REAL-TIME MEASUREMENT OF AIR CONTENT IN FRESH, AIR-ENTRAINED CONCRETE AT TILCON

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Real-time measurement of air content in fresh, air-entrained concrete

8 CY of nominal 4000 psi, air-entrained (6%) concrete were batched from a stationary mixer into an Oshkosh front-discharge ready-mix truck with an 11 CY drum, fitted with a CiDRA, "SMART*hatch*" acoustic air meter. The truck arrived at the test-site 20 minutes after batching. Concrete was sampled four times over 95 minutes on-site per ASTM C172, with two intermediate discharges of concrete into forms, and two additions of water. At each sampling, ASTM C231 (pressure-meter) and C138 (gravimetric) air tests were conducted by ACI-certified technicians, and 4x8 cylinders were cast for compression-strength and hardened-air analysis per ASTM C457. All test equipment was calibrated immediately prior to test. Acoustic air content was monitored continuously throughout the experiment for comparison with results of currently accepted, standard methods. All results are compiled in the graph and briefly discussed below.

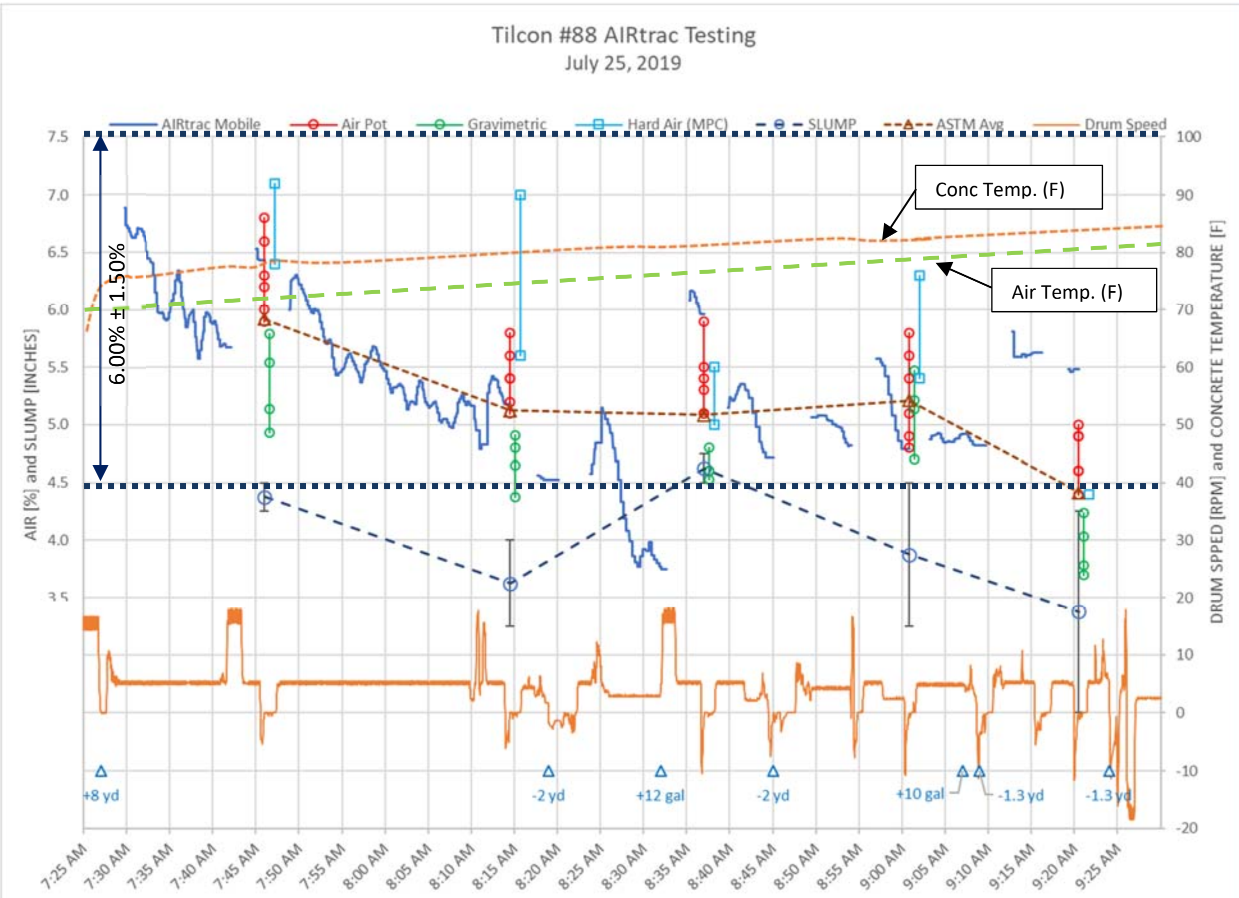

Table 1: Mixture Proportions

Portland Cement (Type I/II)	*611 lb/CY*	*Air-Entraining Admixture*	*4 fluid oz./CY*
Coarse, Intermed., & Fine Agg.	*3120 lb/CY (SSD)**	*Mid-Range WRA*	*31 fluid oz./CY*
Water	*275 lb/CY*	*Retarder*	*12 fluid oz./CY*
Coarse aggregate is hard, dense, low porosity basalt with reported average specific gravity of 2.97			

The acoustic air meter provided a continuous record of drum rpm. Positive spikes in rpm indicate initial mixing at plant or re-mixing on-site prior to sampling, or are associated with water-addition. Short negative spikes indicate discharge for ASTM C172 sampling, while more extended negative rpm indicates discharge into forms. Irregular rpm indicates truck-in-motion with stops, starts, and turns.

Observations

1. Air content in fresh concrete varied from 4.4 to 6.8% over the first 90 minutes after batching. Any one result from the ASTM C231 or C138 tests could have been the one, single value used to characterize this batch of concrete per standard specifications.

2. For samples collected at any given time: a.) pressure-meter readings were consistently higher than gravimetric by an average of 1 percentage point; b.) multiple readings of air content by pressure-meter varied by 0.8 percentage points; b.) multiple readings of air content by unit-weight (gravimetric) varied by an average of 0.6 percentage points; c.) and between both standard ASTM tests of fresh concrete, air content varied by 1 to 2% percentage points. (ASTM C231 comments that both test methods should produce "substantially the same air contents.")

3. For both C231 and C138, the total range of results generally fits within the 1-1/2% tolerance for air content of the ACI 318 Building Code. (That tolerance is echoed in many other specifications.) For example, had the air content for this batch of concrete been specified at 6.0%, all but one standard test performed on this truck would have been within the range of 4.5 to 7.5 % (the outlier is the lowest gravimetric test @ 8:15 AM).

4. Acoustic air content captured the continuously varying air content with time. This variability was confirmed by standard tests. Rate of decrease of air content with time was about the same immediately before and after the first sample-collection. Sensitivity of air content to mixer rpm and water-addition was also observed. Between the first and second samples, changes in acoustic air content closely follow the trajectory anchored by standard tests, and acoustic air content closely matched the average value of combined C231 and C138 air measurements. After the first hour, irregular mixer rpm (a consequence of truck operations unique to this program) masked acoustic air content readings.

5. Concrete temperature varied from 64 to 86 (F) as slump varied from 3.25 to 4.7 inches. Variations between two slump tests of up to 1-3/4 inch, taken from the same sample at the same time, are shown by the error bars on the graph. No clear relationships among slump, temperature, and air content are apparent.

6. Except for the 3rd sampling, hardened air results were significantly higher than fresh air results. The difference between standard fresh and hardened air content for this one truckload of concrete varied from zero to 2.6%.

7. By the fourth sampling, and after water addition, the concrete reached the ASTM C94 limit of 90 minutes after batching. At this point the results of all four test methods converged to within about 1 percentage point of the overall average.

Discussion and Conclusions

The testing program clearly demonstrates the variability of air content in fresh concrete. For this one truck, carrying a single batch of conventional air-entrained concrete, any single, standard ASTM test, conducted by certified testing professionals could have legally identified this mixture as having an air content of 4.4 to 7.0%. One source of variation is the testing error inherent to the methods. ASTM C231 and C138 suggest that for the same sample, two independent operators could find a difference of 0.75% air between two readings with a pressure-meter, and a difference of 1.4% air between two readings with the gravimetric test (on this mixture). Results reported here more or less confirm those ranges within a given sample. It is clear, however, that each sampling from the truck captured a different concrete with a different slump and air content. All samples of concrete from a ready-mix truck are not equal when it comes to air content. Concrete is fundamentally non-homogeneous when it comes to the volume of air bubbles in a given sample, whether it is the ¼ cubic foot of the pressure-meter (864 possible samples in 8 CY) , the ½ cubic foot of the gravimetric test (432 possible samples), or the continuous stream of fluid concrete passing the acoustic sensor (over 5000 samples at 1 per second). This introduces other reasons for differences among test results: a.) the pressure-meter estimates air content based on compressibility of air bubbles; b.) the gravimetric test depends on differences in density; c.) hardened-air tests are based on a statistical survey of random slices through random air voids, and d.) the acoustic method depends on the influence of air bubbles on the transmission of sound waves through fluid concrete. Each method provides an estimate of air content based on relevant physics, optics, or statistics, but no method provides an actual measurement. The “true value” of air content in fresh or hardened concrete remains unknown. (This is why ASTM C231 and C138 include no statements of “bias.”) But unless multiple tests are performed, this fundamental variability remains hidden, and the reliability of any one test result cannot be assessed. Note also that for this one, single batch of concrete, this range of estimated air content was obtained without batch-to-batch variations, changes in mixture ingredients, or the complications caused by placing, conveying, dropping, pumping, pressurizing, de-pressurizing, consolidating, or finishing the concrete.

Against this background of standard test results, continuous, real-time monitoring of air content tracks changes occurring in the mixture, highlighting the reality that air content, like slump, is not constant in fresh concrete. At the points where acoustic-air can be reliably assessed and C231 and C138 results can be compared, the acoustic air content is consistently within about ½ to 1 percent of the overall average of the C231 and C138 readings, with acoustic air usually 1% or less lower than the commonly used pressure-meter, and slightly higher than the gravimetric method. For conditions similar those in this test program, these results support use of the acoustic meter as a lower-bound estimate for C231 when a minimum air content is specified and a reliable estimator of the overall average of C231 AND C138. The acoustic air meter provides data useful for monitoring factors that influence air content over time, (such as admixture and SCM interaction, for example), can be helpful in estimating the results of standard tests, and could be used to support a request for performing a “check test,” as permitted by ASTM specifications.

Figure 1 - SMARThatch system with integrated AIRtrac acoustic technology sensor installed on mixer drum

Figure 2 - Air Pot calibration prior to starting test

Figure 3 - Sample collection into three wheelbarrows. Each tester used independent samples.

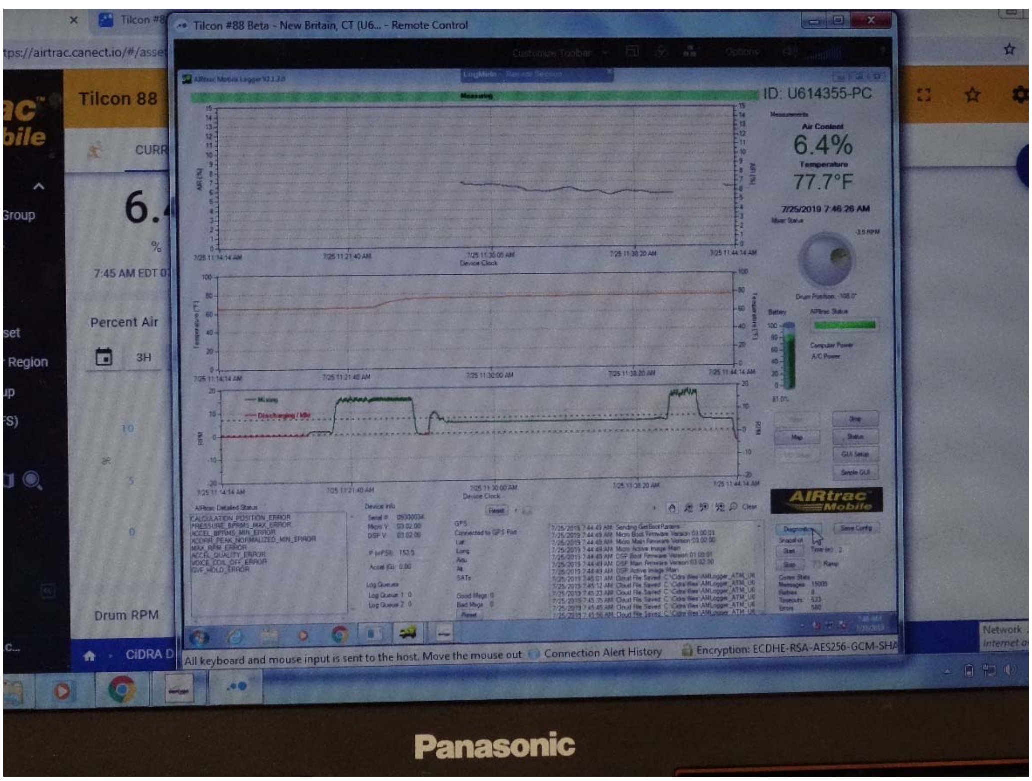

Figure 4 - SMARThatch software displaying real-time air content, temperature and drum rotation