DISCUSSION

The effect of fly ash properties on concrete strength – E P Kearsley and P J Wainwright

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The conclusions given in this paper contradict to some extent the findings obtained from extensive local and international research using South African fly ashes and are also not supported by the practical experience gained in the last 20 years using these fly ashes in southern Africa as well as the Middle East (exports) as extender and constituent in cement.

Worldwide in-house research currently undertaken by the writer's organisation, which ranks as world No 1 cement manufacturer, supports this statement.

Point 1

The effect of fly ash on the water demand in a mortar or concrete system is not only influenced by the morphology of the fly ash (including the presence of unburned carbon), but more so by the presence of fine spherical particles and the interaction with the particle size distribution of the cement used (packing density / filler effect).

There is, however, another good reason why specifications for fly ash (as extender or constituent in cement) limit the unburned carbon (~ LOI) to 5 %: during concrete compaction carbon will float to the surface because of the low density, and larger amounts can cause discoloration.

Point 2

Locally we have all the evidence that the +45 micron residue test is an excellent indicator for South African fly ash quality. One can look for example at the different grades of fly ash commercially available from Lethabo Power Station.

The classified fly ash (Dura-Pozz) complying with SABS 1491: Part II has a nominal size smaller than 45 micron (μm) resulting in a proven water reduction of ~/5 ℓ/m³ when used as 30 % replacement in concrete. This ash also shows a good strength development by stimulating cement hydration (fine filler effect) and forming additional C-S-H 'needles' (pozzolanic reaction). A number of density-related durability aspects can also be linked to the controlled top particle size of classified fly ash.

The unclassified fly ash (Pozz-Fill) taken from the ash bunkers (before conditioning), with the nominal particle size depending on prevailing burning conditions, coal milling and the condition of each of the seven electrostatic precipitator fields, will be a bit variable and not as effective in reducing the water requirement of a mix.

Pozzolanic reactivity, whilst not bad, will be somewhat lower than with classified ash (controlled by 45 micron residue). The overall performance of this ash can obviously not be judged through a single evaluation since there are too many factors which could have an influence, and the above performance statement is based on a test series in concrete lasting two years.

The superfine ash (Super-Pozz) from Lethabo, with a nominal particle size smaller than 15 μm (produced by a special separation process), on the other hand has a high reactivity and excellent water-reducing capability because of the positive effect on the combined granulometry with cement.

The successful use of the 45 micron residue test and the max limit of 12,5 % go back to the early days of fly ash production in South Africa when ash was still selected from the hoppers of Fields 3 and 4 underneath the electrostatic precipitators at the so-called 'new generation' dry bottom boiler power stations fired with pulverised coal.

Changes in the ash disposal technology not allowing access to individual hoppers anymore and increased demand for quality fly ash necessitated the use of air-classification plants, which resulted in two benefits: ash from all precipitator fields could be utilised for the separation process (basically a split at 45 micron resulting in improved fractional recovery) guaranteeing at the same time a very consistent material in terms of physical properties and crystalline phases / glassy parts.

Point 3

While specifications often limit the use of fly ash to 30 % replacement in structural concrete, South African quality-controlled fly ashes have been successfully used at much higher levels. A large number of concrete structures at the recently completed Maguga Dam project in Swaziland used a 40 % replacement; up to 70 % were used in large rollcrete dams, 40–50 % in a number of mass concrete structures, 40 % at the Katse intake tower and in the lining of the Delivery Tunnel South – to name a few.[2]

Point 4

Having evaluated most fly ash sources in southern Africa, the writer can only stress again the importance of a limited carbon content as well as a low and consistent 45 micron residue.

Testing all the sources 'deemed unfit' (by whom?) on a most probably once-off basis for performance in concrete together with a number of cements does not seem to be the right approach, since ash quality/properties have to be monitored for some time before any judgement can be made.

Quality-controlled fly ash supported by extensive research programmes has managed to establish a good track record in South Africa. There is no shortage of this material and the evaluation of other sources would only be of limited academic interest.

As a concluding remark, an explanation why South African fly ashes perform often slightly different to fly ashes 'produced' somewhere else in the world and why some overseas research findings have to be read with caution.

South Africa had decided some time ago to 'transport' electricity and has therefore built their coal-fired power stations on top of a coal field.

While coal sources / coal supply to power stations around the world vary on an ongoing basis, a South African power station is fed for its lifetime with the same grade of coal. This allows a specific boiler design for optimised burning conditions and is one of the reasons why local fly ash have often very low carbon contents (LOI ~ 1 %) and are much more consistent in performance compared to other fly ashes, combined with the fact that only base load power stations have been selected as a source of ash to be used in concrete.

Notes

1 J E Krüger, 2003, South African fly ash: a cement extender, South African Coal Ash Association (on CD-Rom).

2 R Amtsbüchler, 1995, fly ash in large water supply project: a South African case history, *Proceedings* of Fifth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete

Dr R Amtsbüchler, PrEng,
Lafarge South Africa
(Manager – Product Assistance Department)

RESPONSE

The authors appreciate the comments made by Dr Amtsbüchler and wish to emphasise that we believe that classified fly ash is an excellent product, but our view is that there are other ashes available that do not meet the current specifications, which could also be used in concrete without having any detrimental effects on the concrete properties. The main point we are trying to make is that one should not automatically reject an ash just because it fails to meet the standard. One should test the performance (not the prescription) of the ash and also take into account the applications to which it is going to be put before accepting or rejecting it. As far as the individual comments are concerned, we wish to reply as follows:

Point 1

We agree with Dr Amtsbüchler that the packing density of the fine filler has a significant influence on the effect of the fly ash on water demand. In normal concrete with relatively low fly ash contents and limited fines the finer ash does result in more workable concrete, but in mortars with high fly ash contents and very fine cements an increase in the particle size of the ash can in fact lead to an improvement in packing density.

Published literature indicates that the coarser particles tend to contain more carbon (Sarkar & Ghosh 1993), but as Dr Amtsbüchler mentions, South African fly ashes do tend to have low carbon content and the discoloration that can be caused by high carbon content should therefore not be a problem. If performance tests do indeed show discoloration to be a problem, then of course the ash should not be used.

Point 2

We agree with Dr Amtsbüchler that quality control and consistency of building materials are of utmost importance when producing high-quality concrete. The variability of a fly ash from a specific source is not normally such that the variability of the concrete produced is likely to be any greater than that of a comparable mix without fly ash (Cannon 1968). For quality control purposes, records should be kept of the physical and chemical properties of any fly ash used in concrete.

The finer fly ash does seem to result in higher early strengths (up to 28 days). We have, however, found that after a long period in time (one year) unclassified ash can reach strengths similar to that of finer ash from the same source at the same water/cement ratio (Kearsley & Wainwright 2001).

The use of the 45 micron residue test as a means of quality control has long been a point of debate and disagreement amongst researchers from different countries. It may well be that all ashes that pass this test are good-quality ashes, but in our opinion this does not necessarily follow that all ashes that fail the test are unsuitable for use in concrete. The results we have presented in our paper serve to illustrate this point.

Point 3

Dr Amtsbüchler lists a few of the projects where high fly ash contents have been successfully used. Our concern is that there are many instances where decision-makers insist on the limits set in specifications being met without taking the possible advantages of alternative solutions into account. Again, the point we are trying to make is that we believe that the specifiers should specify only the desired properties of concrete and give an indication as to which materials might be suitable. They should, however, be prepared to consider using materials that fall outside the traditional norms set if the suppliers can scientifically prove the suitability and benefits of using these materials.

Point 4

We agree with Dr Amtsbüchler that ash properties have to be monitored for a period of time before any judgement on the suitability of an ash source can be made and it would be unwise to use materials without proven track records. Currently only Lethabo, Matla and Kendall power stations have the ability to process fly ash (Krüger 1999) and with increasing transportation cost there are many reputable concrete suppliers that could benefit from using alternative fly ash sources – even if the properties of the fly ash from these sources do not meet the requirements set by the current standards.

References

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Krüger, J E 1999. Guide 2: Origin, history and properties of South African fly ash and Portland fly ash Cements. Guides on the use of South African fly ash as a cement extender. The South African Coal Ash Association.

Sarkar, L S & Ghosh, S N 1993. *Progress in cement and concrete: mineral admixtures in cement and concrete*, Vol 4. New Delhi: ABI Books.

E P Kearsley and
P J Wainwright