Lightweight Aggregate Optimizes the Sustainability of Concrete

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www.escsi.org
So what is Sustainability?

• It’s a design issue
• Nature doesn’t have a design problem
• Sustainability is just good design and common sense
Design for Intended Service Life

Concrete Fails at the Crack
  Durability is about crack control
  Start with micro cracks (Micro structure)
  Reducing micro-cracking Improves durability

Structural lightweight aggregate controls cracks
  Bond between aggregate and paste (Contact Zone)
  Elastic compatibility
  Internal curing
What is Lightweight Aggregate?

• ASTM C 330 & C 331
• Volcanic:
  Pumice, Scoria, Tuff (Romans)
• Manufactured:
  Blast Furnace Slag
  Expanded Shale, Clay or Slate (1908)
  Sintered Fly Ash
• By products of coal or coke combustion
  Bottom ash, cinders
Lightweight Aggregate is About One Half the Bulk Density
Cost / Volume / Weight ratio

25 Tons (1 Load)
Ordinary Aggregate

25 Tons (1 Load)
ESCS Aggregate
LWA has been used for 2000 yrs
WHY?

• Because there is something special…
• Because it makes concrete more durable…
• Because it’s cost effective…
• These same reasons make it sustainable…. (green material)
2000 yrs of Sustainability

• Roman Period used lots of LWA
  – Port of Cosa 273 BC (only surface abrasion)
  – Coliseum 75 to 80 AD (50,000 seat capacity)
  – Pantheon 126 AD (142 ft dome)

• Crushed and hauled in volcanic lava 25 miles by wagon (not the local sand or agg)

• Shards calcined clay vases and crushed brick aggregate
Pantheon 1884 yrs old
Pantheon
142 ft dome with decreasing density

Was not exceeded for over 1800 yrs
Lightweight Concrete Ships

• 14 ships built during WW1 (1918-21)
  – Design 5000 psi min. (Actual 5550 psi)
  – Tested 1953, 1979, & 1999 (8700-10,000 psi)
  – Density 95-106 lbs/cf
  – Hull is 4” to 5” thick
  – 5/8” – 3/4” of cover over rebar
  – Ship 7500 tons, 2660 cy, 1550 tons smooth bar

• 90 built during WW2 density (120-125) lbs/cy  The largest had 140,000 ton capacity
U.S.S. Selma June 1919

434 ft long, 43 feet wide
Draft of 26 feet, 4-5” thick, 5/8” cover
The first slump cone
LIGHTWEIGHT CONCRETE SHIP PASSING UNDER LIGHTWEIGHT CONCRETE BRIDGE 1944

14 built WW 1
90 built WW 2
104 Total Ships
10 Ships located at Powell River, BC Canada
90 yrs in sea water, design 5000 psi 106 pcf
Current strength 8700-10,000 psi
80 year old Peralta with 5/8” to 3/4” cover
CTL 1999 “The concrete is of exceptionally good quality and overall is in excellent condition.”
Bond between Aggregate and Paste

- Improved mechanical bond - rough surface texture
- Improved Chemical bond - surface is slightly pozzolanic
- Reduces micro-cracking
Normalweight concrete
Normalweight concrete

Fig. 3.14. SEM micrograph of a freshly fractured surface of 28-day old portland cement mortar showing the occurrence of calcium hydroxide at the paste-sand interfacial zone (w/c = 0.40); 1 — sand particle; 2 — calcium hydroxide crystals; 3 — cement paste; c = crack; f = fracture.
Normal weight concrete
Elastic Compatibility

• Modulus of elasticity of LWA is close to the modulus of the cement paste
• Reduces stress concentrations
• Reduces microcracking, autogenous shrinkage, and shrinkage cracking
Internal Curing

- Process by which water is provided throughout the concrete to enhance cement hydration
- Accomplished by adding saturated LWA (fines or intermediate) or super absorbent polymer material (diapers)
- Especially helpful for HPC, low w/cm ratio, improve durability, longer service life
- Also works for every day concrete .45 - .55 w/cm
Internal Curing at the Contact Zone

LWA
Interface between two porous materials [LWA, pores and Hydrating Cementitious Paste (HCP)]

NWA
Interface between Hydrating Cement Paste (HCP) and the non-absorbing dense normal weight aggregate "wall"

Two-way moisture movement between porous LWA and porous HCP allows for hygral equilibrium.

Empty pores

Water entrained in LWA pores (5-300µm) moves to finely developing HCP pores (<1µm)

Irregular pyro-processsed contact surface is pozzolanic.

Integrity of Transition Zone improves at the LWA interface.

Higher water content may develop at dense aggregate "wall" interface

Smooth Contact Surface

DENSE NORMAL-WEIGHT AGGREGATE

Transition Zone: W/Cm tends to increase in transition zone at approach to dense normal weight aggregate "wall"
Absorption into Lightweight Aggregate
Why use Internal Curing
(all about the micro structure)

• Minimizes Plastic Shrinkage Cracks
• Reduces Autogeneous Shrinkage
• Delays Drying Shrinkage
• Mitigates Self Dessication
• Mitigates micro cracks
• Disconnects capillaries (chloride intrusion)
• Improves the Contact Zone
• Helps offset poor curing
Academic Studies
Internal Curing Affect on Shrinkage

Purdue Univ - Henkenseifken, et al. Restrained shrinkage of sealed mortar specimens (Cracking Ring)
Figure 8 - Free shrinkage results of plain and LWA-K mortar mixtures in sealed curing conditions during the first 7 days.
Deck Cracking Tests, Auburn Univ
Preliminary results, 1 LWA, 2 more to test

![Graph showing concrete cracking](image)

- **Spring - 73 deg.**
  - NWC
  - IC
  - SLW
  - ALW

- **Summer - 95 deg.**
  - NWC
  - IC
  - SLW
  - ALW

2010 Concrete Sustainability Conference
Paving Mixture With Internal Curing

300 lbs of LWA intermediates (# 4-16)

4000 psi at 4d
6000+ at 28d

At 2 ½ months less than ½ the cracks & smaller cracks

SH 121, Dallas, TX
IC Benefits for Concrete Pavement

- Reduce number of shrinkage cracks
- Reduce the width of cracks
- Increase strength of the concrete
- Improves durability
- Increase the probability of quality concrete (In the real world IC acts as insurance)
Slab Curling

- ACI SP-256-3 Pre-soaked LWA Fines as additives for Internal Curing in Concrete (Wei and Hansen, Univ. Michigan)
- w/c .35 & .45
- Sand replacement of 20% and 40% by volume
- Results: “IC is effective in mitigating autogenous shrinkage but also reduces slab uplift from moisture warping due to drying at the top and wetting at the bottom.”
Resistance to Chloride Intrusion

- LWA has improved resistance to chloride intrusion
- Silver Creek Overpass, UT constructed in 1968
- Chloride content after 23½ years in service

<table>
<thead>
<tr>
<th>Depth</th>
<th>LWC Deck</th>
<th>NWC Appr. Slab</th>
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<tbody>
<tr>
<td>0&quot; to ½&quot;</td>
<td>36.7 lbs / CY</td>
<td>20.5 lbs / CY</td>
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<tr>
<td>½&quot; to 1&quot;</td>
<td>18.0 lbs / CY</td>
<td>18.0 lbs / CY</td>
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<tr>
<td>1&quot; to 1½&quot;</td>
<td>7.7 lbs / CY</td>
<td>15.7 lbs / CY</td>
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<tr>
<td>1½&quot; to 2&quot;</td>
<td>0.5 lbs / CY</td>
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LWC Deck Wear Performance

• Nickel bridge, Richmond VA
• LWC deck was removed after 34 years in service
• Several F/T cycles and salted regularly

Wear was uniform, 1/8”
Well over 100m crossings
No deterioration or corrosion
Near perfect condition (34yr)
Optimize Bridge Design
(600+ major bridges in NA)

• Wider bridge deck (additional lanes) on existing structural supports
• Balance cantilever (longer on the LW side)
• Deck may be thicker for better drainage
• More cover over reinforcement
• Longer bridge spans, fewer bridge piers
• Pier location flexibility
Raftsundet Bridge, Norway
Wabash River Bridge
Lafayette, Indiana
96 girders, 175 ft long – 7.5 ft height
96 tons, 7000 psi @ 5 days
17% weight reduction
Cost savings $1.7 m  Total project  $9.4 million
Hibernia Offshore Platform
St. John’s Newfoundland
LWC 126-150 pcf  10-13,000 psi
Hibernia Offshore Platform
Hibernia Final
1.2 million tons
Optimize Building Design

• Less weight helps sustainability
• Smaller foundations, beams and columns
• Reduced seismic inertia
• Less overall material used
• Longer spans increasing design flexibility
• Better fire ratings
Fire Rated Steel Deck Assemblies
Why on Steel Decks?

• Reducing Floor Dead Load
• Typical LW Concrete 20-25% Less
  NW 145 – 150 lb/ft³
  LW 110 + 3 lb/ft³
• LW Concrete Floor Load 45 – 50% Less
  2 hour fire rating @ 110 lb/ft³
  NW 5 1/4“ – 63 lb/ft²
  LW 3 3/4“ – 34 lb/ft²
Embodied Energy of Floor

- Total slab thickness (NW 6 ½”, LW 5 ¼”)
- Embodied Energy
  - NW 1.3 Mbtu/cy; LW 1.8 Mbtu/cy
  - Energy about equal (less concrete & steel)
Floor Drying in Dalton, GA
Relative Humidity Probe Results

- July
- LW Burnished
- NW Burnished
- LW-S Burnished
- Ambient

Graph showing relative humidity levels in different months.
Relative Humidity Probe Results

- LW Burnished
- NW Burnished
- LW-S Burnished
NW Burnished vs Non-Burnished

NW Burnished

NW Non-Burnished
MVER Tests (moisture vapor emission rate)

July

LW
LW-S
NW
Linear (3 lb)

Jan-Feb
Bottom Line… Floor Drying

- On suspended slabs there is no difference between LW concrete and NW concrete performance, drying or adhesives
- The 3 pound MVER is questionable
- The 75% relative humidity is questionable
Specified Density Concrete

Double tees: 128 ft. long
110 pcf, 6000 psi
## Construction Efficiency

### Shipping Lightweight Precast Concrete

<table>
<thead>
<tr>
<th></th>
<th>Project Example Number 1</th>
<th>Project Example Number 2</th>
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<tbody>
<tr>
<td><strong>Shipping Cost Per Truck Load</strong></td>
<td>$1,100</td>
<td>$1,339</td>
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<tr>
<td><strong>Number of Loads Required</strong></td>
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<tr>
<td>Normalweight</td>
<td>431</td>
<td>87</td>
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<tr>
<td>Lightweight</td>
<td>287</td>
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<tr>
<td><strong>Reduction in Truck Loads</strong></td>
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<td>21</td>
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<tr>
<td><strong>Transportation Savings</strong></td>
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<td><strong>Transportation Savings</strong></td>
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<td><strong>Profit Impact</strong></td>
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<tr>
<td>Transportation Savings</td>
<td>$158,400</td>
<td>$28,119</td>
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<tr>
<td>(Less) Premium Cost of LWC</td>
<td>-17,245</td>
<td>-3,799</td>
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<tr>
<td><strong>Increased Gross Margin</strong></td>
<td>$141,155</td>
<td>$24,320</td>
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Lightweight concrete provides better fire performance
Chesterfield Fire Training House

6000 Fires,
6000 Hose streams
25 Years

It doesn’t get any better
## Annual Energy Cost Savings

Calculated Using 1999 Energy Costs

<table>
<thead>
<tr>
<th>City</th>
<th>$/Block/Year</th>
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<tbody>
<tr>
<td>Boston</td>
<td>$0.17</td>
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<tr>
<td>Omaha</td>
<td>$0.13</td>
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<tr>
<td>Los Angeles</td>
<td>$0.05</td>
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Comparing 90 lb/ft³ SmartWall Systems to 135 lb/ft³ Heavy Weight Wall
Roof Top Garden,
LDC Conference Center
Salt Lake City
Are we part of the problem or part of the solution?

Sometimes a little energy must be consumed in the beginning to save a lot of energy over a long service Life.
Making ESCS Lightweight Aggregate
Mining of raw material shale, clay or slate
Fired in a Rotary Kiln
Fired At 2000°F plus
Expanded Shale, Clay and Slate Uses

- Lightweight Geotechnical Fill
- Asphalt Chip Seal
- Structural Lightweight Concrete
Sustainability is about

• Expanding on what works
• Modifying what does not work
• Transcending our current beliefs on how we do things
• It’s all about THE DESIGN PROCESS taking a Holistic approach from the beginning
All great truth begin as blasphemy.
And one great truth is

Everything Goes Better with Lightweight Aggregate
Thank you

John Ries

www.escsi.org