Ground Granulated Blast-Furnace Slag

Although portland blast furnace slag cement, which is made by intergrinding the granulated slag with portland cement clinker (blended cement), has been used for more than 60 years, the use of separately ground slag combined with portland cement at the mixer as a mineral admixture did not start until the late 1970s (Lewis 1981). Ground granulated blast-furnace slag is the granular material formed when molten iron blast furnace slag is rapidly chilled (quenched) by immersion in water. It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, hydrates like portland cement (Admixtures and ground slag 1990; Lewis 1981; ACI Comm. 226 1987a).

Specifications

ASTM C 989-82 and AASHTO M 302 were developed to cover ground granulated blast furnace slag for use in concrete and mortar. The three grades are 80, 100, and 120.

Mix Design

The use of grade 80 ground granulated blast furnace slag should be avoided unless warranted in special circumstances. The grade of a ground granulated blast furnace slag is based on its activity index, which is the ratio of the compressive strength of a mortar cube made with a 50 percent ground granulated blast furnace slag-cement blend to that of a mortar cube made with a reference cement. For a given mix, the substitution of grade 120 ground granulated blast furnace slag for up to 50 percent of the cement will generally yield a compressive strength at 7 days and beyond equivalent to or greater than that of the same concrete made without ground granulated blast furnace slag. Substitution of grade 100 ground granulated blast furnace slag will generally yield an equivalent or greater strength at 28 days. However, concrete made with grade 80 ground granulated blast furnace slag will have a lower compressive strength at all ages. To provide a product with equivalent or greater compressive strengths, only grades 100 and 120 ground granulated blast furnace slag should be used. However, in mass concrete, the heat of hydration may be an overriding factor, and the use of grade 80 slag may be appropriate.

Ground granulated blast furnace slag is a cementitious material and can be substituted for cement on a 1:1 basis. In the absence of special circumstances or mix specific data, the substitution of ground granulated blast furnace slag should be limited to 50 percent for areas not exposed to deicing salts and to 25 percent for concretes which will be exposed to deicing salts. While substitution of ground granulated blast furnace slag for up to 70 percent of the portland cement in a mix has been used, there appears to be an optimum substitution percentage which produces the greatest 28 day strength. This is typically 50 percent of the total cementitious material but depends on the grade of ground granulated blast furnace slag used. Also, research has shown that the scaling resistance of concretes decreases with ground granulated blast furnace slag substitution rates greater than 25 percent.

These guidelines on ground granulated blast furnace slag substitution rates are intended to provide a starting point for designers with little or no experience in the use of cement and concrete containing ground granulated blast furnace slag. If local data shows good performance at greater percentages, this information can be used in lieu of the recommended guidelines. Section 4.2.3.2 of ACI 318-89, "Building Code Requirements for Reinforced Concrete," indicates that substitution rates of up to 50 percent may be acceptable for concretes exposed to deicing chemicals. In addition, in mass concreting operations, the heat of hydration may be an overriding factor and substitution rates greater than 50 percent may be appropriate.

Effects of Slags on Properties of Fresh Concrete. Use of slag or slag cements usually improves workability and decreases the water demand due to the increase in paste volume caused by the lower relative density of slag (Hinczak 1990). The higher strength potential of Grade 120 slag may allow for a reduction of total cementitious material. In such cases, further reductions in water demand may be possible (Admixtures and ground slag 1990).

Setting times of concretes containing slag increases as the slag content increases. An increase of slag content from 35 to 65% by mass can extend the setting time by as much as 60 minutes. This delay can be beneficial, particularly in large pours and in hot weather conditions in which this property prevents the formation of "cold joints" in successive pours.

The rate and quantity of bleeding in concrete containing slag or slag cements is usually less than that in concrete containing no slag because of the relatively higher fineness of slag. The higher fineness of slag also increases the air-entraining agent required, compared to conventional concrete. However, slag unlike fly ash does not contain carbon, which may cause instability and air loss in concrete.

Effect on Strength of Hardened Concrete. The compressive strength development of slag concrete depends primarily upon the type, fineness, activity index, and the proportions of slag used in concrete mixtures (Malhotra 1987). In general, the strength development of concrete incorporating slags is slow at 1-5 days compared with that of the control concrete. Between 7 and 28 days, the strength approaches that of the control concrete; beyond this period, the strength of the slag concrete exceeds the strength of control concrete (Admixtures and ground slag 1990). Flexural strength is usually improved by the use of slag cement, which makes it beneficial to concrete paving application where flexural strengths are important. It is believed that the increased flexural strength is the result of the stronger bonds in the cement-slag-aggregate system because of the shape and surface texture of the slag particles.

Problems occur when slag concrete is used in cold weather applications. At low temperatures, the strengths are substantially reduced up to 14 days, and the percentage of slag is usually reduced to 25-30% of replacement levels; when saw cutting of joints is required, the use of slag is discontinued (Admixtures and ground slag 1990).

Effects on Permeability of Hardened Concrete. Incorporation of granulated slags in cement paste helps in the transformation of large pores in the paste into smaller pores, resulting in decreased permeability of the matrix and of the concrete (Malhotra 1987). Rose (1987) indicated that significant reduction in permeability is achieved as the replacement level of the slag increases from 40 to 65% of total cementitious material by mass. Because of the reduction in permeability, concrete containing granulated slag may require less depth of cover than conventional concrete requires to protect the reinforcing steel.

Effects on Freeze-Thaw Durability of Hardened Concrete. Freeze-thaw durability of slag concrete has been studied by many researchers. It has been reported that resistance of air-entrained concrete incorporating Ground granulated blast furnace slag is comparable to that of conventional concrete (Malhotra 1987). Malhotra (1983) reported results of freeze-thaw tests on concrete incorporating 25-65% slag. Test results indicate that regardless of the water-to-(cement + slag) ratio, air-entrained slag concrete specimens performed excellently in freeze-thaw tests, with relative durability factors greater than 91%.

Effect on ASR of Hardened Concrete. Effectiveness of slag in preventing damage due to ASR is attributed to the reduction of total alkalies in the cement-slag blend, the lower permeability of the system, and the tying up of the alkalies in the hydration process. There have been many studies of Ground granulated blast furnace slag that has been used as partial replacement for portland cement in concrete to reduce expansion caused by alkali-aggregate reaction (Yamamoto and Makita 1986; Moir and Lumley 1989; Mullick, Wason, and Rajkumar 1989).

Handling, Storage, and Batching

Ground granulated blast furnace slag should be stored in separate watertight silos (such as those used for cement) and should be clearly marked to avoid confusion with cement. In batching, it is recommended that portland cement be weighed first and then followed by the slag. Slag is like cement in that normal valves are adequate to stop the flow of material.

Curing

Care should be taken to ensure that proper curing is maintained for concretes in which ground granulated blast furnace slag has been substituted for a portion of the Portland cement. The reduced heat of hydration and reduced rate of strength gain at early ages exhibited by ground granulated blast furnace slag modified concretes reinforces the need for proper curing of these mixes. With an increased time of set and a reduced rate of strength gain, concretes containing ground granulated blast furnace slag may be more susceptible to cracking caused by drying shrinkage. Additionally, the set retardation caused by ground granulated blast furnace slag is temperature sensitive and becomes more pronounced at lower temperatures. During cold weather concreting, favorable curing temperatures should be maintained until the concrete has reached a sufficient strength to resist the effects of freezing temperatures and allow safe form removal. The use of matched curing or non-destructive testing can be used to determine in-place concrete strength for determination of removal of cold weather protection and safe form removal.

Recommendations

1. In the absence of special circumstances, the use of ground granulated blast furnace slag as a cement

replacement should be limited to grades 100 and 120 ground granulated blast furnace slag.

2. In the absence of special circumstances or mix specific data, the substitution of ground granulated blast furnace slag should be limited to 50 percent for areas not exposed to deicing salts and to 25 percent for concretes which will be exposed to deicing salts.

3. The necessity of proper curing should be emphasized with the use of ground granulated blast furnace slag.

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