American Concrete Institute®
Advancing concrete knowledge

Sustainability of Concrete Pavement Part 2 of 3

ACI Fall 2010 Convention
October 24 - 28, Pittsburgh, PA

ACI WEB SESSIONS

Julie Buffenbarger, LEEDT AP BD+C, is an Engineering and Architectural Sales Specialist with Lafarge Cement, promoting cement and supplementary cementitious materials and sustainable design and building practice initiatives through technical education, promotion and specification with owners, architects, engineers, and design agencies. She is an active member of ACI, the Concrete Joint Sustainability Committee, and the NRMCA and PCA technical committees relating to sustainability. She has over 15 years of experience in concrete construction marketing and research, and has authored over 15 publications on supplementary cementitious materials, concrete sustainability and durability, and admixtures in mining backfill. She holds B.S. and M.S. degrees in Synthetic Organic Chemistry from Bowling Green State University, Bowling Green, Ohio.

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Cement

LAFARGE
bringing materials to *life*

Blended Cements: Achieving Sustainability and Durability in Concrete Pavements

Julie Buffenbarger, LEED AP, Lafarge
Matthew Miltenberger, Tourney Consulting
October 24, 2010

TCG TOURNEY CONSULTING GROUP

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Roadways Today

The number of worldwide paved roads is 15.99 million kilometers which is almost 20 roundtrips to the moon.

In 97% of the continental United States, you're no more than three miles from a paved road of one kind or another.

ASCE Grade Card	
D-	Roads

$186 Billion is required to just improve US highways!

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Road Construction Today

The US spends $85 billion annually on rolling out tens of thousands more miles.

Building and maintaining a single mile of freeway

- Energy use of 200 US homes use in a year.
- Consumes as much raw material as 1,000 households in 365 days
- Generates more waste than 1200 homes produce annually.

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Environmental Impacts of Transportation

- Transportation was responsible for 27% of total US Greenhouse Gas (GHG) in 2008.
  - Over the last two decades, transportation has been the nation's fastest growing GHG source, responsible for 47% of the net increase in emission between 1990 and 2007.
- Transportation accounts for close to 70% of US oil consumption.
  - The national driving rate has increased three times the rate of population growth since 1970 (driving more miles per capita, more frequently).

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Social and Economic Impacts of Transportation

- Americans spend 4.2 billion hours a year stuck in traffic at a cost to the economy of $78.2 billion, or $710 per motorist.
- Poor road conditions cost motorists $67 billion a year in repairs and operating costs
- And cost 14,000 Americans their lives.

Sustainability

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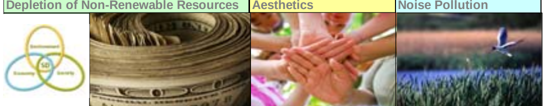
Transportation Impacts and Indicators on Sustainability

Economic	Social	Environmental
Traffic Congestion	Inequity of Impacts	Air Pollution
Mobility Barriers	Mobility Disadvantaged	Climate Change
Crash Damages	Human Health Impacts	Habitat Loss
Transportation Facility Costs	Community Cohesion	Water Pollution
Consumer Transportation Costs	Community Livability	Hydrological Impacts
Depletion of Non-Renewable Resources	Aesthetics	Noise Pollution



Economic	Social	Environmental
Accessibility - Commuting	Safety	Climate Change Emissions
Accessibility - Land Use Mix	Health and Fitness	Other Air Pollution
Accessibility - Smart Growth	Community Liveability	Noise Pollution
Transport Diversity	Equity - Fairness	Water Pollution
Affordability	Equity - Non-drivers	Land Use Impacts
Facility Costs	Equity - Disabilities	Habitat Protection
Freight Efficiency	Non-motorized Transport Planning	Resource Efficiency
Planning	Citizen Involvement	

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Sustainable Transportation Initiatives

- GreenLites – Leadership in Transportation and Environmental Sustainability
- Illinois – Livable and Sustainable Transportation Rating System and Guide; WisDOT – Connections 2030; Mississippi
- MTO – Green Pave
- BE^{2}ST In-Highways – Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways
- Greenroads
- Guide to Green Roads – Alberta/Stantec
- Green Guide for Roads – Transportation Association of Canada
- Green Highway – Federal Highway Administration
- CEEQUAL
- STARS – Sustainable Transportation Access Rating System

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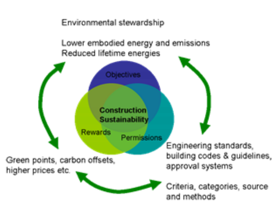
The Seven Principles of Sustainable Construction

- Reduce Virgin Resource Consumption (Reduce)
- Reuse Resources (Reuse)
- Use Recyclable Resources (Recycle)
- Protect Nature (Nature)
- Eliminate Toxins (Toxins)
- Apply Life-cycle Costing (Economics)
- Focus on Quality (Quality)



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Carbon Emissions and Concrete

With the annual consumption approaching 20,000 million metric tonnes (mmt), concrete is the most voluminous manufactured product in the world.

1. Main source of CO_2 in concrete
2. Levers to reduce CO_2 emissions
3. Cementitious blends as method of reducing CO_2
4. Innovation
5. The future challenges of the industry

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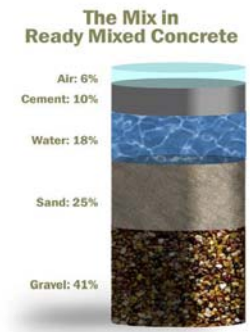
Concrete Manufacturing and CO_2 Production

- Small percentage embodied energy in concrete
  - 100 to 300 kg of CO_2 embodied per cubic meter
- Concrete uses 7% and 15% cement by weight
- That is 5% to 13% of the weight of concrete
- CO_2 reabsorbed into concrete through carbonation
- 33% to 57% of CO_2 emitted from calcination is reabsorbed through carbonation over 100-year life

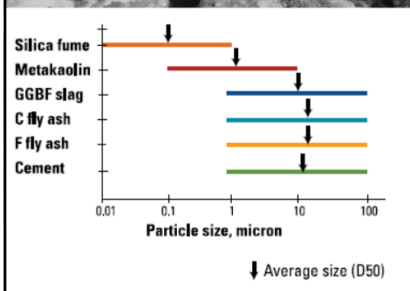


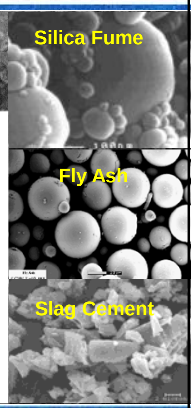
Types of Blended Cements

- **Binary Blends**
  - Slag cement and Portland
  - Fly ash and Portland
  - Silica Fume and Portland
- **Ternary Blends**
  - Slag Cement, Silica Fume and Portland
  - Fly ash, Silica Fume and Portland
  - Fly ash, Slag Cement and Portland
- **Quaternary Blends**
  - Slag, Silica Fume, Fly Ash and Portland

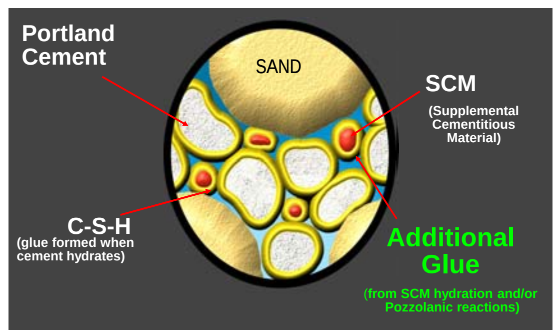
The Pei Bridge

Particle Size of SCMs





How Do SCMs Work?



SCMs as Reuse & Recyclable Materials

When appropriately used, recycled materials can effectively and safely reduce cost, save time, offer equal or, in some cases, significant improvement to performance qualities and provide long-term environmental benefits.

Concrete Properties

- Plastic Properties
- Hardened Properties
  - Durability

How are Fly Ash, Slag Cement and Silica Fume Proportioned into Concrete Mixtures?

- SCMs are used as a partial replacement for the portland cement in concrete.
- Fly ash is commonly used at replacement levels up to 25%; slag cement up to 60%; and silica fume up to 8%.
- When slag cement replaces 50% of the portland cement in a 7500 psi concrete, greenhouse gas emissions per yd^3 of concrete are reduced by 45%.
- Because the cementitious content of concrete is about 7 to 15%, these SCMs typically account for only 2% to 8% of the overall concrete material in buildings.

How do SCMs contribute to Green Design?

- As industrial by-products, their use as a partial replacement for portland cement does not contribute to the embodied energy and CO_2 impacts of cement in concrete.
- Virgin material usage is reduced in the manufacture of concrete.
- Reduced landfill disposal and increased use of recovered industrial materials
- SCMs improve concrete service life through greater concrete durability.

Durability

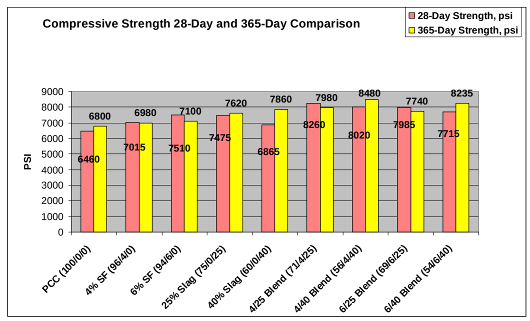
- Durability refers to components and whole to perform functions in its service environment over planned period of time without cost of maintenance.
- Durable materials remain useful for longer periods of time, reducing:
  - Environmental impacts of component/wholesale replacement (waste, manufacturing, deconstruction debris)
- The increase in service life of the infrastructure is a very efficient way to increase the eco-efficiency of the economy. (Division of the total environmental load cradle-to-grave basis by its service life.)

Sustainable Ternary Blended Cements

- Blended cements can be optimized with a synergistic effect, allowing component ingredients to compensate for any mutual shortcomings.
- Tailor made properties can be developed to achieve the needed balance between the industry's quest for high-performance concrete and increasingly restrictive environmental regulations.
- Sustainable Ternary-Blended (STB) cements have very low clinker factor, achieved by substituting at least 40% (by mass) of two complementary cementing materials.

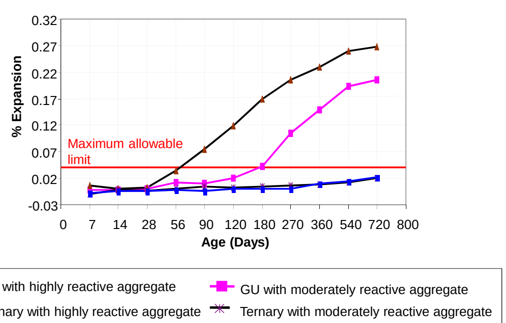
Tsing Ma Bridge, Hong Kong

Compressive Strengths

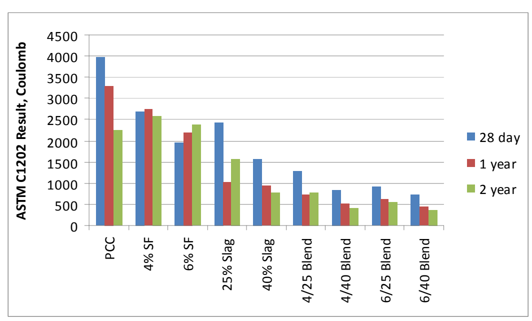


658 lb/yd^3 cementitious materials content, 0.43 w/cm, 6.5-8.0% Air; 5-7 in. Slump

ASR Mitigation –Ternary Blend (Slag and SF)



RCP Test Data – ASTM 1202



658 lb/yd^3 cementitious materials content, 0.43 w/cm, 6.5-8.0% Air; 5-7 in. Slump

Service Life

- The service life and utility of concrete is strongly dependent upon its transport properties (i.e., permeability, sorptivity and chloride permeability).
- The ingress of potentially deleterious materials such as chlorides, sulfates and water by diffusion and capillary transport can lead to the corrosion of steel reinforcement or a reduction of strength due to cracking by frost or sulfate attack.

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Durability and Service Life

- LIFE 365 models concrete corrosion.
- The STADIUM® software is currently being used as the backbone for the industry's most dynamic software development consortium called SUMMA. The SUMMA consortium develops flexible and reliable software applications to assist owners, engineers and concrete producers in the optimum management of concrete infrastructure service life.

STADIUM®

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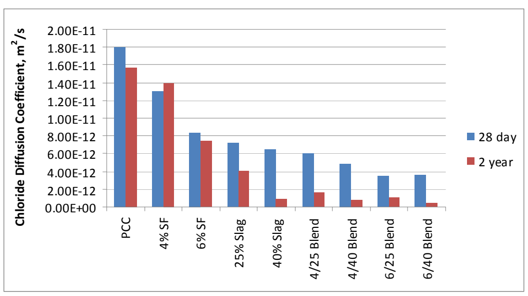
Chloride Diffusion Coefficients – ASTM C1556



658 lb/yd³ cementitious materials content, 0.43 w/cm, 6.5-8.0% Air; 5-7 in. Slump

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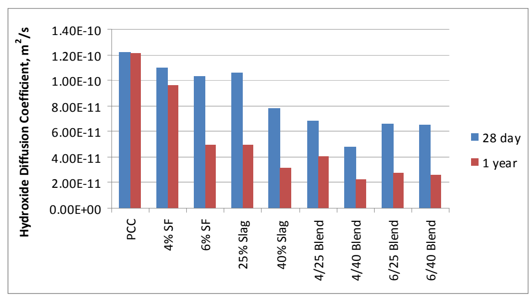
Hydroxide Diffusion Coefficients



658 lb/yd³ cementitious materials content, 0.45 w/cm, 6.5-8.0% Air; 5-7 in. Slump

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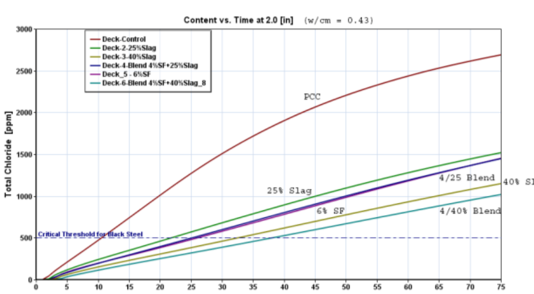
Corrosion Service Life



658 lb/yd³ cementitious materials content, 0.43 w/cm, 6.5-8.0% Air; 5-7 in. Slump

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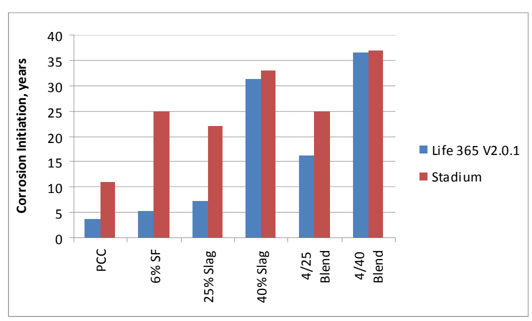
Life 365 vs. STADIUM



658 lb/yd³ cementitious materials content, 0.45 w/cm, 6.5-8.0% Air; 5-7 in. Slump

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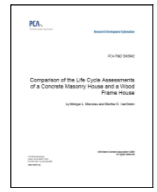
Life Cycle Assessment and Life Cycle Costing Analysis

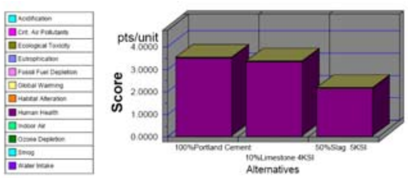
Life Cycle Assessment (LCA)



Life Cycle Assessment (LCA) is a technique for calculating energy, GHG and other impacts of materials, production and processes.

- Life cycle refers to the major activities in the course of the product's life
  - Raw Material Acquisition
  - Manufacture
  - Use
  - Maintenance
  - Final Disposal

Environmental Performance – BEES Program



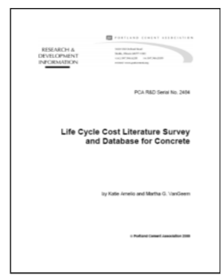
Note: Lower values are better

Category	100% OPC	10Lime4KSI	50Slag5KSI
Acidification--3%	0.0000	0.0000	0.0000
Crit. Air Pollutants--9%	0.0019	0.0019	0.0017
Ecolog. Toxicity--7%	0.0112	0.0109	0.0090
Eutrophication--6%	0.0014	0.0013	0.0012
Fossil Fuel Depl.--10%	0.0032	0.0032	0.0031
Global Warming--29%	0.0191	0.0187	0.0159
Habitat Alteration--6%	0.0000	0.0000	0.0000
Human Health--13%	3.4698	3.2999	2.1187
Indoor Air--3%	0.0000	0.0000	0.0000
Ozone Depletion--2%	0.0000	0.0000	0.0000
Smog--4%	0.0020	0.0020	0.0017
Water Intake--8%	0.0004	0.0004	0.0004
Sum	3.5090	3.3383	2.1517

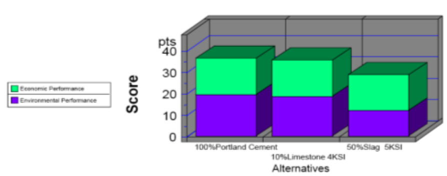
LCA & Life Cycle Cost Analysis

The concept of Life Cycle Cost Analysis (LCCA) is to combine the incurred cost and accrued benefits over different periods of service lifetime in a consistent manner.

LCA & LCCA in sustainable projects where alternatives that fulfill the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings.



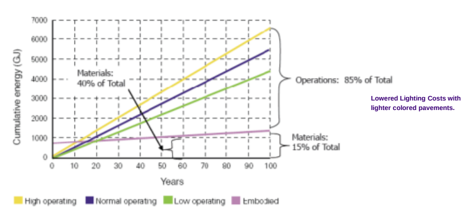
Overall Performance



Note: Lower values are better

Category	100% OPC	10Lime4KSI	50Slag5KSI
Economic Perform.--50%	16.8	16.8	16.4
Environ. Perform.--50 %	19.5	18.5	12.0
Sum	36.3	35.3	28.4

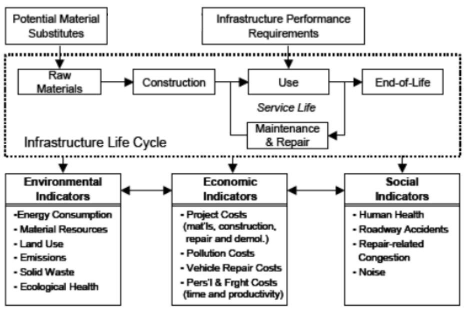
Impact of Service Life and Operating Efficiency



Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery.

The single most important factor in reducing the impact of embodied energy is to design long life, durable and adaptable buildings.

Infrastructure Life Cycle



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Challenges

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Today's Challenges

- The construction industry will have to make a shift from the mindset of fast-speed construction to the mindset of sustainable construction.
- Growth in the codes, standards, guidelines, training and certification programs will play a significant role in the development and acceptance of alternatives to OPC.

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Today's Challenges

- Widely accepted measurement systems for sustainability are yet to emerge.
- Useful metrics should be developed in the near future.
- Emphasis on long-term cost benefit analyses and performance based criteria for designing concrete pavements will result in the selection of a cement for a particular pavement application and promote the selection and familiarity of alternative binders.

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Closing Comments

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Sustainable Attributes of Ternary Blended Cement Concretes

- Reduced CO_2 emissions in manufacture
- Higher Albedo Values
  - Lighter colored pavements with slag cement
    - Lower lighting energy costs
    - Increased safety for motorists
- Reusable & Recyclable Materials
  - Reduction in virgin material use through industrial By-Product Use
- Durability
  - Lowered overall embodied energy
    - Less maintenance
    - Longer service life

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Conclusions

- Sustainability is now being recognized as a vital and central core to urban development.
- Concrete is a construction product that plays an important positive role in minimizing the impacts or our built civilization by providing social, environmental and economic benefits.
- Recycling industrial by-products and construction materials in infrastructure can help generate a "greener" infrastructure where there is a lower embodied energy in its construction through the replacement of virgin materials and the avoidance of large amounts of energy.