Effect of Slag Cement on Shrinkage in Concrete

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Slag Cement in Construction **No. 27**

What is shrinkage in concrete?

Shrinkage is the time-dependant decrease in concrete volume compared with the original placement volume of concrete. Shrinkage results from physical and chemical changes that occur in the paste fraction of concrete. The two principal types of shrinkage are plastic and drying shrinkage. Plastic shrinkage occurs while concrete is in the plastic state. Drying shrinkage occurs after concrete has reached initial set. Technically, drying shrinkage will continue for the life of the concrete, but most shrinkage will occur within the first 90 days after placement.

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What causes shrinkage in concrete?

Plastic shrinkage results from surface evaporation due to environmental conditions, such as humidity, wind speed or ambient temperature. ACI 305R, *Hot Weather Concreteing*,[1] provides guidance for placement of concrete to minimize plastic shrinkage cracking.

Drying shrinkage in concrete is caused by the loss of moisture in the paste. It is influenced by a variety of factors, including:

- Environmental conditions (temperature and relative humidity)
- Size of the member (surface area to volume ratio)
- Concrete material factors:
    - Volume of Aggregate
    - Elastic modulus of the aggregate
    - Water/cementitious ratio (w/cm) of the paste

Effect of shrinkage on concrete

Virtually all concrete is subject to some form of restraint, such as steel reinforcement, forms, subgrade, or adjacent members. As concrete begins to lose volume, the restraint inhibits movement, which then induces tensile stress in the concrete. Once the tensile capacity of the concrete has been exceeded, it will crack. In most cases cracking is not a major concern and is normally controlled with various measures, such as contraction and control joint placement, load transfer devices, and proper reinforcement detailing.

Concrete cracks when its shrinkage is restrained, and the tensile stress induced by the restraint exceeds the tensile capacity of the concrete.

Shrinkage is important in applications such as large slabs on grade, containment structures, and reinforced concrete exposed to deicing chemicals. ACI 224, *Control of Cracking in Concrete Structures*,[2] provides information and guidance on minimizing shrinkage and subsequent cracking.

Influence of slag cement on shrinkage

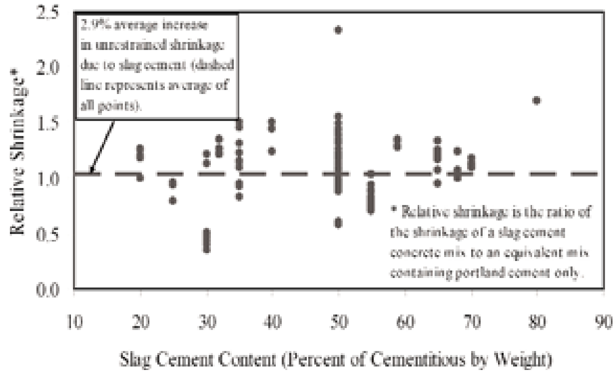
In order to assess the influence of slag cement on drying shrinkage, the SCA commissioned a critical review of available published shrinkage research.[3] This study examined 32 relevant references, and utilized data from 62 concrete mixtures where comparable information on concrete with and without slag was available. In the referenced studies, slag cement was incorporated both as a component of blended cement and as a separately batched material.

Effect of Slag Cement on Shrinkage in Concrete

The review concluded that in unrestrained conditions, the drying shrinkage of concrete containing slag cement was slightly higher than concrete without slag cement; this difference is considered insignificant. Quantatively, the average increase in shrinkage was only 2.9 percent, and when corrected for paste volume, this difference was reduced to about 1.5 percent.

Additionally, the effect of the amount of slag in a concrete mixture (in the range from 20 to 80 percent of cementitious material) was found to have no perceptible influence on the relative drying shrinkage of concrete (Figure 1).

Figure 1: Effect of Slag Cement Content on Relative Shrinkage



Finally, data from one reference[4] indicated that the restrained shrinkage cracking of concrete containing slag cement appeared to be slightly less than that of concrete without slag cement. Cracking with slag cement was delayed to later ages and resulted in smaller crack widths. The SCA is conducting further research to corroborate these restrained cracking results.

In conclusion, the literature available today indicates there is little increase in drying shrinkage when slag cement is used in concrete, regardless of the percentage used. As for all concrete, when shrinkage is a concern, ACI 224 should be consulted for guidance.

The literature today indicates there is little increase in drying shrinkage when slag cement is used in concrete, regardless of the percentage used.

As with all concrete mixtures, trial batches should be performed to verify concrete properties. Results may vary due to a variety of circumstances, including temperature and mixture components, among other things. You should consult your slag cement professional for assistance. Nothing contained herein shall be considered or construed as a warranty or guarantee, either expressed or implied, including any warranty of fitness for a particular purpose.

Reference

1. ACI 305R-99, Hot Weather Concreting; American Concrete Institute, Farmington Hills, Michigan, 1999
2. ACI 224R-01, Control of Cracking in Concrete Structures; American Concrete Institute, Farmington Hills, Michigan, 2001
3. Hooton, R.D., Stanish, K., and Prusinski, J., "The Effect of Ground, Granulated Blast Furnace Slag (Slag Cement) on the Drying Shrinkage of Concrete - A Critical Review of the Literature," Eighth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Supplementary Papers Volume, American Concrete Institute, 2004.
4. Li, Z., Qi, M., Li, Z, and Ma, B., "Crack Width of High-Performance Concrete due to Restrained Shrinkage," Journal of Materials in Civil Engineering, Vol. 11, No. 3, 1999, pp. 214-23.

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About the Slag Cement Association…

The Slag Cement Association is the leading source of knowledge on blast-furnace slag-based cementitious products. We promote the increased use and acceptance of these products by coordinating the resources of member companies. We educate customers, specifiers and other end-users on the varied attributes, benefits and uses of these products.

High volume substitution with Slag Cement dramatically reduces embodied energy and greenhouse gas emissions in concrete.

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HIGH VOLUME SUBSTITUTION OF PORTLAND CEMENT

A principal advantage of using slag cement for improved sustainability is the fact that normal substitution rates of slag for portland cement are quite high (Table 1). Generally, within these guidelines, no unusual mixture designs, extensive trial batching, high levels of chemical admixtures, or increases in total cementitious materials are necessary. Substitution at these high percentages can, in fact, reduce cementitious requirements, as slag cement concrete may require *less* cementitious material to achieve a specified ultimate strength. More importantly, high volume substitution with slag cement dramatically reduces embodied energy and greenhouse gas emissions in concrete (i.e. the resource inputs and emissions outputs resulting from the manufacture of concrete and its constituent materials). For instance, a 50 percent substitution of slag for portland cement in a typical ready mixed concrete batch can save 34% of embodied energy (560,000 btu) and 46% of embodied CO_2 emissions (248 lb) per cubic yard.[5]

Table 1 - Suggested Slag Cement Replacement Levels

Concrete Application	Slag* Cement
Concrete paving	25-50%
Exterior flatwork not exposed to deicer salts	25-50%
Exterior flatwork exposed to deicer salts with w/cm ≤ 0.45	25-50%
Interior flatwork	25-50%
Basement floors	25-50%
Footings	30-65%
Walls & columns	25-50%
Tilt-up panels	25-50%
Pre-stressed concrete	20-50%
Pre-cast concrete	20-50%
Concrete blocks	20-50%
Concrete pavers	20-50%
High strength	25-50%
ASR mitigation	25-70%
Sulfate resistance	
Type II equivalence	25-50%
Type V equivalence	50-65%
Lower permeability	25-65%
Mass concrete	50-80%

**Percentages indicate replacement for portland cement by mass. These replacement rates are suggested for individual applications and are based on historical performance. Variations in material sources and environmental conditions may require alternate substitution rates. Consult your slag cement supplier for additional assistance.*

SLAG CEMENT HELPS ACHIEVE LEED POINTS

The attributes described above can help achieve all or part of ten points in the LEED-NC system. The specific credits are listed in Table 2, and are further detailed in SCA's LEED-NC guide.[6]

SLAG CEMENT AND LEED™

Table 2: Potential LEED-NC Points with Slag Cement

Category	Credit	LEED Ver.	Description	Possible Points	Potential Slag Cement Contribution
Sustainable Sites	SS 3	2.1 and 2.2	Brownfield Redevelopment	1	Slag cement can be used to stabilize and solidify contaminated soils at brownfield sites.
Sustainable Sites	SS 7.1	2.1 and 2.2	Heat Island Effect: Non-Roof	1	Slag cement is a light-colored material, making concrete more reflective compared with other cementitious materials.
Materials and Resources	MR 1.1 and MR 1.2	2.1	Maintain 75 and 100 Percent of Existing Walls, Floors and Roof	2	Slag cement can extend a structure's useful service life (if it was used in the original concrete) because it improves concrete durability in areas such as corrosion resistance, sulfate attack and alkali-silica reaction.
		2.2	Maintain 75 and 95 Percent of Existing Walls, Floors and Roof	2	
Materials and Resources	MR 4.1 and MR 4.2	2.1	Recycled Content: 5 and 10 Percent of (Post Consumer and ½ Post - Industrial)	2	Slag cement is a recovered post-industrial/pre-consumer material; therefore its use contributes to the total recycled content of a structure.
		2.2	10 and 20 Percent of (Post-Consumer and ½ of Pre-Consumer)	2	
Materials and Resources	MR 5.1	2.1	Regional Materials: 20 Percent Manufactured Regionally	1	Most slag cement in the U.S. is recovered at iron blast furnaces located within the U.S. or nearby in Canada. The slag cement supplier can provide point of origin so the 500-mile radius requirement can be calculated for a specific project. SCA also has facility maps available.
Materials and Resources	MR 5.2	2.1	Regional Materials: 50 Percent Extracted Regionally	1	
Materials and Resources	MR 5.1 and MR 5.2	2.2	Regional Materials: 10 and 20 Percent Extracted, Processed & Manufactured Regionally	2	
Innovation in Design	ID 1.1	2.1 and 2.2	Credit Interpretation Ruling IDc11, Reduction of Total Portland Cement Content for Cast-in-Place Concrete	1	This credit is meant to reduce embodied greenhouse gas emissions in concrete. Slag cement can replace significant amounts of portland cement (Table 1), and also may reduce total cementitious material needed.
Innovation in Design	ID 1.2	2.2	Exemplary Performance	2	Additional points can be obtained by exceeding the requirements of MR Credits 4 and 5. If a project demonstrates 30 percent or greater total recycled value an additional point can be earned. Another point can be earned if a project demonstrates 40 percent or greater for regionally extracted, harvested and manufactured materials.

LEED BUILDINGS WITH SLAG CEMENT

Slag cement has been used in numerous structures to help achieve LEED points. At Clearview Elementary School in Hanover, PA (Figure 1), 60% slag cement in the insulated concrete form walls and in other concrete elements helped boost the structure's recycled content to achieve MR 4.1 and 4.2 credits. Clearview Elementary is a LEED™ Gold Certified building, and also was the recipient of SCA's first annual award for "Best Use of Slag Cement in Sustainable Construction."

Jim Shafer Photography

Figure 1: Clearview elementary School, Hanover

Slag cement can help achieve all or part of ten points in the LEED-NC system.

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Figure 2: The Helena, Manhattan

For the 45-story Helena residential high rise in Manhattan (Figure 2), use of 45% slag cement concrete in the structural beams and columns, and other cast-in-place concrete resulted in achieving both MR 4.1 and 4.2 credits, as well as an Innovation in Design point for reducing portland cement and commensurate embodied greenhouse gas emissions. The Helena is a LEED™ Gold Certified building and also achieved a New York State tax credit for sustainable structures.


Figure 3: 7 World Trade Center - Manhattan

The 741 foot tall 7 World Trade Center (Figure 3) is the first major building constructed in the lower Manhatan Financial District since 9/11. Slag cement replaced 40% of the portland cement in the concrete core, and achieved strengths of over 10,000 psi. This LEED™ Gold Certified structure also received SCA's 2006 award for "Best Use of Slag Cement for Strength."

MORE RESOURCES FOR THE DESIGNER

Visit www.slagcement.org or contact the SCA to receive SCA's LEED™ guide, and related environmental information. Also available on the web are numerous Slag Cement in Concrete information sheets to help the designer and specifier properly select the appropriate slag cement concrete mixture for a specific application. Information on LEED™ can be found at www.usgbc.org/leed.

References
1. U. S. Green Building Council, Green Building Rating System for New Construction & Major Renovations (LEED-NCTM), Version 2.1, Washington, D.C., November 2002 (Revised 3/14/03)
2. U. S. Green Building Council, LEED-NC Green Building Rating System for New Construction & Major Renovations, Version 2.2, Washington, D.C, October 2005
3. Environmental Council of Concrete Organizations, LEED Green Building Rating System and Concrete, EV27, Skokie, IL, 2003
4. RMC Research Foundation, The Ready Mixed Concrete Industry LEED Reference Guide, Silver Springs, MD, 2005
5. Construction Technology Laboratories, "Life Cycle Inventory of Slag Cement Concrete," CTL Project No. 312012, Letter Report to Slag Cement Association May 2, 2003, Skokie, IL
6. Slag Cement Association, LEED-NC™ Guide: Using Slag Cement in Sustainable Construction, Version 1.1, Sugar Land, TX, 2006

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SLAG CEMENT AND LEED™

Slag Cement in Concrete **No. 28**

Concrete is a superior material for building sustainable structures.

WHAT IS LEED™?

Leadership in Energy and Environmental Design (LEED) is a national standard developed by the U.S. to certify high performance, sustainable buildings. Currently there are five LEED standards available for use or under development; however LEED-NC, for new construction and major renovation is the most widely used standard.

LEED-NC utilizes a system where points are awarded for achieving specific levels of sustainable performance in six categories: sustainable sites, water efficiency, energy efficiency, materials and resources, and indoor environmental quality, and innovation in design.

Two versions of LEED-NC are currently available for use: 2.1[1] and 2.2[2], with version 2.2 superseding 2.1 for buildings registered after January 1, 2006.

ACHIEVING LEED POINTS WITH CONCRETE

Concrete is a superior material for building sustainable structures. It is durable, uses abundant, local materials in its manufacture, can use recovered industrial materials in its manufacture, has high reflectivity for reduced urban heat island effect, and utilizes thermal mass to contribute to energy efficiency. Industry publications [3, 4] can guide the designer on how to achieve LEED-NC points with concrete.

MAKING CONCRETE GREENER WITH SLAG CEMENT

Slag Cement can replace between 20 and 80 percent of Portland Cement in concrete.

Slag cement is a by-product of iron production in a blast furnace. It is a hydraulic cement that can replace between 20 to 80 percent of portland cement in concrete (Table 1) and adds to concrete's sustainable attributes. Slag cement can:

- Reduce virgin material used in the manufacture of concrete
- Reduce disposal and increase use of a recovered industrial material
- Reduce cementitious material needed to achieve a specified strength
- Improve service life through greater concrete durability
- Reduce embodied energy and greenhouse gas emissions
- Increase concrete reflectivity