AIR CONTENT OF MORTAR

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ABSTRACT
The air content of mortar and that of concrete are determined using the procedures outlined in ASTM C 185 and ASTM C231, respectively. The mortar testing employs a gravimetric method relying on batch proportions, specific gravities, and other laboratory measurements. The level of accuracy of the mortar method is heavily reliant on the accuracy of the technician in both proportioning the batch and performing the test. The procedure outlined in ASTM C 231 is intended to be used solely with concrete, but a literature review has indicated that researchers and industry professionals also employ ASTM C 231 to determine the air content of mortar. The reason appears to be the ease and speed of the pressure method.

This article describes a simple study to evaluate the relationship between the results from testing employing the gravimetric and the pressure methods. The pressure method used for concrete can be performed much more quickly and easily and is universally applicable to any mix design. The gravimetric method used for mortar, on the other hand, is more labor intensive and requires more accuracy on the part of the technician. The conclusion from this research is that the pressure method can be successfully used to determine the air content of mortars. Even though a standard air meter requires more mortar to perform the testing, smaller air meters are available which can mitigate this concern. The obtained positive correlation between the test results from both methods and comparable mean and variances demonstrate an acceptable level of accuracy. Thus, the use of the pressure method is recommended due to time savings and ease of operation.

KEYWORDS: air content, air meter, flow table method, air entrained, masonry air content

INTRODUCTION

Concrete will have entrapped and/or entrained air. Entrapped air will occur in all concrete, and the size of the entrapped air voids is related directly to the characteristics of the aggregate used. Entrapped air content is typically below 2 percent by volume of concrete. Entrained air, as the name suggests, is air intentionally introduced into the concrete mix; entrained air voids are more stable and smaller than those of entrapped air. Entrained air increases the total volume of air voids by 3 to 4 percent of the volume of concrete. Several concrete properties are influenced by both types of air. Entrained air typically enhances some concrete properties while entrapped air is typically harmful to concrete. Entrained air enhances the concrete resistance to freeze-thaw cycles, salts, sulphates and alkali-silica reactivity. Entrained air also influences compressive strength and workability. In the United States, there are several techniques available to measure the air content of concrete. Both American Association of State Highway and Transportation Officials (AASHTO) and ASTM International have standards for measuring the air content of fresh and hard concrete [1]. There have also been alternative methods proposed to measure air content in fresh concrete [2].

Similar to concrete, masonry mortar will have entrapped air and may also have entrained air. The same properties that are influenced by the air content in concrete are influenced by the air content in mortars. Although entrained air in masonry mortar increases the mortar resistance to freeze-thaw cycles [3], durability of mortar in unsaturated masonry is not a serious problem [4], and data indicate that there is no direct correlation between the air content in masonry mortar and the water penetration of masonry walls [5]. Entrained air in masonry mortar also influences water retention and bond strength [6,7]. Though increasing masonry mortar air content may theoretically enhances some mortar properties, the decrease in bond and compressive strength is disturbing to the point that the use of air-entraining admixtures to increase air content of masonry mortar is not recommended [8].

Determining the air content in mortar may be one of the requirements of a quality control tool. Quality assurance is the activity of providing evidence to all concerned parties that the processes required to produce a structure that meets the owner's requirements are being adequately performed. Quality control—a tool used in a quality assurance program—is the process of measuring quality, comparing the measurements to appropriate standards and acting on the comparison results. Quality control is utilized at various key phases of the quality assurance program and may involve testing, inspections, or both [9].

FUNDAMENTALS

This research used the procedure outlined on ASTM C185 [10], standard test method for air content of hydraulic cement mortar, rather than that of ASTM C270 [11], standard specification for mortar for unit masonry. The objective of this research was to compare the air content of mortar obtained using the gravimetric method, the standard procedure, to that obtained using the pressure method, a non-standard procedure; this research did not attempt in any way to indicate which method was more accurate. The comparison will indicate if the measurements made using one method are statistically different than those made using the other method. Because of the comparative nature of this research and because measurements were to be made from exactly same mortar batches, researchers believed that the procedure outlined on ASTM C185 was sufficient to accomplish the objectives of the research. The procedure outlined on ASTM C270 could have been used and, if that were the case, the air content measurements obtained would most likely be more representative of those obtained in the field; researchers, however, speculate that the comparison results would not be much different of the results shown herein.

Unlike concrete, which has several methods for measuring its air content [1], mortar has only one standard testing procedure—a gravimetric method. According to ASTM C185, the method relies on a mortar batch made using 350 grams of cement, 1400 grams of 20-30 standard sand and sufficient water to give the mortar a flow of 87.5 ±7.5 %. Although ASTM C270 and ASTM C91 [12] apply to different types of mortar and/or cement, the specified testing procedure is still a gravimetric method. According to ASTM C185 the air content is determined using equation 1.

$$\text{Air content, volume \%} = 100 - W[(182.7 + P)/(2000 + 4P)] \quad (1)$$

Where W is the mass, in grams, of 400 mL of mortar and P is the percentage of mixing water, based on the mass of cement used. The equation was derived using 3.15 and 2.65 as specific gravities for Portland cement and 20-30 standard sand, respectively.

The accuracy of the gravimetric method is heavily reliant on the experience and precision of the technician in both proportioning the batch and performing the tests. In an attempt to reduce the calculations needed and possibly the inaccuracies involved in the gravimetric method, Maksoud and Ashour [13] proposed a slightly modification to the method. Although the modification proved to be somewhat satisfactory, the basic principles governing the gravimetric method did not change and therefore the reliance of the results on the experience and accuracy of the technician were not addressed.

The pressure method may give satisfactory mortar air content measurements. In a recent study to validate a newly developed standard for evaluating mortar for the repair of historic masonry [14], the authors judged their own mortar air content measurements as questionable and suggested that the pressure method used for air content measurement in concrete be also used for mortar. The pressure method for measuring the air content of fresh mixed concrete is described in ASTM C231/C231M [15]. The test determines the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure. The same principle, therefore, could be used to determine the air content in mortars. As a matter of fact, the pressure method has been successfully used to measure the air content of mortar. Taylor [16] developed one of the first, if not the first air meter to measure mortar air content and determined, using his newly developed apparatus, the air content of several mortar batches and compared those results with the results from the gravimetric method. The main conclusion from that pioneering study was that the mortar air content determined using the pressure method was slightly higher than that determined using the gravimetric method. Unlike the US, Europe has two standard methods to determine the air content of fresh mortar one of which is the pressure method [17]. But even the usual pressure method, using a standard air meter, has been criticized and found to overestimate slightly the air content of mortars [18].

The procedures in ASTM C231/C231M [15] are intended to be used solely with Portland cement concrete. The pressure test is based on Boyle's law which states that the pressure and volume of a closed system, for a constant temperature, are inversely proportional. 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 known pressure. The upper chamber is then released into the lower chamber of the air meter and the change in pressure is recorded by a dial and expressed as a percentage of air content. All components of the concrete other than air are considered incompressible. This method is heavily reliant on the accuracy of the hardware but not as reliant on the experience of the technician. The ease and speed of these procedures along with the heavily reliance of the gravimetric method on the experience of the technician in both proportioning the mortar batch and performing the gravimetric tests could entice the US industry to adopt the pressure method as one of the standards procedure to determine the air content in mortars.

This research has endeavoured to show that the level of accuracy using the procedures in ASTM C231/C231M is indeed comparable to the methods prescribed in ASTM C185 and that the pressure method should be further investigated as a possible standard method to determine mortar air content.

EXERIMENTAL METHODOLOGY

The experimentation that was designed employed both the gravimetric and the pressure method to test the exact same batches of mortar. A total of 14 batches were tested.

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 space and resources constraints 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 such a change in mix design should automatically be accounted for by the pressure method, the equation employed by the gravimetric method cannot be adjusted accordingly. However, since the water content of the sand was constant across all of the samples, the skewing of the gravimetric 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 gravimetric method test results occurred.

The mortar mix design used in the tests was that specified in ASTM C185 section 9.1 [10]: 350 grams of cement, 1400 grams of 20-30 standard sand, and sufficient water to produce a mortar a flow of 87.5 ±7.5 %. The pressure method requires a concrete air meter and two typical sizes of air meter, as shown in Figure 1, are available: 7 liters and 1 liter. Researchers purchased the 1 liter capacity air meter; however, due to delivery delay the apparatus did not arrive on time. Researchers therefore used the 7 liter air meter to conduct the pressure tests. The batch quantities were therefore multiplied by nine to yield enough material to accommodate both sets of tests. A summary of the quantities used for each batch is given in Table 1.

(a) 7 liters Capacity (b) 1 liter Capacity

Figure 1 : Typical Air Meters

Table 1 : Typical Batch Quantities

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

A trial batch was made, which required approximately 2.5 liters of water to give the desired flow. Actual batches were therefore first made with approximately 2.3 liters of water; water was then added carefully to the mix so as not to give a larger flow than that of the specifications; any batch with a larger flow than the specified flow was discarded. The water was first added to a pre-wetted wheel barrow and then Portland cement added and mixed. The sand was finally added gradually and the components mixed with a shovel until it reached a uniform consistency.

GRAVIMETRIC METHOD

The flow table was first cleaned and the flow mold was filled with two equal lifts of mortar, each lift 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. ASTM C185 [10] specifies that the table be dropped 10 times in accordance with ASTM C230/C230M [20], standard specification for flow table for use in tests of hydraulic cements. The reference to ASTM C230/C230M is misleading since it does not specify how to conduct the flow test but rather how to construct a flow table. The authors have since been informed that ASTM C185 is simply modifying ASTM C1437 [21], standard test method for flow of hydraulic cement mortar, which specifies that the flow table be dropped 25 times in 15 seconds. The intended modification was not made and for this research the flow table was dropped in accordance with ASTM C1437 [21]. The effect of not making the modification is not known but the authors speculate that the conclusions herein provided are still valid because of the comparative nature of the research and because the measurements were made from exactly same mortar batches.

The flow was measured at four different points, as shown in Figure 2, and averaged to find a flow percentage. 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. The mortar used for the flow test was discarded. Due to material variation, a few batches were completely discarded because of larger flow than that specified even with only 2.3 liters of water.

Once the mortar flow was within the acceptable range, the air content of the mortar was immediately determined using the mortar from the wheel barrow. First a 400 ml container was filled with three equal layers of mortar; each layer was tamped 20 times. Once the container was filled, it was clean from mortar and water adhering to its outside. The mass of the filled container was determined. The mass in grams of the 400 ml of mortar was determined by subtracting the mass of the empty container. Equation 1 was then used to determine the air content of each batch. Table 2 shows the quantities used, the percentage of water based on the mass of cement, the mortar mass, and the air content for each batch.

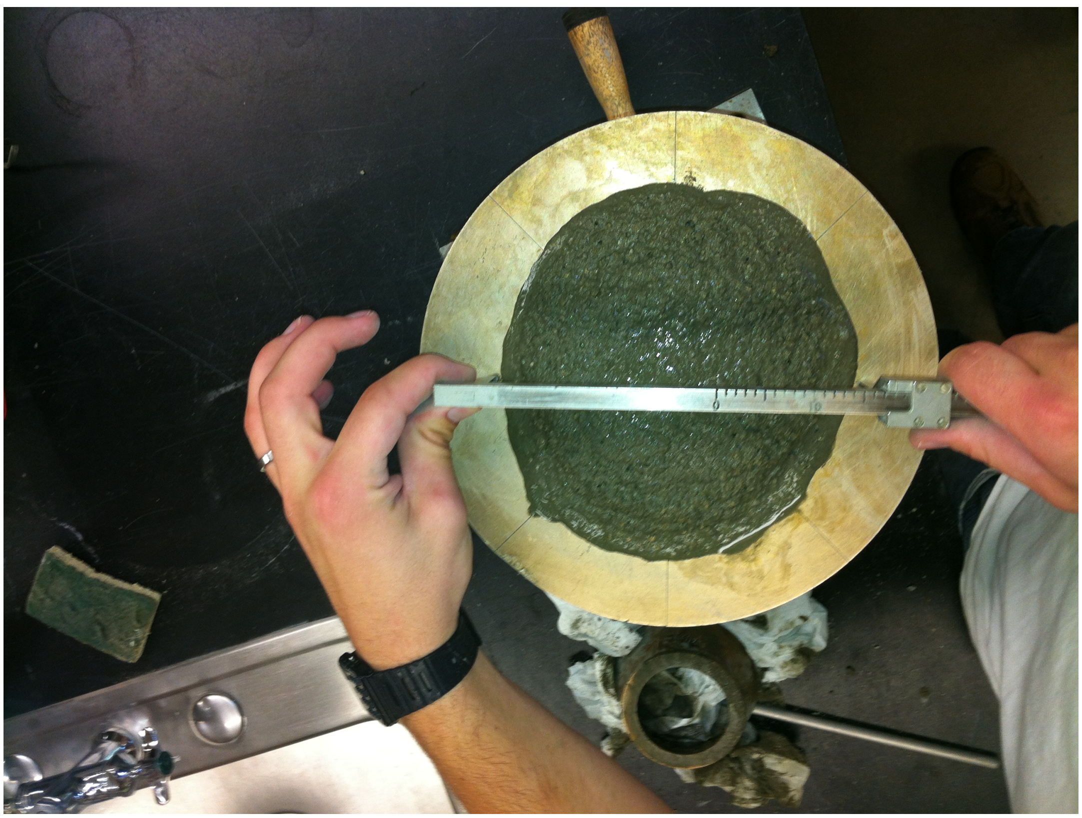

Figure 2 : Flow Table Diameter Measurement

Table 2 : Batch Proportions, Flow, and Air Content

Batch No.	Cement (g)	Sand (g)	Water (ml)	Water (%)	Flow (%)	Mortar (g)	Air (%)
1	3150	12600	2575	81.75	92	855	2.8
2	3150	12600	2400	76.19	85	851	4.4
3	3150	12600	2450	77.78	84	850	4.2
4	3150	12600	2500	79.37	83	846	4.3
5	3150	12600	2450	77.78	80	854	3.8
6	3150	12600	2500	79.37	89	839	5.1
7	3150	12600	2450	77.78	81	844	4.8
8	3150	12600	2500	79.37	80	819	7.4
9	3150	12600	2500	79.37	86	837	5.3
10	3150	12600	2500	79.37	81	843	4.7
11	3150	12600	2500	79.37	90	849	4.0
12	3150	12600	2500	79.37	84	849	4.0
13	3150	12600	2500	79.37	80	831	6.0
14	3150	12600	2500	79.37	86	846	4.4

PRESSURE METHOD

After the mortar air content was determined by the gravimetric method, the excess mortar was used to determine the air content by the pressure method. The air meter bow was filled in three equal lifts. After each lift was tamped 25 times, the bow was struck by a mallet 10 to 15 times around its circumference in approximately opposite direction. The excess mortar was struck off with a piece of glass using a sawing motion according to ASTM C138/C138M [22]. The edge was then cleaned and the lid attached. One of the petcocks was filled with water, as shown in Figure 3, until water flowed out of the opposing petcock and then the chamber was sealed. The meter was pressurized to the appropriate level and then the pressure 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; results are shown in Table 3.

Figure 3 : Pressure Meter Preparation

Table 3 : Mortar Air Content Determined Using the Pressure Method

Batch No.	Air (%)	Batch No.	Air (%)	Batch No.	Air (%)	Batch No.	Air (%)
1	3.1	5	4.4	9	5.0	13	6.4
2	5.1	6	4.0	10	4.6	14	5.5
3	4.9	7	5.4	11	5.5		
4	4.8	8	6.0	12	5.9		

ANALYSIS

The results of the testing that was performed are displayed graphically in Figure 4. The majority of samples tested had between three and six percent air content, which is to be expected without addition of any air entrainers. Roughly, the mortar air content as determined by the pressure method is slightly higher than that determined by the gravimetric method. This finding is consistent to that of Taylor [16], who concluded that the mortar air content determined using the pressure method was slightly higher than that determined using the gravimetric method.

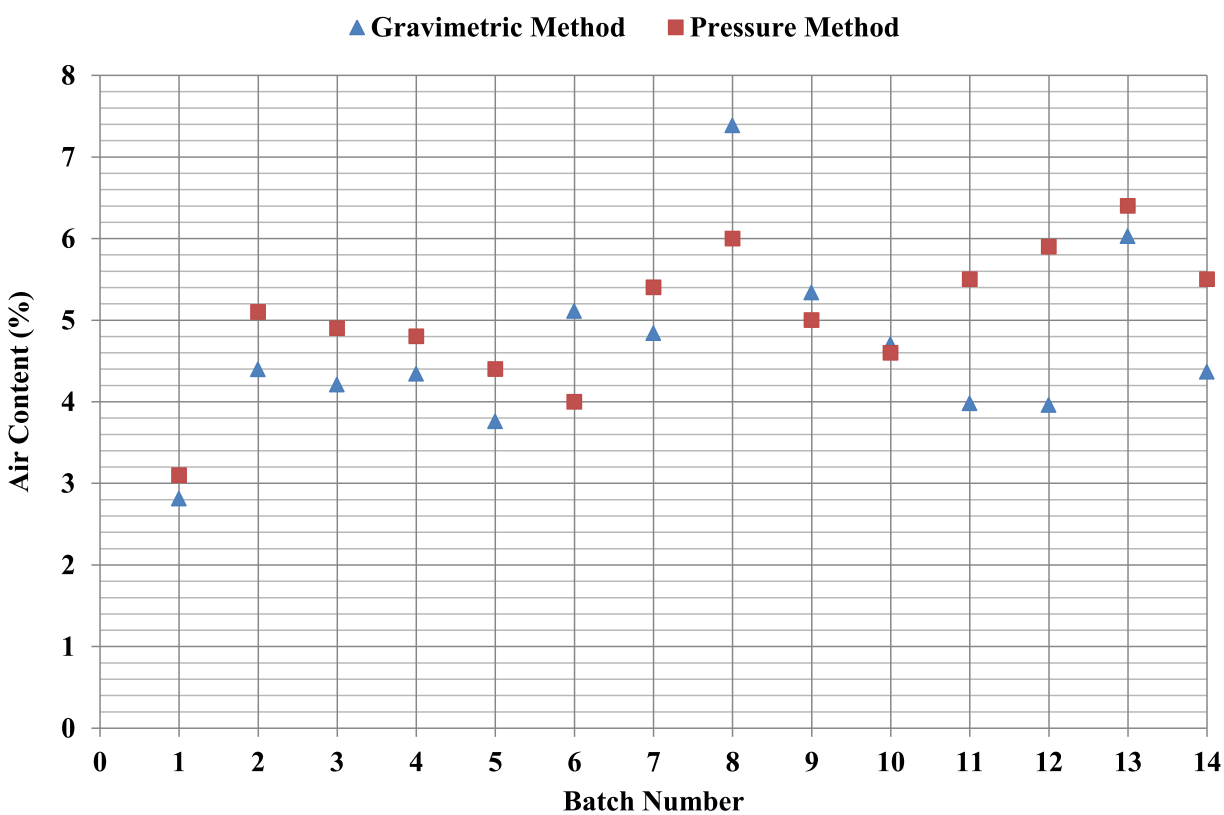

Figure 4 : Air Content Testing Results

The data show, despite all testing being performed in a laboratory under controlled conditions, some variability. The coefficient of variance for the gravimetric results is 23.5% and that for the pressure results is 17%. There is no explanation to this variability unless one takes into account the nature of the tests performed. Air testing in mortar, as well in concrete, is inherently variable due to the nature of the materials involved. Although researchers were extremely careful during batching and testing, the variation may also be due to problems either with the batching, the testing or both. Furthermore, the variation may also indicate that measurements of mortar air content are not as accurate as one thinks it is.

While there is no baseline to determine which test method is more correct, a statistical analysis can determine if the two sets of results are statistically correlated with each other. The batch number plotted on the x-axis is not meaningful except that the data are best interpreted as matched pairs. A paired t-test analysis was conducted to determine if the air content, on average, obtained using the gravimetric method was statistically different than that obtained using the pressure method. The null hypothesis was that there was no statistical difference between the air content, on average, determined using both methods. Table 4 shows the results of the analysis.
The p-value of 0.138 is not sufficiently low to conclude that the methods are different. Thus, the null hypothesis is accepted and the conclusion is that there is no statistical difference between the air content, on average, determined using both methods. In this research, the mean air content value determined by the gravimetric method is slightly lower than what the actual air content would be because of the additional water content of the sand used, as previously discussed. Mortar made with dry sand would therefore result in slightly higher air content, which would make the results herein presented better, meaning the p-value would be greater and more convincing. Although the results have somewhat large variances, the coefficients of variability presented in Table 4 are similar to those found in similar research [23].

Table 4 : Statistical Analysis (t-test: Paired Two Sample for Means)

	Gravimetric	Pressure
Mean	4.66	5.04
Variance	1.20	0.74
Observations	14	14
Pearson Correlation	0.59	
Hypothesized Mean Difference	0	
df	13	
t Stat	-1.58	
P(T<=t) one-tail	0.069	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.138	
t Critical two-tail	2.16	

CONCLUSIONS

This research has demonstrated that the pressure method that has been traditionally used to determine the air content of concrete can be successfully used to determine the air content of mortar. The positive correlation between the test results obtained using the gravimetric and pressure methods and comparable mean and variances demonstrate an acceptable level of accuracy. Because this level of accuracy has been met, the pressure method is more desirable than the gravimetric method on all but the most sensitive of jobs. The gravimetric method requires more accuracy on the part of the technician, and calculations are required for every different mix design tested. As a benefit, the gravimetric method requires less mortar than the pressure method if a standard air meter is used; smaller air meters, however, are available which can mitigate this concern. The pressure method, on the other hand, can be conducted much more quickly and easily and is universally applicable to any mix design without any discarding of batches or adjustment to the mix.

It was unfortunate that the testing was conducted using the 7 liters rather than the 1 liter air meter. Most likely researchers and commercial laboratories will not use the pressure method if the larger volume of mortar is needed to conduct the tests. The authors are planning to repeat the research described herein using the 1 liter air meter and compare not only testing methods but also testing apparatuses.

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