RHEOLOGY MEASUREMENT OF FRESH CONCRETE WITH A MIXING TRUCK

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INTRODUCTION

To describe concrete flow behavior, both yield stress and plastic viscosity, as defined by the Bingham model, are key properties that should be determined. The measurement of these parameters is currently possible only by using a rheometer adapted to concrete (1). The idea of measuring rheological properties during mixing is not new (2, 3). In fact, some existing concrete rheometers are based on this idea. These devices operate by measuring the torque induced on a mixing blade rotated at a range of different speeds. Another possibility for measuring concrete flow properties is based on relating the energy data recorded during mixing, as investigated by de Larrard et al. (2).

The slump test has remained the standard tool throughout the world for characterizing the workability of freshly mixed concrete because of the device's simple calibration, which creates little ambiguity or confusion. The slump test, however, only measures a value related to yield stress, which is insufficient for fully describing the flow properties of concrete. An attempt to modify the slump test to measure plastic viscosity showed the limits of such an approach (4). A simple and reliable method of rheological characterization adapted to the needs of industry is needed. In particular, few studies exist on the prospect of determining the flow properties of concrete in a mixing truck in transit to a jobsite. To the authors' knowledge, only one study has been published on this topic (3). Given this background, an investigation of the feasibility of determining rheological properties by using the available data from a mixing truck was conducted.

EXPERIMENTAL PROGRAM

Materials and mixture proportion

The cementitious materials used in all mixtures consisted of an ASTM C 150 Type I portland cement with a Blaine specific surface of 467 m²/kg and a density of 3050 kg/m^3 and a ground granulated blast furnace slag. The two aggregates were a natural sand denoted "*La Plata*" and a coarse aggregate denoted "*Brandywine*". The sand had a maximum size of 3 mm and had a 2.8 % mass fraction particles with dimensions smaller than 0.15 mm. One mixture was prepared and was subsequently modified by adding a high-range water-reducing admixture to increase slump (C11, C12, C13) and incorporating a viscosity-modifying admixture (VMA) to increase viscosity (C14). C10 contained a water-reducing and retarding admixture based on a sodium salt of organic acid mixture and with a specific gravity of 1.2. The high-range water-reducing admixture (HRWRA) was a polycarboxylate-based admixture with a specific gravity of 1.1. The mixture proportions are summarized in Table 1.

Table 1: Mixture proportions

		Concrete Batch (50 % Capacity)				
		C10	C11	C12	C13	C14
Gravel (Oven Dry)	kg/m^3	1099.4	←Constant→			
Sand (Oven Dry)	kg/m^3	774.0	←Constant→			
Water *	kg/m^3	145.8	←Constant→			
Cement	kg/m^3	163.7	←Constant→			
Slag	kg/m^3	163.2	←Constant→			
Set Retarder	L/m^3	0.656	←Constant→			
HRWRA Addition	L/m^3	0	+1.4	+1.4	+0.6	
VMA	L/m^3	0	0	0	0	+0.2
Testing Time	h	0.5	1.0	1.5	2.0	2.4
Temperature	°C	18	19.5	20	20	21
Slump	mm	70	110	170	240	150

* The water quantity calculations take into account the initial moisture contents of the aggregates.

Mixing truck rheometer[1]

Transforming a truck mixer into a rheometer requires that at least two entities be measured: the rotational speed of the drum (related to the shear rate in concrete) and the power consumption or torque used by the mixer motor during rotation. The methodology to measure the shear rate in the concrete was presented in detail in Ref. (5).

The concrete truck mixer used (Figure 1A) was fitted with a device capable of measuring the oil pressure to turn the drum (also called slump meter). The Bingham test involves sweeping shear rates from high to low and measuring the stress at various shear rates. Therefore, the drum was turned at the highest speed, 1.74 rad/s (16.7 rpm), and then gradually decreased in discrete steps to zero while the oil pressure was measured. The calculation method to determine the shear rate in the drum from the speed and the truck geometrical characteristics was developed in Ref. (5). The truck used had a capacity of

[1] Certain commercial equipment, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it implies that the materials or equipment identified are necessarily the best available for the purpose.

about 7.5 m^3, with a drum radius, R, of 1.20 m. The maximum drum speed, n, was 1.74 rad/s (16.7 rpm or 0.28 rps).

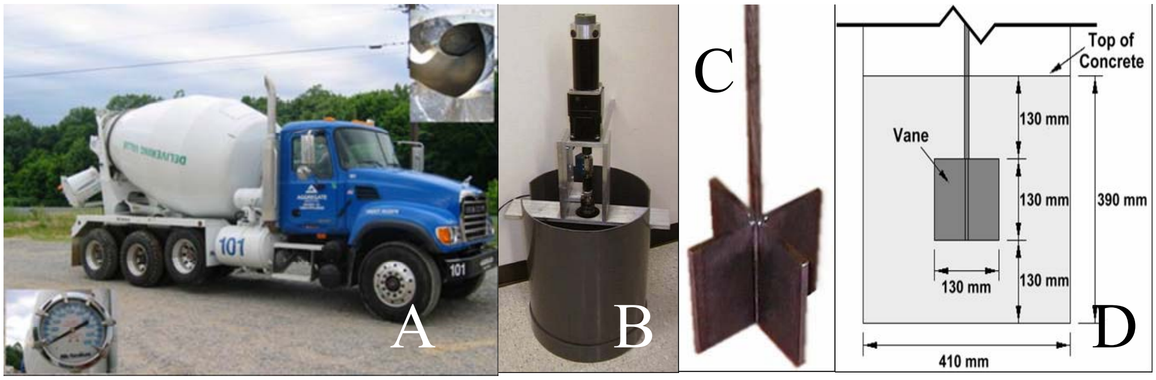

Figure 1 : View of the truck (A), the slump indicator (bottom left-a) the interior of the drum (top right-a); the ICAR rheometer prototype (B), vane (C), principal dimensions (D)

ICAR rheometer

The ICAR rheometer (6,7), shown in prototype form in Figure 1B and 1C, is a portable rheometer for fresh concrete. The device utilizes a four-bladed vane that is immersed into the concrete sample and rotated at a series of fixed speeds. For each concrete mixture, the ICAR rheometer (Figure 1B) was used to measure a flow curve. The concrete was placed in a 410 mm diameter container and filled to a height of 390 mm, as shown in Figure 1. The vane, which measured 130 mm in diameter and 130 mm in height, was positioned in the center of the concrete sample, resulting in a gap size of 140 mm between the vane and the sidewalls and a gap of 130 mm above and below the vane. To obtain the flow curve, the vane was first rotated at a speed of 6.3 rad/s (1.0 rps) for a breakdown period of 25 s. Torque measurements were then recorded for five speeds ranging in descending order from 6.3 rad/s to 1.3 rad/s (1.0 rps to 0.2 rps). The resulting data were analyzed based on the Bingham model, whereby a straight line was fit to the plot of torque, T (N·m), versus rotation speed, N (rad/s).

Testing Procedure

The concrete was mixed in the central plant mixer for 10 min and then transferred to the concrete truck mixer. For the tests C10 to C14, the truck was filled to 50 % of its maximum capacity. The truck drum turned about 100 revolutions during the transport of the concrete between the central plant and the laboratory. For each mixture, a small volume of concrete was discharged from the truck for testing with the ICAR rheometer and the slump test. To use the truck as a rheometer, the highest speed of the drum (1.74 rad/s or 16.7 rpm) was maintained for 10 revolutions while the oil pressure was recorded. The speed of the drum was then reduced in increments of 0.21 rad/s (2 rpm). The oil pressure and speed were recorded at each increment of speed. These measurements produced the curve of oil pressure (related to the torque) vs. rotational speed used to calculate the yield stress and plastic viscosity.

RESULTS AND DISCUSSION

Concrete test data

The fresh concrete measurements are summarized in Table 2. The values of the yield stress and plastic viscosity are deduced from the flow curves (Figures 2 and 3), as described by the Bingham model, by calculating the intercept of the linear fit for the yield stress and the slope as the plastic viscosity.

Table 2: Fresh concrete measurements

Mixture Designation	Slump	Truck Measurements Yield stress	Truck Measurements Plastic Viscosity	ICAR Rheometer Yield stress	ICAR Rheometer Plastic Viscosity
	(mm)	(kPa)	(kPa·s)	(N·m)	(N·m·s)
Empty truck		2131	1397		
C10	70	8074	2034	4.38	0.321
C11	110	7651	1595	3.04	0.155
C12	170	6250	1848	2.65	0.115
C13	240	4115	2374	1.42	0.086
C14	150	6074	1901	1.97	0.151

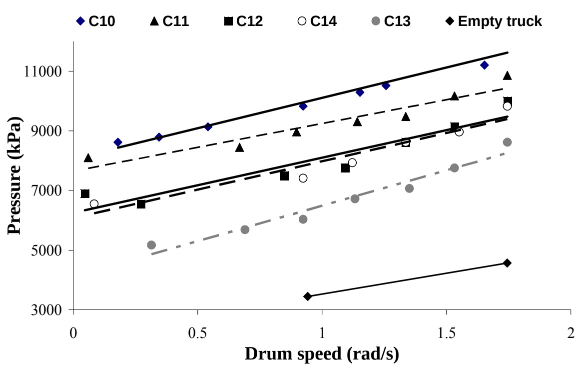

Figure 2 : Flow curves obtained with truck mixer

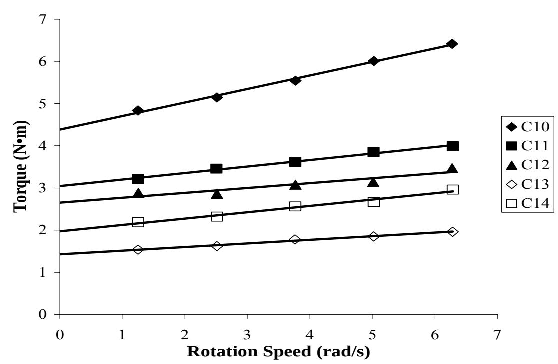

Figure 3 : Flow curves obtained with ICAR rheometer

Evolution of plastic viscosity

In Figure 4, the relative viscosity variation is shown. The relative viscosity is defined as the ratio of the measured viscosity for a given test to the viscosity measured for the respective control mix C10. The addition of the first dosage of HRWRA (C11) to the control mix C10 resulted in a decrease in viscosity as measured by both the truck and the ICAR rheometer. Further additions of HRWRA to the same mix, however, produced different results from the two devices. The addition of a viscosity-modifying admixture (VMA), a product intended to increase viscosity, to mix C13 resulted in an increase in viscosity (C14) as recorded by the ICAR rheometer but a decrease in viscosity as recorded by the truck.

The correlations between the ICAR rheometer and truck measurements for the viscosity values are shown in Figure 5. No apparent relationship exists for plastic viscosity.

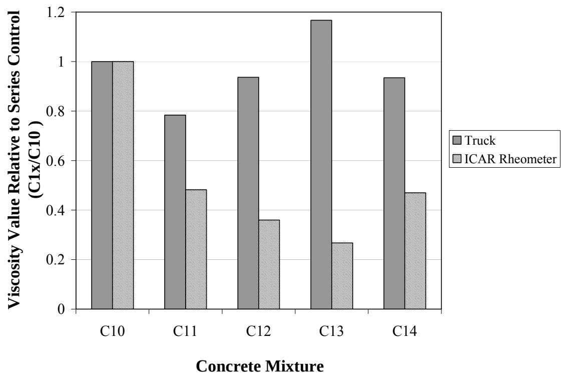

Figure 4 : Relative plastic viscosity, recorded by the mixing truck and ICAR rheometer

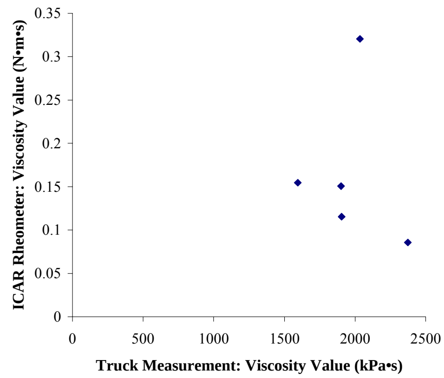

Figure 5 : Correlation of viscosity value between ICAR rheometer and truck

Evolution of yield stress

The relative variations in yield stress as recorded from the truck measurements, ICAR rheometer, and the slump test are shown in Figure 6. The addition of HRWRA for mix C11, C12, and C13 resulted in decreases in the yield values measured by both the ICAR rheometer and the truck. Many authors (9,10) have shown that concrete slump is inversely correlated to yield stress, because a high slump indicates a reduced resistance to flow as does a low yield stress. The use of a viscosity-modifying admixture for mix C14 resulted in increases in yield value as determined by both the truck and the ICAR rheometer and a decrease in slump as compared to mix C13.

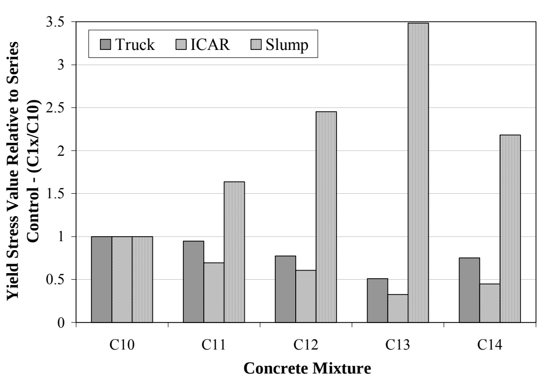

Figure 6 : Relative yield or slump values, as recorded by mixing truck, ICAR rheometer, and slump test

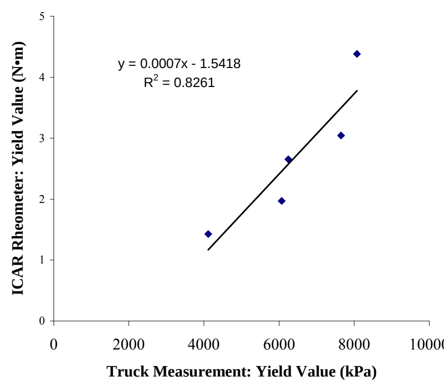

Figure 7 : Correlation of yield value between ICAR rheometer and truck

CONCLUSIONS

Based on the limited investigation (only one day of testing) of the feasibility of measuring rheological properties directly in a mixing truck without any modifications, it was determined that the mixing truck could be used as a tool to obtain flow curves of the mixed material, with the same procedure used with a concrete rheometer, and that the flow curves measured by the mixing truck were sensitive to changes in yield stress and plastic viscosity. The comparison of the plastic viscosity measured by the truck with the ICAR rheometer did not show a high correlation between the values measured. On the other hand, the comparison of the yield stress measured with the slump test, the ICAR rheometer, and the mixing truck showed a good correlation. Further tests are necessary to investigate the promise of this technique.

References

(1) L. Brower, C. F Ferraris, "Comparison of Concrete Rheometers", Concrete International, Vol. 25 #8, August 2003, pp. 41-47.

(2) F. de Larrard, B. Cazacliu, D. Chopin, E. Chateau, "Production of SCC," 3rd International Symposium on Self Compacting Concrete, 17-20 August 2003, Reykjavik, Iceland.

(3) J. A. Daczko, "A Proposal for Measuring Rheology of Production Concrete," Concrete International, **22** (5), 47-49, (2000).

(4) C. F. Ferraris, F. de Larrard, "Modified Slump Test to Measure Rheological Parameters of Fresh Concrete," Cement, Concrete and Aggregates, Vol. 20 #2, 241-247 Dec. 1998.

(5) S. Amziane, C. F. Ferraris , E. P. Koehler "Measurement of Rheological Properties of Fresh Concrete Using a Mixing Truck", accepted for publication to the NIST Journal of Research, January-February 2005.

(6) E. P. Koehler, "Development of a Portable Rheometer for Portland Cement Concrete," MS Thesis, The University of Texas at Austin, Austin, TX, 2004.

(7) E. P. Koehler, D. W. Fowler, C. F. Ferraris, and S. Amziane, "A New Portable Rheometer for Fresh Self-Consolidatinng Concrete", Proc. of session ACI 2005 (New York)

(8) S. Amziane and C. F. Ferraris, " Monitoring of Setting Evolution of Cementitious Materials by Measurements of Rheological Properties and Hydraulic Pressure Variations," Submitted to Mater. Structure RILEM, 2005.

(9) C. F. Ferraris and F. de Larrard, "Testing and Modeling of Fresh Concrete Rheology," NISTIR 6094, National Institute of Standards and Technology, Gaithersburg, MD, February 1998.

(10) W. R. Schowalter and G. Christensen, "Toward a Rationalization of the Slump Test of the Fresh Concrete: Comparison of Calculations and Experiments," J. Rheol., **42** (4) 865-870, (1998).