

---

J.K. Cable, L.L. McDaniel

# Effect of Mix Times on PCC Properties

May 1998

Sponsored by the  
Project Development Division of the  
Iowa Department of Transportation and the  
Iowa Highway Research Board  
and the Federal Highway Administration  
Demonstration Projects Program

Iowa DOT Project HR-1066  
FHWA Work Order No.: DTFH71-96-TE030-IA-42



Iowa Department  
of Transportation

**Final**

---

# ***REPORT***

---

IOWA STATE UNIVERSITY  
OF SCIENCE AND TECHNOLOGY

Department of Civil and Construction Engineering

## 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.

A special thanks also to John Hart, Chris Albrecht, Dave Hickman, Amy Heckathorn, Shanna Duggan, Mike Becker, Kristina Wooley, and Scott Elston for their work in the field testing. This was physical work for all persons involved and they performed well. The laboratory staff under the direction of Scott Schlorholz did an excellent job of analyzing the concrete cores from the test pavements. Lisa McDaniel and Applied Pavement Technologies Inc. are to be commended for their analysis of the data and development of the report materials.

## **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 determine 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 cementitious materials (specifically flyash) and air void characteristics in the pavement. Air void characteristics measured included size, shape and distribution.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	i
ABSTRACT .....	ii
LIST OF TABLES .....	iv
LIST OF FIGURES .....	v
INTRODUCTION .....	1
RESEARCH OBJECTIVES .....	2
EXPERIMENTAL DESIGN .....	6
Physical Testing Methods .....	6
SITE CHARACTERISTICS .....	8
Test Site Selection .....	8
DATA COLLECTION METHODS .....	12
RESEARCH RESULTS .....	15
Slump, PCC Unit Weight, Air Content and Retained Coarse Aggregate .....	15
Compressive Strength (cylinder) and Compressive Strength (core) Tests .....	17
Air Void Analysis of Hardened Concrete Cores .....	19
RESEARCH CONCLUSIONS .....	21
Slump, Unit Weight, Air Content, and Retained Coarse Aggregate .....	21
Compressive Strength (cylinder) and Compressive Strength (core) Tests .....	25
Air Void Analysis of Hardened Concrete Cores .....	25
Carroll, Iowa DOT Mix Design .....	25
Carlisle, Iowa DOT Mix Design .....	29

Carlisle Contractor Mix Design .....	29
Sampling Location .....	30
RECOMENDATIONS .....	31
REFERENCES .....	32

## 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

## LIST OF TABLES

Table 1. ANOVA results on 30-45 second mixing times for Carroll, Iowa DOT mix.....	23
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. ....	23
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. ....	23
Table 4. ANOVA results on test location for Carroll, Iowa DOT mix (30 and 45-second mixing time).....	24
Table 5. ANOVA results on test location for Carlisle, Iowa DOT mix (45, 60 and 90 second mixing time).....	24
Table 6. ANOVA results on test location for Carlisle contractor mix (45, 60 and 90 second mixing time).....	24
Table 7 ANOVA results on 30-45 second mixing times for Carroll, Iowa DOT mix.....	26

Table 8 ANOVA results on 45-60-90 second, 45-60 second and 45-90 second mixing times for Carlisle, Iowa DOT mix. ....	27
Table 9 ANOVA results on 45-60-90 second, 45-60 second and 45-90 second mixing times for Carlisle contractor mix. ....	27
Table 10. ANOVA results on 30-45 second mixing times for Carroll, Iowa DOT mix...	28
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. ....	28
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. ....	28
Table A-1. Mix Times and Test Data –Carroll, Iowa DOT Mix. ....	A-1
Table A-2. Mix Times and Test Data – Carlisle, Iowa DOT Mix. ....	A-2
Table A-3. Mix Times and Test Data – Carlisle, Contractor Mix. ....	A-3
Table A-4. Hardened Air Content (Whole Core Basis) – Carroll, Iowa DOT Mix.....	A-4
Table A-5. Hardened Air Content (Whole Core Basis) – Carlisle, Iowa DOT Mix.....	A-4

## LIST OF FIGURES

Figure 1. Carlisle, Iowa Highway 5 Construction Site. ....	10
Figure 2. Carroll, US Highway 30 Construction Site .....	11
Figure 3. Core Specimen.....	20
Figure 4. Image in Mortar Fraction of Concrete Core .....	20
Figure B-1. Mix Times vs Unit Weight – Carroll, Iowa DOT Mix.....	B-1
Figure B-2. Mix Times vs Slump – Carroll, Iowa DOT Mix. ....	B-2
Figure B-3. Mix Times vs Air Content – Carroll, Iowa DOT Mix.....	B-3

Figure B-4. Mix Times vs Wash – Carroll, Iowa DOT Mix.....	B-4
Figure B-5. Mix Times vs Unit Weight – Carlisle, Iowa DOT Mix.....	B-5
Figure B-6. Mix Times vs Slump – Carlisle, Iowa DOT Mix. ....	B-6
Figure B-7. Mix Times vs Air Content – Carlisle, Iowa DOT Mix.....	B-7
Figure B-8. Mix Times vs Wash – Carlisle, Iowa DOT Mix. ....	B-8
Figure B-9. Mix Times vs Unit Weight – Carlisle Contractor Mix.....	B-9
Figure B-10. Mix Times vs Slump – Carlisle Contractor Mix. ....	B-10
Figure B-11. Mix Times vs Air Content – Carlisle Contractor Mix.....	B-11
Figure B-12. Mix Times vs Wash – Carlisle Contractor Mix.....	B-12
Figure C-1. Mix Time vs Concrete Cylinder Strength – Carroll, Iowa DOT Mix. ....	C-1
Figure C-2. Mix Time vs Concrete Core Strength – Carroll, Iowa DOT Mix.....	C-2
Figure C-3. Mix Time vs Concrete Cylinder Strength – Carlisle, Iowa DOT Mix. ....	C-3
Figure C-4. Mix Time vs Concrete Core Strength – Carlisle, Iowa DOT Mix. ....	C-4
Figure C-5. Mix Time vs Concrete Cylinder Strength – Carlisle Contractor Mix. ....	C-5
Figure C-6. Mix Time vs Concrete Core Strength – Carlisle Contractor Mix. ....	C-6
Figure D-1. Mix Time vs Average Air Content for Hardened Concrete Core – Carroll, Iowa DOT Mix.....	D-1
Figure D-2. Mix Time vs Average Air Content for Hardened Concrete Core – Carlisle, Iowa DOT Mix.....	D-2
Figure D-3. Mix Time vs Average Air Content for Hardened Concrete Core – Carlisle Contractor Mix.....	D-3



## 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 than 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 CHARACTERISTICS**

### **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.



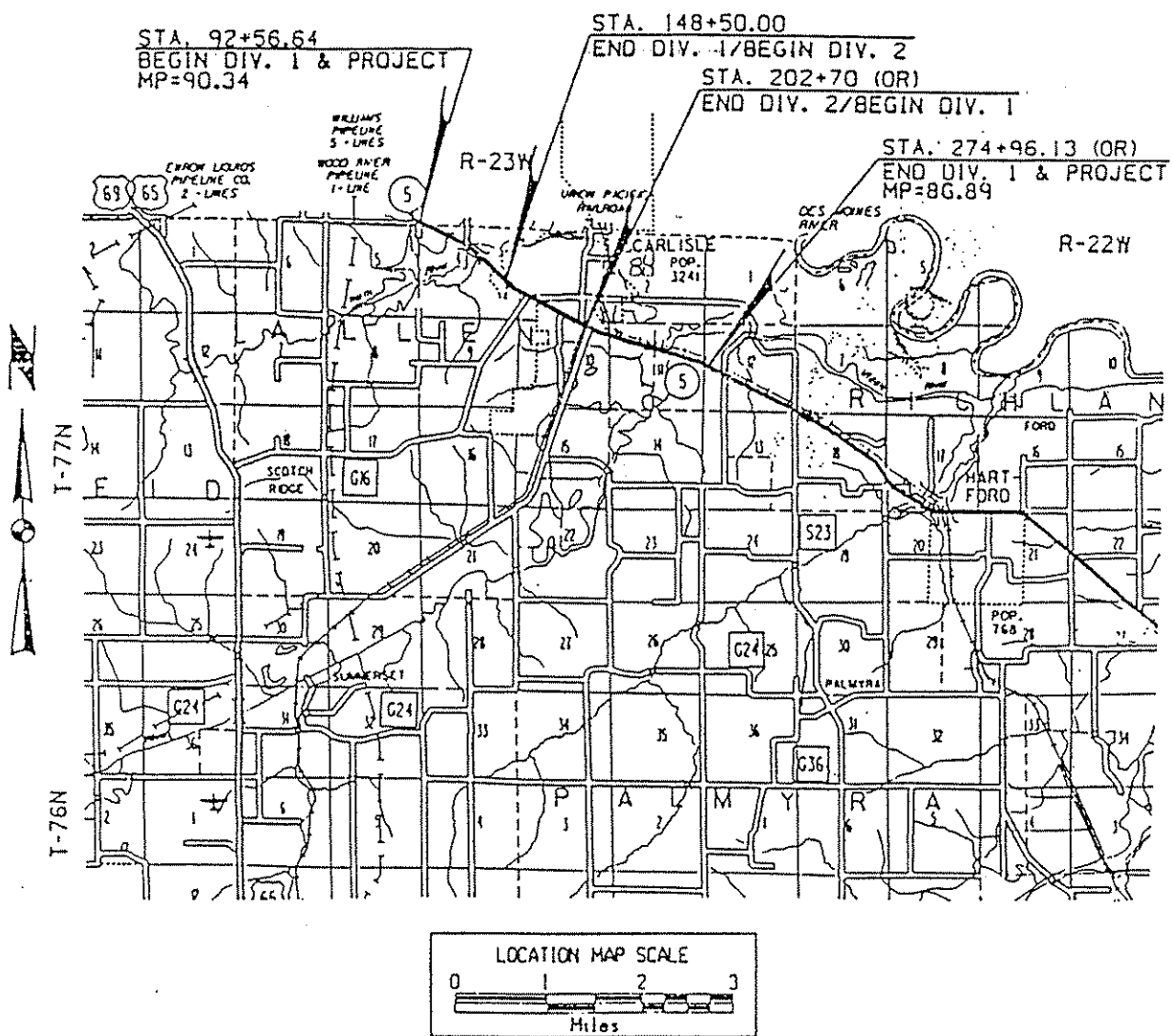


Figure 1. Carlisle, Iowa Highway 5 Construction Site.

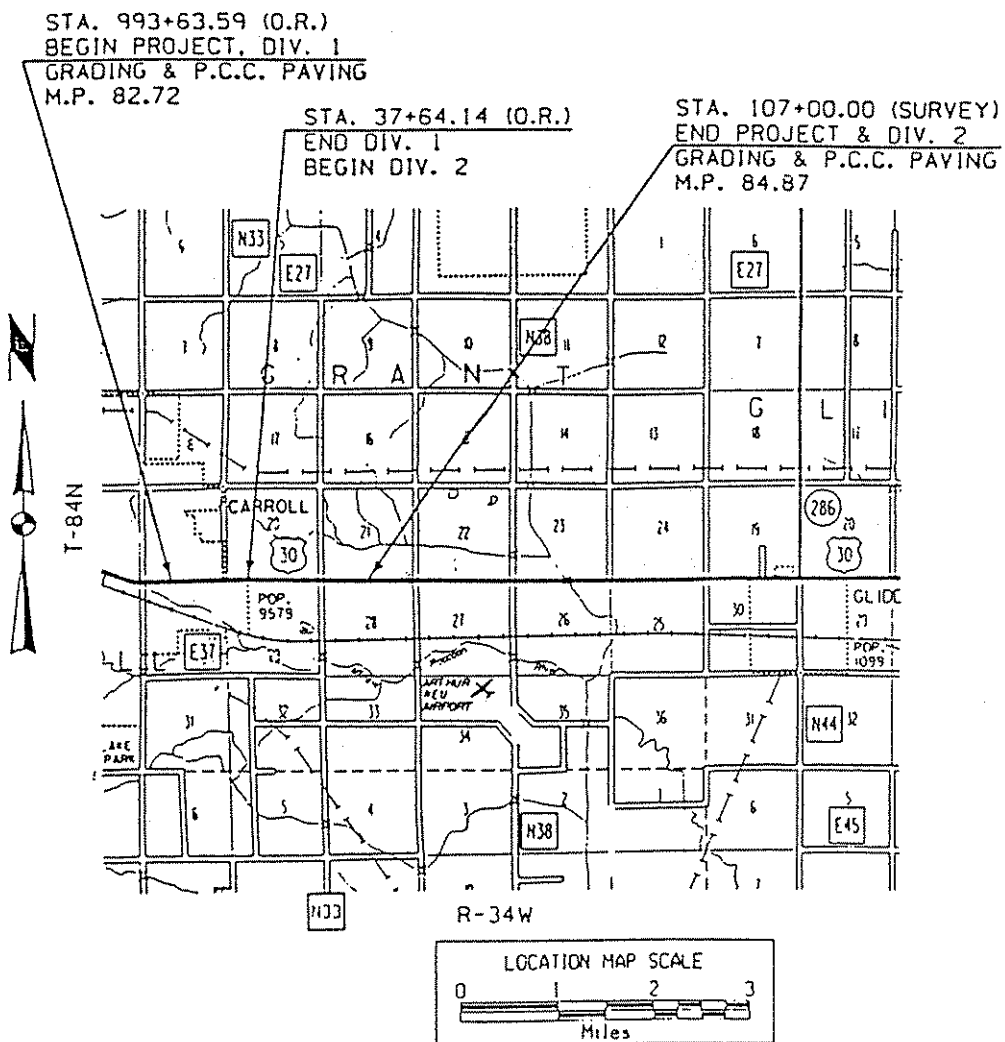


Figure 2. Carroll, US Highway 30 Construction Site.

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 <sup>TM</sup> 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  $5.80 \times 10^{-3}$  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

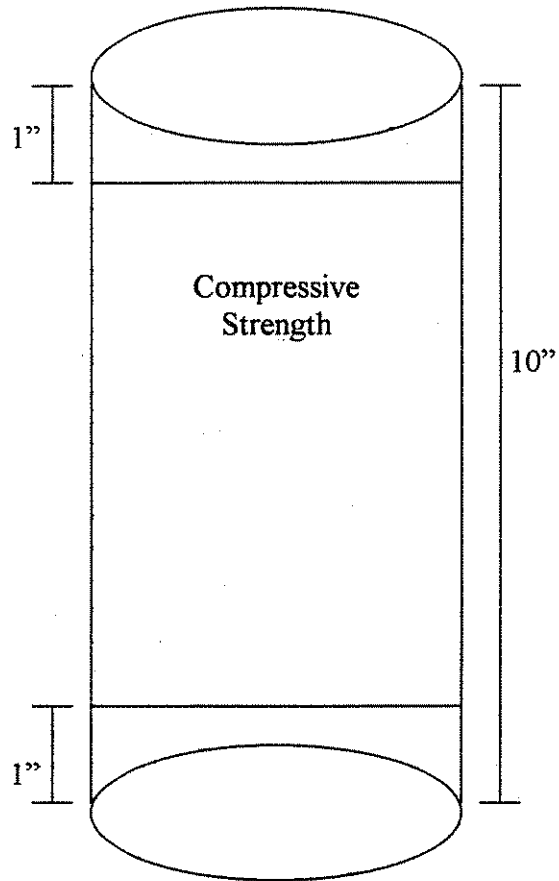
lapped and polished using a #1200 grit SiC paper.

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.

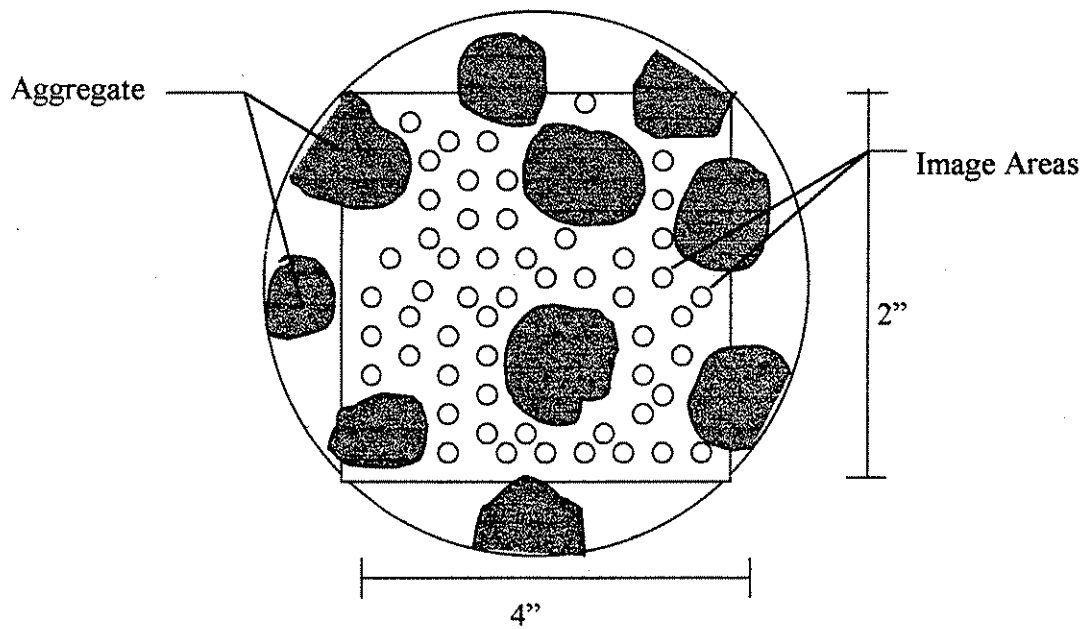
A typical analysis required about one hour for data acquisition and another 30 minutes for data reduction and analysis. A typical analysis counted about 6,000 to 12,000 voids (per 24 images). Also, approximately 1,500 to 3,000 voids were counted that fell into the size range that is normally associated 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	Fcrit	Interpretation
	(Mixing Time, seconds) 30-45	(Mixing Time, seconds) 30-45	(Mixing Time, seconds) 30-45	Y = Significant Difference N = No Significant Difference (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 ( $\alpha$ ) = 0.05

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

Dependent Variable	P-Value	F-ratio	Fcrit	Interpretation
	(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	Y = Significant Difference N = No Significant Difference (Mixing Time, seconds) 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 ( $\alpha$ ) = 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	Fcrit	Interpretation
	(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	Y = Significant Difference N = No Significant Difference (Mixing Time, seconds) 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 ( $\alpha$ ) = 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		Side-Grade Test Locations		Center-Grade Test Locations	
	(Mixing Time, seconds)		(Mixing Time, seconds)		(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 ( $\alpha$ ) = 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			Side-Grade Test Locations			Center-Grade Test Locations		
	(Mixing Time, seconds)			(Mixing Time, seconds)			(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 ( $\alpha$ ) = 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			Side-Grade Test Locations			Center-Grade Test Locations		
	(Mixing Time, seconds)			(Mixing Time, seconds)			(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 ( $\alpha$ ) = 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 <sub>CRIT</sub>	Interpretation
	(Mixing Time, seconds)	(Mixing Time, seconds)	(Mixing Time, seconds)	Y = Significant Difference N = No Significant Difference
	<b>30-45</b>	<b>30-45</b>	<b>30-45</b>	<b>30-45</b>
Cylinder f <sub>c</sub>	0.66	0.22	7.71	N
Core f <sub>c</sub>	0.00	13.45	4.67	Y

Significance level ( $\alpha$ ) = 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 <sub>CRIT</sub>	Interpretation
	(Mixing Time, seconds)	(Mixing Time, seconds)	(Mixing Time, seconds)	Y = Significant Difference N = No Significant Difference
	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>
Cylinder f <sub>c</sub>	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 <sub>c</sub>	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 ( $\alpha$ ) = 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 <sub>CRIT</sub>	Interpretation
	(Mixing Time, seconds)	(Mixing Time, seconds)	(Mixing Time, seconds)	Y = Significant Difference N = No Significant Difference
	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>
Cylinder f <sub>c</sub>	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 <sub>c</sub>	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 ( $\alpha$ ) = 0.05

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

Dependent Variable	P-Value	F-ratio	F <sub>crit</sub>	Interpretation
	(Mixing Time, seconds)	(Mixing Time, seconds)	(Mixing Time, seconds)	Y = Significant Difference N = No Significant Difference (Mixing Time, seconds)
	<b>30-45</b>	<b>30-45</b>	<b>30-45</b>	<b>30-45</b>
%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 ( $\alpha$ ) = 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 <sub>crit</sub>	Interpretation
	(Mixing Time, seconds)	(Mixing Time, seconds)	(Mixing Time, seconds)	Y = Significant Difference N = No Significant Difference (Mixing Time, seconds)
	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>
%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 ( $\alpha$ ) = 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 <sub>crit</sub>	Interpretation
	(Mixing Time, seconds)	(Mixing Time, seconds)	(Mixing Time, seconds)	Y = Significant Difference N = No Significant Difference (Mixing Time, seconds)
	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>	<b>45-60-90 45-60 60-90 45-90</b>
%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 ( $\alpha$ ) = 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**

Applied Pavement Technology, Inc. "Evaluation of Mixing Time vs. Concrete Consistency and Consolidation." 13 March 1997.

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.

Truck #	Avg Actual Mix Time (sec)	TARGET MIX TIME (SEC)	Test Station	CENTER					SIDE					GRADE					CYLIND ER Fc (psi)	CORE Fc (psi)
				Mixing Time	UW	SLAUM P (lb)	AIR CONT (%)	WASH (%)	Mixing Time	UW	SLAUM P (lb)	AIR CONT (%)	WASH (%)	Mixing Time	UW	SLAUM P (lb)	AIR CONT (%)	WASH (%)		
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
	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
			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	5164
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	6807	5630
																		6405		6142
																		6747		6747
																		6969		6969
																		6704		6704
	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	6889	6237

Average



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

TRUCK #	AS-Actual Mix Time (sec)	TARGET Mix Time (sec)	Test Station	CENTER										SIDE										GRADE						CYLINDER R F.C. (psi)	CORE F.C. (psi)
				Abbr Time	UW	SLAUM P (lb)	AIR CONT (%)	WASH F <sup>2</sup> (%)	Mixing Time	UW	SLAUM P (lb)	AIR CONT (%)	WASH F <sup>2</sup> (%)	Mixing Time	UW	SLAUM P (lb)	AIR CONT (%)	WASH F <sup>2</sup> (%)	CYLINDER R F.C. (psi)	CORE F.C. (psi)											
45 SECOND CARLISLE DATA (CONTRACTOR 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	5202									
			142+75	1212	136.46	3.00	9.50	94.59	1215	136.46	2.50	10.00	99.72	1225	136.46	N/A	8.50	99.94	3720												
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												
	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	5874												
			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	6011	6043											
3021	61.65	60	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												
			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	6322												
	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											
			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										
	90.92		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	6086	5773	5729										
					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												

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

STATION	LOCATION	CORE DESIGNATION	% AIR		% AIR		AVG.	COMMENTS
			TOP	STD Dev.	BOTTOM	STD Dev.	% air	
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.	COMMENTS
		TOP	STD Dev.	BOTTOM	STD Dev.	% air	
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

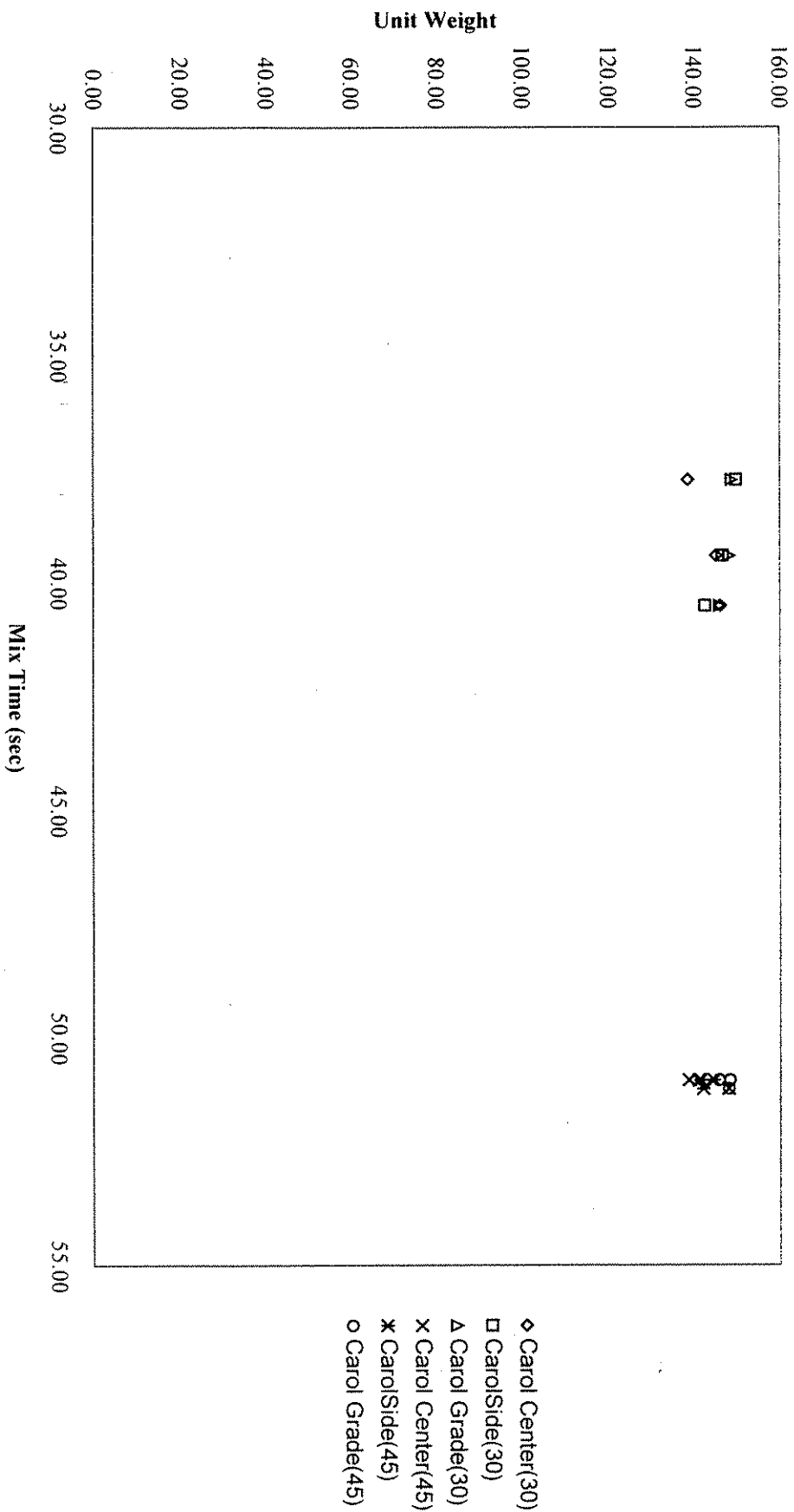


Figure B-2. Mix Time vs Slump - Carroll Iowa DOT Mix.

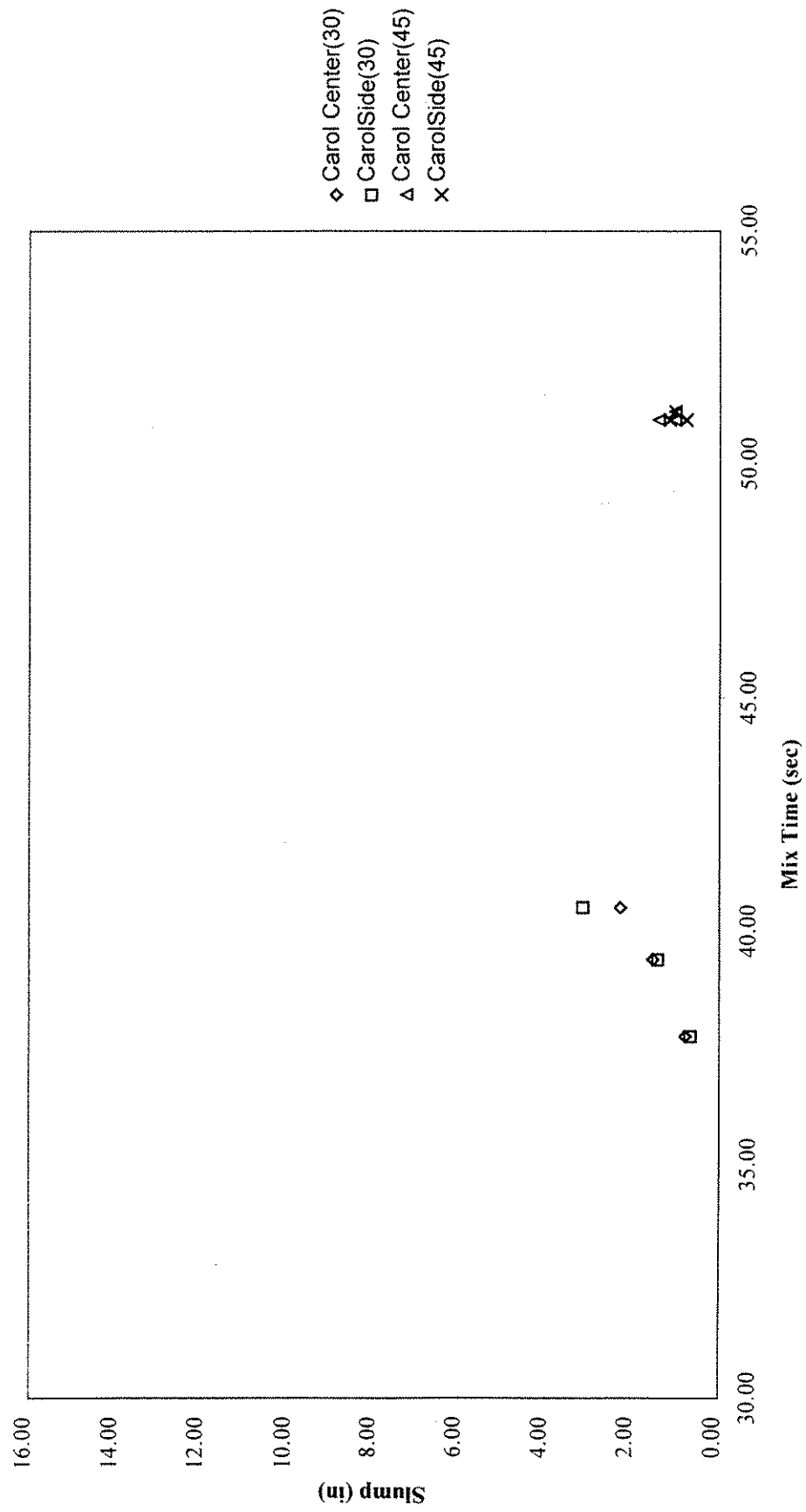




Figure B-3. Mix Time vs Air Content - Carroll Iowa DOT Mix.

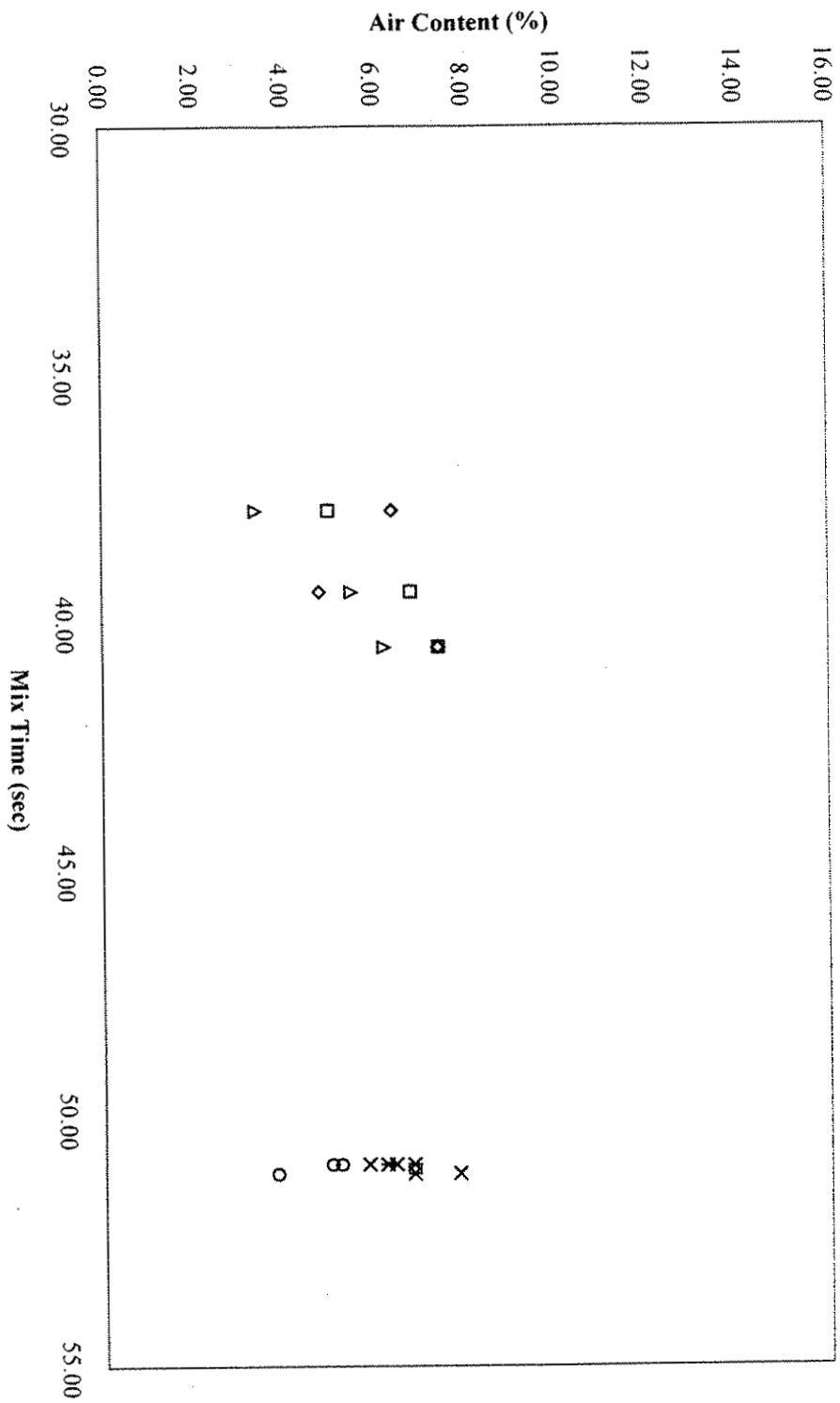


Figure B-4. Mix Time vs Wash - Carroll Iowa DOT Mix.

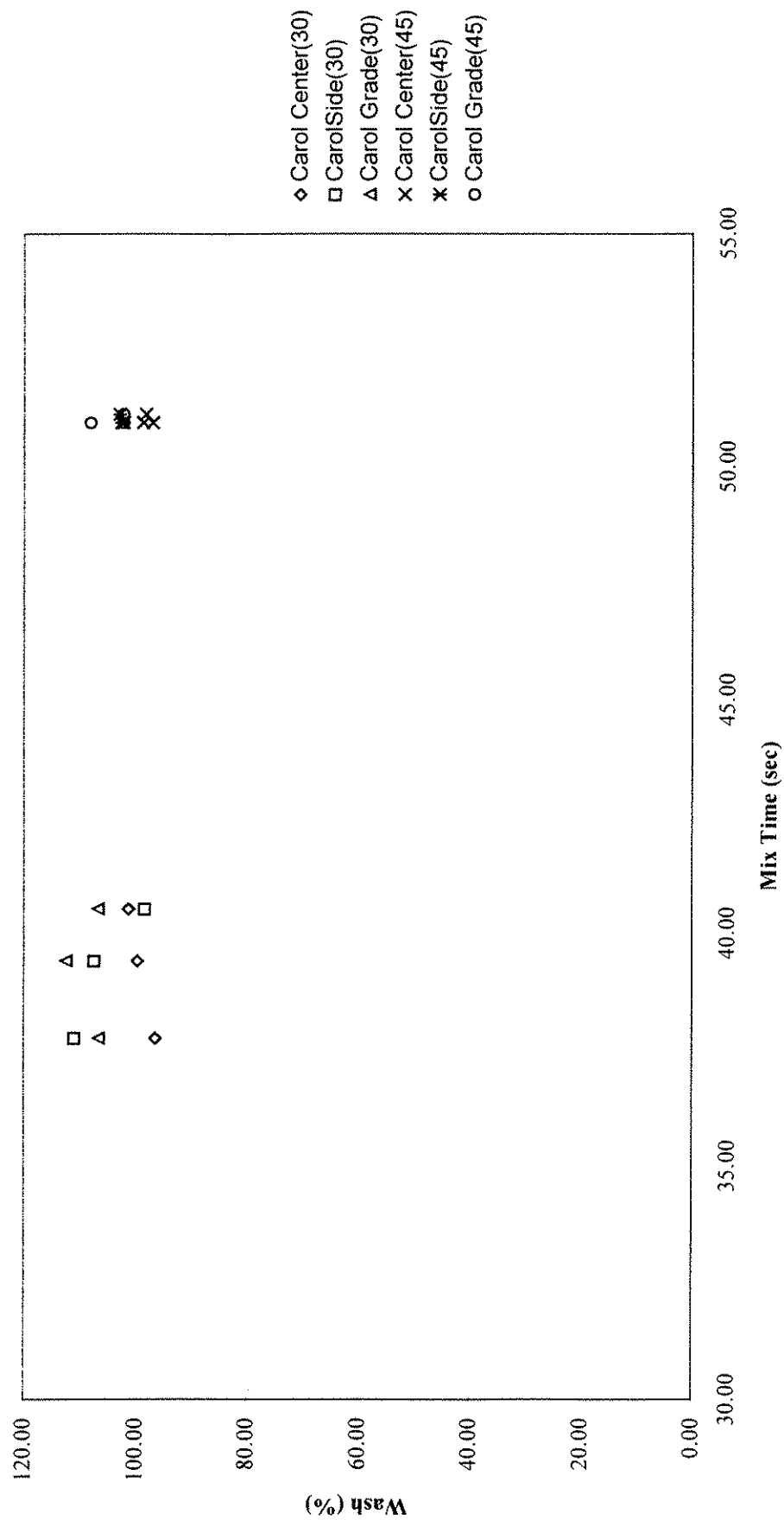


Figure B-5. Mix Times vs Unit Weight - Carlisle Iowa DOT Mix

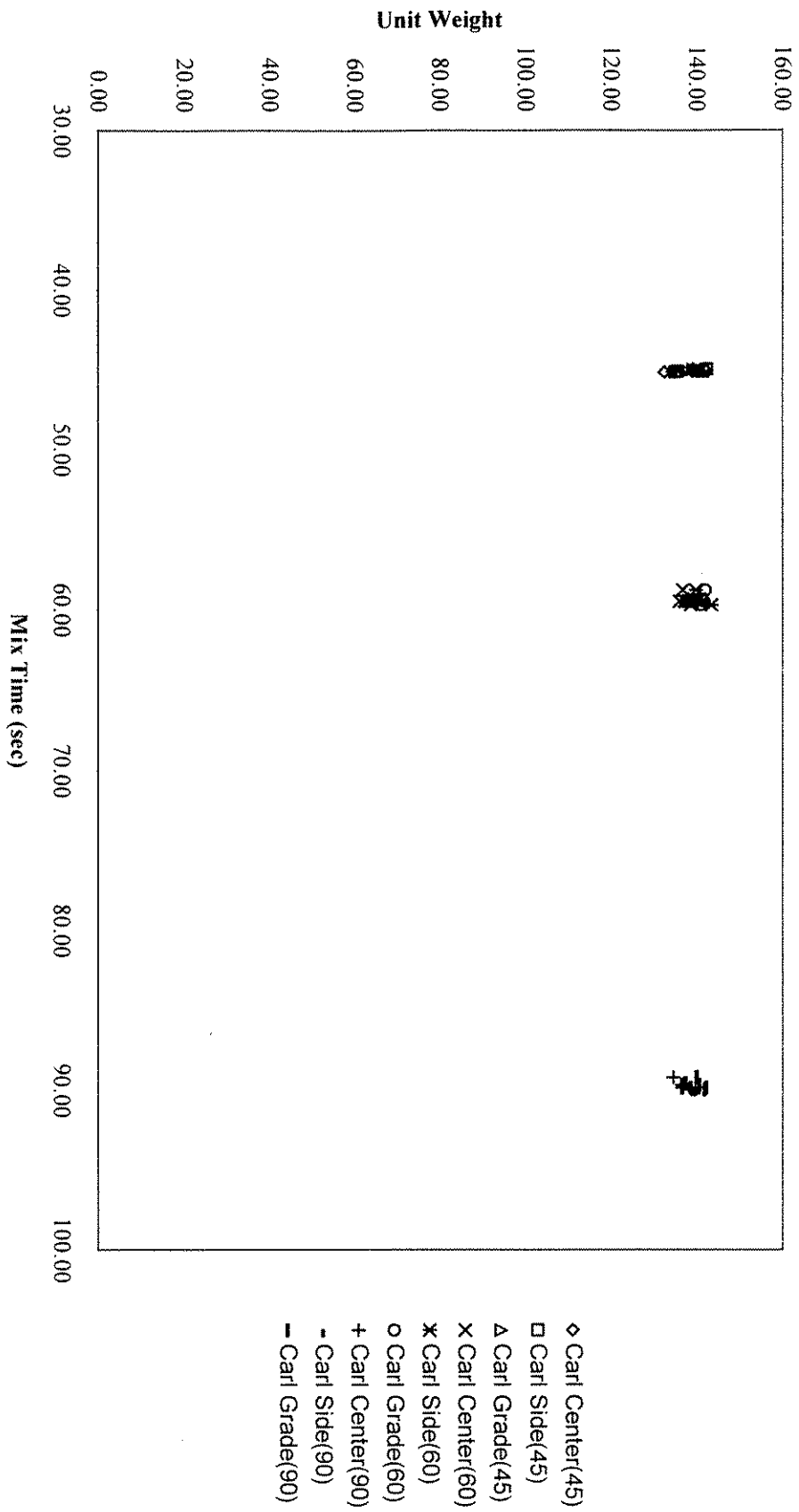


Figure B-6. Mix Time vs Slump - Carlisle Iowa DOT Mix.

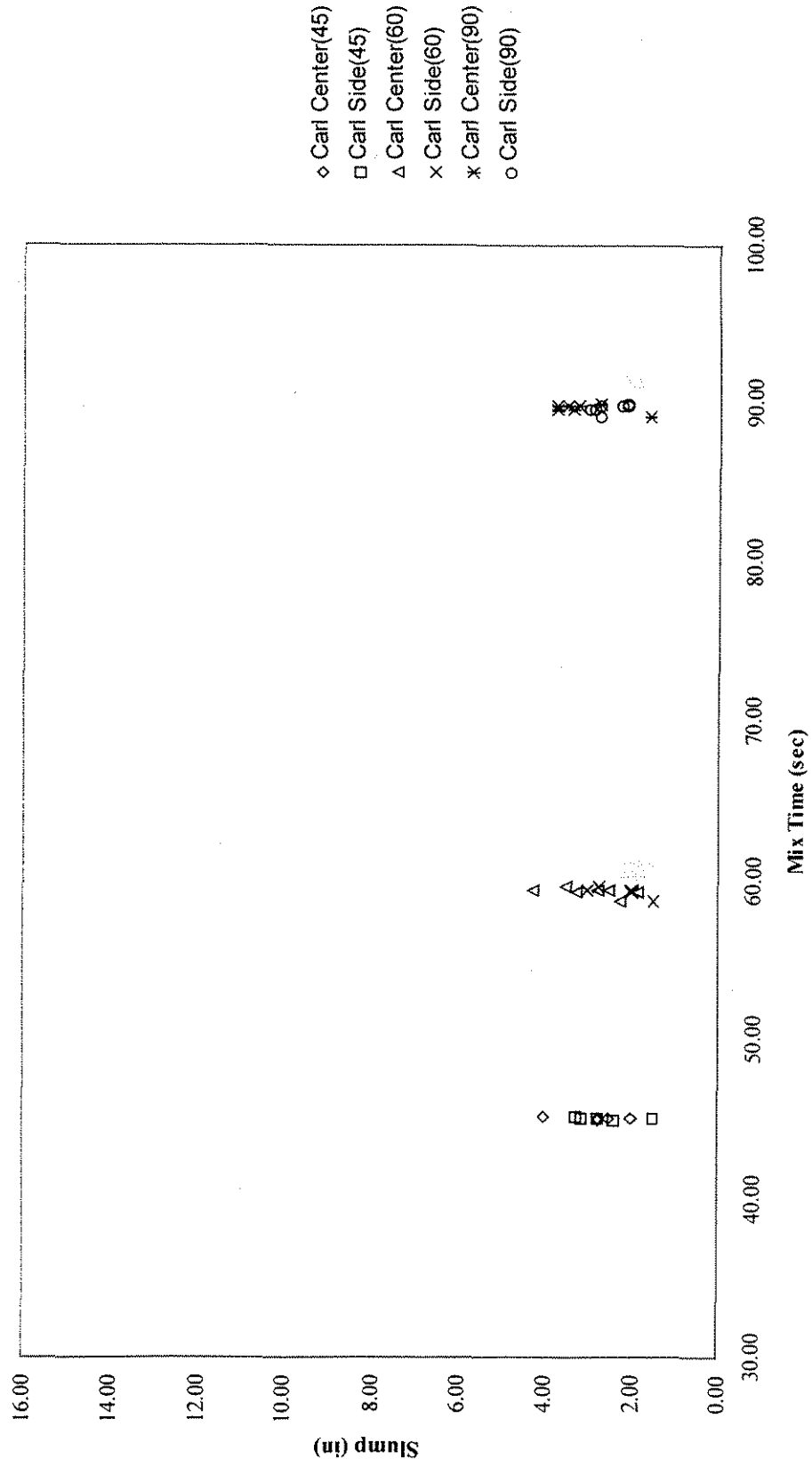


Figure B-7. Mix Time vs Air Content - Carlisle Iowa DOT Mix.

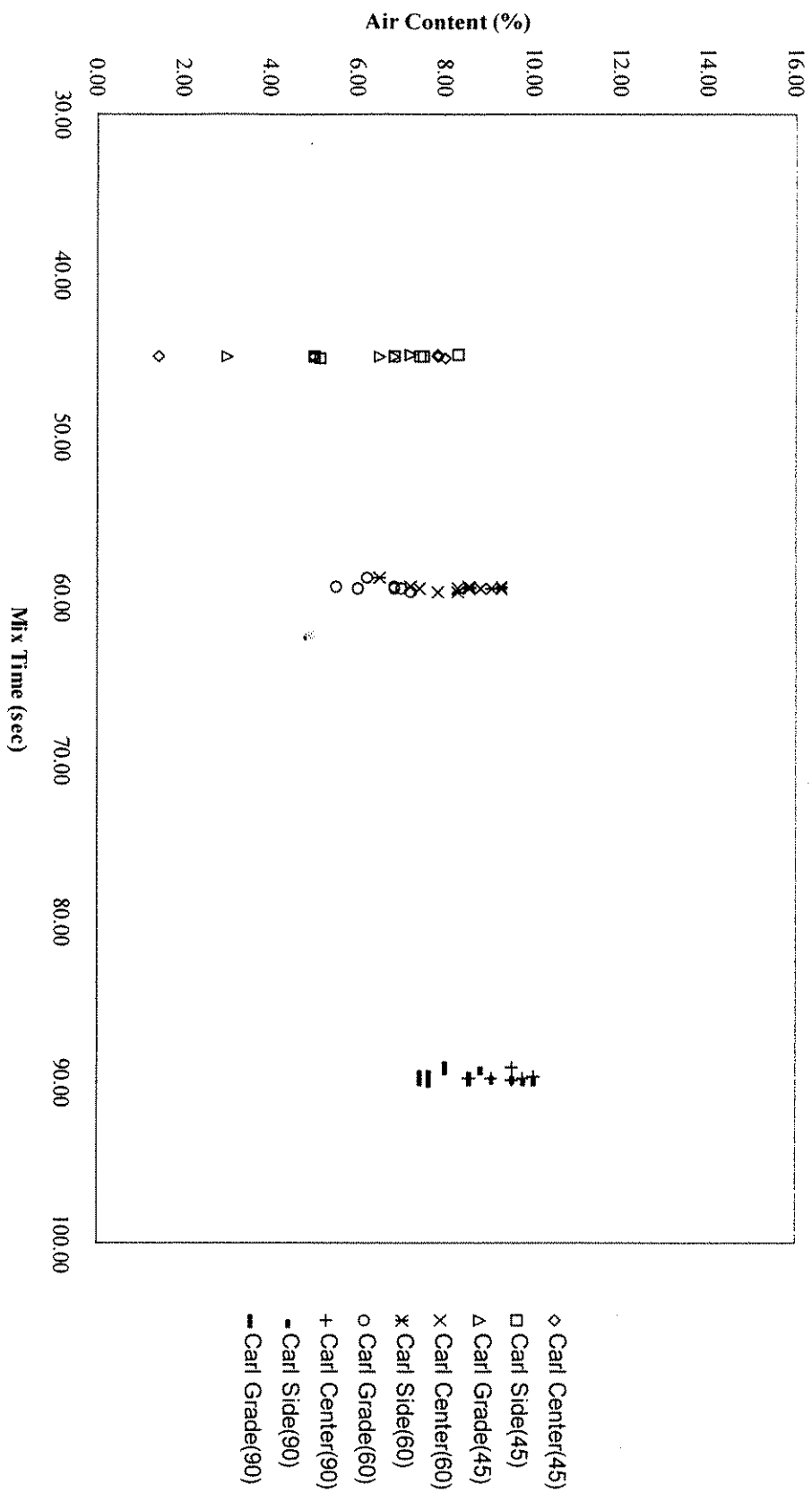


Figure B-8. Mix Time vs Wash - Carlisle Iowa DOT Mix.

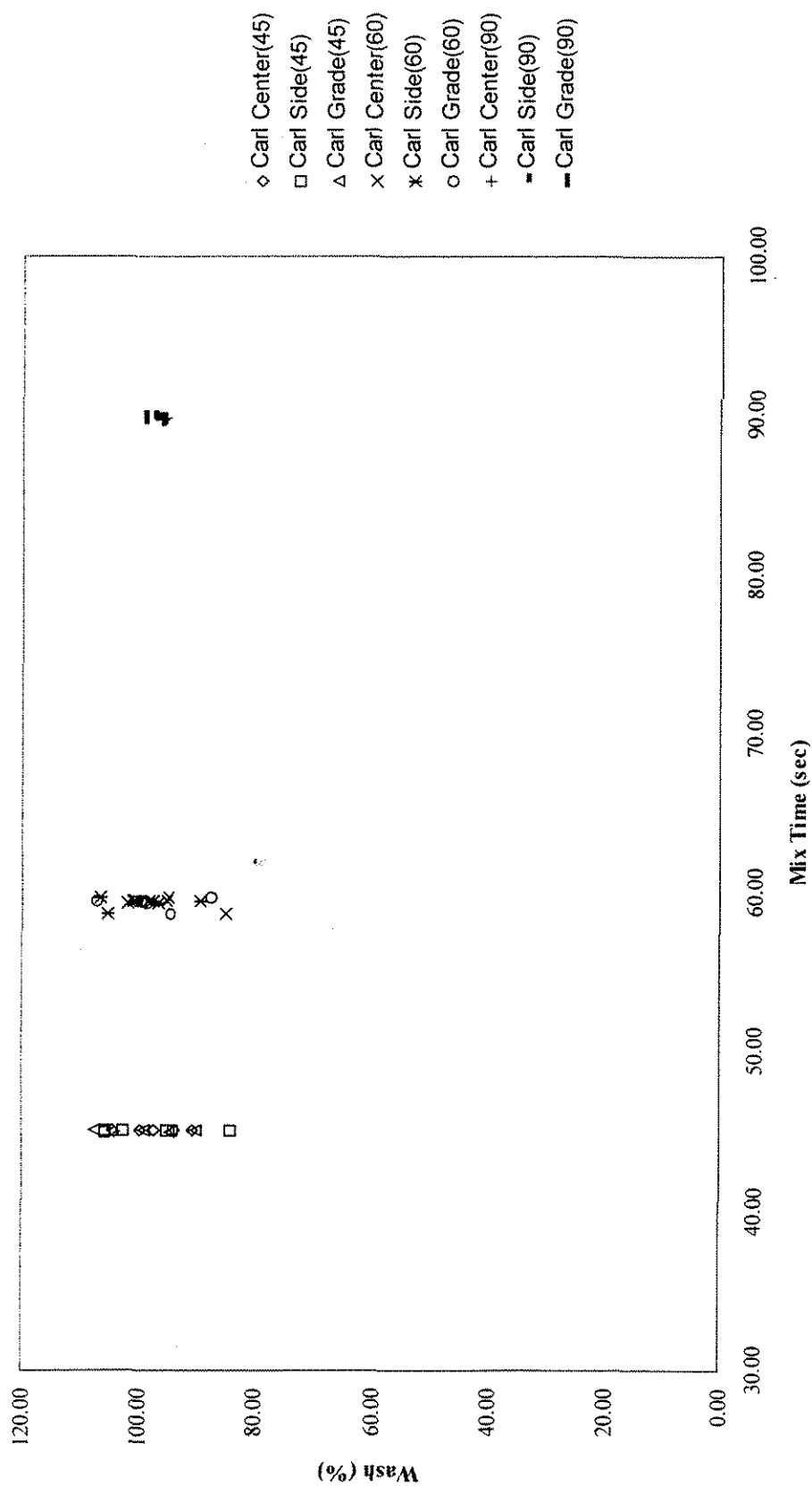


Figure B-9. Mix Times vs Unit Weight - Carlisle Contractor Mix

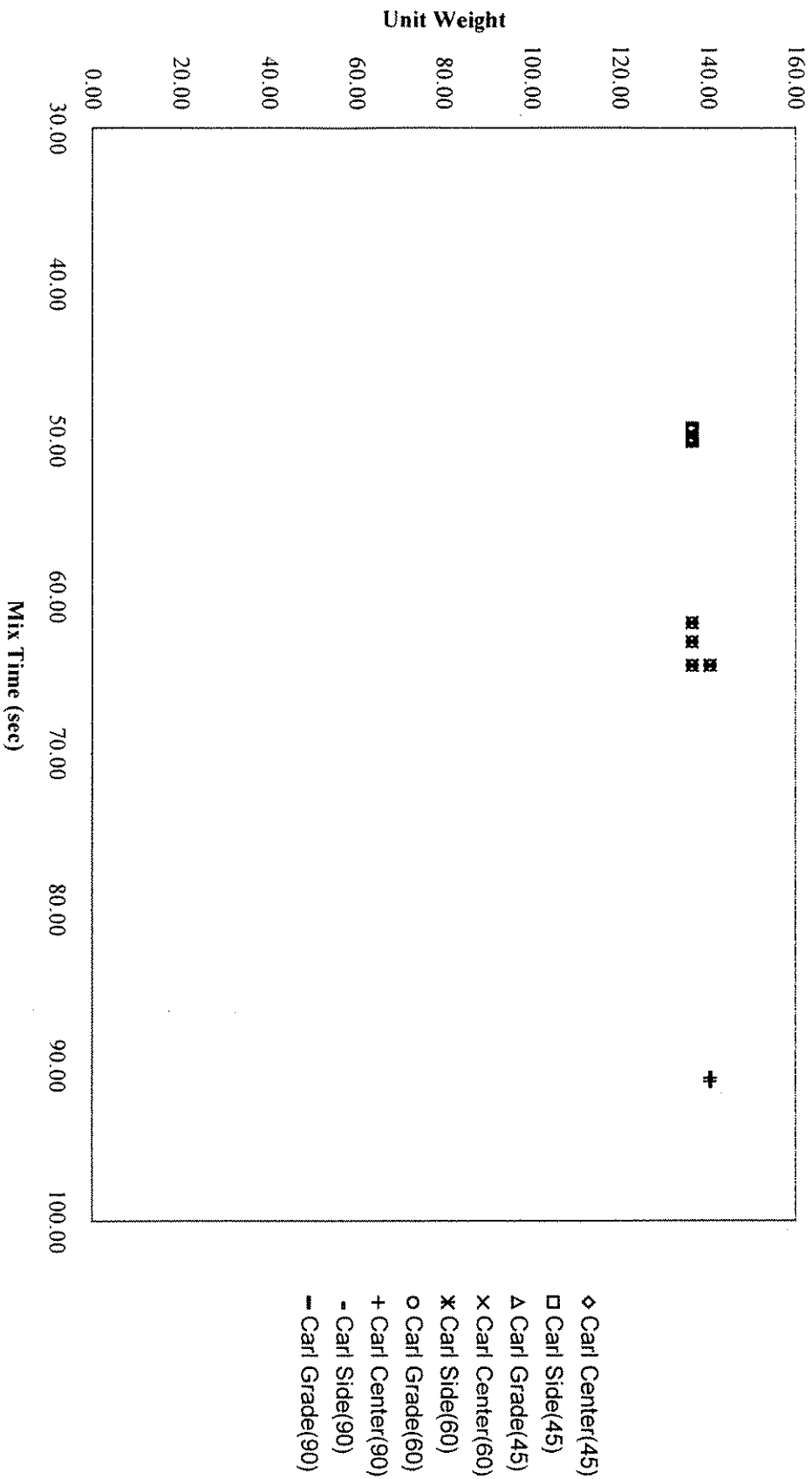
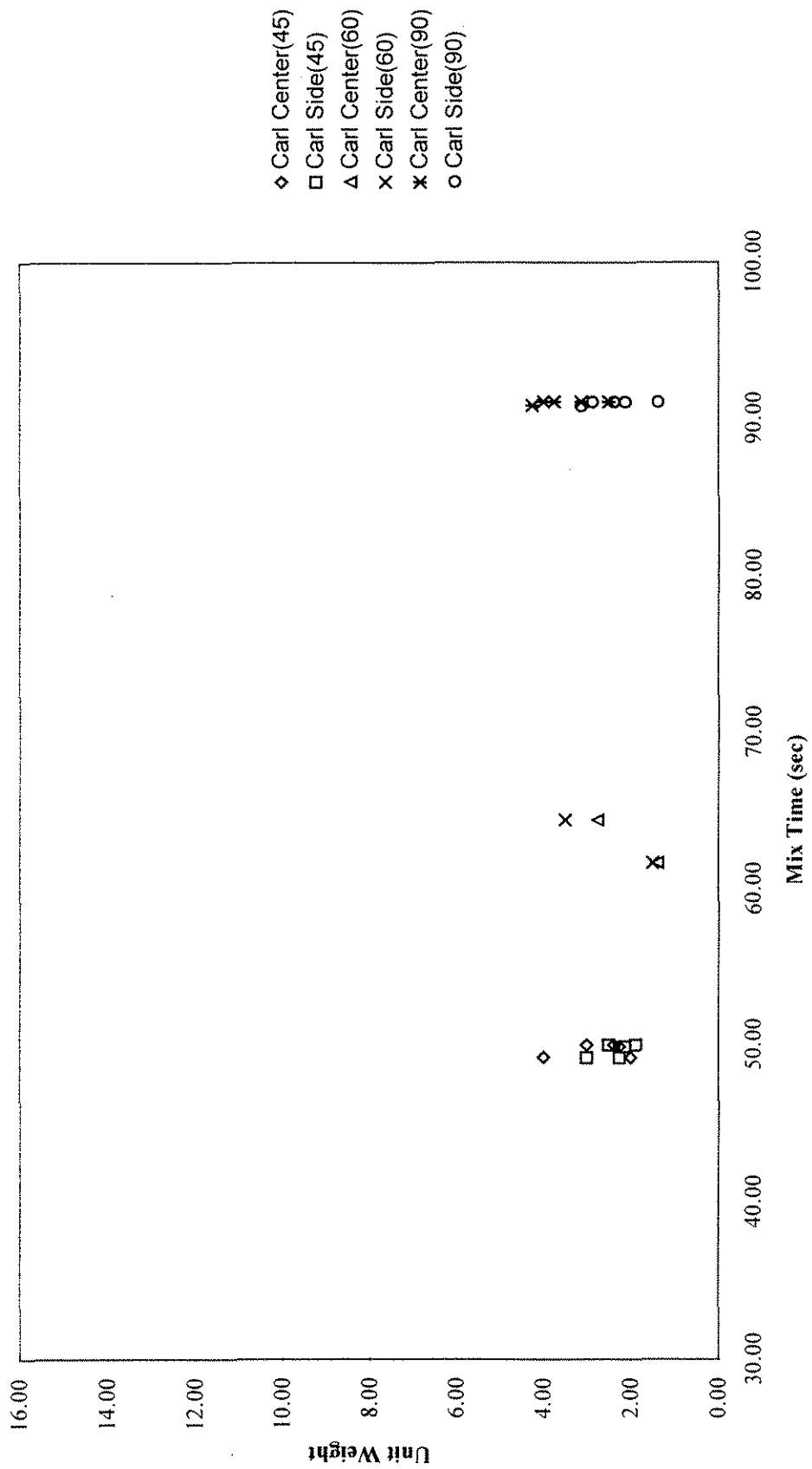


Figure B-10. Mix Times vs Slump - Carlisle Contractor Mix





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

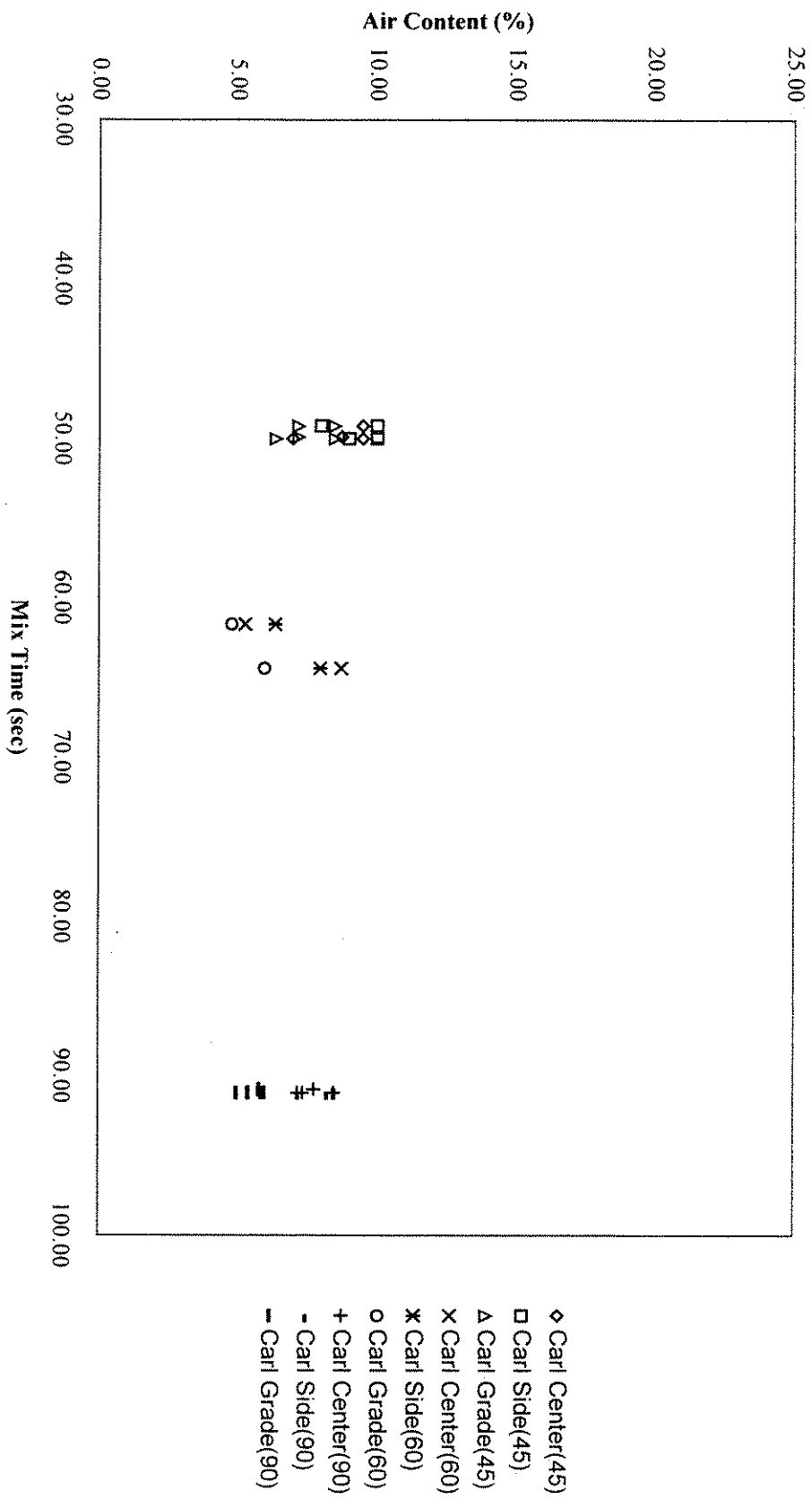


Figure B-12. Mix Time vs Wash - Carlisle Contractor Mix.

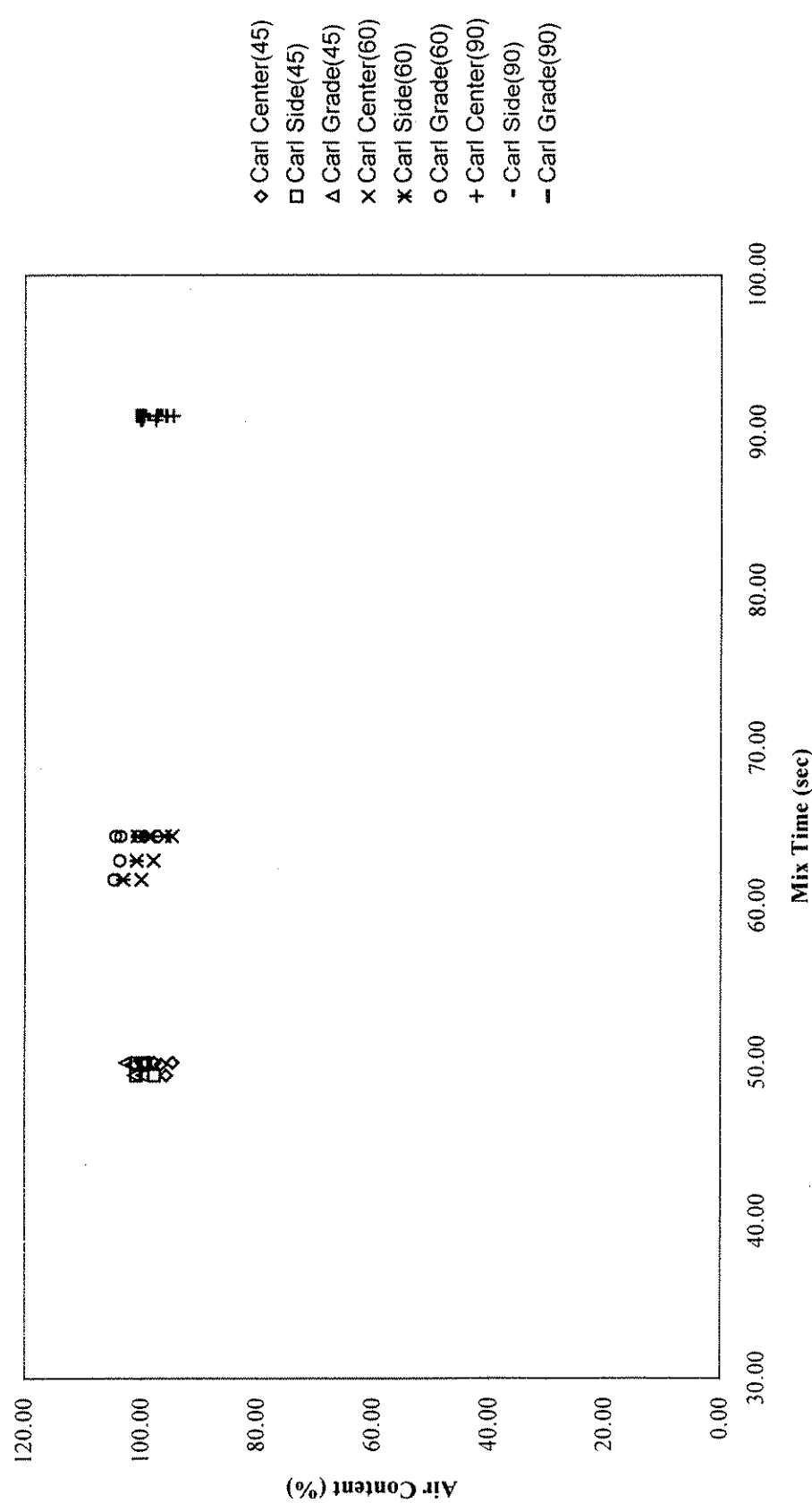


Figure C-1. Mix Time vs Concrete Cylinder Strength - Carroll Iowa DOT Mix.

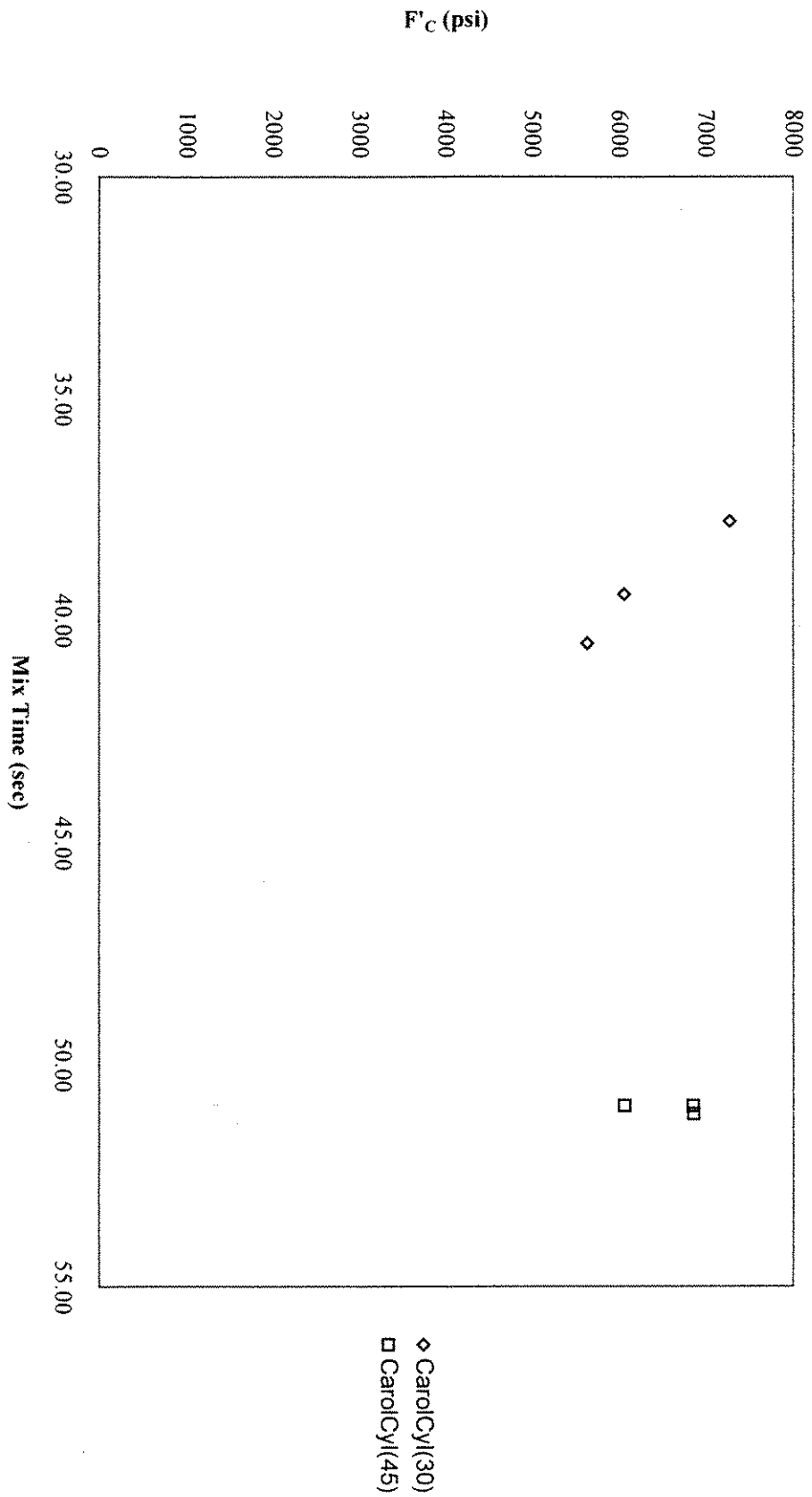


Figure C-2. Mix Time vs Concrete Core Strength - Carroll Iowa DOT Mix.

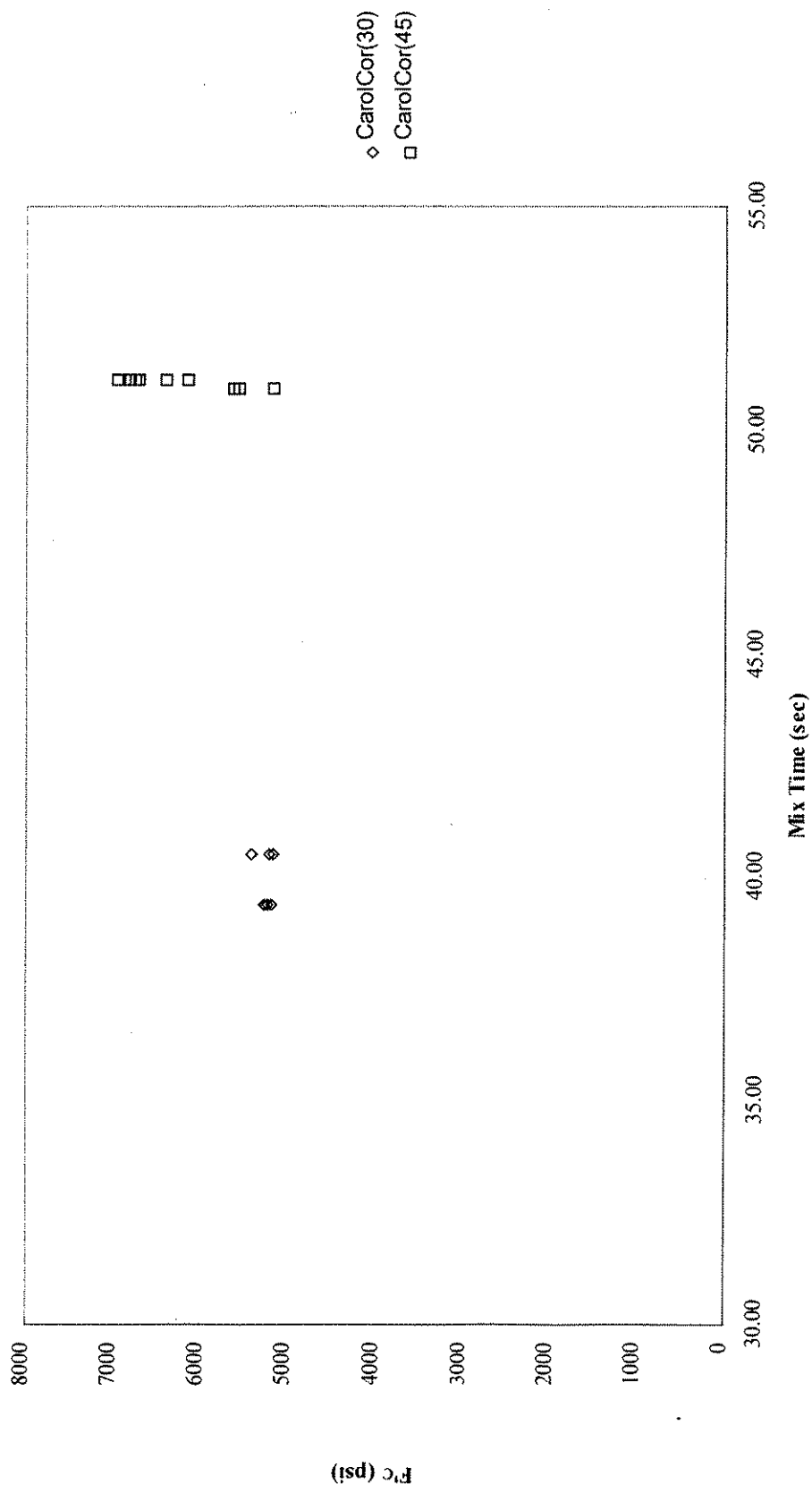


Figure C-3. Mix Time vs Concrete Cylinder Strength - Carlisle Iowa DOT Mix.

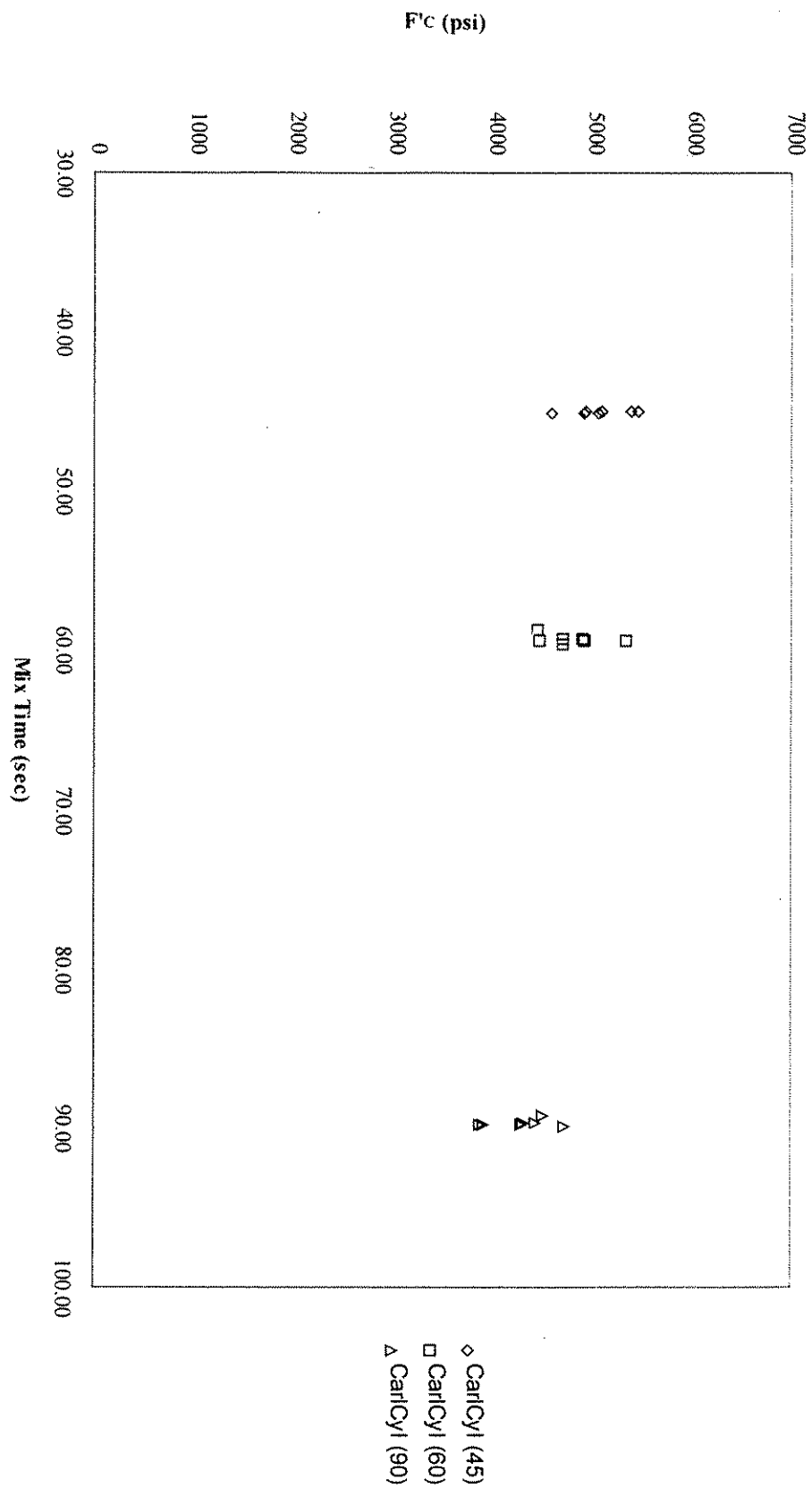


Figure C-4. Mix Time vs Concrete Core Strength - Carlisle Iowa DOT Mix.

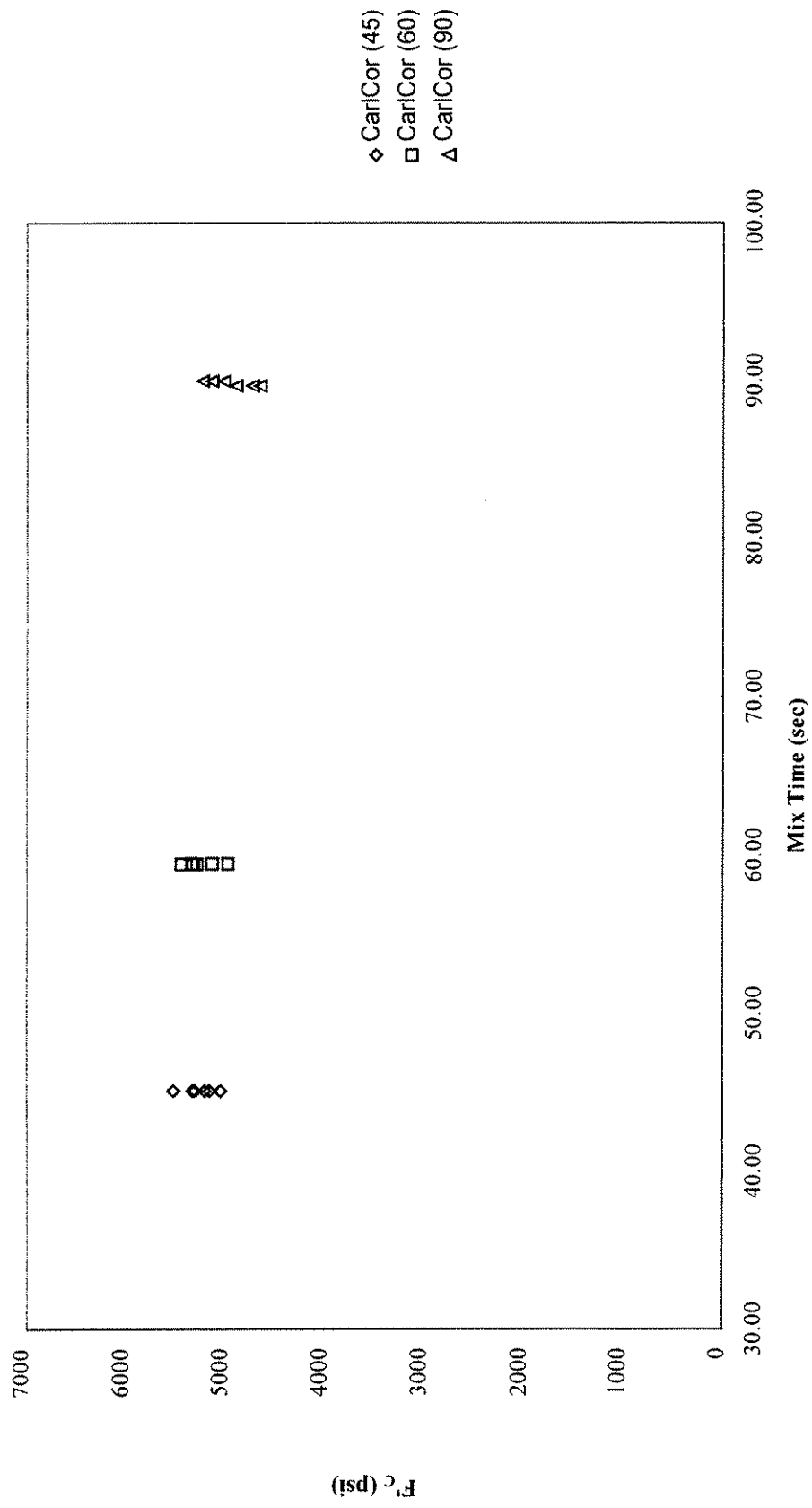


Figure C-5. Mix Time vs Concrete Cylinder Strength - Carlisle Contractor Mix.

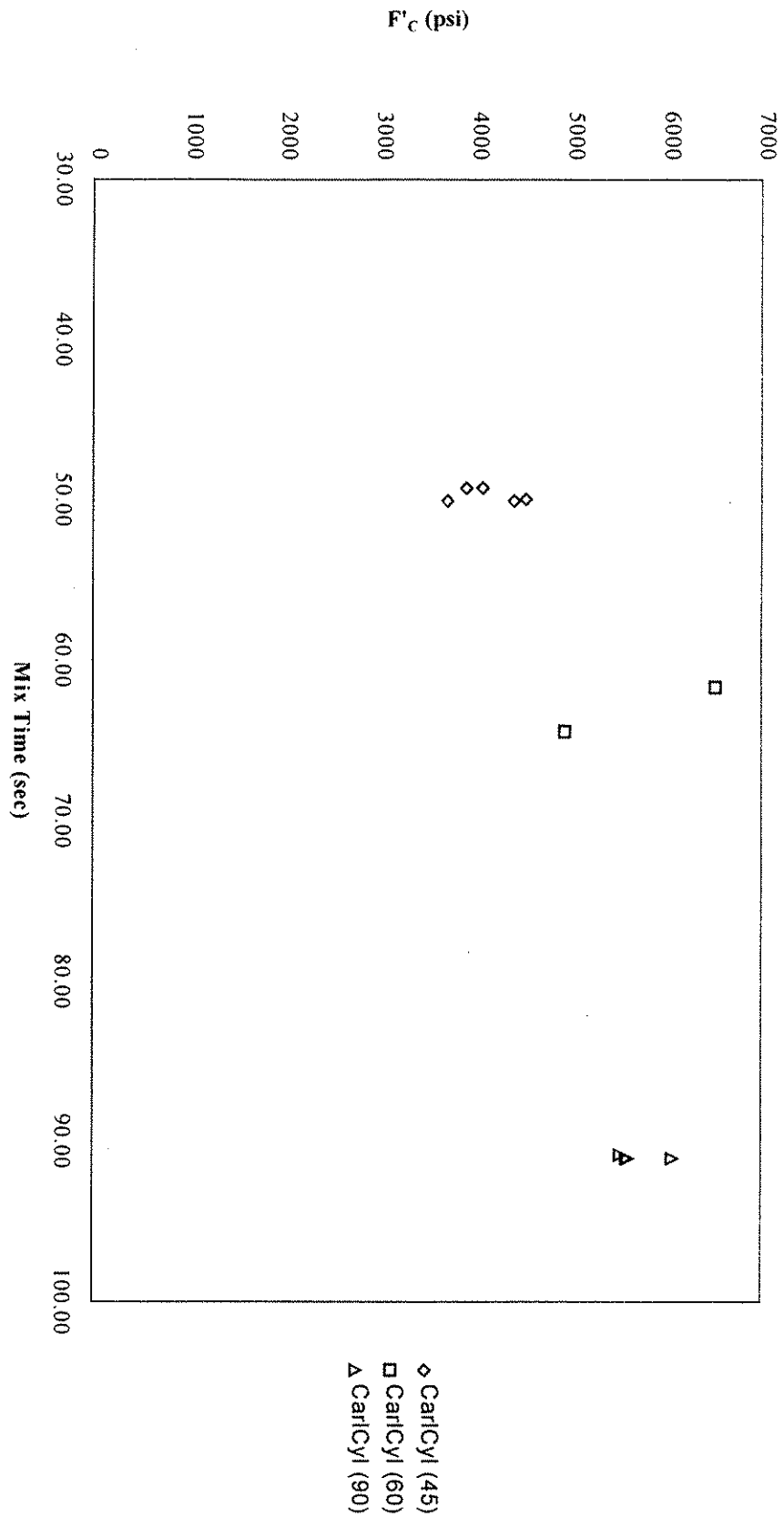


Figure C-6. Mix Time vs Concrete Core Strength - Carlisle Contractor Mix.

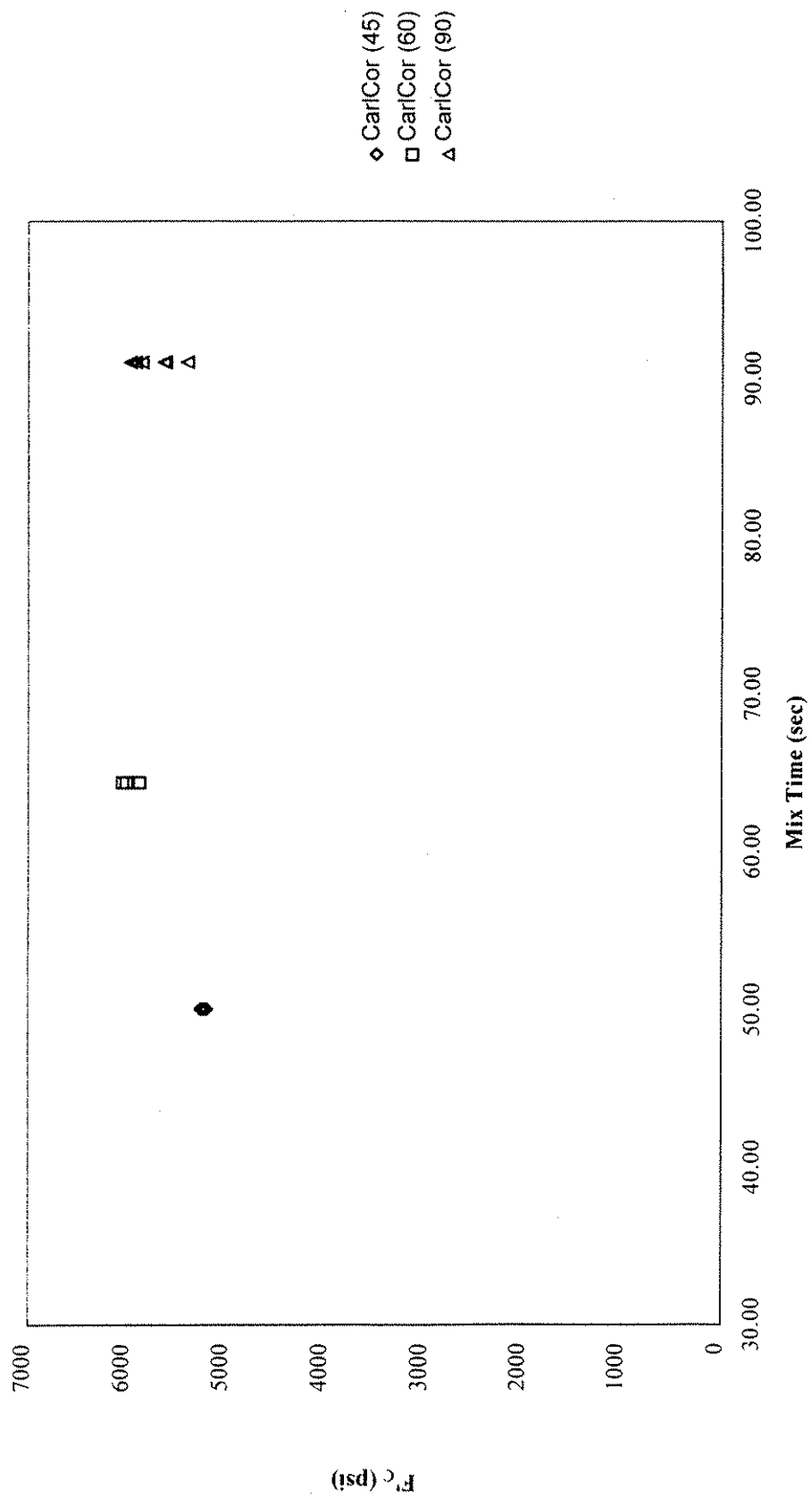




Figure D-1. Mix Times vs Average Air Content for Hardened Concrete Cores - Carroll Iowa Dot Mix

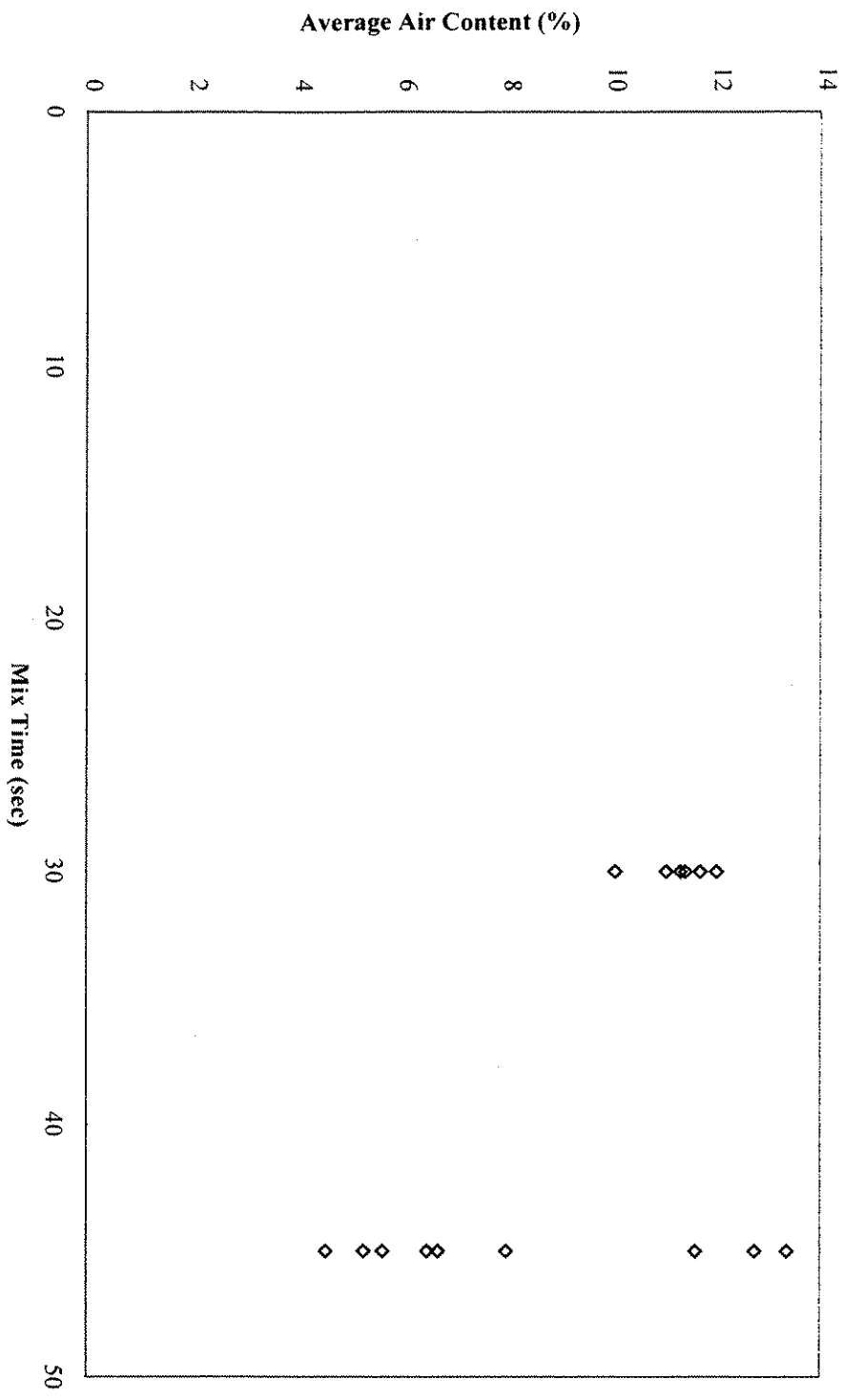


Figure D-2. Mix Times vs Average Air Content for Hardened Concrete Cores - Carlisle Iowa Dot Mix

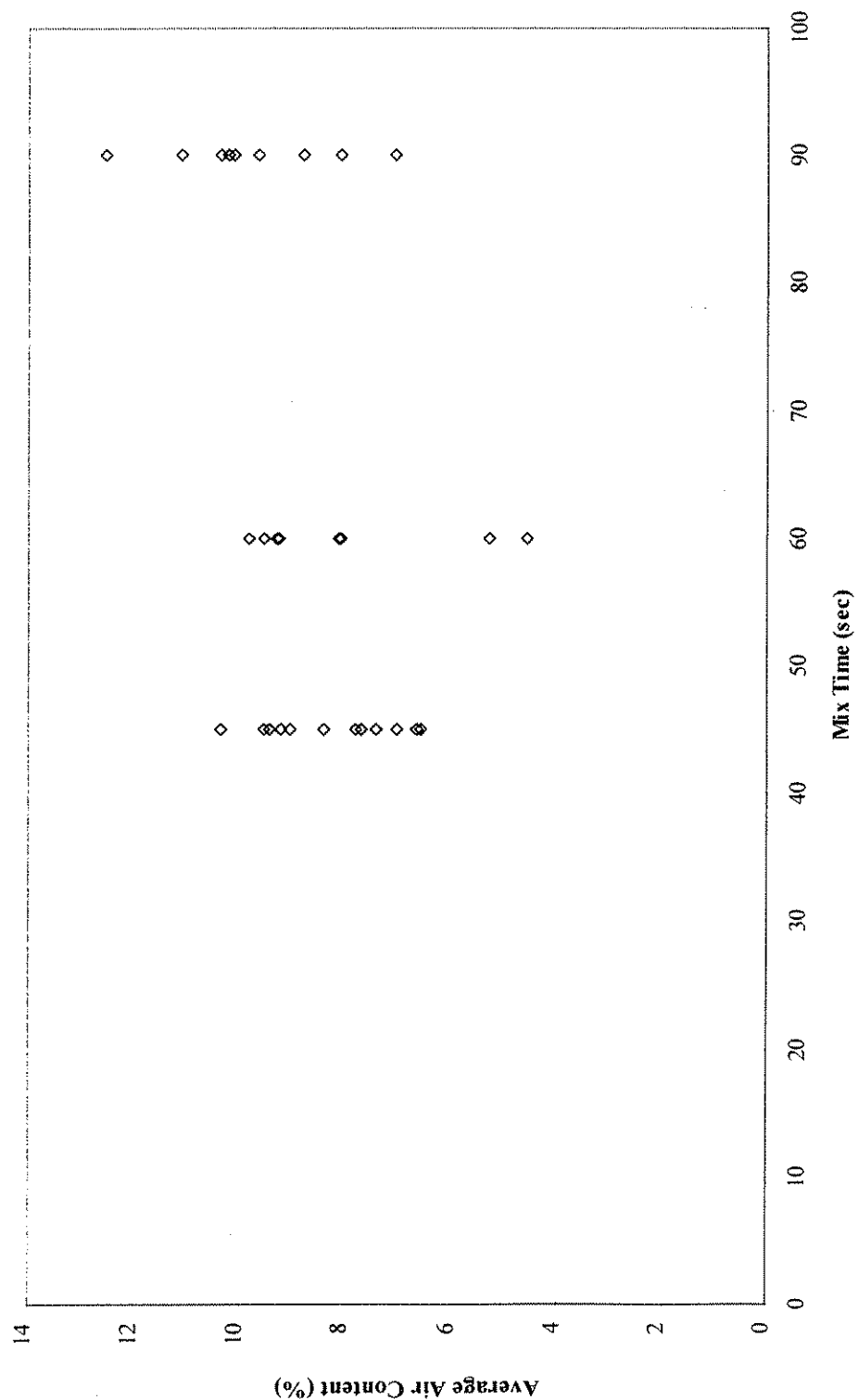


Figure D-3. Mix Time vs Average Air Content for Hardened Concrete Core - Carlisle Contractor Mix.

