R&T UPDATE
Concrete Pavement Research & Technology

SLAG CEMENT AND CONCRETE PAVEMENTS

Slag cement—commonly referred to as ground granulated blast-furnace slag, or GGBFS—is a hydraulic cement that works synergistically with portland cement to improve the strength and durability of concrete pavements.

Slag is a byproduct of processing iron ore to iron and steel in a blast furnace. Molten slag, which floats on the top of the molten iron ore, is separated and granulated. Granulation is the rapid quenching with water of the molten slag into solid, hydraulically reactive glassy granules. These granules are then ground to a suitable fineness to produce slag cement or to incorporate as an ingredient in the manufacture of blended cements.

Hydraulic Activity

When portland cement and water are mixed, a chemical reaction called hydration initiates, resulting in the creation of calcium-silicate-hydrate (CSH) and calcium hydroxide (CH). CSH is a gel that is responsible for strength development in portland cement pastes. CH is a byproduct of the hydration process that does not significantly contribute to strength development in normal portland cement mixtures.

Silicates in slag cement combine with the CH byproduct of hydration and form additional CSH. This in turn leads to a denser, harder cementitious paste, which increases ultimate strength as compared to 100% portland cement systems.

Proportioning

For concrete pavements, slag cement is typically used in proportions of 25 to 35 percent. It is normally substituted for portland cement on a one-to-one basis by mass. The proportion of slag cement is usually dictated by requirements for strength, durability, time of set, and the resistance of the concrete to alkali-silica reaction (ASR). Mixtures should be optimized for strength and durability using appropriate test methods. It is not uncommon to find that total cementitious material can be reduced by using appropriate levels of slag cement to replace portland cement when strength is used as the evaluating criteria.

Benefits of slag cement:

- Improved concrete workability
- Enhanced finishability
- Lower permeability
- Improved resistance to aggressive chemicals
- Increased compressive and flexural strengths
- Lighter color

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Concrete mixtures containing slag cement should be proportioned using conventional design methods. Slag cement should be substituted for portland cement on a one-to-one basis by mass. The specific gravity of slag cement ranges from 2.85 to 2.94, depending upon the slag source, as compared to 3.15 for portland cement. The difference in specific gravity means a greater volume of slag cement will be used to replace the same mass of portland cement. The larger percentage of fines usually allows for the use of a higher percentage of coarse aggregate. As with all concrete mixtures, trial batches are necessary to verify that the desired concrete properties are achieved.

In general, water demand for a given slump in slag concrete mixtures will be 3 to 5 percent lower than ordinary portland cement concrete. Slag cement should always be included when calculating the water-cementitious material ratio. In the field, it is important to avoid adding water during construction even if a slag cement mixture may appear "sticky."

Laboratory testing and field experience has found slag cement to be compatible with all chemical admixtures used in concrete, and the effects of chemical admixtures in concrete containing slag cement are similar to the effects in ordinary portland cement concrete. Slag cement does not contain carbon and will not cause fluctuations in air content. In addition, slag cement is compatible with pozzolans such as fly ash or silica fume. Trial batches help determine proper admixture dosages.

The percentage of slag cement to use for the highest flexural strength varies depending on the specific mix design and constituents used. However, slag cement used at replacement rates greater than 25% can cause a dramatic increase in time of set. The lower heat evolution characteristic of slag cement in the summer can be beneficial because it allows more time for placing and finishing concrete. In spring and fall, the delayed set may cause problems with joint sawing, texturing, and secondary paving operations. A rule of thumb is that the set time is delayed 30 minutes for every 10% slag replacement of portland cement.

Placing and Paving Concrete With Slag Cement

With a few exceptions, placing and finishing concrete with slag cement is similar to placing and finishing conventional portland cement concrete. These few exceptions are related to lower heat generation, the smaller particle size of slag cement, and differences with consolidation. The paving contractor should be aware of the characteristics of concrete containing slag cement, similar to being aware of the effects of admixtures, aggregates, temperature, etc.

Workability and Finishability –

Correctly designed concrete mixtures containing slag cement demonstrate improved workability and finishability when compared with 100% portland cement concrete systems. This is due to several factors including increased paste cohesiveness, glassy structure of slag cement, and low initial water absorption. Slag cement mixtures can achieve required strength at lower cementitious levels while maintaining good workability and finishability. For many of the same reasons, consolidation of slag cement concrete is generally easier than portland cement concrete. When concretes with constant water-cementitious ratios are compared, those containing slag cement generally exhibit higher slumps. Slump control is essential to preventing edge slump during slipform paving.

Contractors on some projects report effective consolidation with reduced vibration energy. In some cases, concrete containing slag cement appeared "sticky" when initially used by contractors unfamiliar with the material. Most times, slight increases in coarse aggregate proportions eliminated this condition. Some seemingly “sticky” mixtures were reported to have placed and finished well in paving operations without adjustments. However, if the paving crew reacts to the “sticky” appearance by increasing mix water, the result is aggregate segregation and surface finish problems.

Some contractors have experienced surface or micro segregation, where the surface of the concrete is mostly paste with very few coarse aggregates. This top layer is not freeze-thaw resistant and can lead to scaling. With proper adjustments to equipment and more experience with slag cement concrete mixtures, these potential problems can be avoided.

Time of Set –

Concrete containing slag cement in excess of 25% replacement dosage generally has noticeably slower set times than ordinary portland cement concrete. Time of set is related to the percentage of slag cement used in the mix, the temperature of the concrete, and the ambient temperature. At an ambient temperature of 73°F, time of initial set is usually extended by one to three hours. At temperatures above 85°F, the time of set difference becomes insignificant.

Bleed Rates –

There are minor differences between bleed rates and bleeding capacities of concrete containing slag cement and concrete containing ordinary portland cement. These differences are from variations in the fineness of the slag cements produced by each manufacturer. Slag cements that are finer than portland cement will generally cause a slower rate of bleeding than concrete made with ordinary portland cement. Coarse slag cements may cause the same or even greater bleed rates and capacities than concrete made with ordinary portland cement. In slipform paving mixtures where w/c ratios are low, bleeding may not occur. In those situations, specified curing methods should begin subsequent to finishing or a finishing aide employed.

Curing –

Curing refers to maintaining a satisfactory moisture and temperature condition in concrete immediately following placing and finishing, and lasting for a prescribed period of time. Strength gain and durability are directly related to the degree of hydration of the cementitious materials. The strength and durability properties of any concrete will fully develop only if it is cured properly.

Curing methods for concrete with slag cement are identical to those of other concrete. The curing method is usually driven by the specification. The lack of a specification should not imply that curing is not needed. Curing practices vary, however, due to several factors including mix proportioning, ambient and environmental factors, and jobsite conditions. The common thread is that curing must begin as soon as feasible and be continuous.

Sawing Joints –

Joints need to be sawed after the concrete has achieved enough strength to keep the sawcut from raveling but before internal stresses in the concrete become great enough to initiate an uncontrolled crack. The earlier the concrete can be cut without raveling, the better the chances are that the concrete will not crack before saw cutting. As a rough guideline, for slag cements the time to saw cut is delayed approximately 30 minutes for every 10 percent of slag cement replacing portland cement.

The difficulty in correctly determining the earliest time for saw cutting is that it changes according to the type of aggregates in the concrete, the ambient temperature and environmental conditions at the site, the cementitious factor, the types and percentages of mineral and chemical admixtures, and the subbase restraint. An example of just how difficult it can be to correctly judge the right time for cutting joints is to consider a change in coarse aggregate from gravel to quartzite. A concrete mixture with quartzite needs to achieve a compressive strength of nearly 800 psi more than a gravel mixture before it can be safely saw cut. The addition of slag cement to a concrete mixture should be assessed in a similar manner as any other change occurring to the mixture or in the environment.

Summary

Slag cement can enhance a concrete pavement by improving workability in the plastic state, and increasing strengths and reducing permeability in the hardened state. The correct amount of slag to use on a particular project depends on the materials and admixtures used, as well as ambient conditions during paving. With careful attention to detail during the concrete mixture design and construction portions of a project, a successful and durable pavement can be produced with slag cement. However, it is critical that contractors and specifiers are aware of the differences between ordinary portland cement mixtures and slag cement mixtures.

Resource List

1. American Concrete Institute, ACI 233-R, *Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete*, Farmington Hills, MI, 1995.
2. Slag Cement Association, *Slag Cement in Concrete*, No. 9, Concrete Proportioning, Sugar Land, TX, 2002.
3. American Society for Testing and Materials, ASTM C989, *Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars*, West Conshohocken, PA, 1999.
4. American Society for Testing and Materials, ASTM C595, *Standard Specification for Blended Hydraulic Cements*, West Conshohocken, PA, 2002.
5. Portland Cement Association, EB001.14, *Design and Control of Concrete Mixtures, 14th Ed.,* Skokie, IL, 2002.
6. Federal Highway Administration, FHWA-RD-91-079, Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements, Volume I: Final Report, McLean, VA, 1994.

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