

Evaluation of the RapidAir 457 Air Void Analyzer

Final Report
For
MLR-12-01

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Sponsored by:
Iowa Department of Transportation
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Highway Division
**Iowa Department
Of Transportation**



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16 Abstract An adequate air void system is imperative to produce concrete with freeze-thaw durability in a wet freeze environment such as found in Iowa. Specifications rely on a percentage of air obtained in the plastic state by the pressure meter. Actual, in place air contents, of some concrete pavements in Iowa, have been found with reduced air content due to a number of factors such as excessive vibration and inadequate mixing. Determining hardened air void parameters is a time consuming process involving potential for human error. The RapidAir 457 air void analyzer is an automated device used to determine hardened air void parameters. The device is used in Europe and has been shown to quickly produce accurate and repeatable hardened air results. This research investigates how well the RapidAir 457 results correlate to plastic air content and the image analysis air technique. The repeatability and operator variation were also investigated, as well as, the impact of aggregate porosity and selection of threshold value on hardened air results.					
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Introduction

An adequate air void system is imperative to produce concrete with freeze-thaw durability in a wet freeze environment such as found in Iowa. Specifications rely on a percentage of air obtained in the plastic state by the pressure meter. Actual, in place air contents, of some concrete pavements in Iowa, have been found with reduced air content^{1,2} due to a number of factors such as excessive vibration³ and inadequate mixing. The lower air content coupled with poor spacing factors has resulted in early deterioration due to inadequate resistance to freezing and thawing⁴.

The Iowa Department of Transportation (DOT) has utilized the high pressure air meter to determine bulk air content of hardened concrete cores since the late 1960's. This test method was developed in the late 1950's by the Illinois DOT⁵. The test gives a fairly good correlation with plastic air content; however, it cannot determine air void parameters, such as specific surface and spacing factor, which are better indicators of freeze-thaw durability. In addition, sample preparation to obtain the bulk air content takes at least four days of processing.



Figure 1 - High pressure air equipment

The standard test method for determining air void parameters is ASTM C 457 Microscopical Determination of the Air-Void System in Hardened Concrete. Introduced in the 1950's, ASTM C 457 linear traverse method is time consuming and tedious, taking several hours to complete an analysis. Since the test requires a human operator

to work behind a microscope for 4 to 6 hours determining concrete constituents, such as air, paste, and aggregates, results become susceptible to operator error due to human fatigue.

Several attempts have been made to automate the method and remove the human intervention. These various systems are similar in that an image is obtained from the sample and analyzed with little aid of a human operator. One such system was developed by Iowa State University (ISU) utilizing images obtained from a scanning electron microscope (SEM)⁶. The images are analyzed using image analysis software and the area measurement of air voids are determined from each image and processed to determine the air void parameters. Although this method does not technically meet the linear traverse method described in ASTM C 457, the results obtained from this method correlate very well. Obtaining the images for processing is a fairly quick process; however, the image analysis program requires some human intervention and manipulation to obtain the results.

The most notable automated system on the market today is the RapidAir 457 Air Void Analyzer available from Concrete Experts International (CXI)⁷. This system utilizes a camera and computer controlled motorized stage to determine air void parameters on a black and white enhanced sample in less than 15 minutes. The results of round robin studies have shown excellent correlation with air void system parameters on a lab to lab basis⁸.

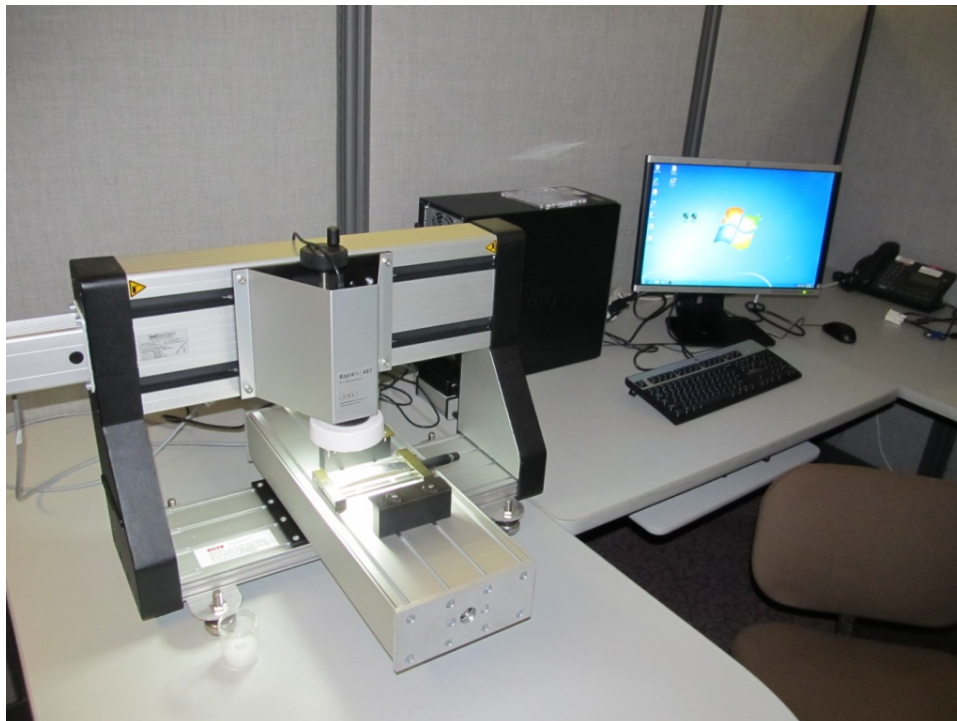


Figure 2 – RapidAir 457 Air Void Analyzer

Objective

The objective of this report is to evaluate the RapidAir 457 air void analyzer. The operation and repeatability will be investigated. A comparison between the RapidAir 457 results and those obtained from the SEM and image analysis will also be investigated.

Experimental method

Four separate batches of an Iowa DOT C-3WR mix were mixed in the Central Materials laboratory. The amount of air entraining admixture was adjusted for each mix to vary the target plastic air content of 4, 6, 8 and 10 percent. The mix design may be found in Appendix A. The coarse aggregate used was from the Fort Dodge mine. The aggregate correction factor was determined to be 0.4 percent. Results of the laboratory mix design are show in Table 1.

Table 1 – Mix properties

Mix No.	Target Air, %	w/c ratio	Unit Weight (pcf)	Plastic Air, %	Plastic Air Corrected, %
1	4	0.41	146.8	4.0	3.6
2	6	0.41	145.6	6.2	5.8
3	8	0.41	143.0	7.6	7.2
4	10	0.41	140.8	10.0	9.6

Four cylinders were cast from each mix batched. Samples were obtained for hardened air analysis using the SEM and RapidAir 457. Two cylinders from each of Mix 1, 3, and 4 were tested using the high pressure air unit in the Materials laboratory. Three cylinders from Mix 2 were used to obtain samples for three different operators using the RapidAir 457. Sample preparation, air void enhancement, and operation of the software for the RapidAir 457 air void analyzer can be found in Appendix B, C, and D.

Comparison of air content

The air content results of the various test methods are combined in Table 2.

Table 2 – Air content by various test methods

Mix No.	Plastic Air, %	High Pressure Air, %	Sample No.	Image Air, %	RapidAir 457 Air, %
1	3.6	3.4	1-24	5.17	4.47
		3.5	1-34	3.87	5.1
		-	1-44	4.86	4.52
Avg.		3.45		4.63	4.70
2	5.8	-	2-26	5.73	5.51
		-	2-36	5.98	5.32
		-	2-46	6.23	6.1
Avg.		-		5.98	5.64
3	7.2	6.5	3-28	7.69	7.04
		6.7	3-38	8.26	7.02
		-	3-48	7.18	6.89
Avg.		6.60		7.71	6.98
4	9.6	8.8	4-210	9.61	8.17
		8.0	4-310	9.09	7.51
		-	4-410	9.42	8.62
Avg.		8.40		9.37	8.10

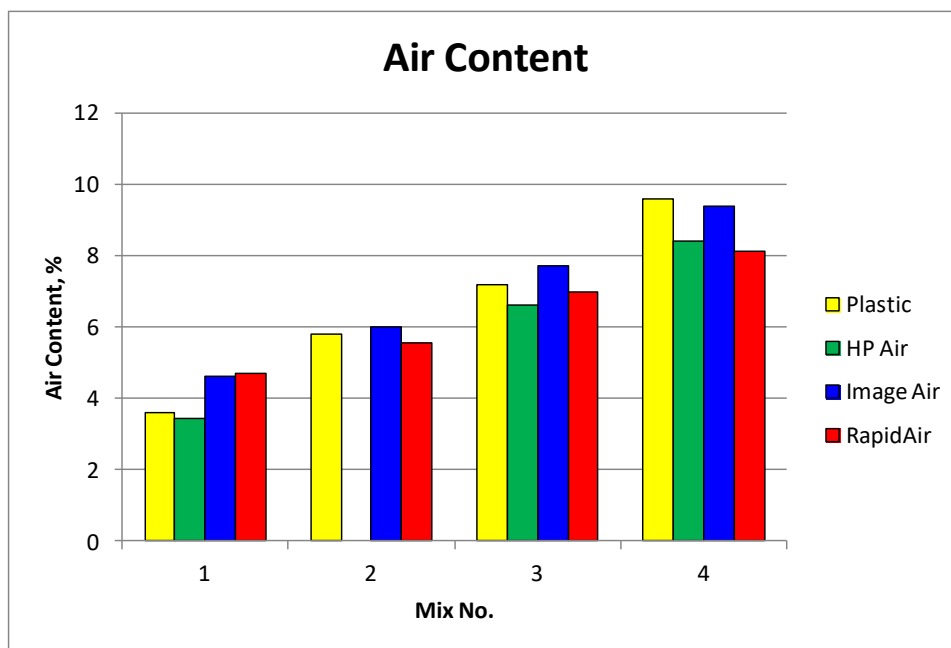


Figure 3 – Air content comparison – all methods

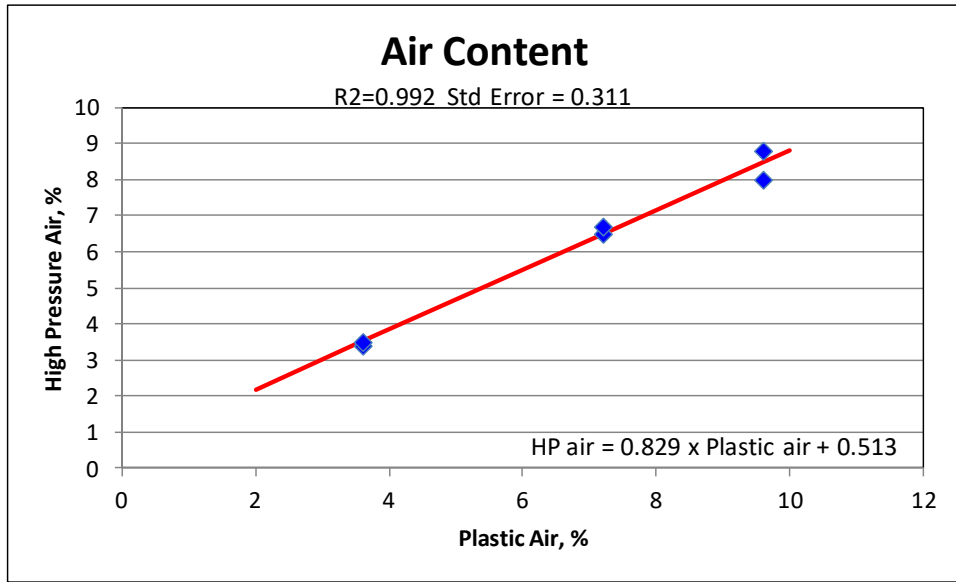


Figure 4 – Air content plastic versus high pressure air

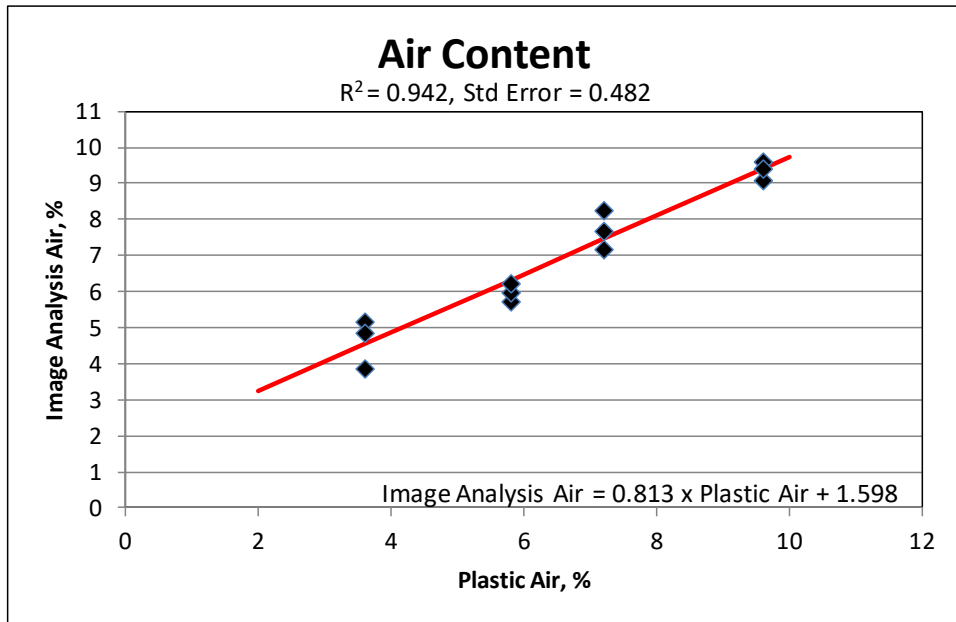


Figure 5 – Air content plastic versus image air results

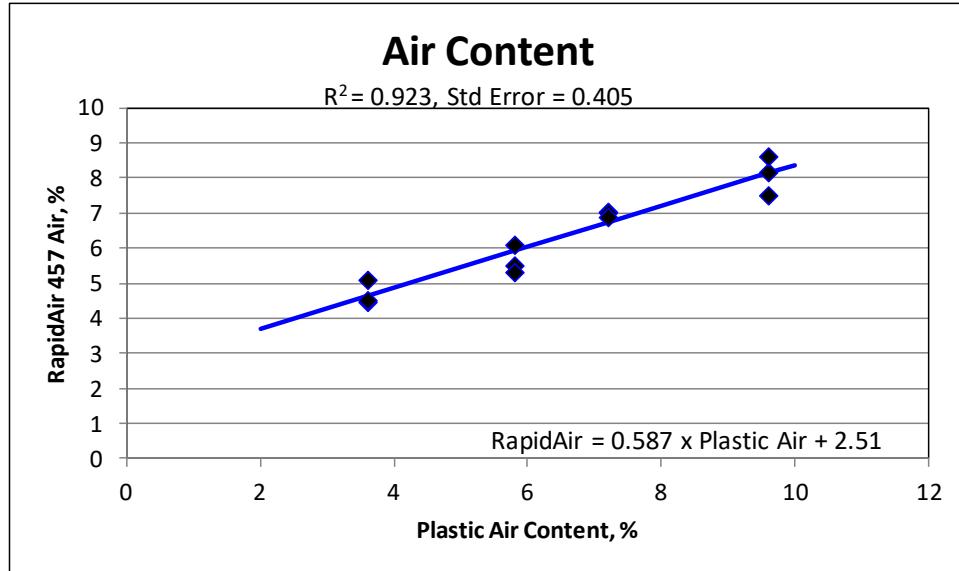


Figure 6 – Air content plastic versus RapidAir 457 results

As has been shown in previous research, the high pressure air test results correlate very well with plastic air results obtained by the pressure meter ($R^2 = 0.992$). The image air results and the RapidAir 457 results also correlate very well to plastic air content ($R^2 = 0.942$ and $R^2 = 0.923$, respectively).

Image analysis and RapidAir 457 results

Samples were obtained from three different cylinders cast from each of the four mixes batched. The samples were polished and tested at Iowa State University (ISU) MARL laboratory using the image analysis technique. After testing at ISU, the samples were subjected to the black and white enhancement procedure at the Iowa DOT and then tested using the RapidAir 457 air void analyzer. It should be noted that all results compared were based on chord lengths and air voids less than 1 millimeter. The air void parameter results including air content, specific surface, and spacing factor are shown in Table 3.

Table 3 – Comparison of air void parameters by image analysis and RapidAir 457

Sample	Image Analysis			RapidAir 457		
	Air %	Specific Surface (mm-1)	Spacing Factor (mm)	Air %	Specific Surface (mm-1)	Spacing Factor (mm)
1-24	5.17	22.305	0.172	4.47	32.92	0.147
1-34	3.87	29.851	0.152	5.10	34.83	0.131
1-44	4.86	22.727	0.175	4.52	34.22	0.141
2-26	5.73	24.390	0.148	5.51	43.52	0.111
2-36	5.98	26.432	0.133	5.32	35.01	0.128
2-46	6.23	22.388	0.153	6.10	33.45	0.121
3-28	7.69	25.105	0.120	7.04	40.94	0.086
3-38	8.26	23.077	0.124	7.02	34.82	0.101
3-48	7.18	28.846	0.109	6.89	44.86	0.081
4-210	9.61	29.851	0.087	8.17	49.12	0.062
4-310	9.09	28.846	0.093	7.51	48.41	0.068
4-410	9.42	26.201	0.101	8.62	48.40	0.059

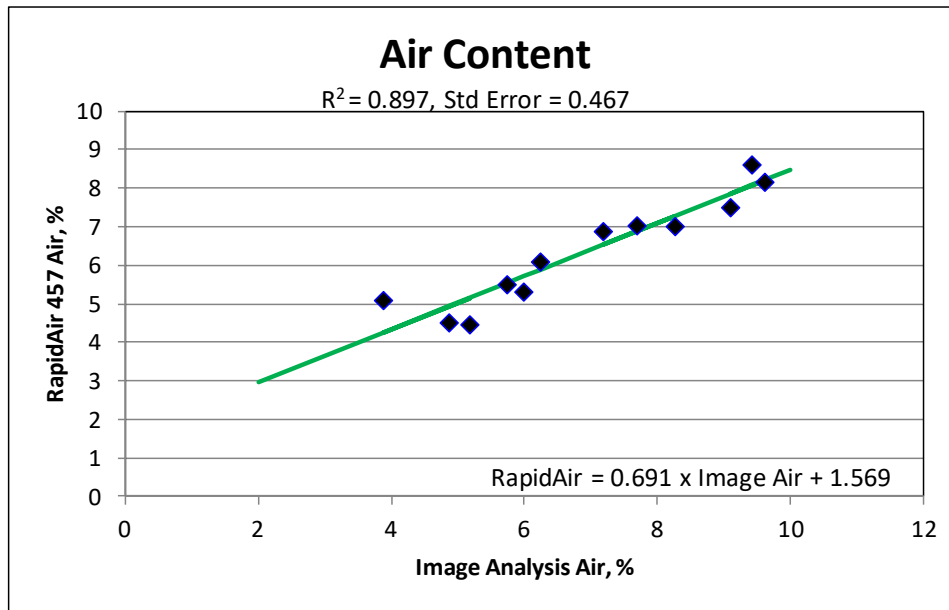


Figure 7 – Air content image analysis versus RapidAir 457 results

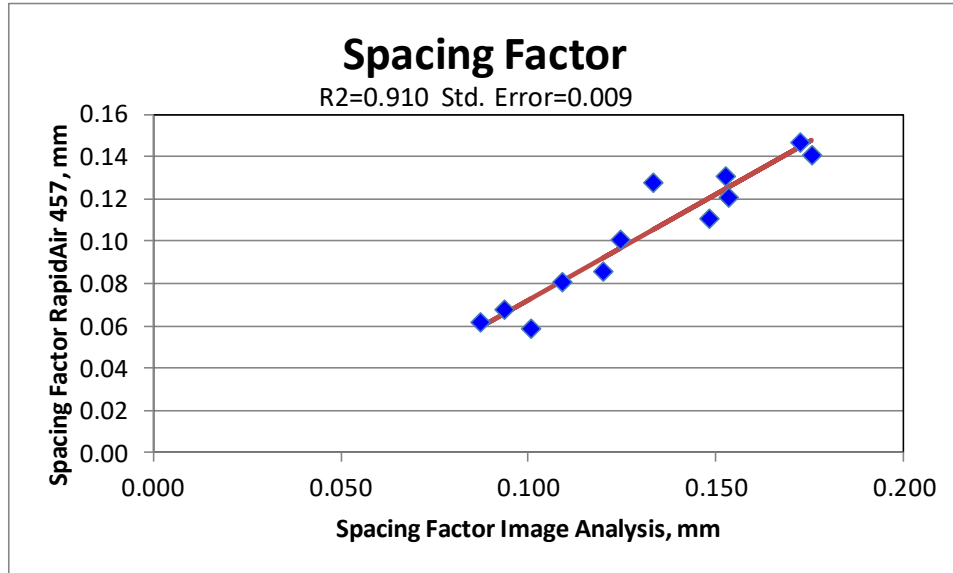


Figure 8 – Spacing factor image analysis versus RapidAir 457 results

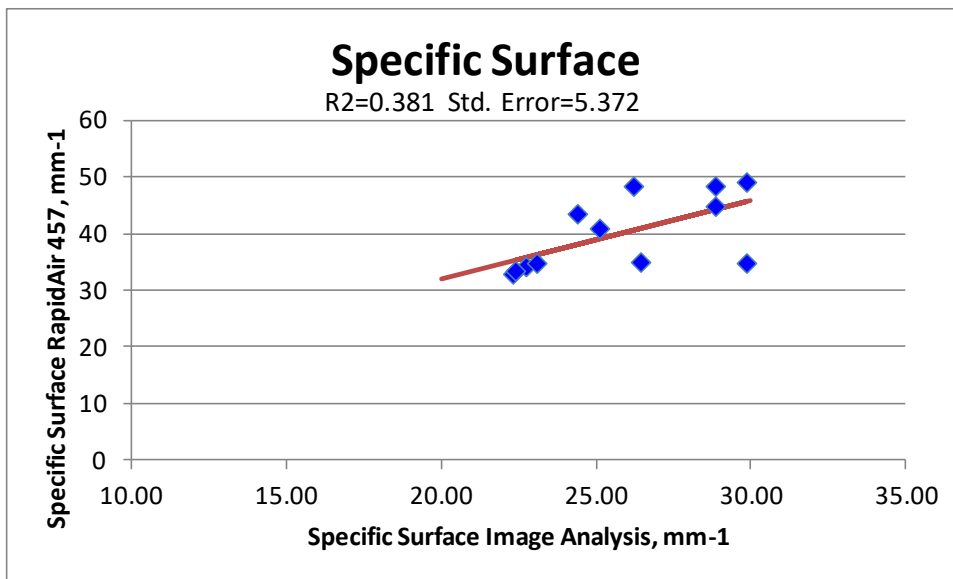


Figure 9 – Specific surface image analysis versus RapidAir 457 results

There is a very good correlation between the image air results and the RapidAir 457 air content results ($R^2 = 0.892$). Although the image air analysis technique measures actual air void diameters in each image as opposed to chord length required by the linear traverse method outlined in ASTM, previous research⁶ has shown good correlation with the image air analysis results and linear traverse results.

The spacing factor also indicated a very good correlation between image air analysis and the RapidAir 457 ($R^2 = 0.910$). The spacing factor is a good indicator of freeze thaw durability.

Specific surface exhibited a poor correlation compared to the air content and spacing factor ($R^2 = 0.381$). Previous research⁶ noted the area weighting of the mean air void size caused the specific surface estimates to be lower than those obtained from linear traverse.

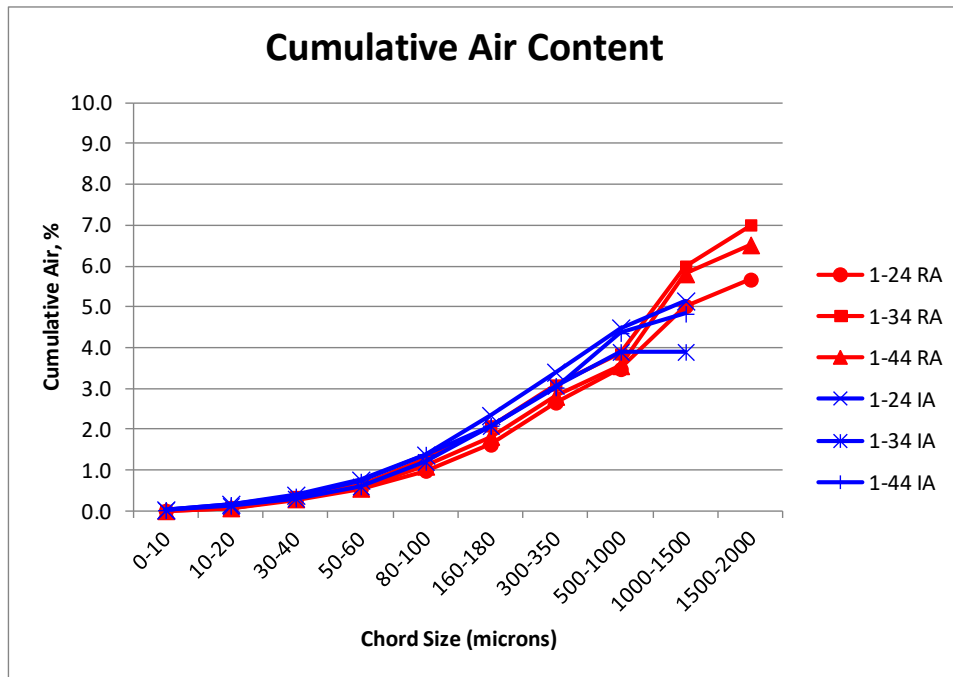


Figure 10 – Cumulative air by chord size RapidAir 457 (RA) and image air (IA) - Mix 1

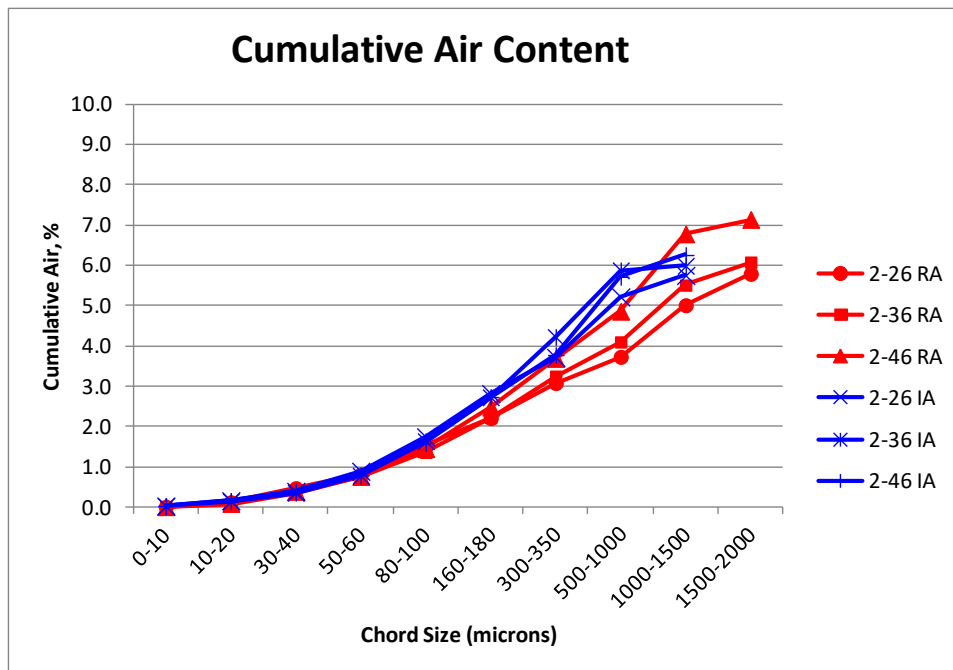


Figure 11 – Cumulative air by chord size RapidAir 457 (RA) and image air (IA) - Mix 2

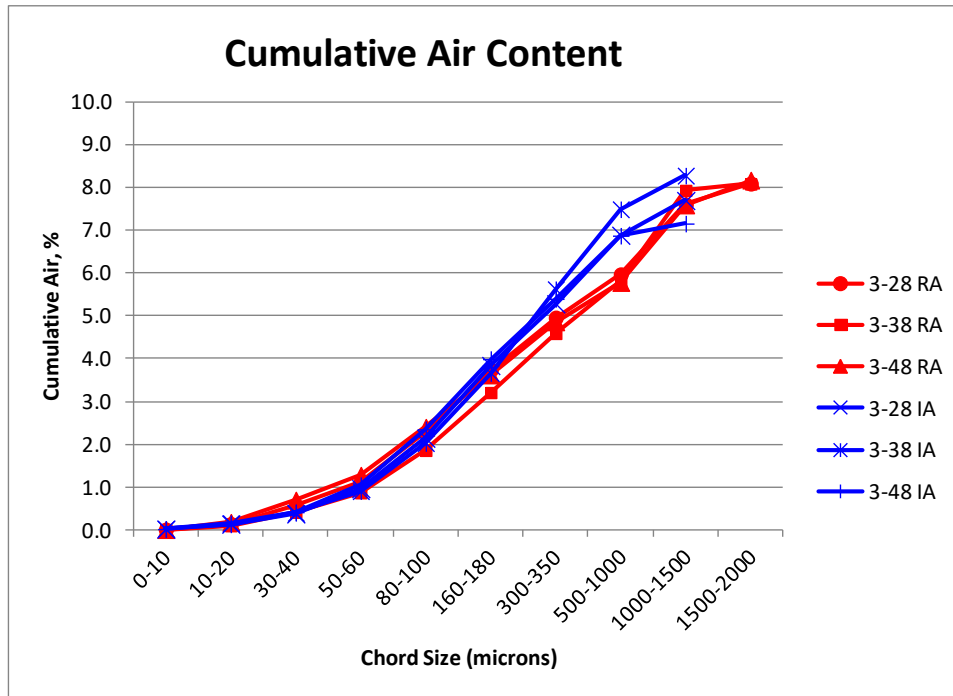


Figure 12 – Cumulative air by chord size RapidAir 457 (RA) and image air (IA) - Mix 3

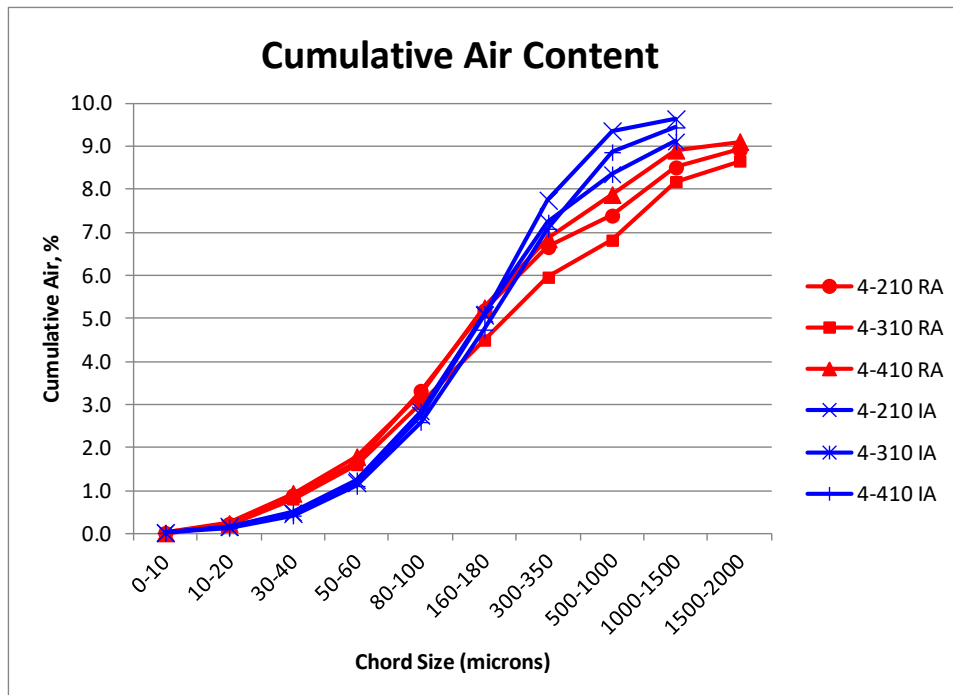


Figure 13 – Cumulative air by chord size RapidAir 457 (RA) and image air (IA) - Mix 4

Freeze-thaw resistance depends on both the cumulative volume of air bubbles and the average bubble size, with smaller bubbles providing greater protection per unit volume. The comparison of cumulative air content for each mix between the image air analysis and RapidAir 457 is shown in Figures 11 through 14. Both techniques produce similar trends of cumulative air content.

Repeatability

One specimen was obtained from Mix 4. The specimen was placed in the sample holder and kept in the same position. Using the same starting point, the specimen was tested over the same traverse five times. The results are found in Table 4.

Table 4 –RapidAir 457 results multiple runs on the same traverse

Run #	Air, %	Specific Surface, mm-1	Spacing Factor, mm
1	6.66	40.57	0.091
2	6.60	40.16	0.093
3	6.59	40.07	0.094
4	6.60	40.08	0.093
5	6.62	40.45	0.092
Average	6.61	40.27	0.093
Std. Deviation	0.03	0.23	0.001

The results obtained indicate that the RapidAir 457 is very repeatable over the same traverse.

Variation between operators

Three different operators were trained to perform the test. Each operator obtained a cylinder from Mix 2. Each operator sawed, polished, prepared, and performed an air void analysis on the specimen they obtained from the cylinder. The samples prepared by each operator were then tested by the other two operators. The results are found in following Table 5.

Table 5 –RapidAir 457 comparison of multiple operators

Air Void Parameter	Sample	Operator			Avg.	Stdev
		#1	#2	#3		
Air Content	1-6	5.16	5.30	4.55	5.00	0.399
	2-6	5.37	5.31	4.77	5.15	0.330
	3-6	3.69	4.05	3.92	3.89	0.182
Specific Surface	1-6	34.72	28.98	29.17	30.96	3.261
	2-6	29.15	30.84	29.39	29.79	0.914
	3-6	36.23	34.80	34.02	35.02	1.121
Spacing Factor	1-6	0.131	0.155	0.152	0.146	0.013
	2-6	0.153	0.145	0.154	0.151	0.005
	3-6	0.146	0.146	0.151	0.148	0.003

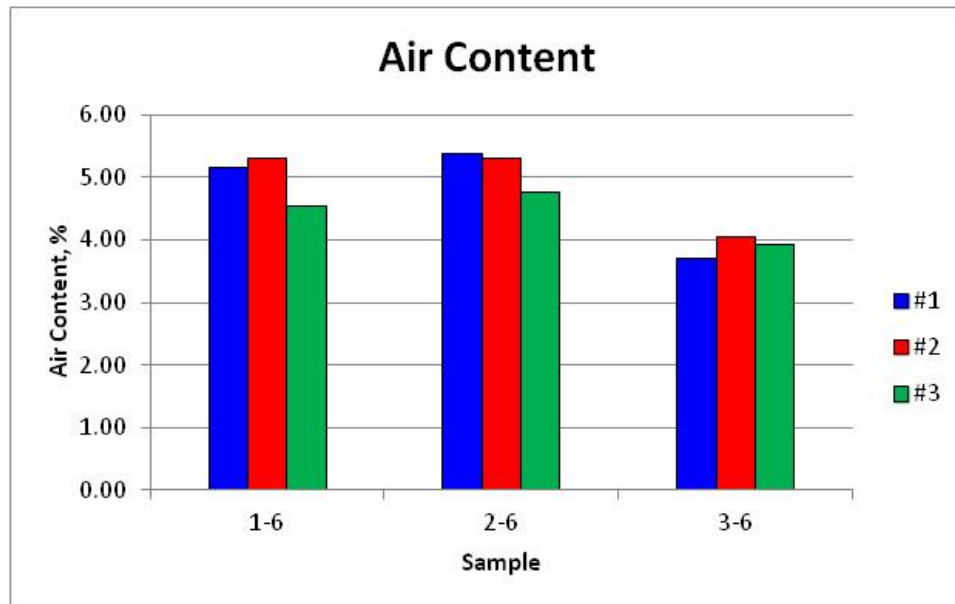


Figure 14– Air content by three operators Mix 2

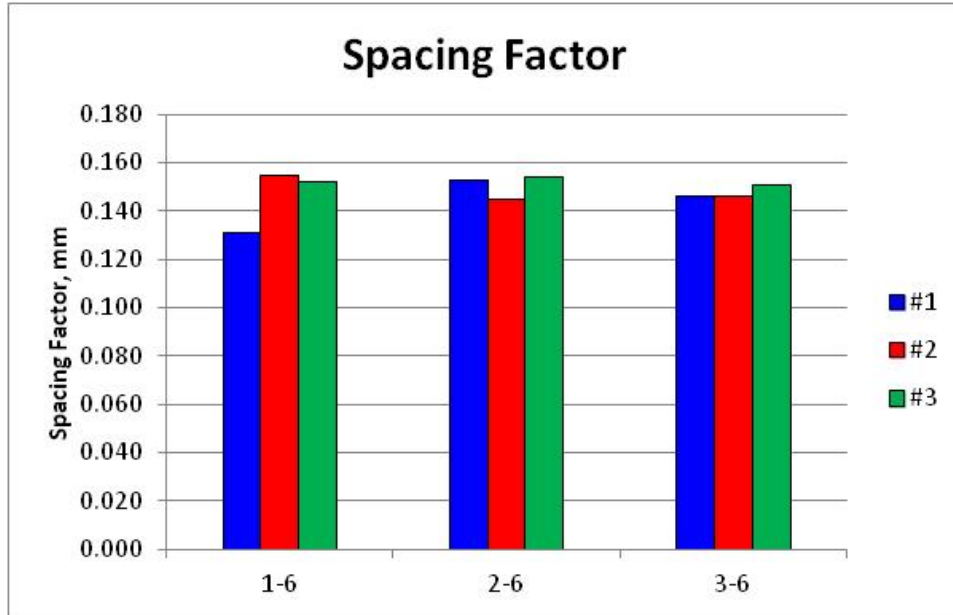


Figure 15– Spacing factor by three operators Mix 2

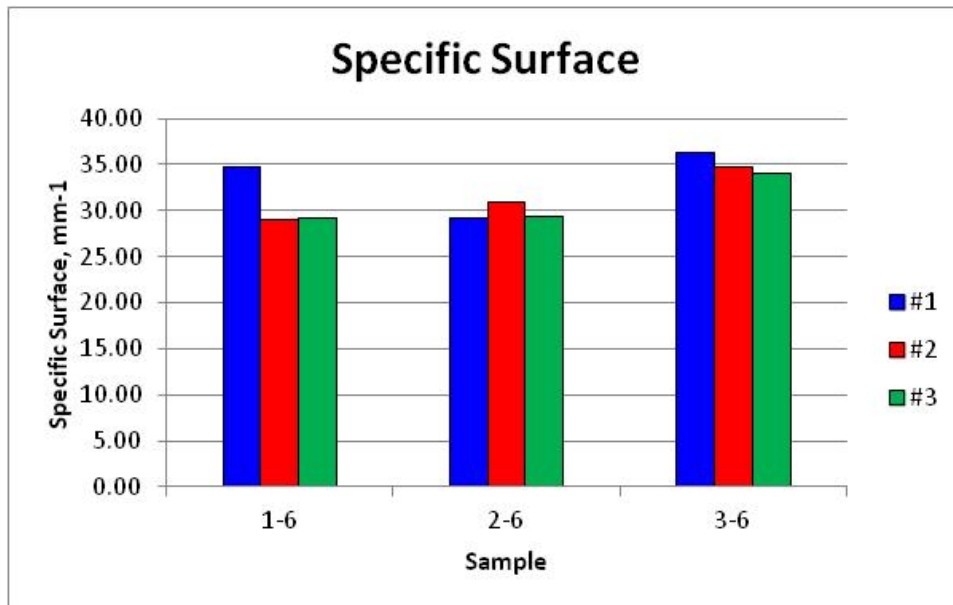


Figure 16– Specific surface by three operators Mix 2

The air content results obtained, by each operator, fall within a normal variation for ASTM C 457 on different samples of the same batch¹⁰.

Influence of aggregate porosity

As part of the black and white enhancement technique, the entire specimen is blackened with a marker. Next the entire surface is covered with barium sulfate and

pressed into the air voids. Any pores in the aggregate particles will also be filled and will be counted as air voids during the analysis. Thus, the aggregate particles need to be colored black with a fine pointed Sharpie. Specimens were tested without filling the aggregate and after coloring the aggregates black to determine the influence of aggregate porosity on air void parameters.

Figure 17– Sample with air voids enhanced before blackening aggregate

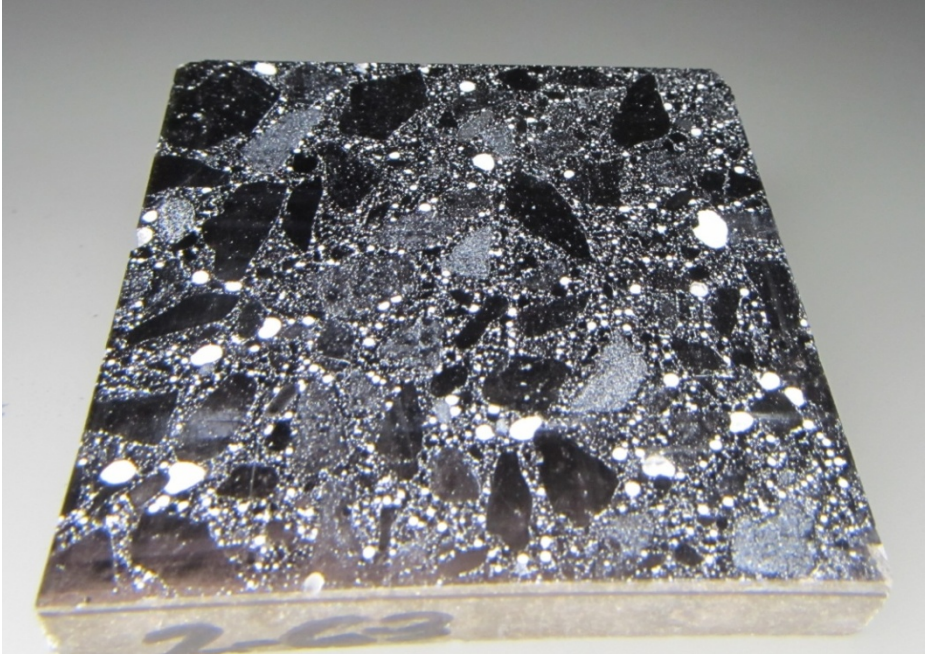


Figure 18– Sample with air voids enhanced after blackening aggregate

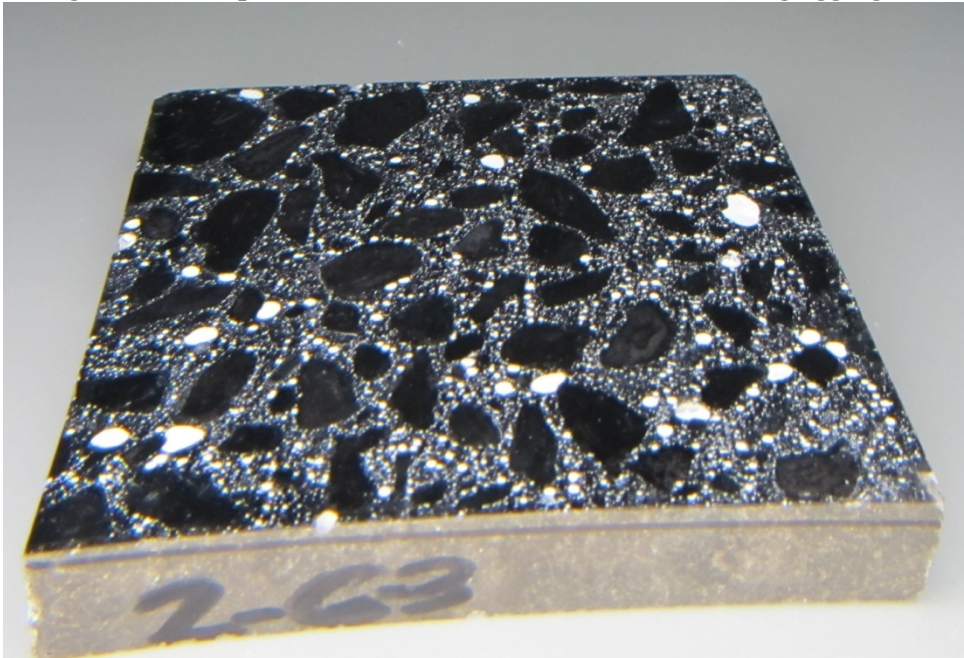


Table 6 –RapidAir 457 results aggregate voids no fill and filled Mix 3

Sample	Air Void Parameter	Aggregate Voids	
		No Fill	Filled
3-81	Number of Voids	1953	1664
	Air Content (%)	7.41	7.10
	Specific Surface (mm-1)	43.68	38.83
	Spacing Factor (mm)	0.076	0.090
3-82	Number of Voids	1845	1626
	Air Content (%)	7.25	6.70
	Specific Surface (mm-1)	42.20	40.23
	Spacing Factor (mm)	0.081	0.092
3-83	Number of Voids	1792	1756
	Air Content (%)	7.42	7.27
	Specific Surface (mm-1)	40.03	40.01
	Spacing Factor (mm)	0.083	0.085

Table 7 – RapidAir 457 results aggregate voids no fill and filled Mix 4

Sample	Air Void Parameter	Aggregate Voids	
		No Fill	Filled
4-101	Number of Voids	2592	2263
	Air Content (%)	9.20	8.41
	Specific Surface (mm-1)	46.70	44.62
	Spacing Factor (mm)	0.058	0.066
4-102	Number of Voids	2648	2200
	Air Content (%)	9.49	8.47
	Specific Surface (mm-1)	46.25	43.03
	Spacing Factor (mm)	0.056	0.068
4-103	Number of Voids	2572	2180
	Air Content (%)	9.11	8.36
	Specific Surface (mm-1)	46.78	43.22
	Spacing Factor (mm)	0.058	0.068

Table 8 – Average air content results aggregate voids no fill and filled Mix 3

Sample	Aggregate	
	No Fill	Filled
3-81	7.41	7.10
3-82	7.25	6.70
3-83	7.42	7.27
Average	7.36	7.02
Std. Dev.	0.10	0.29

Table 9 – Average air content results aggregate voids no fill and filled Mix 4

Sample	Aggregate	
	No Fill	Filled
4-101	9.20	8.41
4-102	9.49	8.47
4-103	9.11	8.36
Average	9.27	8.41
Std. Dev.	0.20	0.06

The Ft Dodge coarse aggregate used in the mixes contains a few particles of porous oolitic limestone. These pores in the aggregate fill with barium sulfate during the air void enhancement process. Based on the results obtained, it appears that blackening the air voids has a lesser impact on Mix 3 with lower air content than Mix 4 with higher air content. Previous investigations by Concrete Experts International (CXI) have shown a minor influence on the air void parameters, if not accounted for⁹.

Impact of threshold value

The operator of the RapidAir 457 automated analysis system must choose a threshold value for the specimen being tested. This parameter sets the definition of what is considered black and white by the software during the analysis. All white areas will be counted as air voids if intercepted by the traverse. Currently, there is no standard method to choose this parameter and it is the responsibility of the user to use their judgment to decide which value to use for the specimen.

The raw black and white raw image is compared with the analysis image on the right. The user is to set the threshold value where the green image on the right matches the white air voids on the left. When the threshold value is set too low, the air voids in green on the right image appear to “bleed” or “pixelate” into the blackened areas of the paste. When the threshold value is set too high, the amount of green is reduced in the air void and an area of white displays within the air voids. Figures 17 and 18 are images of the same area of analysis showing low and high threshold values.

The ambient light conditions and reflection have an impact on the threshold setting. The threshold setting for the samples and environment encountered during this investigation were typically between 120 and 140.

Figure 19– Raw Image and Analysis Image Threshold Setting of 50

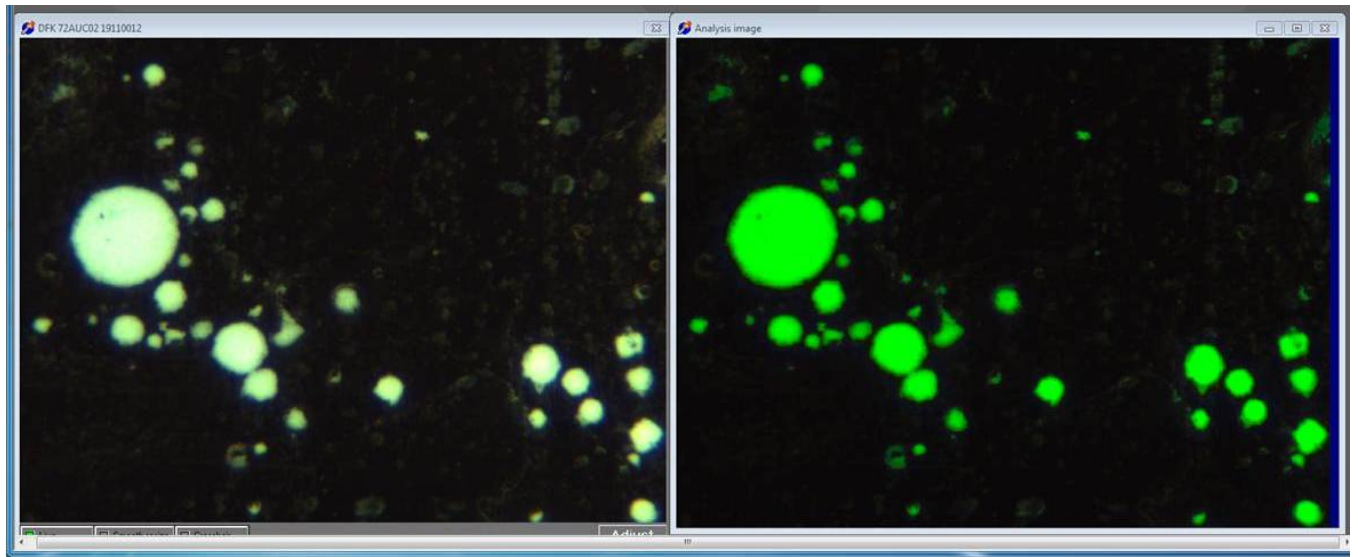


Figure 20– Raw Image and Analysis Image Threshold Setting of 225

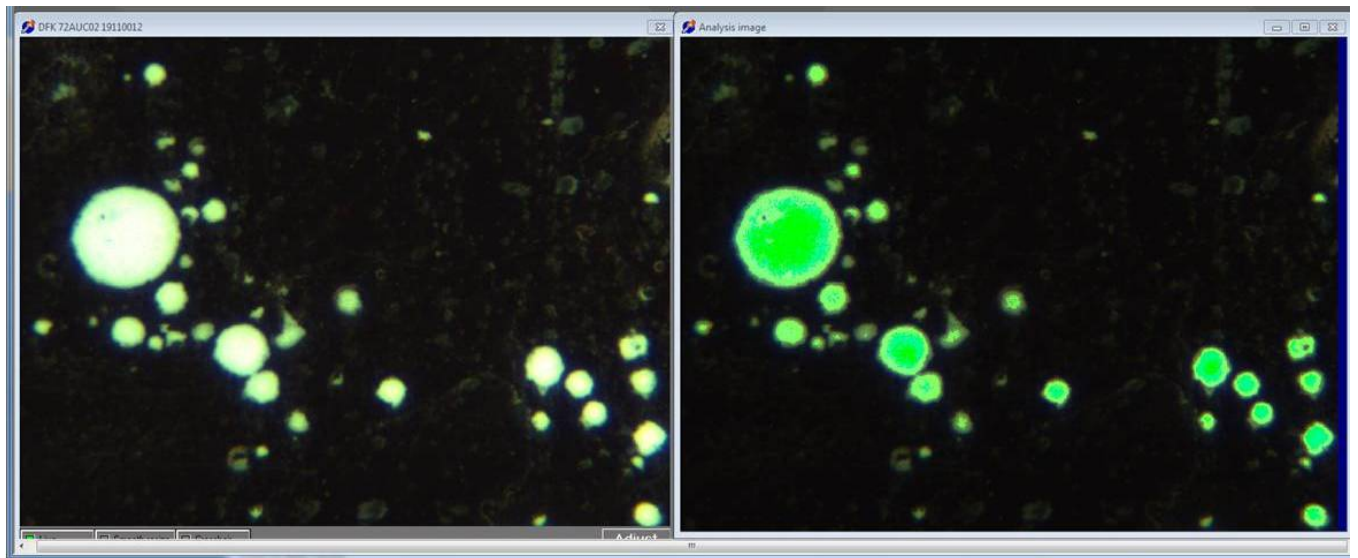


Table 10 – RapidAir 457 Results Varying Threshold Value

Air Void Parameter	Threshold Value					
	80	100	120	140	160	180
Number of Voids	1849	1714	1593	1510	1425	1310
Percent of Total Number of Voids	98.8	98.7	98.6	98.6	98.5	98.3
Length of Air Traversed (mm)	170.75	162.21	155.55	149.85	144.83	139.11
% of Total Length of Air Traversed	82.4	81.68	81.14	80.60	80.07	79.59
Air Content (%)	7.08	6.72	6.45	6.21	6.00	5.76
Average Chord Length (mm)	0.092	0.095	0.098	0.099	0.102	0.106
Paste to Air Ratio	3.49	3.68	3.83	3.98	4.12	4.29
Specific Surface (mm ⁻¹)	43.31	42.27	40.97	40.31	39.36	37.67
Void Frequency (mm ⁻¹)	0.766	0.71	0.66	0.626	0.59	0.543
Spacing Factor (mm)	0.081	0.087	0.094	0.099	0.105	0.114

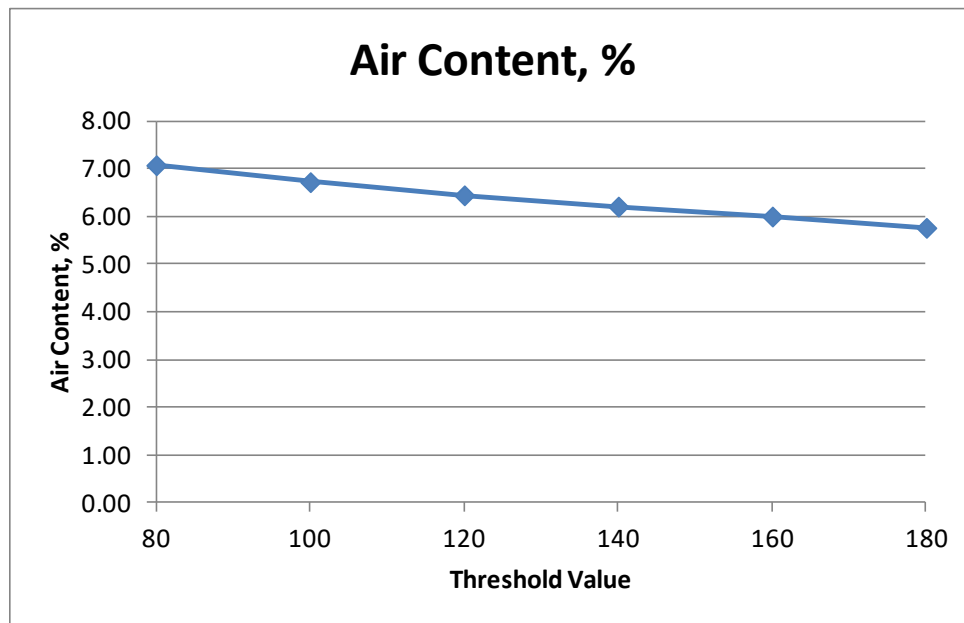


Figure 21 – Influence of Threshold Setting on Air Content

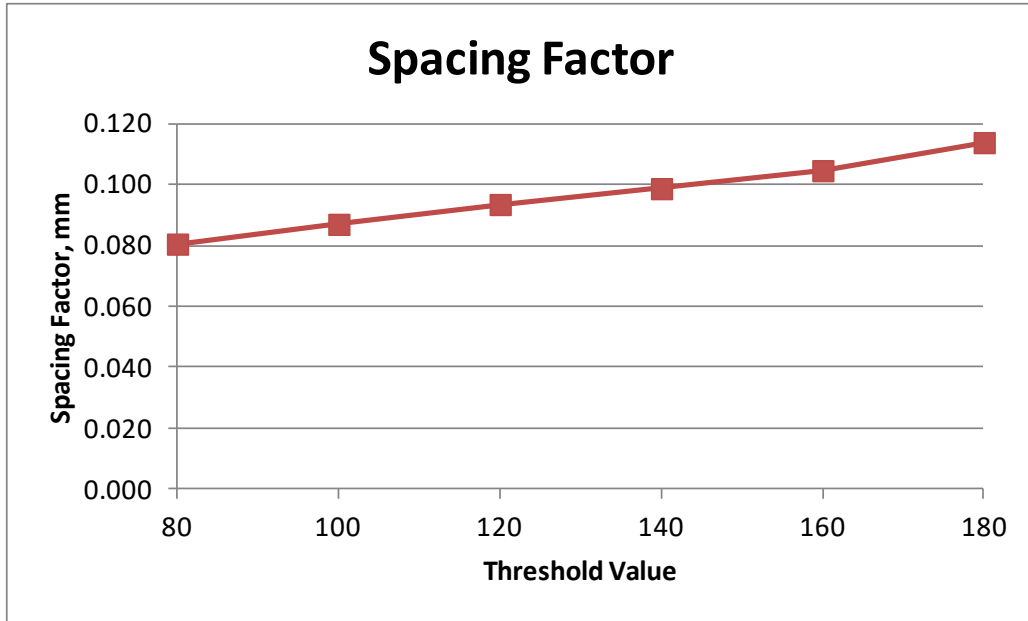


Figure 22 – Influence of Threshold Setting on Spacing Factor

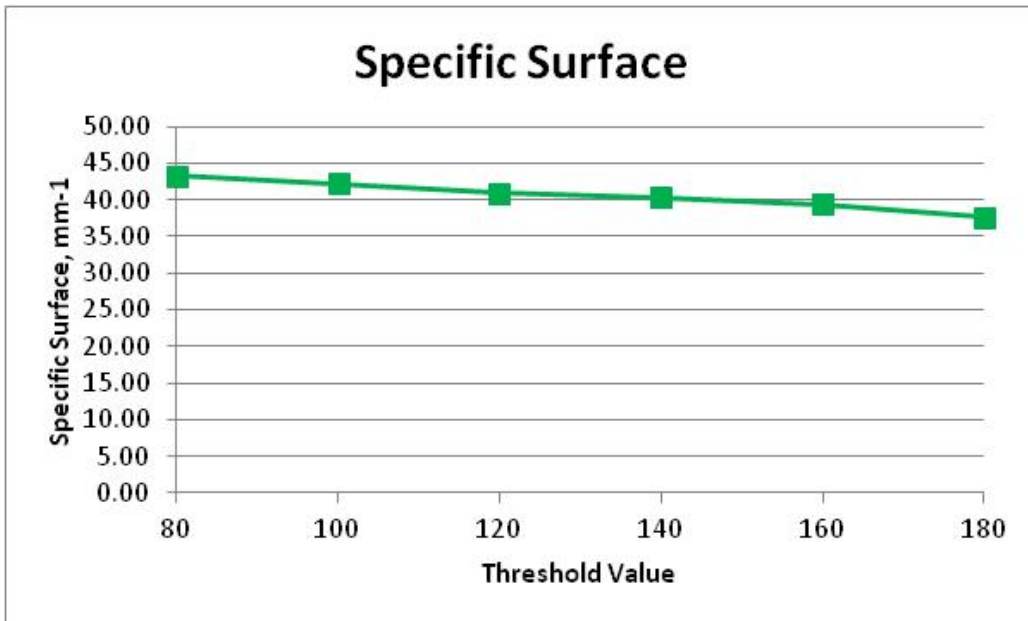


Figure 23 – Influence of Threshold Setting on Specific Surface

Setting an improper threshold value has an impact on the air void parameters obtained. Although, it appears that if the determined threshold value is within a range of 20 (± 10) of the proper threshold value, the air void parameters should fall within normal variation¹⁰ of ASTM C 457.

Results and discussion

The RapidAir 457 correlates very well to plastic air content ($R^2=0.992$) and the image air analysis technique ($R^2=0.897$). The spacing factor obtained from the RapidAir 457 correlates fairly well with that obtained by the image analysis technique ($R^2=0.910$), however, the specific surface does not correlate as well ($R^2=0.381$). This perhaps is due to the fact that the image analysis technique measures air void diameters as opposed to chord lengths.

Even though specific surface does not correlate very well, the cumulative air content by chord lengths follow the same trends between the RapidAir 457 and image air analysis techniques.

The RapidAir 457 is very repeatable when testing multiple runs on the same traverse. Performing five runs, the air content was 6.61 with a standard deviation of 0.03, specific surface of 40.27 with a standard deviation of 0.23, and a spacing factor of 0.093 with a standard deviation of 0.001.

When multiple operators prepare multiple samples of the same batch of concrete, the RapidAir 457 produces repeatable results. Three operators prepared three specimens from the same batch of concrete. Each operator tested the sample they prepared and then tested the other two samples. The average air content for each of the three samples were as follows: sample 1-6 air content 5.00%, standard deviation 0.399; sample 2-6 air content 5.15%, standard deviation 0.330; and sample 3-6 air content 3.89%, standard deviation 0.182.

The black and white enhancement technique causes both air voids and pores in the aggregate to be filled with barium sulfate. Aggregates are blackened after the barium sulfate is pressed into the specimen, otherwise the aggregate voids will be counted as air voids. The aggregate filling impacts the air content results greater as air content increases. For Mix 3, the average air content was 7.36% (standard deviation 0.10) with no fill and 7.02% (standard deviation 0.29) filled. For Mix 4, the average air content was 9.27% (standard deviation 0.20) with no fill and 8.41% (standard deviation 0.06) filled.

Setting the threshold value impacts the chord length by what is measured as an air void, or the number of pixels detected in the image. Adjusting the threshold from 80 to 180 changes the air content results in a range of 7.08 to 5.76%, respectively. The selected threshold setting for the specimen tested was 120. Using a range of ± 20 from the selected threshold affects the air content results to a lesser extent in a range of 6.72 to 6.21%, respectively.

Summary

Based on the results obtained during this research, the RapidAir 457 air void analyzer is an excellent tool used to obtain hardened air void parameters in concrete. The results are accurate, repeatable, and far less time consuming than linear traverse and the image analysis techniques. From sawing to air void enhancement, the total time for sample preparation was approximately 45 minutes. The actual testing takes less than 15 minutes. The system is user friendly and was able to be used by qualified laboratory technicians with minimal training.

Implementation

The Iowa Department of Transportation Office of Materials runs hardened air void analysis on project cores on a routine basis. The cost for conducting a hardened air analysis utilizing image analysis on a sample is approximately \$300 per sample. The cost for conducting a hardened air analysis utilizing linear traverse is approximately \$700 per sample. There is at least a one to two week, or more, turnaround for getting results regardless of the test method used.

The RapidAir 457 can be conducted at the Iowa Department of Transportation Materials Laboratory for approximately \$100 per sample and multiple samples can be tested within a day. The RapidAir 457 will be implemented and used for the following:

- Annual review of hardened air void analysis of project cores to benchmark in place air content trends
- Verification of air content from field project cores when improper testing was performed
- Validation of aggregate correction factor from field cylinders using plastic air content results
- Determine areas of non-complying air content from project cores
- Other concrete research and forensic investigations.

Acknowledgements and credits

The author would like to thank the following people: Mike Coles and Leroy Lutjen of the Cement and Concrete lab for their help mixing and casting the specimens; Paul Hockett and Leroy Lutjen for performing some of the testing using the RapidAir 457 air void analyzer; Kevin Jones and Cheng Ouyang for review of the report; and Dr. Ulla Jakobsen of Concrete Experts International (CXI) for providing techniques for sample preparation and training on equipment operation. The author would also like to thank the MARL lab at Iowa State University for their help testing the air void parameters using image analysis. Also, thanks to Federal Highway Administration for assistance in purchasing the equipment.

Appendix A: Mix design

GENERAL INFORMATION										
PROJECT:	Air Content Various									
PROJECT TITLE:	0									
MIX TYPE:	C-3WR									
MIX NUMBER:	1									
DATE:	6/23/2010									
									Paste Content	24.7
									Mortar Content (abs vol)	61.9
									Mortar Content (% pass)	30.7
MATERIALS										
	Source	Type/Class	SPG	Percent	Percent	Abs. Vol.				
CEMENT:	Lafarge	I/II	3.14			0.108				
FLY ASH:				0.00		0				
MINERAL ADMIXTURE:				0.00		0				
WATER (w/c ratio):		0.41	1.00			0.139				
AIR CONTENT:		6.0				0.060				
FINE AGGREGATE:	Prairie Du Chien		2.67	45.00		0.312				
COARSE AGGREGATE:	Ft. Dodge		2.68	55.00		0.381				
INTERMEDIATE AGGREGATE:	0		0	0.00		0				
AIR ENTRAINING AGENT:	Daravair 1400					Total 1.000				
RETARDER:						Paste+Air 0.307				
WATER REDUCER:	WRDA 82					Agg 0.693				
SUPER WATER REDUCER:										
ACCELERATOR:										
DESIGN SLUMP:	4.0									
QUANTITIES (absolute volume method in SSD condition)										
	Volume ft3	Volume ft3						Weight lbs	Weight lbs	Weight lbs
	Batch Size	Batch Size						Batch Size	Batch Size	Lab Batch Size
	1.0 yd3	1.0 ft3						1.0 ft3	1.0 yd3	0.50
CEMENT:	0.108	2.92	X	3.14	X	62.4	=	21.1	571	10.6
FLY ASH:	0.000	0.00		0.00		0.0		0.0	0	0.0
MINERAL ADMIXTURE:	0.000	0.00		0.00		0.0		0.0	0	0
WATER:	0.139	3.75	X	1.00	X	62.4	=	8.7	234	4.3
FINE AGGREGATE:	0.312	8.42	X	2.67	X	62.4	=	52.0	1404	26.0
COARSE AGGREGATE:	0.381	10.29	X	2.68	X	62.4	=	63.7	1720	31.9
INTERMEDIATE AGGREGATE:	0.000	0.00	X	0.00	X	0.0	=	0.0	0	0.0
AIR:	0.060	1.62	X	0.00	X	62.4	=	0.0	0	0.0
Summation	1.0000	27.00						145.5	3929	72.8
CHEMICAL ADMIXTURES										
	Rate							Rate (ml)	Rate (ml)	Rate (ml)
	oz/100 lbs cementitious							Batch Size	Batch Size	Lab Batch Size
								1.0 ft3	1.0 yd3	0.5
AIR ENTRAINING AGENT:	0.7	21.16	X	0.0065	X	29.57	=	4.1	109.8	2.0
RETARDER:										
WATER REDUCER:	3.5	21.16	X	0.035	X	29.57	=	21.9	591.3	11.0
SUPER WATER REDUCER:										
ACCELERATOR:										
Mix Batch Weights										
		Ft. Dodge		0		Prairie Du Chien				
%	Sieve	Coarse		Intermediate		Fine				
		lbs	cumm. wt.	lbs	cumm. wt.	lbs				
10	3/4"	3.2	3.2	0.0	0.0					
50	1/2"	15.9	19.1	0.0	0.0					
25	3/8"	8.0	27.1	0.0	0.0					
15	#4	4.8	31.9	0.0	0.0					
	Total	31.9		0.0		26.0				

Appendix B: Sample preparation

Equipment

- Buehler Lapro Slab Saw 18
- LECO Spectrum 2000 Grinder Polisher
- Allied High Tech Metal Bonded Diamond Discs (260, 125, 70, 30, 15 and 6 micron)
- Lacquer
- Acetone

Sectioning Cores

For samples less than 28 days old, the paste may be weak and cause sand grains to be removed during lapping. Place the core in a hydrated lime bath at 100°F to 150°F (38°C to 65°C) for 48 hours or longer to strengthen the paste.

A 4 inch by 4 inch by $\frac{3}{4}$ " (100mm by 100 mm x 20 mm) is an appropriate sample size for the RapidAir457 test. For cores 10 inches (250 mm) or longer in length, trim the subbase from the bottom of the core. Then mark the core at 5 inches (125 mm) and 10 inches (250 mm). Label T for top and B for bottom as shown. Place two lines approximately $\frac{3}{4}$ " (20 mm) along the length of the core. For cores and cylinders 8 to 10 inches (200 mm to 250 mm) in length, adjust the cut length. Cores shorter than 8 inches (200 mm) in length may require a smaller specimen size or that only one specimen may be obtained.



Saw the core at the 5 inch (125 mm) mark and the 10 inch (250 mm) mark.



Ensure that the jaw vice of the saw is approximately 20 revolutions of the cross feed handle from the blade. Place the 5 inch section of the top of the core in the saw with the top (T) nearest the saw blade. Core should over hang the jaw vice by more than half of the width of the core.



Turn on the saw and cut the first side of the core. Return the jaw to the starting position. Turn the cross feed handle 12-13 revolutions to achieve a $\frac{3}{4}$ " (20 mm) cut.



Sample will have a burr at the end of the cut. Starting with the top (T) of the core allows the burr to be in an area that can be trimmed.



Measure 4 inches (100mm) from the top of the core and trim cut the sample to a 4 inch by 4 inch (100 mm by 100 mm) specimen. Wash the specimen thoroughly under running water to remove any saw residue.



Repeat the same procedure for the bottom portion of the core, starting with the bottom (B) closest to the saw blade when cutting.

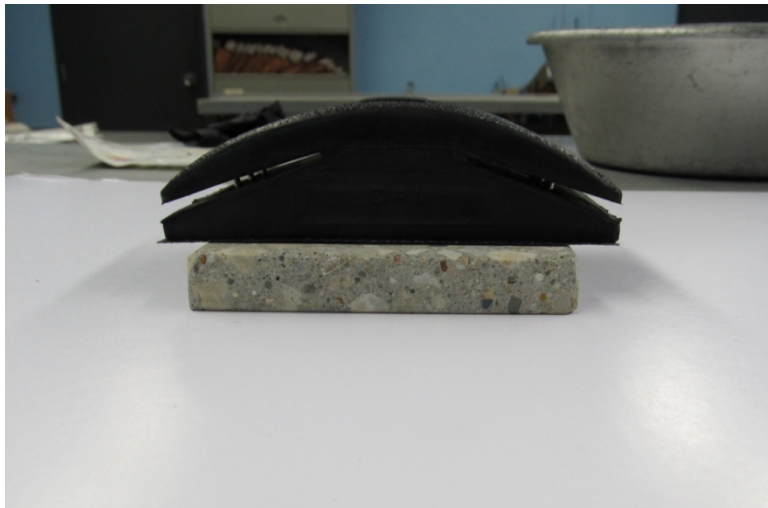
Mark the sample identification and T for top or B for bottom along the edge of the specimen.

Grinding and lapping

Prior to lapping, apply a very thin coat of thinned lacquer (20% lacquer/80% acetone) to reinforce the air voids during lapping.



To aid in holding the sample on the lapping wheel, attach a sanding block with two faced tape to the back of the specimen.



Typically, the slab saw produces a fairly clean cut, so lapping can begin with the 125 micron disc. If there are saw marks on the specimen, it may need grinding on the 260 micron disc first. Lapping wheel should be set to counterclockwise (CCW) and 250 rpm's.



Lap the surface on the 125 micron for 2 ½ minutes, applying even pressure to prevent preferential polishing from one side to the other. A steel rule may be laid across the sample to ensure the specimen is flat.



Thoroughly wash the specimen under running water. May use a soft natural bristle brush to ensure air voids are clean of any debris.



Rotate the sample 90 degrees clockwise and lap for an additional 2 ½ minutes.



Thoroughly wash the specimen again. Allow to dry or dry in 100°F (38°C) oven. Apply a coat of thinned lacquer and allow specimen to dry.

Rotate another 90 degrees clockwise, or 180 degrees from initial, and lap on the 70 micron disc for 2 ½ minutes. Thoroughly wash the sample under running water, rotate the sample an additional 90 degrees clockwise, and lap for an additional 2 ½ minutes. The specimen should be at the original lapping direction.

Repeat the above procedure of washing, rotating sample, and applying thinned lacquer for the 30, 15, and 6 micron discs. Specimen should have a uniform gleam from the reflection when held up to the light with no relief between the paste and the aggregate.



Specimen may be examined under a stereo microscope to check the quality of the polish. Next, soak the specimen in acetone under a hood for 5 to 10 minutes to remove the lacquer.

Thoroughly wash the diamond discs after use and allow them to dry before placing in protective sleeve. Occasionally dress the diamond discs with a dressing tool.



Store the specimens in a plastic sample bag to prevent contamination and material from scratching the surface.



Appendix C: Surface contrast enhancement

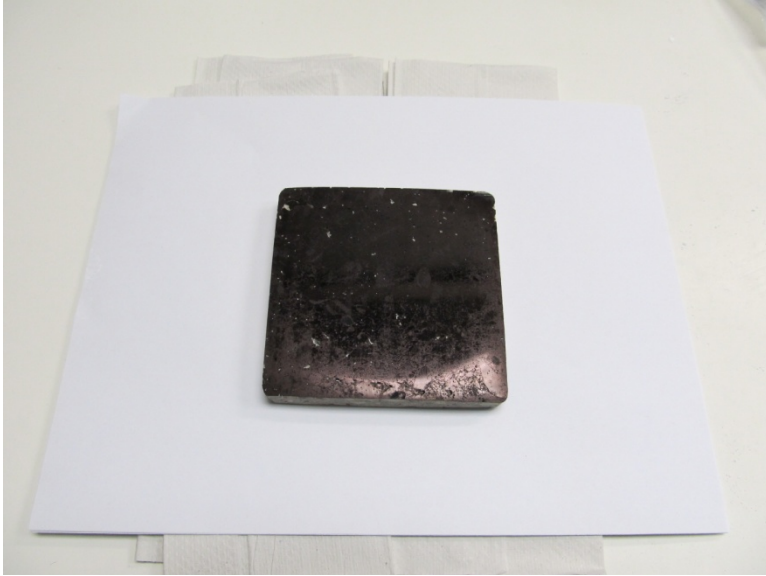
Equipment

- Sharpie Magnum Marker black
- Sharpie Fine Point Marker black
- Sigma-Aldrich Barium Sulfate (BaSO_4)
- Spatula
- Rubber stopper
- Rubber stamper

Using the wide Sharpie pen, color the surface of the specimen with overlapping strokes of the pen. Allow the first coat to dry, rotate the specimen 90 degrees and color the surface again with overlapping strokes of the pen.



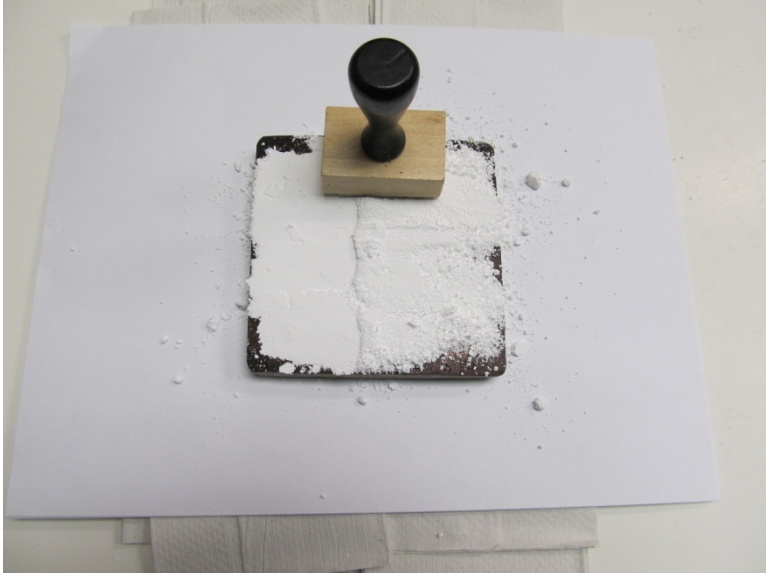
Place the specimen on a foam board with several sheets of paper under the sample.



Place a layer of barium sulfate over the entire surface of the specimen.



Take the rubber stamper and press the barium sulfate into the paste of the sample. Use sufficient force to ensure all the voids get filled with compacted barium sulfate. Add additional material if any bare spots begin to appear.



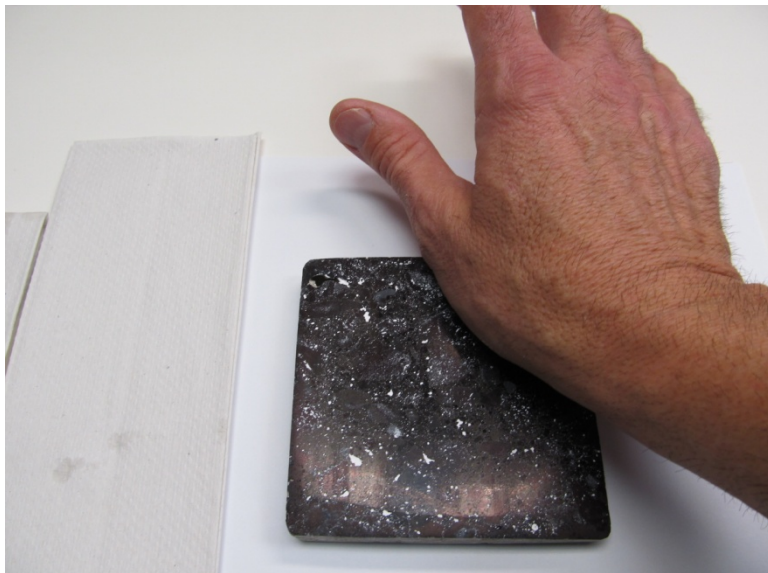
Take the rubber stopper, force the barium sulfate into the paste using a twisting motion of approximately 1/8 to 1/4 turn.



Using the edge of the rubber stopper or the rubber disk, carefully scrape the barium sulfate from the surface of the specimen. Discard the excess material with the top piece of paper.



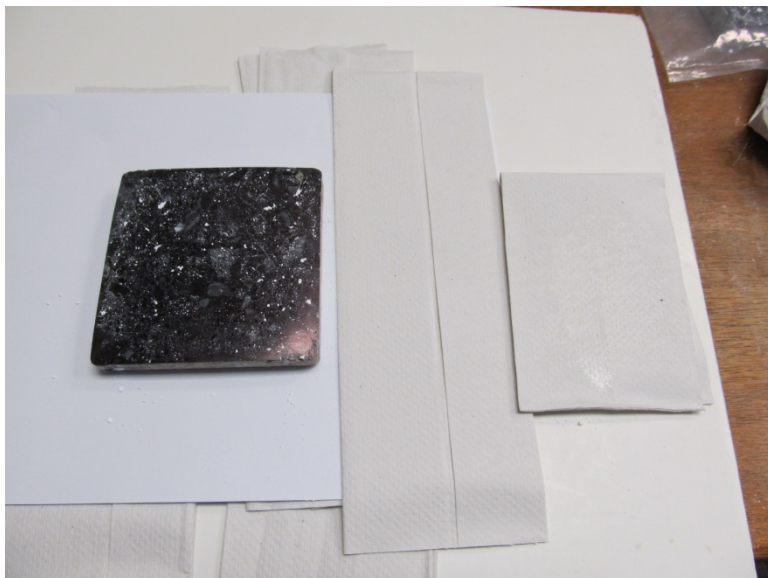
Place a paper towel dampened with water and a clean dry paper towel beside the specimen. Using the palm of your hand, start in the middle of the specimen working in a circular direction, and wipe the excess barium sulfate from the surface. After each swipe of the specimen, rub the palm of your hand on the wet towel and then rub it on the other towel to dry. Cleaning and drying the palm each time will prevent ink from being smeared over the barium sulfate in the air voids. Wash hands after wiping each specimen.



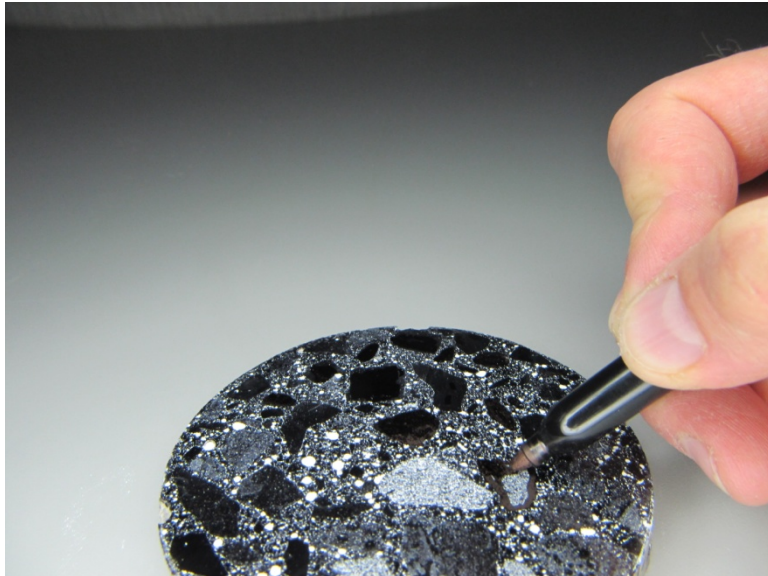
The next process is to remove any particles of barium sulfate left on the surface. Take a very small amount of Vaseline and rub it into a paper towel until there is just a slight sheen on the surface of the towel.



Using a similar technique as described above, wipe the palm of your hand across the towel with Vaseline to achieve a slight sheen on your hand. Wipe your palm across the specimen and then on the dry towel. Repeat until the entire specimen has been covered with a wipe of your palm with a very slight amount of Vaseline.



Now any voids in the aggregate must be colored black so they do not register as entrained air during analysis. This can be achieved by using a magnifier desk lamp. Carefully outline the larger coarse aggregate particles and fill them in using the Sharpie fine point. Large voids may be covered with tape.



Check smaller aggregate particles under a stereo microscope with cross lighting.

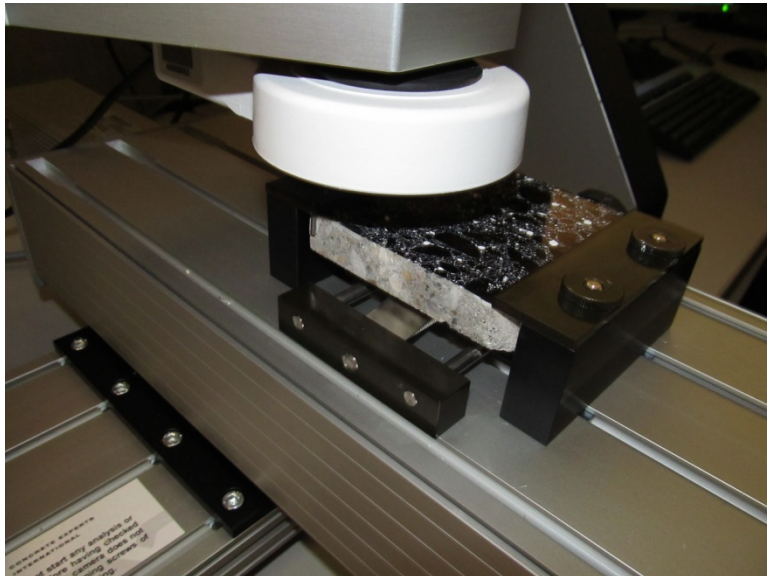


After the aggregates have been blackened, the specimen is now ready to be analyzed with the RapidAir457 equipment.

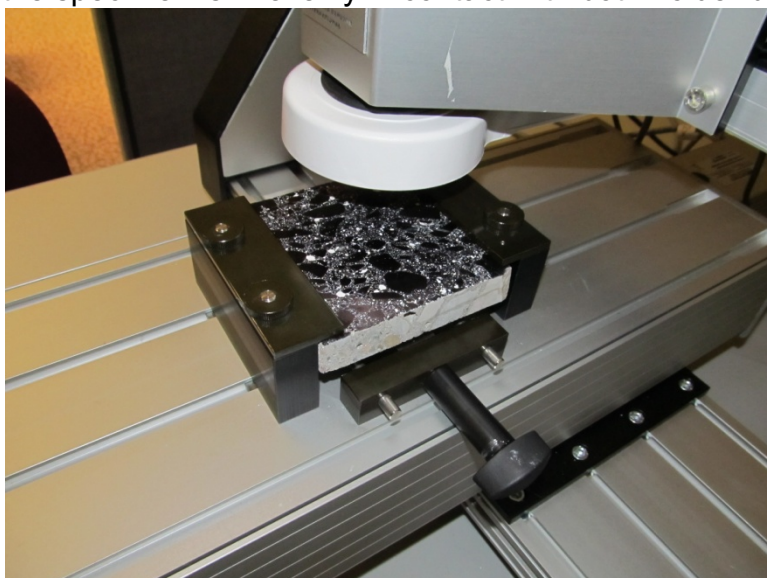
Appendix D: Air void analysis

Sample Holder

Loosen the two screws on the sample holder bar furthest away from the light and slide the holder back. Do not loosen the screws on the sample holder bar with the pins. Place the spring device between the sample holder bars. Place the specimen balanced on the spring device and raise the spring. Move the specimen on the spring device against the two pins and the third pin on the left side.

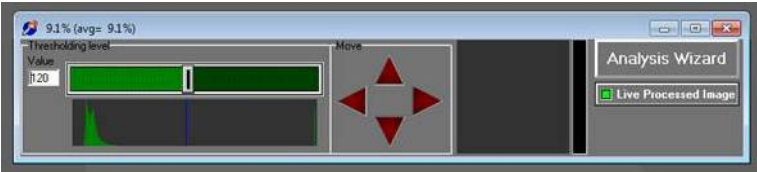


Slide the back holder bar so the plate on the top overhangs the specimen by a couple millimeters. Tighten both screws to hold the bar in place. Turn the spring handle until the specimen is in evenly in contact with both holder bars. **DO NOT OVERTIGHTEN!**

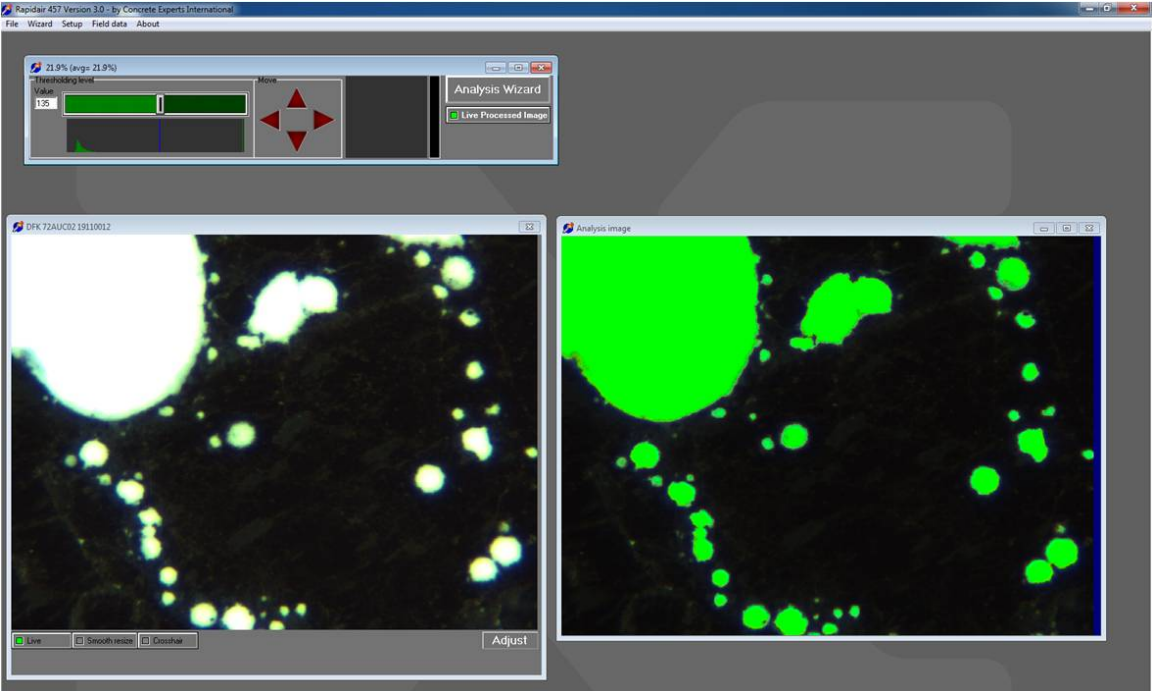


Software

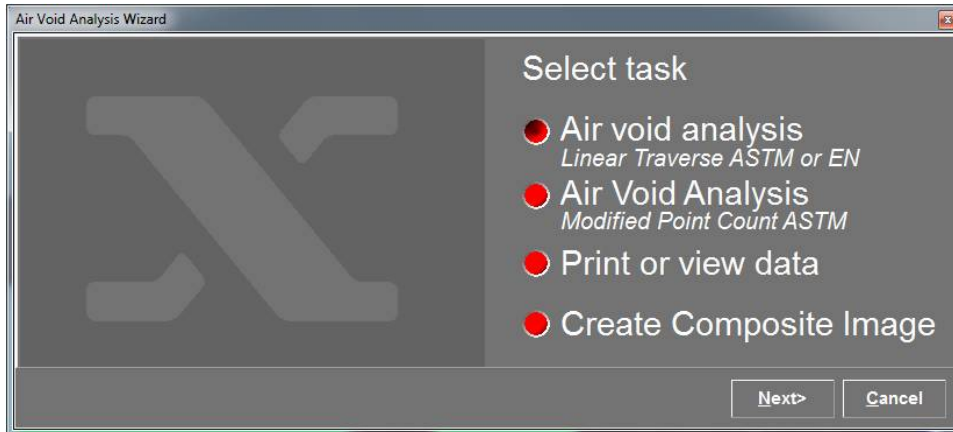
Turn on the ring light, open the program and the first screen will appear. Move the arrows around until several air voids are visible in the images. Ensure the air voids are in focus in the left image (white voids). Click on the Live Processed Image box and adjust the threshold level on the right image (green voids). Set the threshold by moving the slider bar back and forth in the Thresholding level window.



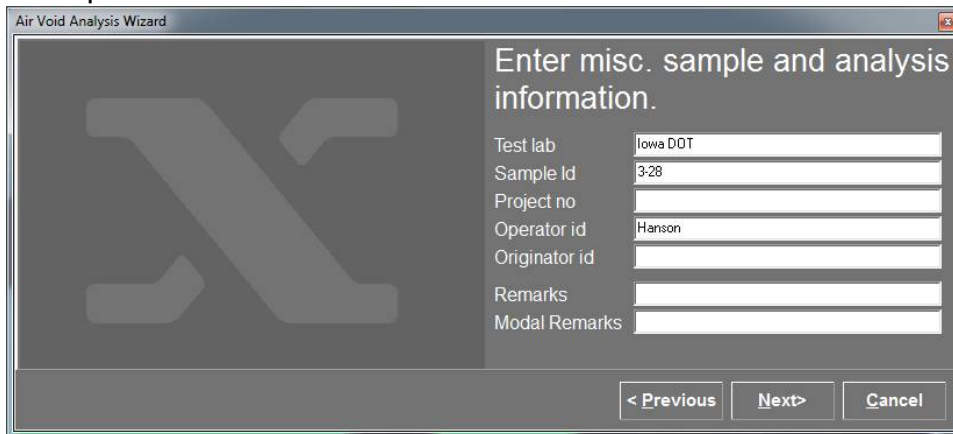
Adjust the threshold so the image on the right matches that on the left with no green rim around the air voids and no white dots (or noise) in the background. After setting the threshold value, be sure to uncheck the Live Processed Image box or the analysis will run very slow.



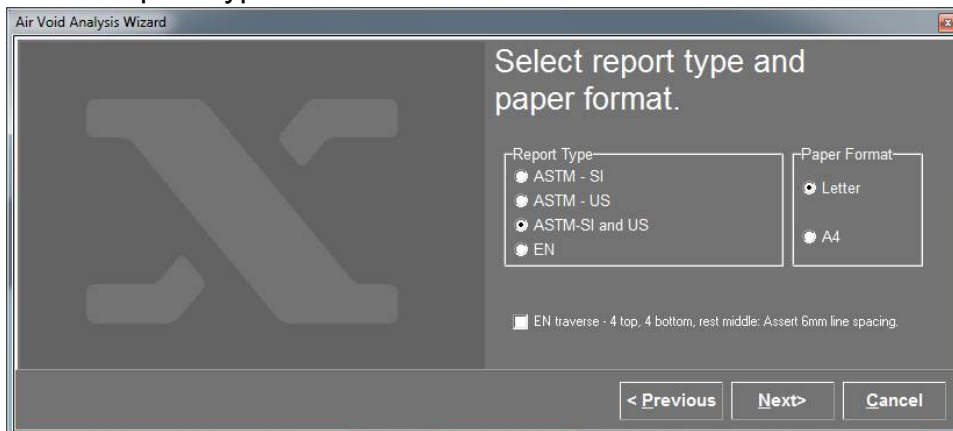
Select Analysis Wizard and the following window will appear. Select Air Void Analysis. Select Next



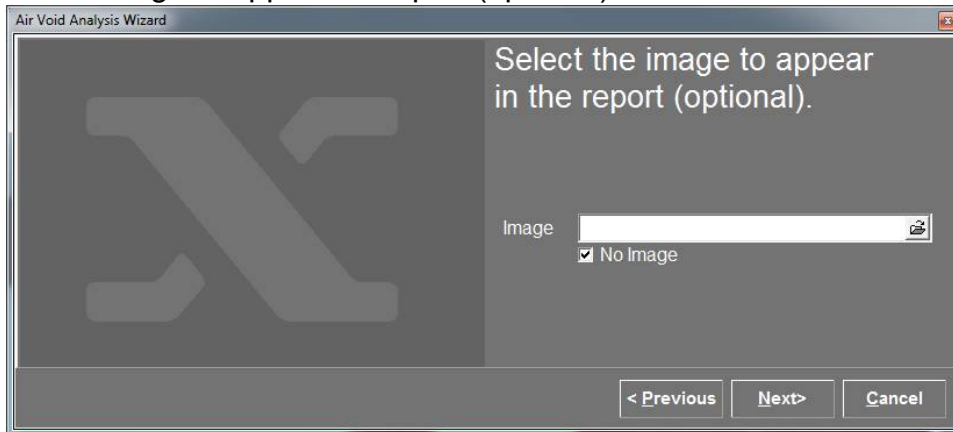
Enter pertinent information. Select Next.



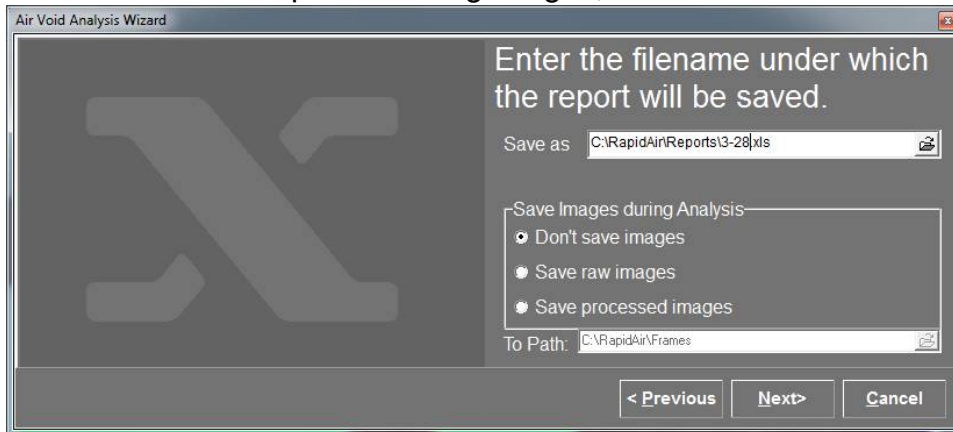
Select Report Type. Select Next.



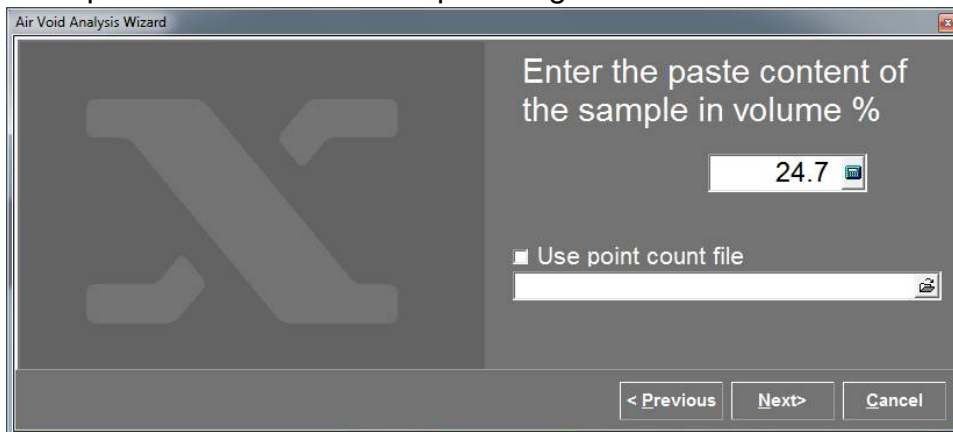
Select image to appear on report (optional). Select Next.



Enter filename for report. If saving images, save to the Frames folder. Select Next



Enter paste content of the sample being tested. Select Next.



Enter desired traverse length. 2413 mm for concrete with 1 inch aggregate. Select Next.

Air Void Analysis Wizard

Enter the desired traverse length in mm.

2,413

< Previous Next> Cancel

Enter sample length and width. Enter an area that will be at least 10 mm from the edge of the specimen. The sample size length is shorter because the holder plates overhang the specimen. Select Next.

Air Void Analysis Wizard

Enter the length and the width of the sample and the area to be traversed, all in mm.

	Length	Width
Sample size:	85	100
Area traversed:	65	80

< Previous Next> Cancel

Enter number of lines of traverse. (Typically 1) Select Next.

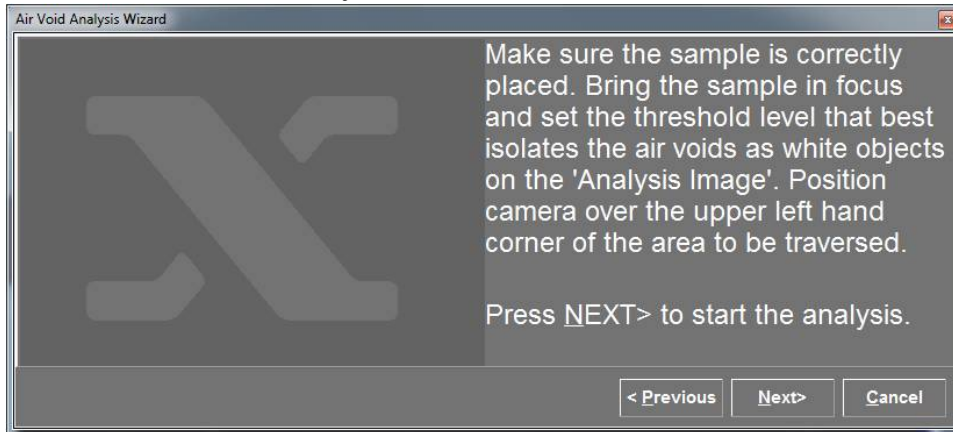
Air Void Analysis Wizard

Enter the number of traverse lines per video frame (1 to 10).

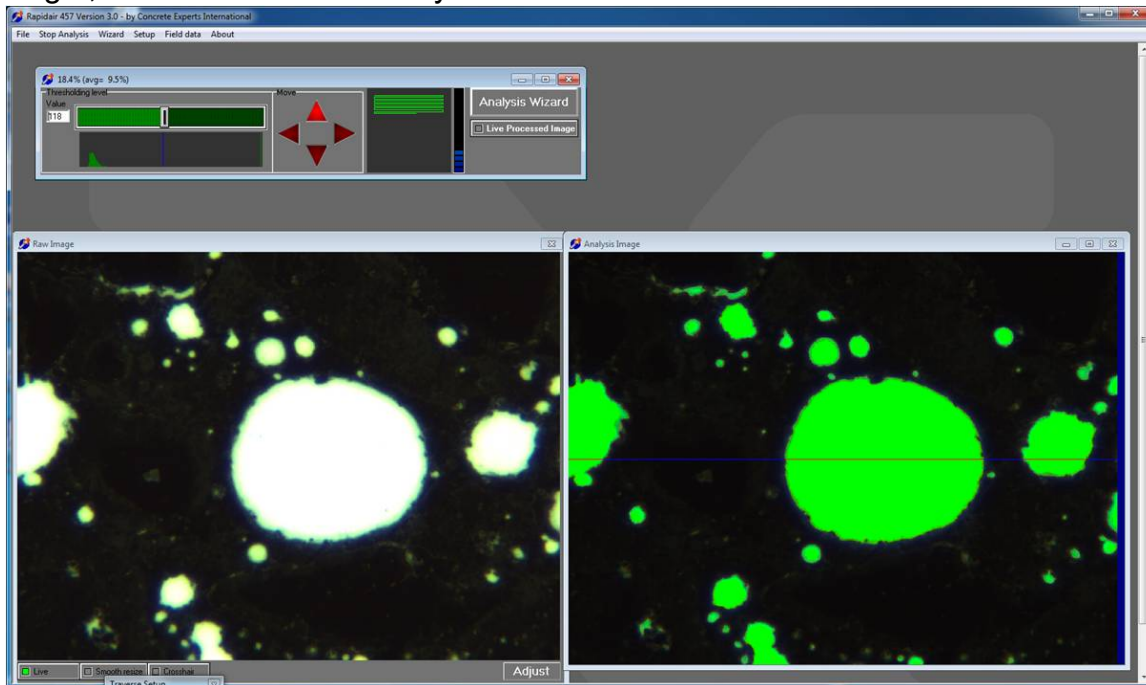
Traverses/frame 1

< Previous Next> Cancel

Window will prompt to make sure sample is in focus and threshold is set correctly. Select Next to start analysis.



During the analysis, a line will display over the image on right. Chord lengths are measured when the line crosses an air void. After the analysis completes the traverse length, the data is automatically saved under the file that was entered.



Appendix E: Sample RapidAir 457 report

Air Void Analysis of Hardened Concrete

Calculated According to ASTM C 457 Procedure A

###picture###

Sample ID:	1-4 1	Date:	1/23/2012
Project No:		Operator:	Hanson
Originator:		Threshold:	122
File Name:	C:\RapidAir\Reports\1-4-1.xls		
Test Laboratory:	Iowa DOT		

Sample ID: 1-4 1

Sample Size (mm x mm):	85 x 100	Length Traversed (mm):	2413.3
Paste Content (%):	24.70	Area Traversed (mm x mm):	65 x 80

Chord Length Distribution - Table

Class No.	Chord size (microns)	Number of Chords in Class	Number of Chords in Percent	Air Content in Class	Cumulated Air Content
1	0-10	28	2.75	0.010	0.010
2	10-20	165	16.21	0.100	0.110
3	20-30	117	16.21	0.120	0.220
4	30-40	106	10.41	0.150	0.370
5	40-50	82	8.06	0.150	0.520
6	50-60	56	5.50	0.130	0.650
7	60-80	94	9.23	0.260	0.920
8	80-100	65	6.39	0.240	1.160
9	100-120	57	5.60	0.260	1.410
10	120-140	30	2.95	0.160	1.570
11	140-160	19	1.87	0.120	1.690
12	160-180	27	2.65	0.190	1.880
13	180-200	13	1.28	0.100	1.980
14	200-220	15	1.47	0.130	2.110
15	220-240	10	0.98	0.090	2.210
16	240-260	8	0.79	0.080	2.290
17	260-280	7	0.69	0.080	2.370
18	280-300	6	0.59	0.070	2.440
19	300-350	17	1.67	0.230	2.670
20	350-400	12	1.18	0.190	2.850
21	400-450	12	1.18	0.210	3.060
22	450-500	7	0.69	0.140	3.200
23	500-1000	36	3.54	1.030	3.330
24	1000-1500	18	1.77	0.890	5.120
25	1500-2000	8	0.79	0.570	5.690
26	2000-2500	2	0.20	0.190	5.870
27	2500-3000	1	0.10	0.110	5.990
28	3000-4000	0	0.00	0.000	5.990

Air Content (%): 5.99

Specific Surface (mm^{-1}): 28.19

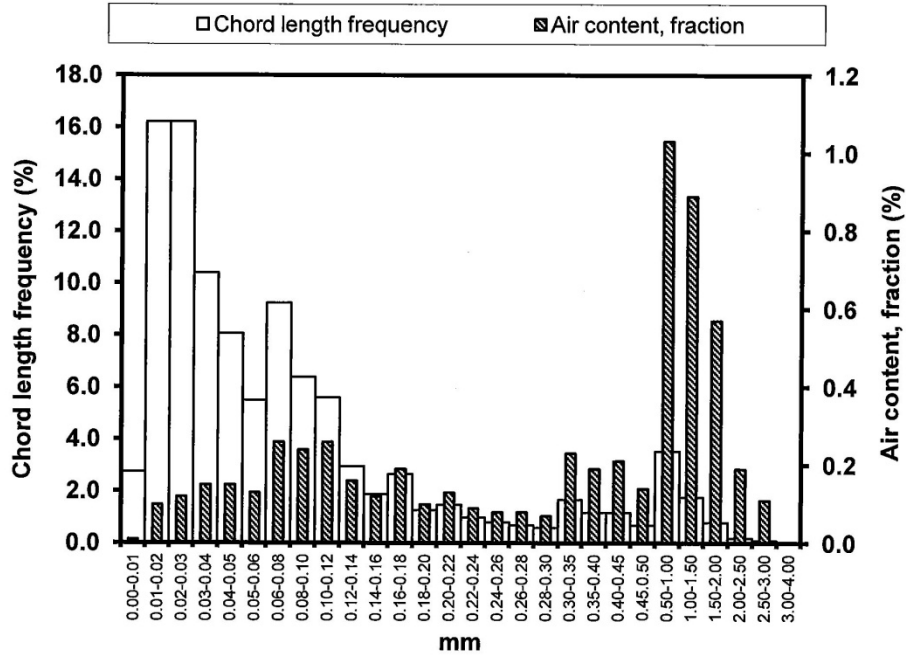
Spacing Factor (mm): 0.146

Void Frequency (mm^{-1}): 0.422

Average Chord Length (mm): 0.142

Paste to Air Ratio: 4.12

Sample ID: 1-4 1

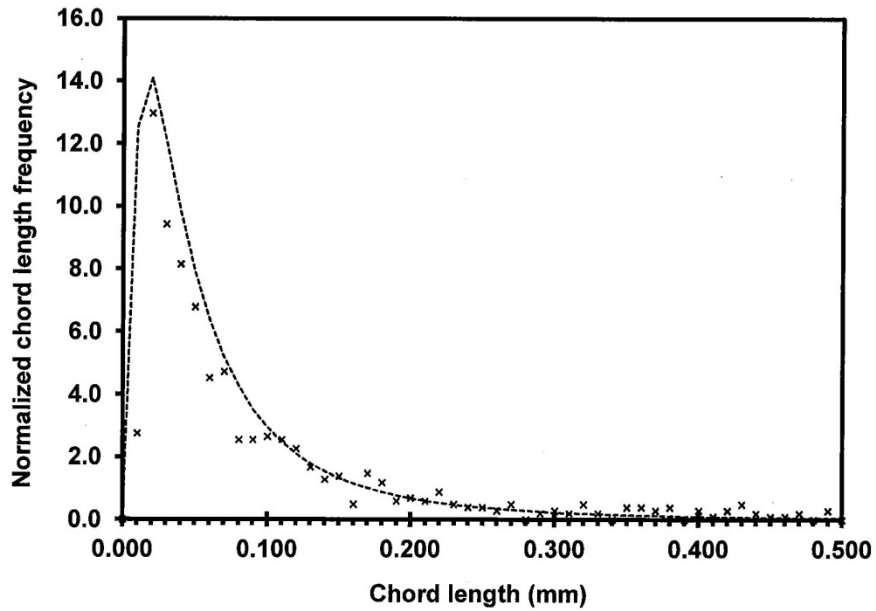


Air Void Parameter	Chords < 0.5 mm	Chords < 1.0 mm	All Chords
Number of Voids	953	989	1018
Percent of Total Number of Voids	93.6	97.2	100
Length of Air Traversed (mm)	77.26	102.04	144.44
Percent of Total Length of Air Traversed	53.5	70.6	100
Air Content (%)	3.20	4.23	5.99
Average Chord Length (mm)	0.081	0.103	0.142
Paste to Air Ratio	7.72	5.84	4.12
Specific Surface (mm ⁻¹)	49.34	38.77	28.19
Void Frequency (mm ⁻¹)	0.395	0.410	0.422
Spacing Factor (mm)	0.114	0.128	0.146

Remarks:

Paste Content Point Counted: NO
 Point Count File: -

log-normal distribution

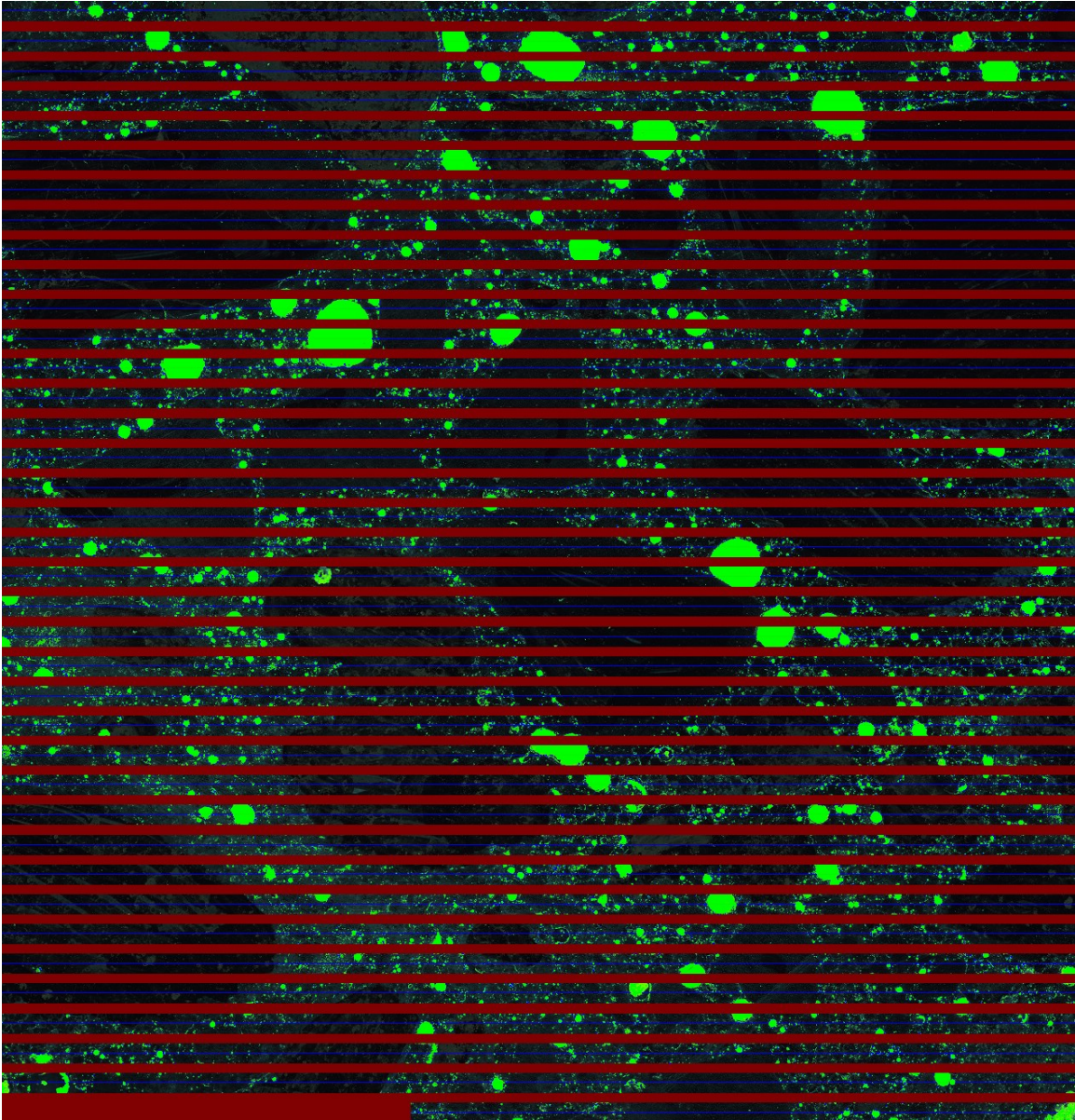


Air Void Distribution Parameters	in	mm
Modal Chord Length	0.00066	0.0168
Average Chord Length	0.0056	0.142
Zeroth-Order Log Standard Deviation	0.0016	1.003
Deviation of Best Fit (sum of squares)	354	

Reference: Roberts, L.R. & Scheiner, P. 1981. Microprocessor-based Linear Traverse Apparatus for Air-Void Distribution Analysis. In: Proc. 3th ICMA, Texas, pp. 211-227

Remarks:

Appendix F: Composite image of traverse



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- ⁸ Jakobsen, U. H., C. Pade, N. Thaulow, D. Brown, S. Sahu, O. Magnusson, S. De Buck, and G. De Schutter. The RapidAir System for Air Void Analysis of Hardened Concrete—A Round Robin Study *Proc., 10th Euroseminar on Microscopy Applied to Building Materials*, Paisley, Scotland, June 2005
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- ¹⁰ Simon, Marcia J., An Interlaboratory Evaluation of Variability in the ASTM C 457 Linear Traverse Method, OR 06-009, Missouri Department of Transportation, 2005