Mix design for PFA concrete

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The Paper provides the first complete engineering solution to concrete mix design and considers the full rheology of the material constituents. The limitations of BS 3892 (specification for PFA for use as a cementitious component in structural concrete) have been obvious to many engineers for a number of years, and this standard would have been reviewed had not the CEN begun the development of a new Euro Standard.

41. To base the calculations for the material properties on the relative volumes is very logical and the best way of achieving a fully homogeneous mix because it takes into account the relative volumetric displacement of each material component. None of the batching accuracy is lost because realistic relative densities are provided to convert the volumetric components into the final batch weights. The method is particularly suitable for PFA/OPC concrete mix design in that the rheological characteristics of all the ingredients are considered and fully analysed for each grade, and for workability and cementitious content. The adjustment charts provide a fully integrated control on the volume fractions by considering the particle shapes, grading and proportions of all materials, each of which contribute to the total cement content for a given workability and target strength.

42. With any concrete mix design, full trial mixes are always necessary, but mix proportions based on a fully integrated design method will provide more correct solutions needing less fine tuning than under present methods. The Authors' comment, in § 38, that the method lends itself to computerization is particularly appropriate. I have found that with all materials' grading characteristics stored on random access files and with the use of a fully interactive computer programme, a complete range of mix designs can be generated in a matter of minutes, enabling various material proportions, air contents, strengths and cementitious contents to be analysed quickly. Armed with such detailed information, the engineer can tailor the mix design more precisely to the exposure conditions and site handling requirements, and thereby have more confidence that the end product will result in more durable concrete.

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Mix design should facilitate the best use of the available materials to provide a concrete with certain desirable characteristics, and mix design for PFA concrete should clearly be no exception. However, the mix design method can facilitate this only if reliable standard tests for the constituent materials are available. As knowledge progresses then standards can be more selective in adopting useful and more relevant test methods and procedures in the future, and will also be less restrictive by rejecting only those materials which are unsuitable. On the basis of our test

DISCUSSION

results, we would hope that the grading modulus of the fly ash criterion will stand the test of time in much the same way as, for example, the angularity factor tests for the coarse and fine aggregates have. These simple tests for use in mix design, unlike their predecessor the 'angularity number', provide satisfactory values for regular bodies, such as spheres, as well as values for natural aggregates which correlated well with the concrete workability results.

44. *Mr Stewart Smith* rightly points out that with any concrete mix design, full trial mixes are always necessary. Many mix designs can be generated in minutes from common data stored in the computer, but only a few trial mixes are actually needed to confirm a much larger number of actual designs, as these designs will generally be related to a very limited number of different materials.

45. Perhaps the two greatest sources of error in the design procedure are the variabilities of the constituent materials and the strength relationship. Consistent quality in the source of fly ash, cement or aggregates is far more important than that any of the materials should conform to any preconceived ideas of size or grading. The other main source of error is the strength relationship. The inter-relationship between cements and fly ash, for example, appears to depend very significantly on chemical interactions, such that two different sources of nominally similar Portland cements can provide quite different strength relationships with the same fly ash. It is therefore suggested that, where possible, four mixes should be cast for each source of cement and required PFA/OPC ratio, with the required fly ash and aggregates, and tested at the required maturity, to provide strengths at four $(c + f)/w$ ratios: two results to locate the lower linear region; and two results to locate the upper linear region of the strength- $(c + f)/w$ ratio relationship.

Corrigenda

p. 641: § 7, line 8	For 'analyses' read 'sieve analyses'.
§ 7, line 20	For '1%' read 'percentage'.
p. 648: § 16, line 6	For '/mm' read ' mm^{-1} '.
p. 651: § 21, line 11	For 'Fig. 4' read 'Fig. 5'.
p. 656: Table 8	For 'Nominal VB' read 'Designed VB' (i.e. VB predicted after making all adjustments, including pfa adjustment).
Also p. 658, Table 10.
Table 8	For MF1, Actual VB of '46.0' read '4.0'.
p. 665: § 34(h), line 8	For ' A_m ' read ' A_s '.