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Effect of Mix Times on PCC Properties

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DISCLAIMER

"The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Iowa Department of Transportation."

ACKNOWLEDGEMENTS

This project was made possible by the cooperative efforts of many groups and persons in the highway industry. The interest of the Federal Highway Administration Iowa Division Office and the Iowa DOT Office of Materials identified a concern in both the consistency and consolidation of portland cement concrete paving materials. The Iowa Concrete Paving Association and the Cedar Valley Construction Co. Inc. were interested in looking at new concrete mix designs and innovative equipment for mixing concrete. Iowa State University partnered with each of the agencies noted to conduct the evaluations in the field. The research would not have been possible without the cooperation of those groups and the field staff of Cedar Valley Construction Co. Inc. on each of the two projects selected for testing.

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ABSTRACT

The objectives of this research were the collection and evaluation of the data pertaining to the importance of concrete mixing time on air content and distribution, consolidation and workability for pavement construction.

American Society for Testing and Materials (ASTM) standard C 94 was used to determined the significance of the mixing time on the consistency of the mix being delivered and placed on grade. Measurements of unit weight, slump, air content, retained coarse aggregate and compressive strength were used to compare the consistency of the mix in the hauling unit at the point of mixing and at the point placement.

An analysis of variance was performed on the data collected from the field tests. Results were used to establish the relationship between selected mixing time and the portland cement concrete properties tested. The results were also used to define the effect of testing location (center and side of truck, and on the grade) on the concrete properties.

Compressive strength test concepts were used to analyze the hardened concrete pavement strength. Cores were obtained at various locations on each project on or between vibrator locations to evaluate the variance in each sample, between locations, and mixing times. A low-vacuum scanning electron microscope (SEM) was used to study air void parameters in the concrete cores. Combining the data from these analysis thickness measurements and ride in Iowa will provide a foundation for the formulation of a performance based matrix.

Analysis of the air voids in the hardened concrete provides a description of the dispersion of the cemtitious materials (specifically flyash) and air void characteristics in the pavement. Air void characteristics measured included size, shape and distribution.

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INTRODUCTION

Continuous quality improvement in the selection of highway building materials and construction methods are two areas that the transportation industry is constantly trying to improve. Iowa has started to focus its interest in the area of continuous quality improvement by studying ways to improve the consistency of the portland cement concrete being delivered to the construction of portland cement concrete pavements.

This research was directed at measuring the consistency of the mix delivered from the portable plant to the grade. Variables considered included plant mixer type, mixing time and mix composition.

Nondestructive maturity concept methods were utilized during this research to analyze the concrete strength gain in the test pavement. In addition, using these methods provided information pertaining to flexural and compressive strength at the time the cores were acquired for analysis.

Recent statements made by new central mix plants have claimed consistent and sufficient mixing in as short as 30 seconds. However, existing plants do not support the claims using such a short mixing time. Because of the conflicting claims, research is needed to determine the effects of mix design and mixing time on the consistency of portland cement concrete. This research will provide data collected from three different locations, center of dump truck, side of dump truck and on grade, to measure the variability in the mix and the finished product. Results obtained from this research provides significant relationships between the mixing time and the quality of the mix being delivered and placed in the pavement.

RESEARCH OBJECTIVES

The goal of this research was the collection and evaluation of data pertaining to the significance of concrete mixing time on air content and distribution, consolidation, and workability for pavement construction. Using these results, the Iowa Department of Transportation (DOT) can move toward performance based specifications, for concrete, that measure the quality, consistency, hardened air content and pavement strength during construction. Developing specifications based on the preceding measurements of characteristics will enable the DOT to estimate the long term performance of the pavement. New testing technologies could be used to measure the air content and concrete strength of hardened concrete at an early age, which will improve the performance of the pavement.

The long term performance of the concrete, workability and consistency of the mix are all heavily influenced by the mixing time. This study assisted in reviewing Iowa DOT guidelines that pertain to the relationship between the mixing time and the introduction of the admixtures into the mix during mixing. The results of this study could help in limiting areas of potential poor performance by allowing contractors to make changes in mixing operations. Reductions in construction time and road user delay costs may be results of reduced mixing times. However, reduced quality and consistency in concrete being delivered to the site may also be effects of reduced mixing times.

Recent statements made by central mix plant manufacturers have claimed consistent and sufficient mixing in as short as 30 seconds. However, existing plant production records did not support claims using such short mixing times. Because of the conflicting claims,

this research was developed to determining the effects of mix design and mixing time on the consistency of portland cement concrete.

This research used testing methods described in ASTM standard C 94 to determine the significance of the mixing time on the consistency of the mix being delivered and placed on the grade. Using this standard, measurements of unit weight, slump, air content, retained coarse aggregate and compressive strength were used to compare the consistency of the mix at different locations in the hauling unit.

Two measures of concrete quality are air content and air distribution. However, the Strategic Highway Research Program (SHRP) has been unable to develop a method of measuring these characteristics for instu pavements. Using an air pot to test the plastic concrete behind the paver provides an average air content for all the concrete being tested, but is not accurate enough to be used as a basis of payment. Besides using a small sample, this method cannot identify variances transversely across the slab, longitudinally along the pavement or vertically through the slab thickness.

Typically, air content in hardened concrete is measured using the linear traverse method. Although the linear traverse method is accurate in measuring air content, there are a few limitations associated with the test that makes it less than desirable. First, this test is time consuming, taking many hours to perform. Second, it is expensive, costing $500 or more per sample. Lastly, this method is dependent on operator skill and equipment. Because of these limitations, there is a need to develop a new method that is quick, inexpensive and easily repeated.

This research considered the use of a low-vacuum scanning electron microscope

(SEM) and imaging technology of air void parameters. Using SEM imaging technology helps eliminate the problems associated with the linear transverse method. Correlation between the plastic air and the hardened concrete, in the same pavement area, has been calculated using air content data collected by pressure pot test methods in the plastic concrete at the paver. Air content changes may be associated with the location of the paver vibrators, forward speed of the paver and the frequency of the vibrators as indicated by existing research in Iowa. Also, measurement of air content in the plastic concrete by air pot testing may only be representative of the air content levels in the top portion of the slab. Significant differences in air content may exist between the top portion and bottom of the slab.

The new test method for hardened air content will provide information on air content levels and consistency in the pavement by analyzing a core sample from top to bottom. It will also be able to analyze multiple cores in less time then the linear traverse can analyze one core. Because of the smaller analysis time, feedback can be provided within two to three days after paving. This allows the contractor and contracting agency to make adjustments during construction, which could result in improved long-term performance of the pavement.

The Iowa DOT quantified the significance between mix design materials, mixing times, paving methods, time of transverse joint sawing, and climatic conditions with the rate of strength gain in the field through the use of the maturity concept. The results described by these relationships will help to indicate the long term strength of the pavement and identify the appropriate time to saw joints and allow construction vehicles

on the slab.

Combining the data collected through the use of the maturity concept and the air void analysis with the existing information on pavement thickness and ride in Iowa provides a foundation for the formation of a performance based payment matrix. The evaluation of anticipated performance could be done during construction rather than after construction. Due to the development of a Special Provision specification aimed at higher performance, future projects may allow the contractor more flexibility in determining the mix design and placement of the concrete.

This research was conducted in two parts:

1. Evaluation of the impact of variable mix times using a conventional Iowa DOT mix, a contractor designed mix and a conventional drum mixer.
2. Evaluation of the impact of variable mix times using an Iowa DOT mix and mixer employing rotation of blades within the drum.

This research provides data collected from three different locations: center of the truck, side of the truck and on the grade, to measure the variability in the mix and the finished product. Results obtained from this research provide significant relationships between the mixing time and the quality of the mix being delivered and placed in the pavement.

The data for this research was collected from two adjacent projects, located in Warren and Carroll Counties under contract for paving in 1996. In the Warren County project (STP 5-4(27)-2C-91), two concrete mixes and a conventional drum mixer were considered. The Iowa DOT also employed the same contractor for a separate paving

project in Carroll County (NHS-30-2 (65)-19-14), where he used an alternative mixer. The mixer is designed with a stationary drum that moves the mixing paddles relative to the drum in opposition to the drum rotation on a conventional plant. Evaluation of this mixer was included in the research objectives to provide guidance to the Iowa DOT on the acceptance or rejection of changes in mix time required for the next generation of mixers.

EXPERIMENTAL DESIGN

Physical Testing Methods

The combined research efforts of the Iowa DOT and Iowa State University identified several items of data to be collected. The objective of this project was to define the relationship between concrete mixing time on air content and distribution, consolidation, and workability for pavement construction. The data of interest was subdivided into the following categories:

1. Mixing time - Visual observations were made to determine the mixing time. The mixing time was defined as the elapsed period between the introduction of all the materials and when the mix was delivered to the hauling unit. The nominal mixing times chosen for each site are as follows:

   Carroll Plant (Iowa DOT mix)

   - 30 second mixing time
   - 45 second mixing time

   Carlisle Plant (Iowa DOT mix)

   - 45 second mixing time
   - 60 second mixing time
   - 90 second mixing time

Carlisle Plant (Contractor mix)

- 45 second mixing time
- 60 second mixing time
- 90 second mixing

2. Slump - The slump test was conducted in accordance with ASTM standard C143. Samples were taken from three different locations (at each construction testing site): center of truck, side of truck and on grade directly in front of the paver.
3. PCC Unit Weight - The PCC unit weight was calculated in accordance with ASTM standard C138. The samples were taken from three different locations (at each construction testing site): center of truck, side of truck and on grade directly in front of the paver.
4. Air Content - For plastic concrete, the air content was measured in accordance with ASTM standard C231. The samples were taken from three different locations (at each construction testing site): center of truck, side of truck and on grade directly in front of the paver.
5. Wash Test (percent of coarse aggregate in mix) - The wash test was performed in accordance with ASTM standard C94. The samples were taken from three different locations (at each construction testing site): center of truck, side of truck and on grade directly in front of the paver.
6. Compressive Strength (cylinders) - The compressive strength (cylinders) was conducted and corrected in accordance with ASTM C42 standard. The compressive strengths were measured on cylinders cast from each specific

batch.

7. Compressive Strengths (cores) - The compressive strength (cores) was conducted and corrected in accordance with ASTM C42 standard. The compressive strengths were measured on cores obtained from known batch locations.
8. Air void distribution of hardened concrete cores - The air void distribution data for the cores was collected using a low-vacuum scanning electron microscope and computer imaging analysis. The cores for this analysis were obtained behind the paver.

SITE CHARATERISTICS

Test Site Selection

The first plant site was located on the Polk-Warren County line. A plant located north and west of Carlisle, Iowa provided concrete for projects STP-5-4 (27) -2C-91 (Warren County). The project selected was located on Iowa Highway 5 and had a length of 3.58 miles. The location of this construction site is shown in Figure 1.

The second test site was located near Carroll, Iowa on project NHS-30-2 (65)-19-14. This project on US Highway 30 was 2.15 miles in length. The location of this construction site is shown in Figure 2. This project involved construction of a four lane undivided facility.

Data was collected from this project after the Iowa DOT tested the cement and flyash materials to determine that they didn't cause early stiffening. The testing was limited to one conventional Iowa DOT mix, two mixing times and one day of paving.

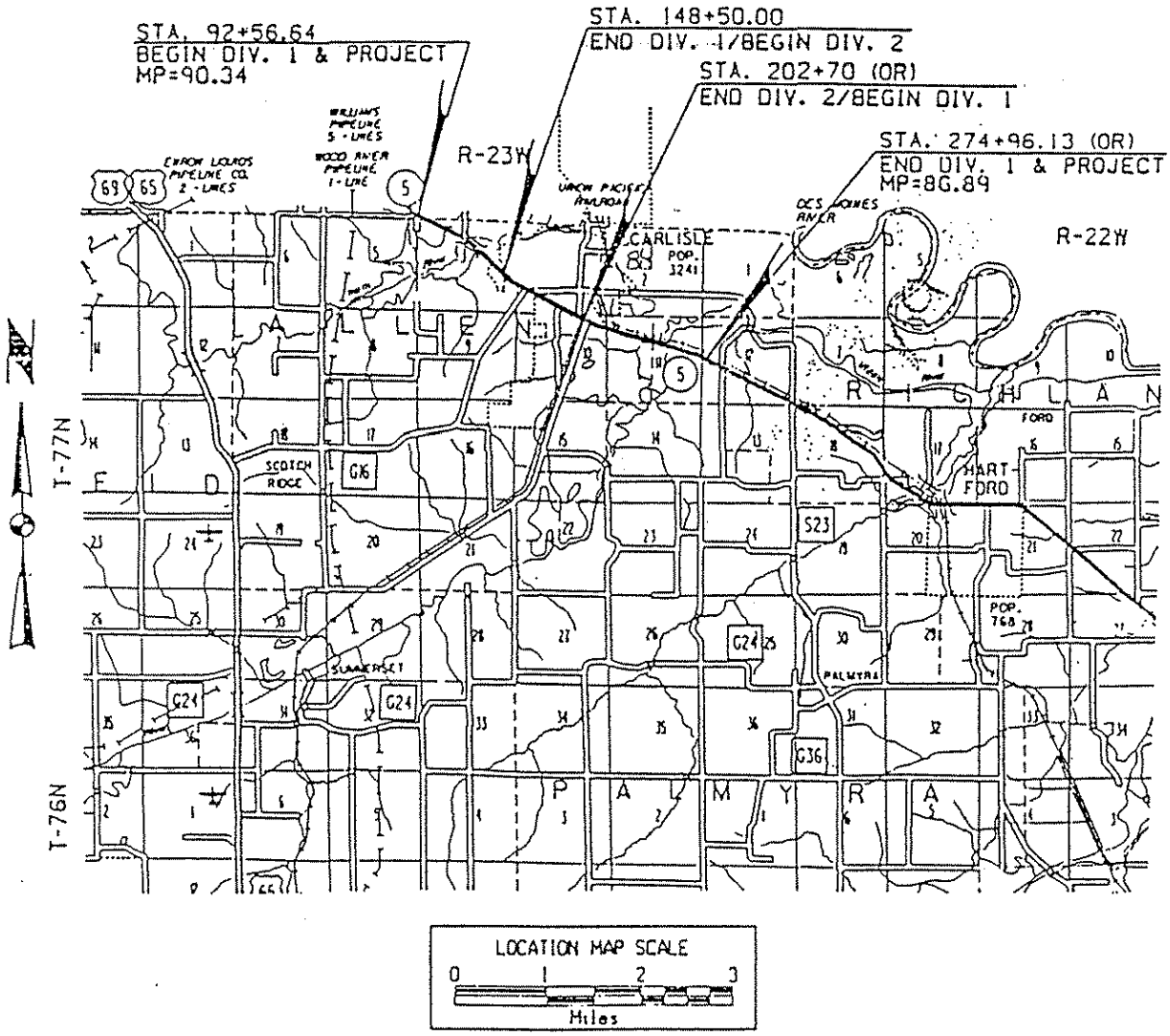


Figure 1. Carlisle, Iowa Highway 5 Construction Site.

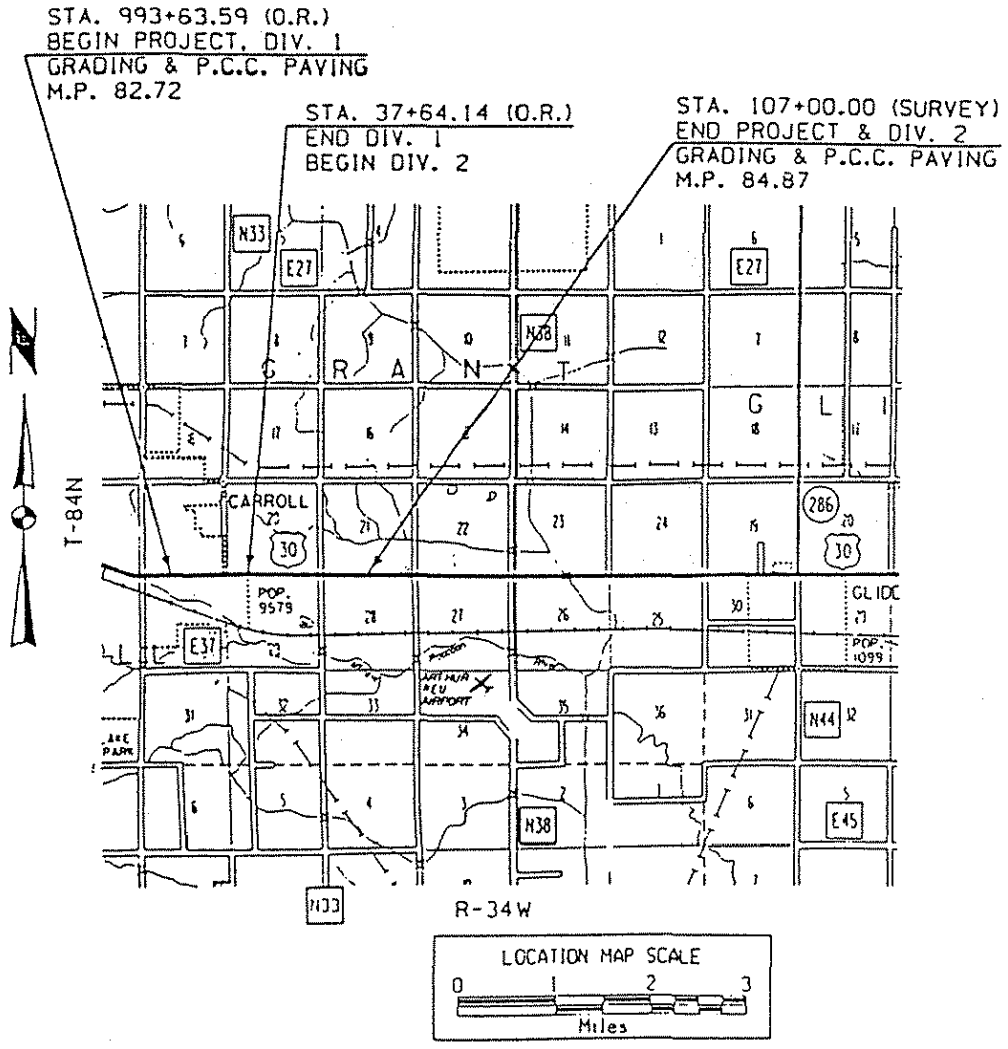


Figure 2. Carroll, US Highway 30 Construction Site.

Test data was obtained from three locations at each of the identified projects. The first testing location was by the exit of the central mix plant site and near a source of water, electricity and the Iowa DOT laboratory trailer. Slump, air content, unit weight and percent of coarse aggregate data were determined from fresh concrete samples obtained from hauling units. The second sampling location was directly in front of the paver. Percent of coarse aggregate in the mix delivered to the site was determined from samples from this location. The third area of testing was made behind the paver. Visual observations of the consistency of the mix were made as the workers were finishing it. This testing location was where the cores for the air void distribution analysis and compressive strengths were obtained. SEM testing used pavement cores taken from the area between the second and third paver vibrators

DATA COLLECTION METHODS

ASTM Standard C 94 testing procedures are assumed to deal with the discharge of concrete from a ready-mix or agitator type hauling vehicle. This type of unit provides continuous mixing of the concrete from the time of mixing at the plant until it is discharged at the construction site. Specification ASTM Standard C-94 is designed to check the consistency of the material at the beginning and near the end of the truck discharge.

This research used dump trucks to transport the concrete from the mixing plant to the paving train. The research objectives indicated a need to test two locations in the truck (center and side of load) and from the same load of material as it was deposited on the grade in front of the paver. The paver represents the last location where the concrete

procedures.

Air Void Analysis of Hardened Concrete Cores

The purpose of testing the hardened concrete was to gain information on the air content variation throughout the length of the core. This was considered important because previous work had indicated that placement problems and excessive vibration tended to lower the air content in the top of the pavement slab. Lower air content can lead to poor durability in field concrete.

The instruments used for the air void analysis of hardened concrete cores were a Hitachi 2460 N low-vacuum scanning electron microscope (SEM), Tetra back scattered electron detector, Deben stage automation and an Oxford Instrument ISIS x-ray analysis system with extensive digital imaging and automation capabilities. The microscope is equipped with Oxfords tetra ™ back scattered electron detector and Deben stage automation. The microscope was operated at a voltage of 6kV. Helium gas was purged through the specimen chamber and the operating pressure was maintained at 5.80×10^{-3} psi (40 Pa) throughout the measurements.

The cores used for the air void analysis were extracted behind the paver when the concrete would support the drill rig. The cores were transported to the laboratory for length measurements. The cores were sectioned using a diamond blade saw to produce specimens for the SEM and compressive strength tests (see Figure 3). One inch was sliced from the top and bottom of the core and used for the SEM hardened air content determinations. The remaining section of the core (approximately eight inches thick) was used to measure the compression strength of the concrete. The SEM specimens were

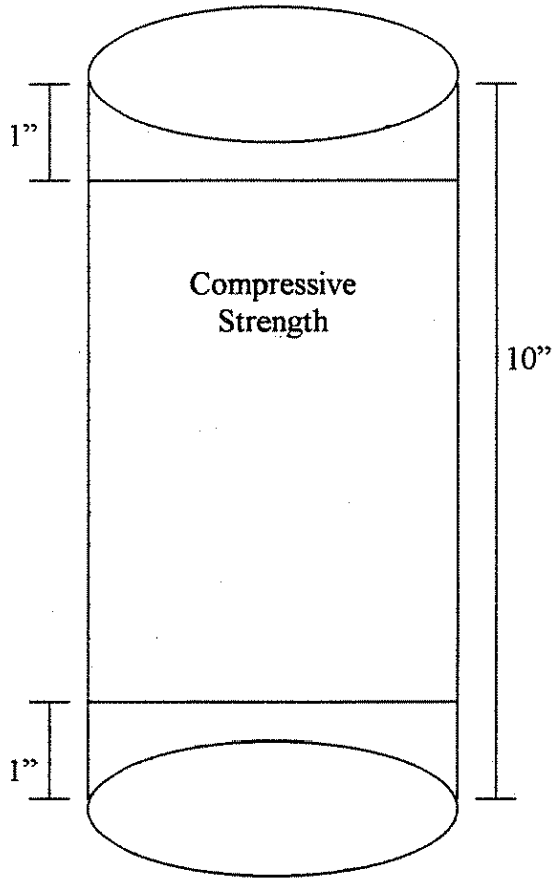
lapped and polished using a #1200 grit SiC paper.

Once the top and bottom samples from each core were prepared, 24 images on each surface were collected (see Figure 4). The image locations were preselected in areas that contained the mortar fraction of the concrete. All images were taken at 50X magnification and a resolution of 1024 x 768 pixels (picture element). At 50X magnification the image reflects an area of two millimeters by two and one half millimeters. The scanning electron microscope magnifies the face of the concrete and with the help of computer analysis looks at the different shades of gray to determine the chemical composition (actually average atomic number) of the material. Hence, regions of low atomic number (i.e. voids) are sharply contrasted against regions of higher atomic number (i.e., aggregate, cement paste, and unhydrated cement particles).

IMQUANT ™ software was used to determine the area and size of the air voids in each image. The data obtained from the 24 separate images was combined to create an average air content and size distribution curve for each specimen. These curves are not included in this report due to the large number of core specimens tested. However, the average air content and standard deviation of the mean is summarized in tables A-4 and A-5 of Appendix A. It should be noted that SEM provides results pertaining to the mortar fraction of the core which is then converted to relate to the whole concrete specimen.

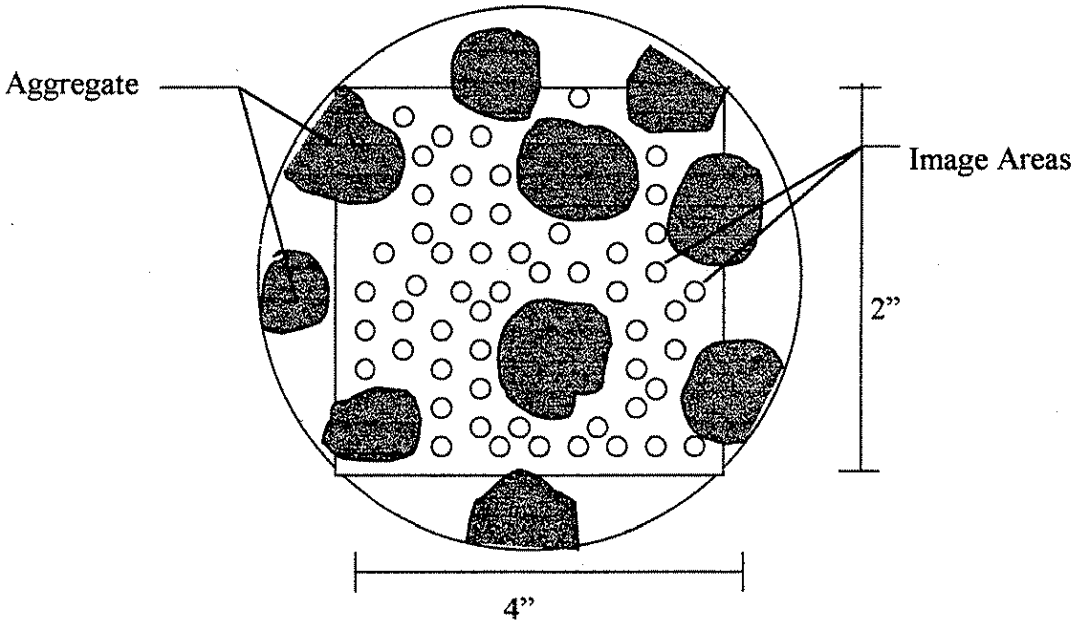
A typical analysis required about one hour for data acquisition and another 30 minutes for data reduction and analysis. A typical analysis counted about 6,000 to 12,000 voids (per 24 images). Also, approximately 1,500 to 3,000 voids were counted that fell into the size range that is normally associated with entrained air voids (between about 50

Figure 3. Core Specimen



Not to Scale

Figure 4. Image in Mortar Fraction of Concrete Core



and 1,000 microns).

The raw data from the SEM analysis can be found in tables A-4 and A-5 in Appendix A. The data in these tables was used to develop sensitivity plots and perform ANOVA tests. These particular sensitivity plots are presented in Appendix D as follows:

* D-1 Mixing Time vs. Hardened Concrete Core Average Air Content, Carroll, Iowa DOT Mix
* D-2 Mixing Time vs. Hardened Concrete Core Average Air Content, Carlisle, Iowa DOT Mix
* D-3 Mixing Time vs. Hardened Concrete Core Average Air Content, Carlisle, Contractor Designed Mix

The use of SEM is a relatively new technological concept that is still in the experimental stages. While conducting this study a few problems were noted that need to be resolved in future work. First, there was the difficulty of counting very shallow voids due to the lack of contrast between the voids and the cement paste. In fact, accurate gray scale measurement could probably be used to measure the depth of many of the voids. Second, segmentation procedures were not performed on the images in this study. This tended to cause some erroneous void size estimates due to the fact that overlapping voids were only counted as a single void. This was not considered to be a significant problem. Third, there was the miscounting of air voids that were filled with miscellaneous material such as alkali-silica gel. This was also generally not a severe problem.

RESEARCH CONCLUSIONS

Slump, Unit Weight, Air Content, and Retained Coarse Aggregate

The following conclusions were drawn from the ANOVA tests (results are shown in tables 1, 2 and 3):

- The 30 to 45 second mixing times for Carroll, Iowa DOT mix (table 1) indicate

that there are no significant differences in slump, PCC unit weight, air content and retained coarse aggregate.

- The selected mixing times for Carlisle, Iowa DOT mix (table 2) indicate that increasing the mixing time from 45 to 60, 45 to 90 and 60 to 90 seconds lead to significant increases in air content, but no changes in any other variable.
- The Carlisle, contractor mix (table 3) shows a significant increase in unit weight and a reduction in air content when the mix time was increased from 45 to 60 seconds. However, increasing the mixing time from 60 to 90 seconds indicates a significant difference in unit weight and retained coarse aggregate test results.

The results of the ANOVA tests regarding the effect of sampling location on slump, PCC unit weight, air content and retained coarse aggregate for each mixing time are in tables 4, 5 and 6. The following conclusions were drawn from these tables:

- For all mix types and times pertaining to sampling at the center and side of the truck indicates no consistent difference in the dependent variables.
- The Carroll, Iowa DOT mix (table 4) indicated a significant difference in the retained coarse aggregate between the side of the truck, center of truck and grade sampling location. The same result was found when the tests for the Carlisle, contractor mix (table 6) were evaluated. The tests indicate that longer mixing times led to significant differences in the air content of samples taken from the side and center of the truck and at the grade

Table 1. ANOVA results on 30-45 second mixing times for Carroll Iowa DOT mix.

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**
Unit Weight	0.38	0.82	4.49	N
Slump	0.18	2.02	4.96	N
Air Content	0.87	0.03	4.49	N
Wash	0.22	1.64	4.49	N

Significance level (α) = 0.05

Table 2. ANOVA results on 45-60-90 second, 45-60 second, 60-90 second and 45-90 second mixing times for Carlisle Iowa DOT mix.

Dependent Variable	P-Value				F-ratio				F_{CRIT}				Interpretation Y = Significant Difference N = No Significant Difference			
	(Mixing Time, seconds)				(Mixing Time, seconds)				(Mixing Time, seconds)				(Mixing Time, seconds)			
	45-60-90	**45-60**	**60-90**	**45-90**	**45-60-90**	**45-60**	**60-90**	**45-90**	**45-60-90**	**45-60**	**60-90**	**45-90**	**45-60-90**	**45-60**	**60-90**	**45-90**
Unit Weight	0.23	0.25	0.06	0.82	1.53	1.38	3.82	0.05	3.17	4.13	4.08	4.13	N	N	N	N
Slump	0.65	0.79	0.38	0.52	0.43	0.07	0.78	0.42	3.25	4.26	4.22	4.26	N	N	N	N
Air Content	0.00	0.01	0.00	0.00	16.75	7.34	13.72	28.52	3.17	4.12	4.10	4.12	Y	Y	Y	Y
Wash	0.78	0.69	0.68	0.49	0.25	0.16	0.17	0.48	3.24	4.13	4.30	4.30	N	N	N	N

Significance level (α) = 0.05

Table 3. ANOVA results on 45-60-90 second, 45-60 second, 60-90 second and 45-90 second mixing times for Carlisle contractor mix

Dependent Variable	P-Value				F-ratio				F_{CRIT}				Interpretation Y = Significant Difference N = No Significant Difference			
	(Mixing Time, seconds)				(Mixing Time, seconds)				(Mixing Time, seconds)				(Mixing Time, seconds)			
	45-60-90	**45-60**	**60-90**	**45-90**	**45-60-90**	**45-60**	**60-90**	**45-90**	**45-60-90**	**45-60**	**60-90**	**45-90**	**45-60-90**	**45-60**	**60-90**	**45-90**
Unit Weight	0.00	0.07	0.00	0.00	73.50	3.50	56.00	65536.00	3.22	4.20	4.20	4.20	Y	N	Y	Y
Slump	0.32	0.57	0.24	0.25	1.18	0.33	1.50	1.43	3.47	4.75	4.75	4.41	N	N	N	N
Air Content	0.00	0.00	0.36	0.00	7.67	10.79	0.88	10.77	3.28	4.38	4.38	4.20	Y	Y	N	Y
Wash	0.05	0.24	0.02	0.19	3.14	1.42	5.96	1.80	3.22	4.21	4.20	4.21	N	N	Y	N

Significance level (α) = 0.05

Table 4. ANOVA results on test location for Carroll Iowa DOT mix (30 and 45-second mixing time).

Interpretation
Y = Significant Difference Between Test Locations
N = No Significant Difference Between Test Locations

Dependent Variable	Center-Side Test Locations (Mixing Time, seconds)		Side-Grade Test Locations (Mixing Time, seconds)		Center-Grade Test Locations (Mixing Time, seconds)	
	30	**45**	**30**	**45**	**30**	**45**
Unit Weight	N	N	N	Y	N	N
Slump	N	N	–	–	–	–
Air Content	N	N	N	Y	N	N
Wash	N	Y	N	N	Y	Y

Significance level (α) = 0.05

Table 5. ANOVA results on test location for Carlisle Iowa DOT mix (45, 60 and 90 second mixing time).

Interpretation
Y = Significant Difference Between Test Locations
N = No Significant Difference Between Test Locations

Dependent Variable	Center-Side Test Locations (Mixing Time, seconds)			Side-Grade Test Locations (Mixing Time, seconds)			Center-Grade Test Locations (Mixing Time, seconds)		
	45	**60**	**90**	**45**	**60**	**90**	**45**	**60**	**90**
Unit Weight	N	N	N	N	N	Y	N	Y	N
Slump	N	N	N	–	–	–	–	–	–
Air Content	N	N	N	N	Y	Y	N	Y	Y
Wash	N	N	N	N	N	N	N	N	N

Significance level (α) = 0.05

Table 6. ANOVA results on test location for Carlisle contractor mix (45, 60 and 90-second mixing time).

Interpretation
Y = Significant Difference Between Test Locations
N = No Significant Difference Between Test Locations

Dependent Variable	Center-Side Test Locations (Mixing Time, seconds)			Side-Grade Test Locations (Mixing Time, seconds)			Center-Grade Test Locations (Mixing Time, seconds)		
	45	**60**	**90**	**45**	**60**	**90**	**45**	**60**	**90**
Unit Weight	N	N	N	N	N	N	N	N	N
Slump	N	N	Y	–	–	–	–	–	–
Air Content	N	N	N	Y	N	Y	N	N	Y
Wash	Y	N	N	N	Y	Y	Y	Y	Y

Significance level (α) = 0.05

Compressive Strength (cylinder) and Compressive Strength (core) Tests

Following are the conclusions reached from evaluating the ANOVA results recorded in tables 7, 8 and 9:

- The effect of mixing time for the Carroll, Iowa DOT mix (table 7) and the Carlisle, contractor mix (table 9) indicate that the longer mixing time did cause significantly different compressive strengths for both the cylinders and cores.
- The Carlisle, Iowa DOT mix (table 8) indicated decreased compressive cylinder and core strength as mixing times increased from 45 to 60 and 60 to 90 seconds.

Air Void Analysis of Hardened Concrete Cores

The objective of this research was focused on the collection of data to define the relationship between concrete mixing time on air content and distribution, consolidation, and workability for pavement construction. Using the ANOVA test to evaluate the raw data lead to a variety of conclusions. The ANOVA results can be found in tables 10, 11 and 12

Carroll, Iowa DOT Mix Design

- The results of the ANOVA for 30 and 45 second mixing times are represented in tables 1, 7, and 10 and the raw test data is found in table A-1, Appendix A.
- The data indicates no significant differences associated with mixing time in slump, PCC unit weight, air content, retained coarse aggregate and air content in the hardened concrete cores.

- Table 7 ANOVA results on 30-45 second mixing times for Carroll Iowa DOT mix

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**
Cylinder f'_c	0.66	0.22	7.71	N
Core f'_c	0.00	13.45	4.67	Y

Significance level (α) = 0.05

Table 8 ANOVA results on 45-60-90 second, 45-60 second and 45-90 second mixing times for Carlisle Iowa DOT mix.

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**
Cylinder f'_c	0.00 0.10 0.01 0.00	11.67 3.09 8.97 22.81	3.55 4.75 4.75 4.74	Y N Y Y
Core f'_c	0.02 0.86 0.02 0.02	5.56 0.03 7.00 7.95	3.68 4.96 4.96 4.96	Y N Y Y

Significance level (α) = 0.05

Table 9 ANOVA results on 45-60-90 second, 45-60 second and 45-90 second mixing times for Carlisle contractor mix.

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**
Cylinder f'_c	0.00 0.02 0.94 0.00	17.33 10.66 0.01 70.80	4.26 6.61 6.61 5.32	Y Y N Y
Core f'_c	0.00 0.00 0.11 0.01	15.17 187.86 3.28 14.20	4.26 7.71 5.59 5.59	Y Y N Y

Significance level (α) = 0.05

Table 10. ANOVA results on 30-45 second mixing times for Carroll Iowa DOT mix.

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**	(Mixing Time, seconds) **30-45**
%Air Content(Top)	0.07	3.76	4.67	N
%Air Content (Bottom)	0.046	4.91	4.67	Y
%Air Content (Avg)	0.05	4.48	4.67	N

Significance level (α) =0.05

Table 11. ANOVA results on 45-60-90 second, 45-60 second, 60-90 second and 45-90 second mixing times for Carlisle Iowa DOT mix.

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**
%Air Content(Top)	>0.25 >0.25 0.051 >0.25	0.42 0.32 4.12 0.60	3.68 4.96 4.96 4.96	N N N N
%Air Content (Bottom)	>0.25 >0.25 >0.25 0.22	1.12 0.13 1.04 1.64	3.68 4.96 4.96 4.95	N N N N
%Air Content (Avg)	>0.25 >0.25 >0.25 >0.25	0.67 0.07 0.72 0.86	3.68 4.96 4.96 4.96	N N N N

Significance level (α) =0.05

Table 12. ANOVA results on 45-60-90 second, 45-60 second, 60-90 second and 45-90 second mixing times for Carlisle contractor mix.

Dependent Variable	P-Value	F-ratio	F_{CRIT}	Interpretation Y = Significant Difference N = No Significant Difference
	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**	(Mixing Time, seconds) **45-60-90 45-60 60-90 45-90**
%Air Content(Top)	>0.25 >0.25 0.051 >0.25	5.88 3.97 16.70 3.31	4.26 5.59 7.71 5.59	Y N Y N
%Air Content (Bottom)	0.024 0.09 0.01 0.90	21.97 17.99 160.61 6.85	4.26 5.59 7.71 5.58	Y Y Y Y
%Air Content (Avg)	<0.001 0.003 0.007 <0.001	26.49 23.30 82.97 10.35	4.26 5.59 7.71 5.59	Y Y Y Y

Significance level (α) =0.05

- Increasing the mixing time led to increased core compressive strengths.
- Visual observations indicate inadequate coating of the aggregate in the hauling unit at the plant and at the grade.

Carlisle, Iowa DOT Mix Design

- The results of the ANOVA for 45, 60 and 90 second mixing times are represented in tables 2, 8 and 11 and the raw test data is found in table A-2, Appendix A.
- Increasing mixing time from 45 to 60 seconds results in an increase in air content with no significant changes in any of the other dependent variables.
- Increasing the mixing time from 60 to 90 and 45 to 90 seconds results in an increase in air content and a decrease in compressive strengths for both cylinders and cores.

Carlisle Contractor Mix Design

- The results of the ANOVA for 45, 60 and 90 second mixing times are represented in tables 3, 9 and 12 and the raw test data is found in table A-3, Appendix A.
- Increasing the mixing time from 45 to 60 and 45 to 90 seconds resulted in a decrease in air content and an increase in compressive strength in both the cylinders and cores.
- Increasing the mixing time from 45 to 90 seconds resulted in an increase in unit weight.
- Increasing the mixing time from 60 to 90 seconds resulted in an increase in unit

weight and a decrease in retained coarse aggregate.

Sampling Location

- The ANOVA results comparing testing location with unit weight, slump, air content and retained coarse aggregate are located in tables 4, 5 and 6.
- No significant differences in any of the test results were identified for sampling from the center or side of the truck.
- Significant loss of air content was identified between the samples from the side of the hauling unit and the grade in the Carlisle, Iowa DOT mix design being mixed for 60 and 90 seconds. The same conclusion was obtained from the Carlisle, contractor mix design and mixing time of 90 seconds.
- Significant increases in retained coarse aggregate percentages were found on the grade vs. the side of the hauling unit for 45 and 60 mixing times with the Carlisle, contractor designed mix.
- Significant increases in retained coarse aggregate percentages were found on the grade vs. the center of the hauling unit for 30 and 45 second mixing times.
- The Carlisle contractor mix design produced significantly higher percentages of retained coarse aggregates on the grade vs. the center of the hauling unit.
- Sampling in the center of the hauling unit produced significantly higher air contents than those from grade tests for the mixing times of 60 and 90 seconds. The same result was true for the Carlisle contractor designed mix and the 90-second mixing time.

RECOMENDATIONS

This research was directed at evaluating the effect of mixing time on the physical characteristics of the finished portland cement concrete pavement. It considered the relationships of four different mixing times, three different mix designs, and two different concrete mixers to the physical property measures associated with pavement performance. The results of physical tests at the plant and grade locations yielded the following recommendations:

1. Dump truck type hauling units do not significantly change the quality of the material being delivered to the paver and should continue to be allowed in addition to agitator or type hauling vehicles for transport of portland cement concrete paving materials.
2. Mixing times of 60 seconds or greater do have a positive influence on the physical characteristics of the concrete product and should be retained as the minimum mixing time for all mixer types.
3. Mixing times did not significantly affect the hardened air content or distribution for the Iowa DOT mix designs.
4. Contractor mix designs should be thoroughly laboratory tested prior to use in the field to determine the impact of admixtures and differences in aggregate/cement matrix on desired physical performance factors.
5. Mixing times of less than 60 seconds should only be allowed when steps have been taken to change the mixing process to assure coating of all aggregate particles prior to mixer discharge into the hauling unit.

REFERENCES

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Schlorholtz, Scott. "Use of Image Analysis for Evaluating Air Void Parameters of Concrete." Iowa State University, 1996.

Schlorholtz, Scott. "Concrete Cylinder Strengths, Current Status." Iowa State University, 1996.

APPENDIX

A –Test Data
B – Mix Time Vs Each of the Dependent PCC Variables for Each Site
C – Mix Time Vs Compressive Strength
D – Mix Time Vs Air Content for Hardened Concrete Cores

Table A-1. Mix Times and Test Data –Carroll, Iowa DOT Mix.

					CENTER					SIDE					GRADE						
	Truck #	Avg Actual Mix Time (sec)	TARGET MIX TIME (SEC)	Test Station	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	CYLINDER F'c (psi)	CORE F'c (psi)
	30 SECOND CARROLL DATA (DOT MIX)																				
	3015	37 74	30	88+25	910	138 59	0.75	6.4	96.41	930	149.80	0 63	5 0	110.90	930	148.68	N/A	3 4	106 56	7281	
	3022	39 39	30	84+80	1020	145.20	1.50	4 8	99.69	1020	146.57	1.38	6 8	107.44	1030	148 18	N/A	5.5	112 41	6064	5276 5228 5200
	3057	40 50	30	86+50	1000	146.23	2.25	7.4	101 25	1000	142 54	3.13	7 4	98 30	1010	146 11	N/A	6 2	106.71	5631	5219 5415 5172
Average		**39.21**				**143.33**	**1.50**	**6.2**	**99.12**		**146.30**	**1.71**	**6.4**	**105.55**		**147.66**	**N/A**	**5.0**	**108.56**	**6325**	**5252**
	45 SECOND CARROLL DATA (DOT MIX)																				
	3057	50 93	45	83+50	1110	141.13	1.00	5.8	98.67	1110	144.60	1.13	6 8	102 19	1130	148.34	N/A	5 2	108 16	6850	5568 5164 5630
				81+20	1240	138 80	1.38	6.4	96.88	1240	141.54	0.75	6.2	102 59	1240	145 80	N/A	5 0	102 19	6059	
	3059	51 11	45	81+75	1145	148 04	1.00	7.8	98.12	1145	142.14	1.00	6.8	102 91	1205	148.12	N/A	3.8	102 19	6858	6807 6405 6142 6747 6969 6704
Average		**51.02**				**142.66**	**1.13**	**6.7**	**97.89**		**142.76**	**0.96**	**6.6**	**102.56**		**147.42**	**N/A**	**4.7**	**104.18**	**6589**	**6237**

Table A-2. Mix Times and Test Data – Carlisle, Iowa DOT Mix.

					CENTER					SIDE					GRADE						
Truck #	Avg Actual Mix Time (sec)	TARGET MIX TIME (SEC)	Test Station	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	CYLINDER F'c (psi)	CORE F'c (psi)
45 SECOND CARILSLE DATA (DOT MIX)																				
3016	45 10	45	115+25	1740	132.40	4 00	8.00	90.85	1745	134.80	3.25	5.10	95.41	1750	136 20	N/A	N/A	90 07	4595	
3019	44 92	45	118+60	840	139.20	2 75	7.80	104.16	840	142.30	2.38	8.25	105.69	850	139 20		7 20	94.60	4939	
3020	45 02	45	111+75 116+50	N/A 730	N/A 142 30	2.50 2 00	5.00 7.80	97.68 104.35	N/A 730	N/A 140 30	3 13 1.50	5.00 6 80	84.29 105.78	N/A 730	N/A 137.80	N/A N/A	5 00 6 50	99 25 107 6 1	5466 5103 5399	
3021	45 06	45	113+85 117+85	1645 810	134 50 139 10	2 75 2 50	1 40 7.80	93.81 99.59	1645 810	135 60 141 50	2.75 2.75	7.50 7 40	94 27 102 65	1710 820	140.40 141.30	N/A N/A	3 00 6 80	99 25 107 5 8	4933 5078	5339 5216 5313 5532 5058 5168
Average		**45.03**				**137.50**	**2.75**	**6.30**	**98.41**		**138.90**	**2.63**	**6.68**	**98.02**		**138.98**	**N/A**	**5.7**	**99.73**	**5073**	**5271**
60 SECOND CARLISLE DATA (DOT MIX)																				
3016	59 29	60	130+61 133+42	1355 1500	139 00 139.52	3 25 1 88	7.20 8.50	101.82 N/A	1400 1505	138.90 140.73	2.00 2.00	8.50 9.25	97.00 N/A	1415 1520	140.93 141.34	N/A N/A	5.50 6 80	98 91 N/A	4715 4905	
3019	59 66	60	134+25	1530	138.71	3 50	7 80	95.17	1530	143 55	2.75	8.25	106.66	1530	140.93	N/A	7.20	87.44	4709	
3020	59 43	60	125+75 129+40	1130 1320	137 50 136 00	2.50 4.25	7.40 8 75	95.30 100.95	1130 1320	138.30 138.91	2.00 3.00	8.50 9.00	97.96 89.34	1140 1325	139 60 141.74	N/A N/A	6.00 6 80	100 27 107 37	5346 4474	5137 4982 5340
3021	58 71	60	124+30	1020	136 70	2 25	N/A	84.98	1020	139.90	1.50	6 50	105.37	1050	142 00	N/A	6.20	94 74	4455	
3058	59 42	60	132+00	1430	138.10	2 75	8.25	98.57	1430	137 10	3.00	9.25	100.61	1435	138 80	N/A	7 00	99 12	4924	5289 5450 5322
Average		**59.30**				**137.93**	**2.91**	**7.98**	**96.13**		**139.63**	**2.32**	**8.46**	**99.49**		**140.76**	**N/A**	**6.50**	**97.98**	**4790**	**5253**
90 SECOND CARLISLE DATA (DOT MIX)																				
3016	89 65	90	207+75 209+75	1325 1440	136 90 136 46	3.38 3 75	10 00 10 00	N/A 96 00	1325 1440	138.31 136 46	2.88 3 00	9 50 9 00	N/A 97.03	1340 1455	140 52 136 46	N/A N/A	7 4 7 6	N/A 96 15	4439 4305	4659 4896 4734
3019	89 17	90	206+80	1245	134 48	1.63	9 50	N/A	1245	137.30	2.75	8 75	N/A	1302	139.92	N/A	8 0	N/A	4502	
3021	89 82	90	204+63 208+65 210+70	1125 1400 1510	139 58 138 31 136 46	3 75 3 50 3.25	8 50 9.75 9.00	N/A N/A 95 35	1125 1357 1510	138 51 140.32 136.46	2 13 2.75 2.25	10.00 10.00 9 75	N/A N/A 97 35	1145 1415 1525	142 14 138 50 136 46	N/A N/A N/A	7 4 8 5 7 6	N/A N/A 98 91	3901 3866 4297	
3058	89 94	90	204+25	1200	138 71	2 75	9 50	N/A	1205	139.52	2 13	7 60	N/A	1225	141 80	N/A	N/A	N/A	4734	5142 5020 5239
Average		**89.65**				**137.27**	**3.14**	**9.46**	**95.68**		**138.13**	**2.56**	**9.23**	**97.19**		**139.40**	**N/A**	**7.8**	**97.53**	**4292**	**4949**

Table A-3. Mix Times and Test Data – Carlisle, Contractor Mix.

					CENTER					SIDE					GRADE						
	TRUCK #	AvgActual Mix Time (sec)	TARGET MIX TIME (sec)	Test Station	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUMP (IN)	AIR CONT (%)	WASH (%)	CYLINSDER Fc (psi)	CORE Fc (psi)
	45 SECOND CARILSLE DATA (CONTRATOR MIX)																				
	3020	50 02	45	140+50	1015	136 46	2.38	7 00	97.77	1015	136.46	1 88	9.00	100.86	1100	136 46	N/A	6 40	102 71	4419	5259
																					5231
				142+75	1212	136.46	3 00	9.50	94 59	1215	136.46	2.50	10.00	99.22	1225	136.46	N/A	8 50	99.94	3720	5202
	3021	49 20	45	139+50	955	136 46	4 00	9.50	95 75	955	136.46	3.00	10.00	97 78	1010	136 46	N/A	8 50	99 80	3916	
				141+50	N/A	136 46	2.00	9 50	N/A	1120	136 46	2.25	8.00	100 81	1128	136 46	N/A	7 20	101 25	4091	
	3058	49 92	45	142+20	1145	136 46	2 25	8.75	96.92	1145	136.46	2 13	10 00	99.51	1200	136 46	N/A	7.20	101.69	4538	
Average		49.71				136.46	2.73	8.85	96.18		136.46	2.35	9.40	99.64		136.46	N/A	7.56	101.08	4137	5231
	60 SECOND CARLISLE DATA (CONTRACTOR MIX)																				
	3016	62 88	60	147+55	1500	136 46	N/A	N/A	97.91	1500	136.46	N/A	N/A	100 81	1522	136 46	N/A	N/A	103 72		
	3020	64 40	60	146+55	1423	136 46	N/A	N/A	98 35	1427	136.46	N/A	N/A	98 35	1445	136 46	N/A	N/A	104 45		
				148+00	1543	136 46	N/A	N/A	98 64	1540	136.46	N/A	N/A	100 66	1600	136 46	N/A	N/A	103 58		5874
																					6011
				149+25	740	140 52	2.75	8 75	94 75	740	140 52	3.50	8.00	96.06	805	140 52	N/A	6 00	100 59	4945	6043
	3021	61 65	60	145+25	1350	136 46	1 38	5.30	100 09	1350	136.46	1.50	6.40	103.12	1407	136 46	N/A	4 80	104 74	6522	
Average		62.98				137.27	2.07	7.03	97.95		137.27	2.50	7.20	99.80		137.27	N/A	5.40	103.42	5734	5976
	90 SECOND CARLISLE DATA (CONTRACTOR MIX)																				
	3016	90 80	90	152+00	945	140.52	4 25	7 80	97.54	940	140 52	3.13	8.50	98.87	950	140.52	N/A	5 80	100 03	5527	
	3058	91 03	90	150+30	820	140.52	3.75	8.50	95 86	820	140.52	2 13	7.20	97.27	845	140.52	N/A	5.00	100 73	5595	
				151+50	906	140 52	4 00	7 20	94 52	910	140 52	1.38	8 50	96 91	917	140 52	N/A	6 00	100 17	6067	5970
																					5917
																					5852
				153+75	1025	140 52	2.50	7 20	97 26	1023	140 52	2.88	8.25	96.65	1030	140 52	N/A	5 90	99 75	5610	5395
																					5630
																					5612
				154+40	1050	140 52	3 13	7 40	95.59	1050	140 52	2.38	8.50	99 43	1055	140 52	N/A	5 40	100 59	6066	
Average		90.92				140.52	3.53	7.62	96.15		140.52	2.38	8.19	97.83		140.52	N/A	5.62	100.25	5773	5729

Table A-4. Hardened Air Content (Whole Core Basis) – Carroll Iowa DOT Mix

STATION	LOCATION	CORE DESIGNATION	% AIR		% AIR		AVG.	
			TOP	STD Dev.	BOTTOM	STD Dev.	% air	COMMENTS
81+50	N. EDGE	A	6.35	0.74	7.10	0.91	6.72	C4-45 sec.
81+50	N. EDGE	B	6.64	0.92	9.42	0.54	8.03	C4-45 sec.
81+50	N. EDGE	C	6.53	0.63	6.48	0.78	6.51	C4-45 sec.
81+50	S. EDGE	A	4.40	0.45	6.92	0.58	5.66	C4-45 sec.
81+50	S. EDGE	B	4.78	0.48	5.80	0.61	5.29	C4-45 sec.
81+50	S. EDGE	C	4.24	0.40	4.90	0.74	4.57	C4-45 sec.
83+50	S. EDGE	A	10.46	0.63	12.82	0.81	11.64	C4-45 sec.
83+50	S. EDGE	B	13.61	0.59	13.13	0.67	13.37	C4-45 sec.
83+50	S. EDGE	C	12.99	1.10	12.83	0.99	12.76	C4-45 sec.
84+50	N. EDGE	C	8.94	0.52	11.29	0.73	10.11	C4-30 sec.
84+80	N. EDGE	A	11.42	0.78	12.04	0.56	11.73	C4-30 sec.
84+80	N. EDGE	B	10.09	0.59	12.62	1.00	11.35	C4-30 sec.
86+50	S. EDGE	A	12.23	0.76	11.85	0.90	12.04	C4-30 sec.
86+50	S. EDGE	B	11.23	0.92	11.66	0.65	11.45	C4-30 sec.
86+50	S. EDGE	C	10.81	1.02	11.35	0.93	11.08	C4-30 sec.

Table A-5. Hardened Air Content (Whole Core Basis) – Carlisle Iowa DOT Mix

STATION	CORE DESIGNATION	% AIR		% AIR		AVG.	
		TOP	STD Dev.	BOTTOM	STD Dev.	% air	COMMENTS
113+85	1-A	4.20	0.43	9.00	0.62	6.60	C4-45 sec.
113+85	1-B	8.66	0.66	9.44	0.74	9.05	C4-45 sec.
113+85	1-C	7.51	0.72	9.26	0.74	8.39	C4-45 sec.
117+85	2-A	9.74	0.70	10.97	0.68	10.35	C4-45 sec.
117+85	2-B	8.15	0.59	10.93	0.49	9.54	C4-45 sec.
117+85	2-C	8.01	0.63	10.42	0.78	9.22	C4-45 sec.
129+40	3-A	6.81	0.56	9.34	0.64	8.08	C4-60 sec.
129+40	3-B	8.32	0.46	11.29	0.80	9.82	C4-60 sec.
129+40	3-C	8.96	0.51	9.54	0.55	9.25	C4-60 sec.
132+00	4-A	7.22	0.66	9.00	0.62	8.11	C4-60 sec.
132+00	4-B	9.22	0.71	9.84	0.59	9.53	C4-60 sec.
132+00	4-C	8.63	0.73	9.98	0.70	9.30	C4-60 sec.
140+50	7-A	8.84	0.61	11.59	0.60	10.21	S-90 sec.
140+50	7-B	8.26	0.49	12.47	0.57	10.37	S-90 sec.
140+50	7-C	6.25	0.45	11.36	0.79	8.81	S-90 sec.
148+00	9-A	4.71	0.43	5.81	0.39	5.26	S-60 sec.
148+00	9-B	3.01	0.48	6.09	0.56	4.55	S-60 sec.
148+00	9-C	4.19	0.49	4.92	0.73	4.55	S-60 sec.
151+50	10-A	6.23	0.56	7.78	0.53	7.01	S-60 sec.
151+50	10-B	6.89	0.50	8.69	0.58	7.79	S-45 sec.
151+50	10-C	8.18	0.51	10.69	0.82	9.44	S-45 sec.
153+75	11-A	4.10	0.46	11.28	1.01	7.69	S-45 sec.
153+75	11-B	4.67	0.50	10.16	1.13	7.42	S-45 sec.
153+75	11-C	5.28	0.65	8.05	0.62	6.67	S-45 sec.
205+25	5-A	8.55	0.60	10.59	0.92	9.67	S-45 sec.
205+25	5-B	10.40	0.67	11.86	0.86	11.13	C4-90 sec.
205+25	5-C	11.78	0.83	13.31	0.75	12.54	C4-90 sec.
209+75	6-A	7.06	0.51	9.13	0.59	8.09	C4-90 sec.
209+75	6-B	4.39	0.45	9.76	0.53	7.07	C4-90 sec.
209+75	6-C	10.35	0.57	9.86	0.70	10.11	C4-90 sec.

Figure B-1. Mix Times vs Unit Weight - Carroll Iowa Dot Mix

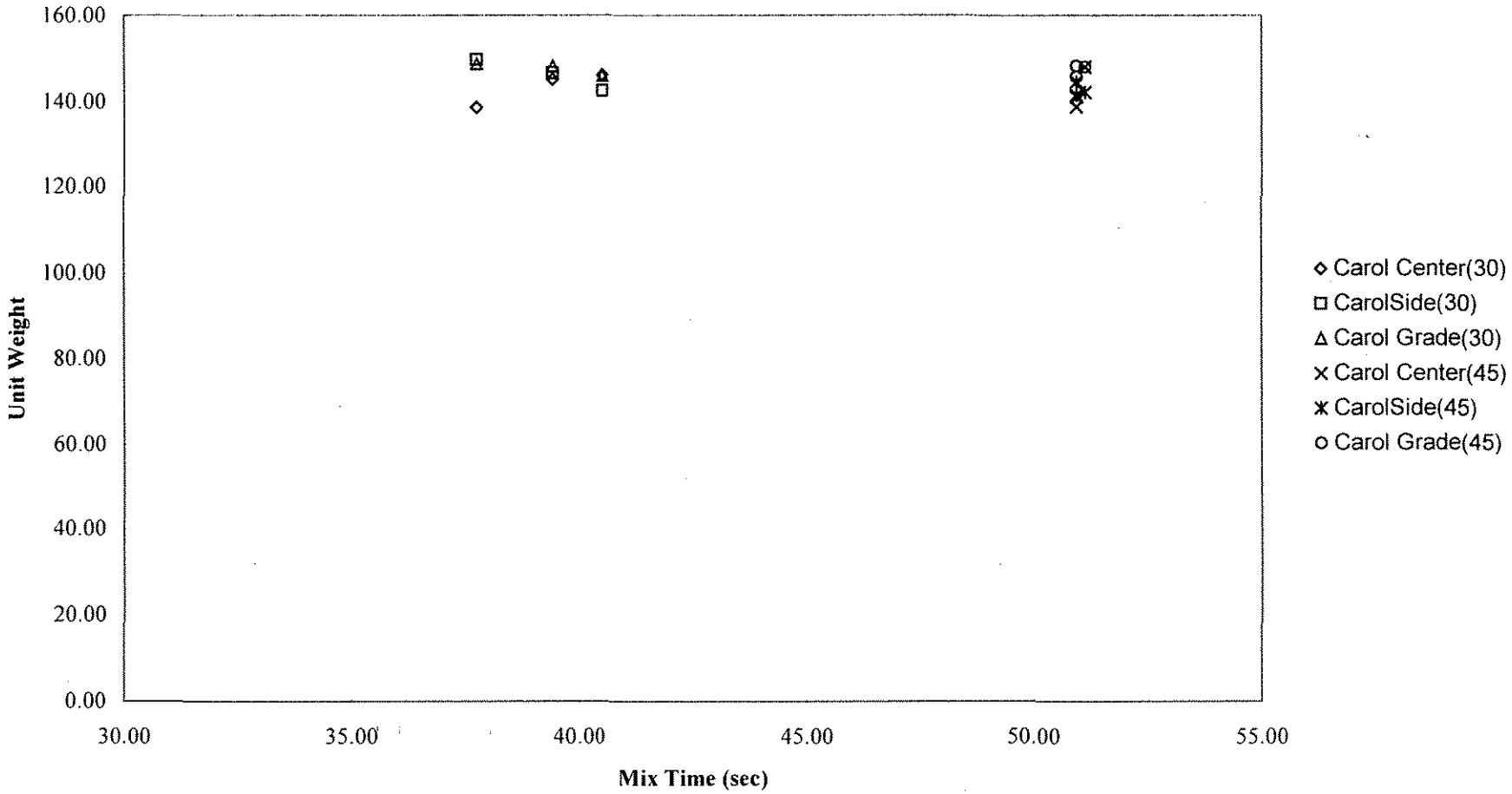

Figure B-2. Mix Time vs Slump - Carroll Iowa DOT Mix.

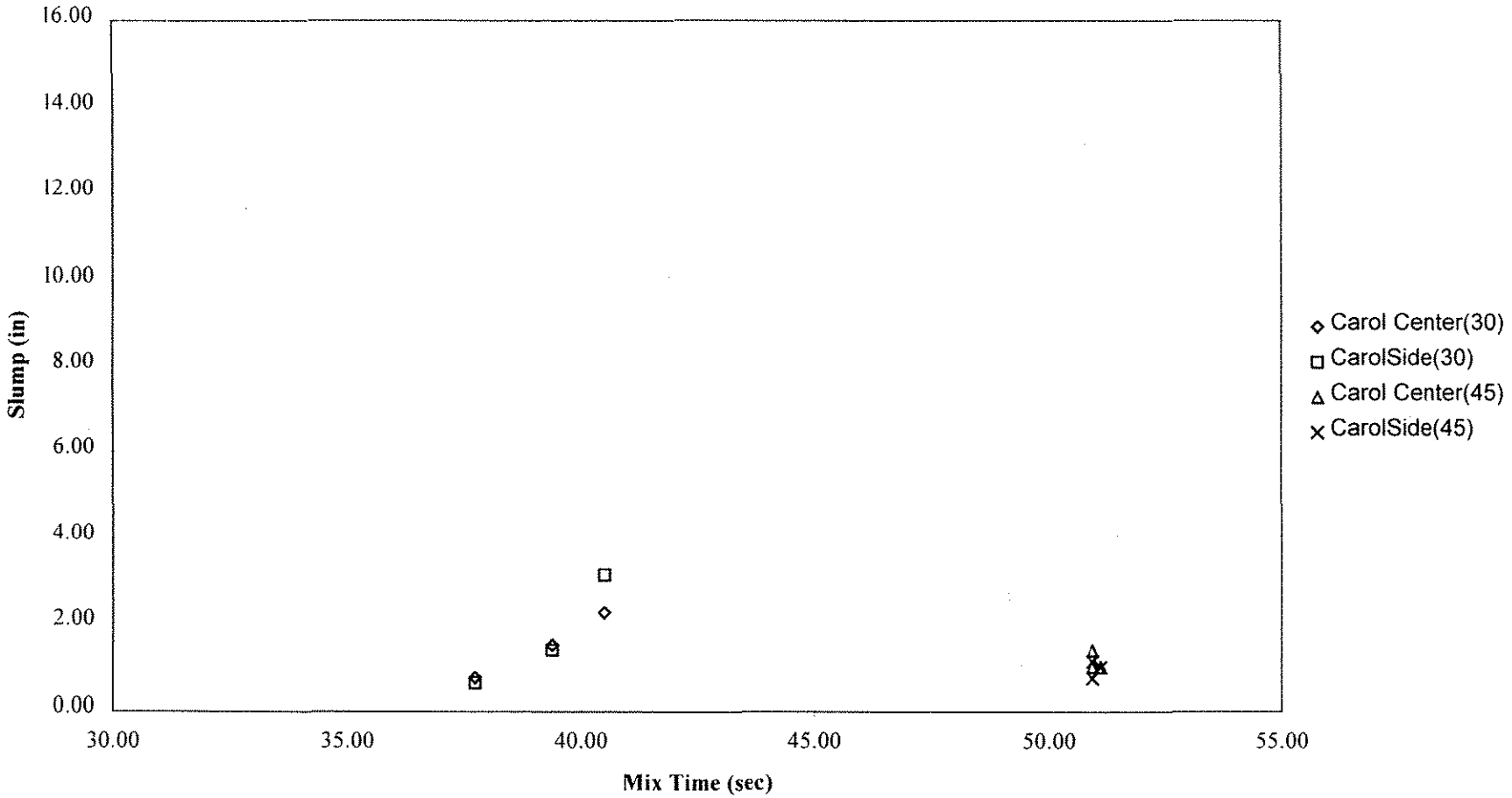

Figure B-3. Mix Time vs Air Content - Carroll Iowa DOT Mix.

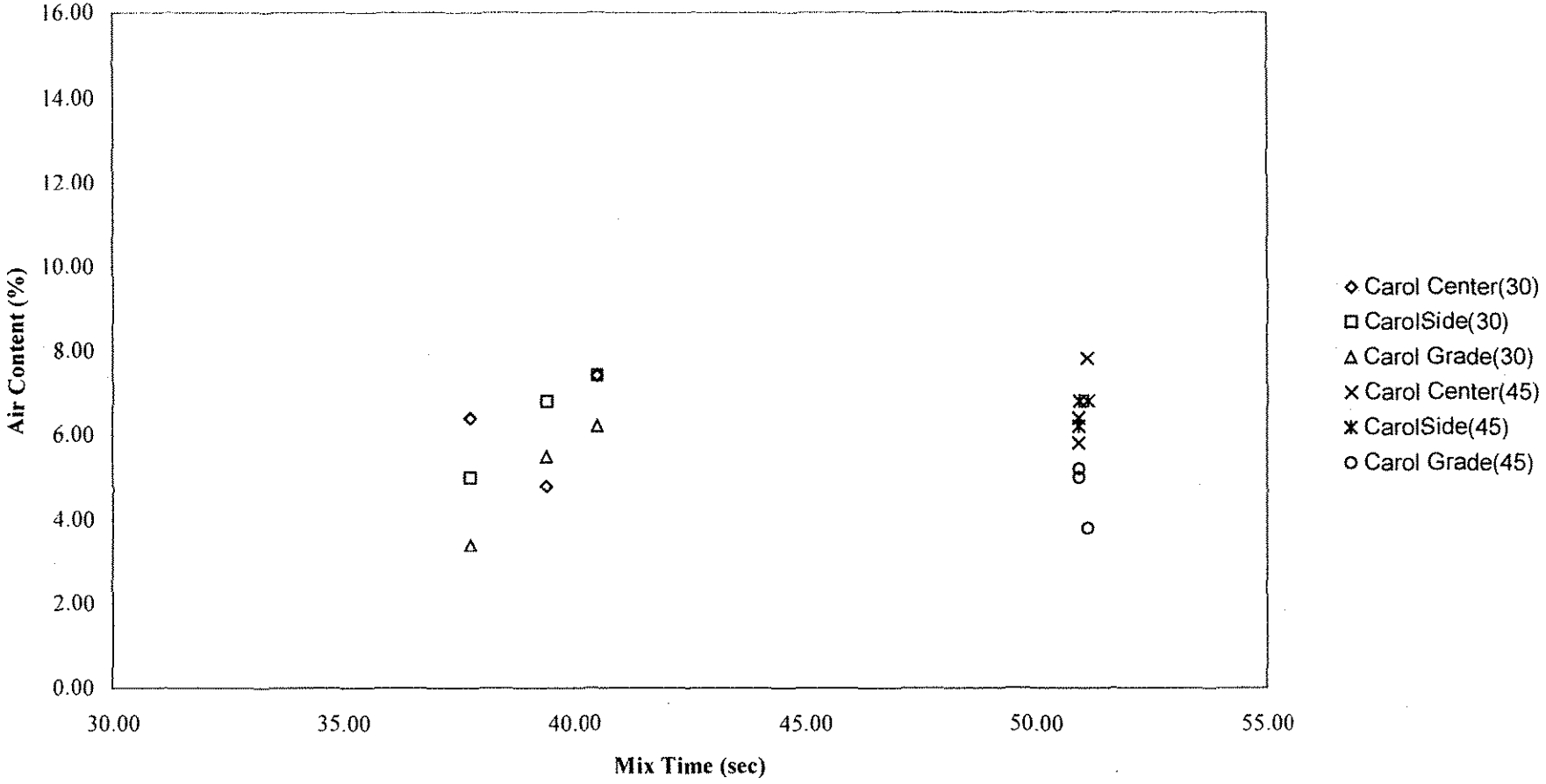

Figure B-4. Mix Time vs Wash - Carroll Iowa DOT Mix.

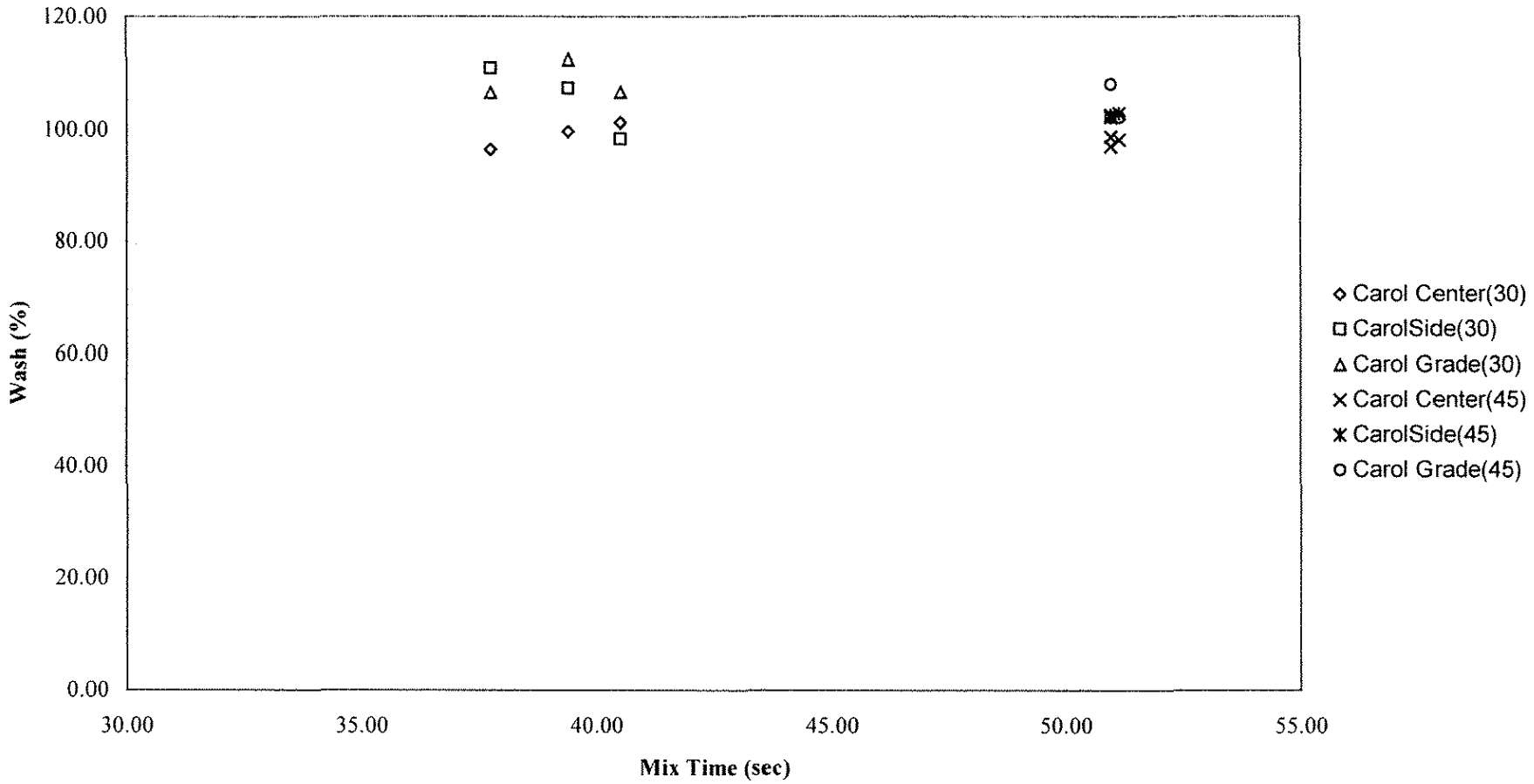

Figure B-5. Mix Times vs Unit Weight - Carlisle Iowa DOT Mix

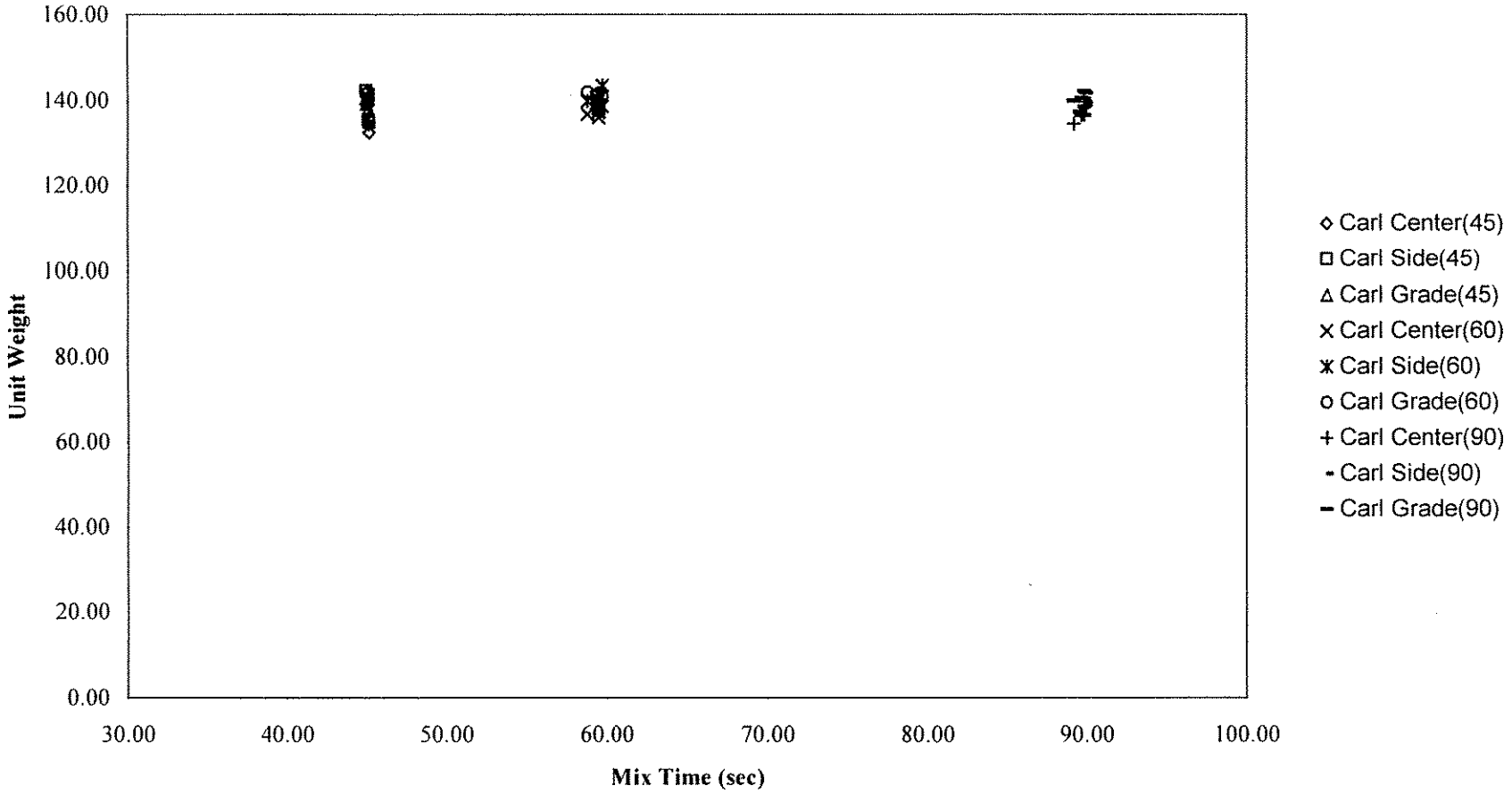

Figure B-6. Mix Time vs Slump - Carlisle Iowa DOT Mix.

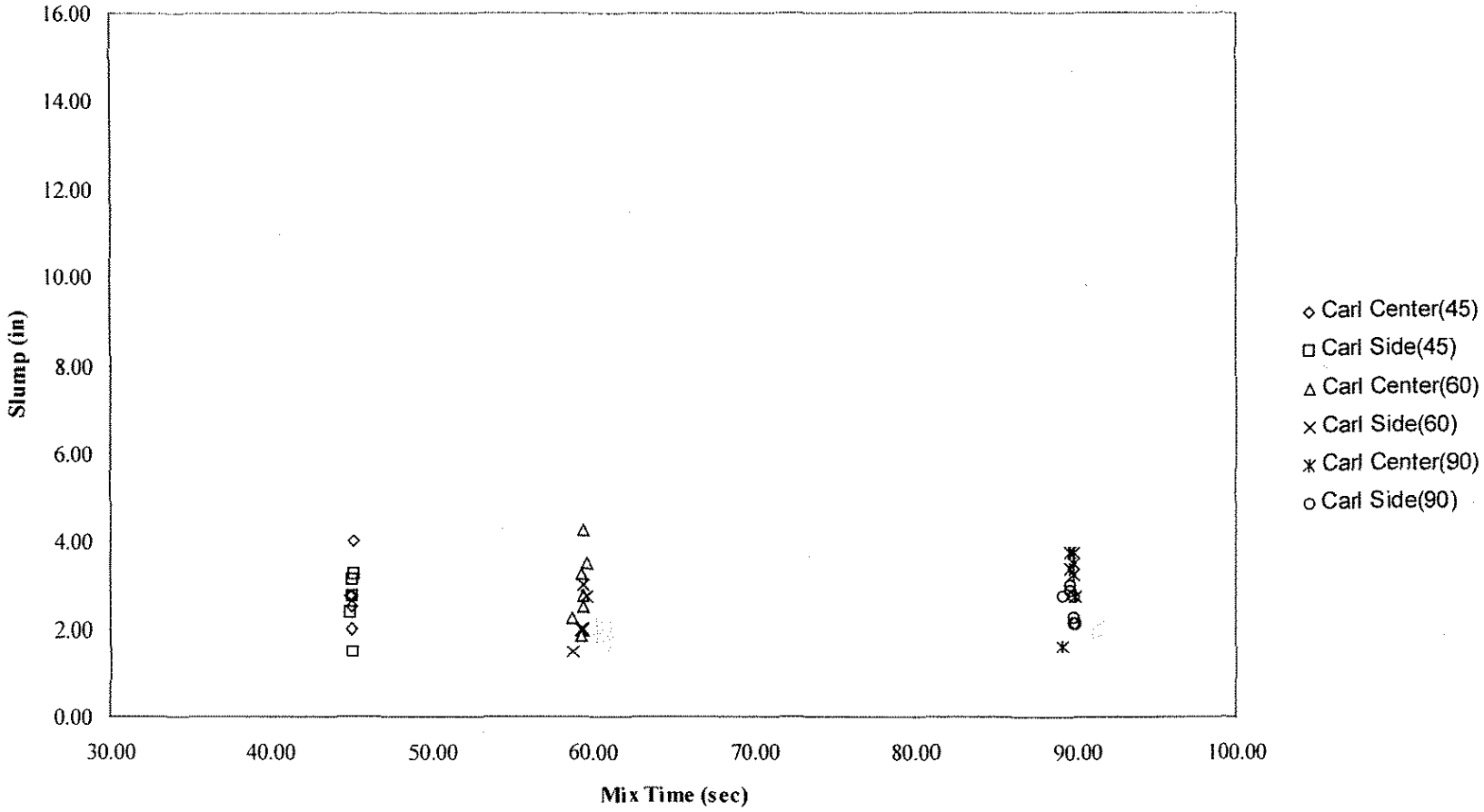

Figure B-7. Mix Time vs Air Content - Carlisle Iowa DOT Mix.

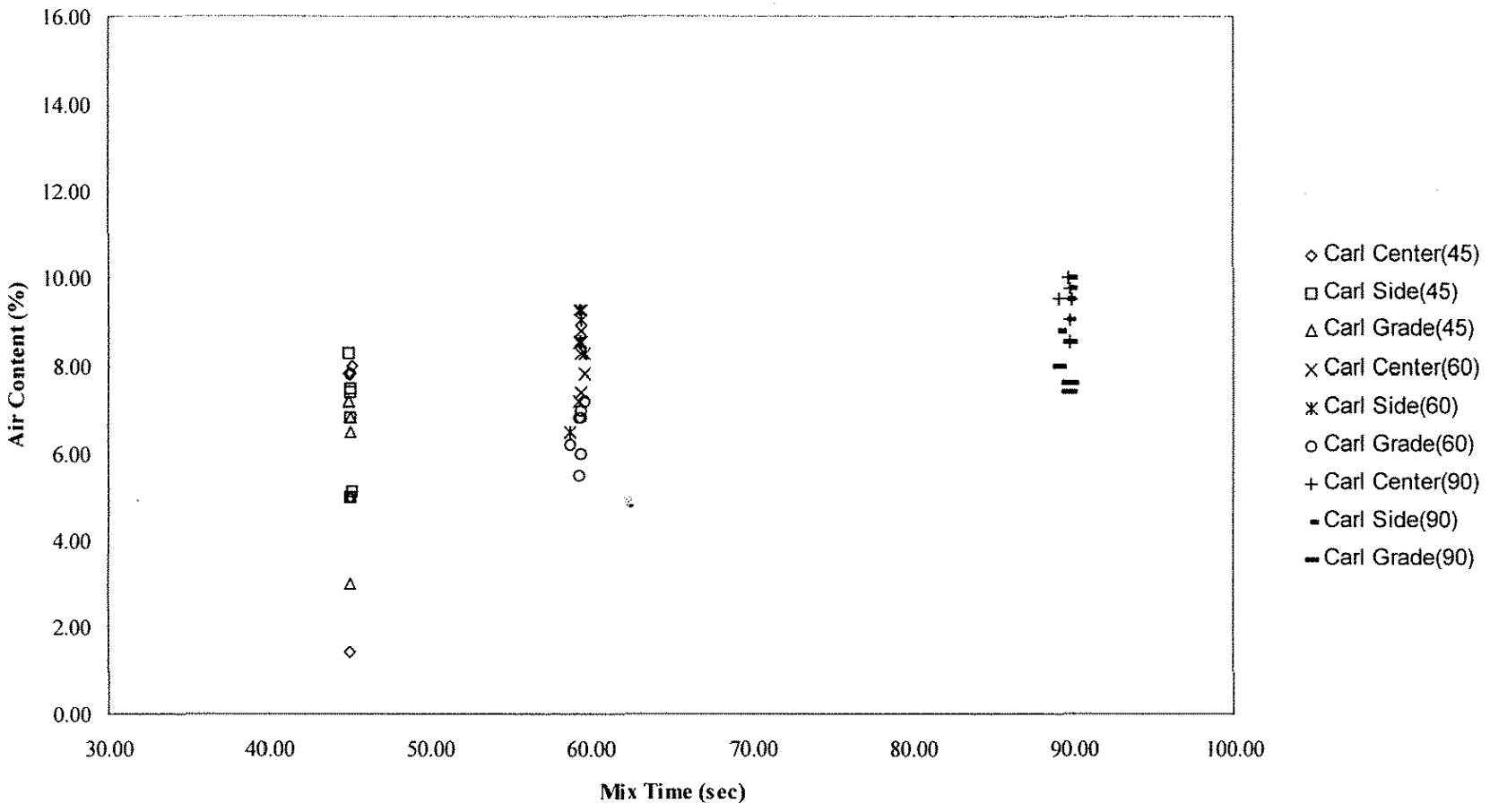

Figure B-8. Mix Time vs Wash - Carlisle Iowa DOT Mix.

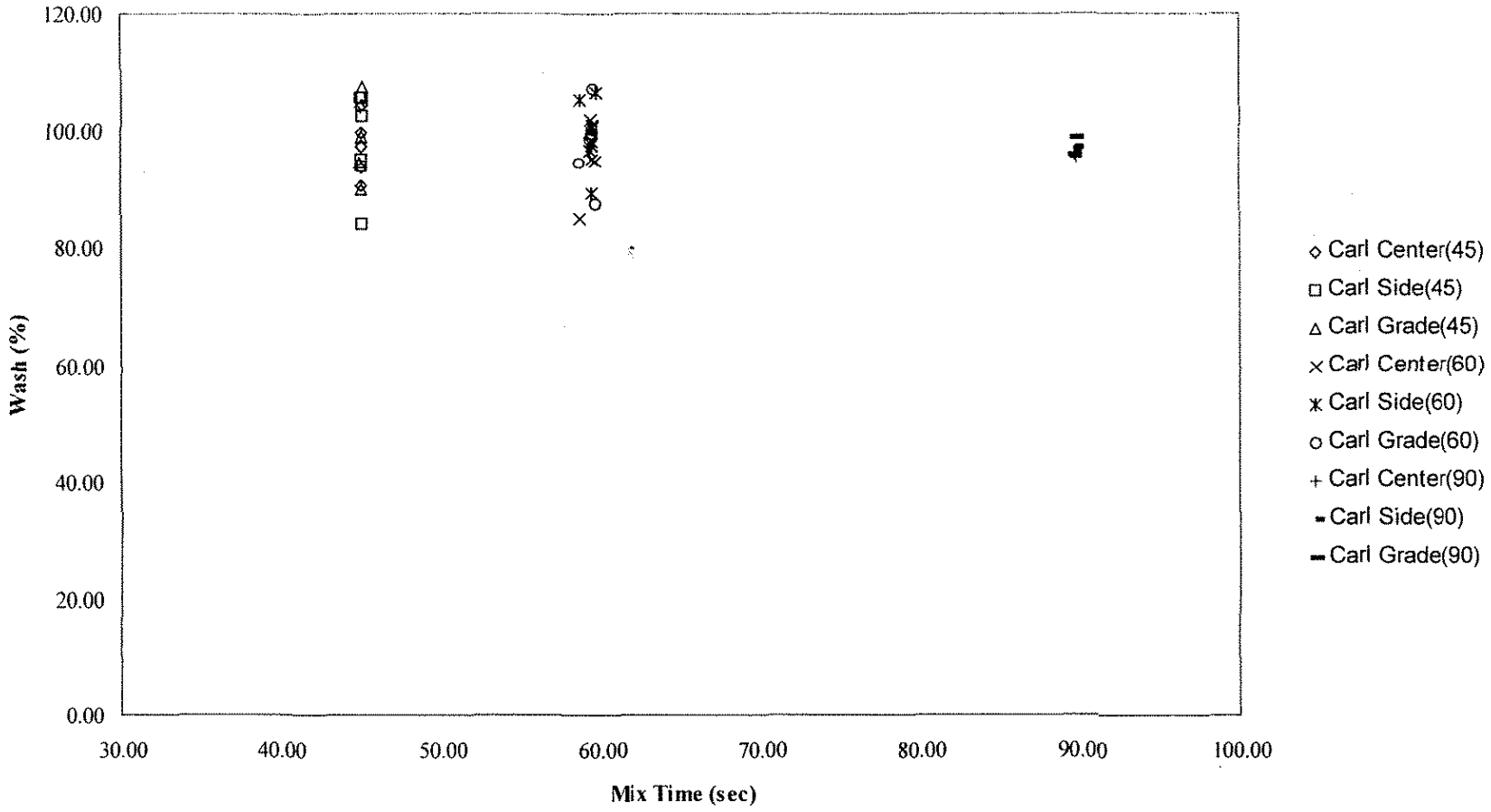

Figure B-9. Mix Times vs Unit Weight - Carlisle Contractor Mix

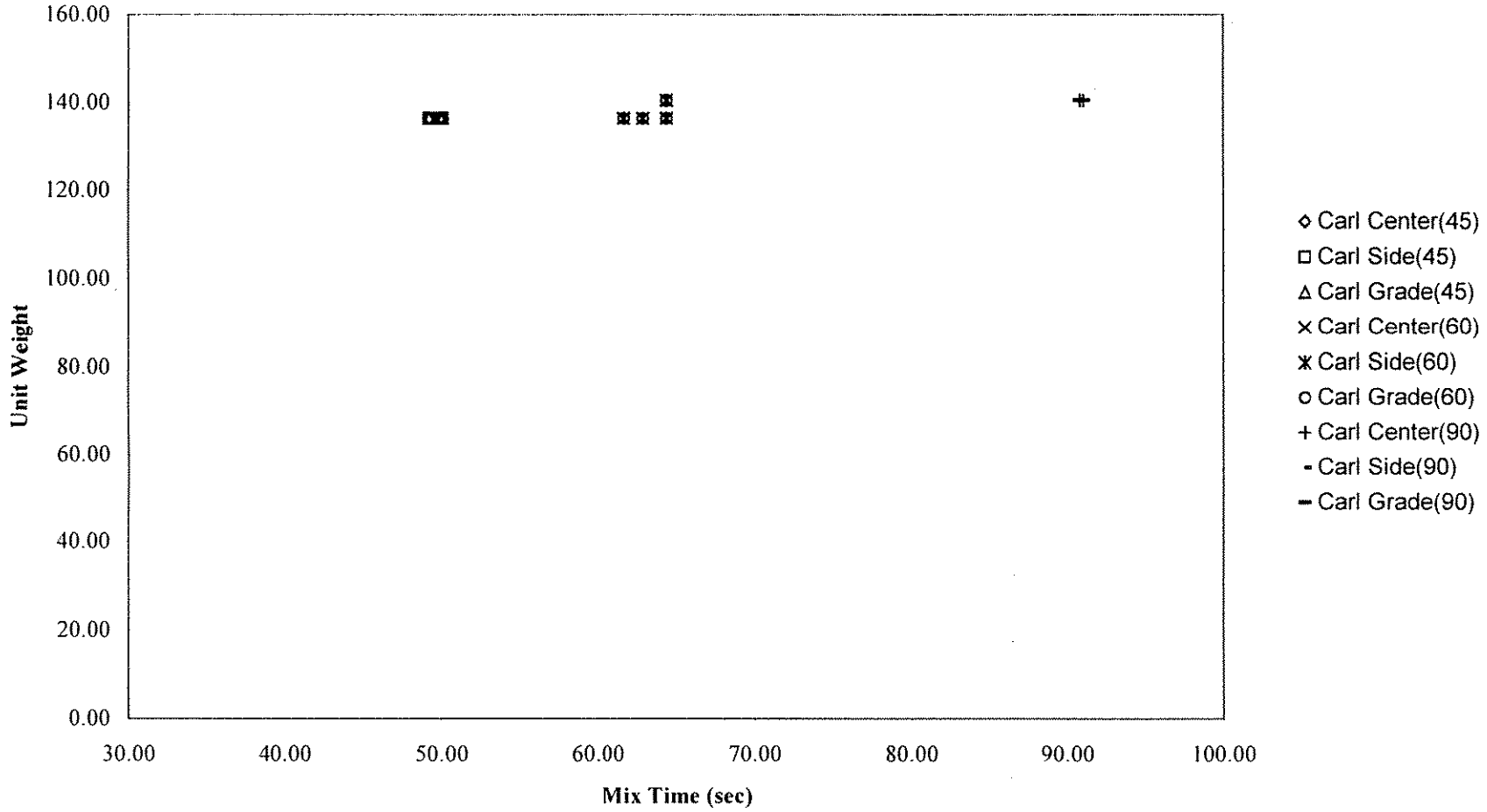

Figure B-10. Mix Times vs Slump - Carlisle Contractor Mix

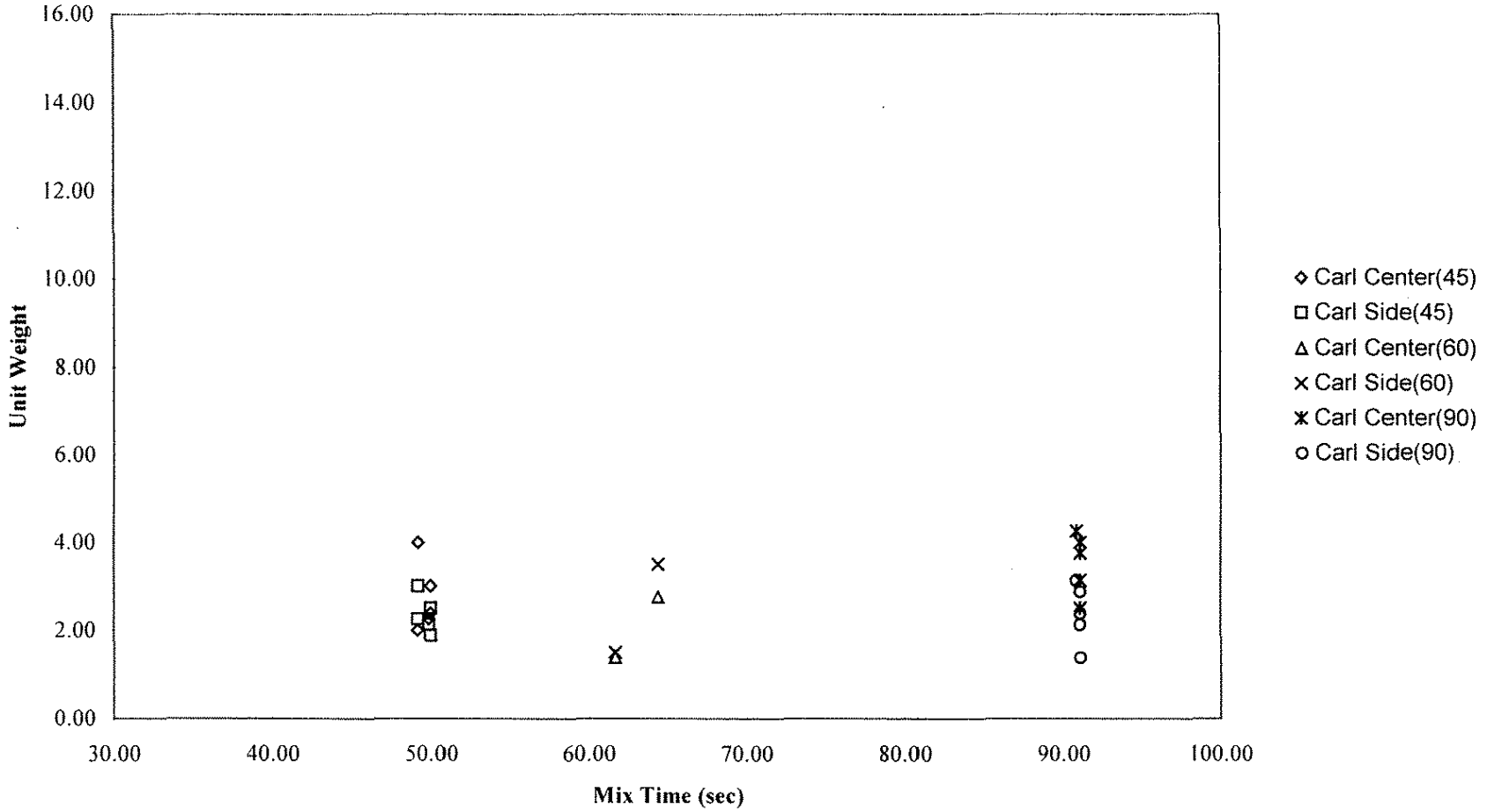

Figure B-11. Mix Time vs Air Content - Carlisle Contractor Mix.

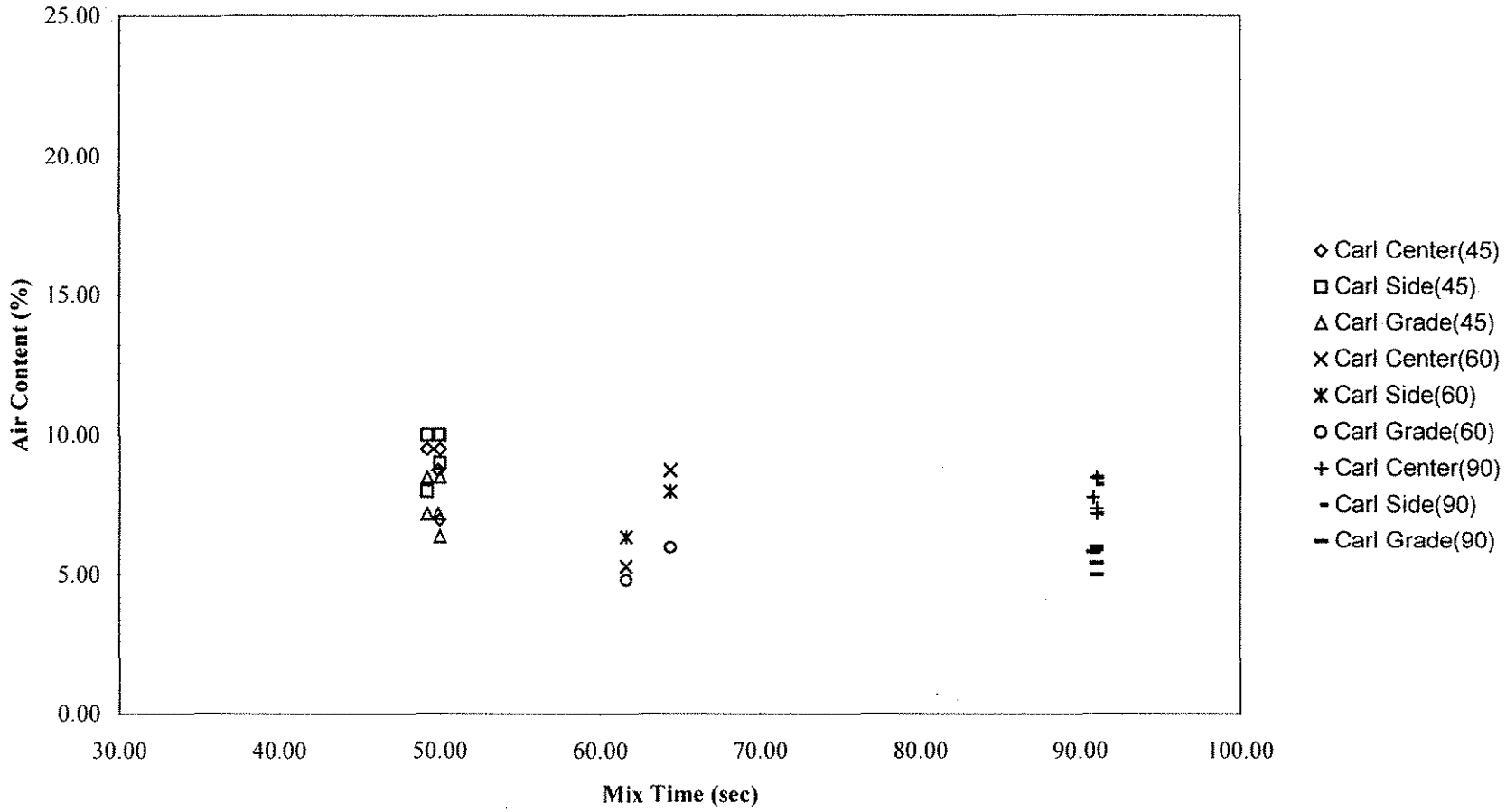

Figure B-12. Mix Time vs Wash - Carlisle Contractor Mix.

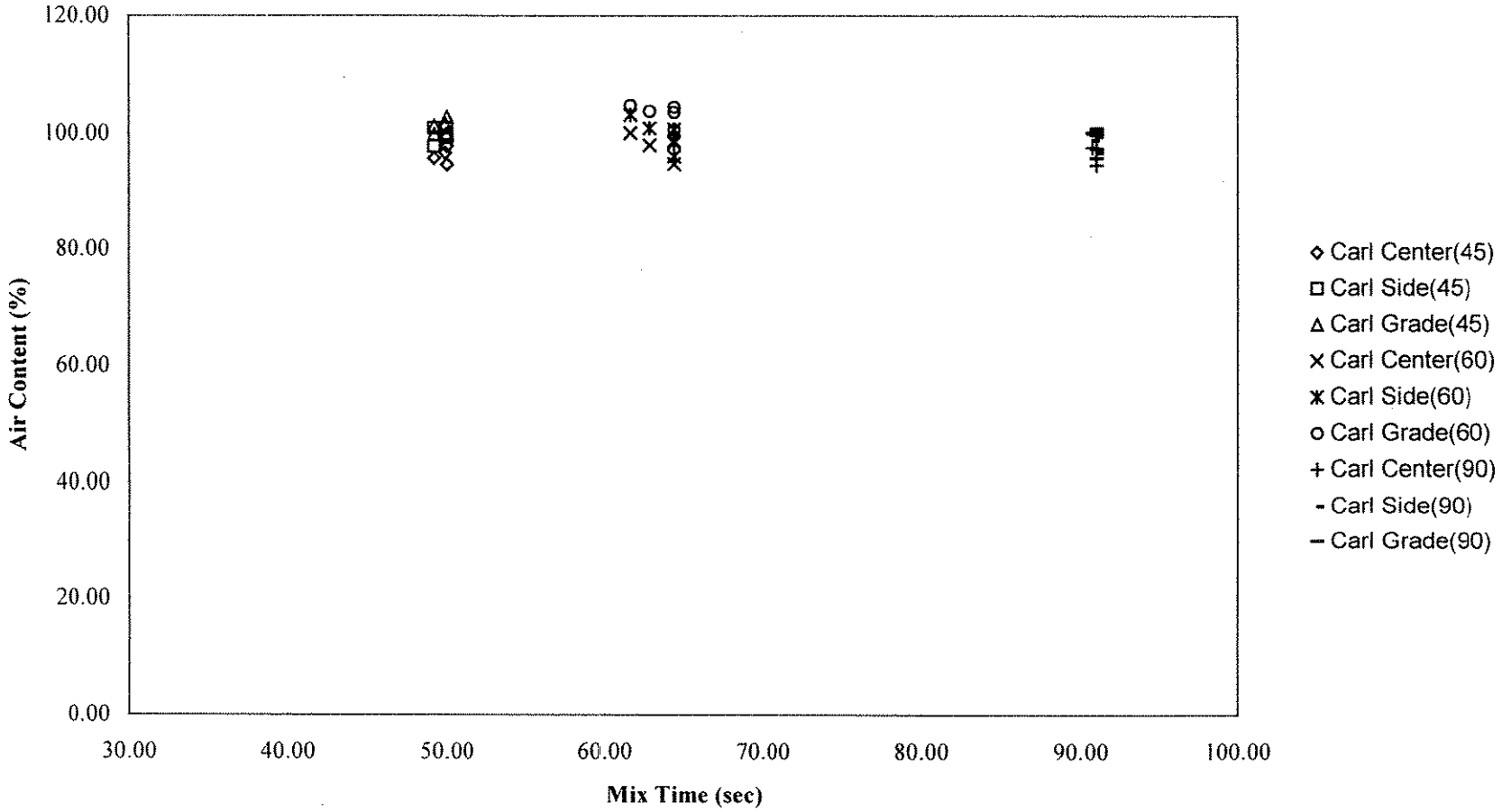

Figure C-1. Mix Time vs Concrete Cylinder Strength - Carroll Iowa DOT Mix.

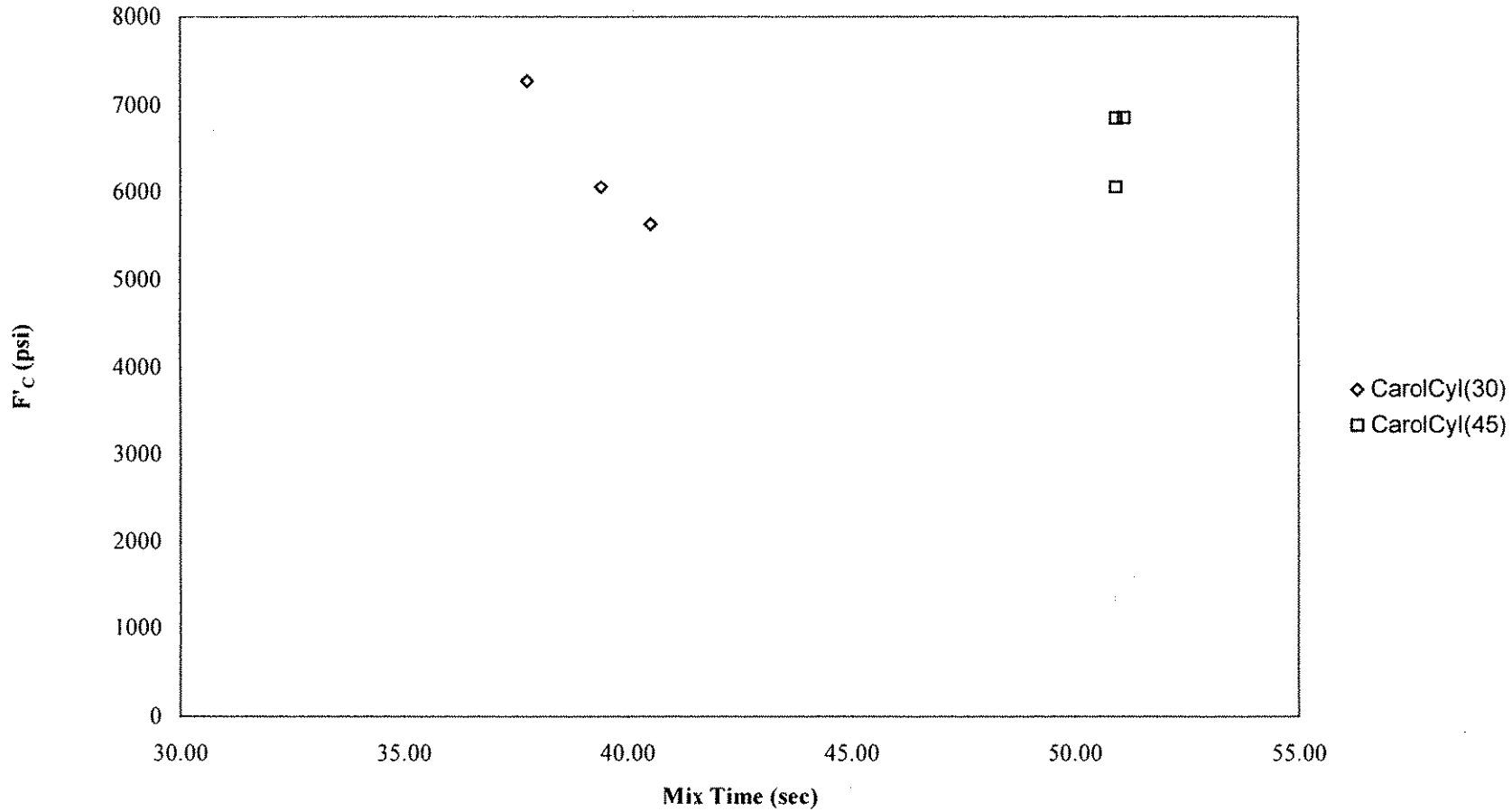

Figure C-2. Mix Time vs Concrete Core Strength - Carroll Iowa DOT Mix.

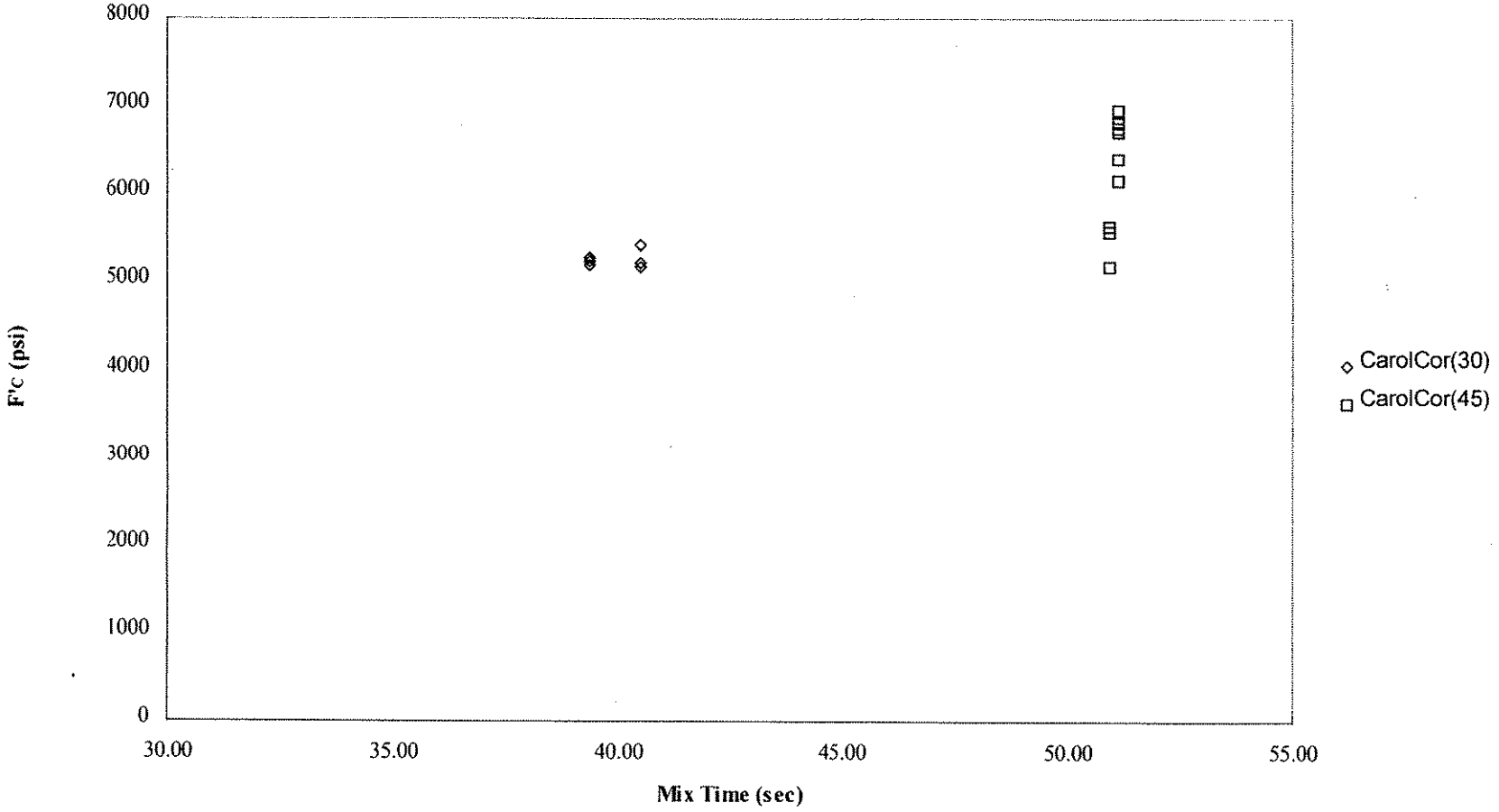

Figure C-3. Mix Time vs Concrete Cylinder Strength - Carlisle Iowa DOT Mix.

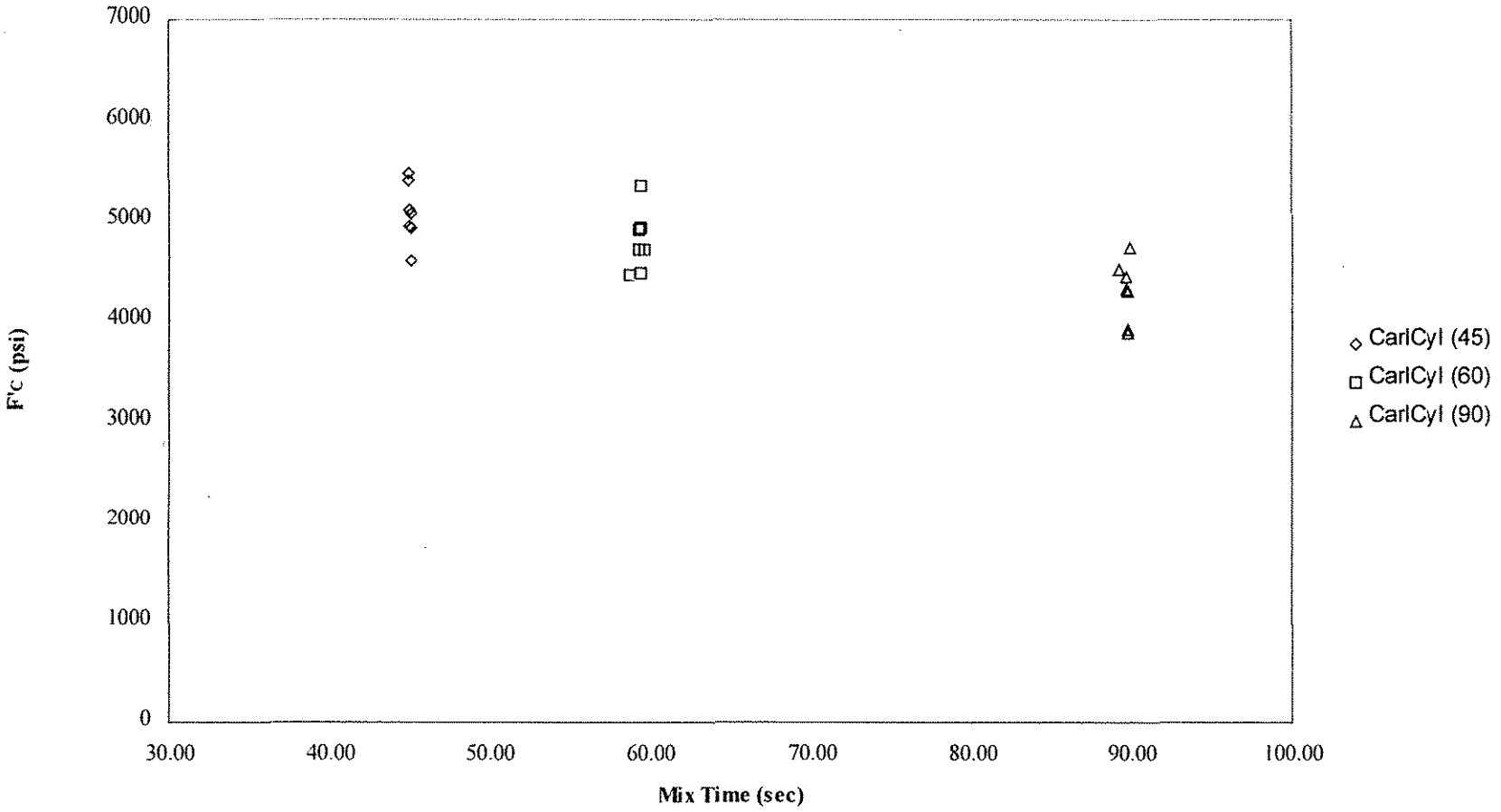

Figure C-4. Mix Time vs Concrete Core Strength - Carlisle Iowa DOT Mix.

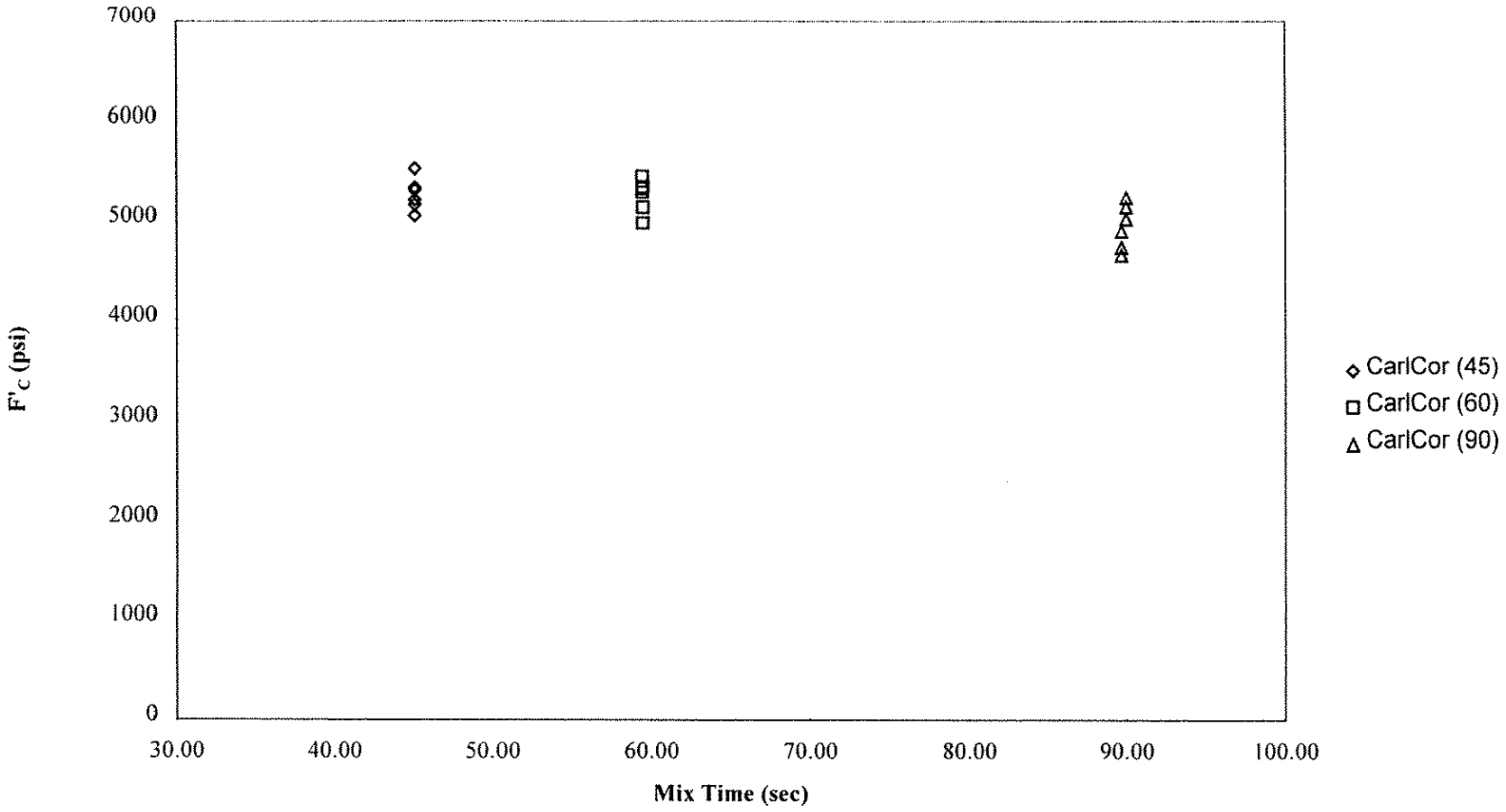

Figure C-5. Mix Time vs Concrete Cylinder Strength - Carlisle Contractor Mix.

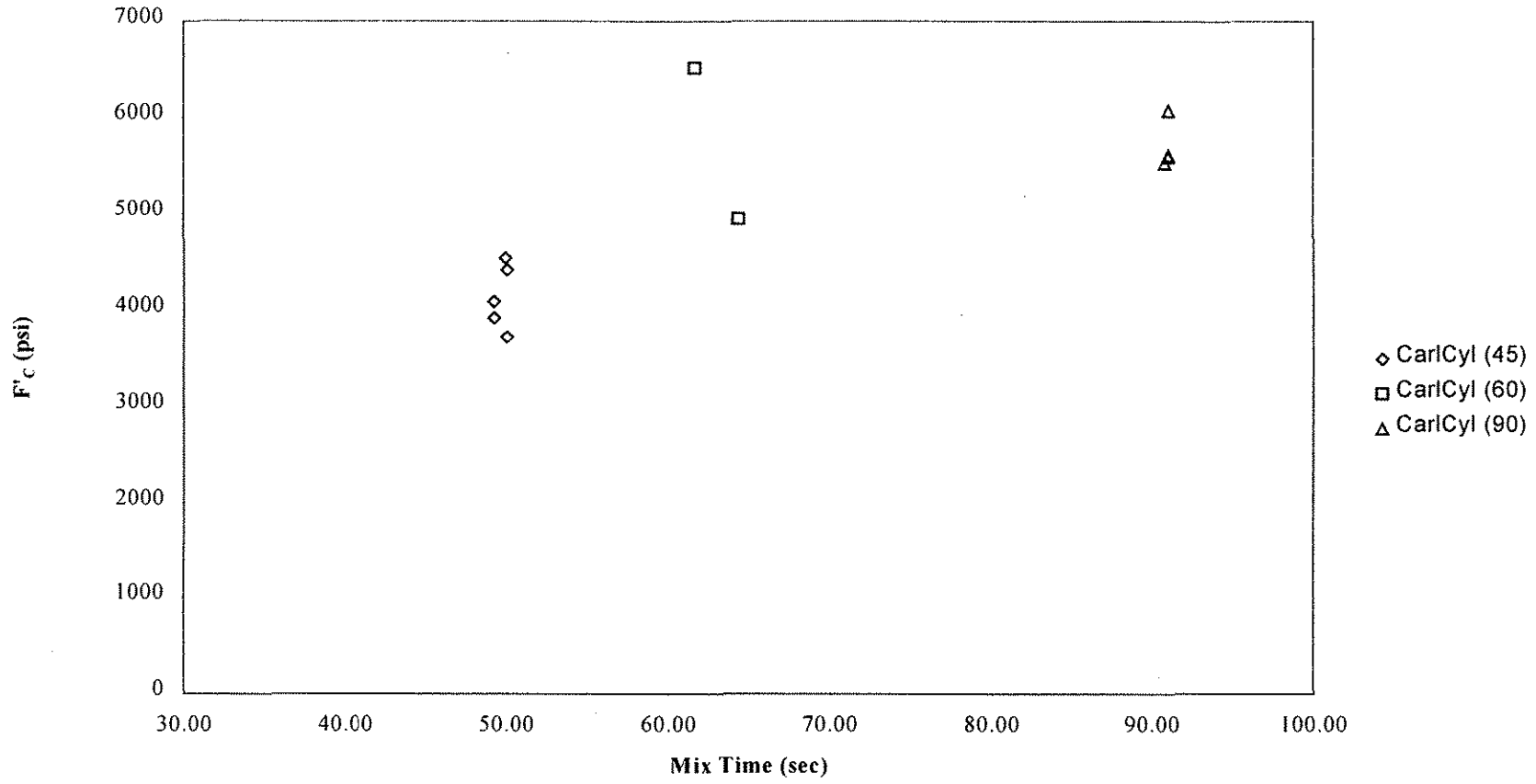

Figure C-6. Mix Time vs Concrete Core Strength - Carlisle Contractor Mix.

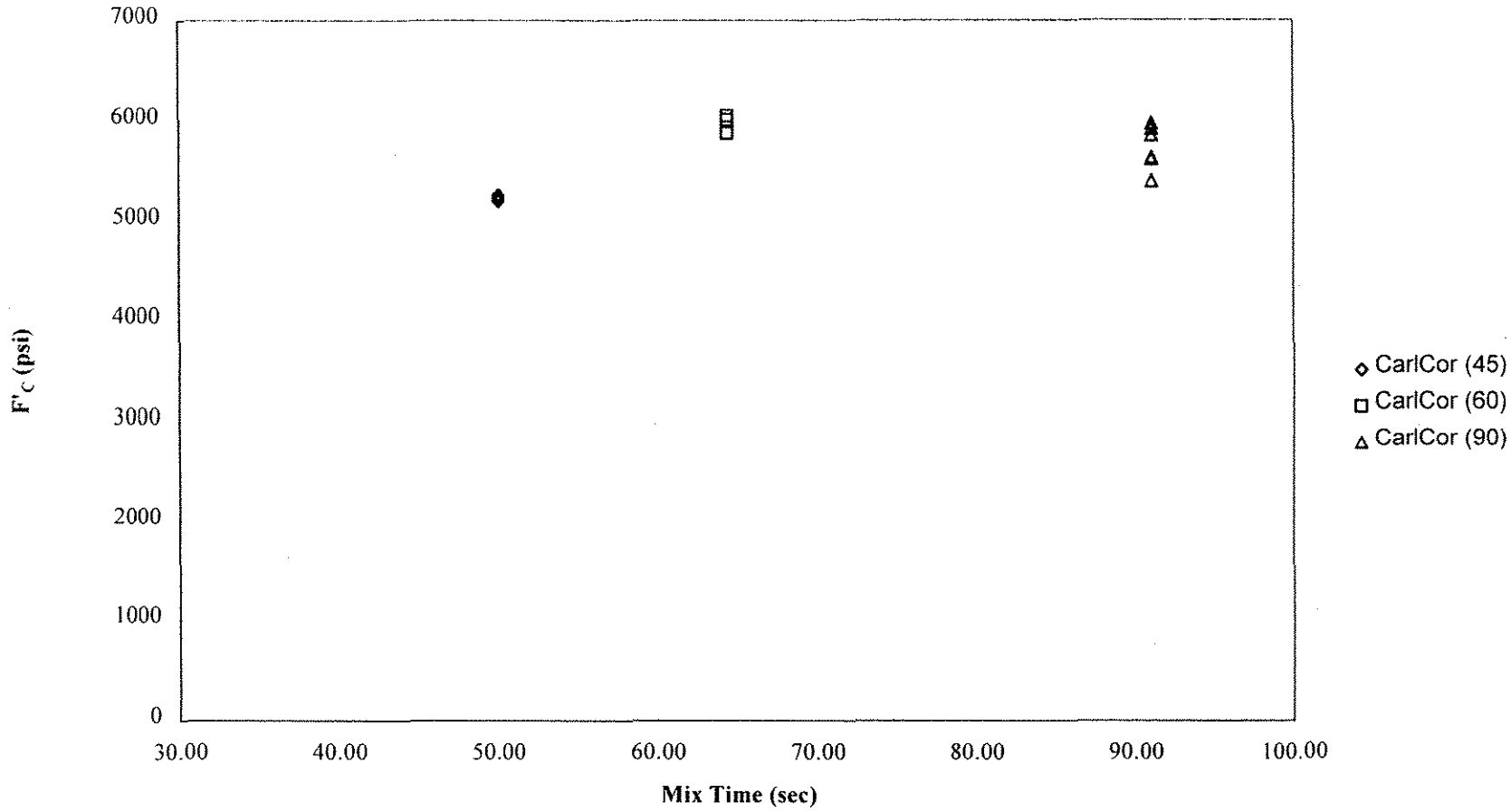

Figure D-1. Mix Times vs Average Air Content for Hardened Concrete Cores - Carroll Iowa Dot Mix

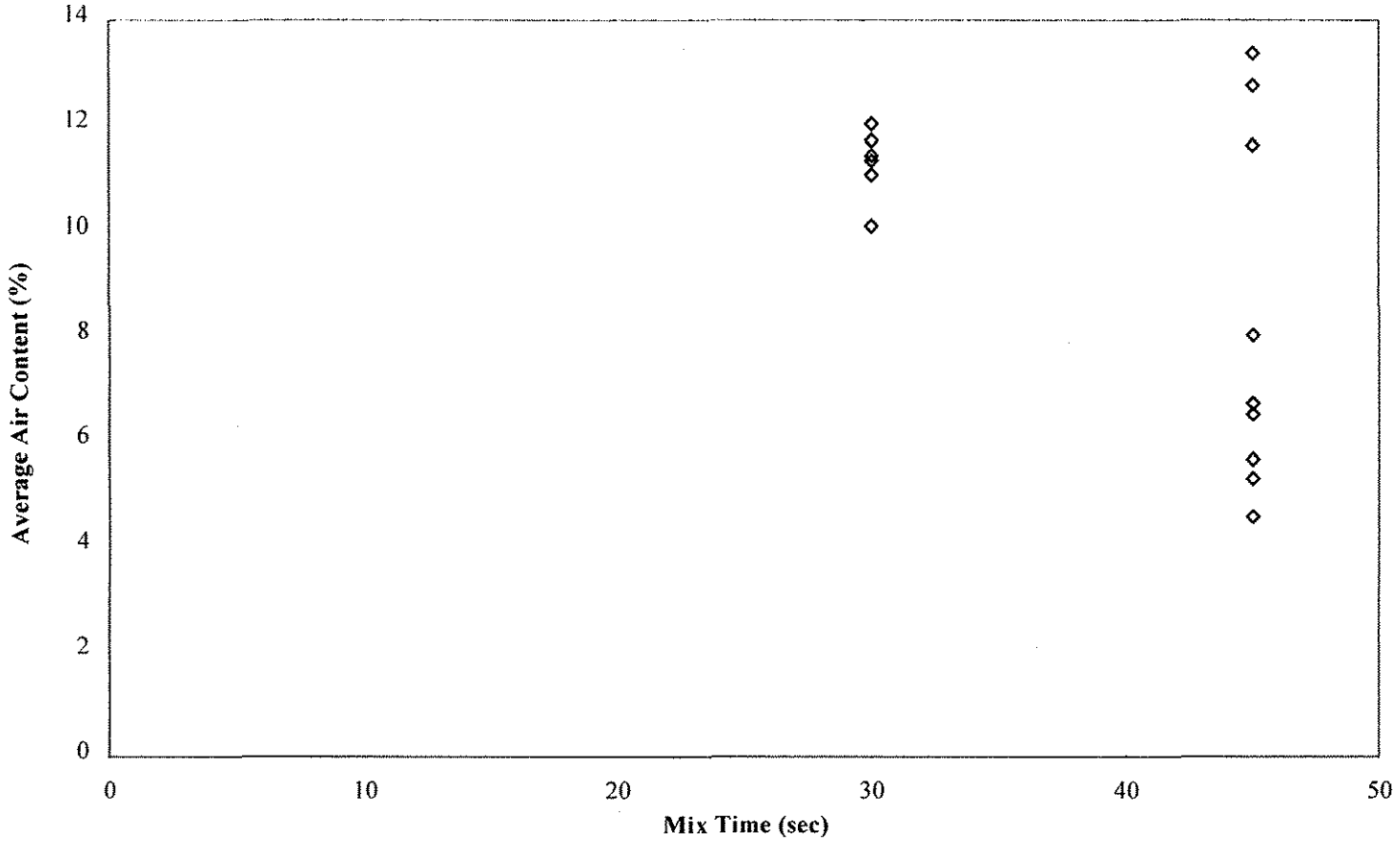

Figure D-2. Mix Times vs Average Air Content for Hardened Concrete Cores - Carlisle Iowa Dot Mix

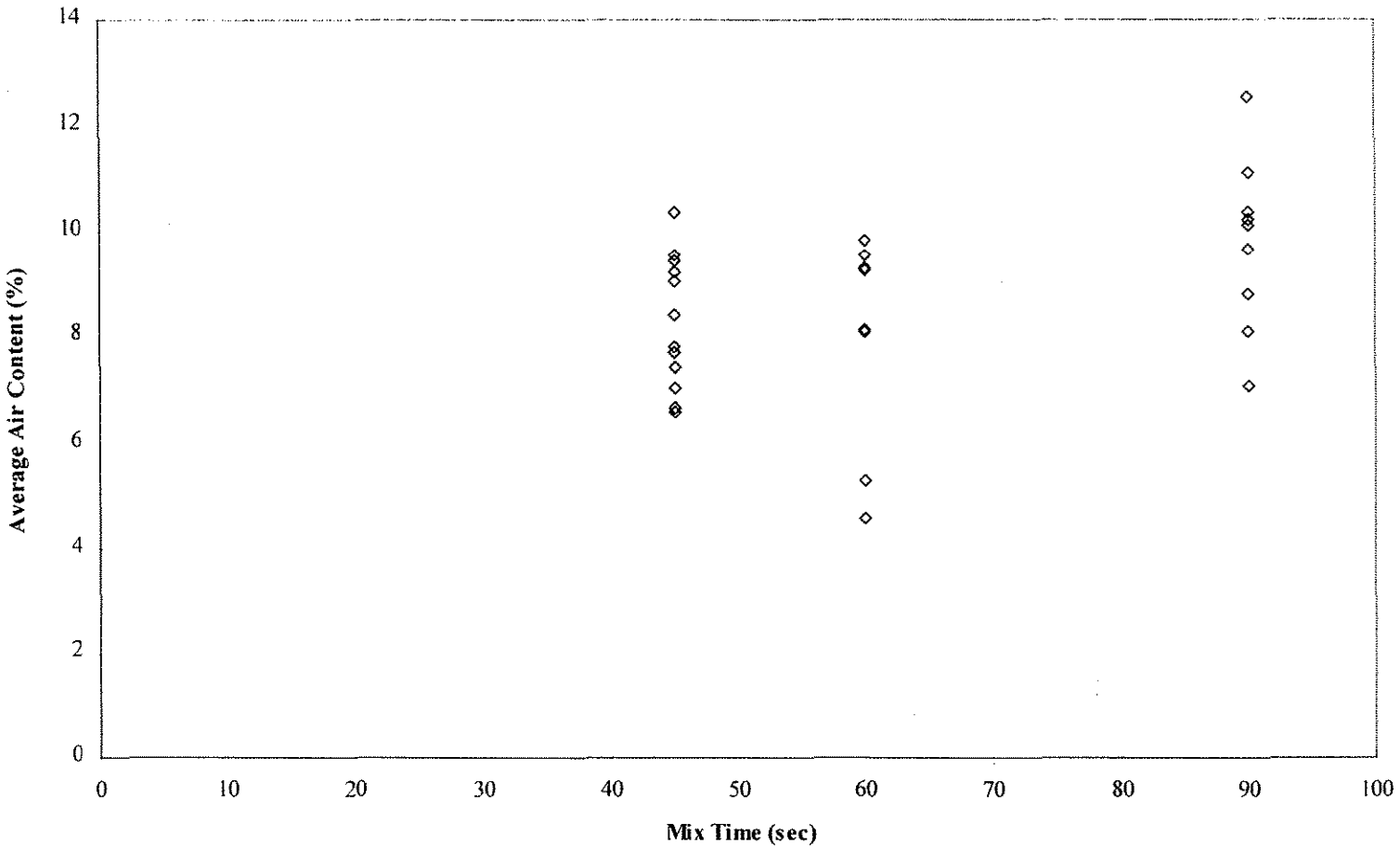

Figure D-3. Mix Time vs Average Air Content for Hardened Concrete Core - Carlisle Contractor Mix.