



Technical



Fact Sheet

## Change Log

<b>Revision</b>	<b>Change Summary</b>
v1.2	Published Factsheet
v1.3	Added Waste Water Section
v1.4	Added Wind Farms Section
v1.5	New Expansion Diagram
v1.6	Added Freeze-Thaw Section
v1.7	Added Durable Farm Concrete Section

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# Technical

*GGBS improves long-term strength, protects concrete from aggressive chemical attack, reduces heat of hydration, and makes concrete more workable.*

## Technical

Concrete is one of the most if not the most versatile building materials in the world allowing for any form and shape and allowing the construction of structures of great size and scale. Its popularity can be seen in the fact that it is the second most widely consumed resource in the world with water being the first.

With the entry of Ecocem into the Irish market, you can now have concrete that is superior in almost every way to the concrete you have traditionally used. Concrete made with Ecocem is:

- Stronger
- More durable
- More resistant to attack from chloride
- More impermeable
- More resistant to sulphate attack
- More resistant to alkali silica attack
- More resistant to fire
- Less prone to thermal cracking
- More resistant to acid

These advantages have been recognised for over 100 years and in many countries around the world. In the sub pages you will note that a lot of these benefits are as a result of the slight differences in the chemistry between OPC (Ordinary Portland Cement) and GGBS (Ground Granulated Blast Furnace Slag) cement. The chemistry is similar in nature with differences in the % of the main compounds. These differences give rise to a concrete with a tighter gel matrix and with less free compounds for aggressors to react with.

# Strength Development

*The higher ultimate strength of concretes made with GGBS is due to the fact that there is a greater proportion of CSH gel.*

## Strength Development

Concrete made with GGBS attains the same 28-day strength as concrete made with ordinary Portland cement (CEM I or CEM II/A), for replacement levels of GGBS up to 50%. Concrete made with GGBS continues to gain strength over a very long period, and the ultimate strength of concrete made with GGBS is consistently higher than concrete made with CEM I or CEM II/A only. It is not unusual for a GGBS concrete to increase its 28-day strength by a further 20% at 90 days. In laboratory investigations, GGBS concrete was shown to double its 28-day strength after 10 to 12 years, (Smolczyk, 1986).

Typical strengths of 35 N concrete (N/mm<sup>2</sup>) made with various percentages of GGBS are shown in the table below:

GGBS %	7 day	28 day	56 day
0	32	42	43
20	30	43	45
35	27	43	47
50	23	40	44

These data are based on 300 kg CEM I mixes, with no admixtures added. CEM II cements in Ireland have the same performance as CEM I cements.

The higher ultimate strength of concretes made with GGBS is due to the fact that there is a greater proportion of the CSH (calcium silicate hydrate) gel and much less lime (calcium hydroxide) in the concrete, when GGBS is used. The CSH gel is the binder that holds together the aggregates and gives concrete its strength, whereas the lime contributes little to concrete strength.

Although the 7-day strength of concrete (at 20°C) with up to 50% GGBS is slightly lower than concrete with Portland cement only, this is not sufficient to affect formwork striking times or delay construction.

Adding GGBS to concrete will result in a small increase in elastic modulus for a given compressive strength, although the differences are not large enough to be of significance in design. Creep of GGBS concrete has been observed to be slightly less than that of concrete made with Portland cement.

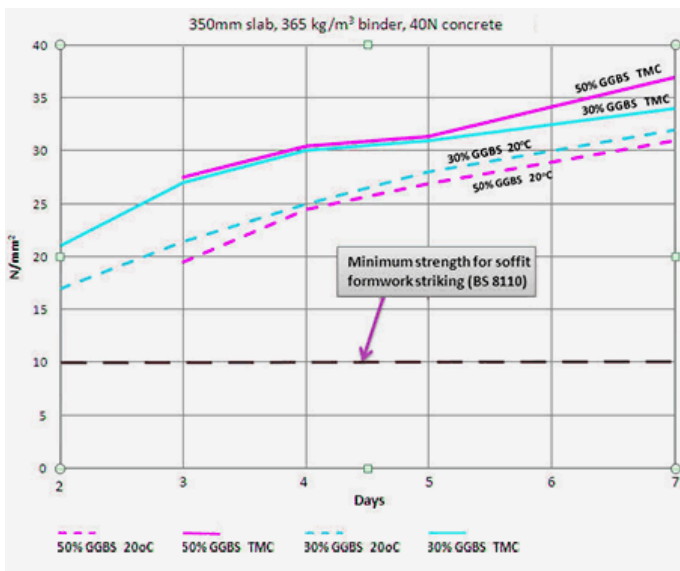
## Field Study 2008

In-situ concrete strength data was obtained on a project under construction in 2008 in Ireland. The following strength data was measured:

- Strength of standard site-cast cubes, which were cured in a lab at 20°C
- Strength of the concrete in the in-situ element, using Temperature Matched Curing<sup>1</sup>

1. Temperature Matched Curing is curing concrete cubes in a water tank whose temperature matches the in-situ temperature in the concrete, using an electrical signal from a thermocouple placed in the concrete.

The results show that both the in-situ strength and the standard cube strengths at 3 days are far greater than the minimum value of 10 N/mm<sup>2</sup> required for soffit formwork striking, as shown below.



TMC and 20°C Strengths of Concretes with 30% and 50% GGBS

## Formwork Striking Times

The time requirement for striking formwork, as per BS 8110 CEM 1 (Structural Use of Concrete), is 4 days for soffit formwork to slabs and 12 hours for vertical formwork (temperature to be 16°C). However, shorter periods can be used, in particular for slabs or beams, if the concrete strength is at least 10 N/mm<sup>2</sup> (insitu), (or twice the stress to which the slab is subjected—which will normally be less than the 10 N/mm<sup>2</sup> value). In concrete slabs, the value of 10 N/mm<sup>2</sup> is normally the greater of these, unless the slab is very thin (less than 250 mm) and also has a large span (greater than 7.5 metres). CIRIA report 136 (Formwork Striking Times) states that concrete is to have a strength of 2 N/mm<sup>2</sup> or greater to prevent mechanical damage to vertical concrete elements when striking.

If the guidelines of BS 8110 are followed, experience in Ireland with concretes containing up to 50% GGBS (replacement for ordinary Portland cement) has shown that these requirements are met. There is also some 50 years plus experience in the UK with concretes where 50% GGBS is regularly used, with no adverse affects to construction programmes. In 'Formwork Striking Times for GGBS Concrete', published by the Institution of Civil Engineers, the author states that:

*"Where only up to 50% GGBS is used, the reduction in early age strength development has not presented problems significant enough to prompt much field investigation."*

Concrete strength is normally measured on cubes cured at 20°C. However in-situ concrete strength will differ from the cube strengths, due to the fact that in-situ concrete cures at temperatures in excess of 20°C, and the section size is much larger than the standard cube dimension of 150 mm. In the winter one needs to take account of the fact that insitu concrete curing temperature may be below 20°C.

The in-situ strength of concrete in a slab depends on:

- Slab thickness
- Binder (cement/GGBS) content
- Formwork type
- Ambient temperature
- Time of formwork striking

Temperature Matched Curing (TMC) can be used to measure early age strength and assess striking times in critical elements. This method can give very accurate strength data, as it accurately monitors the internal temperature of the concrete and the corresponding in-situ strength.

It is normal practice in the UK, Belgium, France, Holland and other EU countries to use 50% GGBS in a standard concrete mix. The experience in these countries has shown that at this replacement level of GGBS there is no need to extend formwork striking times.

Thus the use of 50% GGBS in concrete mixes provides sufficient strength so as not to have any impact on the contractor's formwork striking programme.



*August 2008: 50% Ecocem GGBS is being used on the superstructure of this multi storey building in Dublin—the developer and contractor confirmed that the use of 50% Ecocem has had no impact on the programme. (70% Ecocem was used in the basement for technical reasons.)*

## Temperature Effects

The rate of early age strength gain of GGBS concrete is greatly improved by higher curing temperatures, and is significantly more sensitive to elevated temperatures than that of concrete made with Portland cement only. In practical applications of GGBS, the raised temperature from the heat of hydration in the concrete element causes an increase in the rate of early age strength gain. A temperature increase from 20 to 40°C, commonly reached or exceeded in the curing of in-situ and precast concrete, is sufficient to increase the early strength GGBS concrete by a factor of two to four, (LERM, 2001). However, the same increase in temperature only increases the early strength of Portland cement concrete by a factor of 1.5 (Klieger, 1958).

Barnett et al. have also observed that the effects of high temperatures on the early age in-situ strength development are much more beneficial for GGBS concretes than for concretes with no GGBS. They conclude that these concretes are suitable for fast-track construction.

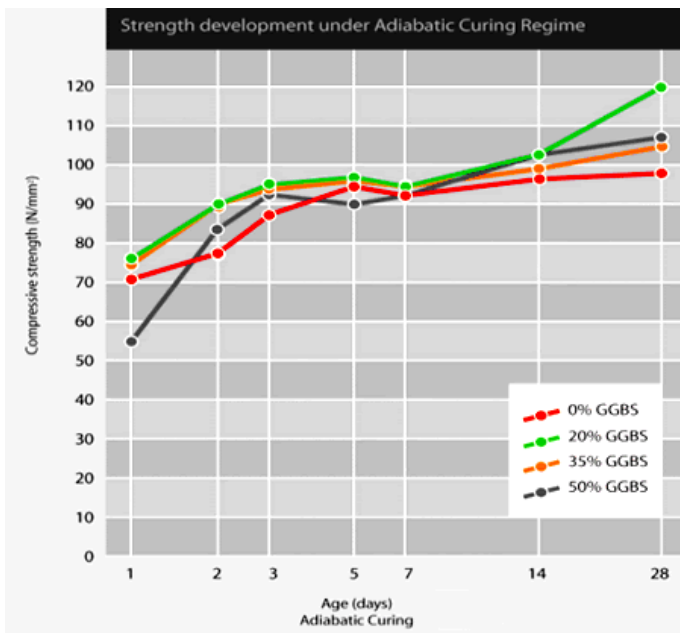
This sensitivity of GGBS concrete to the temperature effect on strength development is often utilised by precast concrete manufacturers, where heated beds are used to accelerate early strength gain. For precast concrete elements, GGBS replacement levels are generally in the order of 25 to 40% although a higher % can be used where required, particularly for technical reasons.

This shows that the early age strength gain of concrete made with GGBS is greater than that made with Portland cement only. This is a direct result of the activation of the GGBS caused by the elevated temperatures present in in-situ concrete, (Soutsos, 2005).

In larger elements where the % of Ecocem GGBS has been increased to offset the risk of thermal cracking on many project in Ireland (up to and beyond 70% in many cases), it has been found that due to the

elevated temperatures the formwork can still be struck the next day in order to allow for the placement of insulations to manage the edge temperatures.

The effects of elevated temperatures on early age strengths (under adiabatic curing conditions) is illustrated in the graph below. Effectively, this graph illustrates that as the insitu curing temperature increases, any delay in strength development that may arise as a result of increasing the % of GGBS may be negated by the increase in temperature



## 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. Horizontal surfaces in particular are susceptible to poor curing due to exposure to direct sunlight and strong drying winds.

For GGBS contents of up to 60%, curing periods as recommended in IS 326 (will be superseded by EC 2) and BS 8110 for Portland cement concretes are sufficient. For higher GGBS contents, these periods may need to be extended. For floor slabs, where high abrasion resistance is required, proper management of the curing regime is essential when GGBS is used in the concrete. A minimum of 7 days curing is required in these instances. Abrasion resistance is more sensitive to curing than to changes in cement or aggregate types. For further guidance on curing industrial floors, see Concrete Society Technical Report No. 34 'Concrete Industrial Ground Floors'.

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# Durability

GGBS protects concrete against sulphate attack, chloride attack, ASR, and reduces heat of hydration.

## Durability of Concrete Made with GGBS

Durability is a subject of increasing importance for concrete design, where longer design life cycles for concrete are demanded for more sustainable development. The external and internal mechanisms that accelerate concrete deterioration are now well understood. These are:

- chloride penetration.
- sulphate attack.
- alkali-silica reaction.

GGBS is effective in preventing all these forms of deterioration, and is now routinely specified for infrastructure projects, where a long service life of concrete is essential.

Latest Irish research from Trinity College Dublin on durability of GGBS concrete exposed to Silage Effluent demonstrates that concrete with 50% GGBS is

*“more durable than concretes made with OPC alone in aggressive environments under the action of acids and salts such as those produced by silage.”*

See below for full details of this study:

<http://www.ecocem.ie/downloads/durability.pdf>

## Structure of GGBS Concrete

The use of GGBS in concrete causes different reactions and results in different hydraulic products than concrete made with Portland cement only. In particular, the hydration products of the GGBS concrete serve to block the open pore structure that characterises Portland cement concrete.

The result is that GGBS concrete has fewer larger pores, and far lower permeability than Portland cement concrete. Sufficiently cured and hardened GGBS structural concrete is much more impermeable to water and reduces ion diffusion by a factor of 30 or so in comparison with Portland cement concrete. This low permeability is the key to GGBS concrete being able to resist attack from sulphates and weak acids.

GGBS cement paste is more effective at binding chlorides than an equivalent Portland cement paste, thus GGBS concrete offers much superior protection to reinforcement from corrosion due to chloride ion penetration.

In addition, concrete made with GGBS is more chemically stable than concrete made with Portland cement only. It contains much less free lime, which in concrete made with Portland cement leads to the formation of further reaction products such as ettringite or efflorescence. In addition, GGBS contains no  $C_3A$ , making GGBS concrete much less reactive to sulphates.

## Chloride Penetration

Chloride ions do not act directly on the concrete itself, but if they can penetrate the concrete they will cause severe damage from corrosion and expansion of any embedded metal reinforcing.

The strength, depth of cover and diffusivity of the concrete all play a role in the prevention of chloride-initiated corrosion of reinforcement. However, the cement type is the key parameter, as it is this that determines the diffusivity of chloride ions.

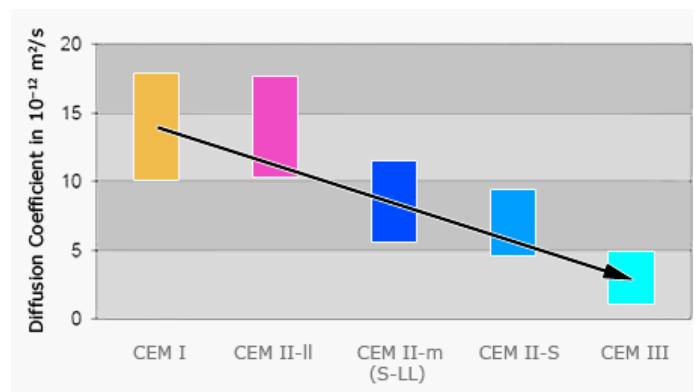
GGBS concrete has lower chloride diffusivity as the penetrating chlorides are bound into chloro-aluminates far more effectively than by Portland cement pastes. In addition the much lower permeability of GGBS concrete limits ingress of chlorides. At GGBS replacements of over 50%, diffusivity of chlorides in GGBS concrete becomes insignificant in practice. GGBS is so superior to Portland cement in preventing chloride penetration that certain specifiers require that GGBS be included in concrete mixes whenever any reinforcing is present.

GGBS concrete has been widely used in Europe in sea defence works, particularly in Holland. At replacement levels of 70–80%, GGBS concrete is particularly effective in preventing deterioration of concretes in tidal and splash zones. Similar replacement levels are also gaining widespread use in roads and bridge applications where exposure to de-icing salts is of concern to engineers.

GGBS is now specified as standard by the National Roads Authority to significantly increase the durability and hence life expectancy of the bridges. GGBS is being used in Greystones harbour and many other marine projects around Ireland. GGBS has been specified in all the basement structures in the Dublin Docklands to increase the resistance to attack by salts. It is also being increasingly specified in multi-storey, at grade car parks and water and wastewater treatment plants.



Chloride attack on concrete post



## Sulphate Attack

Attack by sulphates in ground water is a common form of concrete deterioration. Sulphates react with tri-calcium aluminate ( $C_3A$ ) and calcium hydroxide ( $Ca(OH)_2$ ) to form an expansive compound called secondary ettringite. The expansion of the ettringite causes concrete cracking, allowing ingress of more sulphates and producing an acceleration of the deterioration.

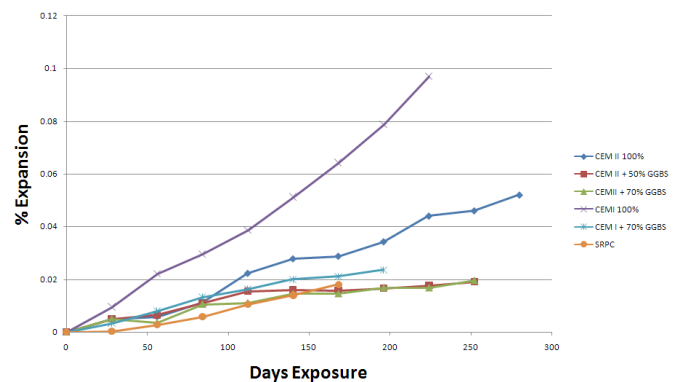
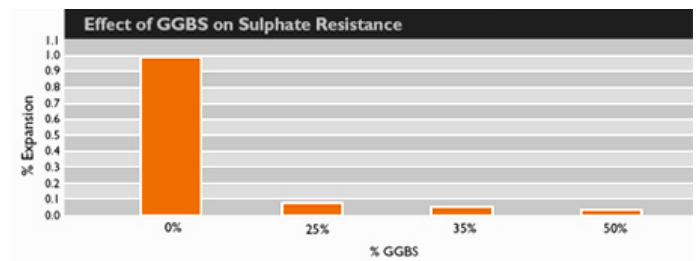
Sulphate resisting Portland cements (SRPC), with low  $C_3A$  content, are much less effective in combating sulphate attack than GGBS. GGBS counters sulphate attack in three ways:

- GGBS does not contain any  $C_3A$ , and its inclusion in concrete reduces the overall proportion of  $C_3A$  in the mix.
- GGBS reacts with  $Ca(OH)_2$  to substantially reduce its presence in the concrete, leaving significantly less  $Ca(OH)_2$  to react to form ettringite. No such effect takes place with SRPC.
- The greatly reduced permeability of GGBS concrete, over concrete made with SRPC, limits the penetration of sulphates into the set concrete.

BRE Special Digest 1 recommends a minimum 66% GGBS to give equivalent sulphate resistance to SRPC. The use of GGBS for resistance to sulphate attack is a far more economical solution than the use of premium-priced SRPC.



*Ettringite crystals in concrete*

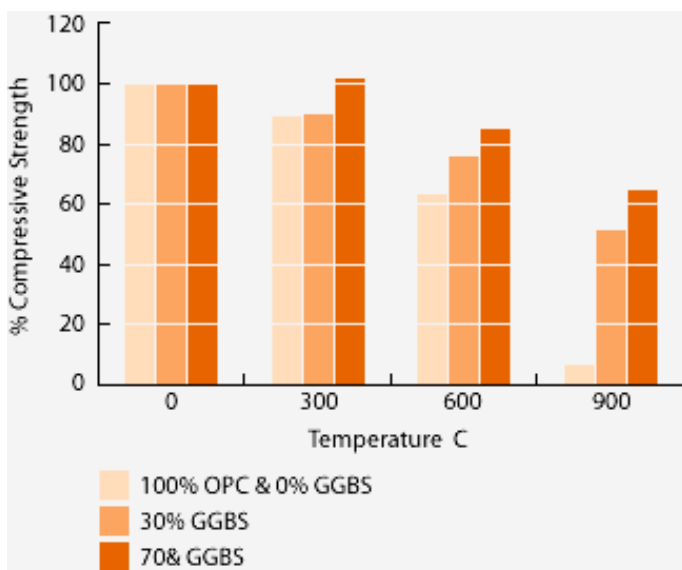


*Results from ongoing sulphate tests being carried out by University College Dublin. These results demonstrate the benefits of using high percentages of GGBS.*

*September 2009*

## Resistance to Fire

The changeover from Portland cement to GGBS leads to an increased stability in the event of fire or quite generally in the effect of the high temperatures. This has differing causes, such as for example the significantly lower content of Portlandite in the hardened cement paste of hydrated cements containing GGBS compared to hydrated Portland cements or the differing softening behaviour. The significantly lower reduction in strength of cements containing GGBS is of special significance.



*Improved Resistance to High Temperatures by Concrete made with GGBS Cement*

## Thaumasite Attack

Recent experience in the UK, the US and South Africa has shown that Sulphate Resisting Portland Cement is susceptible to a newly observed form of sulphate attack—the formation of Thaumasite. Several bridges on the M5 in England have been taken out of service in recent years due to the formation of Thaumasite in the concrete piers.

Thaumasite is a naturally occurring mineral, similar to ettringite, which forms in concrete in the presence of moisture, carbonate (in the groundwater or in limestone aggregates) and sulphate (in subsoil, groundwater, sea-water or de-icing salts). Thaumasite generally forms at temperatures below 15°C.

Thaumasite sulphate attack differs from conventional sulphate attack in that the calcium silicate in the concrete is attacked, and not the calcium aluminate phase. Thaumasite attack results in the formation of a soft white pulpy mass that leads to total disintegration of the concrete, exposing the reinforcement to further deterioration.



*Concrete suffering Thaumasite degradation*

BRE Special Digest 1 "Concrete in Aggressive Ground" 2003 recommends the use of at least 70% GGBS to provide complete protection against all forms of sulphate attack, including Thaumasite.

## Alkali Silica Reaction (ASR)

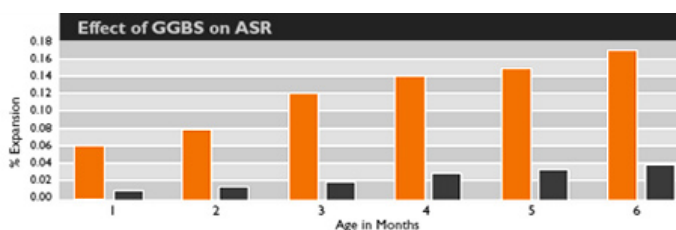
ASR is a chemical reaction between alkalis in Portland cement and certain types of silica in aggregates. It results in the formation of expansive gels, which lead to cracking of the concrete.

The cycle continues until the concrete is no longer serviceable. The presence of ASR will initially produce an expansion of the concrete that can be measured.

Practice in specifying the level of GGBS varies from country to country. In the UK there is general acceptance that a 50% GGBS replacement will be effective against ASR. A number of favourable factors contribute to this good performance by GGBS:

- GGBS reduces the alkalinity of the concrete, and thus the alkali-silica ratio.
- GGBS reduces mobility of alkalis in the concrete.
- GGBS reduces free lime in the concrete (regarded as an important factor for alkali silica reaction).

In the Irish context, the publication by the Institute of Engineers and the Irish Concrete Society "Alkali-Silica Reaction in Concrete" gives general recommendations for dealing with potential ASR occurrences. However, it is noted that no cases of deleterious ASR have been reported in Ireland.



Concrete suffering ASR degradation

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# Heat of Hydration

*The more gradual hydration of GGBS cement generates both lower peak and less total overall heat than Portland cement.*

## Heat of Hydration

GGBS is frequently and successfully used to limit the temperature rise in large concrete pours. Heat of hydration is the consequence of the cement hydration process, which is exothermic. It is important in the curing of concrete, as it produces a marked increase in temperature which accelerates the curing and strength gain of concrete.

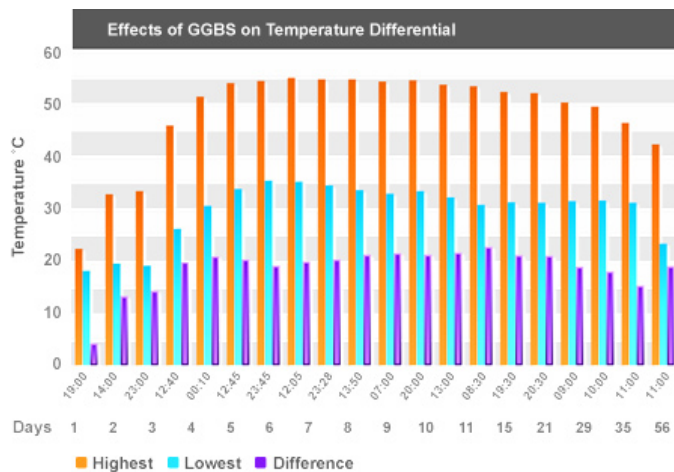
However, in large section concrete pours, the heat of hydration normally produces high temperature gradients in the concrete. High temperature gradients introduce excessive thermal stresses, resulting in micro-cracking which exposes the concrete to external attack and reduces its durability. Cracking is also detrimental to the performance of water-retaining structures and where radiation may be present as is the case in radiotherapy treatment centres in hospitals. Thus the control of thermal stressing of concrete in large mass pours is critical to the durability, quality and performance of the concrete.

The more gradual hydration of GGBS cement generates both lower peak and less total overall heat than Portland cement. The use of GGBS at replacement levels of between 65 to 85% represents the optimum replacement range for mass concrete applications, and will significantly reduce the thermal stressing of mass concrete—a reduction in temperature rise of up to 40% can be achieved for the higher GGBS levels. Replacement levels from 50 to 60% can be used in smaller mass concrete pours.

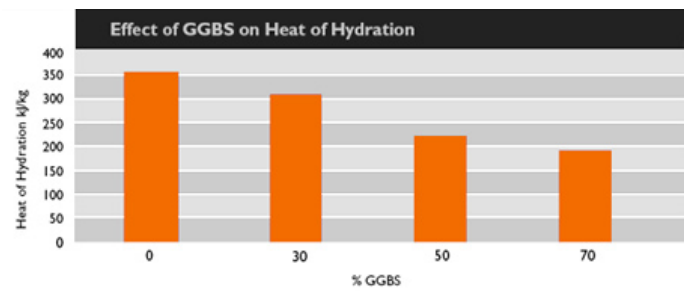
Typical instances where GGBS is used to control heat of hydration include bridge decks, heavy load-bearing foundations and slabs, large section marine structures, retaining walls and water-retaining structures. Adding GGBS to concrete for water-retaining structures will reduce the amount of crack control steel required, significantly reducing overall concrete costs. As well as reducing thermal stressing, the addition of GGBS also enhances the overall durability and longevity of the concrete in these structures.

GGBS has been used to reduce the heat of hydration in major structures in Ireland including the M1 Boyne Bridge, the Luas Taney Bridge in Dundrum, and the Jack Lynch Tunnel in Cork. GGBS was used at replacement levels of up to 65% in these projects. Where high GGBS replacement rates (in the order of 70–85%) are used to limit thermal stressing, the engineer must be aware of the changes in the properties of the fresh concrete, such as the delay in setting time, and also the need for proper curing. The delay in setting time is often not so pronounced, as the extra heat released in large concrete pours offsets the potential delays due to increased percentages of GGBS. Practice in Ireland has shown that in large pours in the right conditions that structures containing 70% GGBS can still be struck the next day.

Contemporary Irish examples where high percentages of GGBS have been used to good effect to reduce heat of hydration include 850 mm podium slabs at Charlestown Centre in Finglas, a 3.6 m basement slab at the National Conference Centre in the Docklands, 2.5 m base at the Point Development in Dublin, the Elysian Tower in Cork, mass concrete plinth for a cement kiln in Drogheda, Co. Louth, and walls, floor and ceiling for radiology units in Waterford, Galway and Dublin, wind farm bases throughout Ireland, water tower base in North Dublin, ESB development in East Cork, Lansdowne Road Stadium and the Limerick Tunnel.



*This graph indicates the result of using 70% Ecocem on a 20 × 20 × 2.4 metre deep base poured during the summer. The base was insulated within 24–36 hours (formwork was struck at 24 hours with the insulation applied on its removal). You can see from the graph that the peak differential in temperature across the structure was maintained at around 20 degrees. Once the temperature started dropping the insulation was removed in stages. If 100% ordinary cement (i.e. no Ecocem GGBS cement) had been used the core temperature would have been approximately 15 degrees higher resulting in a high probability of thermal cracking and long term durability and strength issues.*



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BS 8007:1987 Code of Practice for the design of concrete structures for retaining aqueous liquids.

# Working with GGBS Concrete

*GGBS concrete makes it easier to place the concrete into formwork.*



## 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.

For the same slump class, GGBS concrete exhibits better workability characteristics than Portland cement concrete. This can permit a small reduction in the w/c ratio, without any loss in workability resulting in an increase in strength and durability.

## 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. This is equivalent to a reduction of from 5 to 10 litres of water per metre cubed of concrete. For high GGBS replacement ratios in the order of 70% and 80%, the reduction in water demand may be smaller, due to the much higher concentration of the finer GGBS particles.

## 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. Pumping is also easier, due to the slightly lower relative density and better flow characteristics.



## 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. However, for higher percentages of GGBS, there is an increasing tendency for extra bleeding. This is due to the increase in setting times of these mixes. However this can be countered by using finer cement, lower w/c ratio, finer sand grading, air entrainment, heated concrete or insulation blankets.

## Powerfloating

Concrete produced with GGBS cement can be powerfloated 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 powerfloating, e.g. place the concrete late in the afternoon and powerfloat first thing the following morning.

As with all concrete it is important that the bleed water has evaporated off prior to power floating. Power floating while bleed water is present can lead to remixing at the surface which can lead to a latent layer and subsequent dust generation.



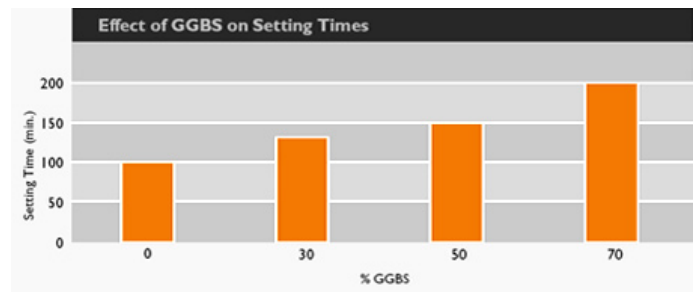
## Admixtures

The performance of chemical admixtures in GGBS concrete is essentially the same as that found with Portland cement mixes. In general, admixtures will work normally with GGBS concrete. However care should be taken if retarding agents are specified, as GGBS itself has a retarding effect on the set, and retarding agents are generally not used with GGBS concrete. If you require specific advice consult your admixture supplier, who will be best placed to advise on the latest products in the market, or contact Ecocem.

## 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.

The longer setting time has the advantage of allowing concrete to be worked for longer periods: thus time delays, including delays in transport, between mixing and using concrete are less critical. It also reduces the risk of cold joints in larger concrete pours.



## References

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Standards for Fresh Concrete – The Application of BS EN206–1 and BS8500. Prof. Tom Harrison, BSI publication, 2004.

# Wind Farms



## Concrete Wind Turbine Foundations

As technology advances and wind turbines become larger so too do their foundations. With foundation depths increasingly exceeding 1.5 metres, the risk of longer term durability problems as a result of thermal cracking is much more of an issue. In this section we examine how the use of GGBS cement is best practice for managing such risk both from a technical and cost perspective.

## Foundation Type

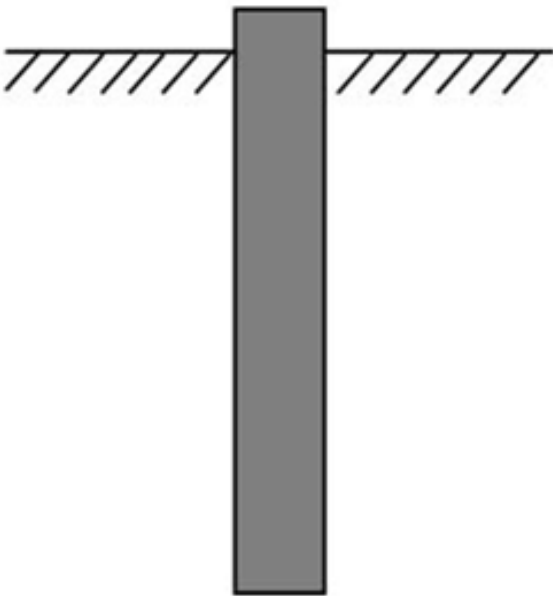
The selection of a foundation depends primarily on the turbine location and site conditions. Onshore turbines typically use a monopile or a reinforced concrete slabs or a composite of multi-pile and concrete slab. Offshore turbine foundation options include concrete caissons, steel gravity, tripod and monopile configurations. Floating foundations that are anchored to the sea bed are also a possibility in deep seas. Foundations for onshore wind turbines are considered in this instance.



## Onshore Foundation Configurations

### Monopile Foundations

Monopile foundations have relatively limited structural dimensions and have a restricted interface with their supporting soil. This limits the overall tower stiffness achievable, particularly in poorer soils. The limit of tower stiffness affects the tower height, the rotor blade diameter and ultimately the power capacity of the wind turbine. Monopile foundations are used predominantly for offshore applications, but they can be used effectively for smaller onshore wind turbines. They can be both precast or in-situ concrete.

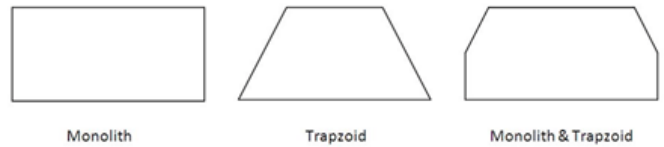


Monopile

### Large Diameter Raft Foundations

Larger diameter raft foundations are necessary to produce stiffer towers to facilitate larger capacity turbines. By increasing levels of soil interaction, concrete gravity foundations can reduce the natural oscillation period of tower systems. Concrete has high material damping properties and provides good scope for optimising dynamic performance. The gravity foundations tend to be reinforced concrete slabs or a composite of a slab and multi-pile. Here, like the monopile, the piles can be precast or in-situ concrete. The selection of foundation type depends on the ground conditions and the turbine capacity. Slab depths of greater than 1.5 m are typical, even if they are supported by piles.

There are many configurations of slab foundation. In cross section they can be a simple monolith, a trapezoid or a combination of both.



In plan they can be rectangular, circular or a diverse cross or star shape. What are common to all shapes of slab are a deep pour and a large volume of concrete that attributes the classification of the foundation slabs as mass concrete.

## Mass Concrete

The Concrete Society Digest No. 2 defines a mass pour as one of sufficient size to demand special attention to logistical and technical considerations such as:

### Concrete supply

plan to achieve continuity of concrete supply with consistent rates of delivery, placing, compacting and finishing

### Casting sequence

to be such that cold joints are avoided

### Cold joints

when a stiff face forms during the pour

### Plastic settlement

may result above top mat of steel in deep foundations

### Heat of hydration

the depth of pour, volume of concrete and mix design will have effects on the overall heat of hydration and early age thermal cracking

### Early age thermal cracking

excessive thermal gradients or restraint to bulk thermal contraction can cause cracking within days or weeks of cracking

The logistical matters of supply require planning and execution. The main technical considerations with regards to mass concrete are the workability of the concrete so that it can be placed and the temperature rise, leading to possible thermal cracking.

## Temperature Rise

Many factors are influential in the temperature rise of concrete, the heat of hydration being the most influential. The hydration of cement is exothermic in that it generates heat (~500 J/g of CEM I). As such, the amount of cement in a mix will have a pronounced effect on the temperature rise of the concrete. For

wind turbine foundations concrete may be required to have strengths greater than 40N, often with cement contents in the range of 380 kg/m<sup>3</sup> to 500 kg/m<sup>3</sup>. These high cement contents will lead to high temperatures rises.

Other factors that influence the temperature rise of concrete are:

- Concrete placing temperature
- Section thickness
- Formwork type and time of removal
- Ambient conditions and the use of temperature control measures such as cooling pipes or insulation.



*Multi-pile and reinforced concrete slab foundation near Kilmore Quay, Co. Wexford.*

## Thermal Cracking

In mass concrete the internal temperature rises and drops slowly, while the surface cools rapidly to ambient temperature. Surface contraction due to cooling is restrained by the hotter interior concrete that doesn't contract as rapidly as the surface. This restraint creates tensile stresses that can crack the surface of the concrete and lead to the loss of the integrity of the concrete. The width and depth of cracks depends upon the temperature differential, physical properties of the concrete, and the reinforcing steel.

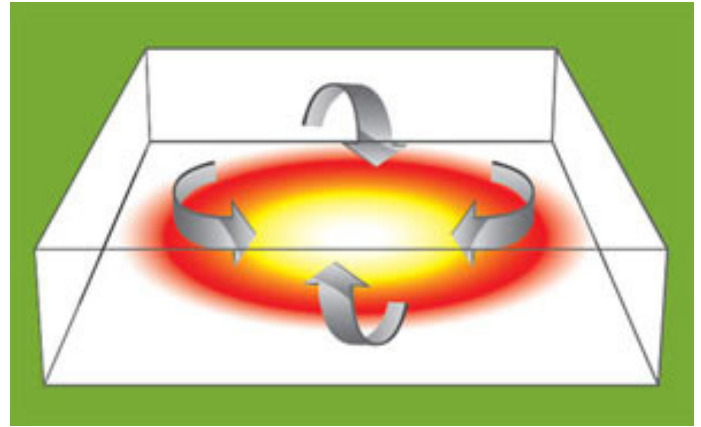
## Reducing Thermal Cracking

The key to reducing thermal cracking is to reduce the peak temperature and to control the temperature differential between the hot core and the cool extremities. Reducing the peak temperature effects the time it takes for an element to reach a stable temperature and effects the temperature differentials. Excessively high internal concrete temperatures (>70°C) may also lead to DEF (Delayed Ettringite Formation) and durability issues.

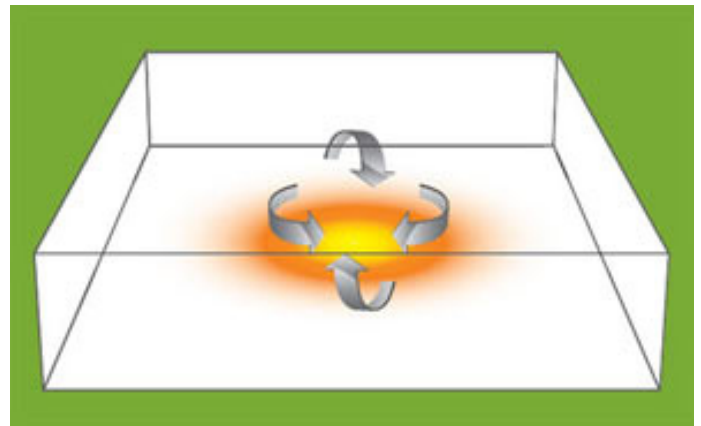
A temperature differential limit attempts to minimise excessive cracking due to differential volume change. A limit of 20°C is the industry norm. However, concrete may crack at lower differentials. Reinforcement adds tensile strain capacity to the concrete and helps to control crack width should the temperature differential be exceeded. There are both material selection and engineering methods of crack control.

### Material Selection

- Reduce the heat of hydration by using the lowest possible cement content for the purpose of obtaining a specified strength and ensuring required durability
- Specifying strength to be assessed at 56 days or later rather than 28 days will allow for a lower cement content to be used in the mix to obtain a specified strength. This may not guarantee durability and guidance should be sought from IS EN206 for cement contents and durability requirements
- The use of supplementary cementitious materials such as PFA or GGBS will greatly reduce the peak temperature and temperature differentials due to their reduced heat of hydration
- Aggregates with a high tensile strain capacity and a low thermal expansion coefficient are most suitable
- Water reducing and superplasticising admixtures will allow for the reduction of cement content for a specified strength. Durability requirements need to be considered
- Chilled water or flaked ice can reduce the placing temperature of the concrete



Heat produced using a concrete mix without Ecocem GGBS



Heat produced using a concrete mix without Ecocem GGBS

### Engineering Methods

- Good communication between the designer, contractor and concrete producer
- Place concrete at low ambient temperature (early morning for instance)
- Timber forms provide insulation, steel formwork do not, use what is appropriate
- Use thermocouples to monitor the in-situ temperature at the core and the extremities
- Insulate the element if differentials approach 20°C
- Remove insulation and formwork based on monitored in-situ temperatures and temperature differentials
- Place cooling pipes in the element

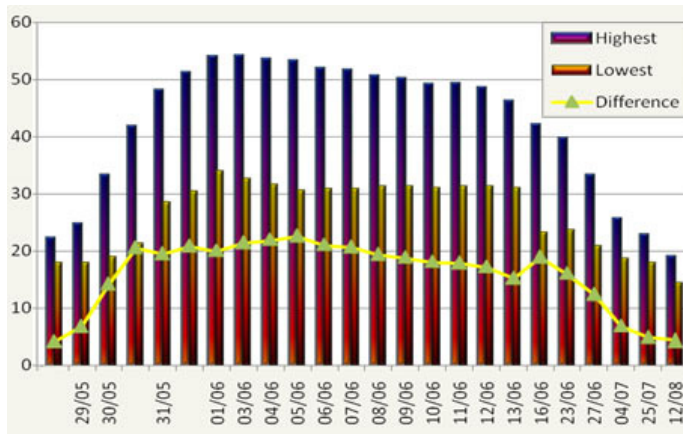
## GGBS and Concrete Wind Turbine Foundations

Using Ecocem GGBS at a replacement level of 70% is the best available practice when constructing concrete wind turbine foundations in terms of cost; strength; durability and sustainability. 70% GGBS replacement level offers the following advantages at no extra cost per m<sup>3</sup> of concrete

- Reduces the likelihood of thermal cracking by reducing the peak temperature and the temperature differentials
- Guarantees durability performance equal to that of SRPC in terms of sulphate attack and superior to any other cement combination in terms of chloride resistance\*
- Unrivalled post 28 day strength development
- Increased workability and setting times, reducing the likelihood of cold joints and making concrete easier to place
- Allows for longer transport and placing times
- Average of 92 tonnes of CO<sub>2</sub> saved per foundation\*\*

\* See durability section

\*\* See environmental calculator: <http://www.lowcarbonconcrete.ie/>



*This graph shows the core and edge temperature and the maximum temperature differential for a 2.4 m deep, 20 x 20 metre base. 70% GGBS was used in this base which maintained the peak temperature below 55°C (it would have been above 70°C if no GGBS had been used). The edge temperatures were elevated through the use of insulation ensuring the maximum temperature differential remained as close as possible to 20°C.*

## Conclusion

Achieving durable long life mass concrete foundations requires paying careful attention to reducing the risk of thermal cracking. The most cost effective ways that will achieve the best results are:

- Replacing 70% of the cement with GGBS – good longer term strength and improved durability as well as significantly reducing the overall heat generated – no cost implications
- Reducing overall cement content by introducing super-plasticisers and accepting strengths at 56 days which reduces cost and heat generated (may offset cost of super-plasticisers)
- Installing thermocouples to facilitate the accurate timing for placing and removal of insulation (this may only be required on one or two bases until the correct practice is established).



# Concrete in Waste Water Environments

Concrete in water and wastewater environments are susceptible to different forms of attack. The use of Ecocem GGBS significantly enhances the durability of the concrete in such an environment. This means that where GGBS is used it will significantly extend the serviceable life of the plant resulting in significant financial benefits to the client. The attack primarily comes in the form of sulphate and acid attack which when in contact with the concrete changes the chemical structure of the cement matrix leading to degradation.

Different forms of attack to concrete are:

- Biologically Produced Sulphuric acid
- Sulphates

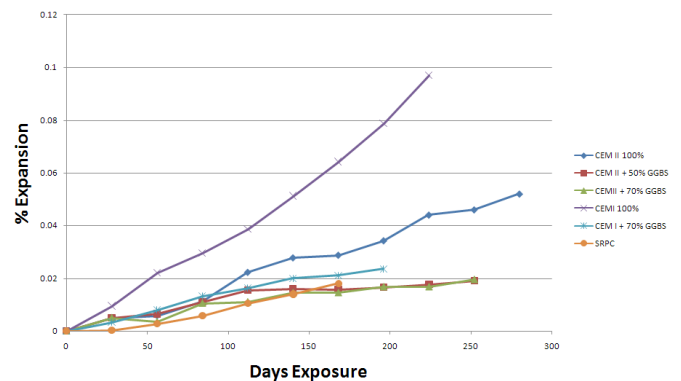
## Introduction to the Mechanism of Concrete Degradation in the Waste Water Environment

The formation of  $H_2S$  gas in wastewater systems leads to the formation of sulphuric acid ( $H_2SO_4$ ) above the waterline in concrete elements and leads to its degradation and possible corrosion of reinforcement. Sulphuric acid reacts with calcium hydroxide (CH) to form gypsum. Gypsum in turn reacts with tricalcium aluminate ( $C_3A$ ) to form ettringite. The formation of gypsum and ettringite is expansive and leads to the loss of cohesion of the cement matrix and possible expansion, cracking, pitting and spalling, leaving reinforcement exposed.

## The Benefits of GGBS in the Waste Water Environment

GGBS is highly resistant to sulphuric acid attack as it contains no  $C_3A$ , resulting in a concrete with a lower  $C_3A$  content and its hydration leads to reduced levels of CH. Replacement levels of 70% GGBS have been proven to be optimal in maximising sulphuric acid resistance.

GGBS has intrinsic sodium sulphate resistance and has been proven to be superior to SRPC (Sulphate Resisting Portland Cement) at a 70% replacement level when combined with Portland cement. A good carbonate aggregate such as limestone is advantageous in limiting the reaction with the cement matrix resulting in an overall improved resistance.



Results from ongoing sulphate tests being carried out by University College Dublin. These results demonstrate the benefits of using high percentages of GGBS.  
September 2009

# The Mechanisms of Attack on Concrete in Waste Water Environments

## 1.0 Biologically Produced Sulphuric acid

### 1.1 Hydrogen Sulphide (H<sub>2</sub>S) formation:

In near anaerobic conditions sulphate reducing bacteria such as *Desulfovibrio* act on the sulphates in raw sewage to form sulphides. The bacteria use the sulphates in the wastewater as their source of essential oxygen and as part of this process sulphur ions are produced. The sulphur ions in turn react with dissolved hydrogen in the wastewater to form hydrogen sulphide (H<sub>2</sub>S). H<sub>2</sub>S alone is not corrosive to concrete. The H<sub>2</sub>S forms as gas above the wastewater. It is this area of a concrete element of a wastewater system, above the water line, that is most susceptible to corrosion.

### 1.2 Absorption of H<sub>2</sub>S:

There exists a slightly moist layer of concrete above the wastewater level. This has a relatively high pH level due to the alkalinity of the concrete. At these high pH levels the H<sub>2</sub>S absorbs into the surface of the concrete and separates into HS<sup>-</sup> or S<sub>2</sub><sup>-</sup> which attracts more H<sub>2</sub>S into the moisture layer and in turn further H<sub>2</sub>S disassociation. As the concentration of H<sub>2</sub>S increases the pH of the concrete decreases which may make it susceptible to possible attack.

### 1.3 Formation of Sulphuric Acid (H<sub>2</sub>SO<sub>4</sub>):

In the presence of oxygen the H<sub>2</sub>S reacts to form elemental sulphur. The bacteria *Thiobacillus* can be found in wastewater. These bacteria oxidise the sulphur to form sulphuric acid. These bacteria only attach themselves to concrete when the pH of the concrete has reduced to around 9 and there is sufficient moisture, oxygen and nutrients available.

### 1.4 Sulphuric acid attack of concrete:

Sulphuric acid reacts with calcium hydroxide (CH) to form calcium sulphate (Gypsum). Gypsum in turn reacts with calcium aluminate hydrate (C<sub>3</sub>A) to form ettringite. This is an expansive process which will degrade the cement matrix.

## 2.0 Sulphates

Sulphuric acid reacts with the calcium hydroxide to produce gypsum. This is a white putty-like deposit, moist and flaky. It acts as a barrier to further penetration but the rougher surface area formed also provides for more places for attack to take hold. The formation of gypsum leads to an eventual loss in cohesion as the cementitious calcium compounds are broken down.

The formation of gypsum may also be due to attack by sodium sulphate (Na<sub>2</sub>SO<sub>4</sub>) or magnesium sulphate (MgSO<sub>4</sub>) or a combination of both. In sodium solutions the CH primarily undergoes decomposition with the calcium being taken up by the formation of gypsum. Only when there is no more CH available will the solution attack the CSH paste. Attack by magnesium solutions is more severe than that of sodium in that it attacks both the CH and CSH simultaneously, but with a preference to CH. The products from the magnesium sulphate reaction include magnesium sulphate hydrate, which lacks cohesive properties, brucite and gypsum.

It has been proven that hydrated cements with high CH contents are more resistant to magnesium sulphate attack.

### 3.0 GGBS Research Results

#### 3.1 Sulphate

Osbourne (1999) broadly concluded that Portland cements performed extremely well against sulphate attack with slag replacement levels of 70–80%.

Clark (2000) also noted the benefit of a 70% GGBS replacement level with limestone cement and good quality carbonate aggregate against conventional forms of sulphate attack.

Higgins and Crammond (2003) described the magnesium sulphate attack on their 100 mm cubes as producing a white 'mushy' material with the outer surface of the concrete merely blowing off. Test were conducted at 70% GGBS at 5°C. They found that the mechanism of attack was very much dependent on the type of aggregate used. In this case good quality carbonate aggregate with GGBS addition yielded the best results.

#### 3.2 Sulphuric Acid

Hill et al. (2003) found that 100 mm concrete cubes with a 65% GGBS replacement level out performed SRPC and PFA @25% when placed in a BRE Digest 363 sulphuric H<sub>2</sub>SO<sub>4</sub> solution for 6 months.

Attigobe (1988), Osbourne (1999) and Pavia et al. (2008) attributed the better performance of GGBS concrete in acidic conditions to either lower porosity, lower levels of CH or both.

Chang et al. (2005) also confirmed the influence of aggregate used. They concluded that the carbonate aggregate served as a sacrificial medium against acid attack and noted that it reduced the quantity of acid at the surface of the specimen.



*Acid erosion of cement matrix leading to exposed aggregate*



*Gypsum formation above the water line*

#### 4.0 Concrete Mix Design

BS 8007 sets the minimum cement content as 325 kg/m<sup>3</sup> and the maximum water/cement ratio of 0.55 for concrete in use in water retaining structures.

#### 4.1 GGBS in use in Water Retaining Structures

Use of Concrete	Source of Reference	Percentage by Mass of GGBS Replacement	
		Normal*	Special*
Concrete Designed to Retain Aqueous Liquid	Civil Engineering Specification for the Water Industry, UKWIR, 2004 & BS 8007:1987	0–50	70–90
Concrete Pipes	IS 6:2004 Concrete Sewer Pipes	36–65	70–85
Concrete Pipes	Specification for Blast Furnace Slag Cement for In Situ Lining of Water Mains, UK Water Industry, 1991		65

\*Note: normal covers Design Chemical Classes DC 1 & 2; Special covers Design Chemical Classes DC 3 & 4 as set out in BRE Special Digest 1. (DC1, least aggressive — DC4, most aggressive). For more information and reference please visit [www.ecocem.ie](http://www.ecocem.ie).

#### *Use of Concrete Source of Reference Percentage by Mass of GGBS Replacement*

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# Durable Farm Concrete

*Exposure to silage effluent, slurry and abrasion from farm vehicles is very damaging to concrete.*

## Durable Farm Concrete

Farm Concrete made with a blend of Ecocem GGBS cement:

- Is more durable
- Lasts longer
- Has greater long-term strength
- Is better for the environment
- Is brighter in colour
- Requires less repair
- Is best value for money

## The Farm Environment

The farm environment is very demanding on concrete. Exposure to silage effluent, slurry and cleaning fluids along with mechanical abrasion from farm vehicles often results in significant damage to concrete, requiring concrete to be repaired or replaced early in its service life.

The most common aggressive agents on the farm are acids and sulphates: lactic and acetic acid are present where silage is stored; sulphates are present in various effluents and manures.

The greatest amount of degradation tends to occur where there is a combination of both chemical attack and physical abrasion, such as silage pit aprons where tractors are handling silage, where animals are trafficking slabs, or where power-hosing washes acids onto concrete floors.

However concrete incorporating Ecocem GGBS cement, correctly placed and cured, will provide additional protection to concrete from this damage

and will extend the service life of farm concrete. The farm environment is very demanding on concrete. Exposure to silage effluent, slurry and cleaning fluids along with mechanical abrasion from farm vehicles often results in significant damage to concrete, requiring concrete to be repaired or replaced early in its service life.

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However concrete incorporating Ecocem GGBS cement, correctly placed and cured, will provide additional protection to concrete from this damage and will extend the service life of farm concrete.

## Protective Characteristics of Ecocem GGBS

### Increased Resistance to Acids

Concrete made with GGBS cement has a lower porosity and permeability than concrete made with Ordinary Portland Cement (OPC)<sup>1</sup> only. Pore sizes are smaller and less numerous. This reduces the rate of penetration of acids into the concrete, giving enhanced protection from acids, erosion and abrasion damage.

### Greater Long Term Strength

Concrete made with GGBS has greater long-term strength than concrete made with OPC, due to the dense r cement matrix of GGBS concrete. The same 28-day strength will be achieved in concrete with 50% GGBS as concrete made with 100% OPC. However beyond 28 days, GGBS concrete continues to hydrate and gain in strength more than concrete made only with OPC.

### Increased Resistance to Sulphates

Sulphates can be present in slurry, manure and wastewater. Sulphates react with C3A and Ca(OH)<sub>2</sub> present in OPC concrete, causing the concrete to expand and crack. GGBS is a sulphate-resisting cement. Specifying GGBS at 50%–70% content gives optimum protection against sulphate attack.

### Increased Resistance to De-icing Salt

De-icing salts and seawater can cause corrosion of reinforcement in concrete leading to cracking of concrete. The presence of GGBS reduces the rate and degree to which chlorides penetrate through concrete, enhancing the service life of concrete exposed to these salts.



*Silage pit where concrete has been damaged as a result of exposure to silage effluent acids*

## Ecocem GGBS Cement

Ground granulated blastfurnace slag (GGBS) cement is a by-product of the manufacture of iron. Because GGBS cement originates from burnt limestone, as does OPC its chemistry is similar to OPC. These similarities permit GGBS cement to replace up to 70% of OPC in concrete, on an equal-part basis. But the minor differences between GGBS and OPC also give enhanced durability to concrete made with GGBS. For most farm applications the most durable concrete will be obtained using a 50:50 blend of GGBS and OPC. In the most aggressive environments the use of 60–70% GGBS might be required.

1. The terms "Ordinary Portland cement", "OPC", and "ordinary cement" refer to the cement types CEM I or CEM II cements.

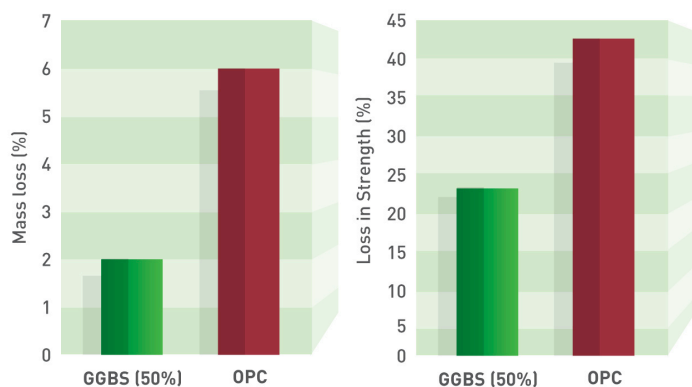
## The Effect of Silage Effluent and Slurry on Concretes

### Acid Attack

Silage effluent is known to be corrosive to ordinary Portland cement concrete. This corrosion, combined with vehicle loads and mechanical abrasion can prematurely damage concrete silos or slabs, necessitating early repair, or in some cases replacement.

However, concrete made with GGBS is more resistant to attack from silage effluent than concrete made with OPC only. A recent study (2008) carried out in Trinity College Dublin<sup>2</sup> compared the durability of concretes exposed to silage effluent of pH 4.0. Concretes made with OPC only and with 50% GGBS were put through three 28-day cycles of exposure to silage effluent. Concrete deterioration was measured visually and by strength loss and mass loss. The superior resistance of the 50% GGBS concrete is illustrated in the photos to the right.

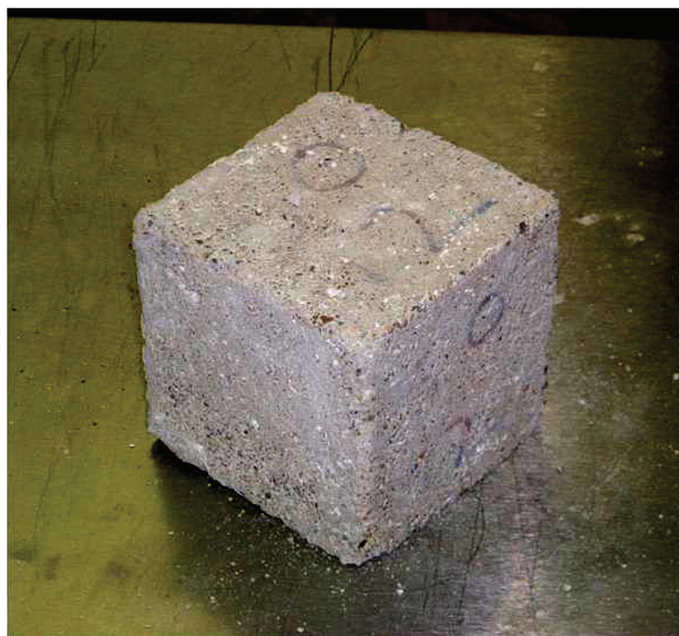
In addition, the GGBS concretes experienced significantly lower losses of compressive strength and mass after exposure to the silage effluent, as shown below:



### Mass loss and strenght loss

The greater durability of concrete made with GGBS will extend the service life of concrete exposed to silage effluent, (see also Farmers Journal of 9/8/2008, or online at [www.farmersjournal.ie](http://www.farmersjournal.ie)).

2. S. Pavía, and E. Condren, "Study of the Durability of OPC versus GGBS Concrete on Exposure to Silage Effluent", ASCE Journal of Materials in Civil Engineering, April, 2008.



50% GGBS Concrete



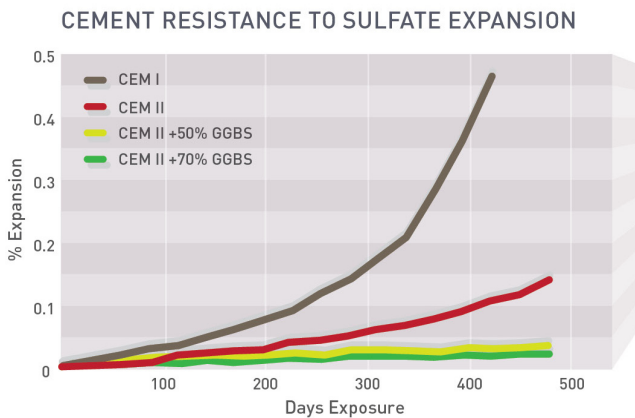
100% OPC Concrete showing more deterioration on exposure to silage effluent

## Sulphate Attack

Concrete in livestock buildings is often subject to  $H_2S$  gas and sulphate concentrations that can corrode the concrete matrix. Sulphates react with  $C_3A$  and  $Ca(OH)_2$  in concrete made with OPC, causing the concrete to expand and lose its strength. Because of the absence of  $C_3A$  and reduced content of  $Ca(OH)_2$  in concrete made with GGBS, the use of GGBS provides the best protection against sulphate attack. This is illustrated from the results of a recent study (2009) carried out in University College Dublin<sup>3</sup> on sulphate attack on concretes.

The best protection against sulphate attack is provided by the use of 50% to 70% GGBS in concrete.

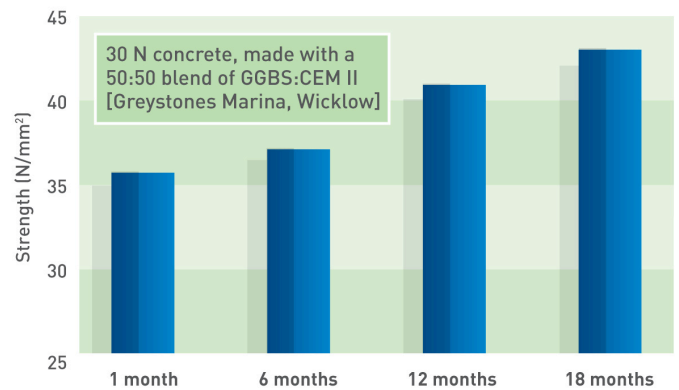
3. M O'Connell, C. McNally, and M.G. Richardson, "The performance of limestone cement with GGBS exposed to elevated sulfate environments", Proceedings: Bridge, Infrastructure and Concrete Research in Ireland, BCRI2010 Cork, Ireland, September, 2011.



## Greater Long Term Strength

Concrete made with GGBS has greater long-term strength than concrete made with OPC. This is because GGBS continues to hydrate and react with the free lime in concrete over time, resulting in a denser matrix with a finer pore structure. The enhanced long-term strength of GGBS concrete is illustrated in the chart to the right.

A strength increase of 20% from 1 month to 1.5 years is achieved with concrete made with 50% GGBS. The greater long-term strength of GGBS concrete minimises the risk of mechanical and structural damage over the lifetime of the concrete structure.



50% GGBS Concrete

## Brighter Coloured Concrete

Ecocem GGBS cement is white in colour, thus concrete made with GGBS is lighter in colour. Lighter coloured concrete increases light reflectance making for a safer working environment, particularly at night.



*Concrete bridge abutment made with 50% Ecocem GGBS; bridge beams are made with 100% OPC.*

## Environmental Benefits of GGBS

Ecocem GGBS cement is a recycled product. It is much more environmentally friendly and has a much lower CO<sub>2</sub> footprint than CEM II or CEM I cements. The CO<sub>2</sub> footprint of Ecocem is just 29kg/tonne (audited by NSAI), whereas that of CEM II cement is in the order of 700kg/tonne.

Using a 50% blend of GGBS in concrete saves 1 tonne of CO<sub>2</sub> per truck load of concrete delivered.

On an average farm slab of 500 m<sup>2</sup>, with two silage pits, this will result in a saving in the order of 100 tonnes of CO<sub>2</sub>—equivalent to the annual greenhouse gas emissions of a herd of 40 dairy cows.

Cement Type	CO <sub>2</sub> Footprint [kg CO <sub>2</sub> /tonne]	Reference
Ecocem GGBS	29	Direct and energy indirect emission of CO <sub>2</sub> . ISO 140064–1:2006. Audited by NSAI, 2010.
CEM I	740–830	EPA: GHG Permit Holders Public
CEM II	680–760 <sup>4</sup>	Files, unpublished data for installations in RoI, 2010.

4. Based on CEM II/A cement with 13% addition of limestone or flyash.

## Working with GGBS Concrete

### *Placing and Compacting*

The requirements for placing concrete with GGBS are the same as that of ordinary concrete. It is essential that all concrete should be fully compacted to ensure long-term durability. The concrete should be mechanically vibrated using a vibrating poker or vibrating screed. Compaction by hand tamping will not lead to the same quality results and may reduce the life of the concrete. It is not permitted to add water to concrete on site—doing so will significantly damage the integrity of the concrete.

It is important to permit bleed water to evaporate from the concrete surface before the final finishing. Finishing the concrete whilst there is bleed water lying on the surface remixes the bleed water into the top surface of the concrete, leading to the formation of a weak layer on the top of the concrete.

### *Curing*

Proper curing is particularly important in farm concrete. The purpose of curing is to ensure that sufficient moisture is available for hydration of the concrete in the first 7 days. Great care must be taken to ensure concrete does not dry out during this period. This can be achieved by covering the concrete with a fabric that is kept moist; covering the concrete with plastic sheeting; using a curing compound; or regular spraying with water. Failure to cure properly will result in a lower strength and more porous surface layer of concrete. This will make the concrete more susceptible to abrasion, acid attack and frost damage, and will shorten the life of the concrete. It is also important to protect fresh concrete from heavy rainfall, and from frost.

## Ordering Concrete with Ecocem GGBS

Durable concrete made with Ecocem GGBS is available nationwide. Check [www.lowcarbonconcrete.com](http://www.lowcarbonconcrete.com) for suppliers in your area. When ordering your concrete, simply state that you wish to use concrete with 50% Ecocem GGBS for general purpose farm concrete, or 70% Ecocem GGBS for concrete in particularly aggressive environments.

### *Precast Concrete*

Precast concrete elements such as cattle slats or tanks made with Ecocem GGBS cement will similarly be more durable than concrete made with OPC. Check with your local supplier if they can provide precast elements made Cement type CO with Ecocem GGBS concrete.

## Technical Advice

For technical advice contact your local concrete supplier, or you can contact Ecocem directly on 01 678 1800 or [technical@ecocem.ie](mailto:technical@ecocem.ie) and we will be pleased to answer any technical or practical questions you may have.

# Freeze-Thaw

*In Ireland's moderate climate, natural cycles of freezing and thawing are frequent and damaging.*

## Freeze-Thaw

Problems related to freeze-thaw attack of concrete arise when unbound water in concrete freezes. When water freezes it expands by around 9%. This causes hydraulic pressure within the concrete pore structure. As concrete reaches its saturation point, and over many cycles of freezing and thawing, this pressure causes tensile forces to build up in the concrete matrix. If these forces exceed the internal tensile strength of the concrete, it will cause the concrete to deteriorate by way of general disruption, cracking, scaling or pop outs leaving it exposed to further attack and ultimately failure.

In countries having cold climates, cycles of freezing and thawing are few over a winter. Usually, the big freeze comes and a few months later the thaw comes. In Ireland's moderate climate, natural cycles of freezing and thawing are more frequent. Cycles of freezing and thawing are exacerbated when de-icing agents are used as they lower the freezing point of water. The effect of this is that when freezing point is reduced to say  $-5^{\circ}\text{C}$  using salt, the temperature only has to rise above  $-5^{\circ}\text{C}$  instead of  $0^{\circ}\text{C}$  for the thawing action to occur, and back to below  $-5^{\circ}\text{C}$  to freeze again. So while ambient temperature may remain below  $0^{\circ}\text{C}$ , cycles of freezing and thawing may be occurring in the concrete as day and night pass. This increases the number of cycles of freezing and thawing and it is possible to experience the effects of several Arctic winters over several weeks.

De-icing agents are usually Sodium Chloride salt, but other agents such as Calcium Chloride, Magnesium Chloride, Ammonium Sulphate, Ammonium Nitrate and Urea are used. These are all particularly

aggressive and damaging towards concrete, and have the added effect of increasing the frequency of cycles of freezing and thawing. For these reasons it is imperative to consider the durability performance of concrete when it will be subject to freeze-thaw exposure.

The first method of protecting against freeze-thaw attack is to use concrete designed to the correct exposure class of I.S. EN 206-1:2002. Non standard concrete will not be of sufficient quality to withstand the effects of freeze-thaw attack.

Table 1 of I.S EN 206-1:2002 sets out the exposure classes related to environmental actions. Under part 5 of this table the exposure classes are set out for freeze-thaw attack with or without de-icing agents. The details of the classes are as follows:

*Table 1 of EN 206:2000*

<b>XF1</b>	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
<b>XF2</b>	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
<b>XF3</b>	High water saturation, without de-icing agent	Horizontal concrete surfaces exposed to rain and freezing
<b>XF4</b>	High water saturation, with de-icing agent or sea water	Road and bridge deck exposed to de-icing agents. Concrete surfaces exposed to direct spray containing de-icing agents and freezing. Splash zones of marine structures exposed to freezing.

he classification of XF3 in Ireland is somewhat of a rarity given our obsession for de-icing agents to clear our driveways, paths, car parks and roads from frost, snow and ice. Driveways and car parks are sometimes specified as XF3 as de-icing agent is often not directly applied. The reality is that these applications are amongst the highest risk group of XF4. As vehicles travel they collect de-icing agents along the way. When they park, packed ice melts and the de-icing agent is deposited on the concrete. With this in mind it is best practice to consider all horizontal concrete surfaces as XF4.

Table NA.6 of the National Annex to I.S EN 206:2002 sets out the recommended limiting values for freeze-thaw exposure classes in terms of minimum concrete strength class amongst other details. The details for XF4 are summarised in the table below:

Table 1 of EN 206:2000

Exposure Class	Min Strength Class	Max W/C ratio	Max air content and min cement content for 20mm max aggregate size
XF4	C32/40	0.50	3.5% 340 kg/m <sup>3</sup>
	C40/50	0.45	- 400 kg/m <sup>3</sup>

The table shows that there are two choices for concrete exposed to XF4. The first choice is C32/40 with a maximum water cement ratio of 0.50; a minimum cement content of 340 kg/m<sup>3</sup> and a minimum air content of 3.5%. The second choice is C40/50 with a maximum water cement ratio of 0.45; a minimum cement content of 400 kg/m<sup>3</sup> and no air entrainment. This concrete can be classified as watertight.

Designing concrete with the minimum possible water/cement ratio will result in a stronger more durable concrete. It means that as the concrete sets, less water migrates to the surface of the concrete, thus reducing the capillary pore structure of the concrete, thus reducing its permeability and increasing its durability. The permeability of the concrete can be

further reduced by using high strength concrete with secondary cementitious materials and admixtures that allow water reduction whilst maintaining workability.

The type of aggregate used affects the water content of concrete. 10mm aggregate has a higher water demand than a nominal size aggregate of 20mm and will increase the w/c ratio of concrete and its use in at risk from freeze-thaw attack should be avoided. Mixes with extra sand should also be avoided as they also require the addition of water to achieve a workable concrete. The addition of water to concrete delivered on site will also increase the w/c ratio which will increase the permeability and reduce the durability of the concrete.

A further method of protection is to allow for the expansion of frozen water in the hardened concrete by introducing air using air entraining agents. These agents create a large number of closely spaced, small air bubbles in the hardened concrete. The air bubbles relieve the pressure build-up caused by ice formation by acting as expansion chambers. The air-bubbles should be well distributed and have a distance between each other of less than 0.25mm in the cement paste. Usually about 4% air by volume is needed to ensure adequate protection. The amount of air needed is dependent of the size of aggregate used; bigger aggregates require less air content. For example, the National Roads Authority (NRA) specifies air content of 5 +/- 1.5% for 20mm nominal size aggregate and 4 +/- 1.5% for 40mm aggregate.

The addition of 1% air leads to a reduction of 5% ultimate concrete strength and for this reason it is difficult to air entrain high strength concretes. As the air increases, cement contents need to be increased to maintain strength which can lead to problems with thermal cracking, especially if placing concrete in cold weather. Air entrainment when using secondary cementitious materials is difficult. These materials that are used for their enhanced engineering properties tend to be very small in nature and can fill up the small air voids as they are created. Higher

dosages of air entraining agent are often required to get adequate performance when using secondary cementitious materials.

It isn't easy to measure the amount of entrained air. Normal techniques measure the total air voids content and not the most important attributes, which are the size and distribution of the air voids. Once air is entrained in concrete it can be lost due to two principal reasons; firstly, over mixing or vibration of fresh concrete during the initial stages and secondly, by the in-filling of air-voids with secondary products such as ice, ettringite and calcium silicate hydrate, due to freezing and the additional hydration of secondary cementitious materials.

Other considerations are the type of concrete finish used and the slope of the surface to ensure that water does not pond on the surface. Correct compaction, again to reduce permeability is important and the use of surface sealers can also help to keep water out of the concrete.

GGBS gives excellent durability in freeze-thaw situations as it reduces the permeability of concrete by means of its latent hydraulic reaction. It can also allow for reductions in w/c ratio for a given workability compared to non GGBS concrete. Good curing practice is of critical importance in the use of GGBS concrete. The key is to have complete hydration at the surface of the concrete so that it is strong and impermeable. Inadequate curing practice will result in the surface drying out and micro-cracking which will leave the concrete susceptible to water and de-icing agent ingress and can lead to freeze-thaw attack. There are limits for GGBS content in the wearing surface of concrete pavements exposed to freeze-thaw. I.S. EN 206:2002 specifies the maximum GGBS content of 65% in combination with CEM I and 50% in combination with CEM II/A.

A recent study at UCD has shown that GGBS at a replacement level of 50% has significantly increased freeze-thaw resistance to that of CEM II/A alone and

has similar resistance to that of CEM II/A with 6% entrained air. The study has also showed the difficulty in entraining GGBS concrete. The study concludes that GGBS increases freeze-thaw resistance in C40/50 concrete and that it also offers increased resistance to chlorides and sulphates that may be present in de-icing agents.

The NRA have specified that structural concrete within the Splash Zone shall be either air-entrained or shall have a minimum concrete strength class of C40/50 to protect against XF4 exposure. They have a further requirement that one of two measures should be taken; (i) concrete should have a minimum 50% GGBS or (ii) concrete shall be reinforced with stainless steel. The Dublin Airport Authority also specified the use of 50% GGBS in combination with CEM II in the new concrete pavement works for Terminal 2 for resistance to XF4 exposure.

The action of freeze-thaw attack on concrete is hugely problematic and requires careful consideration to specification, design, placement and curing for concrete have the desired durability to withstand its action. Low permeability concrete is the key, as the less water in the concrete the lower the risk of freeze-thaw damage. Air entrainment is another option, but it has some draw backs and it has been shown that concrete with low water content, high strength and low permeability is just as effective. Using GGBS reduces the permeability of concrete, increases resistance to attack of de-icing agents and increases concretes resistance to freeze-thaw attack.

## References

I.S EN206:2002 Concrete – Part 1: Specification, performance, production and conformity.

Irish National Annex to I.S EN206:2002 Concrete – Part 1: Specification, performance, production and conformity.

Kelly & Murphy, Prediction of Freeze Thaw Resistance of Concrete, University College Dublin, 2010.

Irish Concrete Society, The effects of Freeze-Thaw on Concrete, half day seminar, March 2011



*Freeze-thaw pop outs*



*General disruption from freeze-thaw attack and the effect of de-icing agent melting from parked car*



*D-Cracking due to freeze-thaw attack*



*Scaling and delamination due to freeze-thaw attack (note small size of aggregate)*

# Concrete Mix Design

*The many engineering benefits of GGBS concrete begin to take effect when the replacement level of GGBS is 30% or greater.*

## Concrete Mix Design Using GGBS

The many engineering benefits of GGBS concrete begin to take effect when the replacement level of GGBS is 30% or greater. Replacement levels of GGBS in concrete vary from 30% up to 85%, but GGBS is most often specified at 50% in Ireland. In the Netherlands, GGBS is often used at replacement levels of up to 70% , which is also increasingly happening in Ireland—primarily for technical reasons but also for environmental and architectural reasons.

In normal concrete (e.g. commercial, light industrial, residential developments), GGBS is generally used at replacement levels of 50%. At this level of replacement GGBS concrete is treated in exactly the same way as Portland cement concrete in the construction process, with no need for adjustment of striking times or the curing regime of the concrete.

Similarly, placing, compacting and powerfloating are carried out in the same way as for Portland cement concrete. In general, concrete admixtures will work normally with GGBS concrete—if in any doubt, contact your admixture supplier, who is best placed to advise you on the latest products in the market, or contact Ecocem.

Specialist civil engineering applications such as low heat of hydration (large section pours), resistance to chemical attack (exposure to de-icing salts, sea-waters, sulphates), use in water-retaining structures (low permeability, crack control) and architectural requirements (lighter colour, prevention of efflorescence) require higher replacement levels, varying from 60 up to 85%. These specific applications are described in detail in the relevant sections of this document.

Recommended replacement levels for GGBS in concrete across all exposure classes (as defined in EN206–1), are given in the section on Recommended GGBS Replacement Levels. These replacement levels are based on current practice in the UK and Europe. This table is based on Table F.1 in IS EN206–1; ‘Recommended limiting values for composition and properties of concrete’. This table has been adjusted to include recommended GGBS replacement levels for each exposure class.

<b>GGBS replacement levels</b>	<b>The engineering benefits of GGBS over OPC-only concrete</b>
30–40%	Increased durability; Reduced permeability; Increased strength Moderate resistance to chloride penetration; Good resistance to sulphate attack; Resistance to ASR Improved workability
40–60%	Increased durability; Reduced permeability; Increased strength Lower heat of hydration High resistance to chloride penetration; High resistance to sulphate attack; Good resistance to ASR Improved workability Suppression of efflorescence Lighter colour
60–85%	Greatly increased durability; Greatly reduced permeability; Increased strength Very low heat of hydration High resistance to chloride penetration; High resistance to sulphate attack; High resistance to ASR Improved workability Elimination of efflorescence Lighter colour

## Sample mix designs using GGBS and OPC

The table below illustrates three typical mix designs using GGBS and OPC, in typical construction situations, for a) an external concrete wall, b) basement slab and c) cast-in-place pile.

### Sample Mix Design OPC

<b>Element</b>	<b>Wall</b>	<b>Shallow Basement Slab</b>	<b>Cast-in-place Pile</b>
Exposure class	XF1	XC2	XA2
Strength class	C30/37	C25/30	C30/37
Cement content	340	310	400
GGBS/CEM I ratio	50/50	50/50	70/30
GGBS	170	155	280
CEM I or CEM II	170	155	120 <sup>1</sup>
Coarse aggregate	1160	1155	815
Fine aggregate	710	735	945
Effective water	180	180	200
Admixture	0.8 litre	0.7 litre	4.0 litre <sup>2</sup>
w/c ratio	0.53	0.58	0.50
Consistence (slump class)	S2	S2	S4

### Sample Specification

<b>Element</b>	<b>Wall</b>	<b>Shallow Basement Slab</b>	<b>Cast-in-place Pile</b>
Exposure class	XF1	XC2	XA2
Minimum strength class	C30/37	C25/30	C30/37
Minimum cement content	340	310	400
Maximum w/c ratio	50/50	50/50	70/30
Consistency class	170	155	280

1. EN 206 allows for up to 50% GGBS with a CEM II and 70% with a CEM I. Practice in Ireland has demonstrated that 70% can be used with both CEM I and CEM II and the EN 206 may reflect this in the near future.

2. Superplasticiser

As is shown in the table, using GGBS simply replaces a given percentage of the cement in each mix, and no other changes are made to the mix design.

## CEM II/A Cements

CEM I and CEM II/A are available in the Irish market. CEM I was the only cement widely available up to 2–3 years ago. Now CEM II/A is more widely available. Both CEM I and CEM II/A are a combination of clinker and another cement constituent, such as fly ash, finely ground limestone or GGBS. The percentage of the added constituent in CEM I is 0 to 5% and in CEM II/A varies from 6 to 20%, with the balance being made up of clinker. The use of GGBS with both CEM I and CEM II/A is approved under EN 206.

CEM II/A is manufactured in accordance with IS EN 197–1, the standard for the manufacture of cement. In Ireland, CEM II/A and CEM I cements are manufactured to the 42.5 N strength classification.

Because of its superior strength and durability, as well as its reduced environmental impact, the use of GGBS cement with CEM II/A cements will improve the performance of concrete and make a significant contribution to sustainable development. Concrete containing CEM II/A and GGBS cement is the best option for optimum technical and environmental performance.

Blending GGBS with CEM II/A cements will yield several significant positive benefits for concrete:

- An improvement in the 28-day strength of the concrete.
- The durability of the concrete is improved, as GGBS added to a CEM II/A will provide protection against chloride attack and sulfate attack, and it will also reduce the heat of hydration.
- Significant environmental benefits are achieved by:
  - i. reducing CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub> and CO emissions,
  - ii. reducing the embodied CO<sub>2</sub> of concrete,
  - iii. reducing depletion of finite natural resources.

# Standards

GGBS is manufactured to I.S. EN 15167, and is approved for use in concrete under I.S. EN 206 –1:2007.

## Standards

### *I.S. EN 206–1 Concrete*

The Irish standard covering the Specification, Performance, Production and Conformity of concrete is I.S. EN 206–1. This represents in effect the adoption and application in Ireland of the European concrete norm EN 206. Modifications of EN 206 as it applies in Ireland are covered in the National Annex I.S. EN 206–1. EN 206 defines additions to concrete as finely divided materials used to improve properties or to achieve special properties. It establishes two categories of addition: nearly inert additions (Type I) and pozzolanic or latent hydraulic additions (Type II).

I.S. EN 206–1 recognises the use of GGBS, manufactured in accordance with I.S. EN15167, for use as a Type II addition in concrete.

### *BS8500 Concrete: Complementary British Standard to BS EN 206–1*

BS8500, the complementary British standard to BS EN 206–1, recognises the use of GGBS to BS6699 for use as a Type II addition in concrete. Table 1 of BS8500–2 allows replacement rates of 6% to 80% when used in combination with CEM 1.

### *BRE Special Digest 1 'Concrete in Aggressive Ground'*

BRE Special Digest 1 'Concrete in Aggressive Ground' 2003, recognises the use of GGBS as a Type II addition in concrete to provide resistance to chemical attack in aggressive ground conditions, (as listed in Tables 3 and 6 in Part 2).

### *IS EN 15167*

#### *Blast Furnace Slag for use with Portland Cement*

The UK standard for GGBS, BS6699, Specification for ground granulated blast furnace slag for use with Portland Cement, is the standard most frequently used for GGBS. IS EN 15167 is the latest version of this standard in Ireland.

IS EN 15167 provides a complete specification of characteristics, quality control and requirements for GGBS manufacture and supply:

- GGBS is tested in combination with the Portland cement with which its use is intended.
- Test frequency and methods of testing are used as for a cement in accordance with the European norms.
- Conformity of the GGBS is verified by a statistical quality control scheme based on continuous inspection of the manufactured GGBS.
- Provision is made for certification of conformity by the GGBS producer (autocontrol) or by a third party.

View our certificate, which shows that Ecocem GGBS conforms to Irish Standard I.S. EN 15167–1:  
[http://www.ecocem.ie/downloads/IS\\_EN\\_15167-1\\_Licence\\_Certificate.pdf](http://www.ecocem.ie/downloads/IS_EN_15167-1_Licence_Certificate.pdf)

## Other Codes of Practice and National Specifications

Other codes of practice and specifications that describe the use of GGBS in concrete are:

- The Use of GGBS and PFA in Concrete, Concrete Society Technical Report No. 40, 1991. (UK).
- Alkali-Silica Reaction in Concrete, Institute of Engineers of Ireland and Irish Concrete Society Report, 2003.
- Standards for Fresh Concrete – The Application of BS EN206-1 and BS8500. Prof. Tom Harrison, BSI publication 2004.
- BS 8007:1987 Code of Practice for the design of concrete structures for retaining aqueous liquids.

## Material Safety Data Sheet

Download the Material Safety Data Sheet here:

[http://www.ecocem.ie/downloads/material\\_safety\\_sheet.pdf](http://www.ecocem.ie/downloads/material_safety_sheet.pdf)

# About GGBS

*GGBS is not a new product. It has already proven itself reliably in its use all over the world since the 1800s.*

## History of the Use of GGBS

GGBS is not a new product. It has already proven itself reliably in its use all over the world since the mid 1800s.

Thirty-eight years after the patent for Portland cement was first lodged by John Aspdin in 1824, Emil Langin discovered GGBS cement. By 1865, commercial production of lime activated GGBS had commenced in Germany and by 1880 GGBS was being used with Portland cement as the activator. In 1889 it was used for construction of the Paris Metro. The United States commenced production of slag cements in 1896.

Since then Europe, with its many blast furnaces and steel industries has used GGBS extensively in all manner of structures. By 1914, GGBS was being manufactured in Scotland. BS 146 was published in 1923 followed by BS 6699 in 1986 for GGBS.

In Britain, over 2 million tonnes of GGBS is used every year. GGBS is also widely used by the cement and concrete industries in continental Europe, with some 17.7 million tonnes now being used annually.

GGBS is specified for its many technical advantages and as a means of reducing the environmental impact of the production of Portland cement.

## Advantages and Benefits of Using GGBS

The many advantages and benefits of specifying GGBS are outlined below:

### *Superior Quality Concrete*

- Improved workability, pumpability and compaction characteristics for concrete placement
- Increased strength
- Reduced permeability
- More chemically stable
- High resistance to chloride penetration
- High resistance to sulphate attack
- High resistance to ASR
- Very low heat of hydration
- Improved resistance to attack from fire

### *Superior Appearance*

- Improved surface finish
- Lighter and more even colour
- Enhanced reflectivity for greater visibility and safety
- Suppresses/eliminates efflorescence

### *Low Environmental Impact*

- Production of GGBS involves virtually zero CO<sub>2</sub> emissions, and no emissions of SO<sub>2</sub>, NO<sub>x</sub>, CO, PM<sub>10</sub>.
- Use of GGBS extends the life cycle of concrete structures
- Enhanced durability, reduced maintenance costs
- Reduces lifetime construction costs

## Better Value for Money

- Enhanced durability and strength—longer life
- Enhanced architectural appearance—reduced need for other expensive finishes or painting
- Enhanced environmental performance—reduce the risk of attracting carbon taxes
- Lower maintenance costs
- Enhanced life cycle
- No additional premium on material costs
- Overall better value for money



*Steel Blastfurnace, the source of GGBS Cement*

## Manufacture of GGBS

GGBS is made from a by-product of the production of iron in a blastfurnace where iron ore, limestone and coke are heated to about 1500°C. When these materials melt in the blastfurnace, two products are produced—molten iron, and molten slag. The molten slag is lighter and floats on the top of the molten iron. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone.



*Molten slag en route from the base of the blastfurnace to the granulation vessel for cooling.*

The process of granulating the slag involves cooling the molten slag through high-pressure water jets. This rapidly quenches the slag and forms granular particles generally no larger than 5 mm in diameter. The rapid cooling prevents the formation of larger crystals, and the resulting granular material comprises some 95% non-crystalline calcium-aluminosilicates.



*The granulated slag, after drying, is ground to a very fine powder in the rotating ball mill, which contains some 3.6 million high chromium cast steel balls.*

The granulated slag is further processed by drying and then ground to a very fine powder, which is GGBS (ground granulated blastfurnace slag) cement. Grinding of the granulated slag is carried out in a rotating ball mill.

## Chemical Composition

Ecocem GGBS comprises mainly of CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, 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 Constituent	Portland	GGBS
CaO	65%	40%
SiO <sub>2</sub>	20%	35%
Al <sub>2</sub> O <sub>3</sub>	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 <sup>3</sup>
Bulk density (vibrated)	1.2–1.3 tonnes/m <sup>3</sup>
Relative density	2.85–2.95
Surface area	400–600 m <sup>2</sup> /kg Blaine

For further details see the Ecocem GGBS Material Safety Data Sheet:

[http://www.ecocem.ie/downloads/material\\_safety\\_sheet.pdf](http://www.ecocem.ie/downloads/material_safety_sheet.pdf).

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.

## Cementitious Reaction

GGBS reacts like Portland cement when in contact with water. But as the rate of reaction is slower, an activator is necessary. The calcium hydroxide released when Portland cement reacts with water serves to activate GGBS, hence GGBS is normally combined with Portland cement.

When GGBS is used in concrete, the resulting hardened cement paste has more, smaller gel pores and fewer larger capillary pores than is the case with concrete made with normal Portland cement. This finer pore structure gives GGBS concrete a much lower permeability, and makes an important contribution to the greater durability of this concrete.

The resulting hardened cement paste using GGBS is also more chemically stable. It contains much less free lime, which in concrete made with Portland cement leads to the formation of further reaction products such as ettringite or efflorescence. In addition, GGBS contains no C<sub>3</sub>A, making GGBS concrete much less reactive to sulphates.



Concrete mix containing GGBS cement

## How GGBS is Used in Concrete

GGBS is added to concrete by addition at the concrete mixer, along with ordinary cement, aggregates and water. The normal ratios and proportions of aggregates and water to cementitious material in the mix remain unchanged. Mixing times are the same as for ordinary cement. Both wet mixing and dry mixing processes can be used for making concrete with GGBS.

GGBS is used as a direct replacement for ordinary cement, and replaces ordinary cement on a one-to-one basis by weight.

Replacement rates for GGBS vary from 30% to up to 85%. Typically 50% is used in most instances. Higher replacement rates up to 85% are used in specialist applications such as in aggressive environments and to reduce heat of hydration. GGBS can be used at replacement levels of 70% in lean mix concrete.

## Storage and Handling of GGBS

Bulk GGBS is stored and handled in conditions identical to that of Portland cement. Bulk storage is in watertight silos. Transportation is by bulk tankers, as for Portland cement. GGBS can also be moved by airlifts, cement screws and bucket elevators.

Dust control is the same as that required for Portland cement. GGBS dust does not present any fire or explosion hazard.

## Health and Safety

GGBS is a fine dust of nuisance value classification. It is stable, non-flammable and results in no hazardous decomposition products. It results in no harmful effects in normal use, but as a fine abrasive powder, may irritate skin eyes, mouth, nose and mucous membranes. Unlike ordinary cements, GGBS does not contain any soluble chromium, and as such does not need to be chemically treated, as required under the Chromium (VI) Directive 2003/53/EC, which became effective in January 2005.

For further details see the Ecocem GGBS Material Safety Data Sheet:

[http://www.ecocem.ie/downloads/material\\_safety\\_sheet.pdf](http://www.ecocem.ie/downloads/material_safety_sheet.pdf)



*Bulk tankers loading at Ecocem*