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Further development of the two-point test for workability and extension of its range*

G. H. Tattersall and S. J. Bloomer

Contribution by Professor O. J. Eze-Uzomaka
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I would like to congratulate Dr Tattersall and Mr Bloomer on their interesting paper and for sustaining effort in a subject which, although very little has really been done on it, still attracts very few researchers. I would, however, like to make some comments on the text as follows.

The second assumption the authors make in discussing some of the conclusions of my earlier work (reference 3 of the paper) is not quite correct. In demonstrating that flow of plastic concrete obeys the Bingham model, I used the peak torque values, i.e. before the onset of 'structural breakdown'.

As stated by the authors, we are in agreement regarding the conception of structural breakdown as used in my paper. However, it should be emphasized that a concrete mix is a composite, and structural breakdown in this context should not necessarily have the same import as structural breakdown in relatively simple fluids. In the case of a concrete mix, it is more of a reduction of the composite structure than the breakdown of the internal structure of the individual composites.

There are certainly considerable discrepancies in the few published results, owing largely to differences in instrument geometry and other fundamental factors consequent upon it. For example, an examination of the work by Murata and Kikukawa (reference 4 of the paper) raises a suspicion of the possibility of slippage in their tests. On the other hand, it is unlikely that Morinaga (reference 5 of the paper), with his more acceptable instrument geometry, obtained flow of the fluid across its entire annulus. The reconciliation of these limitations with manageable power requirement will continue to pose considerable problems with coaxial instruments except when the mix is very fluid.

It is from this point that the approach of Dr Tattersall and Mr Bloomer appears attractive. However, there is no demonstration so far that flow occurs sufficiently within the test material to guarantee that the bulk properties of the material are being effectively measured. Furthermore, although the impeller is an interrupted helix, one wonders whether, after a full revolution, the effect would not be similar to that of a cylindrical bob, especially in fluidizing and causing structural breakdown of the mix within the immediate vicinity of the impeller. I wonder, therefore, whether unequal impeller projections could have any merit?

*Pages 202 to 210 of *MCR* 109

Contribution by Dr P. F. G. Banfill

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As mine is one of the half-dozen laboratories mentioned by Dr Tattersall and Mr Bloomer where the Mk II two-point workability apparatus is in use, I feel justified in making some comments on their paper. Experience has shown that the apparatus is very satisfactory for laboratory work and that the skill required in operation is acquired very quickly. I am so pleased with it that it is now used as an integral part of the reinforced concrete technology laboratory project taken by all first-year civil and building engineering undergraduates in this University.

Quite apart from the fundamental superiority in principle of the two-point test for workability, Dr Tattersall and Mr Bloomer have developed, in the Mk II apparatus, the first really sensitive workability test. In the current standard tests the testing error is always unacceptably large, but recent work by Banfill(1) has shown that the Mk II apparatus is sufficiently sensitive to detect smaller differences in concrete properties than are produced by variations in batching and materials in the laboratory. This means that, for use on site or at ready-mixed concrete plants, where the variations are greater, the Mk II can easily show when the concrete is deviating from the specification.

My main point concerns the necessity for calibration of the apparatus. The Liverpool apparatus was constructed in our own workshops from drawings supplied by the authors, but even so shows slight differences in, for example, the clearance below the impeller and eccentricity of the bowl relative to the impeller. These differences are insufficient to affect the practical operation of the apparatus but, as Table I shows, they change the apparatus constants G and K. This means that the same concrete tested in two different apparatuses may give different values of g and h and that these differences may at first sight be significant, but use of the calibration constants will reconcile the results. A series of cross-calibration experiments was carried out in Sheffield with the Liverpool machine in 1978, when it was hoped that simple apparatus constants could be derived. Unfortunately the experimental design was too complicated and, although qualitatively the various machines agreed well, the results were not numerically conclusive. The subsequent development of the authors' theory at least identifies the calibration constants to be determined.

TABLE I: **Apparatus constants for Mk II machines.**

Machine	University of Liverpool	University of Sheffield
G	0·063	0·045
K	10·5	6·09
K/G	166	135
$1/G$	15·9	22·2

Experimentally, to carry out the calibration requires a series of Newtonian and pseudoplastic fluids. The choice of pseudoplastics is easy, as carboxymethyl cellulose conforms well to the power-law relationship and can be made up in different concentrations (typically 3–4% is suitable), but Newtonian fluids pose a problem. The thickest commercially available oils (W250) are around 5 N/m² s at 20°C. These are too thin to be of use in the two-point apparatus because the change in net pressure ($\pi - \pi_u$) only spans 25 lb/in² over the range of speeds of 0–1000 lb/in². Therefore higher viscosities are needed to match the sensitivity of the apparatus – up to 40 N/m² s giving a pressure range of about 200 lb/in².

These higher viscosities can be achieved by cooling the oil and measuring the relationship between T/N and η at 5°C. This is attractive because it also allows a range of temperatures to be used as the oil warms up, thereby giving more than one determination of the constant G. However, this method which has, I believe, been used at Sheffield up to now is unsatisfactory because of the sensitivity of viscosity to temperature and the difficulty of controlling the temperature of the oil in the bowl without enclosing the whole apparatus in an environmental chamber, which will upset the torque calibration of the Carter gear. At these low temperatures it is common for the temperature of the oil to increase by one or more degrees Celsius during the course of a series of pressure/speed measurements. For W250 oil, one degree decreases the viscosity by 12% at 5°C, so that the calculated value of G in Table I could be in error by this amount.

The obvious improvement on this unsatisfactory situation is to carry out the procedure close to room temperature using a higher viscosity fluid. I have used a blend of oil and bitumen generously supplied by Marston Lubricants, Liverpool 3. This is a mixture of the oil described above and bitumen in approximate proportions 3:1 and has a viscosity of 25 N/m² s at 20°C. Testing in the coaxial-cylinders viscometer shows a linear flow curve with no hysteresis.

The results in Table I were obtained using this oil at 17, 20 and 20°C, but a further improvement would be to use three different blends and operate entirely at room temperature.

In view of the unavailability of suitable commercial oils and the demonstrated importance of calibration of the two-point apparatus, I would like to suggest that the authors consider offering a calibration service so that each apparatus is supplied with constants of proportionality to convert g and h to yield value and plastic viscosity and that these constants should be checked from time to time. This should be done at a central laboratory, preferably at the point of manufacture, using the above improved techniques. Users of compression testing apparatus are aware of the need for regular calibration, so there is no reason why users of this workability apparatus should not accept it. It is hoped that series production of the apparatus will be carried out in a single works where proper quality control of dimension etc. during production is applied.* Here tolerances would be small and the calibration constants less variable than where apparatus is constructed independently in research institutions. Here calibration is essential.

*And SI units are used for the gauge. Ed.

Contribution by M. J. Waddicor

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As manufacturers and suppliers of admixtures, we are particularly interested in the development of techniques for the accurate measurement of changes in workability of concrete modified by the incorporation of admixtures. The BS 1881 tests for measuring workability and the flow-table test described in DIN 1048 are valuable as portable and simple methods for a limited assessment of workability. However, these tests are operator-sensitive, can give large experimental error, and are an incomplete basis for the comparison of workability.

A wider and more reliable analysis of the variables which affect the flow properties of concrete can be made by using the two-point workability test described by Dr Tattersall and Mr Bloomer. Using the rheometer, we have been able to evaluate plasticizing admixtures with greater control, and assess their performance more critically than previously. We have found the two-point test reliable and simple to use, giving a fuller description of workability that otherwise would have required the correlation of several single-point tests. This has given us a saving in time spent on analysis, and a broader basis for the comparison of admixture materials.

A potentially interesting area of application for the rheometer is its usefulness in optimizing mix design in combination with admixtures. Accurate characterization of the flow behaviour of concrete would reduce the uncertainties of (largely intuitive) mix design and minimize the possibility of over-specification of cement or water content to meet the requirements of satisfactory placing, compaction and strength. It is the present lack of information on the parameters that govern this aspect of concrete behaviour which should encourage practical application of the rheometer.

As laboratory apparatus for the development of plasticizers, the rheometer gives the benefit of a test based on sound theoretical principles, which is accurate and simple to operate, and provides a broad basis for the comparison of properties of plasticizers.

Reply by the authors

We are grateful to all three contributors for their helpful comments, and naturally we are pleased to know that other workers, both in industry and at university, have found the apparatus of value.

It is interesting that Mr Waddicor has raised the issue of optimization in mix design as another illustration of the necessity for two-point testing. An examination of figures from British Standard tests[2] showed that the results were consistent with the hypothesis that any single-point test assesses apparent viscosity at some average effective shear rate characteristic of the test, i.e. it measures $k = g/N + h$ where N is a measure of the shear rate. Since any variation of a factor F that affects workability (e.g. fines content or superplasticizer addition) will in general affect g and h differently, it follows that the position of the maximum in the curve of workability as a function of F will depend on N. In other words, if an attempt is made to find the optimum fines content for maximum workability, the value found will depend on the test used to find it. Dr Banfill made a similar point in his recent paper on flowing concrete[1].

We accept Professor Uzomaka's correction of our presumption that his Bingham lines related to minimum torque values and in general agree with his comments about the type of breakdown that might occur in concrete.

During the development of the apparatus we experimented with many different impeller shapes, including asymmetric ones, but finally settled on the interrupted helix. Visual observation is sufficient to show that the bulk of the material does flow and the difficulty postulated by Professor Uzomaka does not arise, provided the apparatus is used in the range of workability for which it was designed, i.e. medium-workability to flowing concrete. For lower workabilities, the Mk II is unsatisfactory because concrete pumped upwards is not immediately replaced and the impeller proceeds to rotate in the hole it has made. Because of this, we developed the Mk III apparatus, which is a simple modification of the Mk II in which the impeller moves in planetary motion and the difficulty is avoided, except for concretes whose workability is so low that they can no longer be regarded as a continuum. Again, we experimented with a range of impeller shapes and eventually chose an H shape. Details of this modification have not yet appeared in print, but we may point out that apparatus is available that can be used in either the Mk II or the Mk III mode; the theory of the Mk III is the same as that of the Mk II, and the results of the two forms have been related theoretically and experimentally so they may both measure on the same scale.

The cross-check between his apparatus and ours, to which Dr Banfill refers, was the first we ever carried out and from it we were able to devise an improved procedure which was used in another cross-check of our apparatus against one we supplied for use by Cementation Research Ltd. The results were as in Table II. In spite of the fact that operator A had never used the apparatus previously, the agreement is within that claimed (i.e. ± 0·1 for g and ± 0·2 for h) except for the $S + B$ result on the 105 mm slump mix, and it should be noted that such a mix has a workability just about at the limit of the range for which the Mk II apparatus is designed.

Nevertheless improvements should be sought, and along the lines suggested by Dr Banfill. Attempts are being made to standardize production of the apparatus so that, for ordinary use, calibration (other than torque calibration) will be unnecessary. There is no doubt that the method of controlling oil viscosity by means of temperature causes serious difficulty and we are grateful for the suggestion (already made to us privately) about the oil–bitumen blend; as a result of following this up, we have been able to find a supply of Newtonian polymer solutions of appropriate viscosities.

Dr Banfill's suggestion that a calibration service should be provided will be considered in discussions on improving the availability of the apparatus to industry, which are at present being conducted.

We should like to take the opportunity to rectify an omission that was due to an oversight on our part, and that is to acknowledge with thanks a financial contribution from Cementation Research Ltd towards the cost of the work and also to express appreciation of their interest. We should also like to acknowledge the valuable contribution made to the work by our colleague Dr C. R. Dimond and to thank Dr J. C. Godfrey of the University of Bradford for helpful discussions.

TABLE II: **Apparatus and operator comparisons.**

Mix (slump)	Workability parameter	Apparatus	Operator	Uncorrected	Corrected *	Mean corrected
175 mm	g	C	A	2·45	2·38	2·34
		C	B	2·54	2·30	
		S	A	2·33	2·33	2·23
		S	B	2·13	2·13	
	h	C	A	1·34	1·31	1·30
		C	B	1·29	1·29	
		S	A	1·50	1·45	1·42
		S	B	1·39	1·39	
105 mm	g	C	A	4·28	4·16	4·12
		C	B	4·49	4·07	
		S	A	4·62	4·62	4·19
		S	B	3·76	3·76	
	h	C	A	1·88	1·83	1·81
		C	B	1·79	1·79	
		S	A	1·93	1·86	2·12
		S	B	2·38	2·38	

C = Cementation apparatus S = Sheffield apparatus
A = Cementation technician B = Sheffield technician
*Taking the combination S + B as standard for comparison.

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