DURABILITY OF SLAG CEMENT CONCRETES
by Donald W. Lewis March, 1981

Slag cement durability has been frequently questioned from many aspects of service requirements since the first development of their use. For years it was suspected that the sulfides contained in the slag would oxidize and cause expansion of the cement and corrosion of the reinforcement, that the cement would not be resistant to weathering if exposed to air (useful only in foundations or underwater), etc.

Investigations in laboratories and field experience in a number of countries have demonstrated that no basis exists for any of these suspicions. F. M. Lea, in Chapter 15 *Cements Made from Blast-Furnace Slag* of *The Chemistry of Cement and Concrete*, Chemical Publishing Co., Inc., 1971, summarizes the knowledge developed at that time. The following conclusions resulted from the extensive literature available:

(a) Blast furnace slag cements have a long history of successful use in all types of applications and develop strengths in either air or water, and in rich or lean mixes, that equal those obtained with Portland cements. (They may require more careful handling at low temperatures when the rate of strength development is decreased more than with Portland cement.)
(b) The sulfides in the cement disappear without causing any expansion or instability of any kind.
(c) Blast-furnace slag cements provide protection for embedded steel as good as that of other cements; there should be no objections to their use for reinforced or prestressed structures.
(d) Resistance of slag cements to freezing-and-thawing is similar to that of Portland cements with conflicting claims regarding effects of cement composition. The cement itself is, at most, a minor factor apart from effects on air-entrainment and the air-void system in the cement paste.
(e) Slag cements are more resistant to sea water and other chemical agents than ordinary Portland cements, having properties similar to those of good sulfate-resistance Portland. Sulfate resistance is affected by the alumina content of the slags, with high alumina slag (about 17%) reported to decrease sulfate resistance at low percentages of cement replacement (50% or less). Low alumina slags (11%) seem to increase sulfate resistance at all levels of use. With high replacement levels (65% or more) all slags increase the sulfate resistance compared to the Portland cement used with them.

(f) Expansion of concretes made with alkali-reactive aggregates is considerably reduced by use of slag cements as compared to Portland cement with the same alkali content.

Recent investigations appear to have added little to the existing knowledge of slag cement durability. Several studies that have been reported are briefly summarized below.

1. "Strength and Freeze-Thaw Characteristics of Concrete Incorporating Granulated Blast-Furnace Slag", by V.M. Malhotra, Report 79-38, Mineral Sciences Laboratories, Canada Centre for Mineral and Energy Technology, 1979. Improper mix design procedures resulted in low strengths of slag-cement combinations. Nonetheless, the author concluded that "Durability Studies indicated that regardless of the water to cement plus slag ratio and whether the concrete was air entrained or air entrained and superplasticized, the test prisms performed satisfactorily in freeze-thaw tests (ASTM C666 Procedure B) except for mixes with a high water to cement plus slag ratio and 65% slag content." It should be noted that even these specimens showed no distress up to 300 freeze-thaw cycles despite the low strengths at 14 days when the freeze-thaw tests began.
2. "The Evaluation for durability and Strength Development of a Ground Granulated Blast-Furnace Slag", by F.R. Hogan and J.W. Meusel, AtlantIc Cement Co., Inc. paper presented at C-9 Symposium on Durability of Concrete, December, 1980. Mortars with 40, 50 and 65% slag substitutions for cement were tested with Type II and V cements for sulfate resistance, for alkali aggregate reactivity with a Type I-II cement and concretes with 50 percent slag replacement were subjected to freezing-and-thawing and scaling resistance tests. It was concluded that use of the slag produced dramatic decreases in expansion from alkali-aggregate reaction and appreciably improved sulfate resistance. It was stated that the slag containing concretes can be expected to have the same quality of air void system and freeze-thaw resistance as straight Portland cement concrete. Deicer scaling tests (on 5 bag/cu yd mixes) showed moderate to severe scaling for both the slag-cement and straight cement mixes.
3. "Performance of Concrete in Marine Environment", Publication SP-65, American Concrete Institute, 1980, contains 33 papers presented at an international conference at St. Andrews by-the-sea, Canada in August, 1980. Many of the papers dealt solely with cements other than blast-furnace slag. Others, such as Durability of Concrete in Sea Water: Method of Accelerated Testing & Evaluation" by Nishibayashi, Yamura and Inoue and "Accelerated Test Method for Durability of Cement Mortars in Sea

Water", by Kosai and Nakamura report attempts to correlate tests involving wetting-and-drying (various salt solutions) and thermal shock tests with sea water exposure. Slag cements were used, but short sea water exposure times for companion specimens do not permit useful longtime correlations.

4. "Durability of Concrete in Marine Environment - A Review", *by* P .K. Mehta is an excellent summary of longtime case histories with various types of cements, and discusses the chemical reactions of sea water and cement hydration products at some length. Cement performance is greatly dependent upon the permeability that controls the rate of penetration of .the chemicals, low permeability is essential for long-term durability. It is concluded that Pozzolan additions to Portland cement or use of blended cements containing large proportions of granulated blast-furnace slag improves the impermeability of concrete by reducing the volume of large pores in the hydrated cement paste."
5. "Durability of Concrete Structures Along the North Sea Coast of the Netherlands", by J.G. Wiebenga reports the results of inspections of 64 structures ranging in age from 3 to 63 years. Most of the structures contained varying amounts of blast-furnace slag cement and were examined for visible damage from spalling, corrosion, cracking, etc. The report notes that blast-furnace slag cements are normally used, any containing 65% or more slag is considered to be sulfate resistant and they design for as much as a 200 year life. Fifty percent of the structures showed no evidence of weathering, 66% were free from cracks, and 88% were free from evidence of corrosion. No visible corrosion was found in any structure less than 30 years old regardless of the cement content, and occurred in older structures only where cover over the steel was relatively small. No correlation was attempted with slag content.
6. "Performance of Mortar Specimens in Chemical and Accelerated Marine Exposure", by V.D. Vanden Bosch reports lab test results on blast-furnace slag and Portland cement mortars for sulfate resistance and describes a number of North Sea structures made with slag cement. It is concluded that any cement containing 70% or more slag "can safely be used in sea water" and that "the existence especially in the Netherlands, of an important number of structures made with BFS cement concrete, 30 to 50 years old, gives an excellent demonstration of the perfect behavior of BFS cement in marine environment."