixes.

Table 2 Mix Designations

Mix Designation	Description
C	Control Mix with NW coarse and fine aggregates
IC	Internally cured mix with NW coarse and fine aggregates, plus LW fines
LW1	Average for LW coarse aggregates with some NW coarse and all NW fine aggregate
LW2	Average for all LW coarse aggregates and NW fine aggregates
LWF	Reverse mix with NW coarse aggregates and LW fine aggregates
ALW	LW coarse and fine aggregates no NW aggregate

Table 3a shows the batching data for all the mixes. Table 3b shows the concrete proportions, plastic and mechanical properties with LW1 and LW2 as defined in Table 2. Information on the materials used are in the appendix. The standard deviations for the mixes used for the average properties for LW1 and LW2 are in Table 3b.

Table 3a Mixture Proportions for Concretes Produced

Mix Description:	LW1			LW2							ALW	LWF	IC	C
	Ltwt C.A. Nat. C.A. Nat F.A.	Ltwt C.A. Nat. C.A. Nat F.A.	Ltwt C.A. Nat. C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Nat F.A.	Ltwt C.A. Ltwt F.A.	Nat. C.A. Ltwt F.A.	Nat C.A. Nat F.A. Ltwt FA	Control Nat C.A. Nat F.A.
Lafarge Alpena Type I lb/yd^3	658	658	658	658	658	658	658	658	658	658	658	658	658	658
Agg.Resource Midway Pit **Natural Fine** Agg SSD lb/yd^3	1360	1342	1320	1119	1119	1074	1568	1346	990	1465	------	------	846	1294
Bay Aggregates Cedarville Pit **Limestone Coarse** Agg. #67 SSD lb/yd^3	450	350	150	------	------	------	------	------	------	------	------	1800	1800	1800
Lightweight Coarse SSD lb/yd^3	500	650	862	1215	1209	1209	862	1038	1273	875	1115	------	------	------
Lightweight Fine SSD lb/yd^3	------	------	------	------	------	------	------	------	------	------	917	833	304	------
Total Water lb/yd^3	250	250	244	243	243	243	242	243	243	246	243	243	243	243
Designed Air %	6.5	6.5	6.0	7.0	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Designed Plastic Density lbs/ft^3	120.5	120.4	118.9	119.7	119.5	117.8	123.3	121.7	117.2	120.1	108.7	130.9	142.6	148.0
Water/Cement Ratio	0.38	0.38	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Admixtures														
BASF Master Air AE100 oz/cwt	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.4	0.5
BASF Glenuim 7500 (HRWR) oz/cwt	3.2	3.6	3.7	3.9	4.3	3.9	5.2	5.8	3.5	5.0	4.3	5.3	5.0	4.4
Physical Properties														
Slump, in.	4.00	5.00	3.50	3.00	8.75	5.00	2.75	5.25	3.00	4.00	3.00	5.00	7.50	4.00
Air % as tested (Volumetric)	6.75	8.00	7.50	7.25	6.50	6.50	7.00	6.25	6.25	7.00	6.25	6.00	7.00	7.10
Water Sat. Bulk Density lb/ft3	37.4	65.2	49.3	60.8	60.7	57.1	56.1	56.9	59.8	54.1	57.6	53.3	53.3	
Density lb/ft3 Plastic (Concrete)	120.5	123.0	118.5	119.1	122.6	122.2	125.7	123.5	121.4	120.7	109.8	133.3	141.6	146.2
Density lb/ft3 Oven Dry (Concrete)	111.9	113.8	108.9	109.2	109.8	108.2	115.7	114.0	109.1	114.1	95.6	130.1	137.2	142.1
Density lb/ft3 Equilibrium Air Dry (Concrete)	118.6	119.9	115.4	117.3	117.7	115.9	122.3	120.7	117.1	120.3	104.8	136.5	142.9	147.3
No. of Days to Reach Equilibrium (avg. 2)	112	84	84	140	140	140	112	112	112	56	140	84	84	67

Table 3b Concrete Mixture Proportions and Plastic and Mechanical Properties

Mix Description:	LW1		LW2		ALW	LWF	IC	C
	Average	Standard Dev.	Average	Standard Dev.				
Lafarge Alpena Type I lb/yd^3	658	0	658	0	658	658	658	658
Agg.Resource Midway Pit **Natural Fine** Agg SSD lb/yd^3	1341	16	1240	203	------	------	846	1294
Bay Aggregates Cedarville Pit **Limestone Coarse** Agg. #67 SSD lb/yd^3	317	125			------	1800	1800	1800
Lightweight Coarse SSD lb/yd^3	671	149	1097	159	1115	------	------	------
Lightweight Fine SSD lb/yd^3					917	833	304	------
Total Water lb/yd^3	248	3	243	1	243	243	243	243
Designed Air %	6.33	0.24	6.50	0.46	6.0	6.0	6.0	6.0
Designed Plastic Density lbs/ft^3	119.9	0.7	119.9	2.0	108.7	130.9	142.6	148.0
Water/Cement Ratio	0.38	0.00	0.37	0.00	0.37	0.37	0.37	0.37
Admixtures								
BASF Master Air AE100 oz/cwt	0.2	0.0	0.2	0.0	0.2	0.2	0.4	0.5
BASF Glenuim 7500 (HRWR) oz/cwt	3.5	0.2	4.5	0.8	4.3	5.3	5.0	4.4
Physical Properties								
Slump, in.	4.2	0.6	4.5	2.0	3.00	5.00	7.50	4.00
Air % as tested (Volumetric)	7.4	0.5	6.7	0.4	6.25	6.00	7.00	7.10
Water Sat. Bulk Density lb/ft3	50.6	11.4	57.9	2.4	57.6	53.3	53.3	
Density lb/ft3 Plastic (Concrete)	120.7	1.8	122.2	1.9	109.8	133.3	141.6	146.2
Density lb/ft3 Oven Dry (Concrete)	111.5	2.0	111.4	2.8	95.6	130.1	137.2	142.1
Density lb/ft3 Equilibrium Air Dry (Concrete)	118.0	1.9	118.8	2.2	104.8	136.5	142.9	147.3
Compressive Strength								
1 Day Strength psi (3 each)	2870	210	3370	420	2700	3500	3570	3310
28 Day Strength psi (3 each)	5650	280	6540	540	6160	7120	6760	5470
90 Day Strength psi (3 each)	6260	410	7240	640	7140	8040	7743	5950

LW1 represents an average of the three LW coarse aggregate concretes that required NW coarse aggregate. LW2 is the average for the seven LW coarse aggregate concretes made without NW coarse aggregate.

Mix Preparation Procedures

In preparation for mixing of the concrete, the coarse LW aggregates were saturated by covering with water in sealed pails, and after 1 day adding water to make sure all the aggregates were submerged. The coarse LW aggregates remained submerged in water for a minimum of 7 days. Before weighing the aggregates for the mixes, they were placed covered in pails with holes on the bottom in the fog room to let excess water drain off. This ensured that the aggregates did not dry out before mixing and that SSD conditions were obtained.

The LW fine aggregates were oven dried, then mixed with 20% water in the concrete mixer as advised by the manufacturer. The aggregate was placed into sealed pails until mixing.

Concrete Testing

Figure 1 shows the drying of the 6 x 12-in cylinders in the controlled RH and T room according to ASTM C567 (as well as other drying specimens). As shown in Table 3a and 3b, the densities of the air-dried concretes were, as expected, higher than the oven-dry specimens. The lightweight mixes show a larger difference than the C and IC mixes indicating that the LW aggregates are retaining moisture.

Figure 1 Drying specimens. MTC specimens on left, ASTM C1585 in center and ASTM C567 in center and right.

Compressive strengths, Table 3b, are increased for the lightweight aggregate mixes and IC mix versus the control. The slight reduction in strength for LW1 versus LW2 could be due to the NW coarse aggregate as well as a little extra air. The increase in strength would be an indication of better aggregate bond and enhanced curing.

Porosity of the concrete according to ASTM C642 was determined, as was the porosity of the LW coarse aggregates. The porosity of the LW fine aggregate was assumed the same as the coarse aggregate from the same source. The porosity of the concrete was then adjusted for the volume of porosity in the LW aggregates in a cubic yard. The volume of permeable voids in the aggregates was somewhat less than the aggregate porosity so that was taken into account in the adjustment. The data are shown in Table 4. After correcting for the voids in the aggregates the LW mixes have similar to better porosity in the paste fraction to the control mixture.

Corrected C642 Porosity = Measured C642 Porosity – (VAg*FA*Vol/27)

Where VAg is the %Voids in the LW aggregate, FA is the % Accessible Voids (as fraction), and Vol is the solid volume of the LW Coarse Aggregate.

Table 4 C642 Porosity Data and Calculations

Property	Material					
	LW1	LW2	ALW	LWF	IC	C
ASTM C642 Volume Permeable Voids	15.4	17	26.41	17.46	13.23	11.72
Void % (in LW aggregate)	33.8	29	31.59	31.59	31.59	-----
% Accessible voids in LW aggregate	40.8	47	70	70	70	-----
Solid Volume of LW Coarse Aggregate (ft^3/yd^3)	10.8	11.8	10.64	-----	-----	-----
Solid Volume of LW Fine Aggregate (ft^3/yd^3)	-----	-----	7.49	7.83	2.71	-----
Corrected ASTM C642 Volume of Permeable Voids	9.9	11.0	11.56	11.05	11.01	11.72

Note that LW1 and LW2 are averaged for several batches, therefore less precision is shown in the numbers.

The conductivity and resistivity properties are in Table 5. As can be seen in Figure 2, the inverse of surface resistivity (surface conductivity), is related to the bulk conductivity. However, as one is measuring a surface effect and the other a bulk property they will be different. The surface resistivity can be correlated to the bulk conductivity at a given time. The bulk conductivity is more closely related to the strength and diffusion values, which are bulk properties. The conductivity is decreasing in time indicating that the concrete permeability is decreasing.

The bulk conductivity is related to the ASTM C1202 Coulomb values as it represents the initial reading in that test. If the specimens don't increase in temperature, then it is related to the final Coulomb value, which is typical for low permeability concretes with SCMs. Table 5 has predicted C1202 values assuming no heating. These values are more closely related to diffusion values. The surface resistivity at 28 days was converted using the relationship developed by J. Weiss et al at 28 days.

Table 5 Resistivity and Conductivity Data

Transport Property	LW1		LW2		ALW	LWF	IC	C
	Average	Standard Deviation	Average	Standard Deviation				
28 d Bulk Elect Resistivity (kΩ-cm) 4 Pin	6.4	0.8	6.5	0.9	6.2	8.2	7.6	9.4
28 days Coulombs 4 Pin FM 5-578	2883	372	2861	386	2957	2220	2408	1941
90 d Bulk Elect Resistivity (kΩ-cm) 4 Pin	7.4	0.4	7.7	0.7	11.8	14.6	10.9	10.9
28 d Bulk Elect Conductivity (mS/m) C1760	15.4	1.3	15.0	1.4	15.5	12.4	8.8	9.5
28 d STDev (mS/m) C1760	0.3	0.2	0.2	0.0	0.001	0.1	0.02	0.4
28 days Coulombs C1760	2799	237	2721	261	2814	2248	1601	1726
90 d Bulk Electrical Conductivity (mS/m)	11.6	1.0	11.3	1.1	7.8	5.9	5.6	6.7
90 d STDev (mS/m) C1760	0.2	0.2	0.1	0.1	0.019	0.009	0.015	0.3
90 days Coulombs	2114	181	2054	204	1410	1069	1020	1212

Only the IC concrete has a lower predicted C1202 Coulomb value than the C concrete at both 28 and 90 days. The LWF concrete has a lower Coulomb value than the C concrete at 90 days. As will be seen, the higher Coulomb values for the lightweight mixes are not associated with faster chloride ingress, but a reflection on the higher ionic conductivity due to the water in the aggregates.

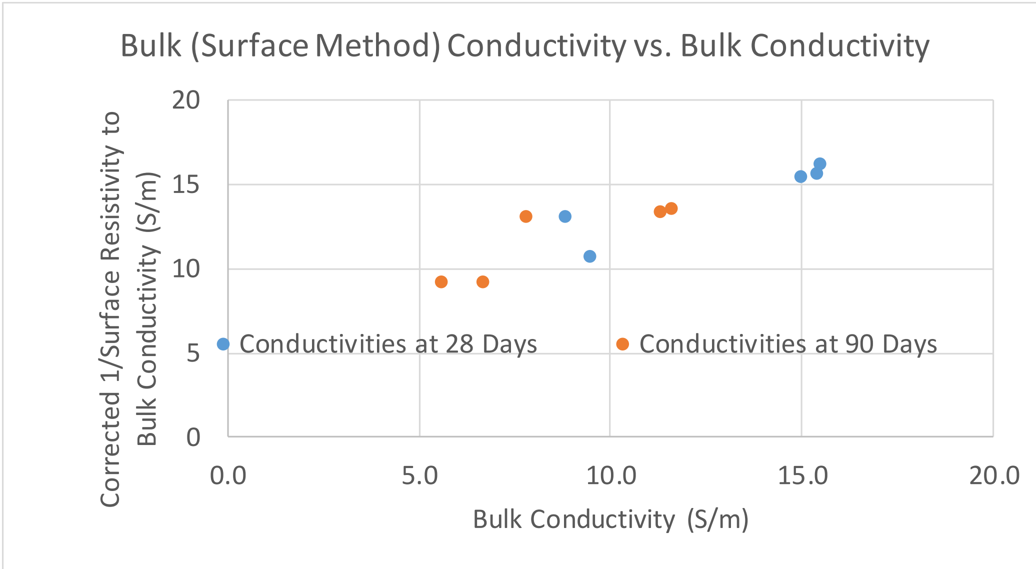


Figure 2 Comparison of Surface Conductivity (1/Surface Resistivity) to Bulk Conductivity.

Table 6 provides the transport properties that can be used in Life 365™ and other models that do not directly address chloride bonding, movement of other ions, and chemical reactions that occur in the concrete over time. These properties are the ASTM C1556 Bulk Diffusion Coefficient or the NT Build 418 Non-Steady State Diffusion Coefficient, and the ASTM C1585 Absorption.

The NT Build 492 and ASTM C1556 values follow the same trend, but the ASTM bulk diffusion values are lower. This is related to the 35 days of additional ponding for the ASTM specimens in the NaCl solution as well as the NT Build 492 being a non-steady-state value. In a few cases NT Build 492 was conducted at 90 days and the values were still higher than those of C1556 at a combined 63 days of moisture (28-days fog room and 35-days ponding), so it appears that NT Build 492 might provide too high a value, but this can be correlated to C1556, as are the ASTM C1202 or C1760 test results.

Table 6 Transport Properties for Use in Life 365™

Transport Property	LW1		LW2		ALW	LWF	IC	C
	Average	St. Deviation	Average	St. Deviation				
Nordtest NT Build 492 (E-12 m^2/s) 28-d	10.7	0.7	10.8	1.0	9.4	9.6	11.6	14.7
C1152 Acid C1556 Back Ground ppm	213	94	95	6.5	99	756	658	686
Diffusion ASTM C1556 (E-12 m^2/s) 28-d	4.6	0.2	4.5	0.7	4.4	1.9	4.5	3.6
Cs (ppm)	10437	1898	11397	2763	20639	21825	8430	8762
Cs (ppm) Adjusted for porosity	6117	2721	6891	1344	13829	13809	7016	8762
ASTM C1585 Intitial Absorption (28 Day)	0.00073	0.00018	0.00083	0.00033	0.00020	0.00094	0.00072	0.00083
ASTM C1585 Secondary Absorption (28 Days)	0.00025	0.00004	0.00029	0.00006	0.00004	0.00037	0.00034	0.00035
ASTM C1585 Intitial Absorption (90 Day)	0.00044	0.00023	0.00051	0.00024	0.00033	0.00023	0.00044	0.00077
ASTM C1585 Secondary Absorption (90 Days)	0.00022	0.00006	0.00026	0.00015	0.00017	0.00028	0.00031	0.00037

Note that C1585 data are in $mm/s^{0.5}$

The NT Build 492 test method has one advantage over other accelerated test methods in that it cancels out the effects of higher conductivity, which would be present if salts or porous lightweight aggregates were present. It shows that the non-steady state diffusion coefficient is lowered when LW aggregates are used. The chloride front is not as deep for the same potential/current range as chlorides are filling the aggregates and not penetrating as far.

Figure 3 shows the cells used for the NT Build 492 test. They are similar to the more familiar C1202 cells, with the key feature being a much larger reservoir of solutions on both ends. Figure 3 also shows the process of breaking open the specimens for NT Build 492 and applying $AgNO_3$ to determine the depth of the chloride front.

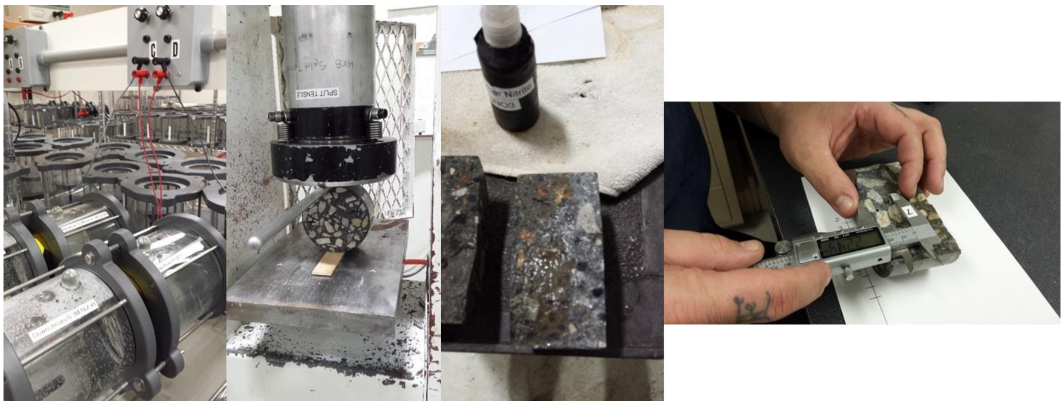


Figure 3 Test cells for NT Build 492 and IDC specimens and procedure to determine chloride front in NT Build 492.

The ASTM C1556 bulk diffusion data show that all of the concretes except for LWF have similar bulk diffusion coefficients even with the much higher porosities for the LWA. The calculated surface concentration (C_s) is higher for the LW concretes as would be expected given the porous aggregate present. A C_s value adjusted for the aggregate porosity is shown. The concretes with LW sand tend to show higher values as noted earlier, indicating that the sand might have a higher porosity than estimated. The values are based upon mass of concrete, so as the LW concretes have a lower unit weight, actual chloride contents in mass/unit volume are lowered. The porosities and mass corrections will be accounted for in the Life 365 modeling.

The ASTM C1585 Absorption data show that LW concretes have lower absorption than NW concrete of the same design. This is in contrast to the higher porosity. The specimens are conditioned in an 85% RH environment at elevated temperature versus above the boiling point of water. The results indicate that at 85% RH that the pores in the aggregates do not absorb moisture quickly. The 85% RH value was chosen for the ASTM method as it results in internal RH values for concretes that are similar to those exposed to environments with deicing or marine salts. Thus, in applications where corrosion is an issue, these tests show that there is a significant reduction in absorption with LW aggregates. This will be accounted for in the Life 365 modeling by increasing the time to reach the maximum chloride concentration at the surface.

The STADIUM transport properties are in Table 7. The IDCs are similar to each other for coarse LW mixes, while the LW mixes with fines or internal curing come in lower as seen for the bulk diffusion data.

Table 7 STADIUM® Transport Data

Transport Property	LW1	LW2	ALW	C	IC	LWF
IDC 28 Day (10^{-11} m^2/s)	13	12	9.8	14.3	10.4	7.2
IDC 90 Day (10^{-11} m^2/s)	10	9	7.1	9.8	7.8	4.2
MTC at 28 days (10^{-22} $m^{2)}$	57	117	154.3	10.0	22.0	46.4
MTC at 90 days (10^{-22} m^2)	92	91	98.6	8.7	15.9	22.5

The MTC values are very high for the LW aggregate concretes. This would normally indicate that they will have much higher sorption propertied than the control, which is not a good property in wetting and drying applications as in bridge and parking decks, or airborne exposures. This was in contrast to the ASTM C1585 absorption data. SIMCO (STADIUM developers) was contacted and this was discussed. The conclusion was that drying at 50% RH might not be representative of the field conditions, and that at higher relative humidity it is harder for water to absorb back into the LW concrete. As noted earlier, this is due to more difficulty in reabsorption of water into the lightweight aggregate. It is clear that significantly less water is being absorbed than is indicated by the MTC values. The MTC value for the control mixture will be multiplied by the ratio of the initial absorption of the LW mix to the control mixture to provide a modified MTC for the LW mixture. In most cases as can be seen in Table 6 the LW will have a modified MTC that is equal to lower than that of the control mixture.

Cracking of high performance concretes in the field is a major concern. The concrete mixes in this study were at a w/c under 0.4 and are susceptible to restrained drying shrinkage cracking from autogenous as well as normal drying shrinkage. ASTM C1581 Restrained Shrinkage Ring tests were conducted on the control mixture, Mix C, and a mixture in which LW sand replaced some of the normal sand Mix IC. The normal weight sand was replaced with LW sand according to the IC Calculator on the ESCSI web site.

Figures 4 and 5 show the restrained shrinkage stresses as a function of time for the two mixes. Figure 6 shows a cracked control ring specimen. The cracking performance is summarized in Table 8.

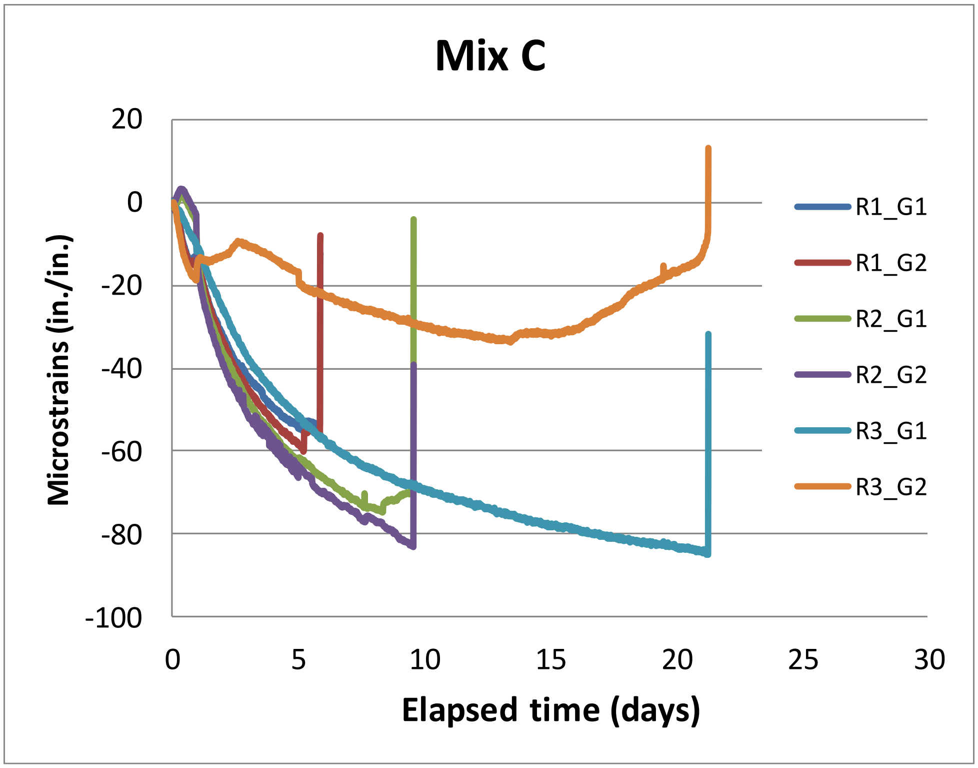


Figure 4 ASTM C1581 strain (stress) data for control rings Mix C.

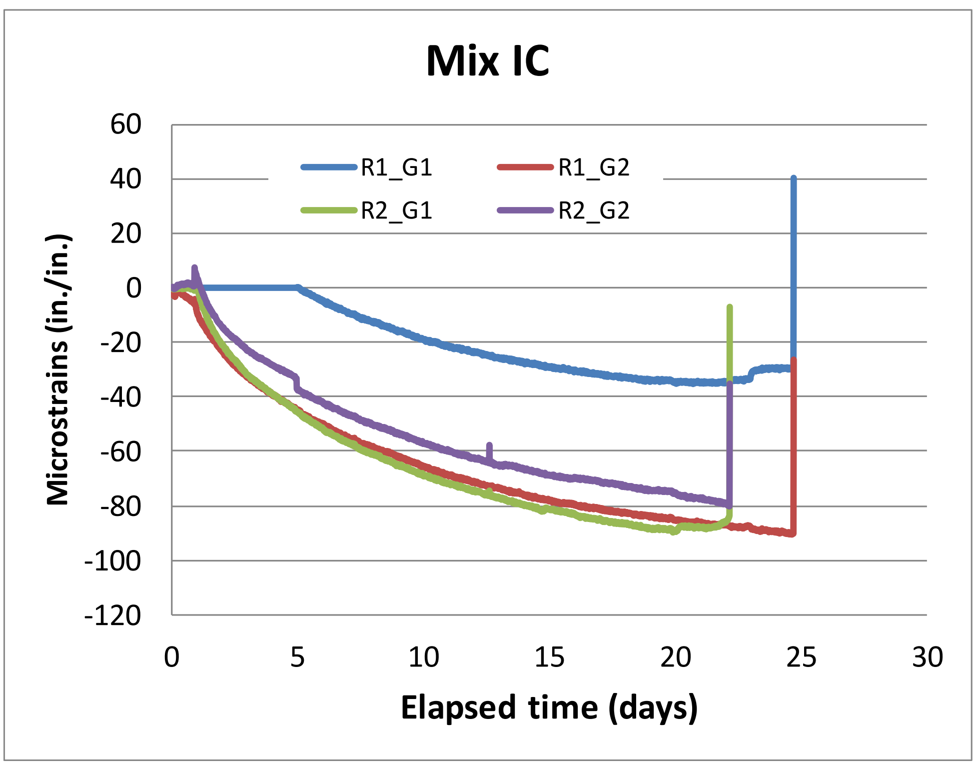


Figure 5 ASTM C1581 strain (stress) data for internal curing rings Mix IC.

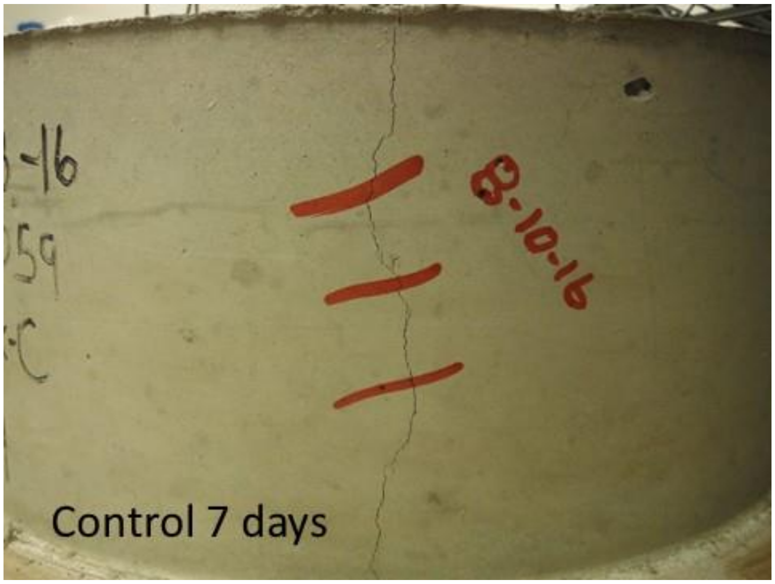


Figure 6 Photo of one of the cracked control C1581 restrained shrinkage specimens.

Table 8 ASTM C1581 Restrained Shrinkage Ring Results

Property	Mix C		Mix IC	
	Average	SD	Average	SD
Initial strain (με)	-13.2	1.4	-1.0	5.4
Maximum Strain (με)	-65.4	19.5	-74.0	26.2
Strain at Cracking (με)	-58.5	28.9	-70.8	28.1
Age of Cracking (days)	12.2	8.0	22.2	1.8
Stress Rate (psi/day)	33.5	17.3	18.0	4.5

The data show an improvement in the time to cracking and a reduction in the shrinkage stress by 46% with the addition of the LW sand in Mix IC. Mix C is classified as a mix with Moderate-High probability of restrained shrinkage cracking, whereas Mix IC is classified as a mix with Moderate-Low probability of restrained shrinkage cracking.

Service Life Analysis

Service life analysis was performed using Life 365 and STADIUM. The Life 365 and STADIUM follow the basic guidelines in fib, which is more of a guide. A bridge deck subjected to deicing salts in Detroit was modeled. Typically, a less permeable mixture containing SCMs would be used, but to show the effects of the LW aggregates the straight OPC concrete mixes at a low w/c were used.

Life 365™ Service Life Analysis

The default values in the Life 365 program for a Detroit urban bridge deck were used for the temperature data. Concrete cover was chosen to be 3 inches as SCMs were not in the mixture and additional corrosion protection was not added. The 28-day ASTM C1556 Bulk Diffusion values in

Table 6 were used versus the default values in Life 365 and they were lower. The default rate of chloride ingress was modified for the LW mixes by multiplying the years of buildup for the control by the ratio of the control ASTM C1585 Primary Absorption to the LW Initial Absorption at 90 days. The mixture design used resulted in lower capillary absorption values for typical mixes upon which the data in Life 365 were determined. The buildup time for the control was multiplied by an additional 2.5 times to account for the ratio of the control at 28 days to that of a typical concrete at 28 days at a higher w/c. Life 365 doesn't directly address porosity which would lead to higher actual chloride concentrations at all levels. Since this chloride is in the porous aggregates and not the paste, it does not contribute to corrosion. Therefore, a correction is not needed for modeling corrosion performance. However, due to the higher porosity the surface concentration that is measured is higher. This will be increased, but then corrected for in determining the threshold value. Note that the maximum chloride content at the surface is the 0.85% on concrete in the Life 365 model multiplied by the ratio of the Cs value of the lightweight concrete to that of the control concrete in Table 6.

Diffusion values converted to units of in^2/s are in Table 9. The amount of significant digits shown reflects the variation in these values.

The diffusion coefficient will decrease in time due to continued cement hydration. The m parameter as defined below is used to develop the relationship of the diffusion coefficient to time. The m values were determined by comparing the ASTM C1760 Bulk Conductivity values at 28 and 90 days and fitting it to the equation:

$$\kappa_{90} = \kappa_{28}(t_{28}/t_{90})^{m},$$

Where κ_t is the conductivity at time *t*, and m is the aging (hydration) coefficient. As the conductivity is directly related to the diffusion coefficient, the m value calculated describes how the diffusion coefficient will decrease in time according to the equation: $D_t = D_{28}(28/t)^m$, where D_t is the diffusion coefficient at time *t*. The default value for m in Life 365 is 0.2 for portland cement. Since only portland cement is present, the diffusion coefficient was assumed to become constant after one year based on OPC mixes evaluated in other studies. Longer curing times with could be used to determine if hydration continues for longer periods with lightweight aggregates.

The last correction that needs to be made for Life 365 is to adjust the corrosion threshold levels. Life 365 assumes all the concretes are at the same unit weight. That is not the case so one needs to multiply the chloride threshold level, C_t by the unit weight of the control concrete divided by that of the lightweight concrete. This number is multiplied again by the ratio of the determined surface chloride to the corrected surface value in Table 6. This results in higher threshold values for the lightweight concretes reflecting that some chloride is not available and that the mass of the concrete is lower even though the cement content is the same as the control mix.

The service life analysis as shown above requires that a mixture with NW aggregates of the same mixture design as the LW aggregate mixtures be produced so that the effects of the aggregate porosity can be addressed.

Table 9 shows the parameters used in the Life 365 modeling as described above.

Transport Property	LW1	LW2	ALW	LWF	IC	C
Diffusion ASTM C1556 (E-9 in^2/s) 28-d	7	7	7	3	7	6
m	0.24	0.24	0.59	0.60	0.39	0.30
Maximum Surface Concentration (% m	1.01	1.10	2.00	2.12	0.82	0.85
Years to Maximum	27.1	23.4	36.2	51.9	27.1	15.5
Chloride Threshold (% mass)	0.08	0.09	0.13	0.08	0.06	0.05

Service life was defined as 6 years after the onset of corrosion as in Life 365. The resulting service lives are shown in Table 10. Curves for chloride as a function of time until corrosion initiation (3-inch level) and service life tables are in Appendix 2. Note that Life 365 does not adjust for the unit weight so the chloride threshold values on mass of concrete would be higher than shown, hence the increased threshold level. The chloride in the LW aggregates is accounted for in the higher surface concentration.

Table 10 Life 365™ Predictions of Service Life (6 years after corrosion initiation)

Concrete	LW1	LW2	ALW	LWF	IC	C
Service Life (years)	37	36	63	108	45	35

The Life 365 analysis is showing that coarse lightweight aggregates are equivalent to slightly better than the control mix. This is so even though conductivity is higher for the lightweight mixes and more chloride would be in the concrete due to porosity in the aggregates. However, as can be seen in Table 10 there is a significant improvement in the ALW and LWF mixes of approximately 1.8 to 3 times (80% to 209% increase), indicating that increasing the LW fine aggregate content is an effective means of increasing service life. The addition of lightweight fines for internal curing results in approximately a 30% improvement in service life estimates. A conservative approach of one year for hydration to continue was used; if it continued longer then the service lives would be higher. This is especially the case for the concretes containing lightweight fines.

STADIUM Modeling

The IDC and MTC values in Table 7 were used in the STADIUM analysis. The porosity was adjusted to reflect the pastes porosity so additional porosity corrections are not necessary to adjust the threshold values. In STADIUM, the surface concentration is treated differently than in Life 365 so accessible porosity in the aggregates does not need to be addressed. To determine actual chloride content in the concrete at any given time would require an adjustment for porosity in the aggregates, which would raise the actual chloride level. However, this is not needed to predict the time to corrosion. As in the case for Life 365 modeling, in the Life 365 analysis the threshold values are raised to reflect the lower unit weight of the concrete, however as noted a correction for porosity is not required. Table 11 shows the parameters used in the STADIUM modeling.

Table 11 Parameters Used in STADIUM Modeling

Transport Property	LW1	LW2	ALW	LWF	IC	C
IDC at 28 Days (10^{-11} m^2/s)	13.0	12.0	9.8	7.2	10.4	14.3
Hydration Parameter - a	0.38	0.39	0.44	0.39	0.39	0.39
Hydration Parameter - α (1/s)	0.0002	0.0004	0.0004	0.0003	0.0003	0.0004
Corrected MTC (10^{-22} m^2)	5.7	6.6	4.3	3.3	5.7	10.0
Porosity (%)	9.9	11.0	11.6	11.0	11.1	11.7
Maximum Chloride at Surface (mM/L)	1000	1000	1000	1000	1000	1000
Chloride Threshold (ppm)	625	625	700	540	515	500

The hydration parameter "a" is the fraction of the 28-day IDC value that will be reached at the end of hydration (ultimate IDC). The hydration parameter "α" relates to the time to reach the ultimate IDC value with higher values corresponding to less time.

The times to spalling and cracking (initiation plus six years for propagation), are shown in Table 12, and the chloride profiles as a function of time are in Figure 6. Note that actual chloride contents in the concrete would be higher as the chloride in the lightweight aggregate is not considered.

Table 12 STADIUM Predictions of Service Life (6 years after corrosion initiation)

Concrete	LW1	LW2	ALW	LWF	IC	C
Service Life (years)	41	42	46	64	45	34

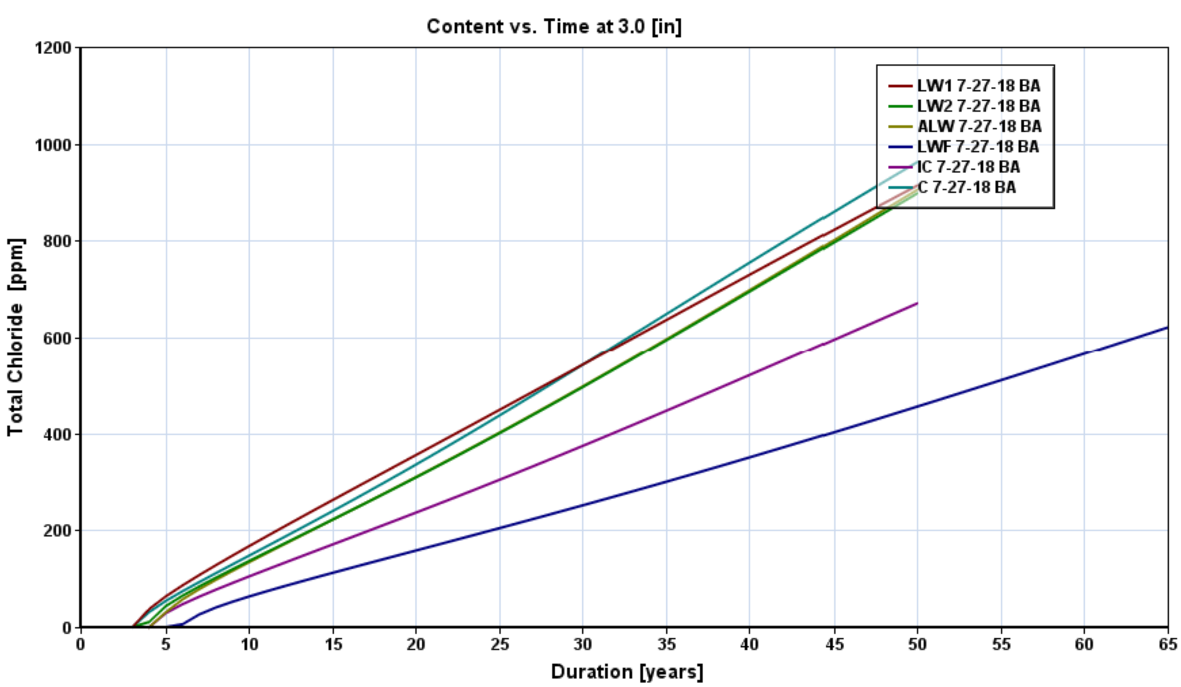


Figure 6 STADIUM curves at 3-inches of cover for Control and LW aggregate mixtures for a bridge deck exposure in Detroit, MI.

The times to repair, for LW1 and LW2 are higher than the Life 365 predictions. However, the STADIUM analysis showed no change in performance for the control, so these mixes outperform the control by approximately 22%. As in the Life 365 analysis all of the LW fine mixes are significantly outperforming the control mixtures, but to a lesser extent than predicted in the Life 365 modeling. The predicted times to cracking and spalling are equal to or better than the control concrete for all of the lightweight mixes for both analyses.

The STADIUM inputs and individual curves are in Appendix 3.

Summary and Conclusions

Transport properties of concretes with LW aggregates were determined versus a control mixture without lightweight aggregates. The service life performance, of a bridge deck in the Detroit area, was determined using the transport properties determined for use in Life 365™ or STADIUM.

The STADIUM results showed that that the service life would be increased compared to the control as follows:

- For lightweight coarse aggregate mixtures by approximately 22%.
- For replacement of normal weight sand with lightweight fines, approximately a 34% to 88% increase in service life was predicted.

Life 365 analysis showed similar results for LW coarse aggregate mixtures and the normal weight control mixture, but approximately a 1.8 to 3 times increase in service life for lightweight fines replacing the normal sand. The IC mix showed a 30% increase in service life similar to the STADIUM results.

To address the effects of aggregate porosity, it was necessary to use several test methods and a comparison to a NW aggregate control concrete of the same mixture design and materials.

An internal curing mix with a small quantity of LW fines improved time to restrained shrinkage cracking, produced higher strength, and a longer service life than the control concrete.

In this study, LW aggregate concretes were shown to increase the compressive strength of concrete.

Conductivity tests can be used to determine how permeability changes in time, but higher conductivity (corresponds to higher C1202 rapid chloride permeability), or lower surface resistivity, do not necessarily indicate a higher chloride ingress rate for LW aggregate concrete.

Likewise, the loss of moisture is high in the migration drying tests conducted for STADIUM. However, the reintroduction of moisture at relative humidity found in regions, where deicing salts are used, was found to be reduced using the ASTM C1585 absorption test method.

Key Finding

The addition of a small quantity of LW fines for internal curing was shown to reduce restrained shrinkage cracking and to increase compressive strength and the service life. These results coupled to the results with the LW fine replacements of all the fine aggregates indicate that increasing the LW fine replacement of NW fines beyond that needed for internal curing could increase the service life of the concrete up to a factor of 1.5-3 for total replacement of NW fines.

Disclaimer

The results and conclusions are based upon the materials tested and a specific mixture design, the models used, and TCG's engineering judgement. Different mixture designs and materials would be expected to follow the trends found, but validation of the transport properties is recommended, before modeling. The service life models do not address cracking and the analysis is based on repair of cracks greater than 0.004-inch in width.

Sincerely,

Tourney Consulting Group, LLC

Neal S. Berke
Vice President

CC: Vincent Wheeler

Appendix 1 Lightweight Aggregates Tested

Frazier Park

17410 E. Lockwood Valley Road Frazier Park CA. 93225 661-245-3736

ASTM Light Weight Analysis | **Trinity Frazier Park**

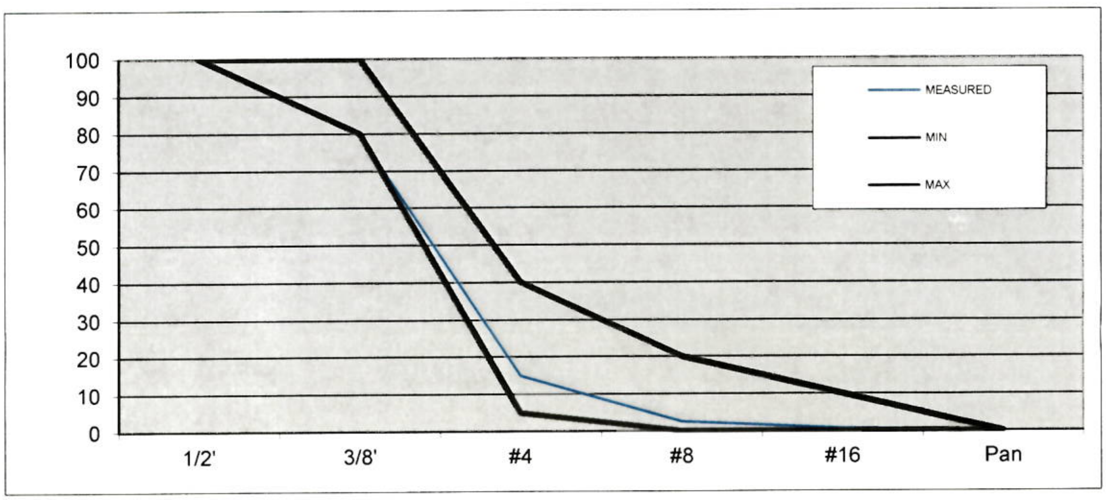
Ticket # Hydro Sample

Sampler JJ

Date: 06/29/16

Time

Customer



Sieve	MEASURED WEIGHTS	MEASURED C%R	MEASURED C%P	Target MIN	Target MAX
1/2'	0	0.0	100	100.0	100.0
3/8'	100	20	80	80.0	100.0
#4	417	85	15	5.0	40.0
#8	478	98	2	0.0	20.0
#16	487	99	1	0.0	10.0
Pan	490	100	0	0.0	0.0

% MOISTURE	27.6				
Gross Weight	1646	Tare Weight	1391	Sp. Gravity	1.69
Bucket Weight	53.5	Lab B/W			
Wet Weight	625				
Dry Weight	490				

TRINITY LIGHTWEIGHT
EXPANDED SHALE & CLAY

Construction Type: Lightweight Concrete

Constructor:

Mix Number: Riverlite AL Intermediates

Specified Slump: 6 inches

Project Description: Tourney Consulting

Aggegate Supplier: Trinity Lightweight

Specified Compressive Strength: ______ psi.

Specified Air Content 6.5 %

Material Properties and Source

Cementitious Material		Type		Source		Specific Gravity
Portland Cement		1				3.15
Fly Ash		F				2.20
(Slag)						

Admixtures		Name		Supplier		Dosage, Fl. Oz.
Per Producer						Per Mfg
Per Producer						Per Mfg
Per Producer						Per Mfg
Note: Dosage rate will require adjustments for field and environmental conditions.						

Aggregate Size	Type	Supplier	Sp. Gr. SSD	Sp. Gr. OD	Lose unit weight	F.M.
Riverlite AL Intermed	Exp. Clay	Trinity	1.13		40.00	
Sand / SSD	Silica		2.65		102.00	
Stone 57 67 or 89	Stone		2.80		90.00	

Batch Quantities

Material	Quantities lb/yd^3 SSD	Absolute Volume ft^3	cuft
Cement, lb.	658	3.35	
Fly Ash, lb	0	0.00	
Mix Water 33	250	4.01	
89 67 or 57 Stone	450	2.58	5.00
Riverlite AL	500	7.09	12.50
Sand	1360	8.22	13.33
Air Content, %	6.5	1.76	
Total Mass, lb.	**3218**	**27.00**	**30.83**

Water / cement ratio: 0.38

Density Plastic **119.19** pcf
Equilibrium Air Dry **112.19** pcf

Mix Design Information:

Mix Class

Comments: Equilibrium Dry Weight 112.00

Designed by:
Title:

TRINITY LIGHTWEIGHT
EXPANDED SHALE & CLAY

Construction Type: Lightweight Concrete
Constructor:
Mix Number: Riverlite LA CM
Specified Slump: 6 inches

Project Description: Tourney Consulting
Aggregate Supplier: Trinity Lightweight
Specified Compressive Strength: psi.
Specified Air Content 6.5 %

Material Properties and Source

Cementitious Material		Type		Source		Specific Gravity
Portland Cement		1				3.15
Fly Ash		F				2.20
(Slag)						

Admixtures		Name		Supplier		Dosage, Fl. Oz.
Per Producer						Per Mfg
Per Producer						Per Mfg
Per Producer						Per Mfg
Note: Dosage rate will require adjustments for field and environmental conditions.						

Aggregate Size	Type	Supplier	Sp. Gr. SSD	Sp. Gr. OD	Lose Unit weight	F.M.
Riverlite LA CM	Exp Clay	Trinity	1.34		45.00	
Sand / SSD	Silica		2.65		102.00	
Stone 57 67 89	Stone		2.80		90.00	

Batch Quantities

Material	Quantities lb/yd^3 SSD	Absolute Volume ft^3	cuft
Cement, lb.	658	3.35	
Fly Ash, lb	0	0.00	
Mix Water 33	250	4.01	
89 67 or 57 Stone	350	2.00	3.89
Riverlite LA CM	650	7.77	14.44
Sand ssd	1342	8.11	13.15
Air Content, %	6.5	1.76	
Total Mass, lb.	**3250**	**27.00**	**31.49**

Water / cement ratio: 0.38

Density Plastic **120.36** pcf
Equilibrium Air Dry **115.36** pcf

Mix Design Information:

Mix Class
Comments: Equilibrium Dry Weight 115.00 pcf

Designed by:
Title:

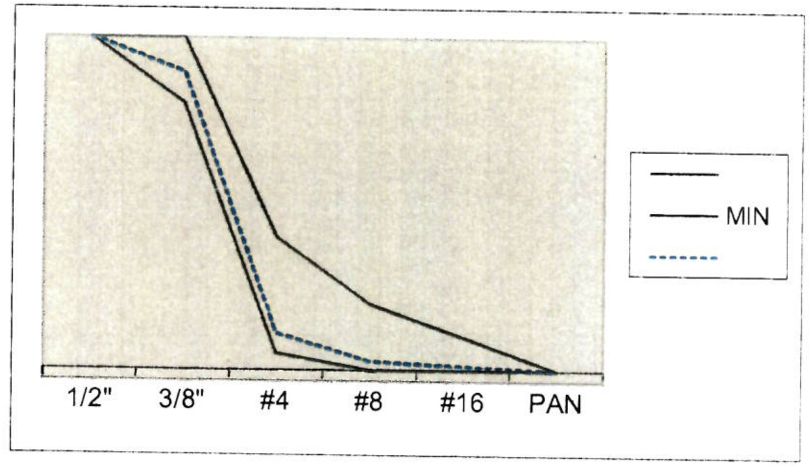
29-Jun-16

		MIN	Trk sample
1/2"	100	100	**100.0**
3/8"	100	80	**89.5**
#4	40	5	**11.1**
#8	20	0	**2.7**
#16	10	0	**1.3**
PAN	0	0	**0.0**

	WT	%R	%P
1/2"	0	**0.0**	100.0
3/8"	154	**10.5**	89.5
#4	1298	**88.9**	11.1
#8	1420	**97.3**	2.7
#16	1441	**98.7**	1.3
PAN	1460	**100.0**	0.0
		0.0	100.0

1/4 bucket	15.2
wet weight	1780
dry weight	1463
% moisture	21.7
lbs. /cu ft. wet	58.3
lbs. /cu ft. dry	48.0

PRESOAK



PRINT

TRINITY BOULDER - EXPANDED SHALE

7/7/16
11 Pails @ 43 lb each
473 lb

Trinity Lightweight ESC
12652 HWY 190 West
P.O. Box 190
Erwinville LA. 70729
Ph 225-627-9998
Fax

Rotex Global, LLC.
1230 Knowlton Street
Cincinnati, OHIO 45223-1845
Ph (513) 541-1236
Fax (513) 541-4888

Configuration: CM
Date: 7/7/2016
Time: 9:09:00 AM

Sample Information
Operator Barry
Customer Railcar

SIEVE	OPENING mm	WEIGHT	% RETAINED	% CUMULATIVE	% PASSING
1/2"	12.5000	2.10	1.43%	1.43%	98.57%
3/8"	9.5000	11.40	7.76%	9.19%	90.81%
4 US	4.7500	114.50	77.94%	87.13%	12.87%
8 US	2.3600	13.70	9.33%	96.46%	3.54%
16 US	1.1800	2.20	1.50%	97.96%	2.04%
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---
PAN	0.0000	3.00	2.04%	100.00%	0.00%
TOTAL		146.90			

Percent Retained

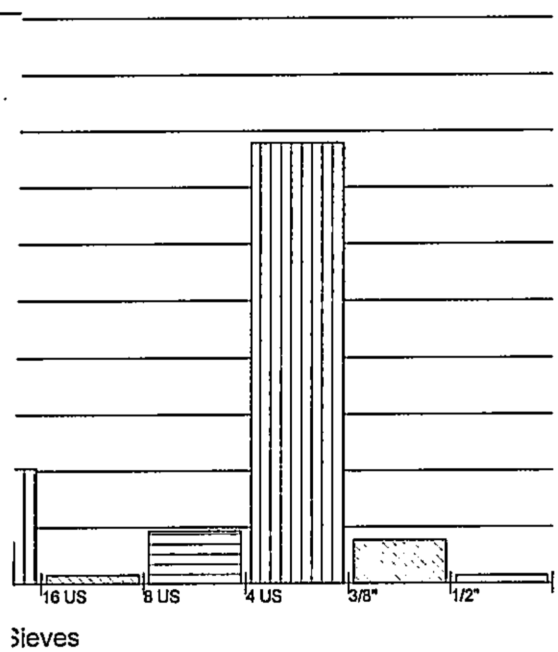
7-7-16 | R/C | CM

41.26 = 4.303

3/4- - -
1/2- - -
3/8- - -
4- - -
8- - -
16- - -
30- - -
50- - -
#100- - -
Pan-

D.L.-
D.R.-

_____ = _____



Haydite 3/4"
16059
7/8/16 Recv.

DIGERONIMO AGGREGATES

MATERIALS RESEARCH LABORATORY
P.O. BOX 31330
CLEVELAND, OH 44131- 0330
216-524-2950 Fax 216-524-4069

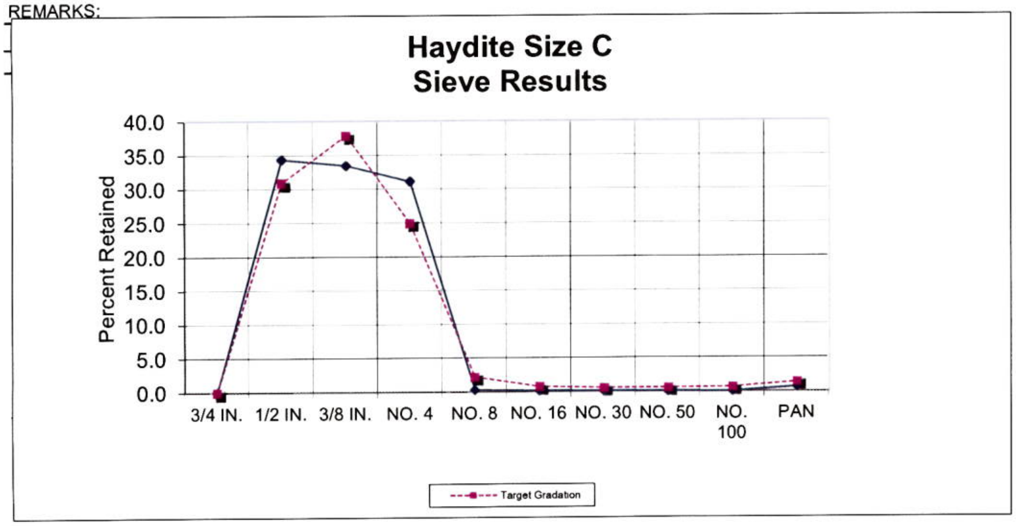
HAYDITE SIEVE ANALYSIS

PLANT:	Cleveland	GRADE:	C	SAMPLE DATE:	7/7/2016
				sample time:	12:50pm
CUSTOMER:	Tourney Consulting Group	SIZE:	3/4x#4	sample by:	Brett K.

SCREEN SIZE	WEIGHT RETAINED	% RETAINED	CUM % RETAINED	% PASSING	ASTM LIMITS - % PASSING A	B	BX	C
2 1/2 IN.	0	0	0	100				
2 IN.	0	0.0	0.0	100.0				
1-3/4 IN.	0	0.0	0.0	100.0				
1-1/2 IN.	0.0	0.0	0.0	100.0				
1 IN.	0.0	0.0	0.0	100.0				
3/4 IN.	0.0	0.0	0.0	100.0				90-100
1/2 IN.	86.3	34.3	34.3	65.7		100	100	
3/8 IN.	84.1	33.4	67.8	32.2	100	80-100	90-100	10-50
NO. 4	78.1	31.1	98.8	1.2	85-100	5-40	65-90	0-15
NO. 8	0.6	0.2	99.0	1.0		0-20	35-65	
NO. 16	0.3	0.1	99.2	0.8	40-80	0-10		
NO. 30	0.2	0.1	99.2	0.8				
NO. 50	0.1	0.0	99.3	0.7	10-35		10-25	
NO. 100	0.0	0.0	99.3	0.7	5-25		5-15	
PAN	1.6	0.6	99.9	0.1				
	251.3							

INITIAL WGT	255.8 grams	FINENESS MODULUS	6.97	
DRY WGT	251.5 grams	47.8 pcf (damp)		47.0 pcf (dried)
MOISTURE	1.7 %	1290.6 pcy (damp)		1269.0 pcy (dried)

REMARKS:



0
30.9
37.9
24.9
2.2
0.8
0.6
0.6
0.7
1.4

Haydite 3/8"
16059
7/8/16 Received.

Haydite Sieve Analysis Report

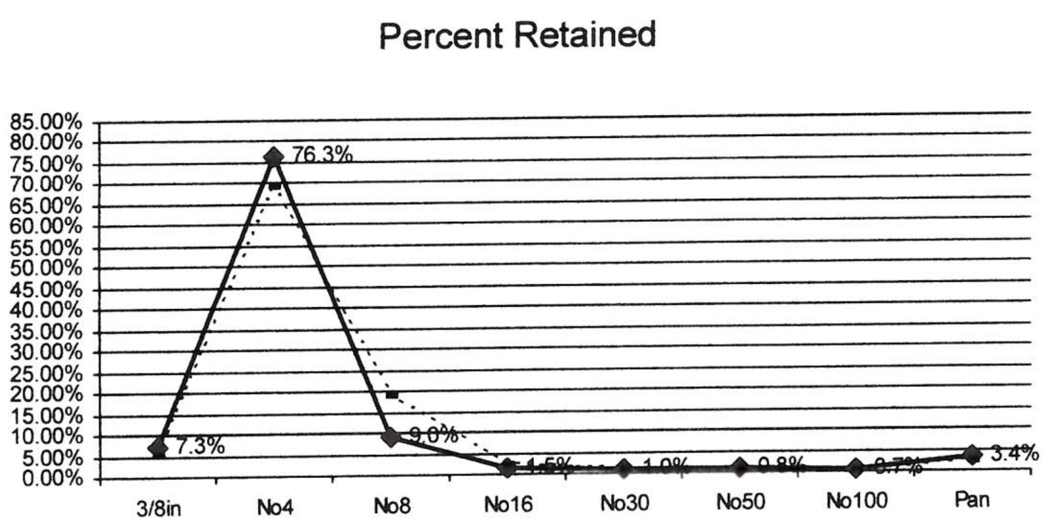
B-pw Hydraulic Press Brick Company

Brooklyn, IN

Date	7/07/2016			Customer	
Wt per CF	46.9 damp loose	39.6	oven dry	Type	Do Not Show in His
Wt per CY	1266 damp loose	1068	oven dry		
Moisture	18.58%				
FM	5.66				

Screen	Wt. (gm)	% Ret	% Cum	% Pass	ASTM C-330	Limit Check
3/8 in	30.70	7.35%	7.35%	92.65%	80-100	Okay
No4	318.70	76.30%	83.65%	16.35%	5-40	Okay
No8	37.60	9.00%	92.65%	7.35%	0-20	Okay
No16	6.30	1.51%	94.16%	5.84%	0-10	Okay
No30	4.20	1.01%	95.16%	4.84%		
No50	3.30	0.79%	95.95%	4.05%		
No100	2.90	0.69%	96.65%	3.35%		
Pan	14.00	3.35%	100.00%	0.00%		
Total	417.70	IntWt 496.60		DryWt 418.80	Residual 0.26%	.3% loss Limit

Note F M check on production



3/4 Aggregate

LABORATORY ANALYSIS OF LIGHTWEIGHT AGGREGATE

DATE SAMPLED: July 12, 2016

TIME SAMPLED: 3:00:00 PM

TRANSPORTER: Tourney

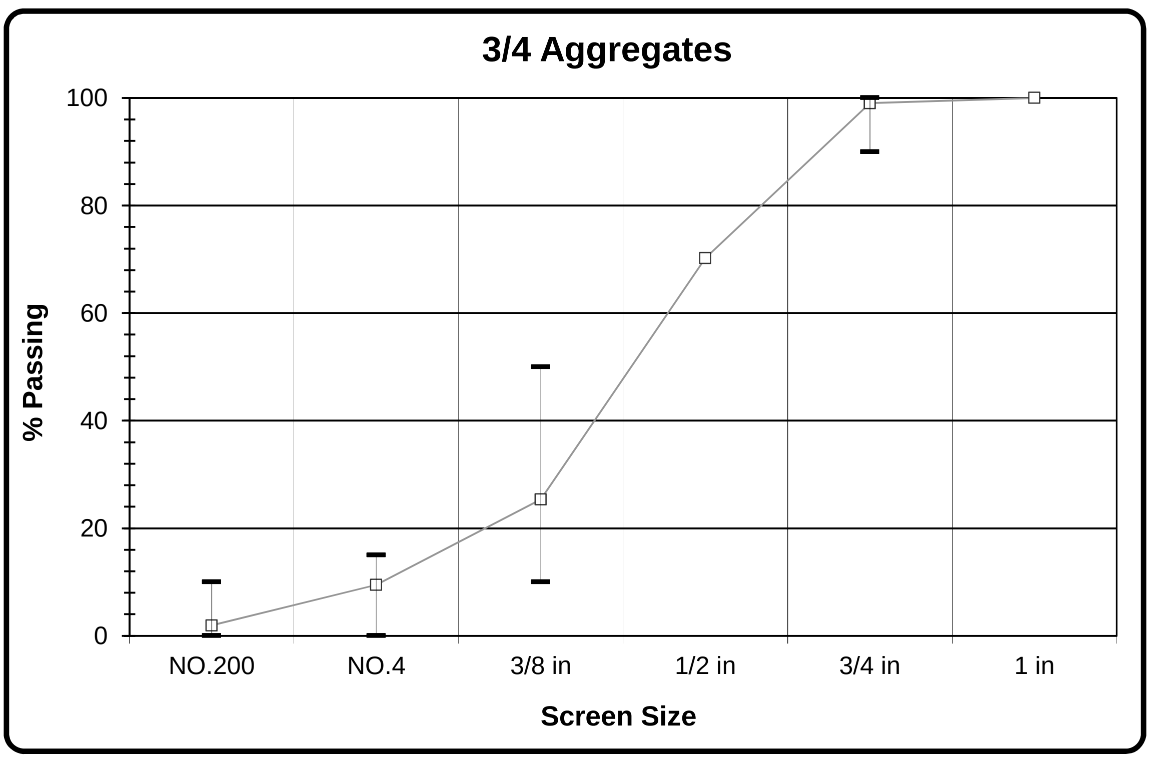
LAB FILE ID#: 160713f

SIEVE SIZE	WT.	% RETAINED	% PASSING	CUM% RETAINED	ASTM C330-04	NORLITE LIMITS	MOISTURE	
1	0.0	0.0	**100.0**	**0.0**	100	100	WET WT.	1000.0
3/4	8.0	1.0	**99.0**	**1.0**	90-100	90-100	DRY WT.	820.0
1/2	236.0	28.8	**70.2**	**29.8**	-	-		
3/8	368.0	44.9	**25.4**	**74.6**	10-50	10-50	**% MOISTURE**	**21.95**
NO. 4	130.0	15.9	**9.5**	**90.5**	0-15	0-15		
NO.200	62.0	7.6	**2.0**	**98.0**	0-10	0-10		
PAN	16.0	2.0						
TOTAL	820.0							

UNIT WEIGHT = MOIST lbs./cu.ft.: 53.01

FM= 6.19

Target FM= 7.08



CAROLINA STALITE SAMPLE DATA FORM

MATERIAL:	1/2" Structural Material	DATE SAMPLED:	28-Jun-16
SAMPLED BY:	D.Diggs	SAMPLED FROM:	Stockpile
QC NUMBER:		SAMPLED FOR:	Quality Control
DATE TESTED:	28-Jun-16	TESTED BY:	D.Diggs
		REVIEWED BY:	M.Hammill

GRADATION

SIEVE NO.	WT. RETAINED	% RETAINED	% Passing	SPEC.
3/4"	0	0.0	100.0	100.0
1/2"	0.60	8.7	91.3	90.0-100.0
3/8"	3.05	44.2	55.8	40.0-80.0
4	6.55	94.9	5.1	0.0-20.0
8	6.70	97.1	2.9	0.0-10.0
PAN	6.90			

MOISTURE %

A: PAN+WET MAT'L	7.50
B: PAN+ DRY MAT'L	
C: PAN WEIGHT	
D: DRY MAT'L	6.90
E: H2O WEIGHT	0.60
MOISTURE % (E/D*100)	8.7

UNIT WEIGHT

A: BUCKET+MAT'L	
B: WT.BUCKET	
C: WT. MAT'L (A-B)	
D: FACTOR	
UNIT WEIGHT (C*D)	49.8

SPECIFIC GRAVITY (SSD)

A: WT. JAR+ MAT'L	1220
B: WT. JAR	424
C: WT. MAT'L (A-B)	796
D: WT. JAR+ H2O	1444
E: (C+D)	2240
F: WT. JAR+H2O+MAT'L	1710
G: (E-F)	530
SPECIFIC GRAVITY (C/G)	1.50

Specs 1.49-1.55

200 WASH

A: DRY SAMPLE WT.	
B: DRY WASHED WT.	
C: (A-B)	
D: (C/B*100)	

ABSORPTION

A: DRY SAMPLE WT.	
B: 24 HR. SOAKED WT.	
C: (B-A)	
D: ABSORPTION (C/A*100	

COMMENTS:

STALITE Lightweight Aggregate Properties and Gradations for Structural Applications

	3/4" (18mm)		1/2" (12.5mm)		3/8" (9.5mm)		MS16 Fines (#4 - 0)	
Typical Density (Unit Weight)	lbs/cf	kg/m^3	lbs/cf	kg/m^3	lbs/cf	kg/m^3	lbs/cf	kg/m^3
Dry Loose (ASTM C 29)	48	768	50	800	52	832	60	960
Dry Rodded (ASTM C 29)	55	880	56	896	58	928	65	1040
Saturated Surface Dry Loose (ASTM C 29)	50	800	52	832	53	848	55	880
Maximum Dry Density (ASTM D 4253)	60	960	-		-		-	
Damp Loose (ASTM C 29)	48-52	768-832	50-54	800-864	51-55	816-880	53-57	848-912
Typical Relative Density (Specific Gravity)								
Dry (ASTM C 127)	1.46		1.47		1.54		1.69	
Saturated Surface Dry (ASTM C 127)	1.52		1.53		1.60		1.75	
Range in Saturated Surface Dry (ASTM C 127)	1.47 - 1.54		1.49 - 1.55		1.57 - 1.64		1.70 - 1.80	
Sieve Size	% Passing		% Passing		% Passing		% Passing	
1" (25mm)	100		100		100		100	
3/4" (19mm)	90-100		100		100		100	
1/2" (12.5mm)	-		90-100		100		100	
3/8" (9.5mm)	10-50		40-80		80-100		100	
#4 (4.75mm)	0-15		0-20		5-40		97-100	
#8 (2.36mm)	-		0-10		0-20		89-100	
#16 (1.18mm)	-		-		0-10		46-66	
#30 (600um)	-		-		-		28-41	
#50 (300um)	-		-		-		17-25	
#100 (150um)	-		-		-		8-16	

STALITE
ROTARY KILN EXPANDED LIGHTWEIGHT AGGREGATE

Tourney Consulting Group LLC
3401 Midlink Drive
Kalamazoo, MI 49048

Phone (269)-384-9980
Fax (269)-384-9981
www.tourneyconsulting.com

ASTM C 642 Density, Absorption, and Voids Aggregate

Client: ESCSI
35 East Wacker Drive Suite 850
Chicago, IL 60601-2106

Date Received: 07/14/16
Date Reported: 08/11/16

Attention: Abigail Gabbard

TCG Project No. 16059
Job Description: Lightweight Aggregate Permeable Porosity Comparison
Lightweight Manuf.: **Utelite Coarse Aggregate**
Sample Description: 100% retained on #8 screen
TCG Technician: Tim Henry

		Towel Dry weight		
		Saturated Mass (g)		Suspended
Specimen	**Oven Dry Mass (g) [A]**	**SSD [B]**	**After Boiling [C]**	**Immersed Apparent Mass (g) [D]**
Utelite Coarse Aggregate	730.45	867.66	883.01	400.02

Calculations:
Absorption after immersion, % = [(B - A)/A] x 100
Absorption after immersion and boiling, % = [(C - A)/A] x 100
Bulk density, dry = [A/(C - D)] x ρ = g1 ρ = 1 g/cm3 (Mg/m3)
Apparent density = [A/(A - D)] x ρ = g2 (Mg/m3)
Volume of permeable pore space (voids), % = (g2 - g1)/g2 x 100
Density = Bulk density, dry x 62.4 lbs/ft3

Specimen	Absorption (%)	Bulk Dry	Apparent	Volume Permeable	Density*
	Immersion & Boiling	Density (Mg/m3)	Density (Mg/m3)	Voids (%)	lbs/ft3
Utelite Coarse Aggregate	**20.89**	**1.51**	**2.21**	**31.59**	**94.37**

ASTM C 642 on Lightweight Aggregate

Wash sample over #8 Screen and retain (1 Quart Cup quantiy)
Oven Dry and weigh @ 24 & 48 hrs Max 0.5% of lesser value change
Weigh without cheese Cloth. (A Oven Dry)
Place in double cheese cloth and zip tie
Soak under water for 7 days.
Towel Dry and weight (B SSD)
Place back in cheese cloth and boil 5 hrs and allow to cool overnight.
Towel Dry and weight (C After Boil SSD)
Place back in fine screen basket with screen lid. Suspend under water
Weigh Suspended (D Immersed Apparent)

UTELITE CORPORATION
MATERIAL TEST REPORT

DATE 7/7/2016
MATERIAL C.F FINES
SPECIFICATION ASTM C330

P.O. # 0

SAMPLED FOR Tourney Consulting
SAMPLED FROM STOCKPILE
SAMPLED BY TAS

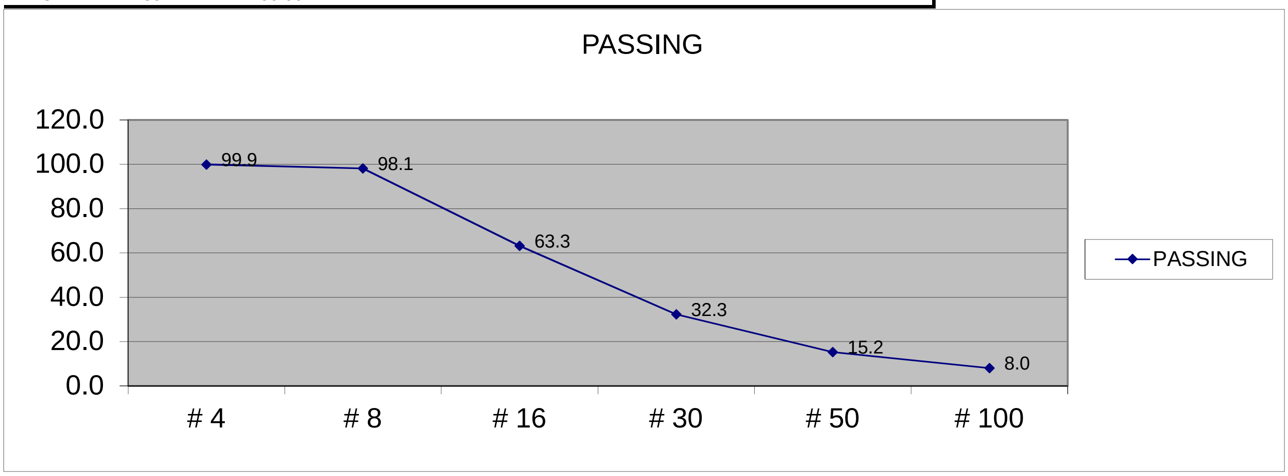
REMARKS Project No. 16059

WET SAMPLE WEIGHT 644.7 GRAMS
DRY SAMPLE WEIGHT 594.7 GRAMS
TOTAL MOISTURE 8.41%

MOIST LOOSE UNIT WEIGHT 57
O.D UNIT WEIGHT 55.8

FINENESS MODULUS 0.00

U.S. SIEVE	WEIGHT	% RET.	CUM % RET.	% PASSING	%PASSING	% RETAINED
3/8"	0	0.0	0.0	100.0	0	
1/4"	0	0.0	0.0	100.0	0	
# 4	0	0.0	0.0	100.0	85-100	
#6	0.5	0.1	0.1	99.9		
# 8	10.6	1.8	1.9	98.1	70-100	
# 16	207.4	34.9	36.7	63.3	45-65	
# 30	184.1	31.0	67.7	32.3	15-35	
# 50	101.5	17.1	84.8	15.2	10-25	
# 100	42.8	7.2	92.0	8.0	5-15	
PAN	47.8	8.0	100.0			
TOTAL	594.7	100.00				



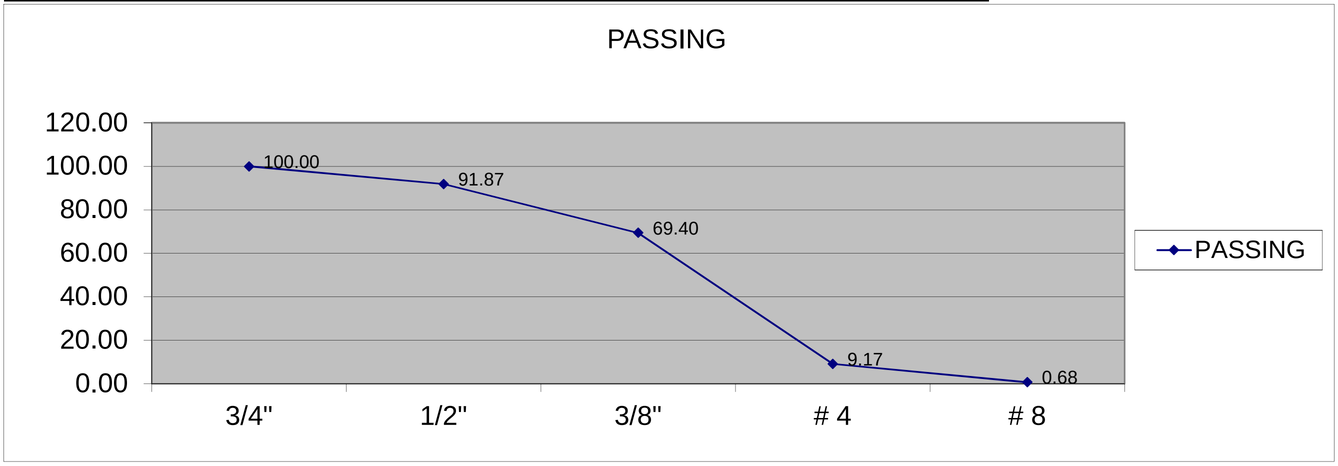
UTELITE CORPORATION
MATERIAL TEST REPORT

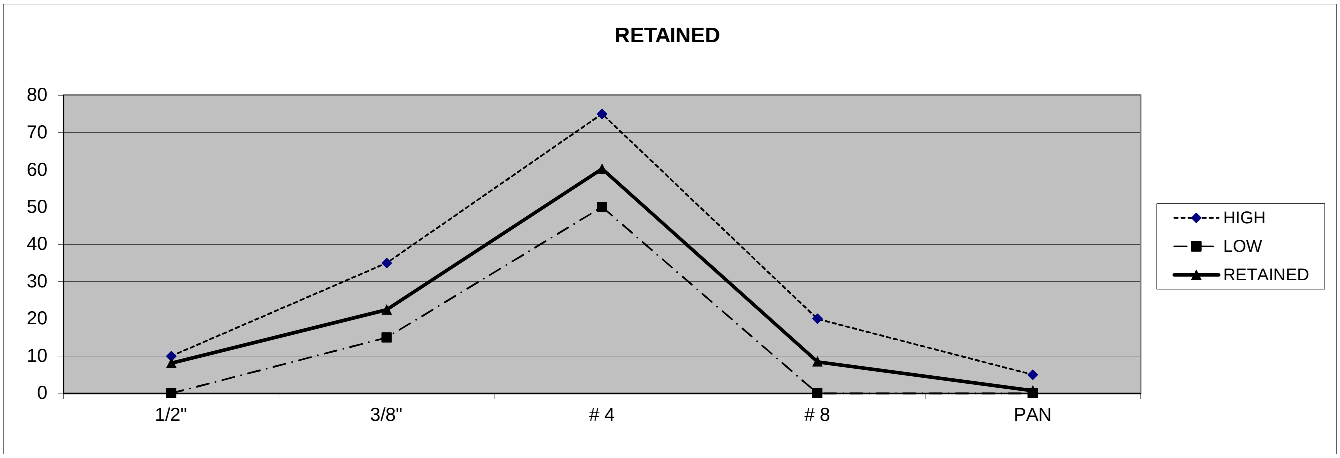
DATE	7/7/2016	P.O. #	0	SAMPLED FOR	Tourney Consulting
MATERIAL	COARSE			SAMPLED FROM	BELT
SPECIFICATION	ASTM - C330			SAMPLED BY	TAS

REMARKS Project No. 16059

WET SAMPLE WEIGHT	1134.4	GRAMS	MOIST LOOSE UNIT WEIGHT	50.6
DRY SAMPLE WEIGHT	1093	GRAMS	O.D UNIT WEIGHT	48.6
TOTAL MOISTURE	3.79%			
FINENESS MODULUS	3.06			

U.S. SIEVE	WEIGHT	% RET.	CUM % RET.	% PASSING	PASSING SPEC	RETAINED
3/4"	0	0.00	0.00	100.00	100	
1/2"	88.9	8.13	8.13	91.87	90-100	10-0
3/8"	245.6	22.47	30.60	69.40	40-80	35-15
1/4	504.8	46.18	76.79	23.21		
# 4	153.5	14.04	90.83	9.17	0-20	15-30
# 8	92.8	8.49	99.32	0.68	0-10	20-0
PAN	7.4	0.68	100.00			5-0
TOTAL	1093	100.00				





CMT ENGINEERING LABORATORIES
Construction • Materials • Technologies
Geotechnical, Environmental, & Materials Engineering/Testing/Research

STANDARD SPECIFICATION FOR LIGHTWEIGHT STRUCTURAL FINES (ASTM C330) (FINAL REPORT)

Project:	Lab Services	Project #:	0534	Report Date:	3/4/2016
Client:	Utelite	Tested By:	CMT		
Material Type:	Structural Fines	Source:	Utelite		

Sieve Analysis		
ASTM C136, AASHTO T27		
Sieve Size	% Passing	Spec
50 mm (2 in.)		
37.5 mm (1.5 in.)		
25 mm (1 in.)		
19 mm (0.75 in.)		
12.5 mm (0.5 in.)		
9.5 mm (0.375 in.)	100	100
6.3 mm (0.25 in.)		
4.75 mm (No. 4)	100	85-100
2.36 mm (No. 8)	97	
2.00 mm (No. 10)		
1.18 mm (No. 16)	60	40-80
0.6 mm (No. 30)	36	
0.425 mm (No. 40)		
0.300 mm (No. 50)	19	10-35
0.180 mm (No. 80)		
0.150 mm (No. 100)	12	5-25
0.075 mm (No. 200)	7.6	
Gradation Lab Number		522553
ASTM C136, AASHTO T27 Fineness Modulus		2.76

Chemical Composition		
Standard/Lab Number	Results	Specification
ASTM C40 Organic Impurities (522569)	Lighter than 1	Lighter than Standard
ASTM C641 Staining (522568)	0	60 MAX
ASTM C114 Loss on Ignition (522565)	0.76	5% MAX

Physical Properties				
Standard	Test Method	Lab Number	Result	Specification
ASTM C142/AASHTO T112	Clay Lumps & Friable Particles	552556	0	2% MAX
ASTM C29/AASHTO T19	Dry Loose Bulk Density	522562	58.0	70 lb/ft^3 MAX
	Loose SSD Density		59.3	
ACI 211.2	Specific Gravity	552559	1.559	-
NY 703-19E	Absorption		22.2	-
ASTM C39	Compressive Strength	525235	5360	4000 psi MIN
ASTM C567	Fresh Density	524831	120.7	
	Equilibrium Density		114.8	115 MAX
	Oven Dry Density		111.8	-
ASTM C496	Splitting Tensile Strength	524832	430	320 psi MIN
ASTM C157/C330 8.4	Drying Shrinkage	524833	0.044	0.07% MAX
ASTM C151	Popouts	-	-	No Popouts
ASTM C666	Resistance to Freeze/Thaw	-	-	-

Additional Tests				
Standard	Test Method	Lab Number	Result	Specification
ASTM C88	Sodium Soundness Loss (%)	-	-	
	Number of Cycles	-	-	
ASTM C88	Magnesium Soundness	-	-	
	Number of Cycles	-	-	
ASTM C1260	Reactivity	-	-	
ASTM C131	LA Wear Coarse Loss (%)	-	-	
	Grading/Revolutions	-	-	
ASTM D5821	Fracture Face (1 or 2 Faces)	-	-	
	Fractured Face (%)	-	-	
ASTM D4791	Flat and Elongated (%)	-	-	

Sincerely,

Laboratory Manager

APPENDIX 2 Life 365™ Modeling Results

LW1 Life 365™ Results

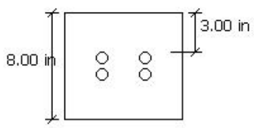
Life-365 v2.2 - Concrete Mixes and Service Lives

Project: New Project

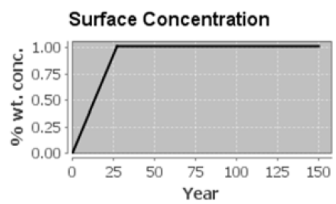
Description: Default settings for a new project

Analyst: Analyst

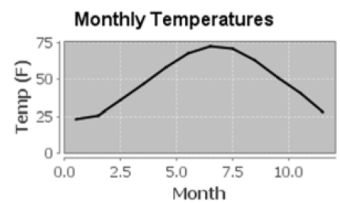
Date: 7/27/2018



slabs and walls (1-D)
Outer dim: 8in; clear cover: 3in



Max surface: 1.010 % wt. conc.
Years to buildup: 27.1



Loc: user-defined
Type: user-defined

Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
LW1	yes	n/a	n/a	n/a		Black Steel

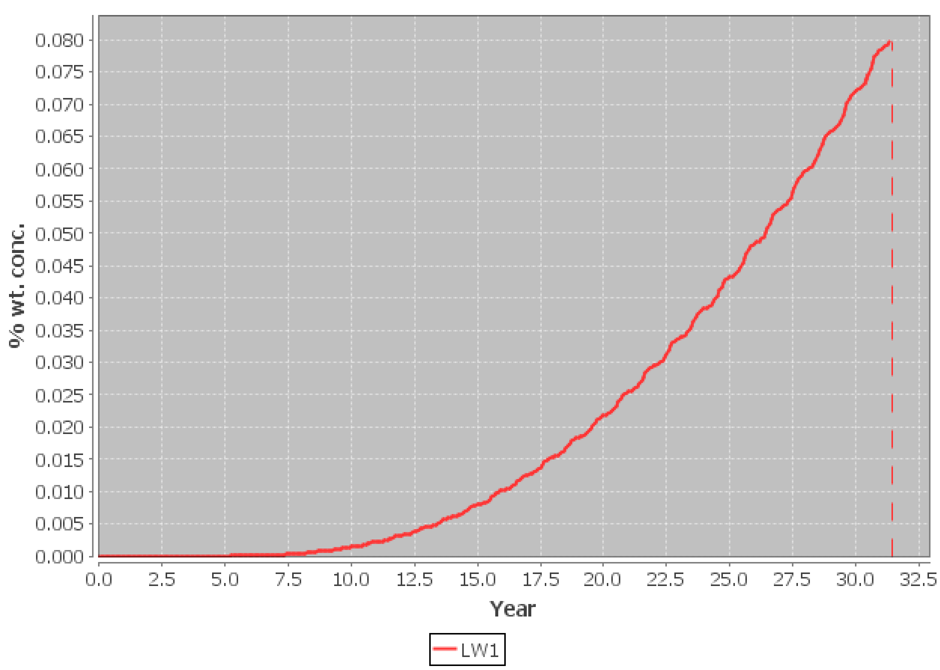
"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
LW1	-> 7.00E-9 in*in/sec	-> 0.24	-> 0.08 % wt. conc.	31.3 yrs	-> 6 yrs	**37.3 yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Conc Versus Time at Depth = 3 in



LW2 Life 365™ Service Life

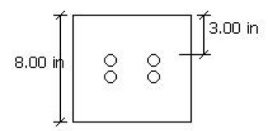
Life-365 v2.2 - Concrete Mixes and Service Lives

Project: New Project

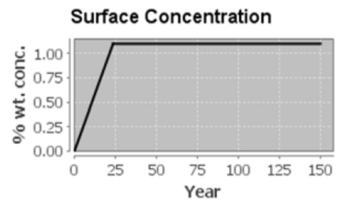
Description: Default settings for a new project

Analyst: Analyst

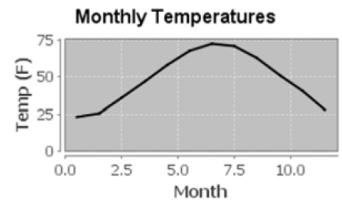
Date: 0727//2018



slabs and walls (1-D)
Outer dim: 8in; clear cover: 3in



Max surface: 1.100 % wt. conc.
Years to buildup: 23.4



Loc: user-defined
Type: user-defined

Concrete Mixes

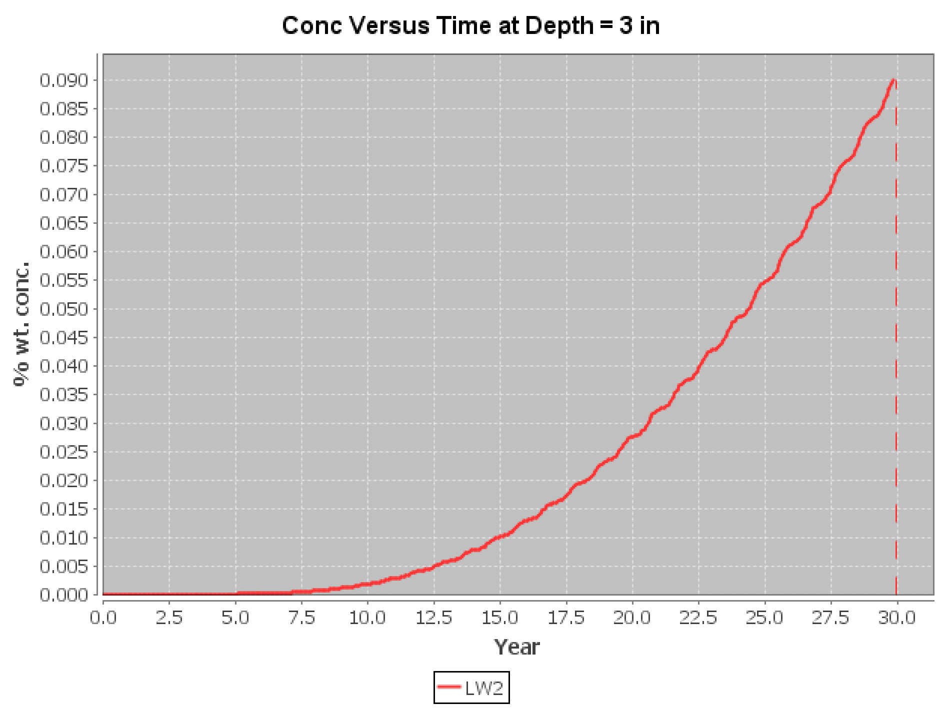
Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
LW2	yes	n/a	n/a	n/a		Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
LW2	-> 7.00E-9 in*in/sec	-> 0.24	-> 0.09 % wt. conc.	29.8 yrs	-> 6 yrs	**35.8 yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.



ALW Life 365™ Service Life

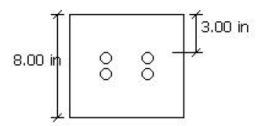
Life-365 v2.2 - Concrete Mixes and Service Lives

Project: New Project

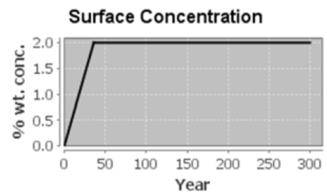
Description: Default settings for a new project

Analyst: Analyst

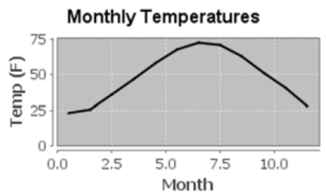
Date: 8/2/2018



slabs and walls (1-D)
Outer dim: 8in; clear cover: 3in



Max surface: 2.000 % wt. conc.
Years to buildup: 36.2



Loc: user-defined
Type: user-defined

Concrete Mixes

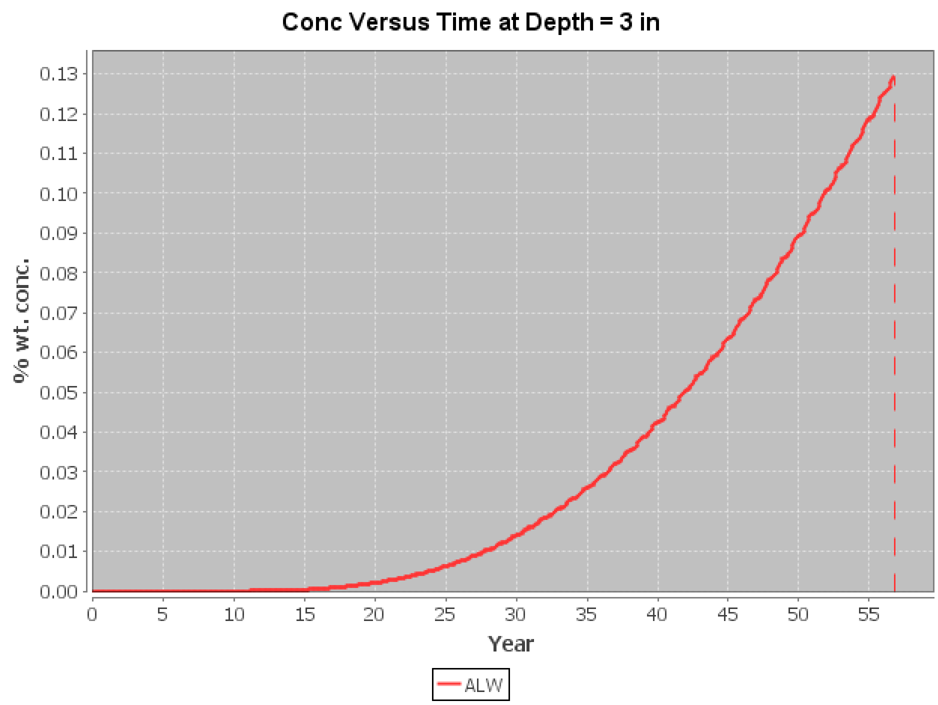
Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
ALW	yes	n/a	n/a	n/a		Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
ALW	-> 7.00E-9 in*in/sec	-> 0.59	-> 0.13 % wt. conc.	56.7 yrs	-> 6 yrs	**62.7 yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.



LWF Life 365™ Service Life

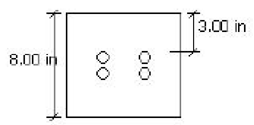
Life-365 v2.2 - Concrete Mixes and Service Lives

Project: New Project

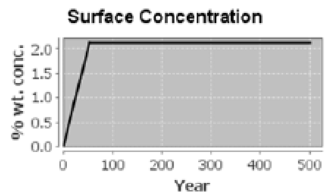
Description: Default settings for a new project

Analyst: Analyst

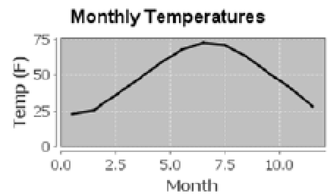
Date: 8/3/2018



slabs and walls (1-D)
Outer dim: 8in; clear cover: 3in



Max surface: 2.120 % wt. conc.
Years to buildup: 51.9



Loc: user-defined
Type: user-defined

Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
LW Fines	yes	n/a	n/a	n/a		Black Steel

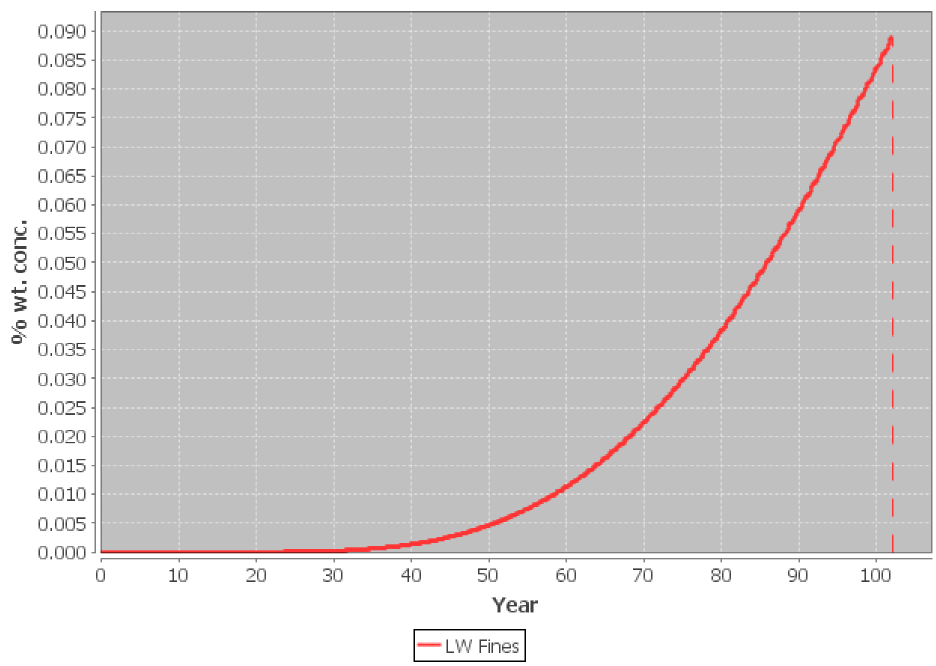
"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
LW Fines	-> 3.00E-9 in*in/sec	-> 0.6	-> 0.09 % wt. conc.	101.9 yrs	-> 6 yrs	**107.9 yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Conc Versus Time at Depth = 3 in



IC Life 365™ Service Life

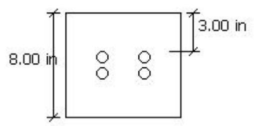
Life-365 v2.2 - Concrete Mixes and Service Lives

Project: New Project

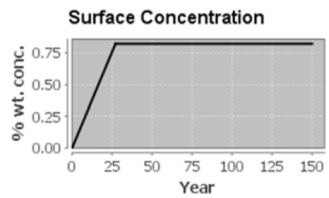
Description: Default settings for a new project

Analyst: Analyst

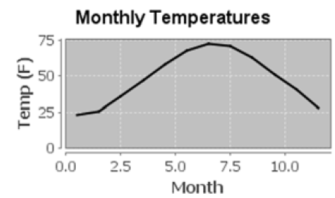
Date: 8/3/2018



slabs and walls (1-D)
Outer dim: 8in; clear cover: 3in



Max surface: 0.820 % wt. conc.
Years to buildup: 27.1



Loc: user-defined
Type: user-defined

Concrete Mixes

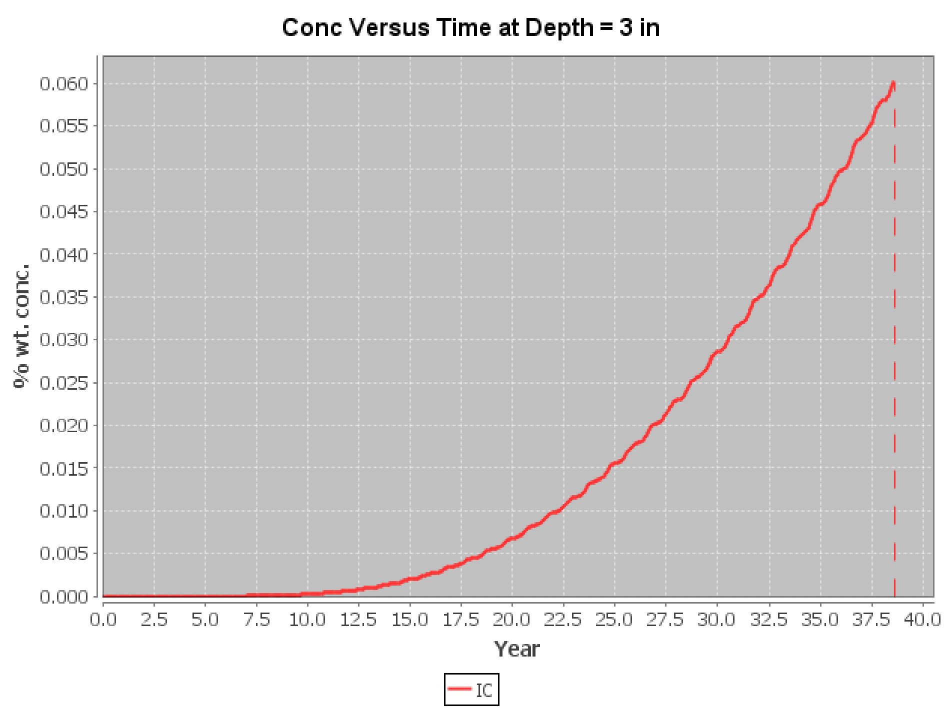
Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
IC	yes	n/a	n/a	n/a		Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
IC	-> 7.00E-9 in*in/sec	-> 0.39	-> 0.06 % wt. conc.	38.6 yrs	-> 6 yrs	**44.6 yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.



C Life 365™ Service Life

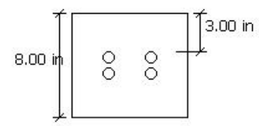
Life-365 v2.2 - Concrete Mixes and Service Lives

Project: New Project

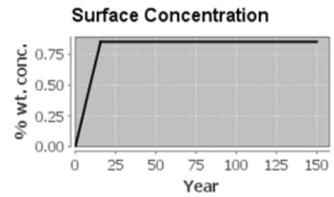
Description: Default settings for a new project

Analyst: Analyst

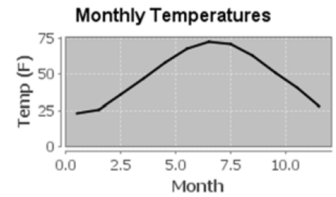
Date: 8/3/2018



slabs and walls (1-D)
Outer dim: 8in; clear cover: 3in



Max surface: 0.850 % wt. conc.
Years to buildup: 15.5



Loc: user-defined
Type: user-defined

Concrete Mixes

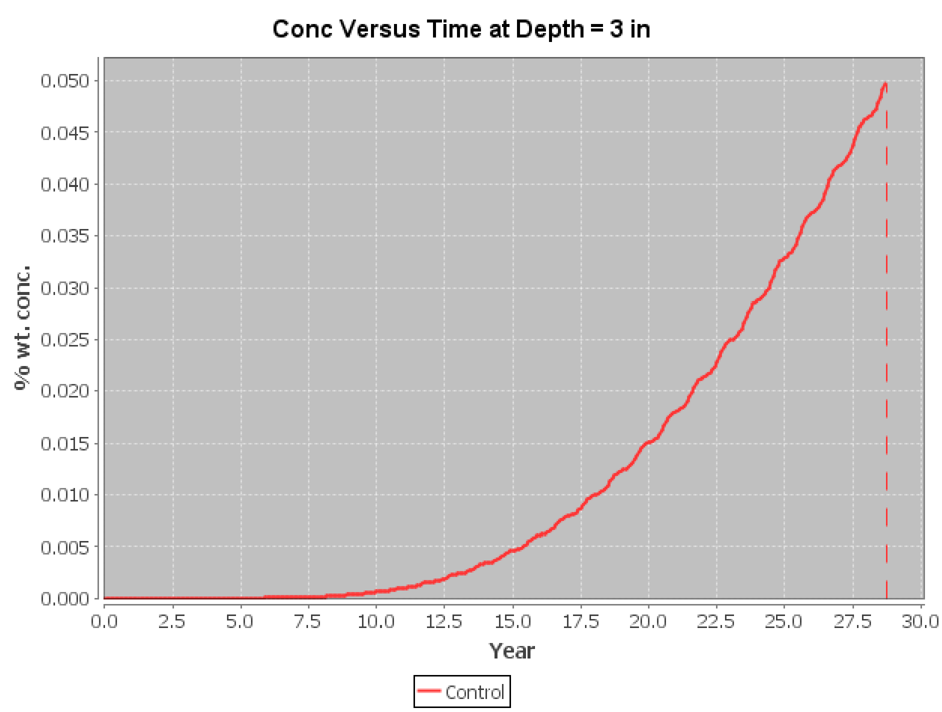
Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Control	yes	n/a	n/a	n/a		Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Control	-> 6.00E-9 in*in/sec	-> 0.3	-> 0.05 % wt. conc.	28.7 yrs	-> 6 yrs	**34.7 yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.



APPENDIX 3 STADIUM® RESULTS

SIMCO Technologies inc.

16059

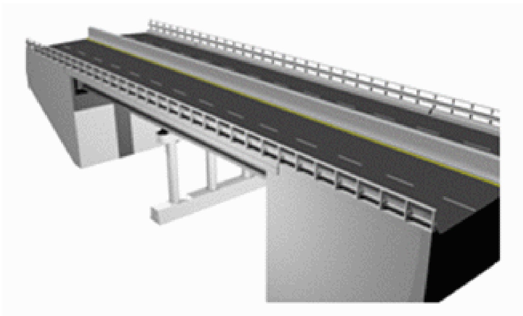
STADIUM® VERSION 2.997

STADIUM® SIMULATION REPORT

Location: Detroit

Structure Type: Bridge

Project Ref.:.................................



Aug. 03, 2018

STADIUM®

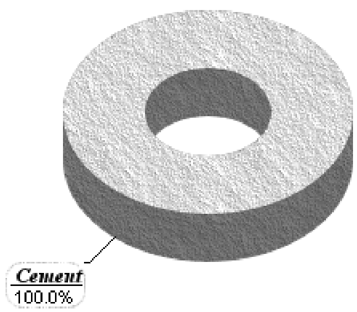
www.simcotechnologies.com

LWF 7-27-18 BA

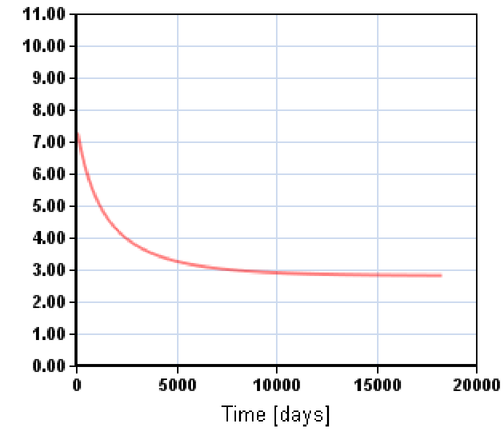
Structure Type: Bridge
Structural Element Type: [Deck]
Material Name:
[Modified Material - for LWF 7-27-18 BA]

Cement Type	TYPE I
Water/Binder Ratio	0.38
Cement Content: (lb/yd³)	657
SCM #1: None (lb/yd³)	0
SCM #2: None (lb/yd³)	0
SCM #3: None (lb/yd³)	0
Fine Aggregates: (lb/yd³)	833
Coarse Aggregates: (lb/yd³)	1800
Water: (lb/yd³)	250
Air: [%]	7.1
Material Density: (lb/ft³)	131
Mixture Volume: (ft³)	27.404
Paste Volume: [%]	27.19

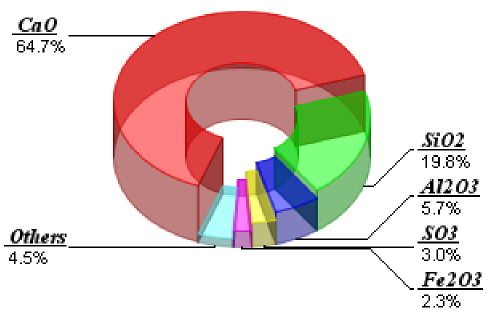
Binder Composition



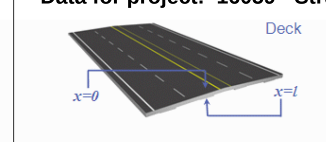
Diffusion Coefficient (e-11 m²/s)- a=.39 - alpha=3.00E-4



Cement Composition



Data for project: 16059 - Structural element [LWF 7-27-18 BA]



Dimension (in) = 8.

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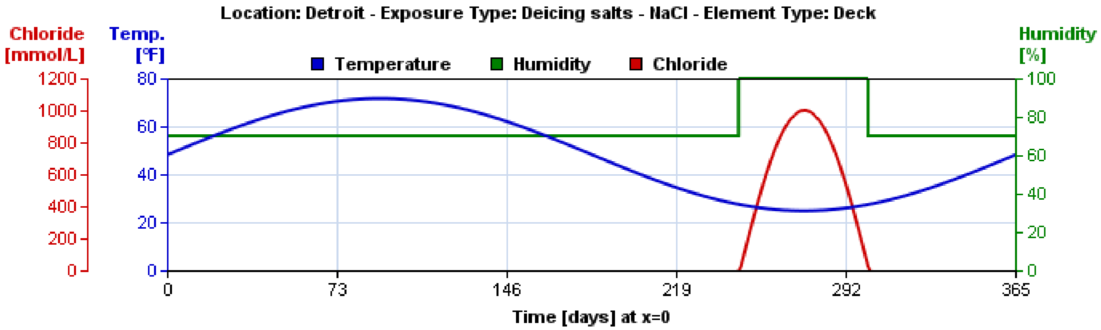
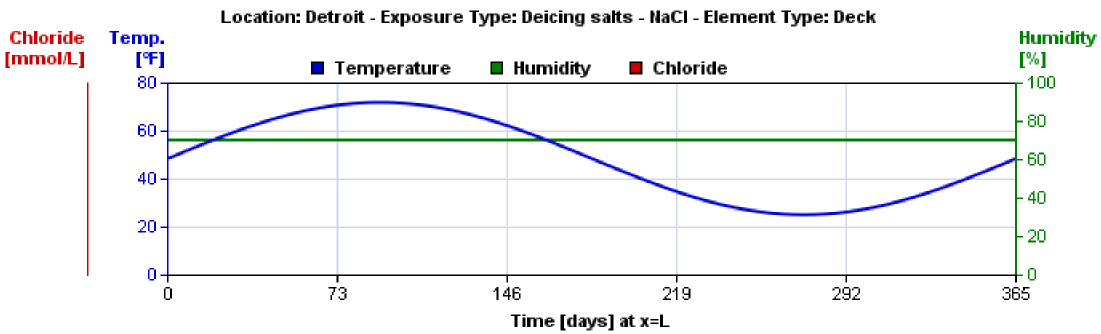
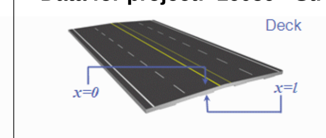
Project Database: [16059.sdb]





Data for project: 16059 - Structural element [LWF 7-27-18 BA] - Scenario: INITIAL



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.38
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2633
Binder Density (lb/yd³) = 5309
Porosity = 0.11
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 7.20
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.39
Hydration Param. - alpha (1/s) = 3.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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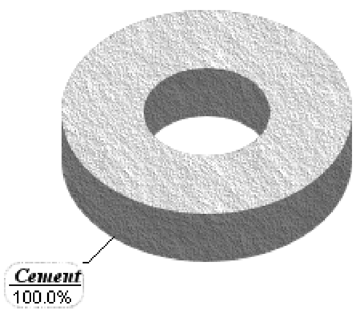
Project Database: [16059.sdb]

LW1 7-27-18 BA

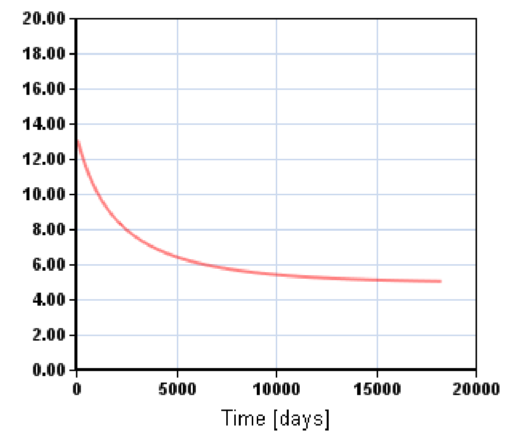
Structure Type: Bridge
Structural Element Type: [Deck]
Material Name:
[Modified Material - for LW1 7-27-18 BA]

Cement Type	TYPE I
Water/Binder Ratio	0.38
Cement Content: (lb/yd³)	657
SCM #1: None (lb/yd³)	0
SCM #2: None (lb/yd³)	0
SCM #3: None (lb/yd³)	0
Fine Aggregates: (lb/yd³)	1342
Coarse Aggregates: (lb/yd³)	988
Water: (lb/yd³)	250
Air: [%]	7.4
Material Density: (lb/ft³)	120
Mixture Volume: (ft³)	27.399
Paste Volume: [%]	27.19

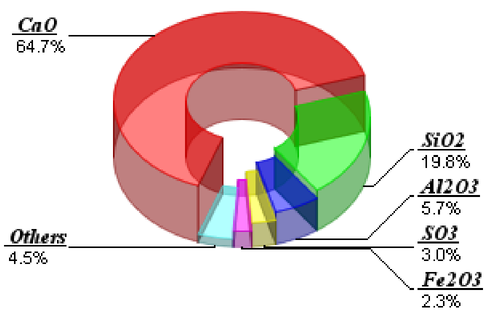
Binder Composition



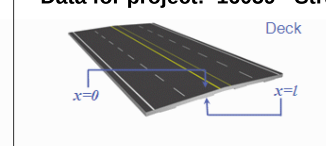
Diffusion Coefficient (e-11 m²/s)- a=.38 - alpha=2.00E-4



Cement Composition



Data for project: 16059 - Structural element [LW1 7-27-18 BA]



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.38
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2329
Binder Density (lb/yd³) = 5309
Porosity = 0.099
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 13.00
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.38
Hydration Param. - alpha (1/s) = 2.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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Design Calculation

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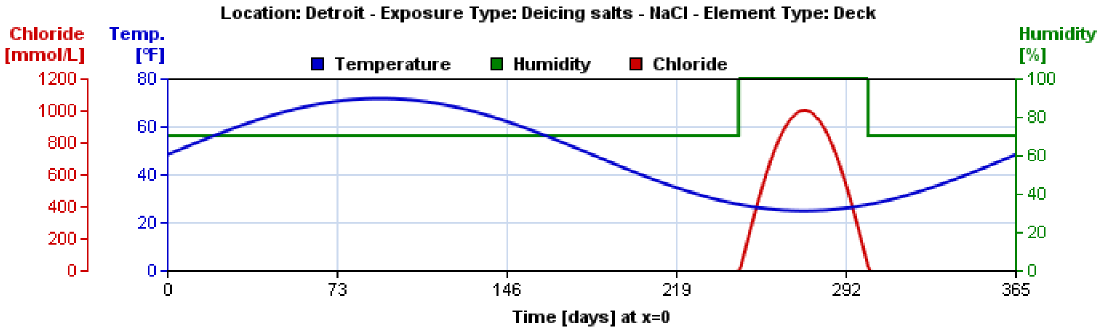
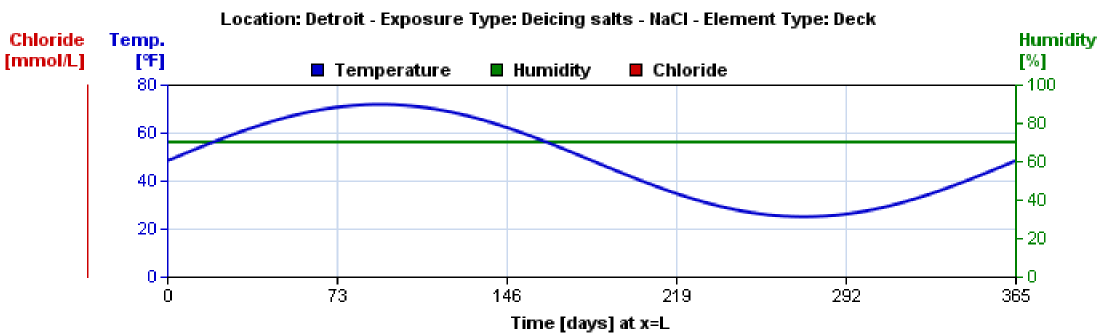
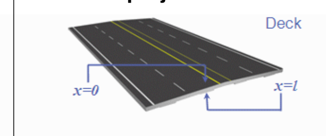
Project Database: [16059.sdb]





Data for project: 16059 - Structural element [LW1 7-27-18 BA] - Scenario: INITIAL



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.38
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2330
Binder Density (lb/yd³) = 5309
Porosity = 0.099
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 13.00
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.38
Hydration Param. - alpha (1/s) = 2.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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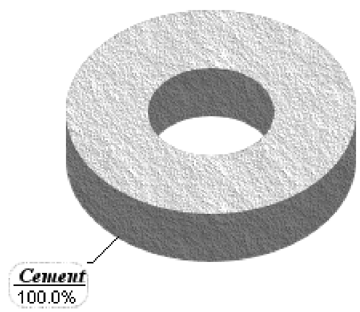
LW2 7-27-18 BA

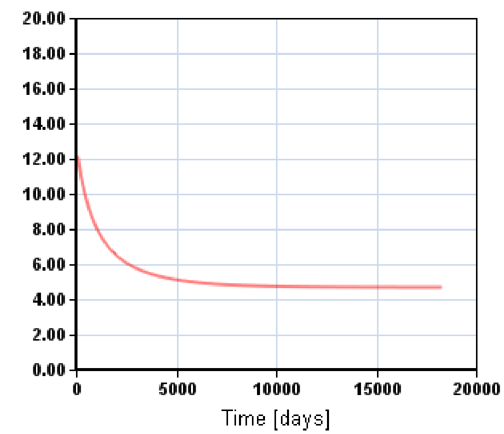
Structure Type: Bridge
Structural Element Type: [Deck]
Material Name:
[Modified Material - for LW2 7-27-18 BA]

Cement Type	TYPE I
Water/Binder Ratio	0.37
Cement Content: (lb/yd³)	657
SCM #1: None (lb/yd³)	0
SCM #2: None (lb/yd³)	0
SCM #3: None (lb/yd³)	0
Fine Aggregates: (lb/yd³)	1251
Coarse Aggregates: (lb/yd³)	1087
Water: (lb/yd³)	243
Air: [%]	6.7
Material Density: (lb/ft³)	120
Mixture Volume: (ft³)	27.412
Paste Volume: [%]	26.8

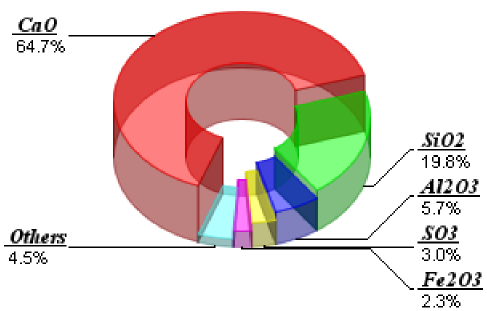
Binder Composition



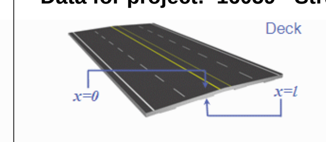
Diffusion Coefficient (e-11 m²/s)- a=.39 - alpha=4.00E-4



Cement Composition



Data for project: 16059 - Structural element [LW2 7-27-18 BA]



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.37
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2338
Binder Density (lb/yd³) = 5309
Porosity = 0.11
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 12.00
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.39
Hydration Param. - alpha (1/s) = 4.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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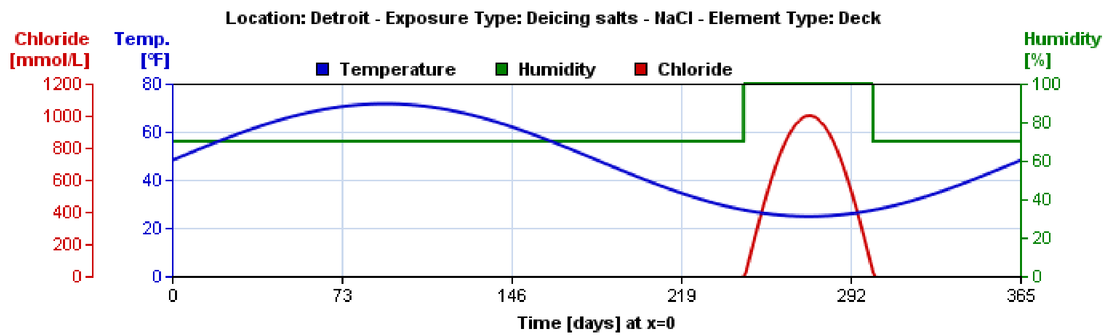
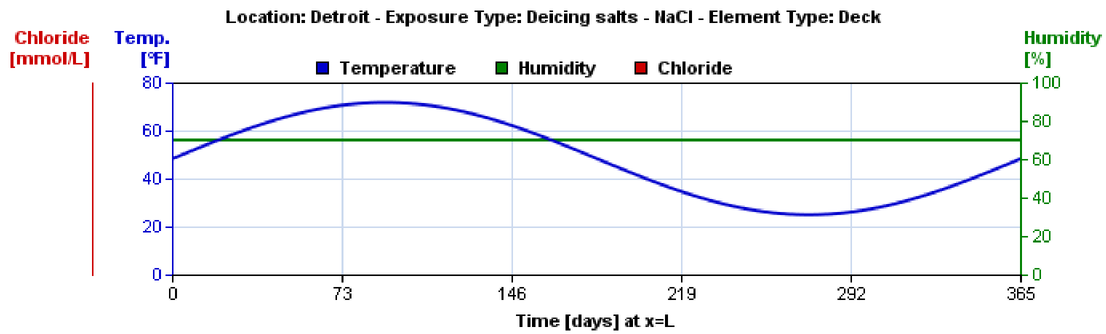
Project Database: [16059.sdb]





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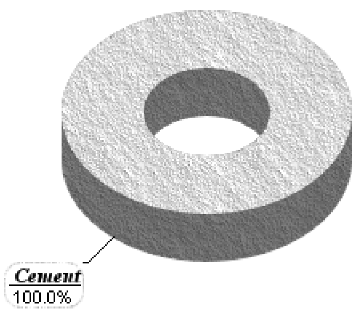
Project Database: [16059.sdb]

ALW 7-27-18 BA

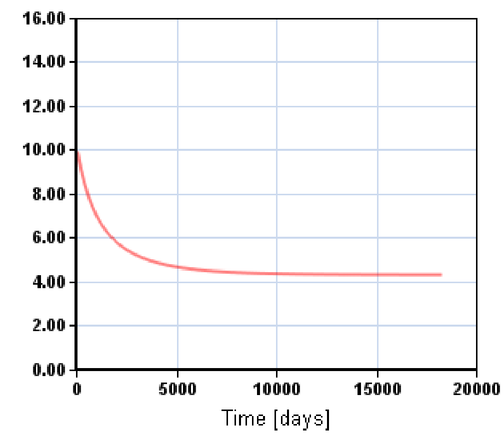
Structure Type: Bridge
Structural Element Type: [Deck]
Material Name:
[Modified Material - for ALW 7-27-18 BA]

Cement Type	TYPE I
Water/Binder Ratio	0.37
Cement Content: (lb/yd³)	657
SCM #1: None (lb/yd³)	0
SCM #2: None (lb/yd³)	0
SCM #3: None (lb/yd³)	0
Fine Aggregates: (lb/yd³)	917
Coarse Aggregates: (lb/yd³)	1116
Water: (lb/yd³)	243
Air: [%]	6.7
Material Density: (lb/ft³)	109
Mixture Volume: (ft³)	27.181
Paste Volume: [%]	26.81

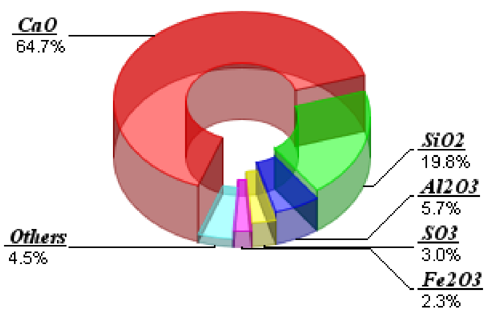
Binder Composition



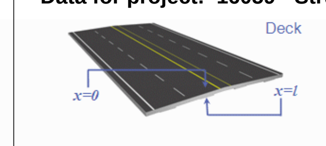
Diffusion Coefficient (e-11 m²/s)- a=.44 - alpha=4.00E-4



Cement Composition



Data for project: 16059 - Structural element [ALW 7-27-18 BA]



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.37
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2033
Binder Density (lb/yd³) = 5309
Porosity = 0.116
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 9.80
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.44
Hydration Param. - alpha (1/s) = 4.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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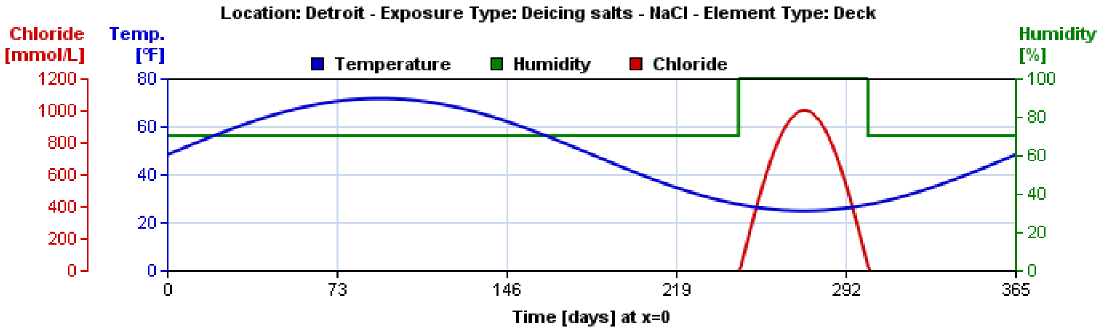
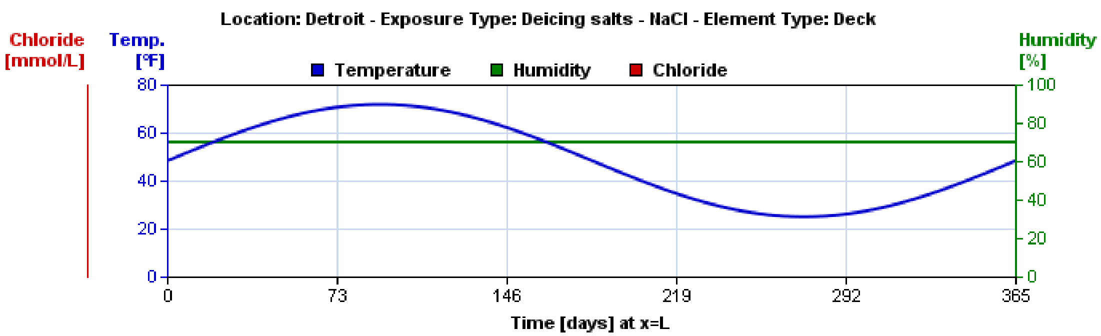
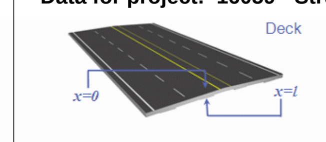
Project Database: [16059.sdb]





Data for project: 16059 - Structural element [ALW 7-27-18 BA] - Scenario: INITIAL



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.37
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2033
Binder Density (lb/yd³) = 5309
Porosity = 0.116
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 9.80
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.44
Hydration Param. - alpha (1/s) = 4.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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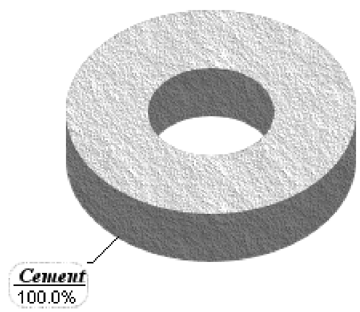
Project Database: [16059.sdb]

IC 7-27-18 BA

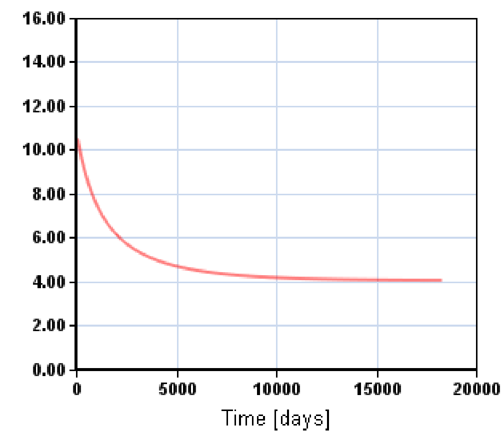
Structure Type: Bridge
Structural Element Type: [Deck]
Material Name:
[Modified Material - for IC 7-27-18 BA]

Cement Type	TYPE I
Water/Binder Ratio	0.38
Cement Content: (lb/yd³)	657
SCM #1: None (lb/yd³)	0
SCM #2: None (lb/yd³)	0
SCM #3: None (lb/yd³)	0
Fine Aggregates: (lb/yd³)	1150
Coarse Aggregates: (lb/yd³)	1800
Water: (lb/yd³)	250
Air: [%]	7.1
Material Density: (lb/ft³)	143
Mixture Volume: (ft³)	27.394
Paste Volume: [%]	27.19

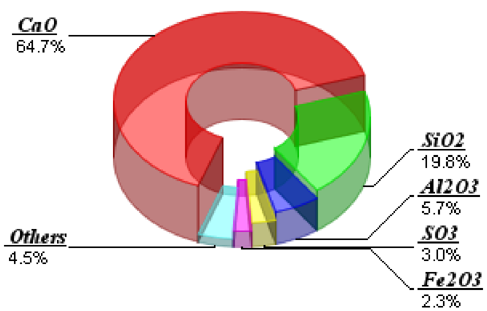
Binder Composition



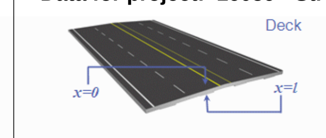
Diffusion Coefficient (e-11 m²/s)- a=.39 - alpha=3.00E-4



Cement Composition



Data for project: 16059 - Structural element [IC 7-27-18 BA]



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.38
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2950
Binder Density (lb/yd³) = 5309
Porosity = 0.111
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 10.40
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.39
Hydration Param. - alpha (1/s) = 3.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

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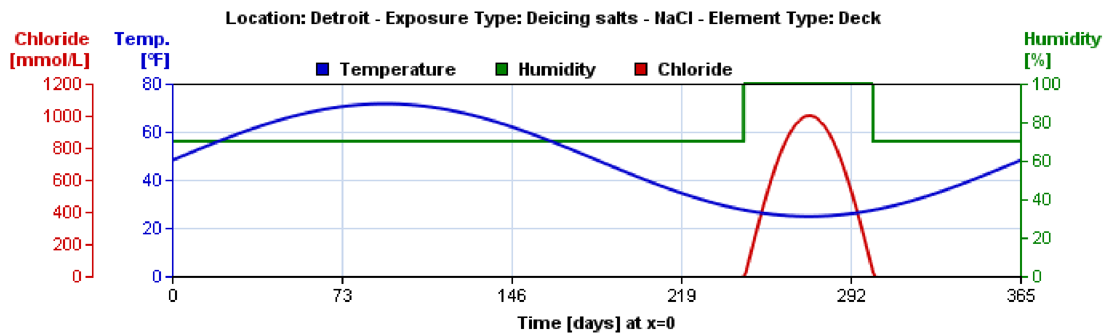
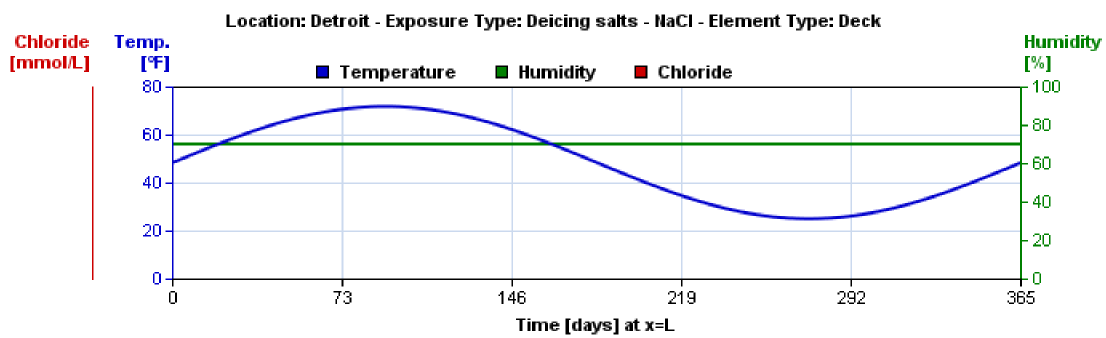
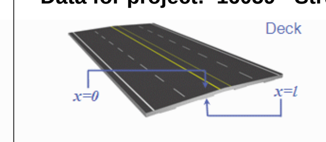
Project Database: [16059.sdb]





Data for project: 16059 - Structural element [IC 7-27-18 BA] - Scenario: INITIAL



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.38
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 2950
Binder Density (lb/yd³) = 5309
Porosity = 0.111
Cement Type = TYPE I

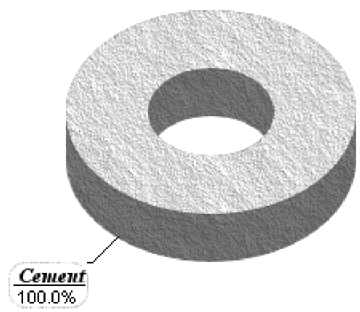
OH- Diffusion Coeff. (e-11 m²/s)= 10.40
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.39
Hydration Param. - alpha (1/s) = 3.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03

C 7-27-18 BA

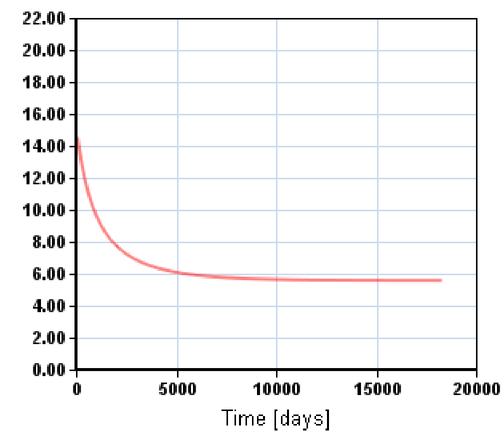
Structure Type: Bridge
Structural Element Type: [Deck]
Material Name:
[Modified Material - for C 7-27-18 BA]

Cement Type	TYPE I
Water/Binder Ratio	0.38
Cement Content: (lb/yd³)	657
SCM #1: None (lb/yd³)	0
SCM #2: None (lb/yd³)	0
SCM #3: None (lb/yd³)	0
Fine Aggregates: (lb/yd³)	1294
Coarse Aggregates: (lb/yd³)	1800
Water: (lb/yd³)	250
Air: [%]	7.1
Material Density: (lb/ft³)	148
Mixture Volume: (ft³)	27.385
Paste Volume: [%]	27.2

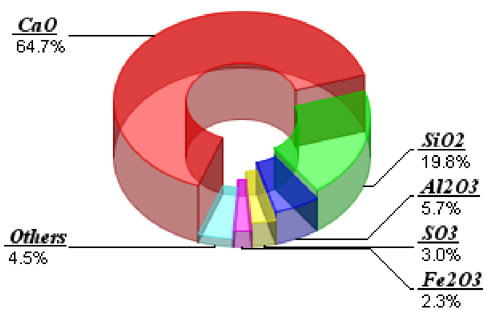
Binder Composition



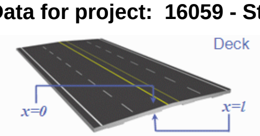
Diffusion Coefficient (e-11 m²/s)- a=.39 - alpha=4.00E-4



Cement Composition

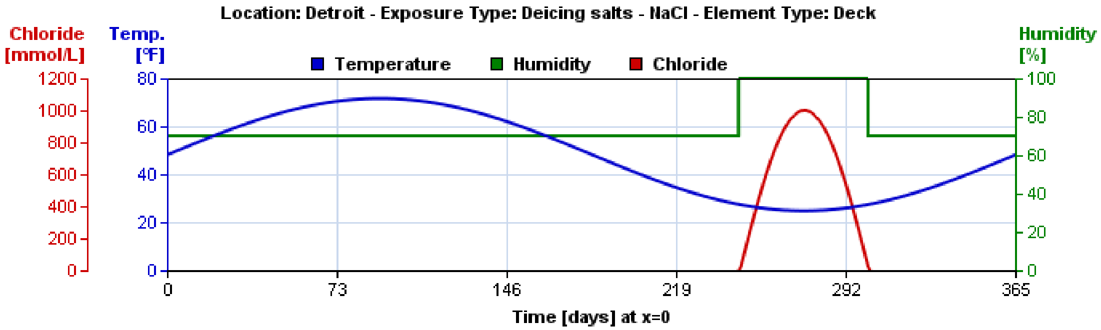


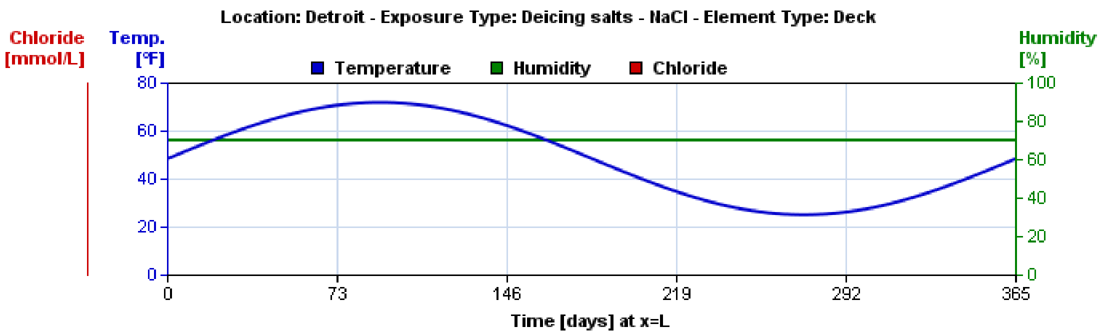
Data for project: 16059 - Structural element [C 7-27-18 BA]



Dimension (in) = 8.
Scenario Duration (years) = 50
Temperature (°F) = 73.4
Water/Binder Ratio = 0.38
Binder Content (lb/yd³) = 657
Total Aggregates (lb/yd³) = 3095
Binder Density (lb/yd³) = 5309
Porosity = 0.117
Cement Type = TYPE I

OH- Diffusion Coeff. (e-11 m²/s)= 14.30
Saturation at 50% R.H.= 0.48
Age of First Exposure (days)= 28
Age at Lab Testing (days)= 28
Hydration Param. - a = 0.39
Hydration Param. - alpha (1/s) = 4.000E-04
Thermal Conductivity (W/m.K) = 2.000E+00
Specific Heat (J/kg/K) = 1.000E+03





STADIUM® VERSION 2.997