Low Carbon Concrete for the Water Industry

INTRODUCTION

Clients are increasingly looking to designers such as Stantec to ensure that new structures are built with the lowest carbon impact possible.Concrete structures built with traditional ordinary Portland cement (OPC) mixes typically involve high carbon emissions.

The purpose of this technical bulletin is to discuss the current use and specification of lower and low carbon concretes to BS 850: Concrete - Complementary British Standard to BS EN 206, specifically in relation to the water industry. It does not deal with the non-cement concrete of PAS 8820 Construction Materials - Alkali-activated cementitious material (AACM). These are concretes which may contain up to 5% OPC and are sometimes referred to as geopolymer concrete. The Publicly Available Specification (PAS) does not carry the authority of Euro or British Standards and the concretes specified will not comply with water industry internal client design standards, CESWI or DWI requirements.

This memo discusses the commonly available concrete specification, available in the UK, that provide lower carbon concretes and can be competitively priced.

SHORT HISTORY OF LOW CARBON CONCRETE

The history of low carbon concrete (UK) relates to the use of cement replacement materials. This is where a percentage of the OPC is placed by other materials. Cement replacement materials in BS 8500 include:

- Silica fume, 6-10%
- Pulverised fly ash (PFA), up to 55% but typically less than 25%
- Ground granulated blast furnace slag (GGBS), up to 80% but typically never more than 70%

The use of cement replacements has been in UK standards since 1923.

The two commonly used cement replacements are PFA and GGBS. These are UK-produced products whereas silica fume is imported and rarely available. Silica fume concrete is not discussed here.

PFA and GGBS are what is termed pozzolanic materials. The calcium hydroxide released by Portland cement makes the mix alkaline which in turn activates the replacement material. In AACM concrete typically the Portland cement is replaced by another reagent but the PFA and GGBS are still generally the pozzolanic material used.

PFA and GGBS are classified as by product materials from other industries: PFA from coal fired power stations and GGBS from blast furnaces of the steel industry. As such, in the carbon counting industry this has significant benefit as the costs are taken against the primary manufacturing use, not the secondary use within concrete.

Historically PFA was used as a fill material often under industrial buildings. In the 1970 contractors were paid to take the material away from the power stations to use as an industrial fill. Then there was a period when the contractors had to pay the transportation cost themselves, and today contractors and concrete industry are charged for it.

In early usage, the replacement was there to reduce the cost of the concrete. It was then realised that the replacement mixes had other benefits such as chemical resistance and the reduction in heat of hydration. Today they are recognised as being lower and low carbon concretes.

The adjacent tables show the standard cement types used within the UK and embodied carbon dioxide for concretes made with these cements.

BS 8500 STANDARD CEMENTS AND EMBODIED CARBON DIOXIDE

Common standard cements to BS 8500 are below.

Cement designations in concrete	
CEM I	Portland cement
CEM IIA / CIIA	CEM I with 6 to 20% other material
CEM IIB / CIIB	CEM I with 21 to 35% fly ash or Regen GGBS
CEM IIIA / CIIIA	**CEM I with 36 to 65% Regen GGBS (typical 50%)**
CEM IIIB / CIIIB	**PC with 66 to 80% Regen GGBS (typical 70%)**
CEM IVB / CIVB	PC with 36 to 55% fly ash
+SR	Add when needing sulfate resistance
BS8500 – variants	Allows for mixer combination types

The indicative embodied carbon for class C32/40 concrete mixes are shown below. The four mixes below are generic mixes.

Concrete embodied CO_2 from cement and additions (kg/m³)

Cementitious material	100% CEM I	30% fly ash	50% GGBS	70% GGBS
Portland cement	320	250	165	110
Fly ash	–	110	–	–
GGBS	–	–	165	260
Total	320	360	330	370
Embodied CO_2	275	215	155	115

Values for additional cement contents derived from 'Specifying Sustainable Concrete' MPA – The Concrete Centre 2011.

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Some concrete suppliers have their own proprietary mixes, such as Hanson who offer the Regen GGBS mix. CEMEX and other suppliers produce their own equivalents.

The mixes are indicative of those specified as lower or low carbon mixes.

ADVANTAGES AND DISADVANTAGES IN PERFORMANCE OF REPLACEMENT MIXES

Typically, replacement mixes offer better durability performance in chloride and sulphate conditions and are often specified in the water industry for that reason. This is codified in BS 8500 in table A.4 and A.5, which show that a standard CEM I mix (100% OPC) will require an increased concrete strength, lower water content and increased reinforcement cover compared with a CEM III/B mix (70% GGBS replacement). In other words, the 70% GGBS mix offers better durability and lower cost. CEM III/B also represents the lowest embodied carbon dioxide mix and is the preferred specification.

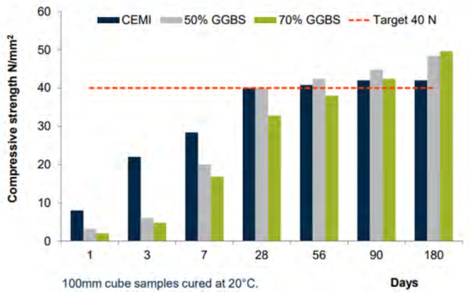
The heat of hydration generated after pouring this mix is also significantly reduced and consequently, there will be a decrease in the amount of steel reinforcement required to control shrinkage in water retaining structures.

The historic lower cost of the 70% GGBS replacement mix and reduction in minimum shrinkage steel requirements has been a historic driver for structural engineers to specify it.

There are some disadvantages to using replacement mixes. These include:

- Some replacement proportions have an impact on the efficacy of air-entraining admixtures.
- Mixes with GGBS proportions above 55% and PFA proportions above 36% are not normally recommended for pavements, due to the risk of surface scaling and wearing of the surface.
- Slower curing rates for cast in situ concrete, delaying formwork striking and loading and hence, increasing programme. GGBS replacement may be limited to 50% to mitigate this effect (CEM IIIA), see table below for 40 N mix.
- Not used in cases where there is attritional wear, say from say a scraper bridge wheel. This is disputed by the concrete industry who say that if properly cured it is hard wearing, but historical performance has indicated issues.
- Colour. GGBS concrete is white, but ordinary concrete is grey. There are instances where a white concrete, which can be highly reflective, is not acceptable. This may need to be discussed with the client or architect.

GGBS concrete strength development at 20°C



OPTIMUM CHOICE OF REPLACEMENT MIX FOR LOW CARBON CONCRETE

CEM I (or OPC) is the mix that other mixes are measured against when considering whether a concrete is lower or low carbon concrete. PFA mixes up to 35% and 50% GBBS mixes are typically considered lower carbon concretes with a reduction in embodied carbon dioxide of between 22-45%.

The 70% GGBS mix has a reduction of circa 60% and is considered a low carbon concrete.

The Concrete Centre provides background information on concrete and embodied carbon dioxide. GGBS mixes are typically considered better than the PFA mixes for embodied concrete and are the first choice. Ideally at a maximum level of 70% replacement.

However, the distribution of replacement mixes is variable across the country with some areas using PFA and others GGBS. Typically ringing around the nationwide ready-mix suppliers in the local area will inform you whether a design with a GGBS or PFA mix will be possible to procure. In rare circumstances, a supplier may be able to change a silo from PFA to GGBS, but this would only be for projects requiring very large concrete volumes and would be a project cost.

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Low Carbon Concrete

An example client specification from the Yorkshire Water CESWI.

	Yorkshire Water Standard Mixes									Freeze/ thaw XF3 resistant
YW Concrete Reference	WR2	WR3	WR4	SMIL	SMOD	UMB	KMF	RHS 1	RHS 2	
Designated Concrete Reference				RC25/3 0	RC30/3 7	GEN 3	GEN 1	PAV 2		
Design Strength Class	C28/35	C35/45	C35/45	C25/ 30	C30/ 37	C16/ 20	C8/10	C28/35	C28/35	C40/50
Design Chemical Class	DC-2	DC-3	DC-4	DC-1	DC-1	DC-1	N/A	N/A	N/A	
Nominal Maximum Size of Aggregate (mm)	20	20	20	20	20	20	20	20	20	20
Type of aggregate								Freeze-thaw resisting	Freeze-thaw resisting	Freeze-thaw resisting
Cement Types and Combinations	CIIB-V + SR (min 25% pfa), CIIIA + SR	CIVB-V or CIIIB	CIIB-V + SR (min 25% pfa), CIIIA + SR	Table A.14 BS8500 -1:2015	Table A.14 BS8500 -1:2015 Excl. IVB-V	Table A.14 BS850 0- 1:2015	Table A.14 BS8500 -1:2015	CEMI, CIIB-V or CIIIA	CEMI, CIIB-V or CIIIA	CEM 111A Alternative is CEM 11B-V, or CEM 11B-S or CEM 1
Minimum Cementitious Content, kg/m³	Where the recommendations given for DC-2 to DC-4m control the concrete specification, the DC-Class should be specified and not the limiting values." Clause A.4.4 BS8500-1:2015.	Where the recommendations given for DC-2 to DC-4m control the concrete specification, the DC-Class should be specified and not the limiting values." Clause A.4.4 BS8500-1:2015.	Where the recommendations given for DC-2 to DC-4m control the concrete specification, the DC-Class should be specified and not the limiting values." Clause A.4.4 BS8500-1:2015.	260	300	220	180	300	340	360
Maximum Cementitious Content, kg/m³				-	-	-	-	-	-	450
Maximum Free Water/Cement Ratio				0.65	0.55	-	-	0.55	0.5	0.45
Minimum entrained air Content Volume, %								3.5	3.5	None

NOTES:

1. Designated concrete GEN 0 to BS 8500-2 may be used instead of concrete KMF.
2. Freeze-thaw resisting aggregates must be used wherever air-entrainment is specified.
3. RHS 1 should not be used when the structure is subjected to de-icing agents in accordance with Table A.3 BS8500-1:2015. Where de-icing agents are used, RHS 2 should be used.
4. Lowest nominal cover for base slabs cast against blinding to be in accordance with Table A.9 of BS8500-1:2015.

For the water-retaining mixes (WR2 to WR4), they are differentiated by the design chemical classification, that is DC-2 to DC-4, each with increasing chemical resistance. The mixes contain two options, a PFA or GGBS. The SR nomenclature indicates additional properties for sulphate resistance.

To improve the mix for a project in terms of lower carbon concrete, a variation could be requested for ground conditions that require DC-2 resistance, a CEM III/B mix could be used at max 70% replacement. For ground conditions that demand DC-4, a CIIIB+SR could be used with a 70% max replacement.

SUMMARY

Clients are increasingly looking to their designers to ensure that the new concrete structures they build have the lowest carbon impact.

For the water industry, this can be achieved by using 70% GGBS mixes that comply with BS 8500. To specify these mixes, they must:

- Comply with the client's internal design standards and DWI requirements.
- Be locally available.
- Suit the local conditions and usage. A water retaining mix does not have the same requirements as that for a road pavement.

Note there are suppliers who specifically market low carbon concrete. Discussion with these suppliers indicates that they are essentially 70% GGBS mixes with minor adjustments to make it a proprietary mix at a premium price. Specification of a CEM III/B mix with 70% GGBS will provide a similar product which the contractor can price competitively in the marketplace.

Looking forward, major concrete suppliers are undertaking research into AACM and CEM free products with new industry guidance expected within 2-3 years. This is likely to change the optimum mix to be specified for low carbon concrete.

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