Guide to the Use of Slag Cement in Concrete and Mortar

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Committee 233 expresses its gratitude to the late D. Elliot, former Chair of Committee 233.

This report addresses the use of slag cement as a separate cementitious material added along with portland cement in the production of concrete. This report does not address slags derived from the smelting of materials other than iron ores. The material characteristics described and the recommendations for its use pertain solely to cement ground from granulated iron blast-furnace slag.

Keywords: blast-furnace slag; cementitious material; granulated blast-furnace slag; hydraulic cement; mixture proportion; mortar; portland cement; slag cement.

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CHAPTER 1—GENERAL INFORMATION

1.1—History

The use of slag cement as a cementitious material dates back to 1774, when a mortar was made using slag cement in combination with slaked lime (Mather 1957). In 1862, a granulation process was proposed to facilitate removal and handling of iron blast-furnace slag leaving the blast furnace. The use of granulation produced glassy material that played an important part in the development of iron blast-furnace slag as a hydraulic binder (Thomas 1979). This development resulted in the first commercial use of slag-lime cements in Germany in 1865. In France, these slag cements were used as early as 1889 to build the Paris underground metro system (Thomas 1979).

Mary (1951) described the preparation of slag cement by the Trief wet-process and its use in the Bort-les-Orgues Dam. This was done after World War II when the supply of portland cement was limited. The dam involved 660,000 m^3 (863,000 yd^3) of concrete. The slag was ground wet and charged into the mixer as a thick slurry.

A sample of the Trief wet-process cement was obtained by the Corps of Engineers in December 1950 and tested at the Waterways Experiment Station (WES) (1953). In the WES tests, the behavior of the ground slag from Europe was compared with slag ground in the laboratory from expanded slag from Birmingham, AL. Each slag was activated with 1.5 percent sodium hydroxide and 1.5 percent sodium chloride by mass, with generally similar results.

In the former Soviet Union and several European countries, the use of slag cement in alkali-activated systems where no portland cement is used has been found to provide special properties (Talling and Brandstetr 1989).

The first recorded production of blended cement in which blast-furnace slag was combined with portland cement was in Germany in 1892; the first United States production was in 1896. By 1980, the use of slag cement in the production of blended cement accounted for nearly 20 percent of the total hydraulic cement produced in Europe (Hogan and Meusel 1981).

Until the 1950s, slag cement was used in two basic ways: as a raw material for the manufacture of portland cement, and as a cementitious material combined with portland cement, hydrated lime, gypsum, or anhydrite (Lewis 1981).

Since the late 1950s, use of slag cement as a separate cementitious material added at the concrete mixer with portland cement has gained acceptance in South Africa, Australia, the United Kingdom, Japan, Canada, and the United States, among other countries.

In 2000, production capacity for slag cement was estimated to exceed 2,000,000 metric tons or Megagrams (Mg) annually in North America. In the United States, production of slag cement was estimated to exceed 1,500,000 Mg, up from approximately 700,000 Mg in 1990. Currently, slag cement and granules are also being imported from various countries into the United States.

According to Van Oss (2015), 7,600,000 Mg of iron blast-furnace slag was produced in the United States in 2013; 2,300,000 Mg of that being granulated, and 5,300,000 Mg air-cooled. According to the Slag Cement Association, 2,500,000 Mg of slag cement and 540,000 Mg of slag blended cement were used in concrete and other construction applications (some of which used imported granules). More sources of slag cement may become available due to energy and environmental stimuli.

The majority of slag cement in the United States is batched as a separate ingredient at concrete production plants. Approximately 9 percent, however, is used to produce blended hydraulic cements. Slag cement is also used for other applications, including stabilizing mine tailings and industrial waste.

1.2—Scope and objective

The objective of this report is to compile and to present experiences in research and field use of slag cement in concrete and mortar, and to offer guidance in its specification, proportioning, and use. Presented is a detailed discussion of the composition and production of slag cement, its use, and its effects on the properties of concrete and mortar. Slags from the production of metals other than iron differ greatly in composition from slag cement and are not within the scope of this report.

1.3—Environmental considerations

The use of slag cement in concrete and mortar is an environmentally sound and efficient use of existing resources. Slag cement offers several benefits when used to replace a portion of the portland cement, including reduced energy consumption, reduced greenhouse gas emissions, and reduced consumption of virgin raw materials. For a more complete discussion on sustainability, refer to Chapter 9.

1.4—Production

1.4.1 *Origin of blast-furnace slag*—In the production of iron, the blast furnace is continuously charged from the top with iron oxide (ore, pellets, and sinter), fluxing stone (limestone or dolomite), and fuel (coke). Two products are obtained from the furnace: molten iron that collects in the bottom of the furnace (hearth) and liquid iron blast-furnace slag floating on the pool of molten iron. Both are periodically tapped from the furnace at a temperature of approximately 2700°F (1500°C).

1.4.2 *Granulated slag*—Quenching with water is the most common process for production of granulated slag to be used as a cementitious material. Simple immersion of the molten slag in water was often used in the past. This quenching method is sometimes called the pit process. More efficient modern granulation systems use high-pressure water jets that impinge on the stream of molten slag at a water-slag ratio of approximately 10 to 1 by mass. In this quenching method, called jet process granulation, the blast-furnace slag is quenched almost instantaneously to a temperature below the boiling point of water, producing slag particles with high glass content. This material is called granulated blast-furnace slag (GBFS) or slag granules. A close-up view of the part of a jet-process granulator system where the water meets the molten blast-furnace slag is shown in Fig. 1.4.2a.

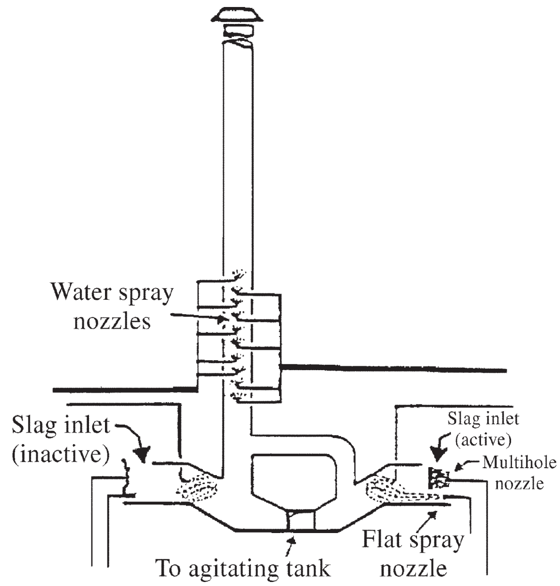

Fig. 1.4.2a—Configuration of blast-furnace slag water granulator to include steam-condensing tower (Hogan and Meusel 1981).

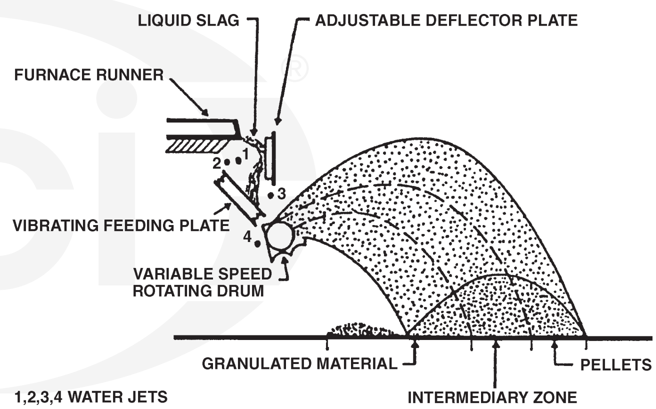

Fig. 1.4.2b—Blast-furnace slag palletization process, using a minimum of water usually applied at the feed plate (Hogan and Meusel 1981).

Another process, sometimes referred to as air granulation, involves use of the pelletizer (Cotsworth 1981). In this process, the molten slag passes over a vibrating feed plate where it is expanded and cooled by water sprays. It then passes onto a rotating finned drum, which throws the slag into the air where it rapidly solidifies to spherical pellets (Fig. 1.4.2b). The resulting product may also have a high glass content and can be used either as a cementitious material or, in the larger particle sizes, as a lightweight aggregate. Other processes for combining slag with water, which are used primarily for the production of lightweight aggregates, are also capable of producing a sufficiently glassy slag for use as a cementitious material (Robertson 1982).