Air Content Testing Methods for Mortar

Scott D Esplin

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Fernando S. Fonseca, Chair
Paul W. Richards
Richard J. Balling

Department of Civil & Environmental Engineering

Brigham Young University

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ABSTRACT

Air Content Testing Methods for Grout

Scott D Esplin
Department of Civil & Environmental Engineering, BYU
Master of Science

The method prescribed in the American Society for Testing and Materials (ASTM) standard C 185 for testing the air content in mortar is a time consuming process which requires the use of various laboratory equipment and derivation of different formulas for individual mix designs. An alternate approach uses an air meter and follows the process prescribed in ASTM C 231 for use with portland cement concrete. The correlation between this alternate method and the prescribed method was tested. The results of these tests proved to be statistically correlated. Even though there appears to be no advantage with respect to accuracy, the use of an air meter is recommended due to time savings and ease of operation.

Keywords: Scott Esplin, mortar, air content, air meter, ASTM C 185, ASTM C 231

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1 INTRODUCTION

1.1 Background

The air content in mortar is often tested to help ensure such desirable traits as freeze-thaw resistance, sulfate resistance and increased workability. If the air is entrained in the mortar then these traits can be achieved without increasing susceptibility to water penetration because the entrained air bubbles are too small to allow water droplets through (Sun and Scherer 2010). If the air is entrapped (generally defined as air bubbles that are visible with the naked eye) then water and sulfate penetration as well as stress concentrations in the mortar can occur. Entrapped air can usually be avoided with proper mixing and consolidation techniques.

The American Society for Testing and Materials (ASTM) standard that applies to testing the air content of mortar is ASTM C 185 but through literature review it has been noted that modifications on ASTM C 231 are popularly employed by researchers and industry professionals (Lawrence et al. 1999). The procedures in ASTM C 231 are intended to be used solely with portland cement concrete but it seems that the ease and speed of the procedures along with a comparable level of accuracy has led to the more general application. This research has endeavored to affirm that the level of accuracy using the procedures in ASTM C 231 is indeed comparable to the methods prescribed in ASTM C 185.

1.2 Fundamentals

ASTM C 185 – Standard Test Method for Air Content of Hydraulic Cement Mortar employs a gravimetric method relying on provided batch proportions, specific gravities, and laboratory measurements. The standard provides the following equation:

$$\text{Air content, volume \%} = W[(182.7 + P)/(2000 + 4P)] \quad (1\text{-}1)$$

where:
W = mass of 400 mL of mortar, g, and
P = percentage of mixing water, based on mass of cement used.

The equation assumes standard specific gravity values for portland cement and 20-30 standard sand and allows the user to easily adjust for different water contents. The equation derivation is also provided in the standard to help account for differences in sand and cement type. In this research the example proportions and materials were used for the sake of simplicity. Once the mortar is mixed it is subjected to a flow test to ensure that the flow is in a specific range. Once the mortar passes the flow test, a known volume (400 ml) is weighed, which is the weight used in the equation. Using known values for specific gravities and batch proportions, an air content is calculated. The level of accuracy of this method is heavily reliant on the accuracy of the technician in both proportioning the batch and performing the tests which makes the utilization of this method in the field difficult.

ASTM C 231 – Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method employs a pressure based method for finding the air content of concrete. The test is based on Boyle's law which states that the pressure and volume of a closed system are inversely proportional (assuming no change in temperature). The pressure meter is filled to a known volume of mortar and sealed. Any excess space around the lid is filled with water and the upper chamber of the meter is pressurized to a predetermined pressure. The upper chamber is then released into the lower chamber of the air meter and the change in pressure is measured by a dial and expressed as a percentage of air content. For this method, all ingredients in the concrete other than air are considered incompressible. This method is heavily reliant on the accuracy of the hardware but not as reliant on a technician, which makes the method more suitable to be used in the field.

2 EXPERIMENTAL METHODOLOGY

2.1 Experimental Design

The experimentation that was designed employed both of the methods in question to test the exact same batches of mortar. While there is no baseline to determine which test is more correct, a statistical analysis could be run on the two sets of results to determine if they were statistically correlated with each other.

2.1.1 Assumptions

The most tenuous assumption made was that the aggregate was dry. This assumption clearly wasn't completely true, but the effects should have been mitigated fairly well. Due to a lack of available resources the sand wasn't put in an oven before testing but all of the sand was taken from the same stockpile and stored in sealed five gallon buckets before testing. The sand inevitably carried some water, which filled some voids in the aggregate. Because these voids were filled with water instead of air, the sample inevitably contained less air and more water than it would have with dry sand. While this effective change in mix design should automatically be accounted for by the air meter method, the equation employed by the flow table method cannot be adjusted accordingly. However, since the water content of the sand was constant across all of the samples, the skewing of the flow table method results should be constant across all of the samples. For this reason, this research is primarily evaluating the relationship between the results from the two testing methods with an understanding that a small but consistent skewing of the flow table method test results occurred.

2.2 Testing Procedures

The mortar mix design used in these tests was taken directly from the example in ASTM C 185 section 9.1 and multiplied by nine as displayed in **Table 1** to yield enough material to accommodate both tests. It was determined that 2.50 L of water would provide adequate flow but the samples were first tested at 2.40 L and then 2.45 L so as not to overshoot the required flow and have to discard the batch. A few samples were tested at these lower water contents (as is detailed in Appendix A) because they met the flow requirements for the flow table method.

Portland Cement	3.15 kg
20-30 Standard Sand	12.6 kg
Potable Water	Sufficient to give a flow of 87.5 + or – 7.5%

Table 1: Mortar Mix Design

The water was first added to a wheel barrow which had been pre-wetted and was mixed with the allotted portland cement. The sand was then added gradually and the entire mixture was mixed with a shovel until it reached a uniform consistency. At this point the flow table method was commenced, followed closely by the air meter method.

2.2.1 Flow Table Method (ASTM C 185)

The flow table was first cleaned and the flow mold was filled with two equal lifts of mortar, each tamped 20 times. The mortar was then cut flush with the top of the mold using a hand trowel in a sawing motion. The excess mortar was wiped away, the table was dried, and the mold was removed. The table was immediately dropped through a height of 0.5 inches 25 times. The flow was measured at four different points, as shown in Figure 1, and averaged to find a flow percentage. These results are included in Appendix A. If the flow was within the acceptable range the test moved forward, otherwise extra water was added to the mix and the flow table procedure was repeated. Once the mortar flow was within the acceptable range a 400 ml container was filled with three equal lifts of mortar, tamped 20 times per lift and weighed. The resulting weight of the mortar was plugged into the provided equation (see section 1.2) and an air content value was calculated.

Figure 1: Flow Table Diameter Measurement

2.2.2 Air Meter Method (ASTM C 231)

After the flow table method was completed, the excess mortar was used to fill the 0.25 ft^3 air meter in three equal lifts, tamped 25 times each and struck by a mallet 10 to 15 times each. The excess mortar was struck off with a piece of glass using a sawing motion over the first third and then the remaining two thirds of the air meter. The edge was then cleaned and the lid attached. The petcocks were filled with water, as shown in Figure 2, until it flowed out of the opposing side and then sealed. The meter was pressurized to the appropriate level and then the pressure was released into the main chamber while simultaneously being struck by a rubber mallet. The resulting reading was recorded as the air content of the mortar.

Figure 2: Pressure Meter Preparation

3 RESULTS

The results of the testing that was performed are displayed graphically in Figure 3. The sample number that is on the x-axis of the graph is not meaningful except that the data are best interpreted as matched pairs. Accordingly, a paired t-test was performed on the results in Figure 3 which resulted in a 95% level of confidence that these tests are positively correlated. The majority of samples tested fell between three and six percent air content, which is to be expected without addition of any air entrainers. It is also clear that despite all testing being performed in a laboratory under controlled conditions, the results are fairly inconsistent. It's hard to explain this level of inconsistency unless one takes into account the nature of the tests performed.

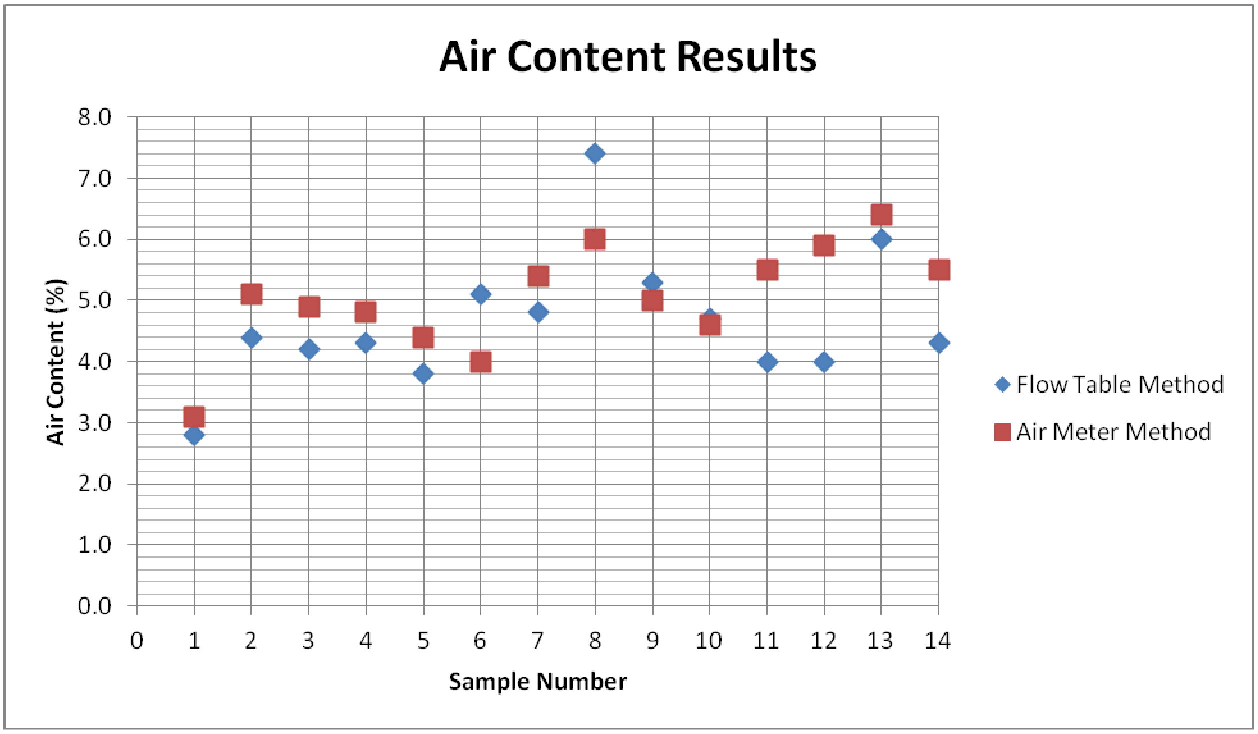

Figure 3: Air Content Testing Results

Air testing in mortar and concrete is inherently variable due to the nature of the natural materials involved. In most field applications of these testing methods there is a window of acceptable air content values that spans a few percentage points. However, the coefficients of variability presented in **Table 2** are nominally higher than those found in similar research (Zhang 1996). There is no explanation postulated for this increased variability aside from possible material inconsistencies and/or operator error. The table also shows that the mean value for the flow table method is slightly lower than that of the air meter method, which is to be expected considering the water content of the sand, as previously discussed. It should also be noted that these statistical results were obtained by removing one outlier (sample #8) which is in excess of two standard deviations from the mean, in accordance with Chauvenet's criterion (Ross 2003).

	Flow Table Method	Air Meter Method
Mean	4.45	4.93
Variance	.67	0.75
Standard Deviation	0.819	0.866

Table 2: Statistical Analysis of Air Content Testing Results

4 CONCLUSIONS

This research has demonstrated that the air meter method that has traditionally been used to test concrete can be successfully applied to mortar. The positive correlation between the test results and comparable mean and standard deviation values demonstrate an acceptable level of accuracy. Because this level of accuracy has been met, the air meter method is more desirable than the flow table method on all but the most sensitive of jobs. The flow table method requires more accuracy on the part of the technician and calculations must be run for every different mix design tested. It can be run with less mortar than is needed for a standard air meter but smaller air meters are available which can mitigate this concern. The air meter method, on the other hand, can be performed much more quickly and easily and is universally applicable to any mix design without any tweaking.

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APPENDIX A. SUPPLEMENTAL TEST DATA

Test #	Cement (g)	Sand (g)	Water (ml)	Flow (in)	Mass of 400 ml of Mortar (g)	Air Meter Reading (%)
1	3150	12600	2575	92	855.2	3.1
2	3150	12600	2400	85	851.1	5.1
3	3150	12600	2450	74	849.9	4.9
4	3150	12600	2500	83	845.9	4.8
5	3150	12600	2450	80	853.9	4.4
6	3150	12600	2500	89	839.1	4
7	3150	12600	2450	81	844.3	5.4
8	3150	12600	2500	80	819	6
9	3150	12600	2500	86	837.1	5
10	3150	12600	2500	81	842.7	4.6
11	3150	12600	2500	90	849.1	5.5
12	3150	12600	2500	84	849.3	5.9
13	3150	12600	2500	80	831.0	6.4
14	3150	12600	2500	86	845.7	5.5