Cementitious Materials Update

The effect of ggbs, fly ash, silica fume and limestone on the properties of concrete.

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Concrete Society Technical Report: 
Cementitious Materials - The effect of ggbs, fly ash, silica fume and limestone on the properties of concrete.

Updates much of the content of 
TR 40, The use of GGBS and PFA in concrete 
TR 41, Microsilica in concrete

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1. Introduction to the materials
2. Effect on fresh concrete properties
3. Effect on concrete strength
4. Effect on concrete durability
5. Effect on concrete’s physical properties
6. Effect on environmental impacts
7. Special applications
PRODUCTION

The raw materials for ground granulated blastfurnace slag (ggbs), fly ash and silica fume are by-products from the production of electricity, steel and silicon.

Limestone fines are normally produced by crushing quarried limestone.
Fiskaa Silicon Plant, Norway
Hope Cement Works, which produces ‘Portland-limestone’ and ‘Portland-fly ash’ cements
CEMENTITIOUS PROPERTIES

GGBS is a latent hydraulic binder, i.e. when mixed with water, it slowly sets and hardens.

Fly ash and silica fume are pozzolanas, i.e. they do not react with water alone but do react chemically with the calcium hydroxide produced by the hydration of CEM I

Limestone is chemically, relatively inert but limestone fines, because of their fine particle size, can contribute towards strength by a physical, void-filling mechanism.
• Chemical and Physical Properties
• Cementitious properties
• Use in concrete – standards, grinding & blending
• Current availability and use

Blending plant for producing composite cements
Concrete batching plant: Note the two silos, one for CEM I and one for an addition, in order to produce within-mixer combinations.
EFFECT ON FRESH CONCRETE PROPERTIES

COMPATIBILITY WITH ADMIXTURES

Generally chemical admixtures can be used with ggbs, fly ash, silica fume and limestone fines, in the same way as for conventional CEM I concretes. Silica fume is normally used with a super-plasticiser.

WATER DEMAND

GGBS, fly ash or limestone fines may either decrease or slightly increase, the quantity of water needed to achieve a given slump
WORKABILITY/CONSISTENCE

GGBS, fly ash and limestone tend to improve the workability of concrete.

Silica fume increases the cohesiveness but may make the concrete ‘sticky’

The Angel Building
London: A self-compacting 36% fly ash concrete was used to eliminate the need for conventional methods of compaction, such as vibrating pokers
SETTIGN TIME

• The setting times for ggbs and fly ash concretes are greater than for the equivalent strength class CEM I concretes.

• The effect is magnified at higher percentages of ggbs or fly ash. The slower reaction rate also reduces the rate of workability loss i.e. it extends working time.

• Silica fume does not significantly affect setting time.

• Limestone fines may reduce it.
BLEEDING

After concrete has been placed there is a tendency for the solids (aggregates and cementitious) to settle and displace the water, which is pushed upwards.

The tendency of a concrete to bleed is affected by the constituents and their proportions, particularly the grading of the fine aggregate, the water content and any admixtures.

Excessive bleeding can produce a layer of weak laitance on the top of the concrete and may result in plastic settlement cracks.

Generally, fly ash, silica fume and limestone fines will reduce bleeding, whilst ggbs will increase it.
HEAT OF HYDRATION

Because of their slower hydration rates, ggbs and fly ash generate heat of hydration less quickly, early age temperature rise will normally be lower.

Can reduce the risk of early-age thermal cracking (CIRIA Report C660, *Early-age thermal crack control in concrete*)

Silica fume and limestone fines have little effect.
Massive base for a Wind Turbine 70% ggbs used to reduce temperature rise
Kingairloch Hydro Scheme: Portland-fly ash cement was used in the concrete for the dam wall and spillway
SENSITIVITY TO CURING

• GGBS, fly ash and limestone fines concretes can be more sensitive to poor curing because of their slower hydration rates.

• The layer close to the surface seems to be the most sensitive.

• At greater depth, the effect of curing appears to be less critical.

• TR66 ‘External in-situ concrete paving’ recommends that for external paving the ggbs content should normally be limited to a maximum of 55%, to avoid the need for more rigorous curing procedures.

• With silica fume, the concrete may contain very little free water and with significantly reduced bleed there needs to be extra emphasis on curing so that the surface layer retains the water needed for development of the properties of the concrete.
EFFECT ON CONCRETE STRENGTH

Indicative Strength Development (at fixed w/c and relative to the 28-day strength of CEM I)
Indicative Longer-term Strength Gain (relative to 28-day strength)
Secant Piling:
85% ggbs used to reduce early-age strength gain of female piles, to facilitate drilling of the intersecting male piles.
The 80 MPa concrete for the superstructure of the Burj Khalifa building in Dubai contains 10% silica fume.
The initial strength gain of concrete with ggbs or fly ash is likely to be slower than CEM I concrete.

Formwork striking times may need to be extended, especially at lower temperatures.

- The temperature of surface concrete should not fall below freezing until it has developed a strength of 5 MPa.
- The concrete needs to have developed sufficient strength to resist mechanical damage during formwork removal.
- For soffit formwork, sufficient strength is required for the concrete to be self-supporting. Construct ‘Guide to flat slab falsework and formwork'.
Indicative early-strengths shown as % of 28-day strength

- CEM I
- 8% SF
- 15% LF
- 30% FA
- 50% GGBS
- 70% GGBS

Strength as % of that achieved at 28-days

- 0% to 100%

- 1 day
- 3 days
- 7 days
- 28 days
Under normal circumstances, the striking times for concretes containing up to 50% ggbs do not increase sufficiently to significantly affect the construction programme.

Under normal circumstances, the striking times for concrete containing up to 30% fly ash do not increase sufficiently to affect the construction programme significantly.
Tyne tunnel: 70% ggbs concrete used for chemical resistance, with temperature-matched curing used to determine the striking times for the roof slabs
EFFECT ON CONCRETE DURABILITY

PERMEABILITY

In well cured laboratory specimens the water permeability of concretes containing ggbs or fly ash will ultimately be lower than CEM I concrete of the same strength class.

Silica fume can produce very large reductions in water permeability.

Limestone fines have little effect on permeability.
PROTECTION TO EMBEDDED STEEL (CARBONATION)

Despite any reduction in alkalinity, resulting from the incorporation of ggbs, fly ash, silica fume or limestone fines, the pH of the cement paste remains at an adequately high level to protect steel.

Rates of carbonation of CEM I, ggbs, fly ash and limestone fines concretes, generally correlate well with their 28-day cube strength, with the cementitious type having little effect on the carbonation rate.

Silica fume concrete tends to show greater carbonation than CEM I mixes of equivalent 28 day strength.
PROTECTION TO EMBEDDED STEEL
(CHLORIDES)

Concrete made with ggbs, fly ash or silica fume is generally substantially more resistant to chloride diffusion than CEM I concrete and for reinforced concrete structures exposed to chlorides, their use will give enhanced durability.

Limestone fines will not produce any significant improvement in resistance to chloride diffusion.
Oresund Bridge 15% fly ash and 5% SF for durability in a marine environment
SULFATE RESISTANCE
Detailed Recommendations for avoiding sulfate attack using ggbs and fly ash can be found in BS 8500:2006

This does not provide any guidance for utilising the increase in sulfate resistance from incorporating silica fume.
RESISTANCE TO ACIDS

Quality of the concrete has been considered to be of greater importance than the type of cementitious material.
FREEZE-THAW RESISTANCE

For concrete pavements subject to heavy vehicles and de-icing salts, BS 8500, TR 66 *External In-situ Concrete Paving* and Britpave *Concrete Hardstandings – Design Handbook* recommend the use of proportions of ggbs up to 55% and fly ash up to 35%.

However, the Highways Agency *Specification for Highway Works* restricts their proportions to a maximum of 35% and 25%, respectively for the surface layer of pavement concrete.
ALKALI-SILICA REACTION

GGBS, fly ash or silica fume can reduce the risk of damage due to ASR but limestone fines will not have any great effectiveness.

RESISTANCE TO FIRE

There is no evidence to suggest that the type of cementitious material will have a large effect on the resistance to fire.
ABRASION RESISTANCE

When a good standard of curing is applied, (wet curing for seven days or a 90% efficiency resin compound), it has been reported that there is no significant difference in the abrasion resistance of concretes containing CEM I, ggbs up to 50%, of fly ash up to 35%, with the same total cement content.

Silica fume can increase abrasion resistance through increased strength.
EFFECT ON CONCRETE’S PHYSICAL PROPERTIES

COLOUR
ELASTIC MODULUS

GGBS, fly ash or silica fume usually increase the ultimate modulus, but the magnitude of the increase is generally not significant in terms of design.
CREEP
For most practical situations where drying shrinkage is moderate, the behaviour of ggbs, fly ash, silica fume and limestone concretes is likely to be similar to that of CEM I concretes
TENSILE STRAIN CAPACITY

Concrete containing ggbs or fly ash might exhibit marginally more brittle failure characteristics.

DRYING SHRINKAGE

Because of the differing conditions under which tests have been carried out, it is difficult to make direct comparisons.
AUTOGENOUS SHRINKAGE

It is generally only considered to occur in concretes with w/c less than 0.45, much of the published data on autogenous shrinkage is for concrete with silica fume.

On the basis of limited evidence, it has been suggested that autogenous shrinkage is reduced in direct proportion to the percentage of fly ash in the mix, is increased by 8% for every 10% of ggbs present, and is increased by 10% for every 1% of silica fume included.
COEFFICIENT OF THERMAL EXPANSION

Largely influenced by the coarse aggregate use. The type of cementitious material will have little influence.

THERMAL CONDUCTIVITY AND DIFFUSIVITY

Influenced mainly by the aggregate type.

THERMAL MASS

The cementitious material will have only a marginal effect on the thermal mass of concrete and other factors such as aggregate-type, w/c and aggregate/cement ratio will have much more effect.
EFFECT ON ENVIRONMENTAL IMPACTS

For ggbs, fly ash and silica fume:

• their manufacture does not require the quarrying of virgin minerals
• their use in concrete avoids them being disposed of to landfill
• they use much less energy in their manufacture than CEM I.

The last point also applies for limestone fines
‘The Shard’. 75% ggbs was used in the base slab, not only to reduce the propensity for early-age cracking but also to reduce embodied CO2.
TERNARY BLENDS

Bridge in Hong Kong, 65% ggbs and 5% SF for durability in marine exposure
<table>
<thead>
<tr>
<th>Property</th>
<th>CEM I (CEM II/A-LL)</th>
<th>Limestone Cement (CEM II/B-V)</th>
<th>Fly ash Cement (CEM III/A)</th>
<th>Blastfurnace Cement (CEM III/B)</th>
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<tbody>
<tr>
<td>Early strength</td>
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<td>Workability retention</td>
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<td>Plastic shrinkage</td>
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<td>Strength</td>
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<td>Long term strength</td>
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