UNITED KINGDOM QUALITY ASH ASSOCIATION

Technical Datasheet

The use of Fly Ash for reducing the heat of hydration

Introduction

Cracking in concrete resulting from the thermal processes associated with the hydration of cementitious components has been recognised as a problem for many years. In the construction of the Hoover Dam, in the early 1930's provision was made for cooling the concrete using water passed through internal pipework, simply because it would have taken >100 years for the heat to dissipate naturally.

When Portland cement (CEM I) reacts with water within the concrete mix, heat is generated. In thinner sections this heat is readily conducted to the surface of the concrete and dissipates. However, in thick sections of concrete, especially at higher ambient temperatures when the rate of reaction is accelerated, the low thermal conductivity results in a heat build-up and subsequent increased temperatures in the core of the concrete. The concrete in the centre sets and gains strength in a thermally expanded state in comparison with the outside surfaces. When this heated core eventually cools the degree of thermal contraction can be sufficiently different resulting in cracks. These cracks may range from being surface phenomena of little structural significance to cracks that pass through the full depth of the structure.

Minimising the risk of thermal cracking

There are a large number of factors that influence the formation of thermal cracks as summarised below;

1. **Temperature rise:** Clearly limiting the risk of the temperature rise within the concrete will reduce the temperature differentials between the concrete surface and core. The factors influencing this are;
    a. **Cement content:** The lower the cementitious content the less heat will be generated during the hydration process.
    b. **Type and source of cementitious materials:** The more reactive the components at early ages the more heat will be generated that is unable to diffuse quickly enough.
    c. **Concrete properties:** Thermal conductivity of the concrete, the coefficient of thermal expansion of the aggregates being used, autogenous shrinkage, drying shrinkage and tensile strain capacity.
2. **Restraint:** If the concrete is in some way restrained either internally or externally, the greater the risk of cracks developing. This may be simply resulting from being placed against adjacent concrete through to the restraint related to heavy reinforcement, so the provision of movement joints is critical, see Figure 1.
3. **Other factors:** These include a range of relevant issues, including the formwork type and its insulating properties, the ambient temperature at placing and during the curing period, pre-cooling of materials, ice addition, insitu cooling of the structure, movement joints, solar gain, drying shrinkage, etc.

This technical datasheet will only concentrate on the effect of the cementitious type, specifically fly ash as an addition, on the heat of hydration. For fully assessing a particular construction it is advisable to consult appropriate guideline documents, such as "Early Age crack control in concrete", CIRIA report C660[i], Concrete Society report TR67[ii] or Dhir et al[iii] work on very low heat special cements.

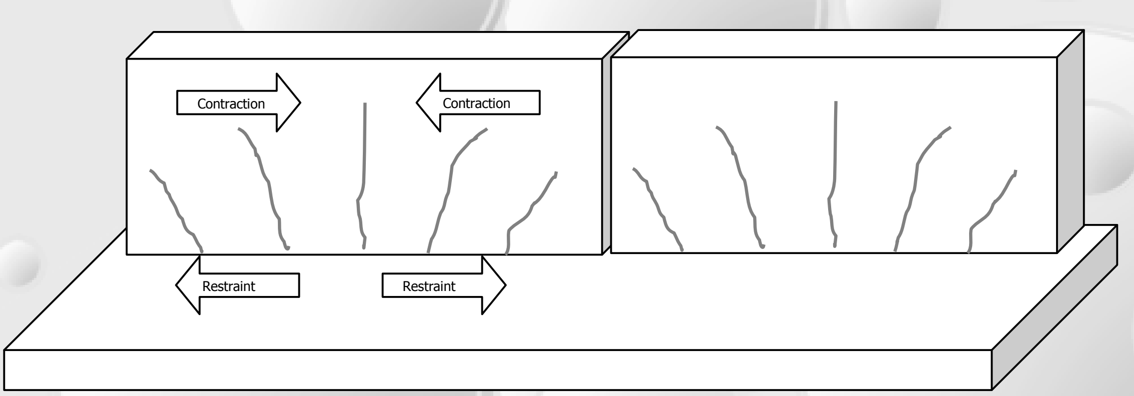

Figure 1 - Schematic of thermal cracking caused by external restraint

The effect of differing cementitious materials

The considerable majority of the heat produced when concrete is curing is generated by the Portland cement component (CEM I) reacting with the water. Additions such as fly ash (Pulverised Fuel Ash – PFA) or Ground Granulated Blastfurnace Slag (GGBS) are pozzolanic or at least less reactive. Therefore, by partially substituting the CEM I component in the concrete with these additions the overall heat generated is reduced significantly.

Estimating the effect of fly ash and GGBS is best done using the specialist software, such as that given in C660. The following figures in this datasheet were produced using the software provided within C660.

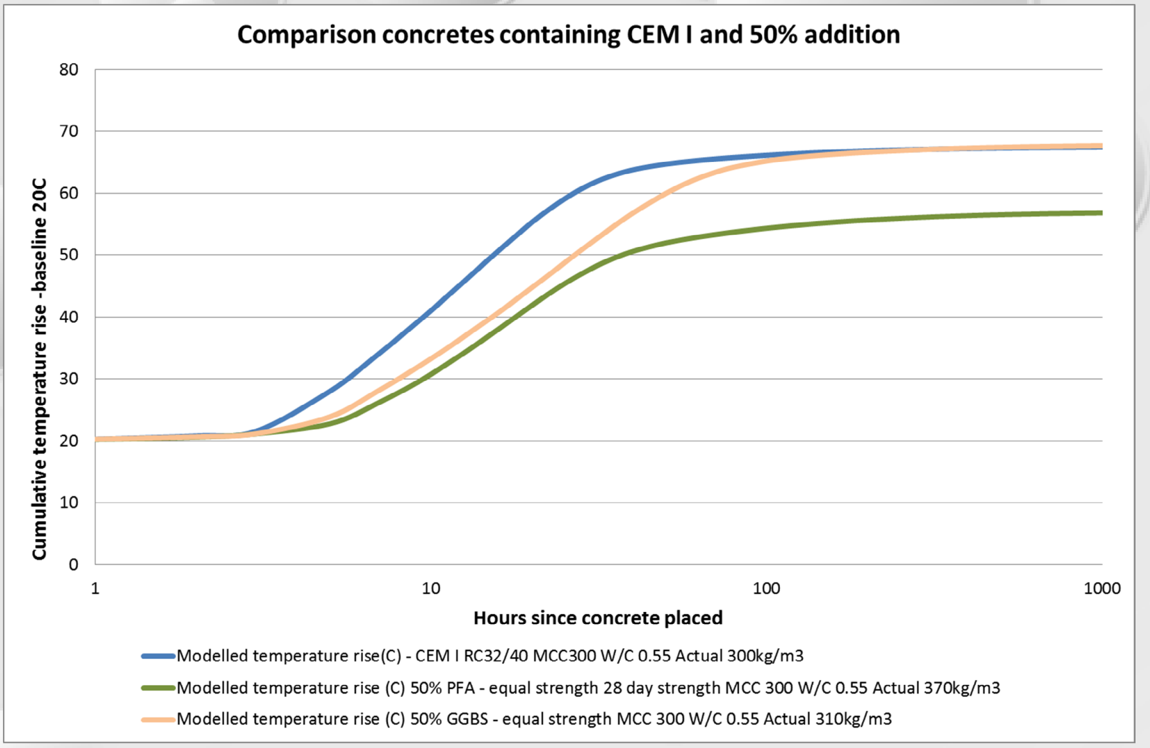

Figure 2 - Temperature rise for various cementitious types

Figure 2 compares the temperature rise modelled in concrete in adiabatic conditions with time for concrete mixes containing CEM I, 50% GGBS and 50% fly ash, which have been designed to give the same 28 day strength. It is immediately clear that the 50% fly ash mix results in a very much lower temperature. The pozzolanic reaction is in fact highly temperature dependant, but not an exothermic reaction. Effectively, the resulting temperature profile is one of the CEM I component only, which will be significantly reduced by substitution with the fly ash. It is this effect that results in the 10C reduction in temperature as seen in Figure 2.

Figure 3 shows even higher rates of substitution with 70% fly ash and GGBS. The pozzolanic reaction associated with the hydration of fly ash is a relatively slow process and the specification of strength at 28 days often results in higher cementitious contents being specified than is required to achieve minimum insitu strength needs when the structure is loaded. An alternative approach would be to specify the concrete for 56 day strengths, allowing time for the benefits of the pozzolanic reaction to be seen in compressive strength. GGBS is partially pozzolanic, but also partially has the chemistry of a Portland cement. The result is some heat is contributed to the hydration processes and therefore not as effective as fly ash in reducing the peak temperatures. Figure 3 is based on such a specification, with the benefit being dramatic reductions in peak temperature that will be generated using 70% PFA. Where more than 50% of the cementitious content is fly ash this is generally known as High Volume Fly Ash (HVFA) concrete.

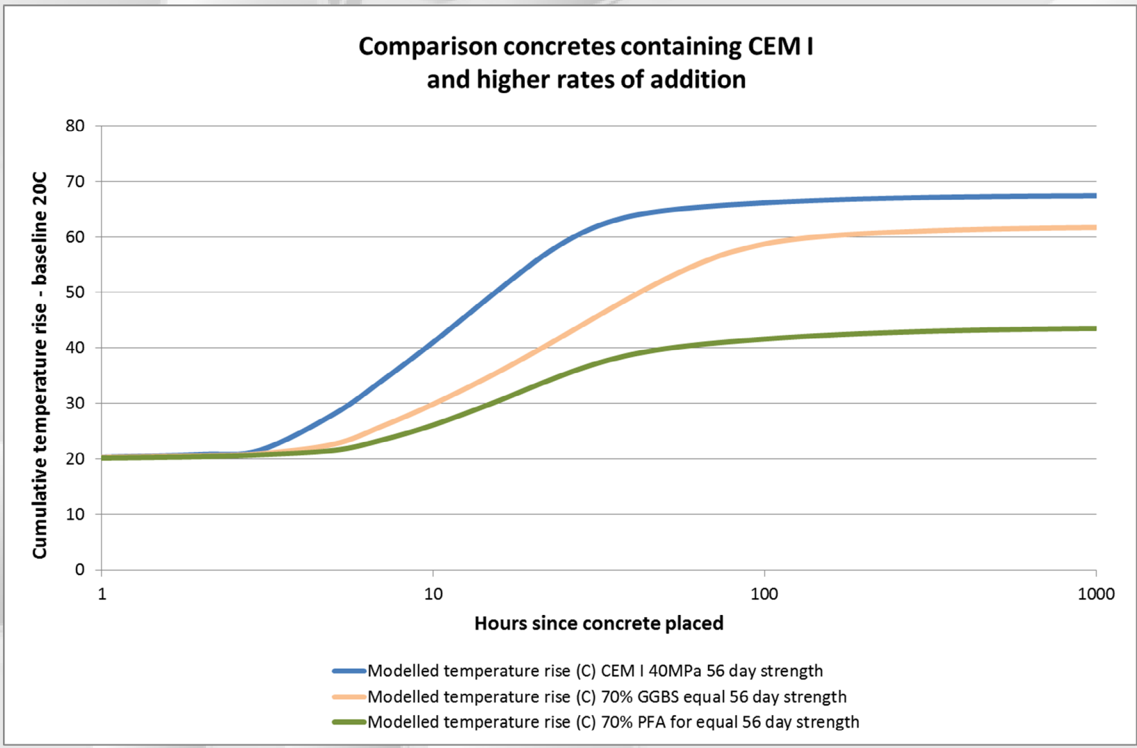

Figure 3 - Higher rates of addition for equal 56 day strengths

Reducing the peak temperature is only part of the issue. If the differential in the temperature at the concrete's surface and core is too great the differential contraction on subsequent cooling may result in cracking. It is generally agreed that a differential of less than 20C will minimise the risk of cracking, because the tensile strength of concrete is usually great enough to prevent such cracks. When the formwork is removed, the maximum differential will quickly be observed, with subsequent gradual cooling. As shown in Figure 4, high proportions of fly ash are capable reducing the temperature differential.

Producing high volume fly ash concrete in the UK

It must be noted that currently European (BS EN206-1[iv] and BS EN197-1[v]) and British standards (BS8500 Parts 1 & 2[vi]) only permit a maximum of 55% of fly ash to count towards the minimum cement content or maximum water/cement ratio. Therefore, in order to achieve the equivalent of 70% of the total cementitious (HVFA) the extra 15% of fly ash will have to be added as Type I addition, e.g. as a filler aggregate. This would normally be compliant with BS EN13055-1[vii]. In most cases the cement manufacturers produce CEM II B-V containing typically 27% fly ash. As a result extra fly ash as a Type II addition to BS EN450-1 and/or to BS EN13055-1 as a Type 1 addition will have to be added at the concrete producing plant. Alternatively, for larger contracts cement companies may produce a blended product specifically for the work.

In order to achieve reasonable early strengths and sufficiently low cementitious contents, the use of high range water reducers may be necessary with HVFA concrete. This effect on the peak temperature may be ignored, though it may delay the occurrence of the peak temperature by up to 10 hours.

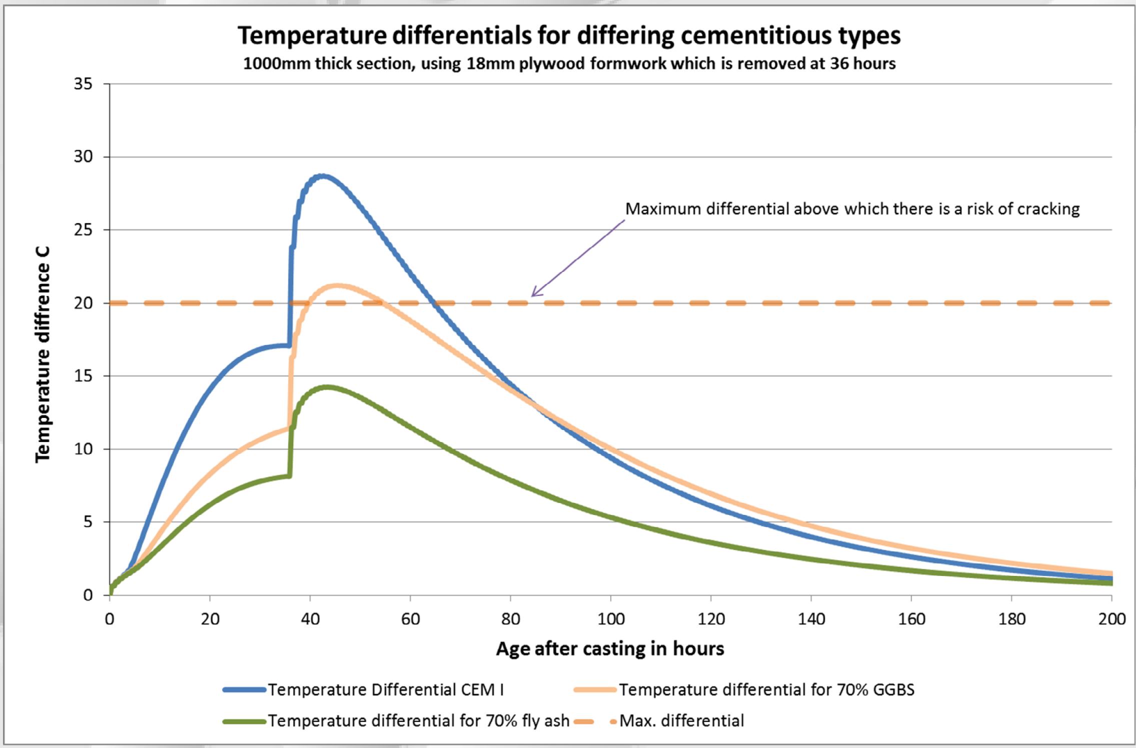

Figure 4 - Using HVFA to keep the peak differential below 20C

Conclusions

There are significant potential advantages in the use of high proportions of fly ash to reduce the heat of hydration in concrete and thereby reduce the risk of thermal cracking. Fly ash being pozzolanic can be used at high substitution rates thereby reducing the heat generated by the hydration of the Portland cement components (CEM I).

The user should seek specialist advice from the concrete producer and publications such as CIRIA report C660 and/or their contract specification, such as the Specification for Highway Works, etc where applicable.

In general usage the term 'fly ash' is used for pulverized coal ash but it can also cover ash from burning other materials. Such 'fly ash' may have significantly differing properties and might not offer the same advantages as ash from burning pulverized coal. UKQAA datasheets only refer to PFA / fly ash produced from the burning of predominantly coal in power stations.

Version 1.0 – August 2011

[i] Bamforth P, Early Age Thermal Crack Control in Concrete, CIRIA report C660, 2007. CIRIA, Classic House, 174-180 Old Street, London, EC1V 9BP, UK

[ii] Movement, restraint and cracking in concrete structures, TR67, April 2008, Concrete Society, Camberley, Surrey, GU17 9AB, UK.

[iii] Dhir R K, Paine K A, Zheng L, Design data for low heat and very low heat special cements, November 2006. University of Dundee, Contract CTU/I53.

[iv] BS EN 206-1:2000, Concrete. Specification, performance, production and conformity, BSI, 389 Chiswick High Road, London, W4 4AL, UK

[v] BS EN 197-1:2000, Cement. Composition, specifications and conformity criteria for common cements, BSI, 389 Chiswick High Road, London, W4 4AL, UK

[vi] BS 8500-1:2006, Concrete. Complementary British Standard to BS EN 206-1. Method of specifying and guidance for the specifier, BSI, 389 Chiswick High Road, London, W4 4AL, UK

BS 8500-2:2006, Concrete. Complementary British Standard to BS EN 206-1. Specification for constituent materials and concrete, BSI, 389 Chiswick High Road, London, W4 4AL, UK

[vii] BS EN 13055-1:2002, Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout, BSI, 389 Chiswick High Road, London, W4 4AL, UK