Investigation of High Performance Concrete Pavement

Final Report
for
MLR-05-01

April 2006

Highway Division

Iowa Department Of Transportation

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8. ABSTRACT

The Iowa DOT has been using blended cements in ternary mixes since 1999. Use of these supplementary cementitious materials gives concrete with higher strengths and much lower permeability. Use of these materials has been incorporated for use in High Performance Concrete (HPC) decks to achieve lower permeability and thus long term performance. Since we have been using these materials in paving, it would be informative to determine what concrete pavement properties are enhanced as related to high performance concrete.

The air void system was excellent at a spacing factor of 0.0047 in (0.120 mm). AVA spacing factor results are much higher than the hardened air void analysis. Although only 3 samples were tested between the image analysis air content and the RapidAir457, there is pretty good agreement between those test methods.

Air void analysis indicates that excessive vibration was not required to place the concrete. Vibration was well within the specification limits with an average of 6683 vpm's with a standard deviation of 461.

Overall ride of the project was very good. The average smoothness for the project was 2.1 in/mile (33.8 mm/km). The International Roughness Index (IRI) was 81 in/mi (1.29 m/km).

The compressive strength was 6260 psi (43.2 MPa) at 28 days and 6830 (47.1 MPa) at 56 days. The modulus of rupture by third point loading (MOR-TPL) tested at 28 days was 660 psi (4.55 MPa).

The AASHTO T277 rapid chloride permeability results at 28 days using the Virginia cure method correlate fairly well with the 56 and 90 day results with standard curing. The Virginia cure method 28 day results were 2475 coulombs and the standard cure 56 and 90 day test results were 2180 and 2118, respectively.

9. KEY WORDS

Blended cement
High performance concrete

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19

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DISCLAIMER

Introduction and Objective

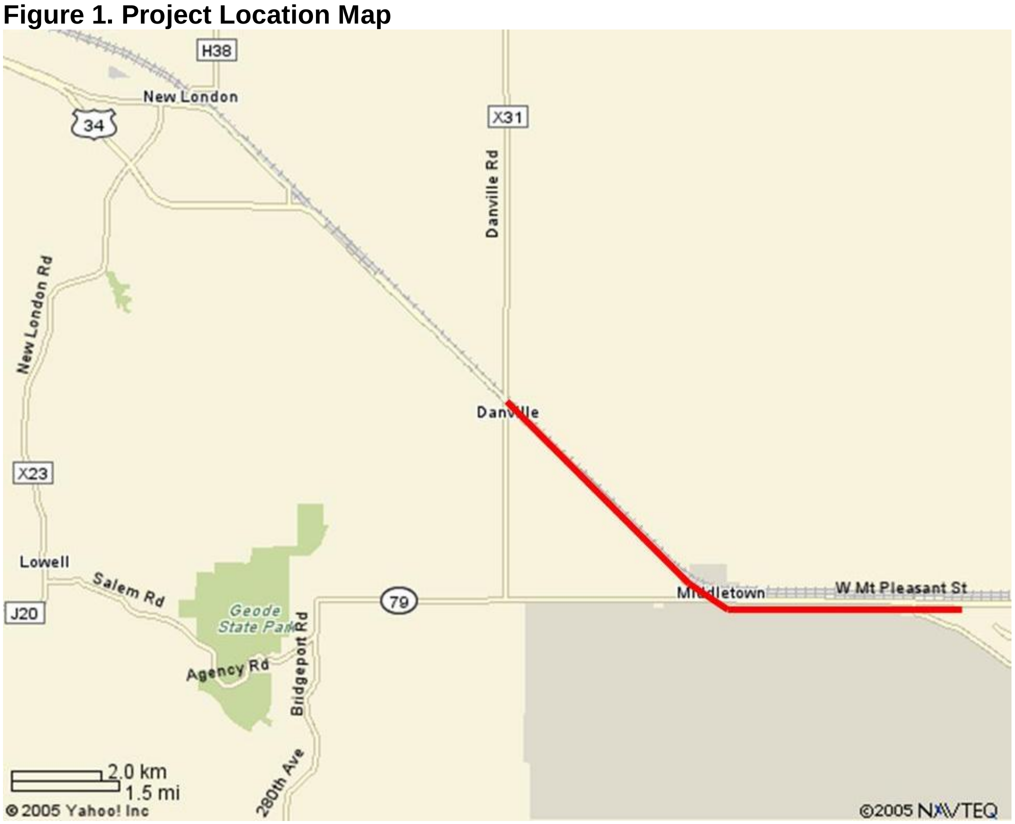
The Iowa DOT has been using blended cements in ternary mixes since 1999. Use of these supplementary cementitious materials gives concrete with higher strengths and much lower permeability. Use of these materials has been incorporated for use in High Performance Concrete (HPC) decks to achieve lower permeability and thus long term performance.

Also, since 2000, the Quality Management Concrete specification provides incentive to the contractor to produce a well graded aggregate mix design based on Shilstone principles. Since we have been using the blended cements and well graded aggregates in paving, there have been virtually no finishing and placement issues. This research will document the improved mix design and the affect on various properties such as air content, vibration, permeability, strength, and smoothness in the pavement.

Project Location

The project was located on US 34 in Des Moines county. The NHSX-34-9(123)—3H-29 project was located from 135th Street northwest of Danville south and east to Boundary Avenue for 6.8 mile (10.957 km). The NHSX-34-9(124)—3H-29 project was located from Boundary Avenue to Mt. Pleasant Street in West Burlington for 4.4 mile (7.147 km). The contract was awarded to the Flynn Company, Inc. of Dubuque, Iowa.

Figure 1. Project Location Map



The Iowa State University (ISU) concrete lab trailer was on the project from June 6 to June 16, 2005. Results obtained from their testing are also included in this report.

Mix Design

The mix design was performed in accordance with SS-01034 Quality Management Concrete. The mix design utilized well graded aggregates following the Shilstone[1] principles. The materials used and absolute volumes are shown in Table 1.

Table 1. Materials Sources

Material	Source	Specific Gravity	Absolute Volume
Cement	Lafarge Davenport I(SM)	3.10	0.085
Fly Ash	Burlington Class C	2.72	0.024
Water w/c = 0.40		1.00	0.132
Air		-	0.060
Fine Aggregate	Cessford Spring Grove	2.66	0.230
Coarse Aggregate	River Products Columbus Jct.	2.55	0.361
Intermediate Aggregate	River Products Columbus Jct.	2.55	0.132
Air Entraining Admixture	Brett AEA 92	-	-
Water Reducing Admixture	Brett Euchon WR	-	-

The target gradation for the mix design had a coarseness factor of 56.8 and a workability factor of 34.8. The mix design and gradation charts are shown in the Appendix Figures 1 through 4. The average coarseness factor and average workability factor obtained on the project was 57.5 and 34.8, respectively. The coarseness and workability factors for the project are shown in the Appendix Figure 5.

Construction

Concrete was hauled in dump trucks dropped onto a belt placer onto the grade. The slab was placed with a Gomaco GHP-2800 four track paving machine with an auto-float.

As is typical of the Shilstone mix designs, the concrete appears rocky at the belt placer. After vibration in the paving machine, the slab is uniform and well consolidated.

Application of curing was checked at various times. Application was between 18 and 30 minutes after the paver.

ISU checked concrete temperatures at placement. Temperatures ranged from 79 ºF (26 ºC) to 86 ºF (30 ºC). Temperature of cement samples ranged from 100 ºF (38 ºC) to 130 ºF (54 ºC). Temperature of fly ash samples ranged from 145 ºF (63 ºC) to 170 ºF (77 ºC).

Figure 2. Mix at Belt Placer

Figure 3. Slab behind paver


Figure 4. Application of Curing Compound

Weather Conditions

The weather conditions during the time the ISU trailer was on the project was fairly hot and humid. An afternoon thunderstorm passed through on June 8, 2005. During the thunderstorm, the ambient temperature dropped 20.2 ºF in one hour and the slab temperature dropped 9.0 ºF in 1.5 hours. Weather data recorded by ISU was as follows:

Table 2. Weather Data

Date	Min. Temp (ºF)	Max. Temp (ºF)	Min. Relative Humidity (%)	Max. Relative Humidity (%)	Min. Dew Point (ºF)	Max. Dew Point (ºF)	Max. Wind Speed (mph)	Total Rainfall (in.)
6/6	70.6	87.4	39	69	58.1	64.9	15	
6/7	67.9	89.7	43	79	43.0	79.0	15	
6/8	63.2	84.1	61	85	57.6	69.9	38	1.00
6/9	65.0	84.9	49	85	60.0	69.1	12	
6/10	67.1	85.1	52	86	61.9	71.4	33	0.02
6/11	65.3	85.7	54	88	61.5	70.5	18	0.01
6/12	66.0	84.9	56	88	59.8	69.1	20	0.01
6/13	68.9	82.4	56	85	62.5	68.2	17	
6/14	65.0	74.9	53	84	55.8	65.2	25	
6/15	61.8	76.3	55	78	54.9	59.5	20	
6/16	55.6	72.5	42	85	47.9	54.4	9	

Air Content Testing

Research[2,3] has shown an inadequate air void system in Iowa pavements is a contributing factor in early deterioration. A variety of methods of air testing, both plastic and hardened, were investigated on the project.

Plastic air content was determined before and after the paver using the pressure meter. The ISU concrete trailer performed air void analysis in the plastic concrete using the air void analyzer (AVA) (Figure 5).

Cores were obtained and hardened air analysis was performed by the MARL laboratory at ISU using the scanning electron microscope (SEM) (Figure 6) and image analysis. In addition, ISU also performed hardened air analysis on cores using the RapidAir 457 (Figure 7).

Iowa DOT specifications require air to be taken behind the paver to determine air loss. The average air loss is added to 6% to determine the target air content in front of the paver with a tolerance of -1% and +1.5%. The average loss of air through the paver was 2.3%. The plastic air contents before and after the paver are shown in Table 3. The plastic air content for the project is shown in the Appendix Figure 6 and the unit weight comparison is shown in the Appendix Figure 7.

Table 3. Plastic Air Content – Pressure Meter

Plastic Air	Before	After
Average	8.4	6.1
Maximum	11.0	7.0
Minimum	6.2	5.4
Standard Deviation	0.55	0.32

Figure 5. Air Void Analysis (AVA) Equipment

The AVA can determine the spacing factor of plastic concrete from a sample of mortar. It utilizes the principles of Stoke's Law to calculate the rise of various size bubbles through a viscous liguid. As the bubbles rise through the liquid, a weight loss is measured under a dish in the liquid. AVA test results are shown in Table 4.

Table 4. AVA Test Results

AVA	% Air Putty	Specific Surface		Spacing Factor	
		in-1	mm-1	in	mm
Average	9.7	737	29.0	0.0087	0.221
Standard Deviation	1.64	160	6.3	0.0023	0.058

Figure 6. Scanning Electron Microscope (SEM)

Hardened air was measured on core slices obtained from the project. The SEM is used to sample 20 images at 40X from a polished sample. The images are analyzed using image analysis software to determine bubble distribution. The hardened air results using the SEM and image analysis are shown in Table 5.

Table 5. SEM & Image Analysis Hardened Air Contents

SEM Image	% Air Mortar	Specific Surface		Spacing Factor	
		in-1	mm-1	in	mm
Average	9.6	795	31.3	0.0047	0.120
Standard Deviation	1.26	140	5.5	0.0008	0.020

Figure 7. RapidAir 457 Equipment

Three core slices were also tested on the RapidAir457 equipment. The unit requires the sample that to be prepared with a black and white contrast. The contrast is achieved with black ink and a white powder ($BaSO_4$) filled into the voids. The sample is scanned and air voids results are quickly obtained. The hardened air results using the RapidAir457 are shown in Table 6.

Table 6. RapidAir457 Hardened Air Results

RapidAir457	Specific Surface		Spacing Factor	
	in-1	mm-1	in	mm
Average	861	33.92	0.0060	0.153
Standard Deviation	233	9.17	0.0016	0.041

The air results from the AVA indicate a higher spacing factor than the hardened air analysis of either the SEM image air analysis or the RapidAir457.

Vibration Testing

Iowa DOT Specifications require an electronic vibrator monitoring device to display the operating frequency of each internal vibrator. The vibrators are to be operated between 4000 and 8000 vibrations per minute (vpm's). Research[4] has shown that over vibration has been related to early pavement deterioration caused by segregation and excessive air loss in the vibrator trails.

The average for the project was well within specifications at 6683 vpm's with a standard deviation of 461.

Smoothness Testing

Iowa DOT Specifications require smoothness to be checked with the 25 foot (7.6 m) California type profilograph tested at the quarter point. An incentive is paid to the contractor on 0.1 mile (160 m) segments below 3.0 in/mi (48 mm/km), using the 0.2 in (5.1 mm) blanking band.

Smoothness results indicated an average for the eastbound direction of 2.29 in/mi (36.1 mm/km) for the inside lane and 3.09 in/mi (48.8 mm/km) for the outside lane. Smoothness results for the westbound direction indicated 1.57 in/mi (24.7 mm/km) for the inside lane and 1.61 in/mi (25.4 mm/km) for the outside lane.

A South Dakota type profiler was also ran over the project. The International Roughness Index (IRI) for the project was 81 in/mi (1.29 m/km). The profiler has a single point laser and the IRI tested with a three laser setup or wide footprint should be lower since the pavement is longitudinally tined.

Strength Testing

The compressive strength and modulus of rupture – third point loading was tested on the project. Cylinders were cast and strength was tested at 28, and 56 days. Cores were also obtained and strength tested at 7, 28 and 56 days. The average compressive strength of the cores and cylinders are shown in Table 7.

Table 7. Compressive Strength Test Results

	Days	Strength, Psi (MPa)	Standard Deviation
Cores	7	3900 (26.9)	126
Cylinders	28	6260 (43.2)	97
Cylinders	56	6830 (47.1)	191

The modulus of rupture by third point loading (MOR-TPL) tested at 28 days was 660 psi (4.55 MPa) with a standard deviation of 45.

Permeability Testing

AASHTO T277 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, or rapid chloride permeability test, was used to determine the permeability of the concrete. After curing, a 2 inch slice from a 4 inch core or cylinder is saturated in a vacuum and placed in the applied voltage cell. One side of the cell is filled with a 3% sodium chloride (NaCl) solution and the other side is filled with a 0.3N sodium hydroxide (NaOH) solution. A constant voltage is applied across the cell and the total current is measured.

Concrete mixes with a lower water cement ratio and concrete containing supplementary cementitious materials typically result in lower permeability ratings. The test results are affected by conductive material in the concrete.

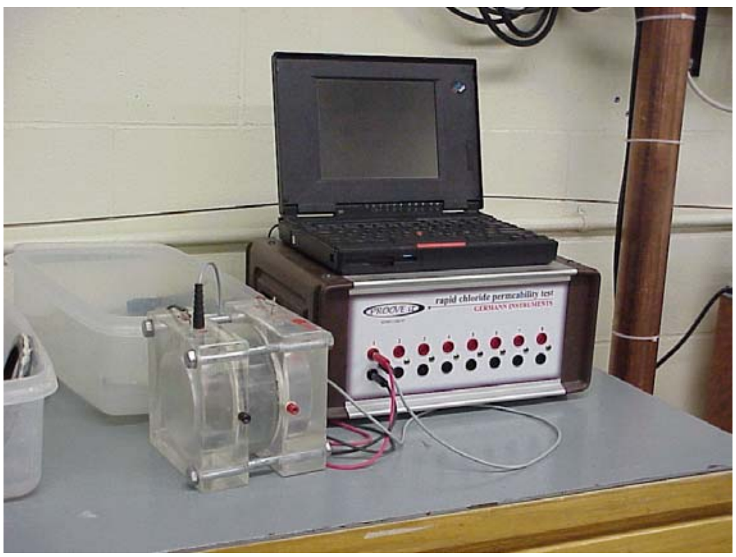


Figure 8. Rapid Chloride Permeability Test Equipment

Cylinders and cores were obtained and tested using the rapid chloride permeability test. The cylinders were subjected to the Virginia cure method where the cylinder is cured at 73 ºF for 7 days in moist room and 21 days in a 100 ºF water bath. This cure method is supposed to replicate permeability at 6 months to 1 year of age standard curing. The cores were subjected to standard lab curing at 73 ºF for 28, 56 and 90 days.

Cores were obtained from the pavement and cured at 73 ºF in the moist room and tested at 28, 56, and 90 days. The permeability test results from the cylinders and cores are shown in Table 8.

Table 8. Rapid Chloride Permeability Test Results

Cure Method	**Days**	**Coulombs**
Virginia - Cylinder	28	2475
Standard - Core	28	4106
Standard - Core	56	2180
Standard - Core	90	2118

Water Cement Ratio Testing

The water cement ratio for the project averaged 0.403 with a standard deviation of 0.010. ISU checked the water cement ratio using the microwave oven test. Values ranged from 0.39 to 0.47. The water cement ratio data for the project is shown in the Appendix Figure 8.

Miscellaneous Testing

Personnel from the ISU concrete lab trailer performed various other testing on the project. Heat signature for the mix was tested using the IQ drum for mortar and concrete. The maximum temperature for mortar was 94.10 ºF (34.5 ºC) at 10.0 hours. The maximum temperature for concrete was 111.38 ºF (44.1 ºC) at 26.5 hours.

Concrete time of set in accordance with ASTM C403 was checked on June 7, 2005. Initial set occurred at 6.42 hours and final set was at 8.32 hours.

HIPERPAV software was also used to detect any potential for stress in the slab which may cause cracking. No potential problems were detected.

A variety of other testing was performed by ISU and a copy of their report[5] is available.

Results and Discussion

The air void system appears to be very good. A spacing factor of 0.0047 in (0.120 mm) is more than adequate to provide freeze thaw protection in a severe environment. It is not clear why the AVA results are much higher than the hardened air void analysis. Although only 3 samples were tested between the image analysis air content and the RapidAir457, there is pretty good agreement between those test methods.

Air void analysis indicates that excessive vibration was not required to place the concrete. Vibration was well within the specification limits with an average of 6683 vpm’s with a standard deviation of 461.

Overall ride of the project was very good. The average smoothness for the project was 2.1 in/mile (33.8 mm/km). The International Roughness Index (IRI) was 81 in/mi (1.29 m/km).

The compressive strength was 6260 psi (43.2 MPa) at 28 days and 6830 (47.1 MPa) at 56 days. The modulus of rupture by third point loading (MOR-TPL) tested at 28 days was 660 psi (4.55 MPa). Strength was more than adequate and was included for information only, as it is not typically a good indicator of long term durability.

The AASHTO T277 rapid chloride permeability results at 28 days using the Virginia cure method correlate fairly well with the 56 and 90 day results with standard curing. The Virginia cure method 28 day results were 2475 coulombs and the standard cure 56 and 90 day test results were 2180 and 2118, respectively.

The permeability was not as low as had been tested in previous projects using Type I(SM) cement and 20% Class C fly ash. Earlier results obtained on a project placed in the fall with cooler weather and a w/c ratio of 0.376 was 765 coulombs. This concrete in this project was placed in much hotter weather with a higher w/c ratio of around 0.42 during the time of placement.

Conclusions and Recommendations

The conclusions of this research are as follows:

1. Using well graded aggregates and blended cements produce concrete pavements with aspects of long term durability such as a good air void system, excellent smoothness, and low permeability.
2. Permeability was not as low as previously tested with this same cement and fly ash combination, most likely due to higher water cement ratio because of hotter weather conditions.

The following recommendations are based on conclusions from this research:

1. More research is needed to determine what results the AVA is giving compared to the air analysis of hardened concrete.
2. Obtain cores at later dates (1 year, 5 years, etc.) to determine in place permeability reduction over time.

Acknowledgement

The author would like to thank the following people for their help in this research: Mike Coles, Leroy Lutjen, and Ken Kennedy from the Iowa DOT Cement and Concrete Section; Jeremy McIntyre, Bryan Zimmerman, and Jim Grove from Iowa State University Concrete Lab Trailer; Gary Fick from Trinity Construction Management; Mark Gorton from Flynn Company, Inc. and Jerry Amenson, Warren Straszheim, and Scott Schlorholtz from Iowa State University Materials Analysis and Research Laboratory.

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2. Schlorholtz, S., Determine Initial Cause for Current Premature Portland Cement Concrete Deterioration, Final Report TR-406, Iowa State University, Ames, Iowa, 2000.
3. Hanson, T., Evaluation of PCC Specification Changes Impact on Durability: 1992 – 1997 Core Study, MLR-98-06, March 2005
4. Tymkowicz, S. & Steffes, R., Vibration Study for Consolidation of Portland Cement Concrete, MLR-9-04, March 1999
5. Grove, J., Fick, Gary, Material and Construction Optimization for Prevention Premature Pavement Distress in PCC Pavements: Iowa Field Testing Report, January 2006

Appendix

Figure 1 - Mix Design.

GENERAL INFORMATION

PROJECT:	NHSX-34-9(123)--3H-29
PROJECT TITLE:	Danville
MIX TYPE:	QMC
MIX NUMBER:	Mix # 2
DATE:	3/1/2005

MATERIALS	*Source*	*Type/Class*	*SPG*	*Percent*	*Percent*		*Abs. Vol.*
CEMENT:	Lafarge Davenport	I(SM)	3.10				0.085
FLY ASH:	Burlington	C	2.72	20.00			0.024
MINERAL ADMIXTURE:				0.00			0.000
WATER (w/c ratio):		0.4	1.00				0.132
AIR CONTENT:		6.0					0.060
FINE AGGREGATE:	Cessford Spring Grove		2.66	33.00			0.230
COARSE AGGREGATE:	River Pro Columbus Jct		2.55	51.59	77.00		0.361
INTERMEDIATE AGGREGATE:	River Pro Columbus Jct		2.55	15.41	23.00		0.108
AIR ENTRAINING AGENT:	Brett AEA 92					*Total*	1.000
RETARDER:						*Paste*	0.301
WATER REDUCER:	Brett Euchon WR					*Agg*	0.699
SUPER WATER REDUCER:							
ACCELERATOR:							
DESIGN SLUMP:	1.5						

QUANTITIES (absolute volume method in SSD condition)

	Volume ft3 Batch Size 1.0 yd3	Volume ft3 Batch Size 1.0 ft3						Weight lbs Batch Size 1.0 ft3	Weight lbs Batch Size 1.0 yd3	Weight lbs Lab Batch Size 4.0
CEMENT:	0.085	2.30	X	3.10	X	62.4	=	16.4	443	65.6
FLY ASH:	0.024	0.65	X	2.72	X	62.4	=	4.1	111	16.4
MINERAL ADMIXTURE:	0.000	0.00						0.0	0	0
WATER:	0.132	3.56	X	1.00	X	62.4	=	8.2	222	32.9
FINE AGGREGATE:	0.230	6.21	X	2.66	X	62.4	=	38.2	1031	152.7
COARSE AGGREGATE:	0.361	9.75	X	2.55	X	62.4	=	57.4	1551	229.8
INTERMEDIATE AGGREGATE:	0.108	2.92	X	2.55	X	62.4	=	17.2	464	68.7
AIR:	0.060	1.62	X	0.00	X	62.4	=	0.0	0	0.0
Summation	**1.0000**	**27.00**						**141.6**	**3822**	**566.2**
Paste Content	**24.1**									
Mortar Content (abs vol)	**53.1**									
Mortar Content (% pass)	**54.4**									

CHEMICAL ADMIXTURES

	Rate oz/100 lbs cementitious							Rate ml Batch Size 1.0 ft3	Rate ml Batch Size 1.0 yd3	Rate ml Lab Batch Size 4.0
AIR ENTRAINING AGENT:	1.0	20.50	X	0.01	X	29.57	=	6.1	163.7	24.3
RETARDER:										
WATER REDUCER:	4.0	20.50	X	0.04	X	29.57	=	24.3	654.8	97.0
SUPER WATER REDUCER:										
ACCELERATOR:										

Figure 2 – Coarseness Workability Factors – Mix Design.

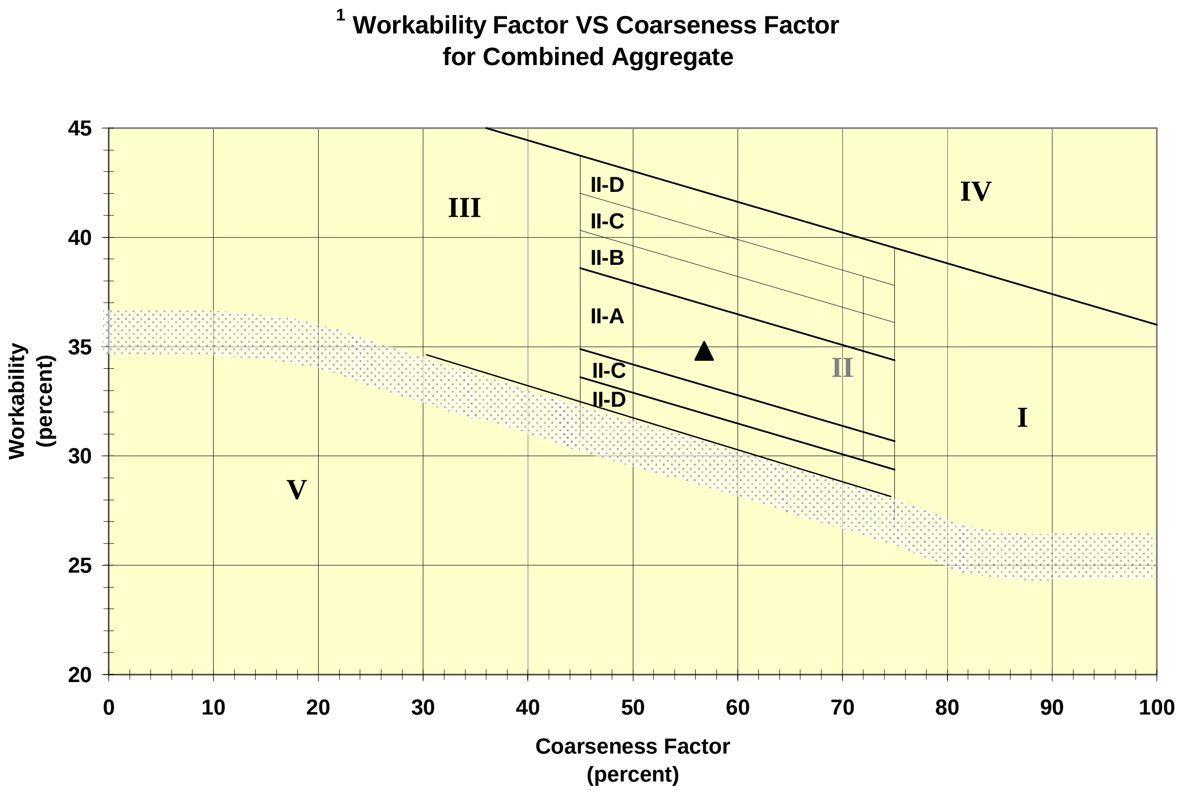

Figure 3 – 0.45 Power Percent Passing Gradation Chart - Mix Design.

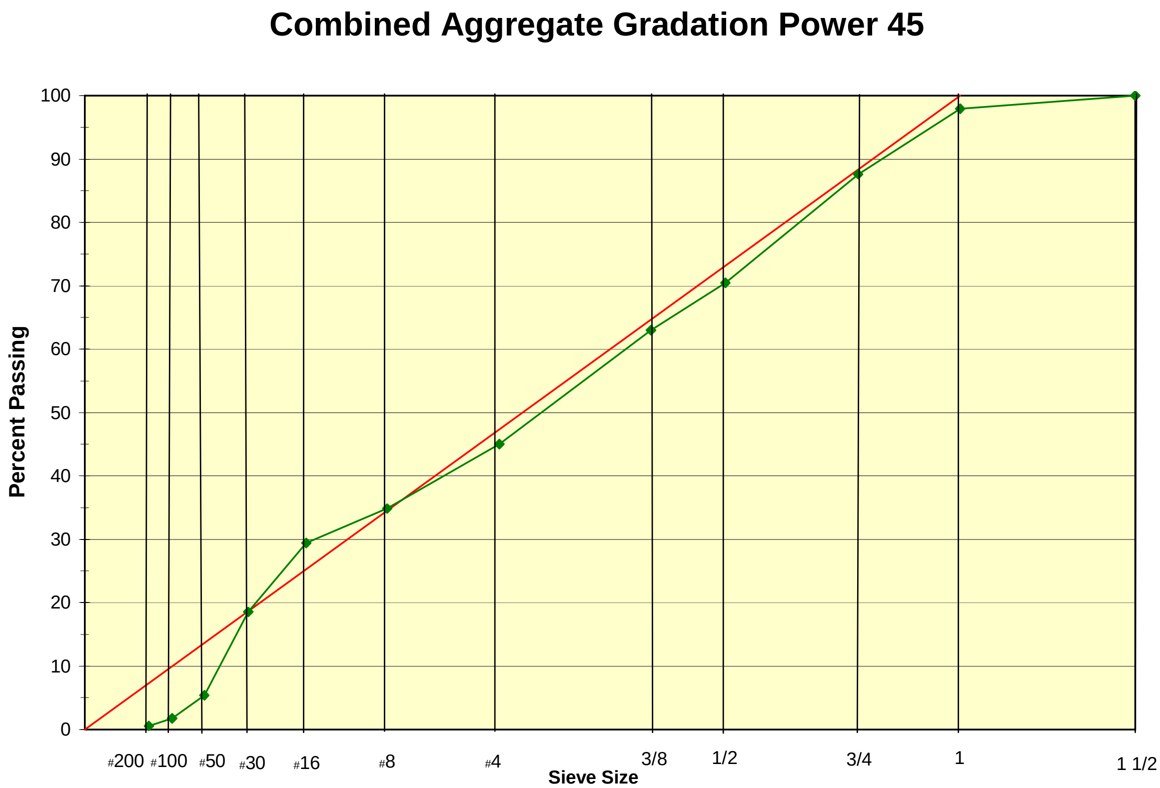

Figure 4 –Percent Retained Gradation Chart - Mix Design.

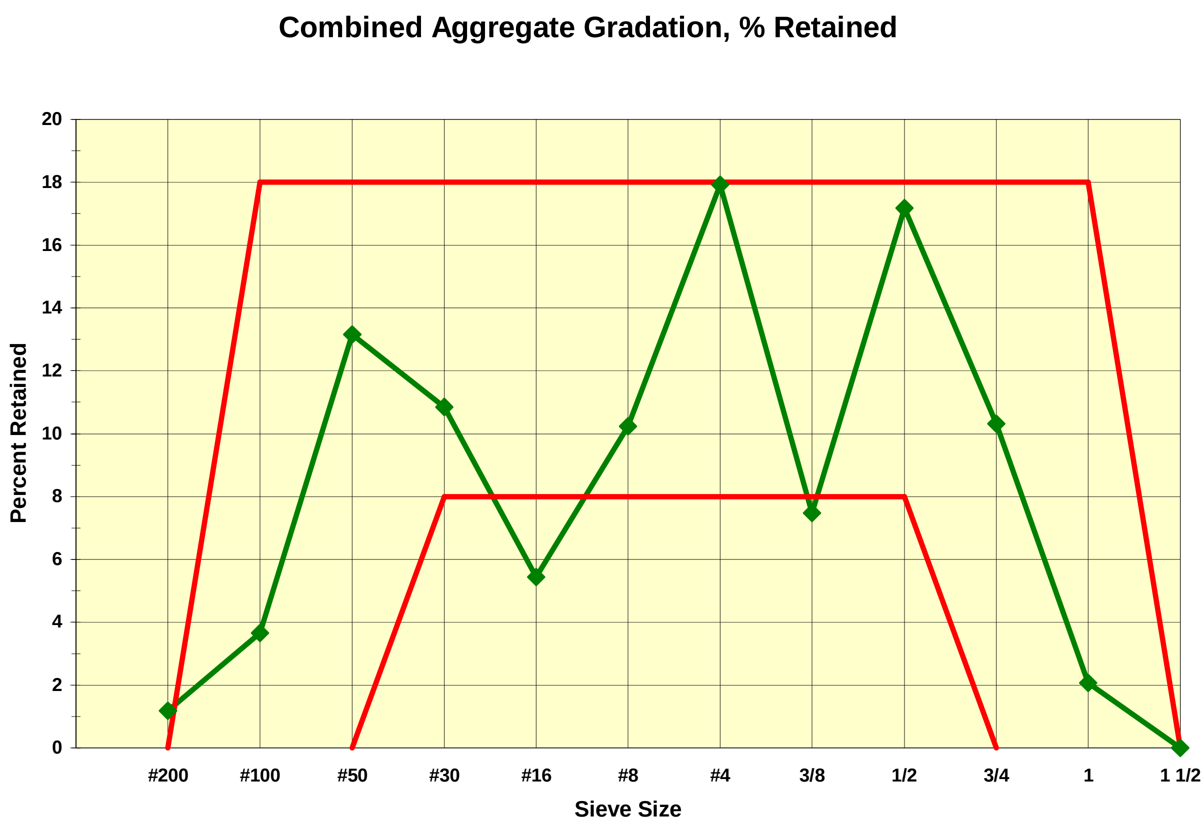

Figure 5 – Coarseness Workability Control Chart Project Data.

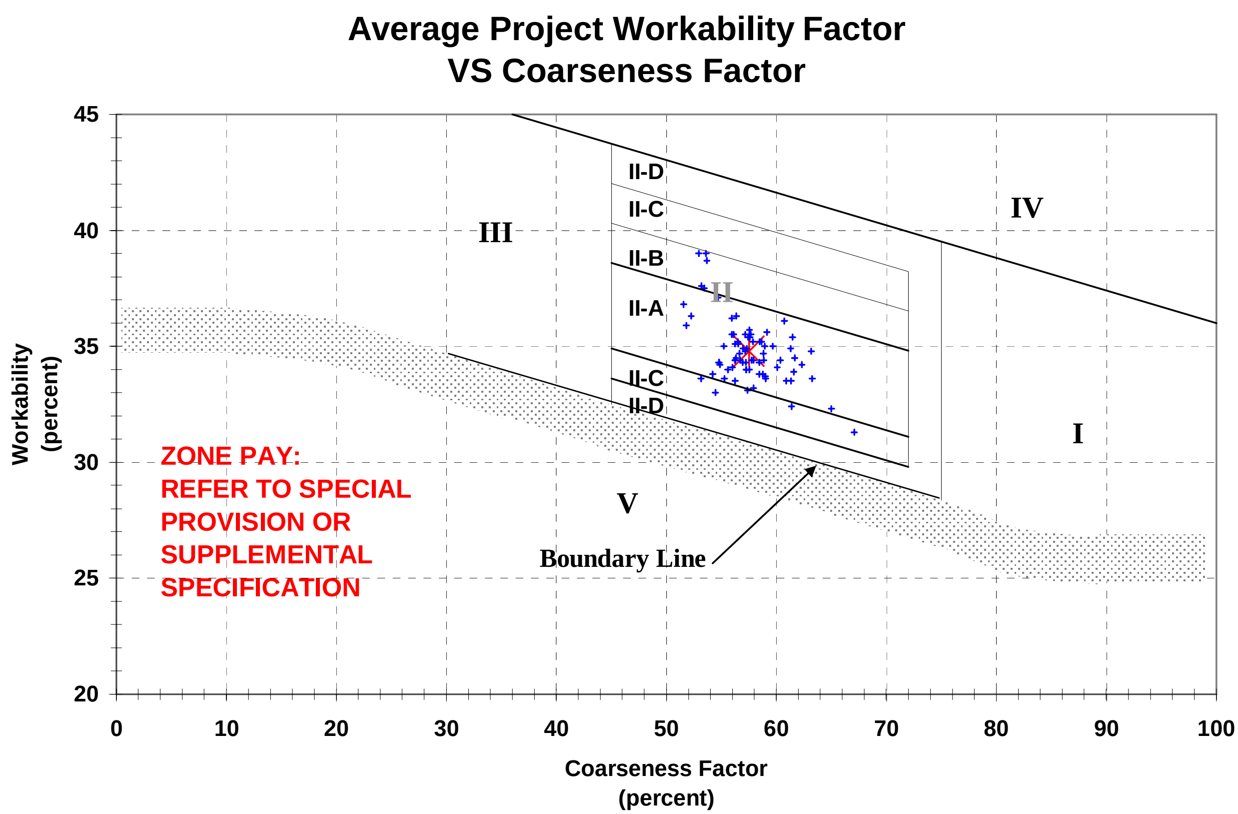

Figure 6 – Plastic Air Before Paver Control Chart.

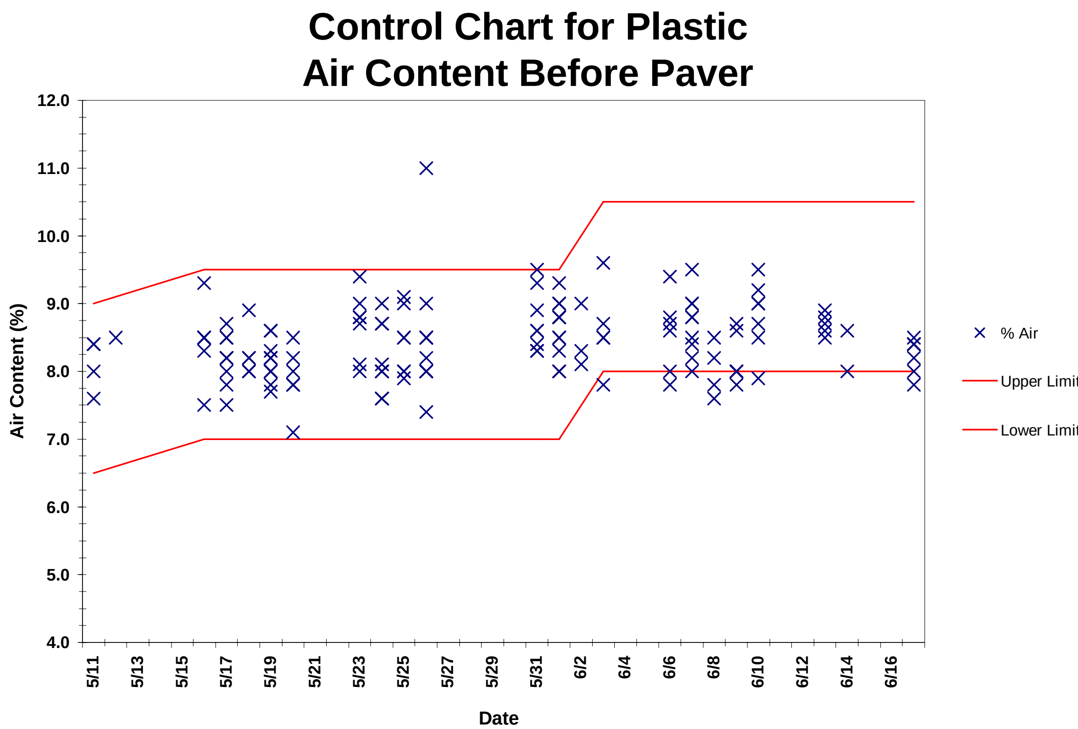

Figure 7 – Unit Weight and Air Content Comparison

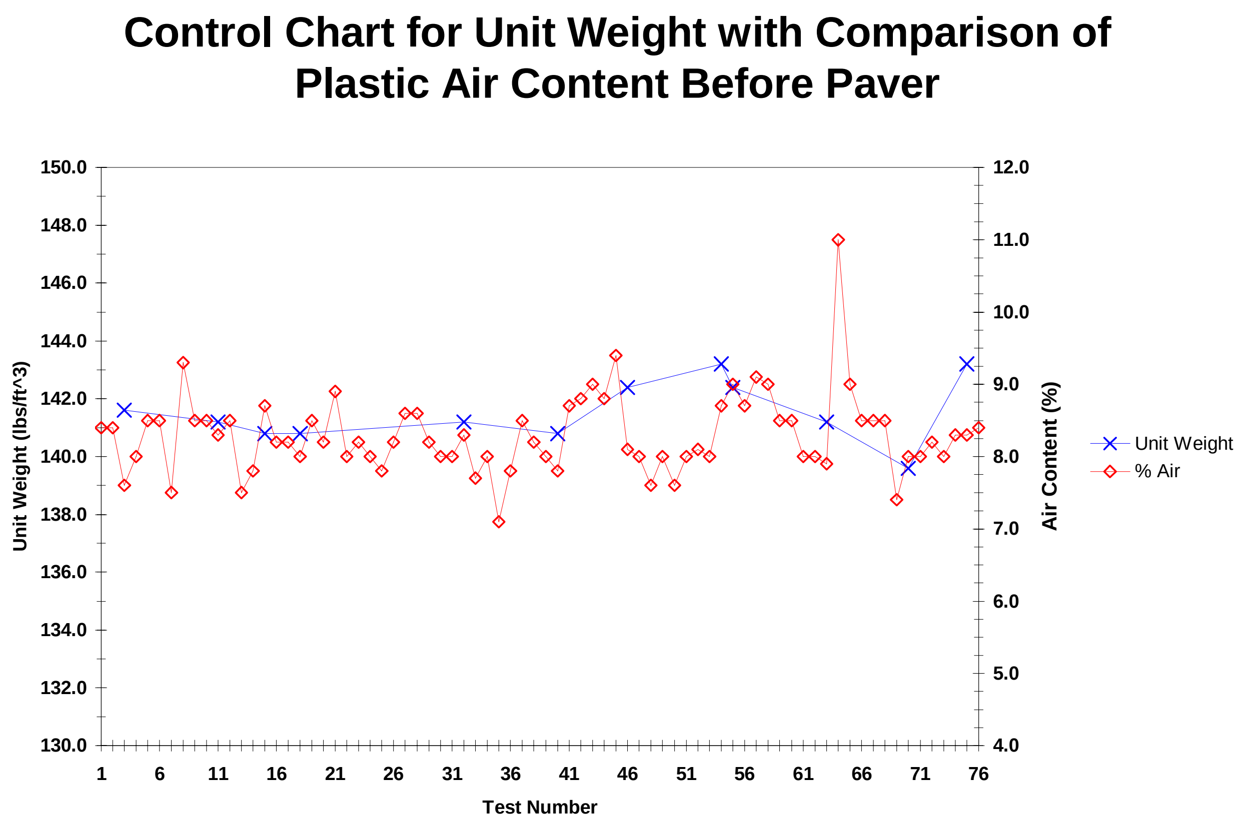

Figure 8 – w/c Ratio Control Chart