ASTM C457 Procedures A, B, and C—A CN Tower extravaganza

Micheal Walsh, Micro Analysis Group, Keyence, 6775 Financial Drive, Suite 202, Mississauga, ON, L5N 0A4, Canada, mwalsh@keyence.com

Karl Peterson, Department of Civil and Mineral Engineering, University of Toronto, 35 Saint George St., Toronto, ON, M5S 1A4, Canada, karl.peterson@utoronto.ca

Ted Sibbick, GCP Applied Technologies, 62 Whittemore Avenue, Cambridge, MA, 02140, USA. richard.sibbick@gcpat.com

INTRODUCTION

In 2016, a new revision of the ASTM C457 *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete* was introduced that includes for the first time a Procedure C automated contrast enhanced method [1]. Automated methods for performing hardened air void analyses are nothing new, and have been around in one form or another since the 1970s [2]. Round-robin test regimes that compare automated methods with the traditional manual linear traverse (Procedure A) and manual modified point count (Procedure B) methods are nothing new either [3-5]. In these previous round robins, concrete samples were prepared and analyzed by one lab, and the same samples circulated to other labs for measurement on the already-prepared surfaces. The only added twist with the round robin regime introduced here, is that each lab had to prepare their own concrete coupon, with all coupons cut from a pair of concrete cylinders—cylinders cast during the construction of the CN Tower. As a result, the variability of sample preparation is included, as well as potential variation within the concrete itself, in addition to the already-explored issues of operator variability, and variability introduced by different analytical equipment. This approach provides a more holistic assessment of the inherent variability within the ASTM C457 test method.

CN TOWER

In 1990, John A. Bickley, Shondeep Sarkar, and Marcel Langlois got their hands on three 100 mm (4 in) dia. 300 mm (12 in) long cores retrieved from the CN Tower, to check the performance of the in-place concrete after almost twenty years of service [6]. Their cores came from a height of 50 m (the full tower rises to 551 m, with 0-460 m consisting of slip-formed concrete). Construction on the tower began in July of 1973, and ended in February of 1974 [6]. The pair of cylinders examined in this round-robin study were both labeled July 30, 1973, so presumably also came from the lower portion. Table 1 shows a mix design for the tower [6]. The coarse aggregate is dolostone originating from the Niagara Escarpment, and the fine aggregate is from a glaciofluvial Ontario sand deposit. Assuming a density of 2.8 g/cc for the dolostone, 2.7 g/cc for the sand, and 3.15 g/cc for the cement, based on the mix design, the paste content is 27.1 vol. %, with an air content of 6.3 vol. %.

Table 1: CN Tower mix design [6].

Constituent	kg/m^3 (lbs/yd^3)
Cement	368 (620)
Water	154 (260)
Crushed dolostone	1127 (1900)
Fine aggregate	712 (1200)

RESULTS

Figures 1-4 summarize the results from hardened air void analyses performed on the coupons prepared from the cast cylinders by the different labs, as well as the results from the 1990 cores [6]. Each lab was assigned a different color. Each lab performed only one of the three Procedures (either A, B, or C). Some of the labs had multiple operators, in which case different operators are designated both numerically in the plot legends, and symbolically in the plots. The violet lab, the only lab to run Procedure A, had one operator perform the analysis twice, but each time at a different magnification. The orange lab performed Procedure C twice, first with an EPSON v850 Pro flatbed scanner, and again with a Keyence VHx-6000 digital microscope controller equipped with a Vh-s660e motorized stage and a Z20 lens. The other Procedure C labs (red and yellow) used a RapidAir 457. Table 2 summarizes the results numerically, and Figures 5-7 show microscope images from a few of the surfaces prepared by different labs, recorded with the same Keyence equipment described previously.

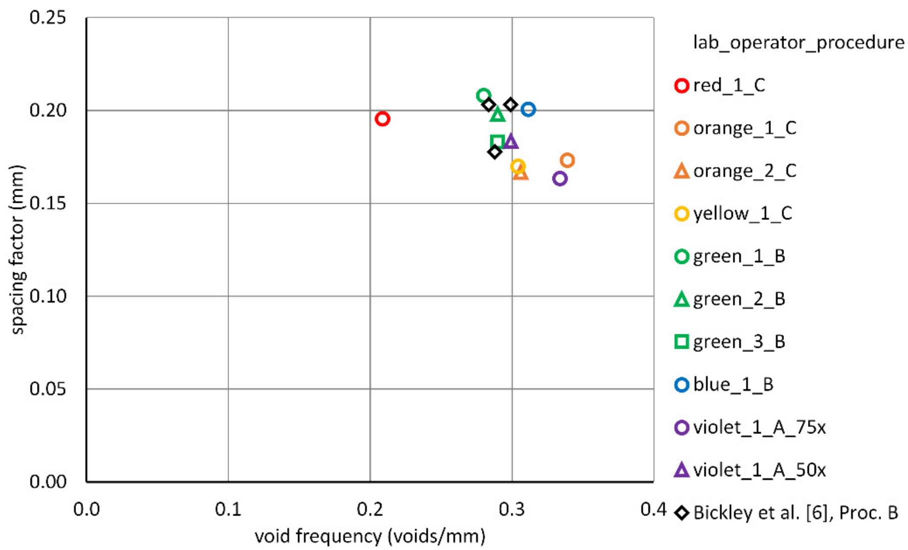

Figure 1: Spacing factor vs. void frequency.

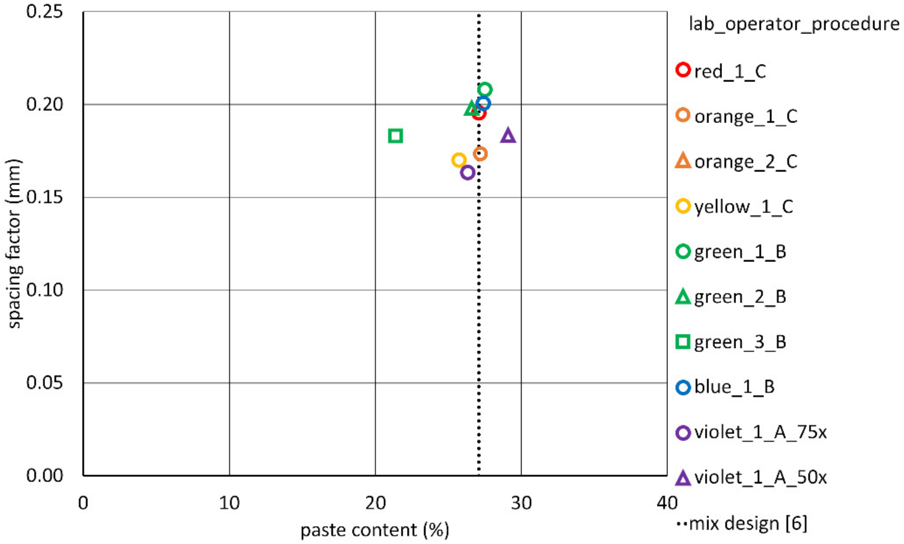

Figure 2: Spacing factor vs. paste content

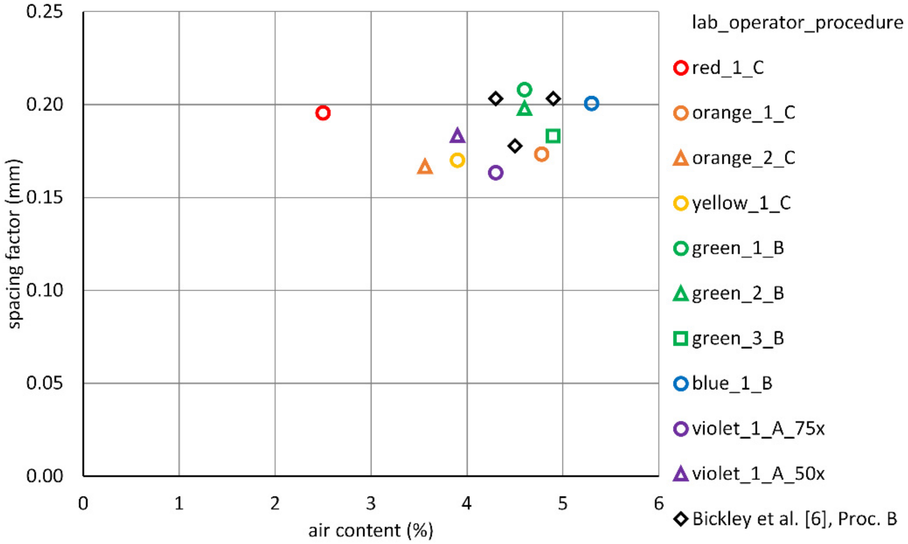

Figure 3: Spacing factor vs. air content.

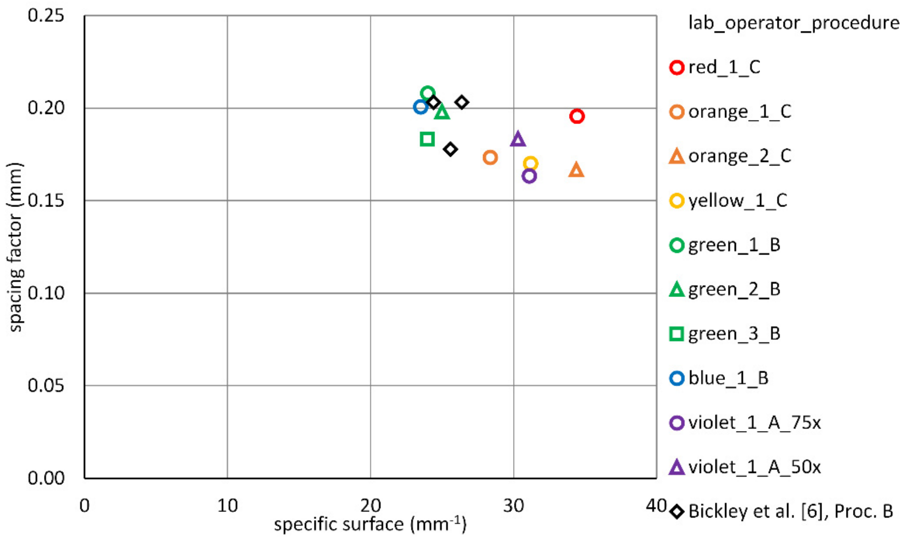

Figure 4: Spacing factor vs. specific surface.

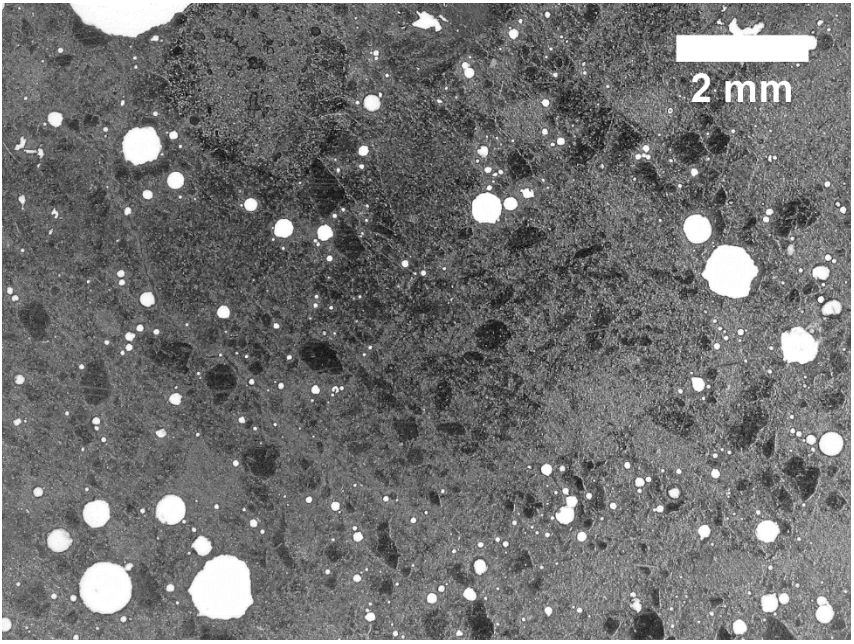

Figure 5: Surface prepared for Procedure C.

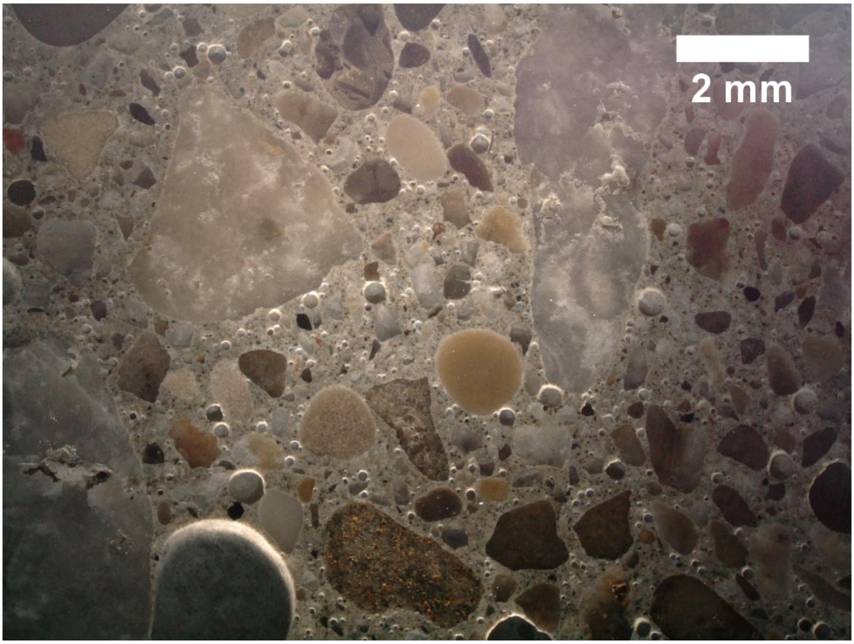

Figure 6: Example surface prepared for Procedures A or B, highly polished.

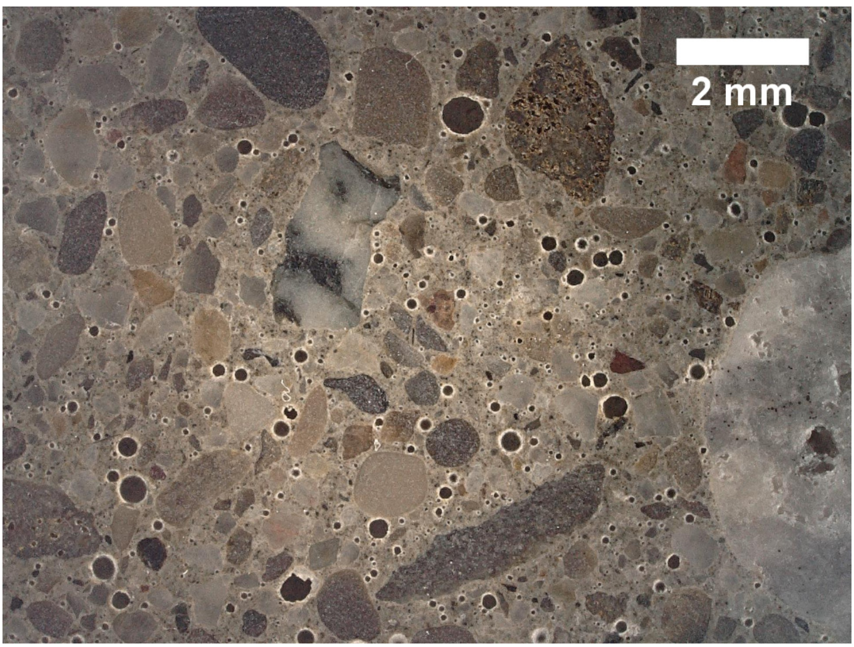

Figure 7: Example surface prepared for Procedures A or B, normal lapping.

Table 2: Hardened air void parameters

lab/operator #/Procedure	air vol. %	paste vol. %	paste/ air ratio	spacing factor, mm	specific surface, mm^{-1}	void frequency, voids/mm
red/1/C	2.5	27.1	10.8	0.196	34.4	0.209
orange/1/C	4.8	27.2	5.70	0.173	28.4	0.339
orange/2/C	3.6	28.4	7.99	0.167	34.4	0.306
yellow/1/C	3.9	25.7	6.60	0.170	31.2	0.304
green/1/B	4.6	27.5	5.98	0.208	24.0	0.280
green/2/B	4.6	26.6	5.78	0.198	25.0	0.290
green/3/B	4.9	21.4	4.37	0.183	24.0	0.290
blue/1/B	5.3	27.4	5.17	0.201	23.5	0.312
violet/1/A 75x magn.	4.3	26.3	6.13	0.163	31.1	0.334
violet/1/A 50x magn.	3.9	29.1	7.46	0.183	30.3	0.299
avg. (n=10)	4.2	26.7	6.60	0.184	28.6	0.296
max	5.3	29.1	10.84	0.208	34.4	0.339
min	2.5	21.4	4.37	0.163	23.5	0.209
stdev.	0.8	2.09	1.82	0.016	4.28	0.036
	4.9	-	-	0.203	24.4	0.299
Bickley et al.. Proc. B [6]	4.3	-	-	0.203	26.4	0.284
	4.5	-	-	0.178	25.6	0.288
avg. (n=3)	4.6	-	-	0.195	25.5	0.290
max	4.9	-	-	0.203	26.4	0.299
min	4.3	-	-	0.178	24.4	0.284
stdev.	0.3	-	-	0.015	0.99	0.008

DISCUSSION

For the most part, there was good agreement between the different labs and different methodologies, but with one outlier in terms of air content and void frequency. However, the same lab had a similar result for spacing factor when compared to the other labs. Another source of variability in Procedure C is the requirement for the operator to manually darken (color in) any voids in aggregate prior to the analysis; this may contribute to discrepancies in the air content and void frequency from operator to operator or from lab to lab. The results are encouraging, and demonstrate the feasibility of running a round robin where labs perform their own sample preparation. The same approach has recently been undertaken by the ASTM Committee C09 Working Group on C457, where multiple labs have each analyzed a pair of coupons from two different concrete mixtures, with results pending this coming June 2019.

ACKNOWLEDGEMENTS

Thank you to all the labs and participants in this round robin study.

REFERENCES

[1] ASTM C457/C457M – 16: Standard Test Method for Microscopical Determination of Parameters of the Air-void in Hardened Concrete, ASTM International, West Conshohocken, PA, USA, 2016.

[2] Chatterji, S., Gudmundsson, H., "Characterization of Entrained Air Bubble Systems in Concrete by Means of an Image Analysing Microscope," Cement Concrete Res., Vol. 7., No. 4, 1977, pp. 423-428.

[3] Jakobsen, U. H., Pade, C., Thaulow, N., Brown, D., Sahu, S., Magnusson, O., De Buck S., De Schutter, G., "Automated Air-Void Analysis of Hardened Concrete - A Round Robin Study," Cement Concrete Res., Vol. 36, No. 8, 2006, pp. 1444-1452.

[4] Elsen, J., "Automated Air-Void Analysis on Hardened Concrete – Results of a European Intercomparison Testing Program," Cement Concrete Res., Vol. 31, 2001, pp. 1027-1031.

[5] Dipayan, J., "A round robin test on measurements of air void parameters in hardened concrete by various automated image analyses and ASTM C 457 methods," Proceedings of the 29th International Conference on Cement Microscopy, International Cement Microscopy Association, pp. 33-68, 2007.

[6] Bickley, J.A., Sarkar, S., Langlois, M., "17-year-old high-performance concrete: The CN Tower," Concrete International, August, 1992, pp. 51-55.