UNITED KINGDOM QUALITY ASH ASSOCIATION

Technical Datasheet

1.4

Resistance to the Thaumasite form of Sulfate Attack and Fly Ash Concrete

Introduction

The UKQAA commissioned BRE in 2003[1] to carry out a research project to investigate whether the natural temperature cycle found in the ground had any significant effect on the performance of Pulverised Fuel Ash (PFA), now known as fly ash in European Standards, based concretes in respect to the thaumasite form of sulfate attack. This was on the basis that the pozzolanic reaction is highly temperature dependant and if concrete containing fly ash was cured at higher temperature initially, it may have an enhanced or different performance for resisting the thaumasite form of sulfate attack.

Three different scenarios were created, curing ranging from 7C to 17C varying sinusoidally over a 12 month period and similarly ranging from 17C and reducing to 7C sinusoidally. These were designed to mirror possible ground concrete curing conditions found in the UK at ~1m depth. Also samples were tested at a fixed temperature of 12C, the UK average ground temperature at ~1m depth. Samples of all the mixes were also cured in the standard manner at 20C in water.

Sulfate solutions of DS 3 and DS 4 were used and compressive strength, visual assessment, wear rating and XRD mineralogical analysis carried out. The samples were assessed at 7 months and every year for 3 years. The following conclusions are partially those of the BRE and partially those of the UKQAA – the latter are marked in *italics*.

Technical Details

Sulfate solutions

The sulfate solutions used were;

1. DS 3: 3.0 g/l SO_4, containing $CaSO_4$ (1.4g/l SO_4) and $MgSO_4$ (1.6g/l SO_4).
2. DS 4: 6.0 g/l SO_4 containing $CaSO_4$ (1.4g/l SO_4) and $MgSO_4$ (4.6g/l SO_4).

PFA complying with BS3892 Part 1 (now EN450-1 fly ash, Cat S) called Ash 1, EN450 Cat N fly ash called Ash 2 were used in the project. CEM I was supplied by Castle Cement and SRPC came from Blue Circle. The SRPC was used to produce a concrete as a control. The fly ash addition rates were 30% and 50% of total binder content. Some mixes had a plasticiser added to ensure cement contents were below 440kg/m^3. A Jurassic Limestone was used as a source of coarse aggregate and a fine aggregate local to BRE being used.

Wear Rating Performance

Wear rating is a standardised BRE method of assessing the loss of concrete concentrating on the corners of test cubes. While there are criticisms with this approach it has proven difficult to devise another test method that would be in anyway superior.

The general findings from these tests using DS3 sulfate conditions were as follows;

- 50% fly ash mixes were better than 30% fly ash mixes, which were better than SRPC mixes in all cases.
- Ash 1 was slightly better at resisting attack than Ash 2.
- The specified Minimum Cement Content and Maximum Water/Cement Ratio would appear to have little bearing on the performance of the concrete in resisting thaumasite attack. *NB: This is a UKQAA observation.*

The general finding from these tests using DS4 sulfate conditions were as follows;

- 50% fly ash mixes were better than 30% fly ash mixes, which were better than SRPC mixes in most cases.

- SRPC was better than fly ash at resisting DS4 conditions at a fixed 12C curing temperature.
- Ash 1 was slightly better at resisting attack than Ash 2.
- The specified Minimum Cement Content and Maximum Water/Cement Ratio seemed to have little bearing on the performance of the concrete in resisting thaumasite attack. In fact these results suggest the higher cement contents/lower W/C ratios performed less well! *NB: This is a UKQAA observation.*

		Constant temperature at 12ºC	Variable temperature starting at 7ºC	Variable temperature starting at 17ºC
Mix 4122 (340 kg/m^3, 50% Ash 1)	7 Months			
		Slight wear on corners but no obvious signs of attack	No signs of attack	No signs of attack
	12 Months			
		Slight wear on corners but no obvious signs of attack.	General good condition except slight damage to one edge and one air void filled with white mush.	Good condition all over, slight edge damage to one top edge.
	24 Months			
		Slight efflorescence on side faces but otherwise no signs of attack.	Slight edge damage to top face. Patches of white scale on side faces.	Slight edge damage to two top edges and corners. Efflorescence / white scale on top and side faces. Otherwise no sign of attack.
	36 Months			
		As before (XRD).	As before (XRD).	As before (XRD).

Figure 1 - An example of the pictures for 50 % fly ash in DS3 conditions.

Visual Observations

High quality colour photographs of the all the specimens were taken at all the assessment ages. Thaumasite is visually easy to detect, causing the concrete to turn to a white, mushy residue, particularly at the corners. Figure 1 and Figure 2 shows a typical series of pictures from the project.

		Constant temperature at 12ºC	Variable temperature starting at 7ºC	Variable temperature starting at 17ºC
Mix 4130 (380 g/m^3, SRPC)	7 Months			
		No signs of attack	No signs of attack	No signs of attack
	12 Months			
		Erosion of corners and edges. White mush on faces.	White mush on faces behind grey skin. Erosion of corners and edges. (XRD)	White mush on faces. Erosion of corners and edges (XRD).
	24 Months			
		Aggregate exposure all over bottom face and most other faces except where there are patches of grey skin and mush behind. Cube is crumbly all over. (XRD)	Aggregate exposure and mush all over.	One bottom and two top corners badly eroded. Approximately 1 cm of mush on top face. Aggregate exposed and small pockets of mush in voids on all faces.
	36 Months			
		As before.	As before but base turned to mush.	As before but base turned to mush.

Figure 2 – SRPC samples as a control in DS 3 conditions.

As will be observed in Figures 1 & 2 the differing performance of the various mixes is easily assessed from photographs.

X-ray Diffraction Results (XRD)

XRD was used when it was clear that thaumasite attack had taken place in the samples. Analysis of such samples shows the presence of thaumasite and ettringite, though the concentrations of both appear to reduce between 12 and 24 months. More gypsum is found in DS3 solutions and brucite, $Mg(OH_2)$, is only found in the DS3 solution.

In general terms the XRD results do not show anything of particular interest.

Conclusions

The following are the overall conclusions from the work;

1. Samples made with 50% fly ash of any type perform at least as well as SRPC in DS4 and better than SRPC in DS3.
2. All samples containing 50% fly ash show no signs of attack after 3 years.
3. Ash 1 (EN450 Cat S) performed only slightly better than Ash 2 (EN450 Cat N).
4. All visually attacked samples contain thaumasite and ettringite from XRD analysis. Those samples that remained visually unaffected had no evidence of thaumasite attack.
5. There was no apparent benefit in increased Minimum Cement Content and or reduced W/C ratio in resisting the thaumasite form of sulfate attack in DS3 or DS4 conditions. *NB: A UKQAA conclusion.*
6. Whether the temperature cycle starts at 17 or 7C seems to have no significant affect on the overall performance of the fly ash or SRPC mixes. All mixes were less affected by thaumasite attack when at a fixed temperature of 12C. *NB: a UKQAA conclusion.*

Advice to the Concrete Specifier

Based on this project and similar projects carried out by a number of researchers, the UKQAA has concluded;

1. The use of fly ash in concrete mixes complying with the recommendations of BS8500[2] (Table 6 of BS8500-2) and BRE Special Digest 1[3] gives adequate protection to concrete from the thaumasite form of sulfate attack.
2. Higher proportions of fly ash than the normal 30% of cementitious content (CIIB-V+SR), up to and including 50% fly ash (CIVB-V), are able to give increasing resistance to the thaumasite form of sulfate attack.
3. There are no significant effects on the durability of fly ash based concretes in resisting sulfate attack associated with the early age curing temperature. We would conclude that the time of year concrete is placed has no bearing on the resulting durability of that concrete

Acknowledgements

The UKQAA would like to thank Dr Andrew Dunster and Dr Norah Crammond of BRE for carrying out this work on our behalf.

V3 August 2009

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[1] Effects of temperature on thaumasite formation in PFA concretes: Final Report, Prepared for: Dr L K Sear, UKQAA, 31 July 07, Client report number 238798

[2] BS 8500-1:2006 BS 8500-1:2006. Concrete. Complementary British Standard to BS EN 206-1. Method of specifying and guidance for the specifier

BS 8500-2:2006 BS 8500-2:2006. Concrete. Complementary British Standard to BS EN 206-1. Specification for constituent materials and concrete

[3] Concrete in aggressive ground (Special Digest 1), BRE Construction Division, June 2005, ISBN: 1 86081 754 8, BRE Bookshop.