CEMENTITIOUS APPLICATIONS OF GROUND IRON BLAST FURNACE SLAG

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IRON BLAST-FURNACE SLAG

In the process of extracting iron from ores, a blast furnace is charged with the ores, flux stones and coke. The two products tapped from the furnace in a molten condition at a temperature of about 1500°C are iron and slag. The slag is principally silicates and alumino-silicates of lime and magnesia formed by reaction of the fluxes with non-metallic components of the ores. Dependent upon the cooling procedures used, any of three forms of blast-furnace slag may be produced from the molten material.

- *Air-Cooled* slag solidified under ambient conditions in pits near the furnace. It is crystalline in nature, has very limited cementitious properties, and is used as a "normal-weight aggregate for all types of construction.
- *Granulated* slag is quickly quenched or chilled by water or air or both to form a glassy, granular product with very limited crystal formation. It is highly cementitious in nature and, ground to cement fineness, hydrates in a manner similar to Portland cement.
- *Expanded slag* is treated, while molten, with limited quantities of water to increase vesicularity and decrease unit weight. Processes and resultant cooling rates vary widely; the product may be highly crystalline or extremely glassy. Used primarily as a lightweight aggregate, some expanded slags such as the pelletized or “air granulated" products are highly glassy and cementitious in nature.

The slags used for cementitious purposes are the highly glassy, granulated iron blast-furnace slags. Most of these are produced either by cooling with large quantities of water or by the pelletizing procedures. Hydration is promoted by activators such as alkalis and calcium hydroxides.

HOW SLAG IS USED

Ground slag has been used in cementitious applications in three major ways over the last hundred years or more.

- *Slag cement* is simply a mixture of ground slag and hydrated lime. This type is covered by ASTM Specification C595 and was introduced into the U.S. from

Europe in 1896. Because of slow setting and low rate of strength gain characteristics, it is now seldom used. Other than in mortars, its past applications in the U.S. were largely blended with Portland cement.

- *Super-sulfated cement* is a mixture of ground granulated slag, gypsum or anhydrite, and a small amount of Portland cement. It has excellent resistance to a large number of aggressive agents: sea water, sulfates, chlorides, alkali hydroxides and weak acids. Such cements found extensive use in Europe in the past, but have not been produced in the United States.
- *Portland blast-furnace slag cements* make up the most successful and widely-used variety of "slag cements". Consisting of a mixture of Portland cement and ground granulated slag, these cements began commercial production in Germany in 1892 and have been made in the U.S. since 1938. They are covered in ASTM Specification C595 which requires them to meet the same strength requirements as Type I. Long-time use throughout the world has demonstrated excellent performance in all types of applications and superior characteristics for a number of uses, particularly with respect to sea water and sulfate resistance, lower heat of hydration, and lower permeability.

PORTLAND BLAST-FURNACE SLAG CEMENT PRODUCTION

Most of the Portland blast-furnace slag cement used in the world is made by inter-grinding the granulated slag with Portland cement clinker. Since the slag is usually the hardest to grind, it forms the coarsest portion of the final product while the cement is ground the finest. The slag is slower setting and, for optimum performance, should be the finer of the two materials. Inter-grinding has the disadvantage of reversing the preferable order of fineness. Separate grinding of the slag and cement permits each to be ground to its own optimum fineness. The two ground materials can then be blended to produce a Portland blast-furnace slag cement with better performance characteristics than that made by inter-grinding. Blending of the slag and cement may be done either at the plant and marketed as blended cement, or the two may be blended at the time of use. In either case, the final cementitious material in the concrete or mortar is a Portland blast-furnace slag cement. Ground granulated slag, combined with portland cement in the mixer, is the subject of discussion at this Forum. While this is a new method of use in this country, the cementitious material is not new: it is an improved Portland blast-furnace slag cement. Compared to the blended cements used in the past, the "new" method of using the slag provides several Improvements:

1. Modern blast-furnace operating practices combined with improved water granulation and pelletizing procedures result in a more uniform slag;
2. Slag and cement are each ground to optimum fineness; and,
3. Proportions of slag and cement can be adjusted to meet the individual project needs.

SPECIFICATIONS

Although the final blended cement in the concrete is simply an improved Portland blast-furnace slag cement, it cannot be subjected to the ordinary cement tests. The blending and use take place simultaneously. Recognizing the need for a specification covering the slag as a separate material, ASTM Specification C989, Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars, has been developed.

Three grades based on the cementitious properties of "activity" of the slag are covered in the specification. The activity of a slag is dependent upon a number of factors; principally the chemical composition, amount and characteristics of glass, fineness, and the characteristics of the cement with which it is combined. The grade classification is, therefore, based on actual mortar strength tests using a "standard" cement (strength and alkali content of the cement are specified). The activity index is the compressive strength of mortar made with 50-50 combinations of the slag and Portland cement expressed as a percentage of the strength of mortars made with the reference cement alone. To maintain specified strength levels, less active slags would need to be used in smaller percentages than would be permissible for more active materials.

Since cement composition influences the slag activity, the reaction with cement used on a given project may vary from that obtained in the specification tests. Final mix proportions for field use need to be based on tests with the materials to be used, in the same manner as for the use of cement along.

PROPERTIES OF CONCRETE WITH GROUND SLAG

The properties of concretes containing mixtures of ground slag and Portland cement compared to concretes containing only Portland cements have been well-established by research and field experience in several countries. The major effects of using ground slag can be summarized as follows:

1. Higher ultimate and usually lower early strengths. The early strength characteristics can be improved by use of Type III cement, chemical accelerators, lower slag percentages, higher curing temperatures, etc.
2. The ratio of flexural to compressive strength is increased.
3. Decreased variability in concrete strengths.
4. Lower permeability, decreased chloride penetration.
5. Improved sulfate and sea-water resistance.
6. Decreased alkali-silica reactions.
7. Equal freeze-thaw resistance when equivalent strengths and adequate air void systems are provided.
8. Decreased temperature rise from hydration.
9. Improved workability.

10. Lighter color.
11. Lower cost.

HISTORY OF USE

Use of separately-ground slag combined with portland cement at the mixer began in South Africa more than 30 years ago. Water-granulated slags are used in 50-50 proportions for ordinary concrete, with the slag proportion increased to 70% in coastal area. Applications have included bridges, slip-formed chimneys or stacks up to 300 meters in height, marine structures, high-strength building and structural concretes, etc.

Use began in Great Britain about 20 years ago with extensive use in dams, bridges, nuclear power plants, marinas, and sewage disposal facilities. It has also been used as an "extender" for white cement in concrete. The largest suspension span in the world on the Humber Bridge is supported by 160-meter-high slip-formed reinforced concrete towers containing 30% ground slag with 70% OPC. Both water-granulated and pelletized slags are used.

North American use dates back some 10 years with use of a ground pelletized slag in Canada. Used in all types of general concrete construction, it has found particular applications in low heat mass concretes and for sulfate resistance.

A ground, machine-expanded slag produced in Bethlehem, PA first became available in the U.S. about seven years ago and has been used primarily in the concrete block industry. Large quantities of ground water-granulated slag have more recently become available near Baltimore. This slag is being widely used along the Atlantic Coast in block, precast and prestressed utility poles and pipe, bridge foundations, building construction and airport paving.

SUMMARY

Ground granulated slag is not a new cementitious material; combining it with cement at the mixer is a relatively new way in the U.S. of using a proven material to obtain greater uniformity and improved characteristics. It can be expected to be used to the full extent of its availability for several reasons:

1. Ground slag combined with Portland cement at the mixer can provide improved concrete uniformity and equal or better strength and durability properties than the Portland cement alone.
2. In some applications - such as sulfate exposure, mass concrete or hot-weather concreting, alkali-silica problems - its use can eliminate a need for special Portland cements or procedures.

3. It will be more economical in areas where available (within economic shipping distances of blast-furnace locations).

A concrete producer with ground granulated slag and Portland cement available to be combined as desired for an individual application can duplicate the desirable characteristics of any of the various types of Portland cement.