

*Shrinkage results from physical and chemical changes that occur in the paste fraction of concrete.*

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

## 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.

## 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*,<sup>1</sup> 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.

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*,<sup>2</sup> 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.<sup>3</sup> 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).

Finally, data from one reference<sup>4</sup> 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.

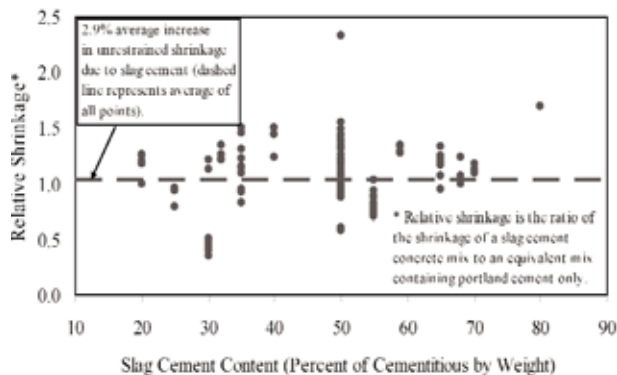
In conclusion, the literature available today indicates there is little increase in drying shrinkage when slag cement is used in concrete, regardless of the percentage used. As for all concrete, when shrinkage is a concern, ACI 224 should be consulted for guidance.

*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 Restraint Shrinkage," Journal of Materials in Civil Engineering, Vol. 11, No. 3, 1999, pp. 214-23.

Figure 1: Effect of Slag Cement Content on Relative Shrinkage



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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.