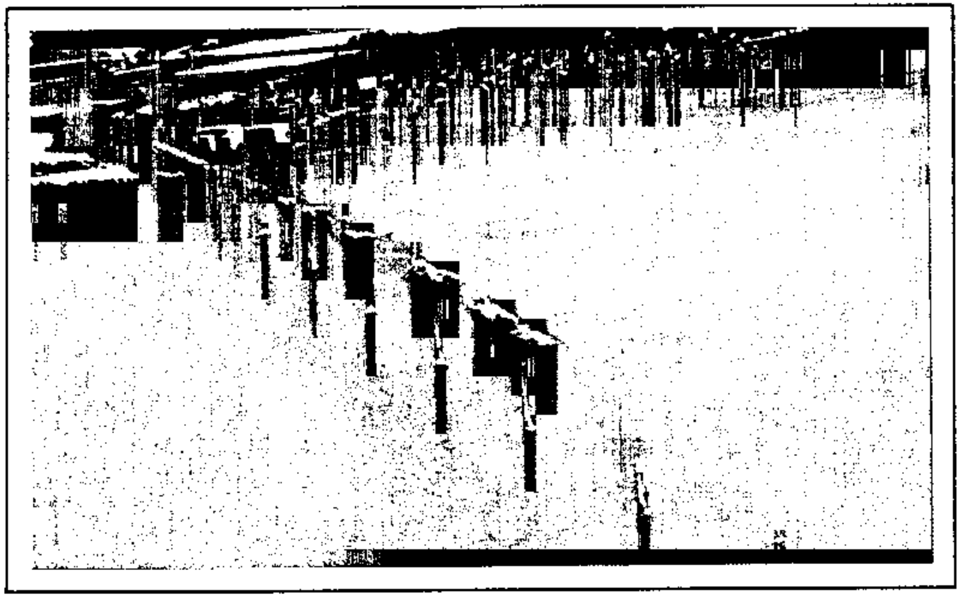
Mario Collepardi Symposium

on

Advances in Concrete Science and Technology



P.K. Mehta
Editor

CONCRETE WORKABILITY:
A MORE BASIC APPROACH NEEDED

By Odd E. Gjørv

Synopsis: Over recent years, there has been a rapid development in the field of concrete technology. New cements and new mineral and chemical admixtures affect the fresh concrete workability in a way that is not properly reflected by empirical test methods. Also, new production techniques require more proper specifications of the fresh concrete properties. There is a great need, therefore, to take a more basic approach to the testing and specification of the fresh concrete workability. In the present paper, some recent experience on the use of a coaxial cylinders viscometer for testing of fresh concrete properties are presented.

Keyword: Fresh concrete, workability, testing, rheology, yield stress, plastic viscosity.

Odd E. Gjørv is Professor at the Faculty of Civil and Environmental Engineering at the Norwegian University of Science and Technology in Trondheim, Norway. Dr. Gjørv who is a Fellow of the American Concrete Institute, has published numerous publications and served on a large number of national and international technical committees in the field of concrete technology. He is also the recipient of awards for his research on the utilization of silica fume in concrete and on the development of high-strength concrete.

BACKGROUND

Since Powers and Wiler (1) introduced their plastometer in 1941, several attempts have been made to take a more basic approach to the testing of concrete workability (2-14). Most of these attempts, however, have only resulted in various types of prototype equipment. In spite of a rapid development from craftsmanship to an advanced concrete industry, still, the most common way of testing fresh concrete workability is based on various types of empirical test methods, such as the slump method that was introduced by Abrams (15) in 1918. It was a great step forward, therefore, when Tattersall (16) introduced his two-point test apparatus for measuring concrete workability in 1973. In 1982 experimental work based on this two-point workability apparatus was started at the Norwegian University of Science and Technology in Trondheim. It soon became clear, however, that two main problems made the operation of this test apparatus somewhat difficult and unreliable. One of the problems was segregation of the concrete during testing. Another problem was errors arising from difficult equipment operation. Therefore, modifications of the equipment and testing procedure were first made (17), and later on, a completely new coaxial cylinders viscometer was developed (Fig. 1). Over recent years, extensive work has been carried out on the basis of this equipment (19-25).

The BML Viscometer is fully automatic and controlled by a computer. A software program provides all information necessary in order to carry out the test. To a certain extent, the software also provides further assistance such as how to adjust a mixture design in order to obtain a required workability. The equipment is easy to operate and appears to give good reproducibility with a minimum of segregation during testing. Basic rheological information on the concrete workability is obtained.

In principle, the testing is based on a Bingham behavior of the fresh concrete, which is roughly the case for the most common shear rates occurring during handling and placing (16). For a Bingham behavior, we have:

$$\tau = \tau_0 + \mu\dot{\gamma}$$

where:

τ = shear stress
τ_0 = yield stress
μ = plastic viscosity
$\dot{\gamma}$ = shear rate

In rheology, yield stress and plastic viscosity are normally measured as parameters dependent of the instrument applied and expressed in torque units. Thus, the units for yield stress and plastic viscosity are Nm and Nms, respectively.

By measuring the torque or the shear stress produced on the stationary, inner cylinder, while the outer cylinder is rotating at various speed settings or shear rates, the values of τ_0 and μ are determined. These two parameters characterize the workability of the fresh concrete in a basic way, where:

τ_o: is a measure of the force necessary to start a movement of the concrete ("flow resistance")

μ: is a measure of the resistance of the concrete against an increased speed of movement ("viscosity")

Upon completion of the test, the speed of the other cylinder automatically goes back to Speed Set 1 for control of the first torque reading. If there is any deviation from that observed at the start of the test, a segregation of the concrete during testing has taken place. Thus, the proneness of the fresh concrete mixture to segregation is also automatically quantified in the form of a segregaton factor.

WORKABILITY TESTING

Since there is a linear relationship between shear stress and shear rate in the concrete, at least two points have to be determined in order to establish this relationship. Therefore, since all empirical test methods only apply one shear rate, the results from two empirical test methods based on two different shear rates can never be compared. The one-point methods can only reflect the response of the fresh concrete to the particular shear rate or action applied.

In Fig. 2, the shear rates $\dot{\gamma}_s$ and $\dot{\gamma}_w$ are equivalent to that of a slump test and a wattmeter test during concrete mixing, respectively. Thus, for two different concrete mixtures A and B, Mixture A has the lowest shear stress at shear rate $\dot{\gamma}_w$ and will be considered to have the "best workability" based on the wattwater test, while Mixture B has the lowest shear stress at shear rate $\dot{\gamma}_s$, and hence will be considered to have the "best workability" based on the slump test.

Therefore, in order to obtain a more general characterization of the concrete workability, it is important to test the flow properties over a certain range of shear rates. By measurement of the yield stress (τ_0) and the plastic viscosity (μ), a good basis for evaluating both the flowability and the compactability of the fresh concrete is obtained (Fig. 3). A very good basis is obtained also for evaluating the effect of various constituent materials on the concrete workability (19-25).

EFFECT OF CONSTITUENT MATERIALS

Effect of water and admixtures

Some typical effects of water (W), a water reducing admixture (P) and a superplasticizer (SP) on the yield stress and the plastic viscosity are shown in Fig. 4. The figure also shows the effect of an air-entraining admixture (AE).

If the dosage of the superplasticizer is increased up to 2.4% by weight of cement while the water content is reduced and the slump is kept constant, the plastic viscosity is significantly increased as shown in Fig. 5. The time effect of the superplasticizer is also demonstrated. If the plastic viscosity becomes too high such as often being the case for a high-performance concrete with much superplasticizer, it can be seen from Fig. 4 that a proper addition of an air-entraining admixture may effectively reduce the plastic viscosity again.

Effect of cement type and silica fume

Some typical effects of ASTM Type I and Type III cements on the yield stress and the plastic viscosity are shown in Fig. 6. The figure also shows the effect of a modified portland cement (MP) containing 20% fly ash. An increasing amount of cement from 200 up to 400 kg/m^3 primarily affected the yield stress, while the plastic viscosity was not so much affected. While there was no big difference between the two types portland cement, the beneficial effect of fly ash on the workability was clearly demonstrated.

If the portland cement is replaced by an increasing amount of condensed silica fume (CSF), Fig. 7 demonstrates that the plastic viscosity is strongly reduced down to a certain threshold level, while the yield stress is almost unaffected. For these particular concrete mixtures, the threshold levels were approximately 2, 4 and 6% for a cement content of 200, 300 and 400 kg/m^3, respectively. For higher contents of silica fume above the threshold levels, a substantial increase of yield stress takes place, while the plastic viscosity starts to increase again. If the silica fume is used as an addition to the cement instead of being used as a replacement, the same behavior is observed, but without so distinct threshold levels (Fig. 8).

By testing the effect of silica fume on plastic viscosity and yield strength, Fig. 7 and 8 clearly demonstrate that even small additions of silica fume may affect the fresh concrete workability in such a way that neither the "static" nor the "dynamic" behavior can be compared to that of a concrete without silica fume. Due to increased cohesiveness, the slump measure does not predict the flow or response to compaction in the usual way. Therefore, an increased slump for silica fume concrete is normally recommended compared to that of "normal" concrete.

Even small additions of silica fume will also impart stability to the fresh concrete mixture. This may be a very important effect both during transportation, handling and placing of the concrete. During the viscometer testing, information about the stability of the concrete mixture is automatically obtained.

Effect of aggregate

In the mixture design, special types and amounts of fine and coarse aggregate may have a special impact on the fresh concrete behavior. From Fig. 9 it can be seen that by increasing the amount of coarse aggregate from 40 to 55%, the yield strength was significantly reduced, while the plastic viscosity was not much affected. By going from a crushed coarse aggregate to a gravel type of aggregate, however, the plastic viscosity was also distinctly reduced. Special types of filler materials may further have a special effect on the rheological behavior of the fresh concrete (23).

CONCLUDING REMARKS

Over recent years, there has been a rapid development in the field of concrete technology. New cements and new mineral and chemical admixtures affect the fresh concrete workability in a way that is not properly reflected by empirical test methods. Also, new production techniques require more proper specifications of the fresh concrete properties. There is a great need, therefore, to take a more basic approach to the testing and specification of the fresh concrete workability.

REFERENCES

1. Power, T.C. and Wiler, E.M., "A Device for Studying the Workability of Conrete", Proceedings, ASTM, Vol. 41, 1941, pp. 1003 - 1015.

2. L'Hermite, M.R. and Tournon, M.G., "La vibration du beton frais", Annales de l'institut technique du batiment et des travaux publics, New series No. 11, 1948, pp. 1-75.

3. L'Hermite, M.R., "The Rheology of Fresh Concrete under Vibration", Cement and Concrete Association, Translation No. 9, 1949, pp. 1-32.

4. Eriksson, A.G., "Development of Fluidity and Mobility Meter for Concrete Consistency Test", Report No. 12, The Cement and Concrete Institute, Stockholm, 1949.

5. Ritchie, A.G.B., "The Triaxial Testing of Fresh Concrete", Magazine of Concrete Research, Vol. 14, No. 40, 1962, pp. 37-41.

6. Tassios, T.P., "Plasticity and Cohesioness of Fresh Concrete", RILEM Seminar. Paper 1.3, Leeds, 1973, pp. 1-38.

7. Mizuguchi, H., Fujisaki, S. and Ohshiro, T., "Measurement of Plastic Viscosity and Yield Value of Fresh Concrete", Review of the 28th General Meeting, The Cement Association of Japan, 1974, pp. 100-102.

8. Mizuguchi, H. Katano, M. and Shimizu, T., "Fundamental Study on the Properties of Fresh Mortar by Means of Rotation Viscometer", Report No. 24, Tokushima University, 1979, pp. 13-23 (in Japanese).

9. Bache, H.H., "Stability of Fresh Concrete", Betonteknikk, No. 3, Aalborg Portland, Aalborg, 1978 (in Danish).

10. Okamoto, H., "Basic Study of Evaluation of Workability of Fresh Concrete", Transactions, Japan Concrete Institute, Tokyo, Dec. 1979.

11. Nishibayashi, S., Yamura, K. and Inoue, S., "Rheological Properties of Superplasticized Concrete", Publication SP-68, American Concrete Institute, Detroit 1981, pp. 441- 466.

12. Kishitani, K., Tomosawa, F. and Oka, S., "Rheological Study of Superplasticized Concrete", Publication SP-68, American Concrete Institute, Detroit 1981, pp. 423-440.

13. Jensen, J.K.J., "Workability of Fresh Concrete", Report No. 8210. Aalborg University Centre, 1982, 231 p. (in Danish).

14. Murata, J. and Kikukawa, H., "Flow and Deformation of Fresh Concrete", Matériaux et Constructions, Vol. 17, No. 98, 1984, pp. 117-129.

15. Abrams, D.A., "Design of Concrete Mixes", Structural Materials Research Laboratory, Levis Institute, May 1925, pp. 1-20, Reprints from Minutes of the Annual Meeting of the Portland Cement Association, New York, December 1918.

16. Tattersall, G.H., "Relationships Between the British Standard Test for Workability and Two-Point Test", Magazine of Concrete Research, Vol. 25, No. 84, 1973, pp. 169-174.

17. Wallevik, O.H. and Gjørv, O.E., "Modification of the Two-Point Workability Apparatus", Magazine of Concrete Research, Vol. 42, No. 152, 1990, pp. 135-142.

18. Wallevik, O.H. and Gjørv, O.E., "Development of a Coaxial Cylinders Viscometer for Fresh Concrete", RILEM, Proceedings of the International Conference on Properties of Fresh Concrete. H.J. Wierig, ed. Chapman and Hall, London, 1990, pp. 213-224.

19. Wallevik, O.H., "The Fresh Concrete Rheology and the Application on Concrete with and without Addition of Silica Fume", Dr.ing. Dissertation 1990:45, Norwegian University of Science and Technology, Trondheim, 1990, 185 p. (in Norwegian).

20. Mork, J. H., "Effect of Gypsum - Hemihydrate Ratio in Cement on Rheological Properties of Fresh Concrete", Dr.ing. Dissertation 1994: 4, Norwegian University of Science and Technology, Trondheim, 1994, 286 p. (in Norwegian).

21. Ghio, V.A., Monteiro, P.J.M. and Gjørv, O.E., "Effect of Polysaccharide Gums on Fresh Concrete Properties", ACI Materials Journal, Vol. 91, No. 6, 1994, pp. 602 - 606.

22. Hu, C., deLarrard, F. and Gjørv, O.E., "Rheological Testing and Modelling of Fresh High Performance Concrete", Materials and Structures, Vol. 28, No. 175, 1995, pp. 1 - 7.

23. Wallevik, O.H., Saasen, A. and Gjørv, O.E., "Effect of Filler Materials on the Rheological Properties of Fresh Concrete", ACI Materials Journal, Vol. 92, No. 5, 1995, pp. 524 - 528.

24. Punkki, J., Golaszewski, J. and Gjørv, O.E. "Workability Loss of High-Strength Concrete", ACI Materials Journal, Vol. 93 No. 5, 1996, pp. 427 - 431.

25. Mork, J.H. and Gjørv, O.E., "Effect of Gypsum-Hemihydrate Ratio in Cement on Rheological Properties of Fresh Concrete", ACI Materials, Vol. 94, No. 2, 1997.

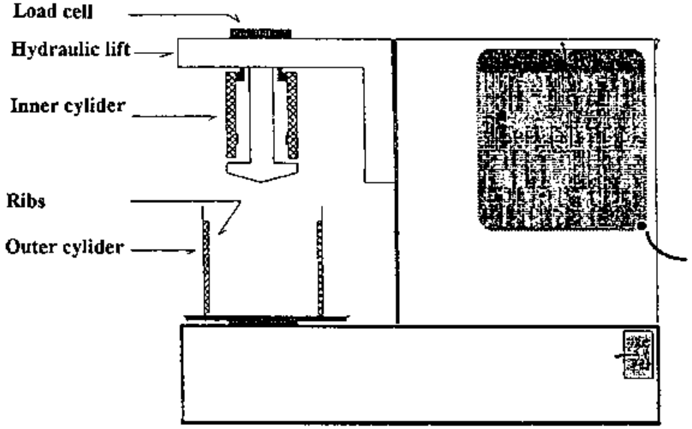


Fig. 1. Schematic diagram of the BML Viscometer (18).

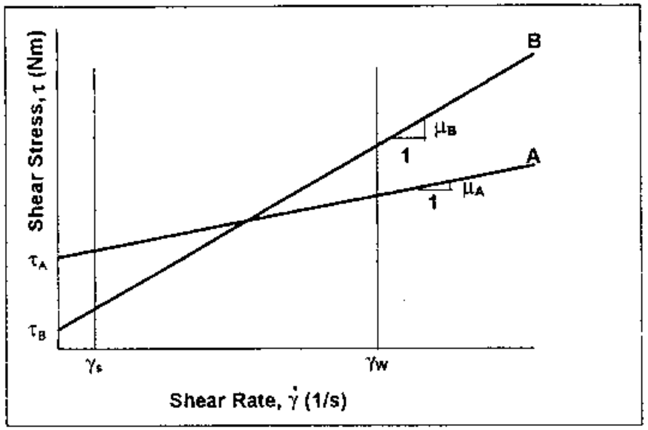


Fig. 2. Relationship between shear rate and shear stress for two types of concrete A and B.

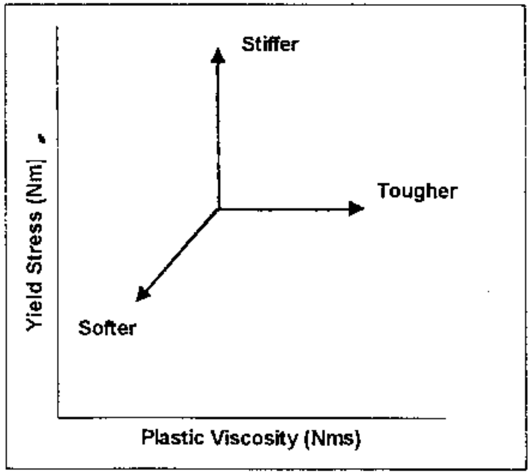


Fig. 3. Relationship between plastic viscosity and yield stress.

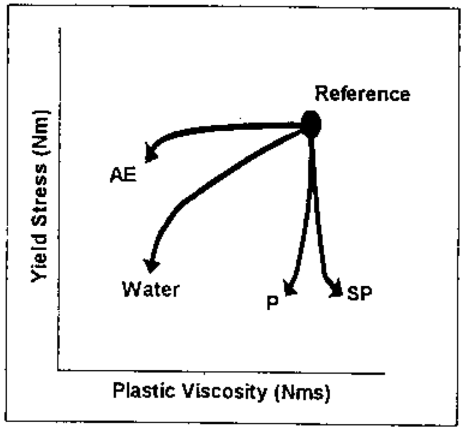


Fig. 4. Effect of water compared to that of a plasticizer (P), a superplasticizer (SP) and and air-entraining admixture (AE) on the rheological behavior of concrete.

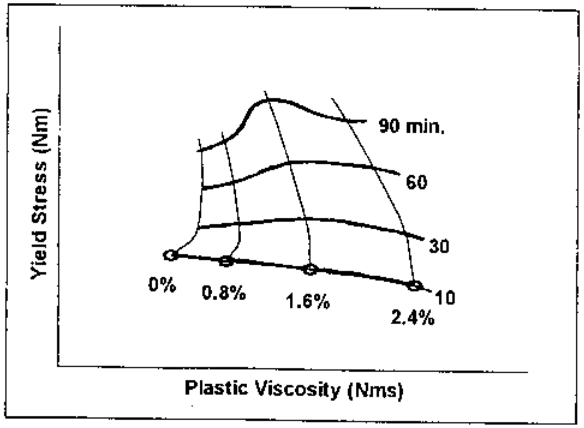


Fig. 5. Effect of a superplasticizer on the rheological behavior of concrete at different times after addition.

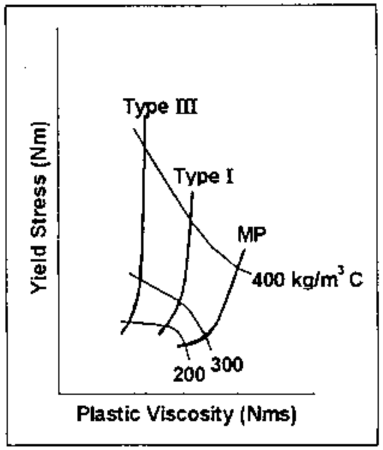


Fig. 6. Effect of different types of cement (ASTM Type I and III and a modified portland cement MP) on the rheological behavior of concrete.

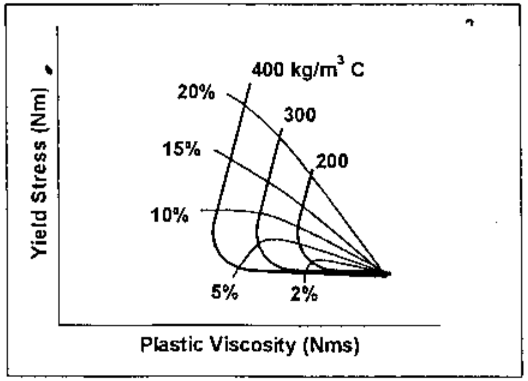


Fig. 7. Effect of condensed silica fume (CSF) on the rheological behavior of concrete on a replacement basis.

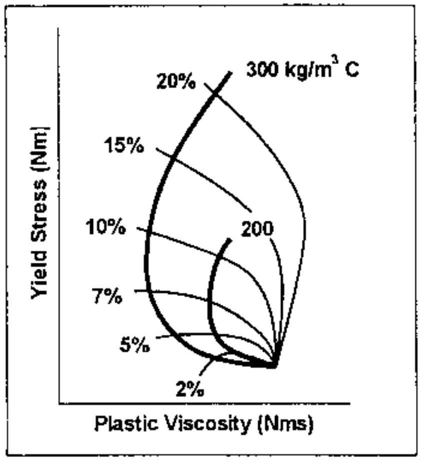


Fig. 8. Effect of condensed silica fume (CSF) on the rheological behavior of concrete on an addition basis.

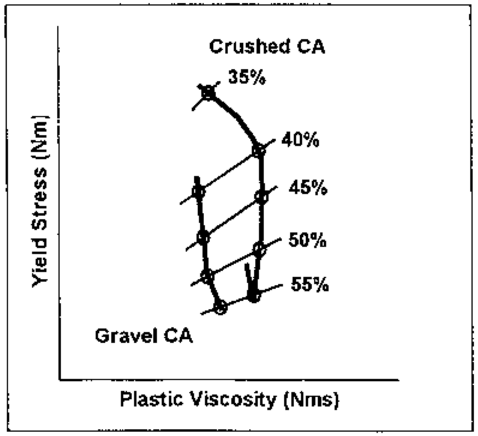


Fig. 9. Effect of a gravel type of coarse aggregate compared to that of a crushed coarse aggregate on the rheological behavior of concrete.