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Ground Granulated Blast Furnace Slag Concrete

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Abstract - Ground granulated blast furnace slag (GGBFS), a byproduct from steel production, is being used with increasing frequency as a partial replacement of cement in portland cement concrete. Because it constitutes a beneficial reuse of a by-product material from steel making, federal directives state it must be considered in projects which receive federal funding. While ordinary portland cement concrete (OPC) is a relatively robust material that can be successfully produced under a variety of conditions, the track record with GGBFS concrete is reportedly mixed. In Wisconsin, GGBFS concrete has been used both successfully and unsuccessfully. The reasons for the inconsistency are unknown and it is not even clear if the poor performance can be attributed to the GGBFS. The objectives of this research were to quantify the strength development and durability performances of GGBFS concrete over a range of cement brands, aggregates and curing conditions used in Wisconsin.

Keyword : Ordinary Portland cement Concrete, GGBFS.

I. INTRODUCTION

The seemingly minor variations that result from different mix constituents in OPC appear to be accentuated in GGBFS concrete. A 50% GGBFS cement replacement level usually results in unsatisfactory performance from primarily a scaling perspective. A 30% GGBFS cement replacement level will often be acceptable but the outcome depends on the specific constituents and curing methods used.

When finely ground and combined with a suitable activator, slag sets in a manner similar to Portland cement. The hydraulic properties of granulated blast-furnace slags have been studied for nearly 200 years, and use of slag in mortars and concretes dates back more than a hundred year.

II. PROPERTIES & EFFECTS OF GGBS

Chemical Composition

Ecocem GGBS comprises mainly of CaO, SiO_2, Al_2O_3, MgO, it contains less than 1% crystalline silica, and contains less than 1 ppm water soluble chromium IV. It has the same main chemical constituents as ordinary Portland cement, but in different proportions:

Chemical Constitutent	Portland	GGBS
CaO	65%	40%
SiO_2	20%	35%
AI_2O_3	5%	10%
MgO	2%	8%

Because of these chemical similarities, Ecocem GGBS can be replaced for Portland cement in concrete mixes by as much as up to 95% (EN 197–1 allows for up to 95% replacement).

Physical Properties

Colour	Off-white powder
Bulk density (loose)	1.0–1.1 tonnes/m^3
Bulk density (vibrated)	1.2–1.3 tonnes/m^3
Relative density	2.85–2.95
Surface area	400–600 m^2/kg Blaine

The ground cement powder is near-white in colour and is a hydraulic cement, i.e. it has the property of setting and hardening through chemical reaction with water.

Effect of slag on concrete properties

The primary effect of ground slag admixtures on the properties of the freshly mixed concrete are to provide better workability and finish ability. As a result, lower water-cement ratios may be used in many cases. Concrete mix proportioning for optimum performance with the slag can be accomplished in accordance with ACI Committee 211 recommendations.

• Higher ultimate strengths with a tendency toward lower early strengths

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• Higher ratio of flexural to compressive strengths
• Improved refractory properties
• Lower coefficients of variation in strengths
• Improved resistance to sulfates and seawater

Advantage of using GGBS

From structural point of view, GGBS replacement enhances lower heat of hydration, higher durability and higher resistance to sulphate and chloride attack when compared with normal ordinary concrete.

The major use of GGBS is in ready-mixed concrete, and it is utilized in a third of all UK 'ready-mix' deliveries. Specifiers are well aware of the technical benefits, which GGBS imparts to concrete, including:

- better workability, making placing and compaction easier

- lower early-age temperature rise, reducing the risk of thermal cracking in large pours

- elimination of the risk of damaging internal reactions such as ASR

- high resistance to chloride ingress, reducing the risk of reinforcement corrosion

III. LABORATORY TESTS

Tests on OPC of 53 grade

1) **Fineness test**
Rate of residue left on sieve for given sample 1 gm
% of residue = 1%
The IS state that fineness of cement should not be more than 10%. Fineness of given sample within this limit. Hence, this cement sample is recommended.
2) **Standard consistency** of OPC using Vicat apparatus
Standard consistency of given sample is 36%
3) **Setting time**
Initial setting time of given cement sample = 141 min.
Final setting time of given cement sample = 248 min.
According to IS specification the initial setting time of OPC should be greater than 30 min. & final setting time should be less than 600 min. As the time shows hence, cement is recommended for use.
4) **Compressive strength**
Compressive strength of cement for period of
3days – 29.17 MPa
7days – 36.11 MPa

Tests on aggregate

1) Specific gravity of aggregate
The mean value of specific gravity of the aggregate = 2.72
As per IS good type of aggregate is in between the 2.7-3

2) Moisture content of aggregate
Moisture content of coarse aggregate = 0.5%
Moisture content of fine aggregate = 1%

3) Properties of fine aggregate
Wt. of sample 1000 gm.

Sr. No.	Sieve sizes (mm)	Wt. retained (gm)	% Wt. retained	Cumulative % retained	% passing
1	4.75	40.00	4.00	4.00	96.00
2	2.36	160.00	16.00	20.00	80.00
3	1.18	180.00	18.00	38.00	62.00
4	0.600	240.00	24.00	62.00	38.00
5	0.300	230.00	23.00	85.00	15.00
6	0.150	150.00	15.00	100.00	0.00

Fineness modulus of fine aggregate = 3.

Test on concrete
Compaction factor test:
Wt. of partially compacted concrete = 17 kg
Wt. of fully compacted concrete = 18.164 kg
Compaction factor = 0.96

1. CONCRETE MIX DESIGN (as per IS 10262-1982)

A) Data for Mix design M30
Maximum size of aggregate (MSA) = 10 mm
Nature of Coarse aggregate = Angular
Fine aggregate conforms to = Zone 1
Specific Gravity of:
Cement = 3.15
Fine aggregate = 2.62
Coarse aggregate = 2.82
Compacting factor = 0.93

B) Target mean strength of concrete
Target mean strength of concrete for M30 grade concrete assuming accepted proportion of low results as 1 in 20
Fck= fck+t*5
= 30+1.65*5
=38.25 N/mm2

C) Selection of water cement ratio
From Fig.1 of IS 10262-1982 for 28 days target mean strength of grade 53 cement for 38.25N/mm2
After interpolation W/C ratio = 0.45

D) Selection of Water Content and Fine to Total aggregate ratio

From table 4 of IS 10262-1982 for max. size of aggregate as 20mm for one cum of M30 absolute vol. of concrete

Water content (assuming ssd agg.) = 208 kg (These values are as per standard conditions)

Sand to Total aggregate ratio = 40 % (These values are as per standard conditions)

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E) After correction is applied

Water content (assuming ssd agg.)(W) =216.32 kg/cu.m

Sand to Total agg. Ratio = 38.5 %

F) Calculation of Cement content

Cement Content (C) =216.32 /0.45

= 480.71 kg/cu.m

G) Calculation of Aggregate content

As per the formula given vide 3.5.1 of IS 10262-1982 with usual notations

V = [W + C/Sc + 1/p. fa/Sfa] x 1/1000

(for calculating fine aggregate content)

Absolute Volume of fresh concrete = 0.97 cu.m

Sand content (fa) = 606.3 kg/cu.m

V = [W + C/Sc + 1/(1-p). Ca/Sca] x 1/1000

(for calculating Coarse aggregate content)

Coarse aggregate content (Ca) = 1042.44 kg/cu.m

2. Compressive Strength Of Concrete Cubes

Typical strengths of concrete grade 30 N/mm^2 made with various percentages of GGBS are shown in the table below:

3 Days Plane cubes test results

Date	Cube	GGBS %	COMPRESSIVE STRENGTH(MPa)
	1	0	15.5
27/04/2012	2	0	16.00
	3	0	15.45
Avg comp strength			15.65

7 Days Plane cubes test results

Date	Cube	GGBS%	COMPRESSIVE STRENGTH(MPa)
	1	0	27.89
27/04/2012	2	0	27.45
	3	0	27.30
Avg comp strength			27.55

3 Days strength of cubes with different GGBS proportions

Date	Cube	GGBS %	COMPRESSIVE STRENGTH(MPa)
	1	20	18.67
27/04/2012	2	20	18.98
	3	20	18.55
Avg.comp strength			18.73
	1	40	19.60
27/04/2012	2	40	18.45
	3	40	19.22
Avg.comp strength			19.09
	1	50	16.60
27/04/2012	2	50	16.90
	3	50	16.55
Avg.comp strength			16.68

7 Days strength of cubes with different GGBS proportions

Date	Cube	GGBS %	COMPRESSIVE STRENGTH(MPa)
	1	20	28.16
27/04/2012	2	20	28.99
	3	20	29.10
Avg.comp strength			28.75
	1	40	29.06
27/04/2012	2	40	29.57
	3	40	29.23
Avg.comp strength			29.28
	1	50	26.59
27/04/2012	2	50	26.30
	3	50	26.99
Avg.comp strength			26.62

3. GGBS CONCRETE PROPERTIES

GGBS proportions

On its own, ground granulated blast furnace slag (GGBS) hardens very slowly and, for use in concrete, it needs to be activated by combining it with Portland cement. A typical combination is 50 per cent GGBS with 50 per cent Portland cement, but percentages of GGBS anywhere between 20 and 80 per cent are commonly used. The greater the percentage of GGBS, the greater will be the effect on concrete properties.

Setting times

The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be extended slightly, perhaps by about 30 minutes. The effect will be more pronounced at high levels of GGBS and/or low temperatures. An extended setting time is advantageous in that the concrete will remain workable longer and there will be less risk of cold joints. This is particularly useful in warm weather.

Water demand

The differences in rheological behaviour between GGBS and Portland cement may enable a small reduction in water content to achieve equivalent consistence class.

Consistence (Slump)

While concretes containing GGBS have a similar, or slightly improved consistence to equivalent Portland cement concretes, fresh concrete containing GGBS tends to require less energy for movement. This makes it easier to place and compact, especially when pumping or using mechanical vibration. In addition, it will retain its workability for longer.

Early age temperature rise

The reactions involved in the setting and hardening of concrete generate significant heat and can produce large temperature rises, particularly in thick-section pours. This can result in thermal cracking. Replacing Portland cement with GGBS reduces the temperature rise and helps to avoid early-age thermal cracking. The greater the percentage of GGBS, the lower will be the rate at which heat is developed and the smaller the maximum temperature rise.

4. WORKING WITH GGBS CONCRETE

Working with GGBS Concrete

Fresh concrete containing GGBS has better mobility characteristics than concrete made with Portland cement. These improvements arise from the consistent fineness and particle shape of the GGBS powder, and from its slightly lower relative density. As GGBS is slightly less dense than Portland cement, there is a small increase in the composite volume of cement paste, as replacement of GGBS for cement is done on a one-to-one basis by weight. The smoother surface texture and glassy surface of GGBS particles also helps to improve workability.

Placing, Compacting and Pumping

GGBS concrete makes it easier to place the concrete into formwork and easier to compact by mechanical vibration. GGBS concrete is less liable to segregation during transport and handling, and also remains workable for longer periods.

Water Demand

The surfaces of GGBS particles are smoother and more glassy than those of Portland cement. As a result, less of the mixing water is adsorbed onto the surface of the GGBS particles. Thus concretes containing GGBS will generally require less water compared to those containing Portland cement only. The typical water demand for GGBS concrete is of the order of 3–5% lower than that for Portland cement concrete.

Curing

Good curing practice is essential for all concrete. Properly cured GGBS concrete is more durable and ultimately stronger than concrete made with Portland cement only. Water in GGBS concrete takes slightly longer to combine chemically to form hydration products, thus making GGBS concrete a little more sensitive to poor curing. To get the full benefit of GGBS in concrete, it is essential to protect against early loss of moisture during curing.

Concrete produced with GGBS cement can be power floated in the same way as Portland cement concrete. As GGBS concrete stays plastic for a longer time than Portland cement concrete, this enables the contractor to achieve a very flat finish. Experience in Ireland has shown that if using greater than 50% GGBS, particularly in cold weather, it may be necessary to change the finishing regime, leaving a 10 to 12 hour period between placing and power floating, e.g. place the concrete late in the afternoon and power float first thing the following morning.

Fig 1 Power floating

Bleeding

Bleeding occurs when water rises to the surface of freshly placed concrete. Properly controlled bleeding is beneficial to the curing regime of concrete. Concrete with up to 40% GGBS replacement does not exhibit different bleeding characteristics from that of concrete made with Portland cement.

Setting Times

The setting time of concrete with GGBS is generally greater than that of similar concrete with Portland cement only. Although under typical Irish conditions, the initial set is unlikely to be extended by more than one hour for concrete containing up to 50% GGBS. Setting times will increase with increasing GGBS content, although factors such as curing temperature and w/c ratio also need to be considered.

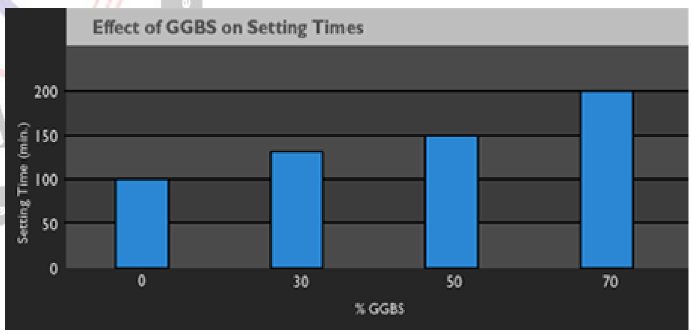

Figure 2 Effect of GGBS on Setting Times

4. APPLICATIONS OF GGBS

In recent years the use of GGBS concrete is well recognized. Combining GGBS & OPC at mixer is treated as equivalent to factory made PSC. Concrete with different properties can be made by varying the proportions of GGBS.

III. CONCLUSION

The delayed strength development associated with GGBFS was also exhibited in the results of this research. The time required to achieve a traffic-opening compressive strength of 3000 psi at least doubles when 30% or more GBFS replaces portland cement.

The results can be summarized as follows with regards to the time required to achieve the 3000 psi strength:

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• 0% GGBFS: range 3 to 5 days, average 4 days with limestone coarse aggregates,

average 3 days with igneous coarse aggregates
• 30% GGBFS: range 4 to 13 days, average 7 days with limestone coarse aggregates,

average 8 days with igneous coarse aggregates
• 50% GGBFS: range 6 to 16 days, average 10 days with limestone coarse aggregates,

average 11 days with igneous coarse aggregates
• At 40°F, 0% GGBFS range: 11 to 18 days, 30% GGBFS range: 20 to 40 days, and

50% GGBFS range: 31 to 49 days.

Deicer scaling results depended primarily on the level of GGBFS usage, the curing regime and the cement brand. These results were quantified based on scaling wash off in grams per square meter of exposed surface. The literature suggests that after 56 cycles, wash-off quantities of 50 g/m2 or less would be considered very good, 500 g/m2 or less good and 1000 g/m2 or more would be considered unacceptable. The results can be summarized as follows for wash-off levels we recorded at 50 cycles:

• 0% GGBFS: range 14 g/m2 to 1101 g/m2, moist curing best
• 30% GGBFS: range 156 g/m2 to 1298 g/m2, best curing depends on cement brand

• 50% GGBFS: range 355 g/m2 to 2022 g/m2, air dry curing best The deicer scaling wash-off results suggested that 50% GGBFS usage would result in unacceptable scaling in most circumstances. The scaling performance of GGBFS concretes appears to be related to carbonation of the surface layer prompted by the chemistry of the hydration process with exposure to C02. Significant improvements in scaling performance will only be achieved when this chemistry can be understood and controlled.

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