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Pulverized fuel ash concrete in construction of natural draught cooling tower

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The use of pulverized fuel ash (PFA) in concrete is now well established in the UK although not many years past the industry's approach was cautious and lagged several years behind concrete practice overseas. The widespread utilization of PFA has been achieved as a result of pioneering work, typical of the subject of the Authors' Paper. The use of PFA in concrete has also been facilitated by a stringent British Standard[3] for specifying the properties of PFA when used in concrete supported by quality assurance.[31] Fineness of the PFA expressed as a residue on a 45 μm sieve has a marked influence on its performance in concrete. The particularly fine limit for fineness within the British Standard ensures variability is within easily managed limits.

50. In the construction of a cooling tower using PFA concrete for the first time it is understandable that the Engineer required a more detailed and stringent specification than the current British Standard, notably the inclusion of 150 μM sieve retention, density and lower loss on ignition values. However, the enormous body of knowledge on the behaviour of PFA in concrete should now allow engineers in the UK to relax, rather than tighten, the present British Standard in the confidence that most PFA will make good concrete. In continental European countries, where standards for PFA exist, the values for fineness are much more coarse than adopted in the UK. Conversely, in controlling the overall quality of ash some European countries prefer a lower value for loss on ignition which is considered by many to have a second order effect. These differences have made compromise over the development of a European Standard for PFA extremely difficult.

51. The Authors referred to the shape factor assessment of PFA which would enable the specification of an envelope of grading to obtain maximum benefit from improvements in workability. As a result, or even in support of the sieve residue test, it appears to offer marginal benefits, if any, for the routine use of PFA in concrete. The sieve residue test has served the needs of ash in concrete extremely well and the determination of shape factors and grading envelopes using sophisticated laser technology, except in the research field or state of the art engineering, is inappropriate for the supply of PFA to the great majority of projects.

52. The Authors have expressed some doubts on the predictability of a strength–maturity relationship in the first 24 hr and the likelihood of non-linearity. Others[32] have investigated the strength–maturity relationship for PFA concretes by comparison with OPC concrete and their results lend some support

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to the Authors' conclusions but additionally they concluded PFA concrete has a different strength–maturity relationship for different curing regimes. At the present time it would appear unwise to rely too much on a strength–maturity relationship for PFA concrete until further work is published.

53. The Authors mentioned a two-week reduction in shell construction owing to earlier stripping of shutters directly attributable to the confidence in concrete strength data provided by the TMC apparatus. Was this time saving significant when compared with the extra costs involved in establishing the onsite monitoring procedures using TMC?

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54. *Mr Joyce* raised a number of points particularly with regard to UK Standards for PFA. Work on the relevance of PFA in concrete[33] initiated by one of the Authors supports the view that the UK should consider a relaxation of sieve residue retention to bring it more into line with Standards in other countries. Conversely if admixtures are to be used the Authors' experience shows that the benefits of these admixtures may be lost in part if loss on ignition increases. This is likely to result in a loss of workability with resulting increase in water/cement ratio and consequent reduction in strength.

55. Assessment of PFA by the shape factor[12] offers to the Engineer a means of identifying the more suitable ashes. Currently BS 3892[3] states limits on ash by retention on a 45 μM sieve. It does not nor indeed cannot identify fineness of ash or grading and so it is possible that an ash may be particularly fine (more water demand) or agglomerated/broken spheres (loss of workability). At site where specific workability is required for placing and compacting a change in fineness and/or loss of spherical shape, albeit satisfactorily passing the 45 μm sieve criteria, can result in loss of workability, an adjustment of water and reduction in compressive strength. The Authors agree that small sites may not wish to use this type of equipment but on larger sites and at ready mix plants it can only contribute to a better quality control system.

56. The Authors are aware of the work published by Dhir *et al.*[32] on strength–maturity relationships of PFA concrete. However, there seems to be a complete absence of published data on early age strength in these structures. Laboratory investigations by their nature enjoy a kind of stability which is not available to site construction. Work completed by one of the Authors on the cooling towers at Drax[8] confirmed the feasibility of using PFA concrete in these thin shells. This type of construction demands early strength to ensure that the construction sequence is maintained safely. Hitherto cubes taken and stored on the access scaffold under wet hessian was the method adopted for checking the adequacy of in situ strength. Fig. 11 shows this feature and demonstrates the difference between scaffold cubes, BS 1881 and temperature matched cubes.

57. Construction of this type is entirely dependent on confidence to move access rigs at the earliest opportunity. Temperature match curing of in situ concrete provided data which confirmed in situ strength, thereby allowing safe movement of the rigs. Because of the uniqueness of shell construction with PFA concrete more temperature probes were used than perhaps would otherwise have been the case. The saving in construction time directly attributable to the use of TMC equipment and the resultant increase in thermal performance of the power station and associated revenue was several orders of magnitude greater than the

cost of developing and using this TMC equipment. Perhaps more importantly it confirmed the safety of the works and gave confidence throughout in the construction.

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