

Variations in the strength of Portland cement*

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Mr Wright has produced an extremely interesting and stimulating analysis of one of the big variables in the manufacture of concrete.

Mr Burke (p. 132) has queried if the variations in strength of cement for the works quoted by Mr Wright are typical of all works in this country. My experience has been that on the whole the variations are less than those found by Mr Wright. The figures below outline our findings.

From Table 1 there seems to be little difference between the merits of the B.S. mortar test and the concrete test used by Mr Wright as a means of assessing the variations in compressive strength. This has not been our experience and the following example, although possibly an extreme case, illustrates this point.

During a job some 10 or 11 years ago we had a period of 8 months when the works cube results were reasonably steady and uniform. Samples of the cement being used were tested by the B.S. mortar test and by a laboratory concrete cube test. The 28-day results obtained over this period were:

Test	Number of tests	Standard deviation (lb/in ²)
Works cubes	160	370
B.S. mortar cubes	44	450
Laboratory concrete cubes	55	225

In our laboratory we therefore adopted a concrete test in preference to the mortar test and have accumulated some data on 26 works producing ordinary Portland cement in this country.

The mix used is 1:2.42:4.02/0.60 by weight. Batches of three 4 in. cubes are mixed mechanically, the three cubes being tested at 3, 7, and 28 days. For each sample of cement, five batches are made on different days and the average of the five cubes at each age is considered as the result. The object of making small batches on different days is to iron out variations in testing occurring from day to day and from batch to batch. The standard deviation within the groups of five cubes for a sample of cement at 28 days is 150 lb/in² (based on the results from the first 900 samples tested).

Records have been kept by us of the strength of cement supplied from 26 works over the past eight years. For about one-third of these works the records are fairly comprehensive and from these it may be seen that the strength of the cement from some works has remained steady; from some works it has increased and from others decreased; whilst from some it has been very erratic. On balance a slight increase in the general average strength seems to have occurred. For some of the remaining works only a few samples have been tested and the reliability of their values is therefore less certain.

For the 26 works the standard deviation "between works" at 28 days is 450 lb/in².

One general conclusion from the results is that in order to get something like a reliable value for the average and standard deviations for any works, it is necessary to extend the sampling over a period of at least nine months and to take at least 30 samples (B.S. 600 states "no estimate of the standard deviation can be considered satisfactory if the total number of observations is less than 30").

A periodic survey was made of our data last November to obtain up-to-date values for the average and standard deviations. Out of the 26 works there were nine for which the information appeared most reliable, having been obtained from at least 35 samples covering a period of at least a year. The average 28-day standard deviation "within works" was 320 lb/in², the highest being 490 and the lowest 220 lb/in².

The values we have obtained for variations "between works" and variations "within works" are 64 and 80% respectively of the values found by Mr Wright. Although these differences could be due to the chance selection of the works from which samples were taken, it seems to me unlikely that this is the whole explanation. Might they not also be due to Mr Wright's having used more data based on B.S. mortar tests than on concrete tests?

Of several other points which occur to me, there is one which has not been mentioned by Mr Wright. There can be variations in the workability of concrete due to the cement, and when one is working to a given workability this has a similar effect to variations in strength of the cement. I wish we had a test for the strength of cement that takes this into account. It is an effect that is sometimes important in the design of concrete mixes.

*Pages 123-132 of Magazine No. 30.

Reply by the author

I would like to thank Mr Burke for his contribution* to the discussion of this paper. It is always valuable to have the manufacturer's view expressed when considering the variability of a product and Mr Burke's contribution has helped considerably in presenting the matter in true perspective.

It is particularly interesting to learn a little of the reasons for the variation in properties of Portland cement and I am not surprised to read that any attempt to reduce the variation would be expensive and in all probability far from economical.

Mr Burke's views on strength tests at early ages coincide closely with my own. Inevitably the age at which concrete is tested is at present a compromise between what is desirable on theoretical grounds and what is practicable. Experience at the Road Research Laboratory suggests that the 7- and 28-day strengths are the most valuable and it is generally undesirable to attempt to base any assessment of a cement on a strength obtained at less than 7 days. Since the paper was originally drafted, the series of tests carried out on each batch of cement at the Road Research Laboratory has been modified, but the 28-day strength tests have been retained, although these are not required in the British Standard.

The contribution from Mr Mears is also extremely useful, particularly in comparing the assessments of variation in cement obtained with mortar cube tests

and with concrete cubes. In this connexion, the introduction of a concrete cube test in B.S.12 is to be welcomed and this test, which approximates closely to the test used by Mr Mears, is at present being carried out at the Road Research Laboratory together with the mortar cube tests. Unfortunately, insufficient information has so far been collected to enable any further comparison to be made between the concrete cube test and the mortar cube test. It seems quite possible, however, that when concrete cubes are used the apparent variation of Portland cement is somewhat lower than when mortar cubes only are used.

I agree with Mr Mears that variations in the workability of concrete due to differences in cement also present a considerable problem in designing concrete mixes. This problem may be particularly noticeable where cement is delivered in bulk at high temperatures. Although the use of hot cement does not appear to affect the strength of concrete appreciably, there is a considerable weight of opinion to suggest that it reduces the workability and in practice the water content has to be increased. This effect is not normally shown up by standard cement tests as a sample generally has adequate time to reach room temperature between being taken and being tested. This and other minor variations all add to the difficulty of controlling concrete quality and Mr Mears is to be congratulated on obtaining standard deviations of works cube strengths as low as 370 lb/in².