Slag Cement in Special Applications
Mass Concrete, Paving, Geotechnical and Waste Stabilization

Mark Van Kleunen - Technical Services/Sales

Skyway Cement/Illinois Cement/Eagle Materials

SCA Slag Cement School

Lehigh Cape Canaveral Slag Cement Plant

5/22 – 5/23/23

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Slag Cement in Special Applications
Mass Concrete

SLAG CEMENT ASSOCIATION Information Sheets

9: Reducing Thermal Stress in Mass Concrete

According to ACI 2071, "mass concrete is any large volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and attendant volume change to minimize cracking." Cement hydration generates heat. Heat dissipates from concrete slowly; the thicker the section, the longer it will take the interior to cool. This can result in large temperature differentials between the concrete surface and its interior. The concrete is then subject to high thermal stresses, which can result in cracking and loss of structural integrity.

Reducing Thermal Stress

There are three generally accepted strategies for reducing thermal stress in concrete:

- Reduce the total cementitious content.
- Reduce the portland cement content.
- Slow down the hydration process using various admixtures or cooling the concrete.

How Does Slag Cement Help?

When slag cement is incorporated in a concrete mixture, less heat is generated and thermal stress is reduced:

- Portland cement content is reduced by the percentage of slag cement used.
- Due to increased strength with slag cement, the total cementitious content can be reduced.
- Hydration characteristics of slag cement are such that the early rate of heat generation and peak temperature of the concrete are reduced.

Slag Replacement Levels

Generally, 65 to 80% is considered an optimum replacement range for mass concrete applications. These levels typically provide significant heat reduction while achieving desired strengths. Levels from 50 to 65% have been used successfully in smaller mass concrete placements. Mixtures should be tested with job materials to ensure required thermal and strength characteristics.

Figure 1: The I-70 Stan Musial Veterans Memorial Bridge (opened 2014) pylons used 70% slag cement in the mass concrete mix, which also was used in other concrete classes of the structures

Figure 2 below shows the effect of slag cement on temperature rise in mass concrete specimens cast in warm and cool weather. The 4.9 ft (1.5 m) cube-shaped concrete specimens were insulated with expanded polystyrene sheets on all but one of the faces. The graphs illustrate a reduction in peak temperature of concrete made using 50 percent slag cement (GGBS) as compared to concrete using all portland cement (OPC). They also indicate a delay in time to peak temperature with use of slag cement. These differences were more pronounced in cool weather as compared to specimens cast in warm weather.

References

1. ACI 207.1R-05, "Mass Concrete," American Concrete Institute, Farmington Hills, MI, 2012.

2. Photo (Stan Musial Bridge) By Mitchell Schultheis - Own work, CC BY-SA 4.0,

3. Soutsos, M.; Hatzitheodorou, A.; Kwasny, J.; and Kanavaris, F., 2016, "Effect of In Situ Temperature on the Early Age Strength Development of Concretes with Supplementary Cementitious Materials," *Construction & Building Materials*, V. 103, pp. 105-116.

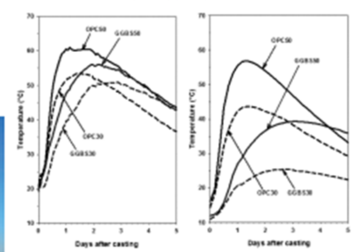

Figure 2: Temperature rise of concrete specimens cast in warm (left) and cool (right) weather with 0 and 50 percent slag cement (adapted from Soutsos et al.3). Note: 30 and 50 refer to the concrete design strengths in MPa (4350 and 7250 psi); degrees Fahrenheit = (degrees Celcius × 1.8) + 32.

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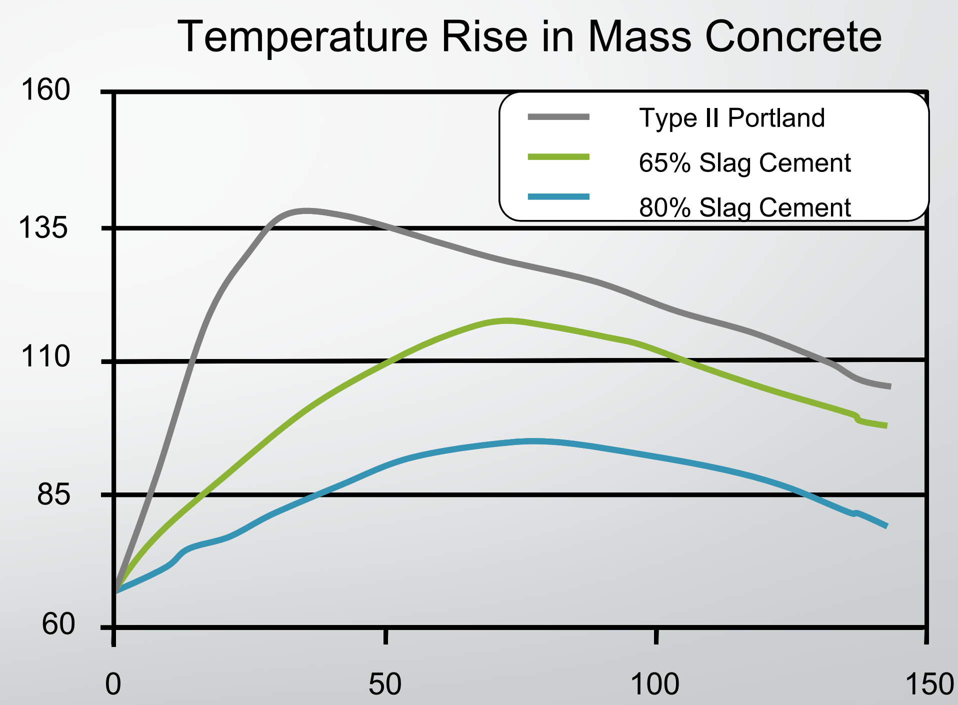
Effect of Slag Cement on Mass Concrete

- According to ACI 207, "mass concrete is any large volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and attendant volume change to minimize cracking." Generally > 3' thick

- Methods of cooling the concrete
  - Chilled water / liquid nitrogen
  - Internal cooling pipes
  - Most economical: Lot's of SCM's

- 40% to 80% is considered an optimum replacement range for mass concrete applications



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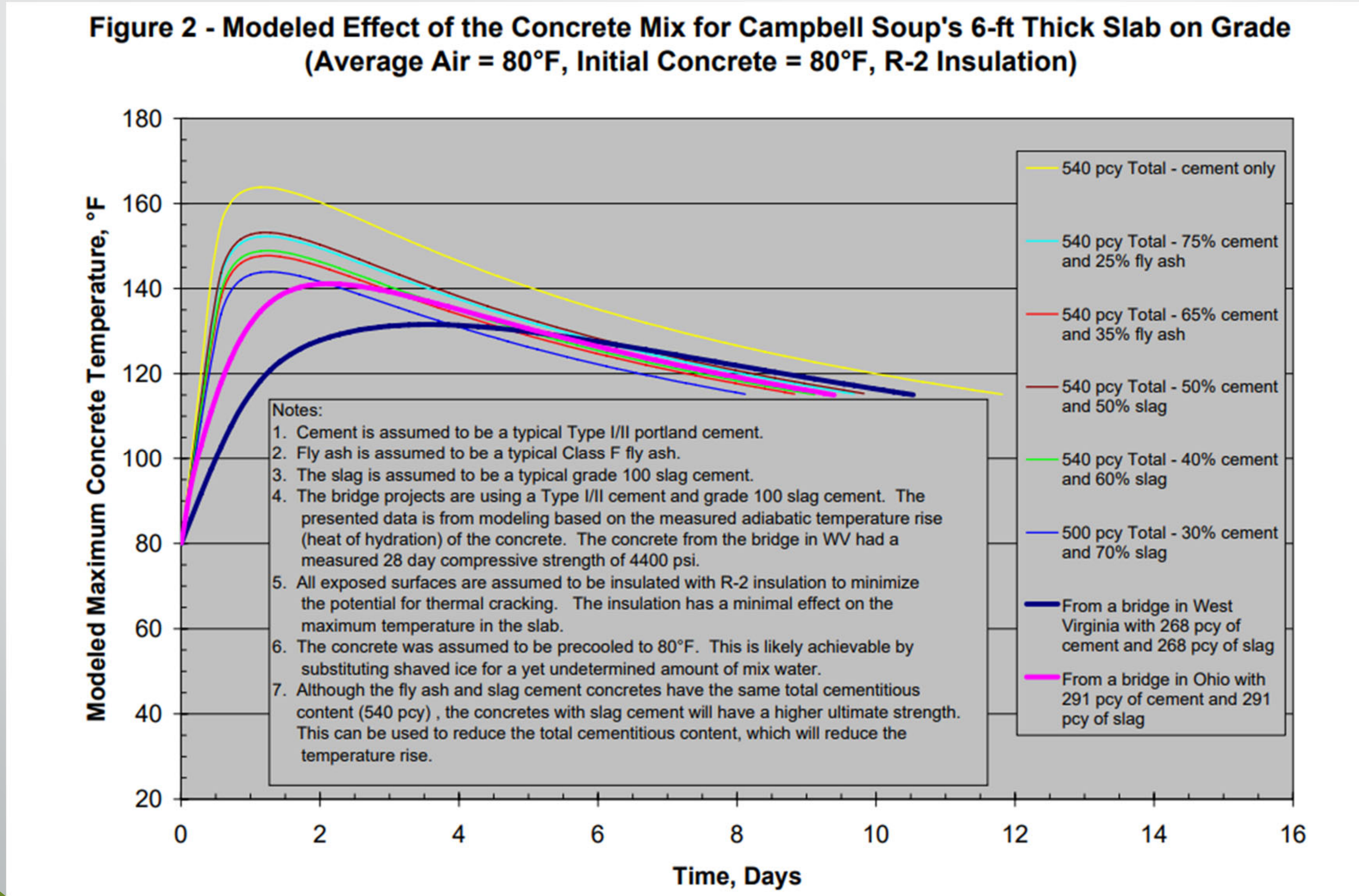
Mass Concrete Temperature Modeling



Maximum In-Place Concrete Temperature Estimator

30% Portland & 70% Slag

Project:	Cayuga
Location:	Indiana

Date:	10/06/05
By:	Darrell Elliot

Meters	1.83	Thickness	6.0	Feet
Meters	42.09	Length	138.0	Feet
Meters	31.42	Width	103.0	Feet
$Meters^3$	2419.73	Volume	85284	$Feet^3$

Metric Units	Senerio #1	Senerio #2	Senerio #3	Senerio #4			Senerio #1	Senerio #2	Senerio #3	Senerio #4	Inch-Pound Units
°C	10	13	16	18	T_i	Initial Concrete Temp.	50	55	60	65	°F
kg/m3	96.1	96.1	96.1	96.1	A	Mass of Cement	162	162	162	162	Lb/Cu.Yd.
kg/m3	224.3	224.3	224.3	224.3	B	Mass of Slag	378	378	378	378	Lb/Cu.Yd.
kg/m3	2333	2333	2333	2333	C	Unit Weight of Concrete	3933	3933	3933	3933	Lb/Cu.Yd.
kj/kg	250	250	250	250	D_1	Heat of Hydration - Cement	59.7	59.7	59.7	59.7	Cal/G
kj/kg	250	250	250	250	D_2	Heat of Hydration - Fly Ash	59.7	59.7	59.7	59.7	Cal/G

Tmax = Ti + "Delta T"

	Senerio #1	Senerio #2	Senerio #3	Senerio #4			Senerio #1	Senerio #2	Senerio #3	Senerio #4	
°C	10.0	12.8	15.6	18.3	T_i	Initial Temperature	50.0	55.0	60.0	65.0	°F
°C	34.11	34.11	34.11	34.11	?T	Temperature Gain	61.40	61.40	61.40	61.40	°F
°C	44.1	46.9	49.7	52.4	T_{max}	Maximum Temperature	111.4	116.4	121.4	126.4	°F

?T = $((A{*}D_1/C) + (B{*}D_2/C) * (1/1006)$ (°C)

Notes:	Calculations are based on a Heat-of-Hydration of 59.7 calories/gram at 7 days for 30% Buzzi GC Type I/II Portland and 70% Holcim Grade 100 S
	The Heat-of-Hydration was determined by the Buzzi Unicem USA Cape Girardeau Cement Laboratory, from samples provided by IMI.
	This is an indicator or estimator of in-place concrete temperature.
	Buzzi Unicem USA accepts no responsibility of the accuracy for these temperatures.
	As always, proper construction practices are required.

One World Trade Center

- Concrete performance requirements included:
  - Heat reduction in mass placements
  - High strength – 14,000 psi
  - Superior rheology
  - Reduced environmental footprint
- Concrete included a quaternary mixture containing 52% slag cement, 32%Portland cement, 8% fly ash and 8% silica fume

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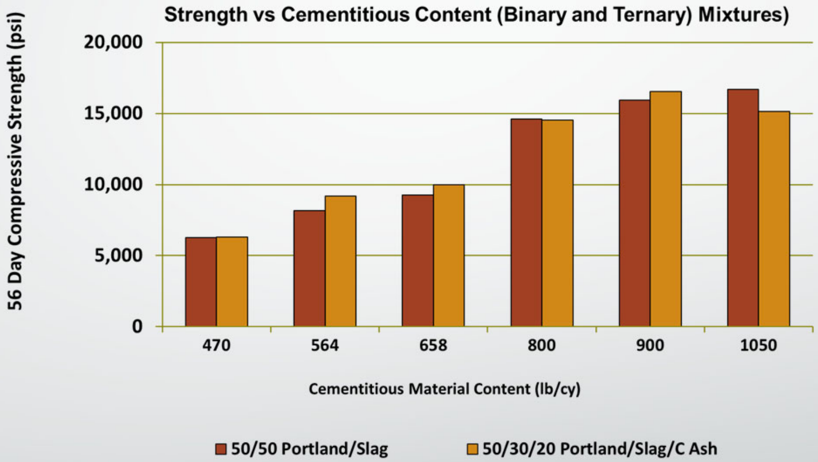
Reliant Stadium
Houston (2001)

- Four “super columns” supporting retractable roof
- Ternary mixture:
  900 lbs/yd
  50% Portland Cement
  30% Slag Cement
  20% Class C fly ash



- Strength:
  13,000 psi required
  15,000 psi field strengths
- Maintained strict temperature differential and peak temperature

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Cinergy, Cayuga, IN

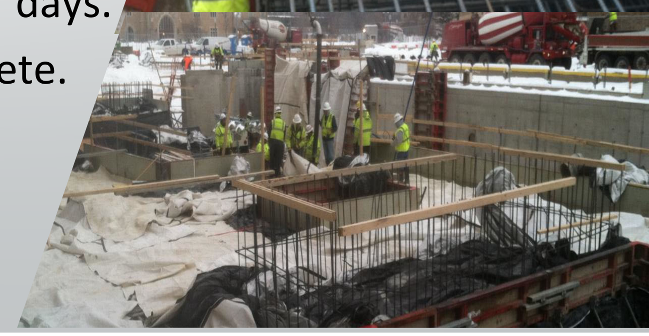
14,300 cubic yards Portland cement/slag cement 30%/70% & 40%/60%
540 total cementitious

<u>Specifications:</u>
Max w/cm Ratio: 0.44
Compressive strength: 4,000 psi @ 56 days
Sump: 4” to 6”
Air content: 4% to 6%
Internal maximum temperature: 160^{o}F
Max internal / external temperature differential: 30^{o}F

Internal max temperatures were 136^{o}F @ and surface temperatures were 129^{o}F. Concrete temps ranged from 57 - 70^{o}F.

Strengths 7 days: 2800 - 3200 psi, 28 days 4700 psi

University of Notre Dame Campus Crossroads Project



- $400 million, LEED Silver, project consisted of attaching three new buildings onto the existing iconic Football Stadium increasing capacity by 750,000 sq. feet.
- Total project entails 58,000 cubic yards of concrete, with over 13,000 yd^3 of mass concrete.
- Mass concrete could not exceed 158 °F at its core. Mass concrete contained 70% slag cement.
- No foundation exceeded 130°F.
- The 28-day design strengths were typically obtained in only 7 days.
- Slag was also used as a SCM in lightweight and general concrete.

JTM Food Group Freezer Floor
Harrison OH

<u>Mix Details</u>
Cement/Slag Cement: 60/40   560 Total Cemenitious
3 Day: 2,200 psi
28 Day: 6,500 psi
56 Day: 7,600 psi

SLAB DETAILS
Slab Dimensions: 39” thick x 300’ long x 60’ wide.
Concrete volume: 2,300 cu.yds. placed in 12 hours.
Curing: Slab covered with insulated sheets and ponded with water for 2 weeks.
Surface cracking: Very little shrinkage cracking. No Control Joints Installed.

National Veterans Memorial and Museum
Columbus, OH

With over 8,000 cubic yards of concrete, the building's frame is one of the most complex concrete structures to ever be built in Ohio.

All mixes on this project utilized slag cement, varying between 35%-65% replacement

Slag cement was used for its aesthetically pleasing finish, lighter color, strength, lower permeability and mass concrete.

The mass concrete placements were successful due to using slag cement to lower initial heat of hydration.

Almost all mixes made design strength within 7 days

Pedestrian Bridge
Dublin, OH

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Slag cement was used in every mixture on the project to meet permeability requirements, reduce early heat of hydration, and for its aesthetically pleasing effects on concrete.

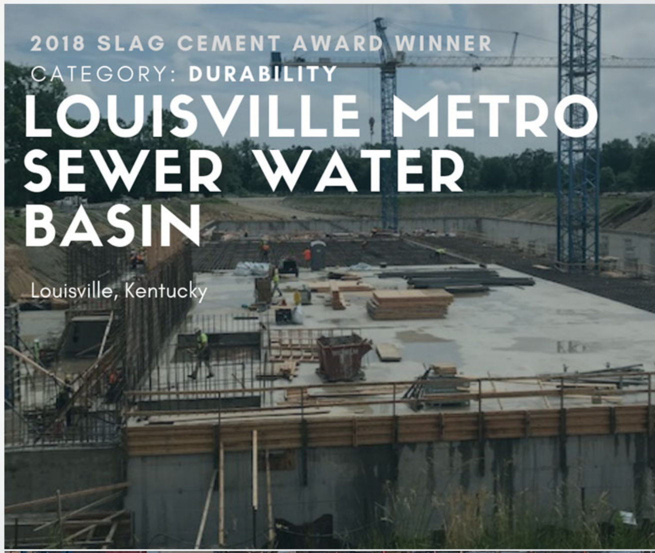
The mass concrete mixture was a 6,000 psi self-consolidating mixture comprised of 730 lb with 65% slag cement.

The mass concrete almost always made full strength in 7 days and never later than 28 days. Concrete flow tests averaged a 26 in flow and a viscosity modifier was used for mixture stability.

Metropolitan Sewer District Northwest Basin
Louisville, KY 8/17

- Spec 5,000 psi @ 28 days
- Internal core max temp: 150^{o}F max

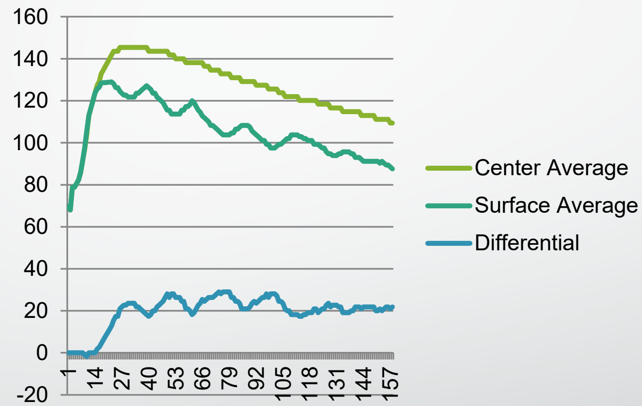
- Mix Design
- 600 lbs total cementitious
- 50%/50% cement/slag cement
- Slump: 7-9”
- Admixture: hrwr, vma
- 1D: 700 psi
- 3D: 2,000 psi
- 7D: 4,500 psi
- 28D: Avg 7,500 psi (15 psi/lb)
- Core temp range: 105 - 115^{o}F

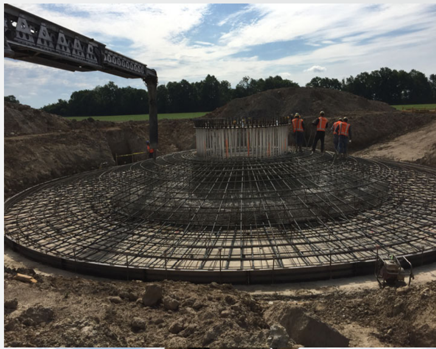


Bluff Point Wind Farm
Richmond, IN 6/17 – 8/17

- Spec 5,000 psi @ 28 days, 3,000 psi @ 3 days
- Internal core max temp: 150°F max

- Mix Design
- 611 lbs total cementitious
- Cement/slag cement 60%/40%
- No air
- Slump: 8"   w/cm: 0.40
- Admixture: HRWR
- 3D: 3,000 – 4,800 psi
- 7D: 4,000 – 9,000 (6.5 – 14.7 psi/lb)
- 28D Avg: 6,500 psi (10.6 psi/lb)
- Core temp range: 130 - 149°F
- Ambient temps range: 70's – mid 90's





Brattleboro Bridge

- Slag cement used for durability concerns/design requirements for a 100-year life from Vermont AOT
- Mass concrete 60% slag cement replacement met heat and strength requirements, exceeding the 4000 psi & 8000 psi requirements
- Ternary mixes ranging from 20-60% used improved workability of the low water/cement ratio with the emphasis of reducing permeability/durability concerns

Willamette, OR River Bridge

- Critical transportation link on I-5 corridor near Eugene, Oregon
- 60% slag cement in mass concrete
  - Met temperature control criteria
  - Exceeded 4,500 psi over 6,200 psi at 56-days
- SCC mix for “Icebreaker breaker” pedestal
- 30% slag cement in bridge decks
  - AASHTO T-277 RCP < 1,000 coulombs

Gate Keeper Roller Coaster
Cedar Point Amusement Park

- Sandusky, Ohio – support columns for highest section of tallest wing roller coaster form entrance to park

- Specifications for columns
  - Max temp = 158° F
    Max temp diff = 36° F
  - *f'c*= 4000 psi

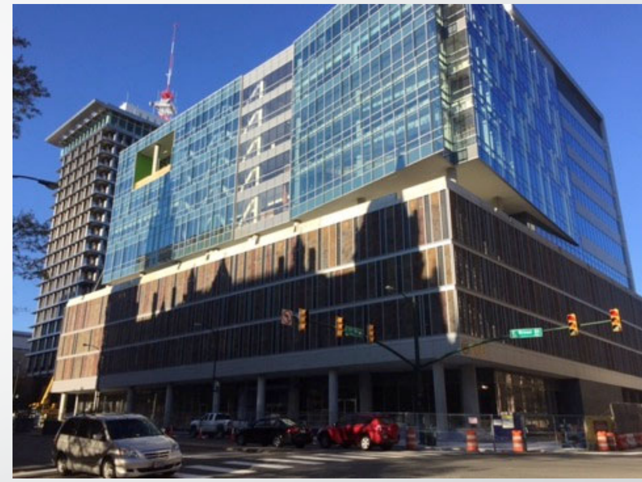
- Slag cement used in 3 mixtures
  - First 6' 25% slag cement with Type III
  - 50% slag cement used with Type III at 6' to 12'
  - 50% slag cement used with Type I for last 12'

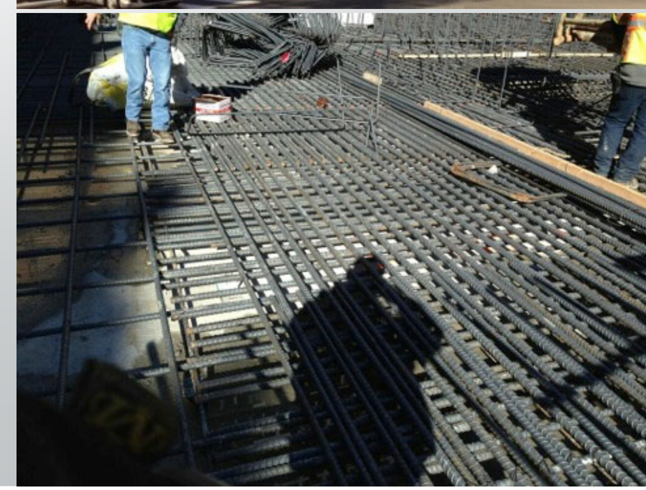
I-95 Pawtucket River Bridge

- Replaced three separate structures – carries I-95 N and I-95 S lanes + on-off ramps
- Art Deco design reflect other Pawtucket landmarks
- Used a 50% replacement level of slag cement for mass concrete and 40% for high strength concrete
- Slag cement made concrete lighter and brighter
- Won IES 2014 illumination Award of Merit & AASHTO 2014 American Transportation Under Budget Award.

Children’s Hospital of Richmond at VCU

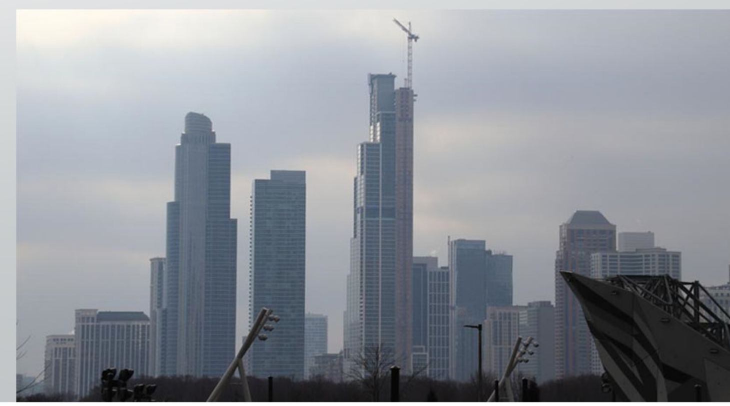
- The 640,000 square-foot outpatient Children’s pavilion features naturalistic elements of light and green space to create an oasis for children
- Slag cement used 60% replacement for mass concrete for mat foundation and 40% for structural lightweight and 5000-psi concrete for parking garage
- Slag cement concrete mixtures met specifications and provided needed constructability





Nema Project – Chicago (2019)
Formerly 1200 S Indiana

- 76 Stories- 893' high
- Low heat – high slag replacement mixes were used for mat, caisson caps and massive grade beams
- Mix design utilized 57% slag replacement with strength requirements of 8,000psi @ 56 days and 10,000psi @ 91 days
- Mix needed strong stability and SCC flow due to rebar congestion of mat – poured at 26" spread
- Center mass of mat reached temp of 102 F with 24 F differential
- Average Strengths exceeded 12,000psi at 91 days



110 N Wacker, Chicago Wanda Vista - 2018

- 93 Stories at 1191 feet high
- 3,000 yards of concrete placed for mat in 8 hours
- 50% replacement using Slag
- 8,000psi @ 56 day mix spec
- Peak core heat reached 119F with max of 135F
- Differential remained with 30F spec with a max diff of 22 F
- Average 56 day breaks exceeded 10,000psi.

Slag Cement in Special Applications
Paving & Roller Compacted Concrete

Paving Applications

Advantages with Slag Cement

- FAA P501 – ASR Mitigation 30% - 40% slag cement
- Durability / Low Permeability / Reduced Corrosion of reinforcing steel
- Sulfate Resistance
- More consistent than Flyash
- Workability
- Strength
- NO Air Entrainment Issues
- Lighter Color
- Sustainability

SR 679 Pinellas Bayway Bridge

JFK International Airport – Runway 4L-22R Reconstruction

- Rehabilitated existing asphalt runway with 18-in concrete pavement overlay
- Concrete Specifications
  - 700 psi min 28-day flexural
  - 550 lb/cy max cementitious
- ASTM C595 Type IS (40) slag blended cement yielded 1300 psi flexural strength at 28-days
- Mixture provided constructability, strength, durability and smoothness, at a reduced environmental impact

Kansas City International Airport

- Concrete mixture with 40% slag cement
- 2015-2019 Avg flex strength > 900 psi

Illinois Tollway I-90 Westbound Mainline Paving Upgrades

- Specifications encouraged use of recycled cementitious materials and aggregates
- Included 20 mi. of innovative two-lift composite pavement
- Bottom 40% slag cement with Type IL(10)
- Top lift 75% Type IL(10) / 25% slag cement
- Provided desired fresh and hardened properties

Arlington River Bridge on University Boulevard, Jacksonville, FL

- New two-lane concrete bridge with 6½ ft-wide sidewalks, 4 ft-wide bicycle lanes, decorative lighting and architectural railings replaces an aging structure
- Slag cement used at 60% with 10% fly ash in ternary concrete mixture to enhance sustainability and durability in salt water environment
- Concrete mixture exceeded surface resistivity criteria and strength requirements at reduced environmental footprint
- Lighter color improves nighttime visibility

I-79/I-70 South Junction
Washington, PA

- Replaced curved I-79 northbound ramp to I-70 west bound with nine-span fly-over bridge and new ramp
- Slag cement used at 50% replacement in both SCC and mass concrete mixtures
- SCC provided specified flow, penetration, segregation resistance visual stability index, strength, permeability, and freeze-thaw durability requirements

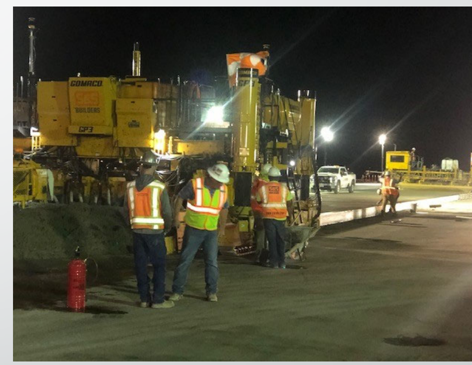
PTC Southern Beltway Interchange SR0576 55C2-1
Cannonsburg, PA

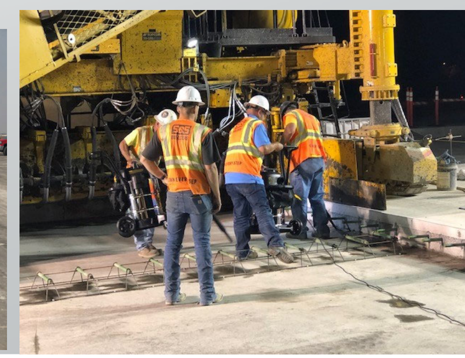
- Pittsburgh Toll Road, 13 Miles Long
- 2022 SCA Infrastructure Award
- 40% Slag Cement used For High Performance and Durability
- 7 Day Spec 3,000 psi , Avg 4,100 psi

  28 Day Spec 3,750 psi, Avg 6,700 psi

Cheyenne, WY Regional Airport Pavement Restoration

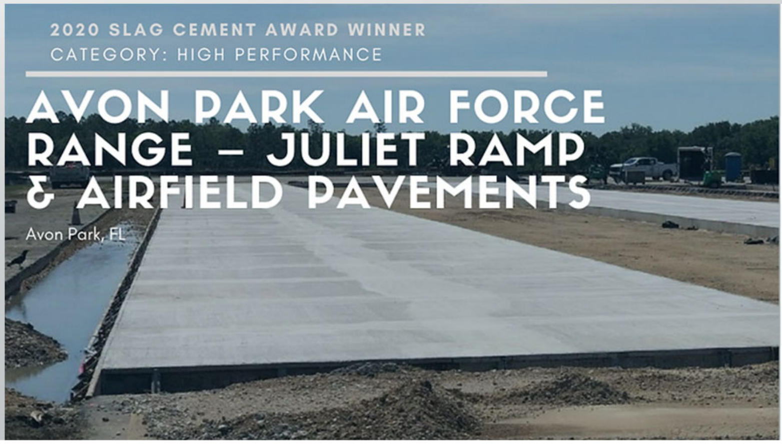
- Slag cement was selected for its durability, strength, ASR mitigation and lighter color.
- Achieving close to 28-day flexural strength in just 7 days
- 620 psi avg flexural strength, with a 28-day flexural strength of 700 – 750
- First pavement in WY using slag cement
- First project FAA allowed slag cement in this Region
- 2021 SCA Infrastructure project award





Avon Park, FL Air Force Range
Juliet Ramp & Airfield Pavements

- This project consisted of 18,000 yd3 of new concrete pavement for the U.S. Air Force at the Avon Park Air Force Bombing Range
- A 650 Flex concrete mixture was used consisting of a 72%/28% Type I cement and slag cement.
- The average flexural strength was 670 psi in 3 days and 850 psi in 14 days.
- Slag cement was used on this project for its ultimate strength characteristics, inherent benefits of easier placeability and improved workability.



Roller Compacted Concrete (RCC)

- Same ingredients as conventional concrete
- RCC is "zero slump"
- RCC is blended in continuous-mixing pugmills
- RCC paving placed with conventional earthmoving or paving equipment, then compacted with vibratory rollers
- Used for mass concrete applications, such as dams
- Typically 4 to 12 inches thick

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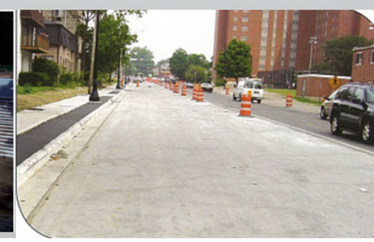
Roller Compacted Concrete (RCC) Projects

- Georgia Port of Savanah, GA Ocean Terminal Expansion
- CDOT J.A. Cochran Bypass truck route , Chester County, SC
- Marion County Regional Institute of Technical Excellence in Kimball, Tennessee
- Volkswagen plant, Chattanooga, TN
- Honda plant, Lincoln, AL
- Columbus, OH city streets
- Denver International Airport
- RCC Dam Replaces 70-Year Old Concrete Big Cherry Dam, Wise County VA
- Hickory Log Creek Dam and reservoir, Cobb County, GA

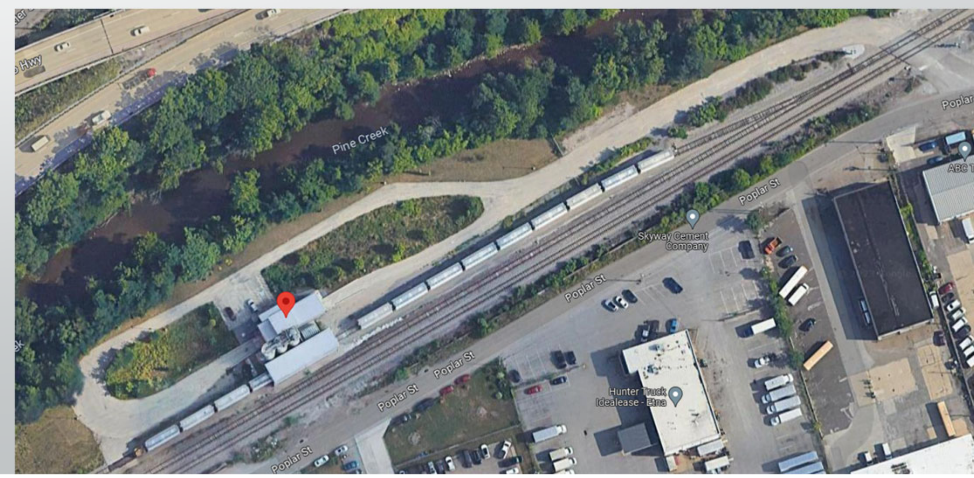




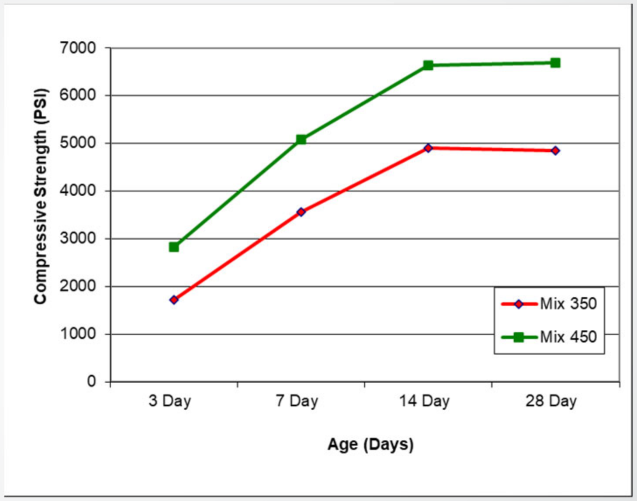

Skyway Pittsburgh Terminal

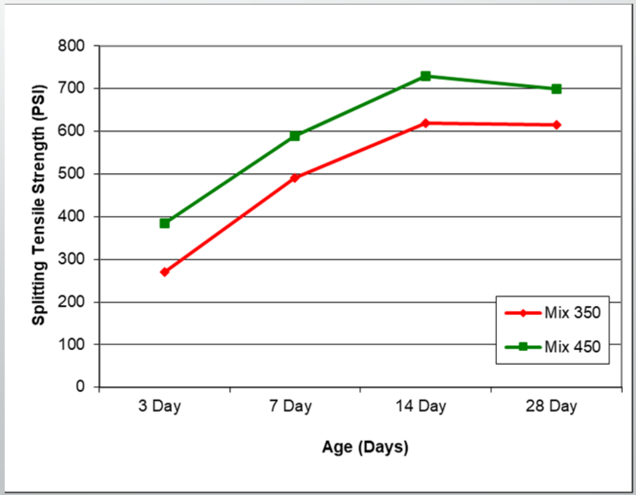
Truck access terminal road RCC paving
580 Total cementitious 25% slag cement
7 day: 5,300 psi
28 Day: 7,500 psi



Roller Compacted Mix Designs

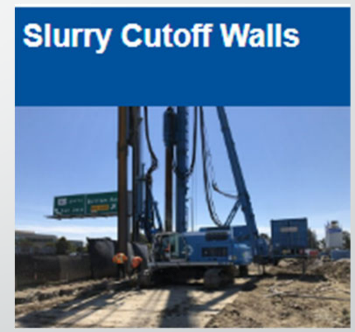
	Mix 350	Mix 450
Mix Design		
Cement T-I (lbs)	175 (50%)	225 (50%)
Slag Cement (lbs)	175 (50%)	225 (50%)
Total Cementitious (lbs)	350	450
Fine Aggregate (lbs)	1425	1388
Coarse Aggregate (578) (lbs)	2140	2082
Fine/Coarse Aggreate Ratio	40 / 60	40 / 60
Water (lbs)	150	160
Water (gals)	18	19.2
Total Wgt Mat's (lbs/cu.yd.)	4,065	4,080
AIR	n/a	n/a
Water/Cementitious Ratio	0.43	0.36
Concrete Properties		
Unit Wgt (lbs/cu.ft.)	151.6	151.2
Compressive Strength (psi)	**Mix 350**	**Mix 450**
3 Day	1720	2840
7 Day	3560	5080
14 Day	4900	6640
28 Day	4850	6700
Spliting Tensile Strength	**Mix 350**	**Mix 450**
3 Day	270	385
7 Day	490	590
14 Day	620	730
28 Day	615	700





Geotechnical Applications

- Waste Solidification and Stabilization
- Deep Soil Mixing
- Slurry Cutoff Walls
- Cementitious Grouting
- Soil Cement



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Waste Solidification/Stabilization Using Slag Cement

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Slag Cement in Construction — *No. 26*

Slag cement has been specified and used on several successful waste stabilization projects.

Waste Solidification and Stabilization using Slag Cement

Portland cement has been used since the 1950's to stabilize potentially hazardous materials in sludges and sediments. Portland cement works by solidification, stabilization, and encapsulation of the waste material.

Research has been conducted on the use of slag cement alone and in combination with portland cement to stabilize waste materials.[1] Based on this research, slag cement has been specified and used on several successful waste stabilization projects.

Solidification

Solidification is the process of reducing the excess water in a waste sludge. Waste management laws generally prohibit waste sludge containing free water to be deposited in landfills. Slag/portland cement mixtures react and chemically bind excess water in a process called hydration.

Stabilization

Stabilization is the process of chemically changing a hazardous waste material into a less soluble or less toxic form. Slag/portland cement combinations accomplish this by raising the pH of the waste material. Many toxic metals found in waste sludge have their lowest solubility at higher pH levels and are therefore less likely to leach out. The presence of ferrous iron and sulfur compounds make slag cement an excellent reducing agent that can change toxic metals into less toxic forms.

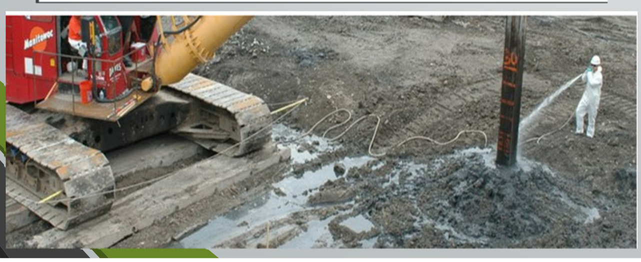
Slag/portland cement combinations raise the pH of waste material, which can lower the solubility of toxic metals, making them less likely to leach out.

Encapsulation

Encapsulation is the process of surrounding waste particles with a layer of material that is very low in permeability. This layer of material inhibits the leaching of the hazardous material. Slag/portland cement combinations lower permeability, providing significant reductions in the mobility of toxic material.

Radioactive Waste

Technetium is an isotope that is a fission product of uranium. It is a major concern in the disposal of radioactive sludge due to its long half life (213,000 years) and its mobility as soluble pertechnate. The reduction potential of slag cement has been found to change technetium to a less soluble valence state. When slag cement is used, the leachability of technetium can be decreased by several orders of magnitude.[2]



Use of Slag Cement in Soil cement

SCA SLAG CEMENT ASSOCIATION

Slag Cement in Construction — *No. 25*

Slag cement can be used alone or in conjunction with portland cement or other cementitious materials to improve soil properties and performance.

What is Soil Cement?

Soils vary widely in engineering properties, and often local soils are not adequate to meet the support requirements for a construction project. Soils can be improved by adding portland cement to the soil, mixing thoroughly with a measured amount of water, and densely compacting the mixture. The resulting blend is called **"soil cement."**

Where is Soil Cement Used?

Soil cement is most often used as a pavement base material for flexible (asphalt or bituminous) pavements or as a subbase for rigid (concrete) pavements. Marginal quality aggregates can also be improved with cement to produce "cement-treated base." A related application is recycling of failed bituminous pavements by pulverizing the surface/base and stabilizing this material with cement to produce a new pavement base. Subgrade soils (the material below the base) can be modified with cement, though normally with lower strength/performance requirements. This produces a weather-resistant work platform. Additional applications of soil cement include slope and bank protection, low-permeability liners, and stabilized fill material.

Slag cement can be used alone or in conjunction with portland cement or other cementitious materials (such as fly ash or lime) to improve soil properties and performance.

How Does Soil Cement Improve Soil?

Hydraulic cement, such as portland or slag cement, binds soil particles together, improves compaction, and decreases void spacing. Usually cementitious material is combined in quantities from 2 to 20 percent by weight of the soil or aggregate material. Benefits include:

- Improved unconfined compressive and shear strengths
- Improved soil properties under saturated conditions
- Greater durability in wet/dry and freeze/thaw conditions
- Higher resilient modulus, reducing fatigue cracking and rutting in asphalt pavements
- Reduced plasticity and moisture retention in fine-grained clay soils

Soil cement provides a cost-effective alternative to removing and replacing poor soils, building thicker pavement sections, or using geotextile fabrics or grids.

How Can Slag-Cement Help?

Soil cement provides a cost-effective alternative to removing and replacing poor soils, building thicker pavement sections, or using geotextile fabrics or grids.

Slag cement generally produces soil cement with lower early age strength and higher strength at later ages. Slower strength development can decrease the cracking potential of the soil cement base which reduces reflective cracking in flexible pavements. Higher later age strength ensures long term durability and fatigue resistance. Additionally, slag cement can improve performance under high moisture conditions.

Waste Solidification/Stabilization using Slag Cement

Solidification

Process of reducing excess water in waste sludge

Encapsulation

Process of surrounding waste particles with low permeability materials

Stabilization

Process of chemically changing a hazardous waste into a less soluble or toxic form

Brownfield Remediation

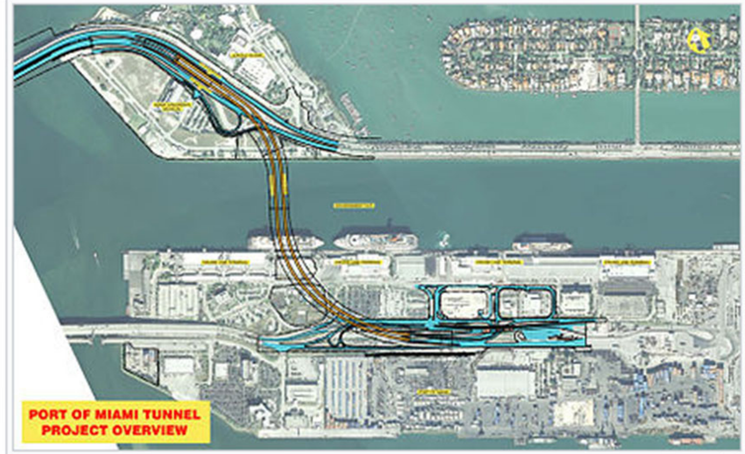
Sites that contain hazardous contaminants. EPA places a high priority to reuse of these sites for redevelopment

Waste Solidification/Stabilization

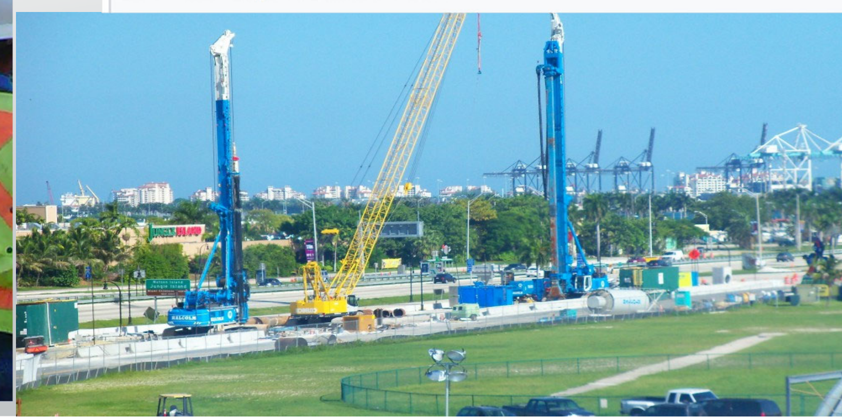
- PSI per pound of cementitious – Slag Cement is more hydraulic, particularly in lower amounts and at higher water cement ratios than Portland cement.
- As strength requirements lower, slag has more defined effect than Portland cement and is used at higher replacements (>70%) requiring less total cementitious
- Less Toxic – TCLP (Toxicity Characteristic Leaching Procedure)
- Has the ability to tie up heavy metals similar or higher compared to Portland cement
- Much lower Permeability than Portland cement by itself or with bentonite clay

Port of Miami Access Tunnel

70% Slag cement was used in shallow soil mixing

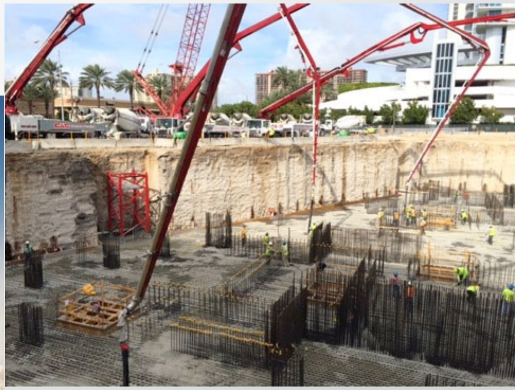


An overview of the Port Miami Tunnel project. In this map, the areas marked in orange signify the route of the tunnel, while areas marked in blue signify associated ramps and infrastructure.



Jade Signature Condominiums
Miami, FL

- "Tower on the Beach" is designed to maximize sun exposure and provide an inspiring connection to sea and sky
- Slag cement used in deep soil mixing process at 80 to 90% of a cement slurry to stabilize soil



Big Sandy Dam Reservoir Enlargement
Farson, WY

- 2022 SCA Award Innovative Aplications
- The cutoff wall is 4,400 feet long, 3-feet wide and was installed through the earthfill dike with self hardening slag cement-Portland cement-bentonite slurry mix
- Slag cement 60% to 80% was used in the self-hardening slurry to improve compressive strength, ductility and lower the permeability of the hydraulic cutoff wall
- Historically, slurry for self-hardening walls were comprised of bentonite and Portland cement

WE Energies Manufactured Gas Plant
Appleton, WI

A manufactured gas plant (MGP) was an industrial facility at which gas was produced from coal, oil and other feedstocks. The gas was stored, and then piped to the surrounding area, where it was used for lighting, cooking, and heating homes and businesses. The first MGPs were constructed in the early 1800's. Most were closed during the early-to-middle 1900s.

A combination of 70% slag cement & 30% portland cement was used to remediate coal tar-contaminated soil at a which operated from 1867 to 1954. The remediated site has been converted into a public park

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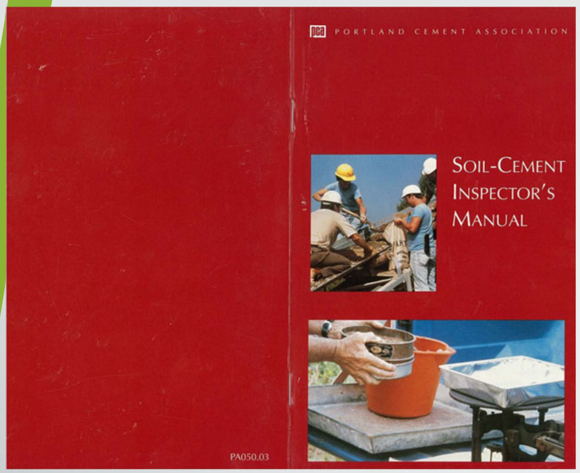
Waste Solidification - Gasification Plant Project (TCLP)
Sanford, FL

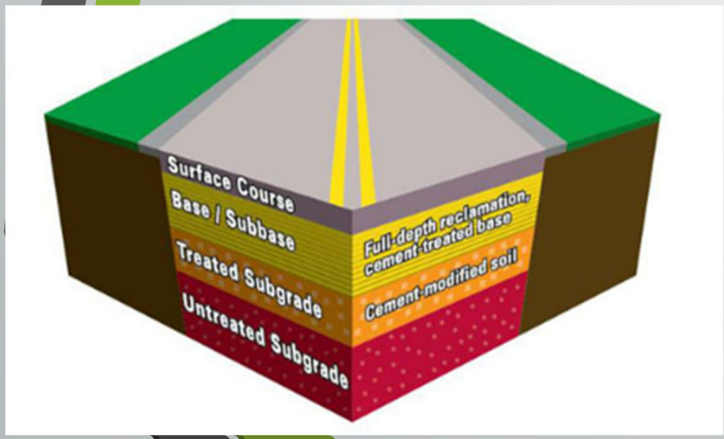
For the Superfund Project slag cement was selected as the major cementitious component for the project due to its ability to bind heavy metals in situ and superior performance in environmental tests such as TCLP which demonstrates that no additional toxic materials leach into the environment.

Manufactured Gas Plant
Cincinnati, OH

- MGP soil remediation to a total depth of 60 feet below ground.
- Remediation with cementitious based grouts (cement and slag) is one of the most common remedial options for MGP sites. Especially for deeper contamination that can't be excavated for removal.
- General mix design – 6% slag cement and 2% Portland to weight of soil
- Typically, more slag cement than cement for permeability. Either 2 parts slag to 1 part cement or 3:1.
- Reagents are mixed with water, pumped into the ground and mixed to create a low permeability mass with 50-100 psi compressive strength.

Slag Cement in Special Applications
Soil Cement





Different Types of Soil Cement Applications

Soil-Cement (SC)
Soil-cement (SC) is an engineered, densely compacted mixture of soil/aggregate, portland or blended cement, other SCM's and water. SC is known by a variety of names including cement-stabilized base, cement-treated aggregate base, cement-treated soil, and even dirtcrete.

Cement-Modified Soil (CMS)
A compacted mixture of pulverized in situ soil, water, and small proportions of portland or blended cement, SCM's that results in an unbound or slightly bound material. The treated material is similar to a soil but has reduced plasticity and a lower susceptibility to moisture, resulting in a more workable material.

Cement-Stabilized Subgrade (CSS) Soil
A compacted, engineered mixture of pulverized in situ soil, water, and moderate proportions of portland or blended cement (slightly more than CMS) that results in a semi-bound to bound material. The treated material has structural engineering properties similar to or better than those of a granular material.

Cement-Treated Base (CTB)
A fully bound, compacted, engineered mixture of aggregate, water, and sufficient portland or blended cement to meet the project-specified minimum durability and strength requirements. Because of the better aggregate selection available for CTB, it typically uses about the same quantity of cement as CSS; however, CTB results in a stronger, more durable, more frost-resistant layer.

Full-Depth Reclamation (FDR)
A type of CTB, FDR is a process that involves pulverizing and blending an existing distressed asphalt roadway surface and its underlying base and/or subgrade materials. Portland or blended cement is mixed with the pulverized material, compacted, and cured, resulting in a new homogenous and stabilized base. This process compares favorably to the complete removal and replacement of a distressed asphalt pavement and underlying granular base material.

Use of Slag Cement in Soil Cement

What is Soil Cement?

A blend of cement, slag cement, flyash or lime

Where is Soil Cement Used?

Soil cement is most often used as a pavement base material for flexible (asphalt or bituminous) pavements or as a subbase for rigid (concrete) pavements

How Does Soil Cement Improve Soil?

- Improved unconfined compressive and shear strengths
- Improved soil properties under saturated conditions
- Greater durability in wet/dry and freeze/thaw conditions
- Higher resilient modulus, reducing fatigue cracking and rutting in asphalt pavements
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How Can Slag Cement Help?

Soil cement provides a cost-effective alternative to removing and replacing poor soils, building thicker pavement sections, or using geotextile fabrics or grids

Proportioning with Slag Cement

- Cementitious material is combined in quantities from 2 to 20 percent by weight of the soil
- Slag cement is normally proportioned in quantities from 25 to 100 percent of the cementitious material

Figure 1: Compressive Strength of a Stabilized Soil

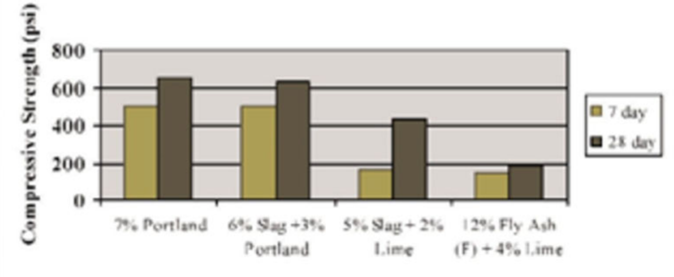
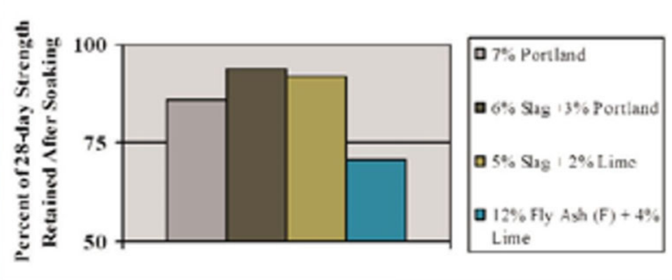
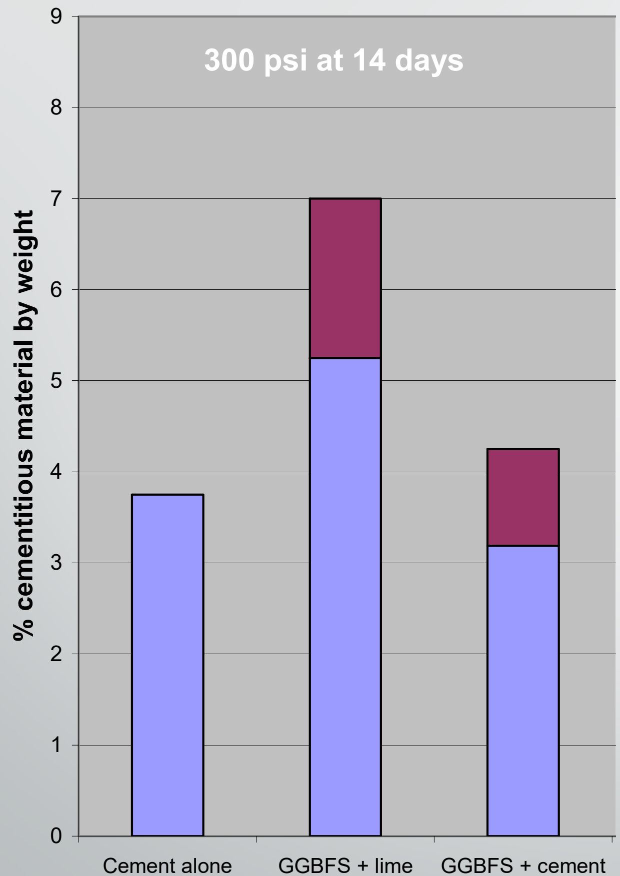
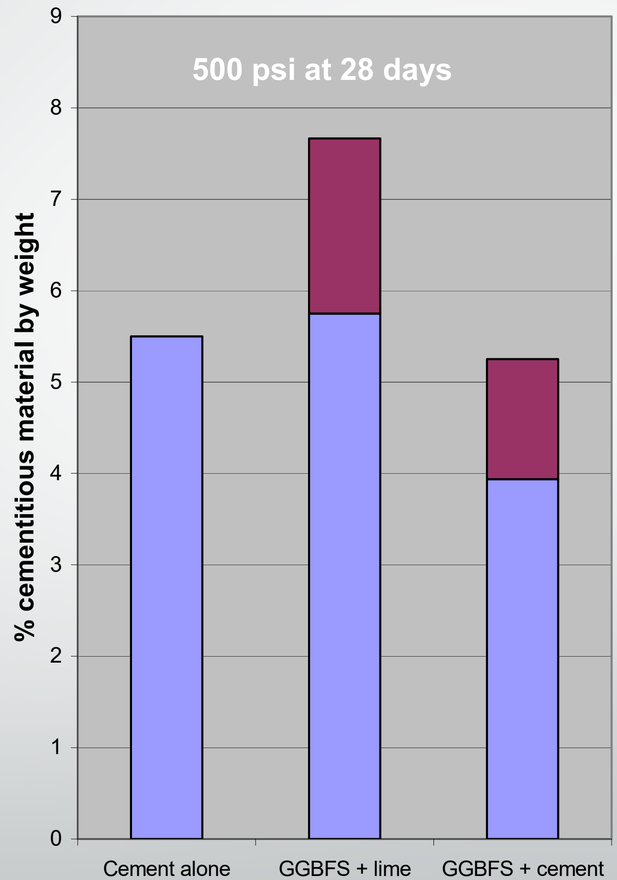


Figure 2: Strength Retention under Soaked Conditions for a Stabilized Soil



Examples of Soil Stabilization Designs





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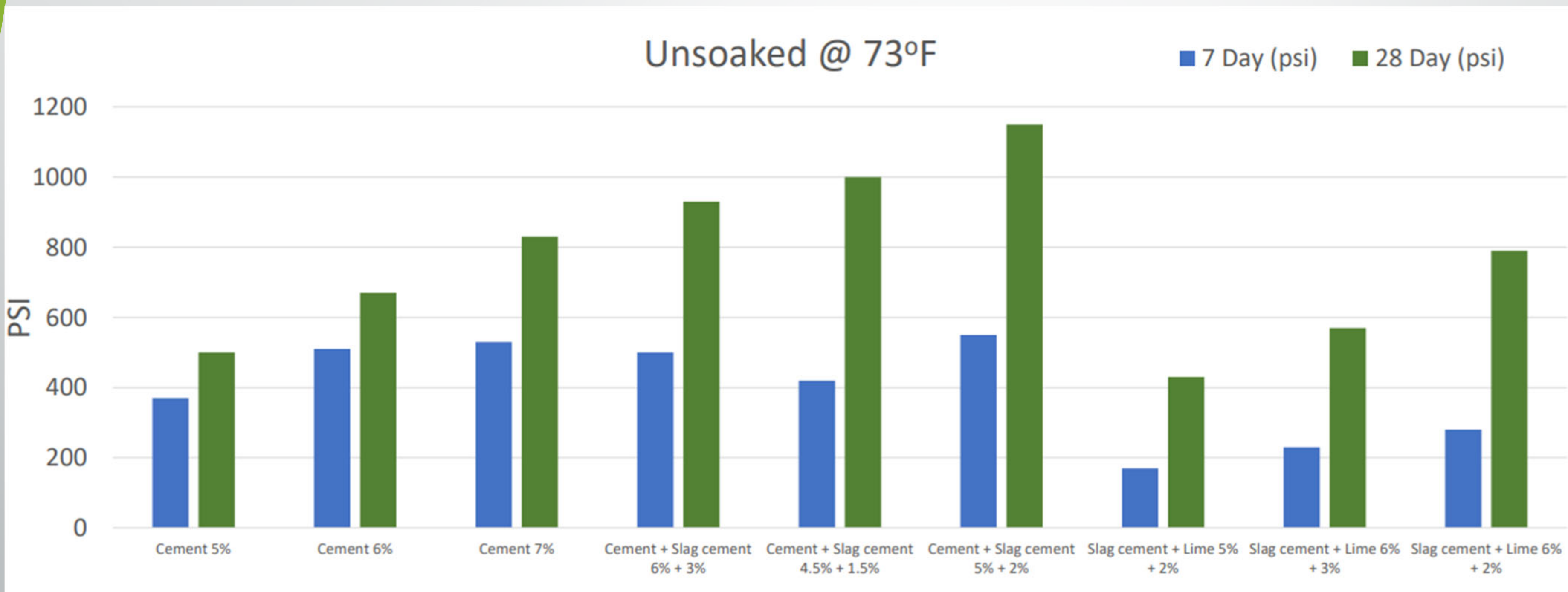
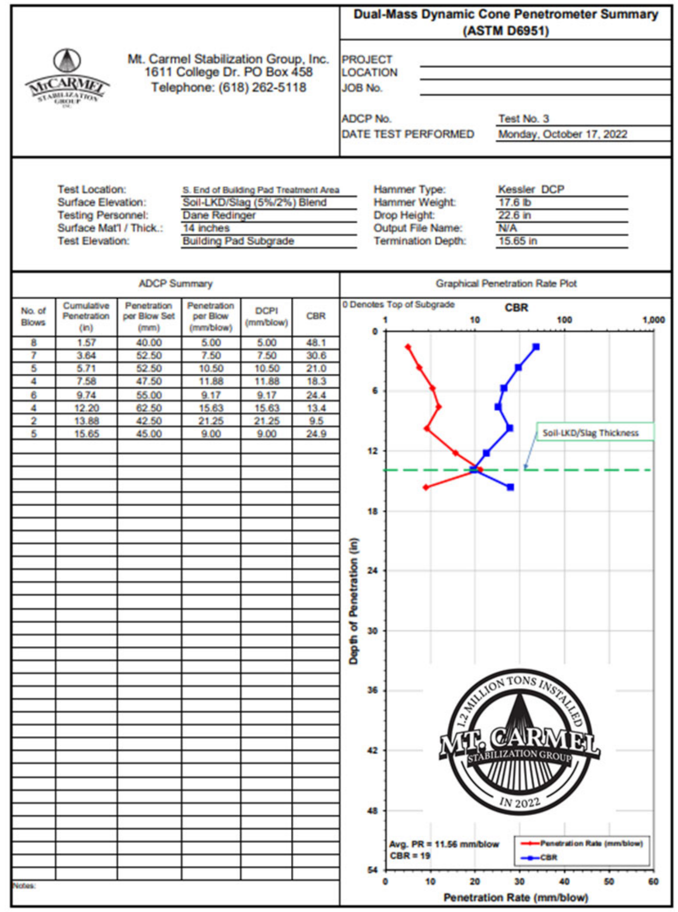
Soil Cement with Slag Cement



Soil Cement Project
Warehouse Pad Subgrade, OH

- Mix 5% Lime Kiln Dust (LKD) & 2% Slag Cement
- First time trying slag cement
- Looking at other mat’ls due to cement supply
- Strengths were impressive



Dual-Mass Dynamic Cone Penetrometer Summary (ASTM D6951)

Mt. Carmel Stabilization Group, Inc.
1611 College Dr. PO Box 458
Telephone: (618) 262-5118

PROJECT
LOCATION
JOB No.

ADCP No.: Test No. 3
DATE TEST PERFORMED: Monday, October 17, 2022

Test Location: S. End of Building Pad Treatment Area
Surface Elevation: Soil-LKD/Slag (5%/2%) Blend
Testing Personnel: Dane Redinger
Surface Mat'l / Thick.: 14 inches
Test Elevation: Building Pad Subgrade

Hammer Type: Kessler DCP
Hammer Weight: 17.6 lb
Drop Height: 22.6 in
Output File Name: N/A
Termination Depth: 15.65 in

ADCP Summary

No. of Blows	Cumulative Penetration (in)	Penetration per Blow Set (mm)	Penetration per Blow (mm/blow)	DCPI (mm/blow)	CBR
8	1.57	40.00	5.00	5.00	48.1
7	3.64	52.50	7.50	7.50	30.6
5	5.71	52.50	10.50	10.50	21.0
4	7.58	47.50	11.88	11.88	18.3
6	9.74	55.00	9.17	9.17	24.4
4	12.20	62.50	15.63	15.63	13.4
2	13.88	42.50	21.25	21.25	9.5
5	15.65	45.00	9.00	9.00	24.9

Notes:

Graphical Penetration Rate Plot

Questions?...