Use of Fly Ash or Slag in Concrete: Proposed PWGSC Guidelines

by

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Abstract

The 1998 Kyoto conference called for the reduction of greenhouse gas emission to 6% below 1990 level by 2010-2012. The declaration was a direct result of the growing awareness and concern of the increasing concentrations of greenhouse gases in the atmosphere, which have adverse effects upon our climate. In 1994, Canada contributed about 615 million metric tonnes of greenhouse gases to the atmosphere. The greenhouse gas of most concern is carbon dioxide. As the production of every tonne of portland cement contributes about one tonne of carbon dioxide into the atmosphere, cement and concrete industry can play an important role in assisting Canada to fulfil its commitment as agreed at the Kyoto conference. In support of Canadian Government's commitment to reduce greenhouse gas emissions, Public Works and Government Services Canada (PWGSC) is developing guidelines for the use of fly ash or ground, granulated blast-furnace slag in concrete. The use of these materials in partial replacement of cement in concrete have numerous benefits: reduced greenhouse gas emissions, environmentally-friendly concrete with excellent long-term strength and durability characteristics, reduced energy consumption and lessened pressure on natural resources. The paper gives an overview of the proposed PWGSC guidelines.

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Introduction

During the past few decades, there has been a growing awareness and concern of the increasing concentrations of greenhouse gases in the atmosphere, which have adverse effects upon our climate. In 1994, Canada contributed about 615 million metric tonnes of greenhouse gases to the atmosphere, about 2% of the total global emissions. The greenhouse gas of most concern is carbon dioxide (CO_2), although its share of the total greenhouse gas emissions in 1994 declined 1% from 1990's share of 80%. By using reclaimed and recyclable industrial byproducts such as fly ash[1] and ground, granulated blast-furnace (GGBF) slag[2], cement and concrete industry can play an important role in assisting Canada to fulfil its commitment to reduce the total greenhouse gas emission to 6% below 1990 level by 2010-2012, as agreed at the Kyoto conference.

The production of every tonne of portland cement contributes about one tonne of CO_2 into the atmosphere. It is, therefore, imperative that supplementary cementing materials such as fly ash or GGBF slag be substituted for portland cement to reduce CO_2 emissions. The use of these materials in concrete not only helps to reduce the greenhouse gas emissions but results in environmentally-friendly concrete that has excellent long-term strength and durability characteristics, and is often more economical than normal portland cement concrete. The use of supplementary cementing materials offers additional and immediate environmental benefits, including reduced energy consumption (such as energy required to produce cement) and lessened pressure on natural resources (such as reduction in water consumption).

In the U.S., the use of fly ash and GGBF slag on federal-aid highway projects is encouraged by their classification as a “recovered” product under the federal Resource Conservation and Recovery Act, which generally mandates use of fly ash in cement or concrete in construction projects using $10,000 or more of federal funds (9).

In Denmark (10), the five environmental impacts given highest priority are CO_2, energy, water, minimization of waste and substances harmful to health or environment. Substituting cement with pozzolanic materials, such as fly ash, produces concrete with lower environmental impact (upon

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[1]Fly ash is the residue of the burning of pulverized coal in thermal power plants. About 15 to 20% of burned coal takes the form of ash.

[2]GGBF slag is a nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium, that is formed when molten blast-furnace slag is rapidly chilled by immersion in water and the resulting glassy and granular particles are ground to cement fineness.

four of above five): the so-called green concrete. Maximum contents of fly ash according to the proposed Danish concrete materials standard are as follows:

Extra aggressive environmental class (moist atmosphere, with significant alkaline or/and chloride influence or layering on the concrete surface): 25%

Aggressive environmental class (moist atmosphere, with significant alkaline and/or chloride influence on the concrete surface or where there is risk of water satisfaction combined with frost): 25%

Moderate environmental class (moist atmosphere, with no risk of frost with water saturation, and with no significant alkaline and/or chloride influence on the concrete surface): 35%

Passive environmental class (dry atmosphere with no risk of corrosion): no requirement

In support of Canadian Government's commitment to reduce greenhouse gas emissions, Public Works and Government Services Canada (PWGSC) is developing guidelines for the use of fly ash or GGBF slag in concrete. Proposed principal clause and guidelines on the use of fly ash and GGBF slag and their future inclusion into the National Master Specifications (NMS) are presented herewith.

Proposed Principal Clause

PWGSC is proposing to adopt the following principal clause for the use of sly ash or GGBF slag in concrete for all federal PWGSC projects.

> "All concrete shall contain fly ash or ground, granulated blast-furnace slag as partial replacement for cement unless it can be shown that the incorporation of these materials is technically and/or economically not feasible. The amount of cement replacement by fly ash or ground, granulated blast-furnace slag will depend on the type of application (see attached Guidelines). The concrete so provided shall meet the workability, strength, durability and other performance requirements as specified."

The proposed clause is to be adopted for use as best practice for a trial period and forms the basis for developing specifications for the National Master Specifications.

Proposed Guidelines for the Use of Fly Ash or Slag in Concrete

Fly Ash

Fly ash is finely divided residue resulting from the combustion of powdered coal in coal burning power stations. It is a siliceous and aluminous material, which in itself possesses little or no cementitious property but will, in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

Canadian Standard A23.5 classifies fly ash into two main classes: Class F and Class C. Class C is further subdivided into Class CI and Class CH depending on the amount of CaO. In Canada, there are primarily Class F and Class CI fly ashes available. The availability of Class CH is very limited. In the U.S., Class CH fly ash is widely available.

Ground, Granulated Blast-Furnace Slag

GGBF slag is a nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium that is developed in a molten condition simultaneously with iron in a blast-furnace, then chilled rapidly to form glassy granular particles. The chilling creates a granular product which is then ground to cement fineness or finer. In concrete the GGBF slag will react with calcium hydroxides from the hydrated cement and form cementitious products.

Fly ash and GGBF slag must meet the requirements of CSA Standard A23-5: Supplementary Cementing Materials. The composite of each fly ash and GGBF slag is unique, and therefore must be evaluated in concrete.

Advantages of Using Fly Ash or GGBF Slag in Concrete:

1) The incorporation of fly ash or GGBF slag in concrete will improve its long-term strength and modulus of elasticity, reduce its long-term shrinkage and creep, decrease its permeability significantly at later ages, and enhance its long-term durability properties.
2) The incorporation of fly ash or GGBF slag in concrete will increase its resistance to the penetration of chloride ions. This is more evident at later ages.
3) The incorporation of Class F fly ash in concrete improves considerably its resistance to

sulphate attack.[3]

4) The use of fly ash and GGBF slag in concrete will reduce the amount of heat generated in the concrete mass that, in turn, will reduce thermal gradients and thermal stresses in concrete.

5) The resistance to freezing and thawing of concrete remains unaffected by the use of fly ash or GGBF slag[4]. This property is a direct function of the air-void spacing factor _ in concrete that is obtained by the proper use of air-entraining admixtures.

6) The incorporation of fly ash in concrete reduces its water demand. The incorporation of GGBF slag may or may not do so.

7) The incorporation of low-calcium (ASTM Class F) fly ash or GGBF slag in concrete helps in mitigating the expansions caused by alkali silica reactions (4). Minimum replacement levels recommended in concretes incorporating reactive aggregates are 20% low-calcium fly ash and 35% GGBF slag[5] (see Appendix B of ref. 6).

8) Concrete incorporating fly ash or GGBF slag will cost less than concrete made with portland cement only. The actual savings will depend on the availability of fly ash or GGBF slag, and the transportation and handling costs involved.

<u>Precautions to be Taken When Using Fly Ash or GGBF Slag</u>:

The use of fly ash or GGBF slag may reduce early-age strength of concrete. However, this drawback can be overcome by reproportioning concrete mixtures. ACI 232.2R96 recommends the use of a trial batch and testing program to evaluate the performance of a given fly ash in concrete and to establish proper mixture proportions for a specific application (1).

In general, the use of fly ash or GGBF slag in concrete will require additional curing. Minimum recommended curing period is 7 days. This is critical in cold weather conditions and may require the maintenance of formwork for a longer period.

The use of fly ash or GGBF slag in concrete will probably increase its demand for air-entraining admixtures. As those admixtures are not expensive, increase in cost of the concrete will

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[3]The use of Class CH fly ash is not recommended for concrete exposed to sulphate attack. Class CI fly ash may be used in concrete to control sulphate attach provided sufficient supporting laboratory data on the subject are available.

[4]In situations when concrete is exposed to the combined attack of freezing and thawing, and the deicing salts, the maximum recommended percentage of fly ash in concrete is 25%.

[5]The use of Class C fly ash is not encouraged for this application.

be only marginal. More recent developments have shown that certain admixtures can provide the required air void systems in concrete using blended cements.

Recommended Percentages of Fly Ash and GGBF Slag to be Used in Concrete

The following recommendations are based on current knowledge of use of fly ash and GGBF slag in concrete. While moderate volumes of fly ash and GGBF slag in concrete have been identified as tested and economical, concrete incorporating large volumes of fly ash and GGBF slag, i.e. 40% or higher, has not been as widely used. Research is ongoing to further compare performance and cost effectiveness of high volume fly ash concrete to that of conventional portland cement concrete..

1. General Structural Concrete*

	Concreting Under Warm Weather Conditions	***Concreting Under Cold Weather Conditions******
Fly Ash**	20-30%	<20%
GGBF Slag**	20-30%	<20%

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* Percentages of fly ash or GGBF slag other than those specified above can be used depending upon the application.

** In case of ternary blends, the total mass of the supplementary cementing materials shall not exceed the above percentages.

*** Cold weather is defined as a period when, for more than 3 consecutive days, the following conditions exist:

1. the average daily temperature is less than 5^{o} C (40^{o} F)
2. the air temperature is not greater than 10^{o} C (50^{o} F) for more than one-half of any 24-hour period.

2. Mass Concrete Where Heat of Hydration

is the Governing Criterion		
Fly Ash	40-70%	40-70%
GGBF Slag	50-70%	50-70%
3. Mass/Structural Concrete Where Both Strength and Heat of Hydration are the Governing Criterion		
Fly Ash*	40-60%	20-30%
GGBF Slag	**	**

* Both adequate early-age strength and high strength at later ages, and low heat of hydration can be achieved simultaneously by using low cement contents, low water-to-cementitious materials ratio, high fly ash contents, and superplasticizer. (See chapter 10 of ref. 4, and ref. 7 and 8).

** No documented data available on GGBF slag for use in this application.

Proposed National Master Specifications on use of Fly Ash or GGBF Slag

Draft specifications for the use of fly ash in concrete as a substitute for Portland cement were recently added to the National Master Specifications (NMS) under section #03300. This section specifies the materials, mixes, preparation and construction for cast-in-place concrete. Requirements for the use of environmentally responsible materials, such as fly ash as partial replacement of cement, in construction work involving concrete are outlined.

NMS states that by incorporating blast furnace slag and power station fly ash as secondary raw materials into the mix for cement, raw materials and energy may be conserved, resource recovery may be increased and quantities of waste requiring disposal will be reduced. In 1994, U.S. produced 89 million tons of coal combustion byproducts. The enormous amount of disposal may be lessened through resource recovery programs such as the use fly ash as partial replacement of cement in concrete.

Under Part 1 General, subsection 1.4 on Samples, 3 kg of each type of Portland cement and 10 kg of each type of supplementary cementing material proposed for use, are to be submitted to engineer/consultant at least four weeks prior to commencing work. Subsection 1.5 on Certificates specifies that, at least four weeks prior to starting concrete work, manufacturer's test data and certification by qualified independent inspection and testing laboratory be submitted to engineer/consultant to certify that the proposed supplementary cementing materials meet specified requirements, such as CSA Standard A23.5 on Supplementary Cementing Materials. Certification that mix proportions selected will (a) produce concrete quality, yield and strength as specified in concrete mixes and (b) comply with CSA Standard A23.1 on Concrete Materials and Methods of Concrete Construction is required.

General statements under Part 2 Products include extending the life-cycle of used materials, contribution to the principle of sustainable development, reducing the contribution to acid rain and global warning typical of coal and oil usage. Subsection 2.1 Materials specifies that fly ash may be used in a number of specifications: (a) as a pozzolan in highway pavement concrete, structural concrete, roller compacted concrete and concrete products; (b) as a mineral filler in asphaltic roads, in embankments and backfills; (c) in soil stabilization and road base; (d) in stabilized backfills (flowable fills). Bottom ash may be used directly as a light-weight aggregate for cement blocks.

Conclusion

As the production every tonne of portland cement contributes about one tonne of carbon dioxide into the atmosphere, cement and concrete industry can play an important role in assisting Canada to fulfil its commitment as agreed at the Kyoto conference. In support of Canadian Government's commitment to reduce greenhouse gas emissions, Public Works and Government Services Canada is developing guidelines and specifications for the use of fly ash or ground, granulated blast-furnace slag in concrete. Objective of the proposed guidelines and specifications is to encourage and promote the wide use of these reclaimed and recyclable industrial byproducts in the production of environmentally friend concrete. The use of these materials in partial replacement of cement in concrete have numerous benefits: reduced greenhouse gas emissions, environmentally-friendly concrete with excellent long-term strength and durability characteristics, reduced energy consumption and lessened pressure on natural resources.

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