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

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and

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Civil and Construction Engineering

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Iowa State University

DISCLAIMER

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 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.

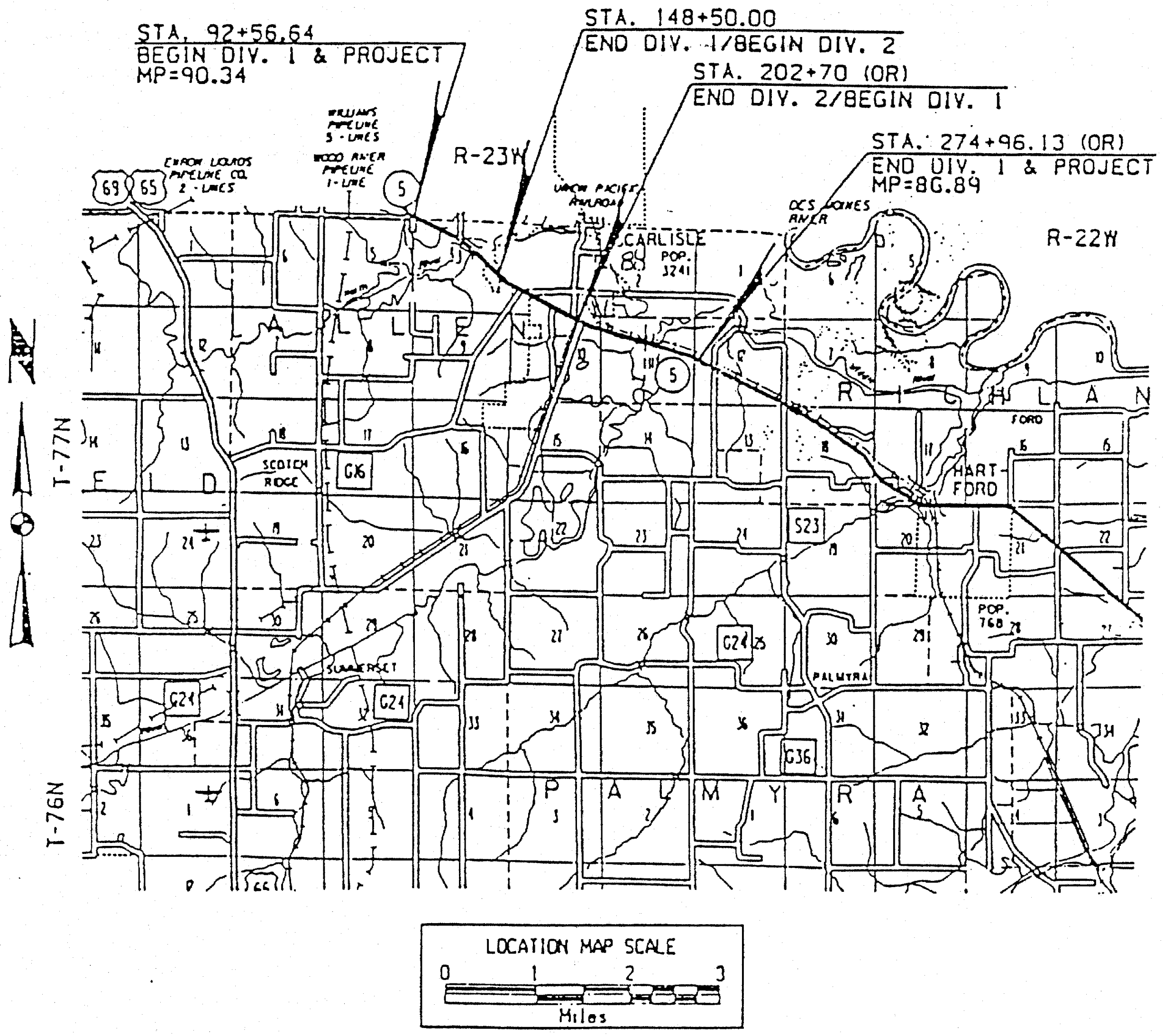
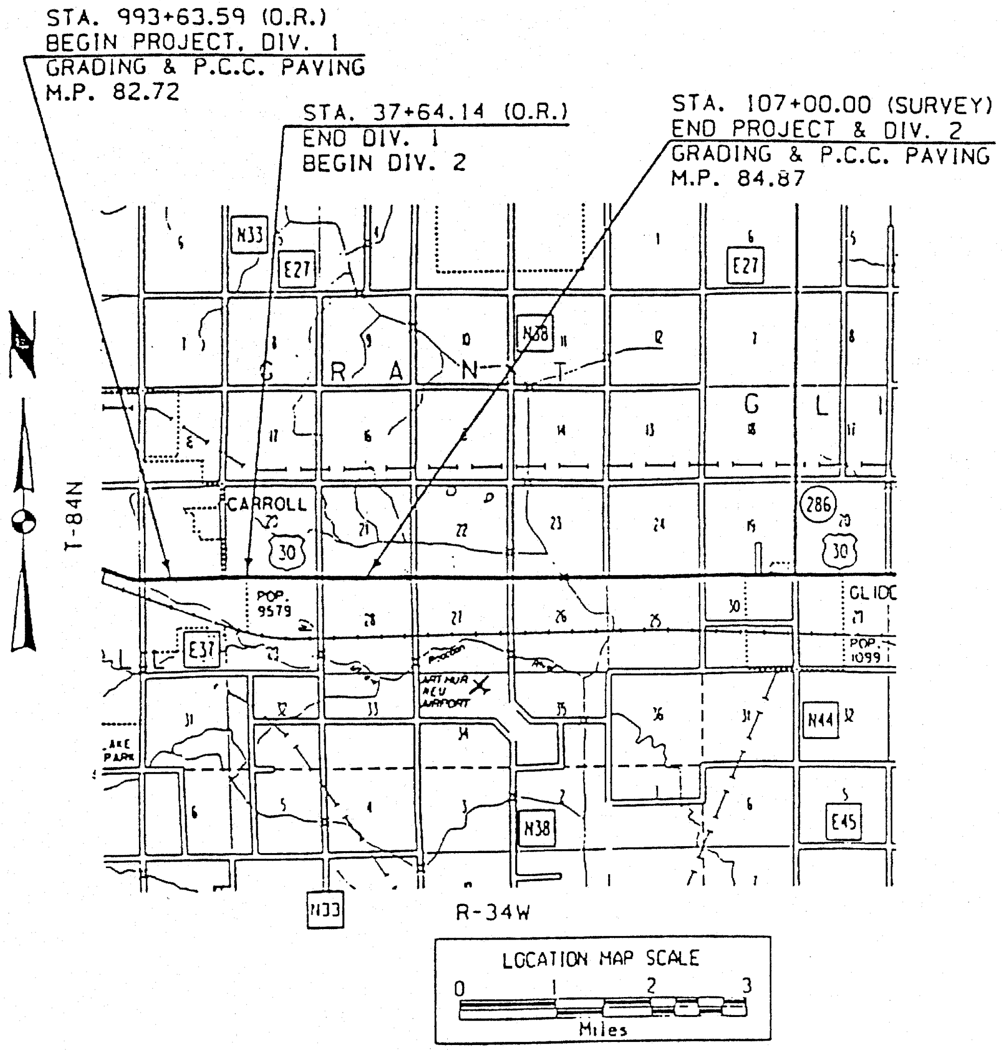


Figure 1. Carlisle, Iowa Highway 5 Construction Site.


STA. 993+63.59 (O.R.)
BEGIN PROJECT, DIV. 1
GRADING & P.C.C. PAVING
M.P. 82.72

STA. 37+64.14 (O.R.)
END DIV. 1
BEGIN DIV. 2

STA. 107+00.00 (SURVEY)
END PROJECT & DIV. 2
GRADING & P.C.C. PAVING
M.P. 84.87

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 can be identified with a particular hauling unit and mixing time. It also allows the research team to correlate the results of the plant and grade location testing.

Testing at the mixing plant site posed the greatest challenge to the research team. The question was how to obtain two large samples (buckets) of concrete from the center and side of a truck box that is 6-8 feet above the ground? The research team overcame this problem by employing the use of a construction sissors lift and a piece of aluminum construction scaffold planking. The sissors lift provided a way to move two persons from the ground to the level of the top of the truck. The planking was slid from the sissors platform, across the truck top, balanced on the sideboards, and used as a walkway access to the top of the truck for two persons. Sampling from this plank was accomplished by the use of two "modified" post holes "jobbers" for extraction of the concrete from the truck. The curved ends of the "jobbers" were straightened to allow for more closure capability. Two five-gallon buckets of concrete could be extracted in less than five minutes and allow for the truck to be back on its way to the paving site. Trucks were chosen at random from the hauling fleet on approximately one half to one-hour increments during the day. The time between test trucks was determined by the ability of the research team to complete the battery of tests at the plant site. Care was taken to select trucks from the fleet only when the paver and plant were in continuous operation and not at the beginning or end of the day.

Sufficient concrete was obtained from each truck to provide for a slump, air content, unit weight test and the construction of compressive cylinders. Upon completion of the unit weight test, the material in the unit weight bucket was washed through a sieve to remove all fines and cement from the mix. The retained coarse aggregate was weight and compared to the unit weight and the expected weight of coarse aggregate in the unit weight bucket. The resultant percentage of retained coarse aggregate was recorded.

Sampling at the paver was accomplished in much the same manner as normal quality control testing is accomplished by the Iowa DOT staff. The test truck carried a red ribbon to alert the researcher at the grade of the particular load. The truck was off loaded by use of a belt placer onto the center of the paving area. A sample bucket of concrete was obtained by shovel from this site for testing. It was immediately returned to the plant site for testing and recording in conjunction with the plant tests for the same vehicle.

The approximate location of the incorporation of the test truckload of material into the pavement was recorded in conjunction with any special workability problems in the field. This location served as a potential site for extraction of cores for laboratory testing. Coring was accomplished after the concrete had reached 500 psi flexural strength and allowed for the travel of a truck mounted Iowa DOT core drill to drive on the slab and extract the cores.

Sampling at the plant site also included the timing of the mixing cycle. A person equipped with a stopwatch was employed to monitor each load mixing time and truck number. Actual mixing times then could be compared to the target time given to the construction plant operator.

RESEARCH RESULTS

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

The field tests were conducted on the plastic concrete at three different locations (at each site): center of the truck, side of the truck and directly in front of the paver. The raw data was collected using standard ASTM C 94 procedures for slump, PCC unit weight, air content and retained coarse aggregate. The following tables in Appendix A display the raw data gathered at each test site:

- Table A-1 Mix Times and Test Data – Carroll (Iowa DOT Mix)
- Table A-2 Mix Times and Test Data – Carlisle (Iowa DOT Mix)
- Table A-3 Mix Times and Test Data – Carlisle (Contractor Mix)

In each table, column one identifies the test truck number. Columns two and three indicate the actual mixing time and the target mixing time, respectively. Column four identifies the station where the grade sample was obtained. The tables are subdivided into the three different sections to represent the test locations: center of truck, side of truck, and grade (directly in front of the paver). Under each test location heading a column is provided for the test time (military). In addition, columns are provided to record the results of the test performed to determine the unit weight, slump, air content and retained coarse aggregate at that location.

The raw data in tables 1, 2 and 3 in appendix A was used to develop preliminary sensitivity plots for each mix. These plots show each dependent variable (unit weight, slump, air content and retained coarse aggregate) as a function of actual mixing time. The sensitivity plots were developed to help identify any trends that may occur between the data from separate target mixing times. The list of sensitivity plots developed and included in Appendix B are as follows:

* Figures B-1 through B-4	Mix time vs. each dependent variable for the Carroll plant site (Iowa DOT Mix)
* Figures B-5 through B-8	Mix time vs. each dependent variable for the Carlisle plant site (Iowa DOT Mix)
* Figures B-9 through B-13	Mix time vs. each dependent variable for the Carlisle plant site (Contractor Designed Mix)

Included on each sensitivity plot is a legend that explains the symbols used for each set of data at a specific mixing time.

In addition to developing sensitivity plots, an analysis of variance (ANOVA) test was also performed. ANOVA tests were used to assess the effect of mixing time on slump, PCC unit weight, air content and wash. ANOVA tests were also applied to determine the effect of sampling location (center of truck, side of truck and directly in front of the paver) on slump, PCC unit weight, air content and wash test for a single mixing time.

An analysis of variance is a statistical test used to determine whether a group of samples come from a population with the same mean. In an ANOVA, the variance of the population is estimated using the difference between the sample means and a separate estimate of the population variance is made based on the difference of the observations within each sample. The differences between the sample means will be relatively small if the all the samples come from populations with the same mean. ANOVA uses the following test statistic to test the equality of the population mean:

$$F = \frac{(S_b)^2}{(S_w)^2}$$

where:

$(s_b)^2$ = Population variance between means of the groups
$(s_w)^2$ = Population variance within means of the groups

F is calculated for each set or group of data being compared and may have either of the following conclusions:

If $F > 1$	The variance within groups is less than the variance between groups. Depending on the level of significance, there may be a significant difference between the two groups.
If $F < 1$	The variance within groups is greater than or equal to the variance between the groups. There is insufficient evidence that there is a significant difference between the groups.

After the F value is calculated, it must be compared to a tabulated F value (known as F_{CRIT}), taken from statistical tables for the given sample size and significance level (a). Theoretically, the significance level represents the confidence level that the probability of any apparent difference is due to chance. Therefore, if F calculated is greater than F_{CRIT} then it can be determined with 95 percent confidence that there is a significant difference between the groups being evaluated. The significance level selected for this study is 0.05.

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

The compressive strength was measured on cylinders cast from each specific batch and cores extracted from known locations. Laboratory tests were conducted and corrected in accordance with ASTM C45, with some exceptions. All the specimens were broken at day 28, except for Carlisle cores 1A, 1B and 1C, and cylinders 1 through 6. These specimens were broke at day 29. The error due to the time difference isn't large because ASTM C42 allows time errors as large as 3% (+ 20 hours in this case, so the specimens could be broken between 27 and 29 days). The specimens were not submerged in water prior to testing and were broken in a dry state. It was determined that the use of unbonded capping pads throughout the study were sufficient to test concrete samples with compressive strengths between 2,000 and 6,000 psi. The raw data indicated that some of the cores and cylinders tested exceeded the 6,000 psi upper limit (most of these samples were from the Carroll sections). The machine used to test the specimens was operated in the following procedure:

1. Loads between 7,500 lbs and 10,000 lbs were applied to each specimen.
2. The load was applied to obtain a specimen stress rate between 25 and 35 psi/second.
3. No interruption of the loading occurred until the specimen had reached total failure.

Laboratory results for compressive strengths of cylinder and compressive strengths of cores are included in tables A-4, A-5 and A-6 of Appendix A. The data provided in these tables were used to develop sensitivity plots and perform ANOVA. The list of sensitivity plots presented in Appendix C is as follows:

* C-1 Mixing Time vs. Concrete Cylinder Strength-Carroll, Iowa DOT Mix

* C-2 Mixing Time vs. Concrete Cylinder Strength-Carroll, Iowa DOT Mix

* C-3 Mixing Time vs. Concrete Core Strength-Carlisle, Iowa DOT Mix

* C-4 Mixing Time vs. Concrete Core Strength-Carlisle, Iowa DOT Mix

* C-5 Mixing Time vs. Concrete Cylinder Strength-Carlisle, Contractor Mix

* C-6 Mixing Time vs. Concrete Core Strength-Carlisle, Contractor Mix

The ANOVA results can be found in tables 7, 8 and 9 on the following page. As shown in these tables there is no data gathered to compare slump for side or center of truck vs. grade test locations. No slump tests of the material were taken at the grade locations to eliminate confusion or redundancy with existing Iowa DOT quality testing 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.

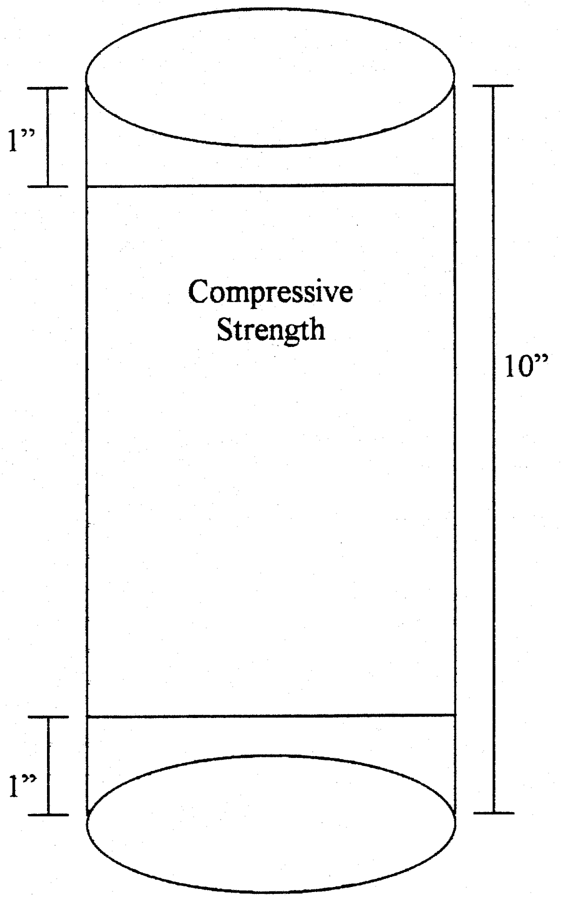
The cores used for the air void analysis were extracted behind the paver when the concrete would support the drill rig. The cores were transported to the laboratory for length measurements. The cores were sectioned using a diamond blade saw to produce specimens for the SEM and compressive strength tests (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.

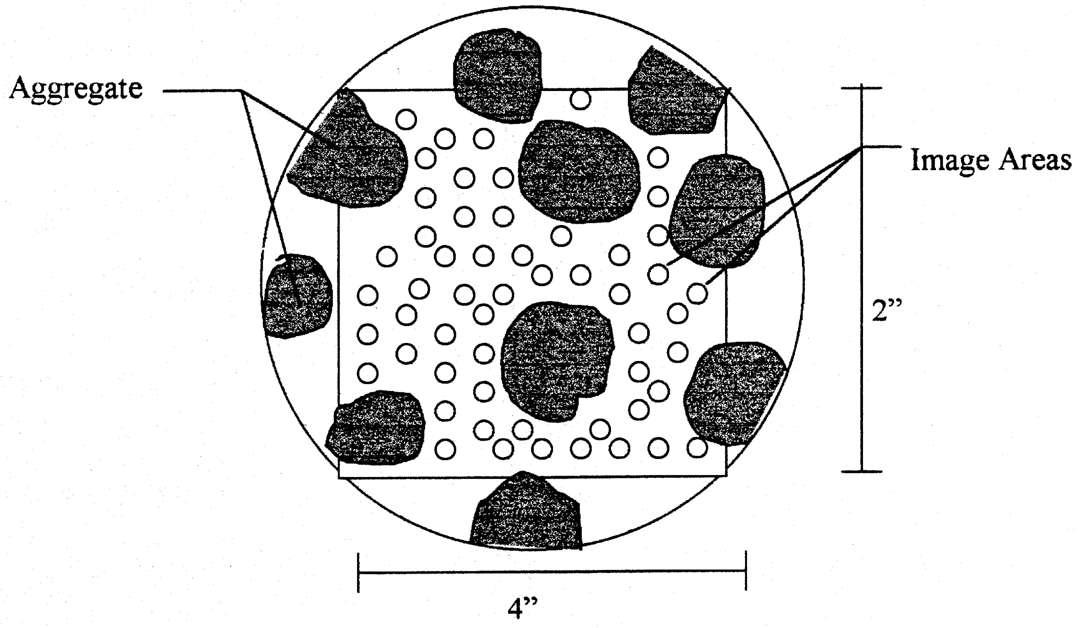
A typical analysis required about one hour for data acquisition and another 30 minutes for data reduction and analysis. A typical analysis counted about 6,000 to 12,000 voids (per 24 images). Also, approximately 1,500 to 3,000 voids were counted that fell into the size range that is normally associated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

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

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

				CENTER					SIDE					GRADE						
Truck #	AvgActual Mix Time (sec)	TARGET MIX TIME (SEC)	Test Station	Military Time	UW	SLAUM P (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUM P (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUM P (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	146.20	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 #	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 (%)	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	99.25 107.61	5466 5101 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	99.25 107.58	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	SLAUM P (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUM P (IN)	AIR CONT (%)	WASH (%)	Military Time	UW	SLAUM P (IN)	AIR CONT (%)	WASH (%)	CYLINDER F'c (psi)	CORE F'c (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 5202
				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	
	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		5874 6011 6043
				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		
				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	
	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	5970 5917 5852 5395 5630 5612
				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	
				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	
				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

			% AIR		% AIR		AVG.	
STATION	LOCATION	CORE DESIGNATION	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

		% AIR		% AIR		AVG.	
STATION	CORE DESIGNATION	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

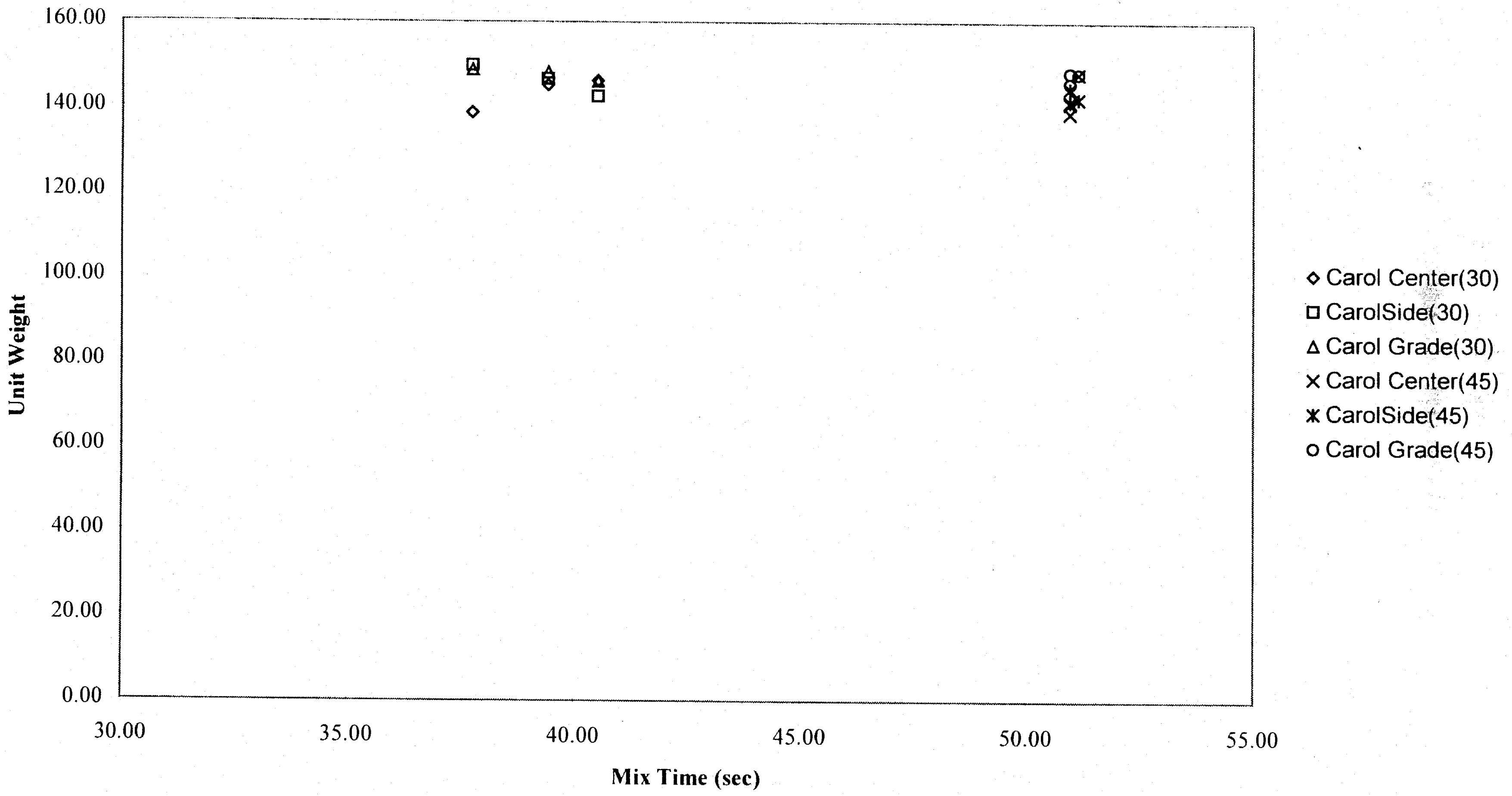


Figure B-2.   Mix Time vs Slump - Carroll Iowa DOT Mix.

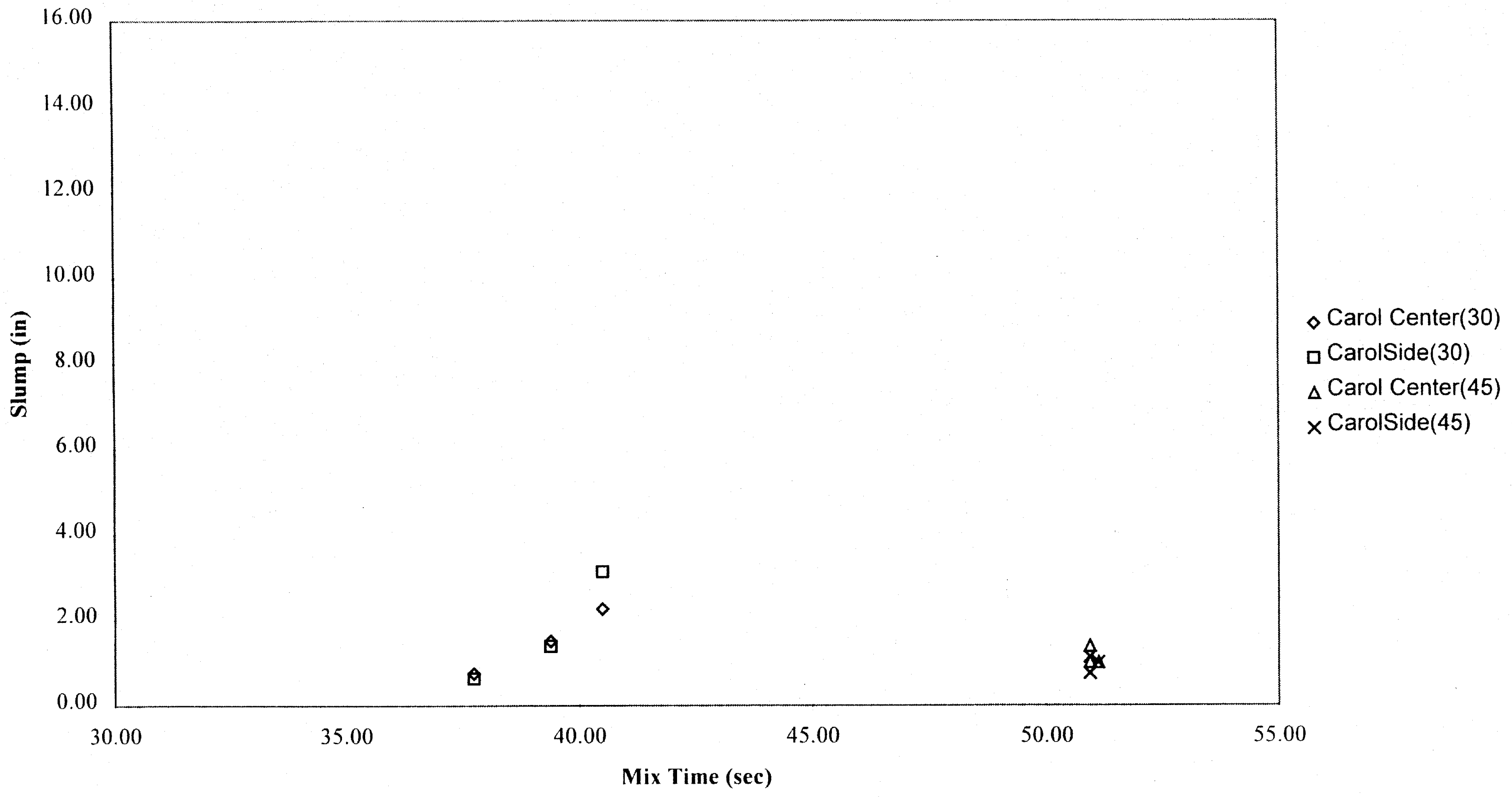


Figure B-3. Mix Time vs Air Content - Carroll Iowa DOT Mix.

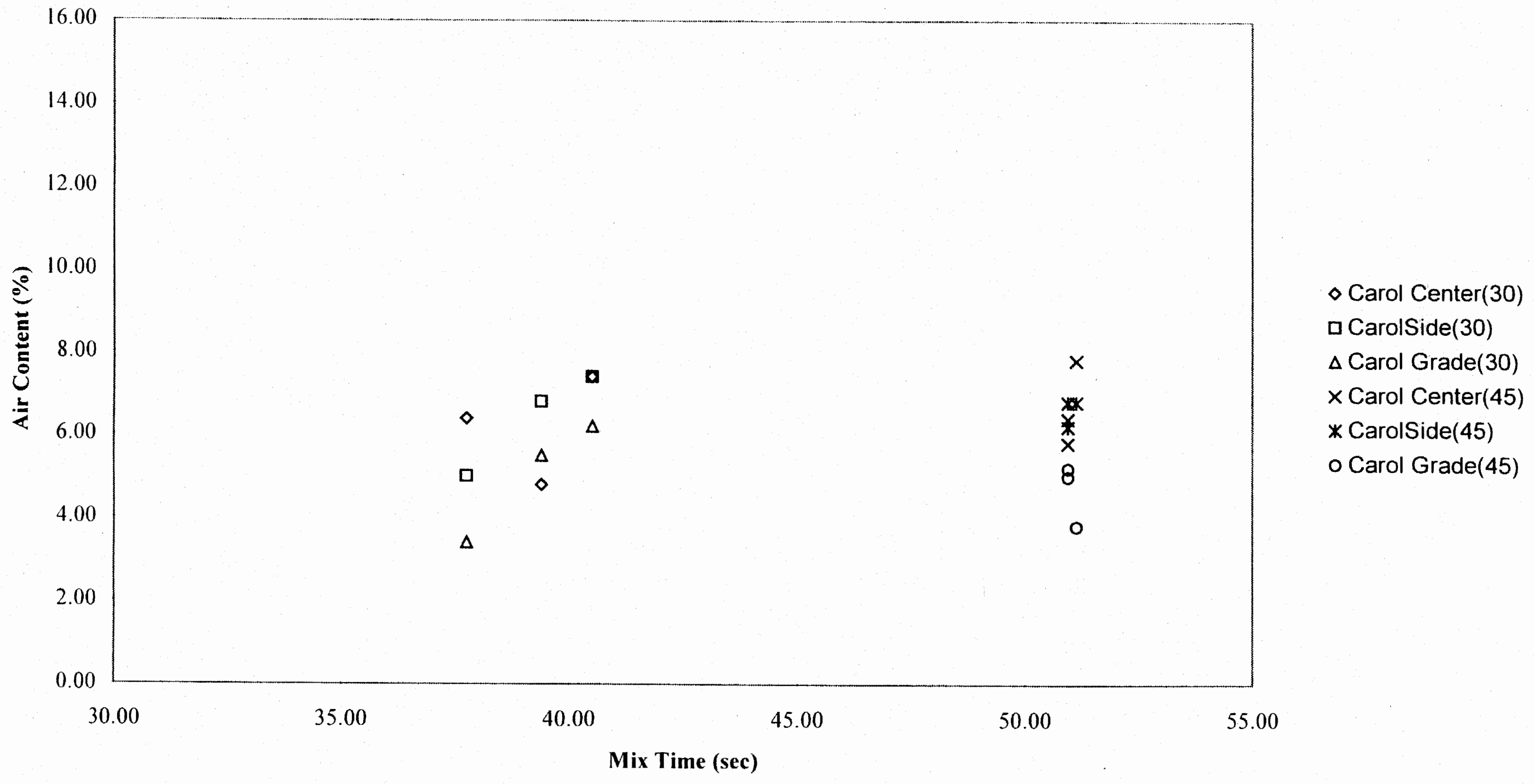


Figure B-4. Mix Time vs Wash - Carroll Iowa DOT Mix.

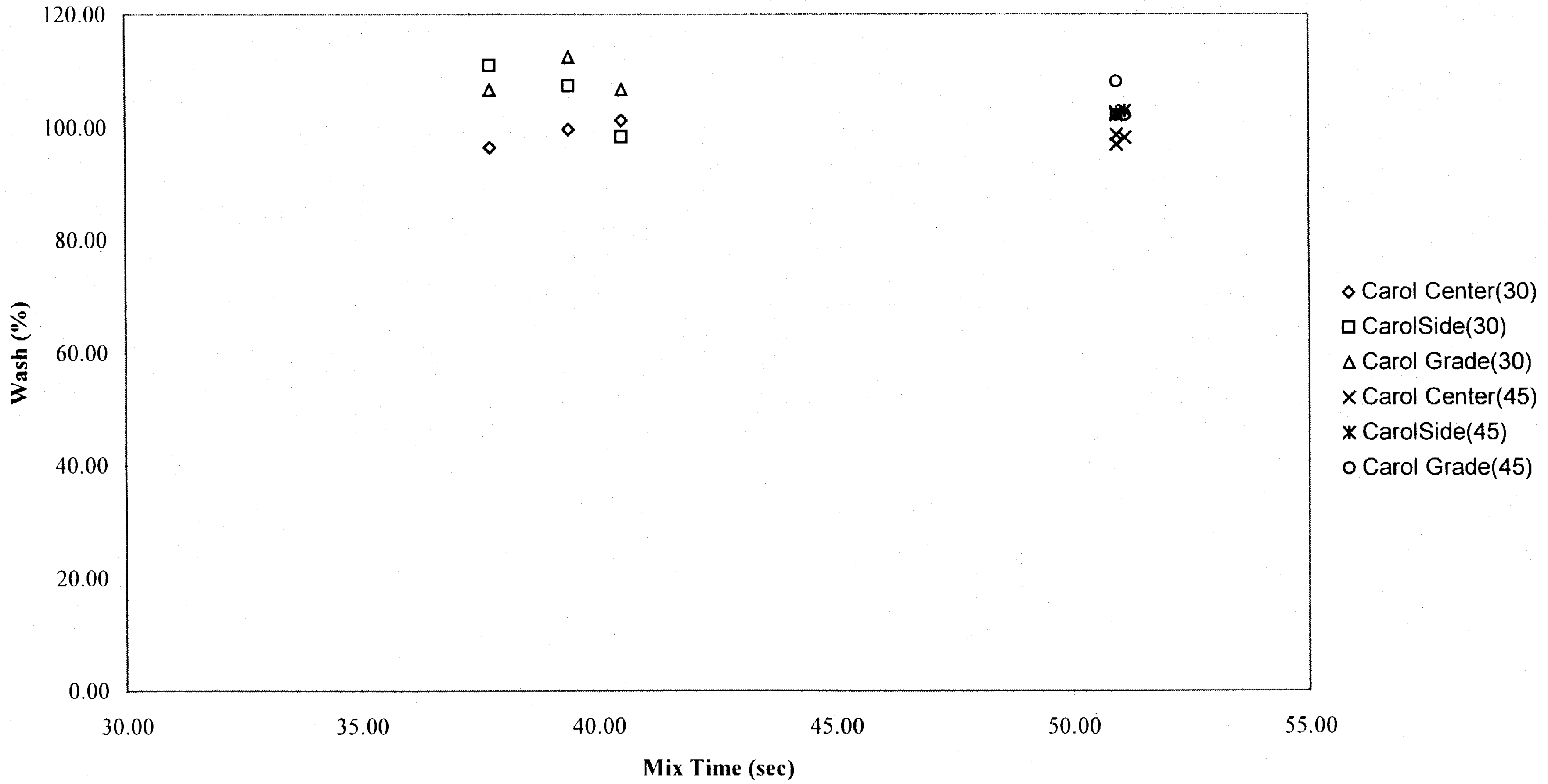


Figure B-5. Mix Times vs Unit Weight - Carlisle Iowa DOT Mix

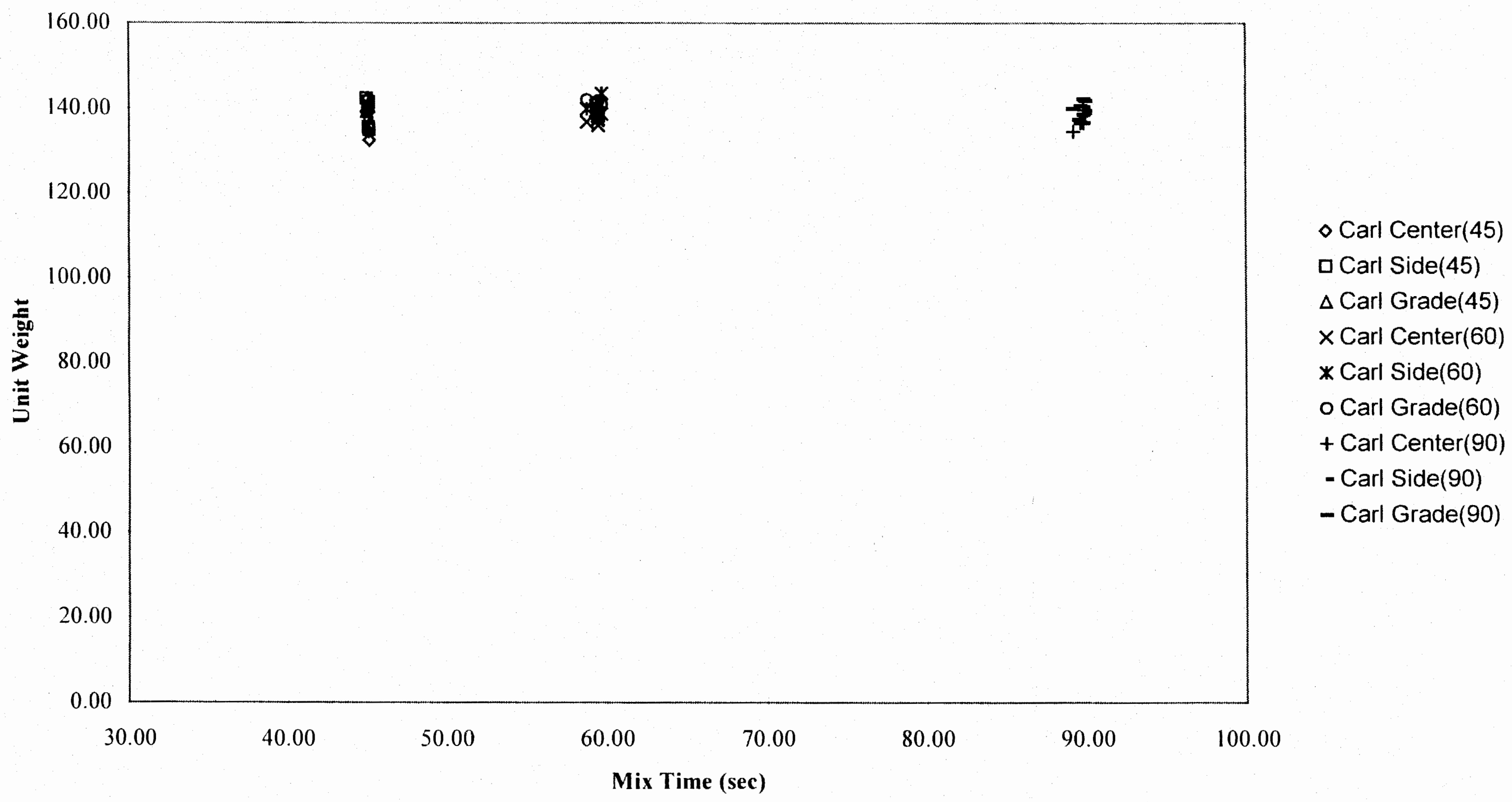


Figure B-6. Mix Time vs Slump - Carlisle Iowa DOT Mix.

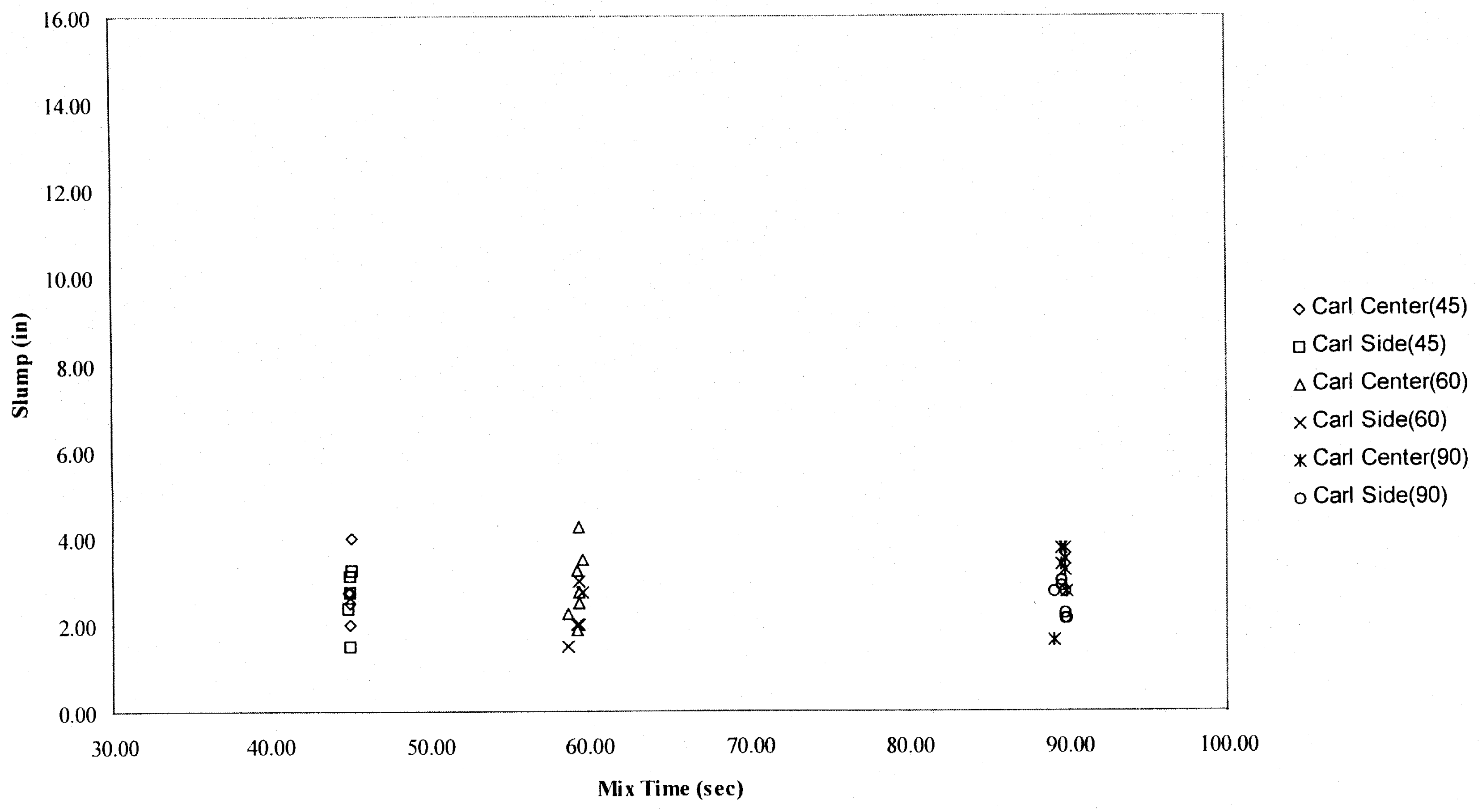


Figure B-7. Mix Time vs Air Content - Carlisle Iowa DOT Mix.

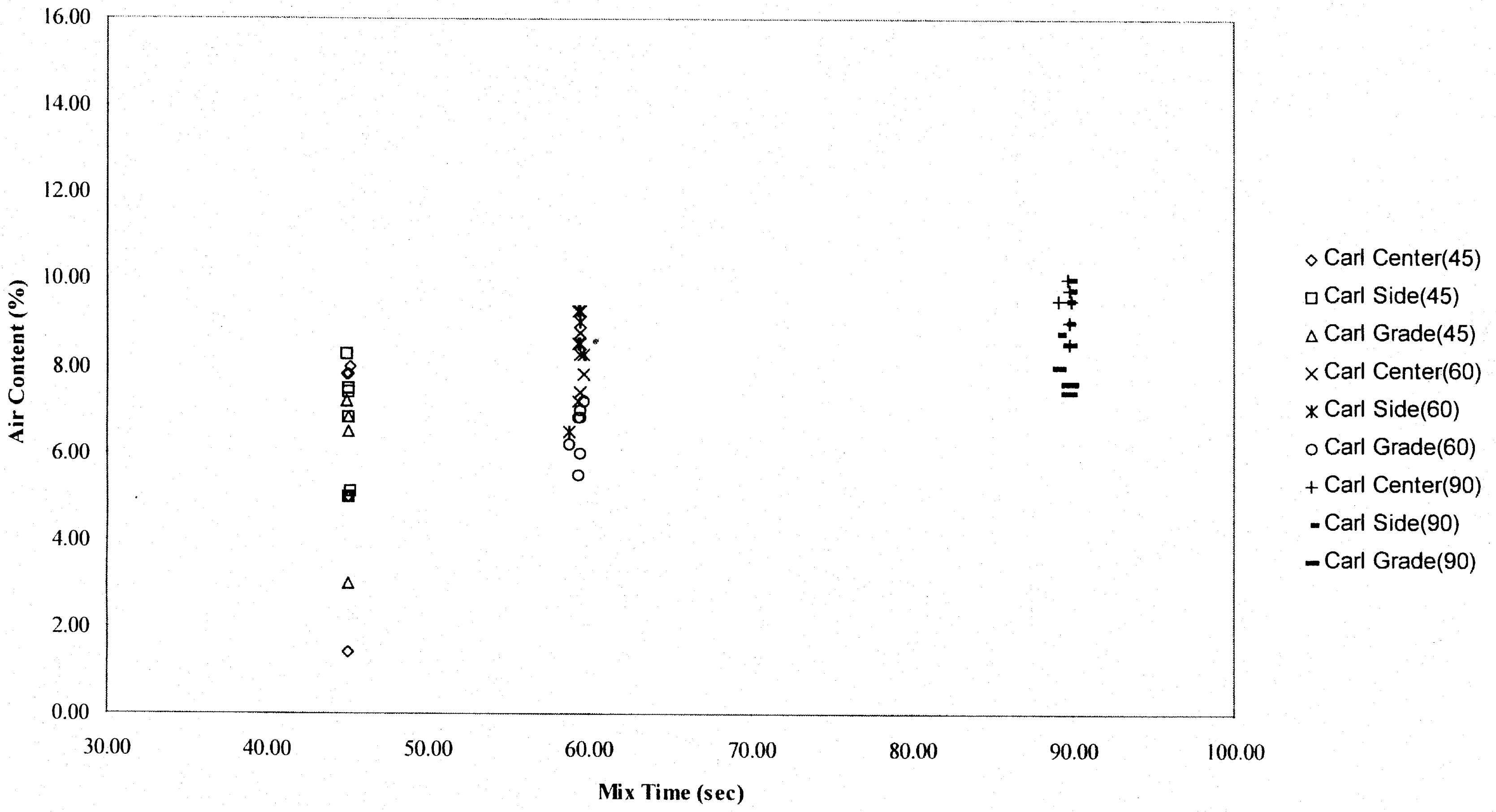


Figure B-8. Mix Time vs Wash - Carlisle Iowa DOT Mix.

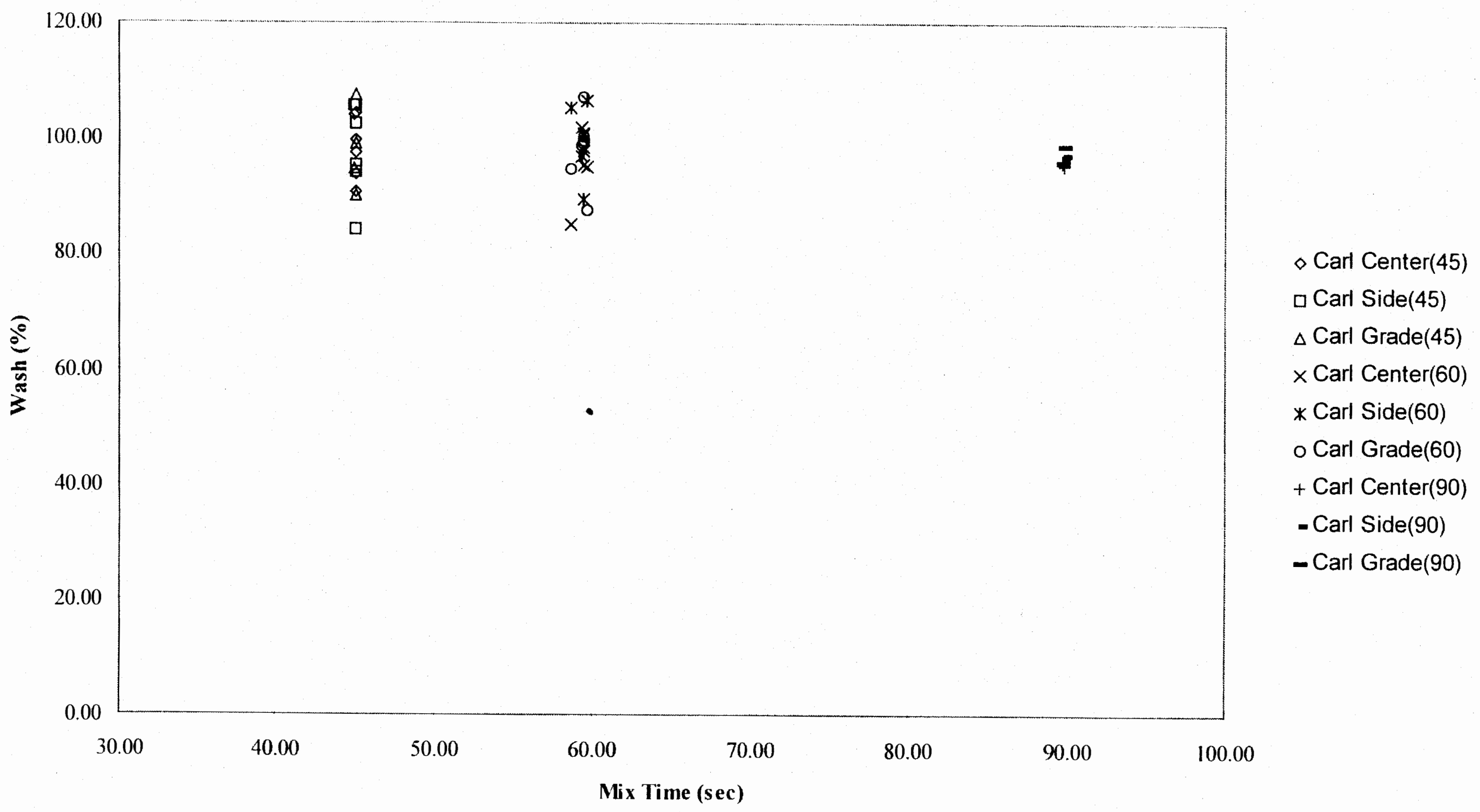


Figure B-9. Mix Times vs Unit Weight - Carlisle Contractor Mix

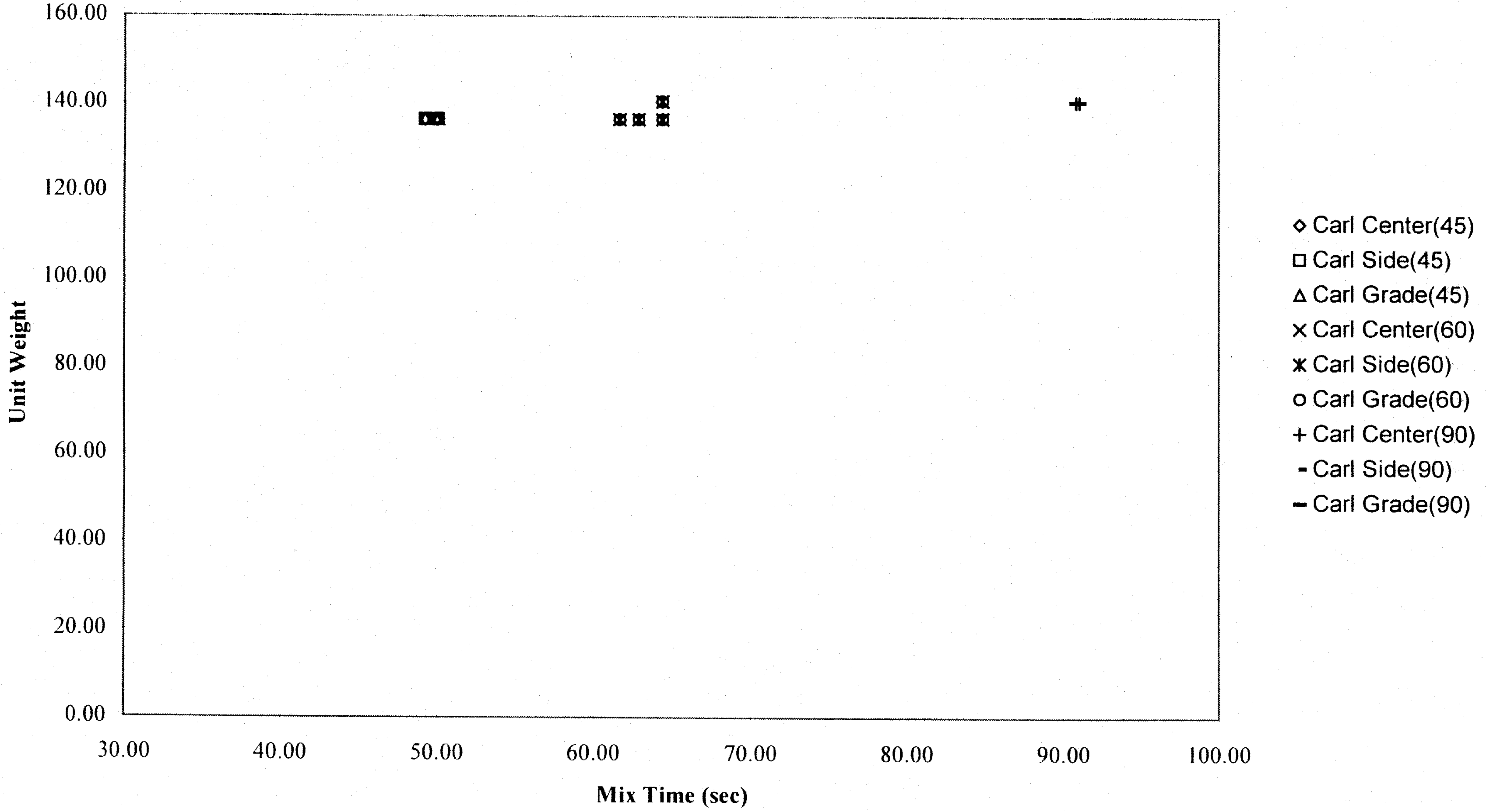


Figure B-10. Mix Times vs Slump - Carlisle Contractor Mix

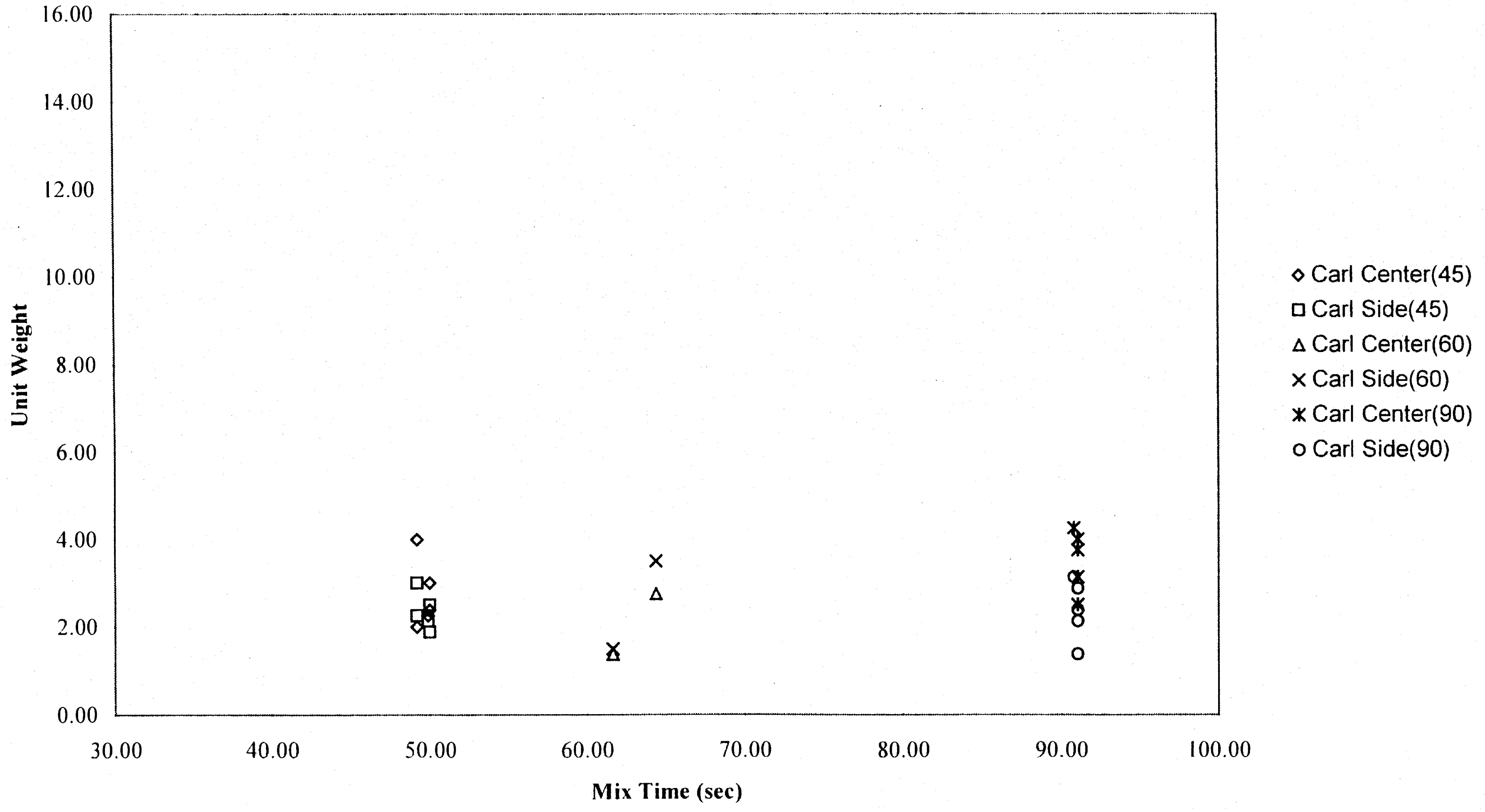


Figure B-11. Mix Time vs Air Content - Carlisle Contractor Mix.

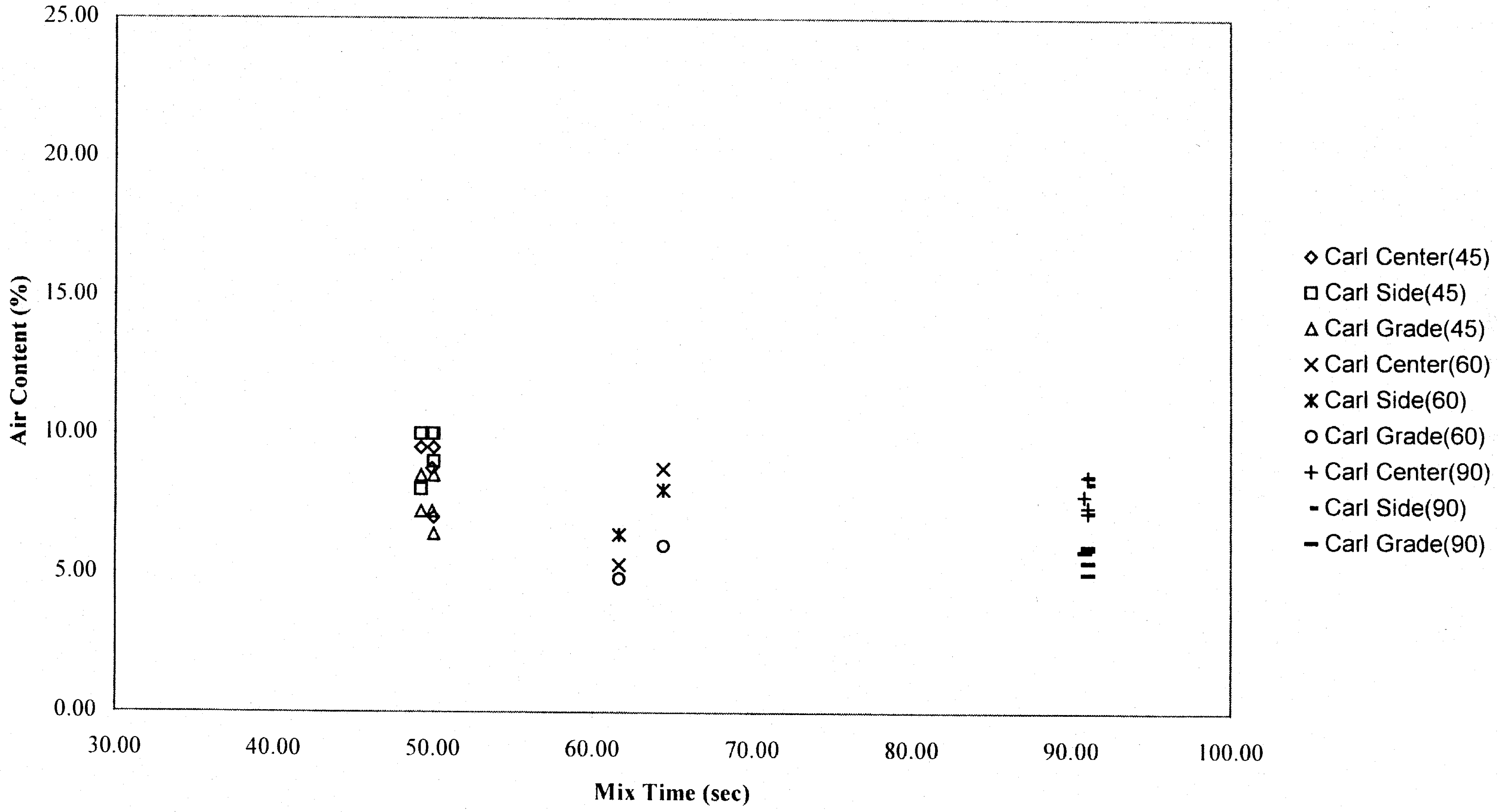


Figure B-12. Mix Time vs Wash - Carlisle Contractor Mix.

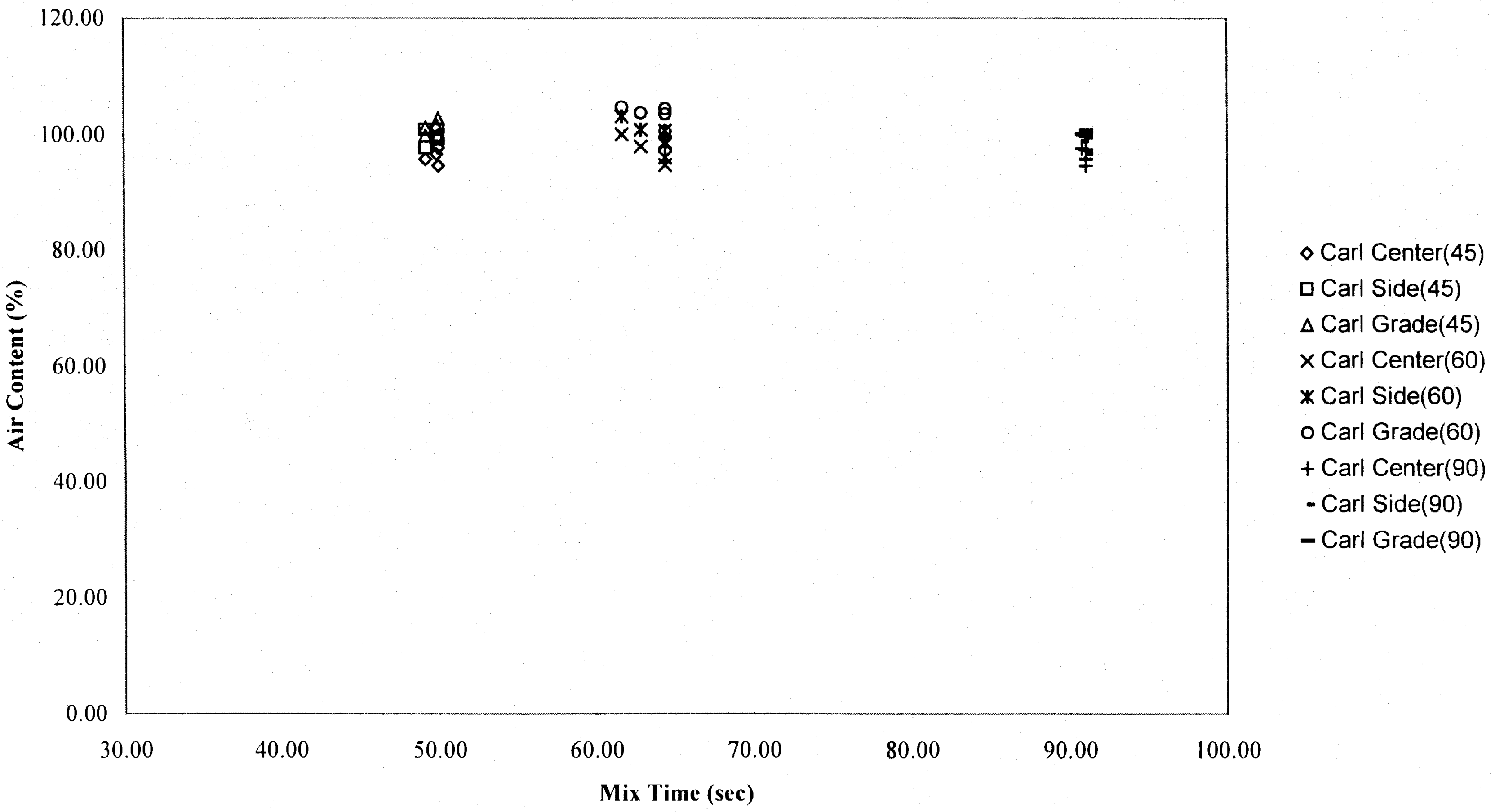


Figure C-1. Mix Time vs Concrete Cylinder Strength - Carroll Iowa DOT Mix.

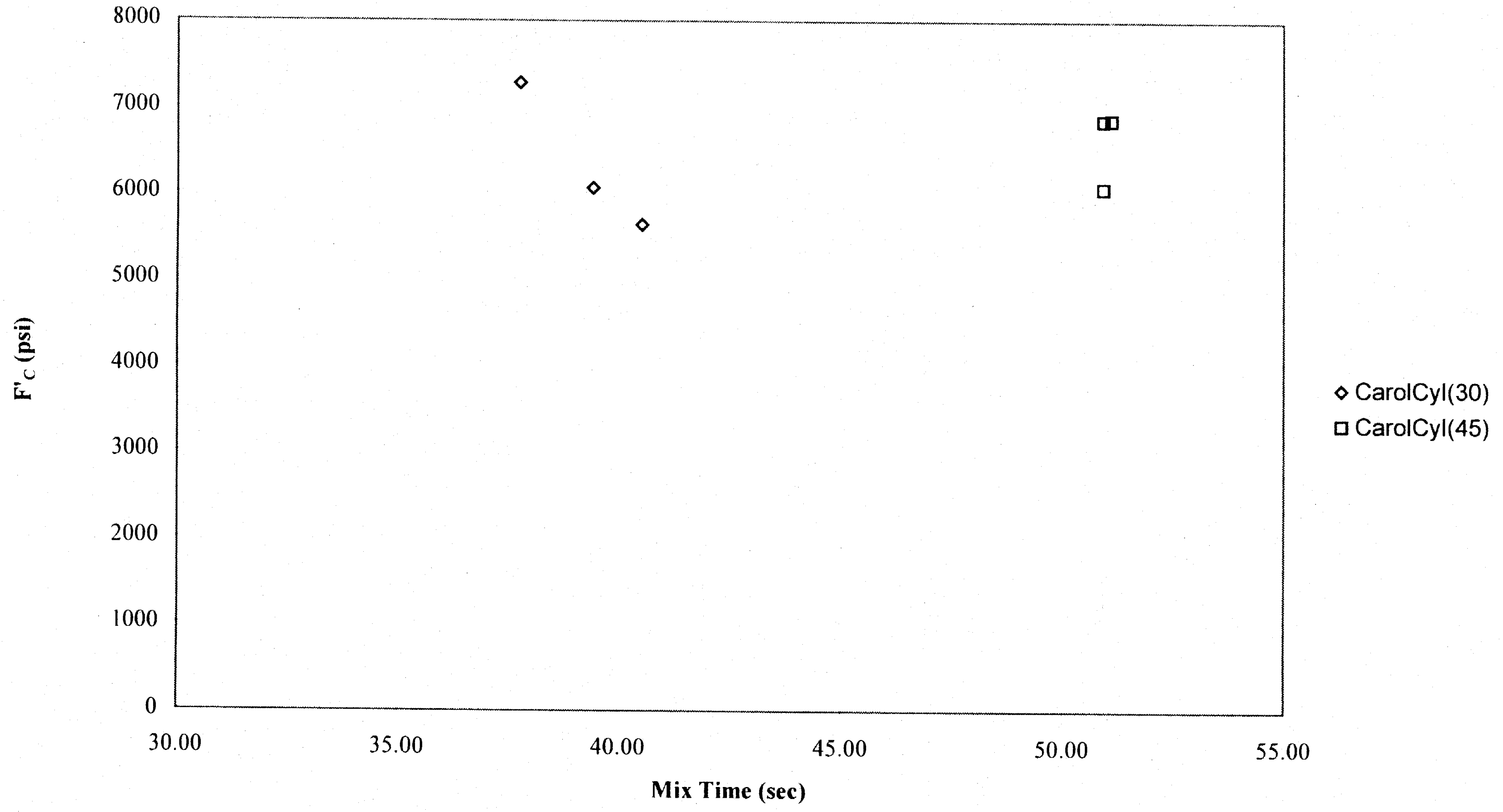


Figure C-2. Mix Time vs Concrete Core Strength - Carroll Iowa DOT Mix.

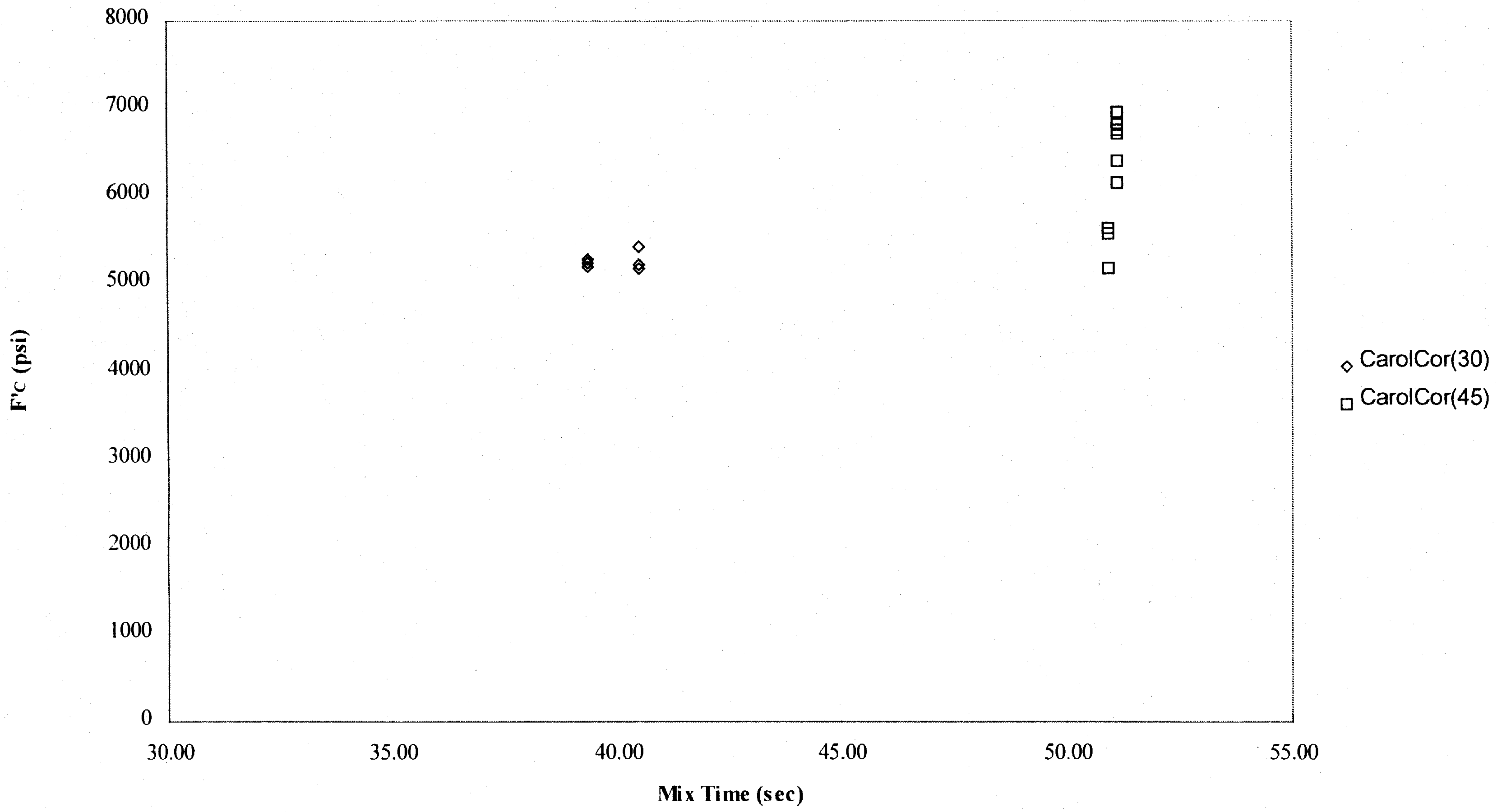


Figure C-3.   Mix Time vs Concrete Cylinder Strength - Carlisle Iowa DOT Mix.

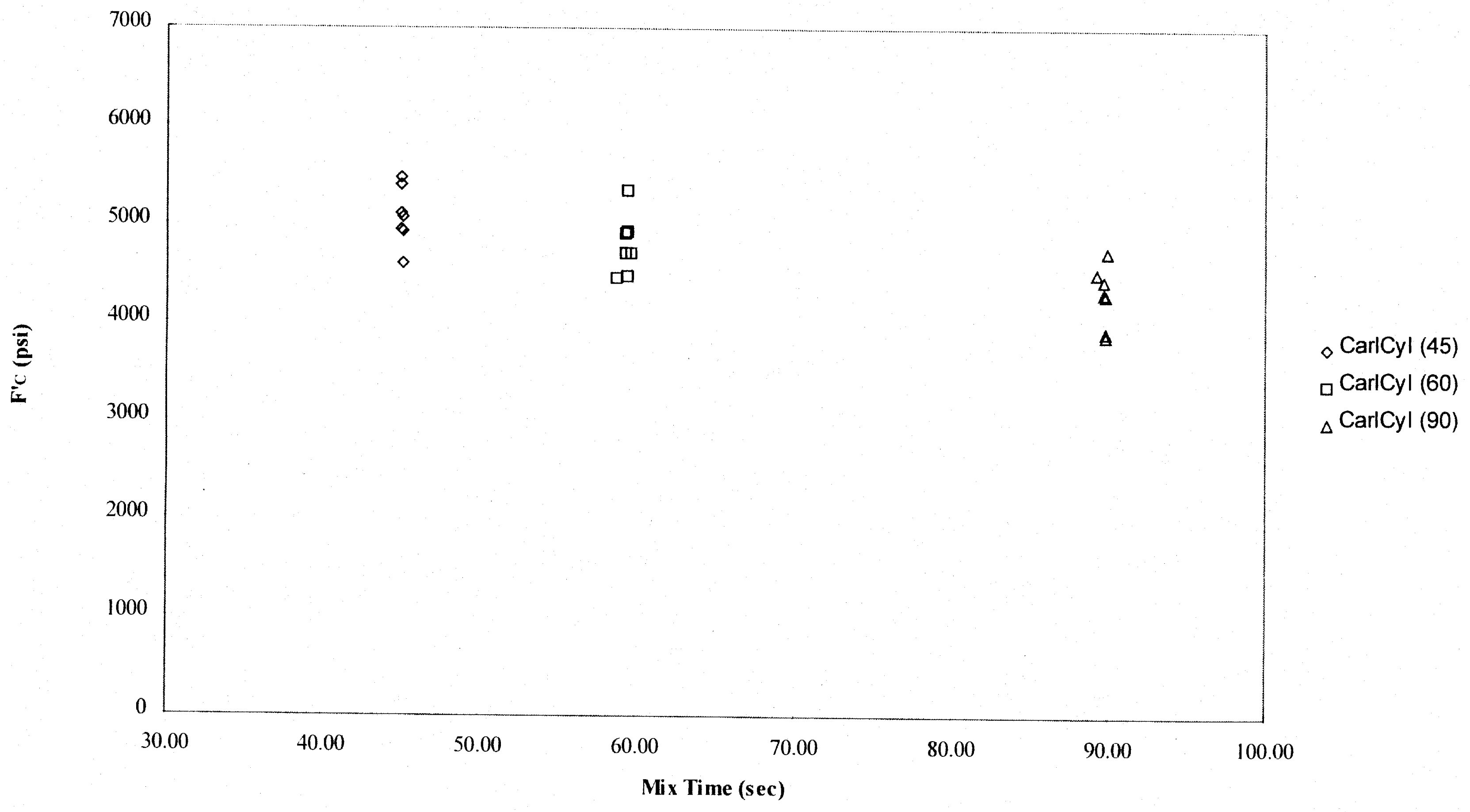


Figure C-4. Mix Time vs Concrete Core Strength - Carlisle Iowa DOT Mix.

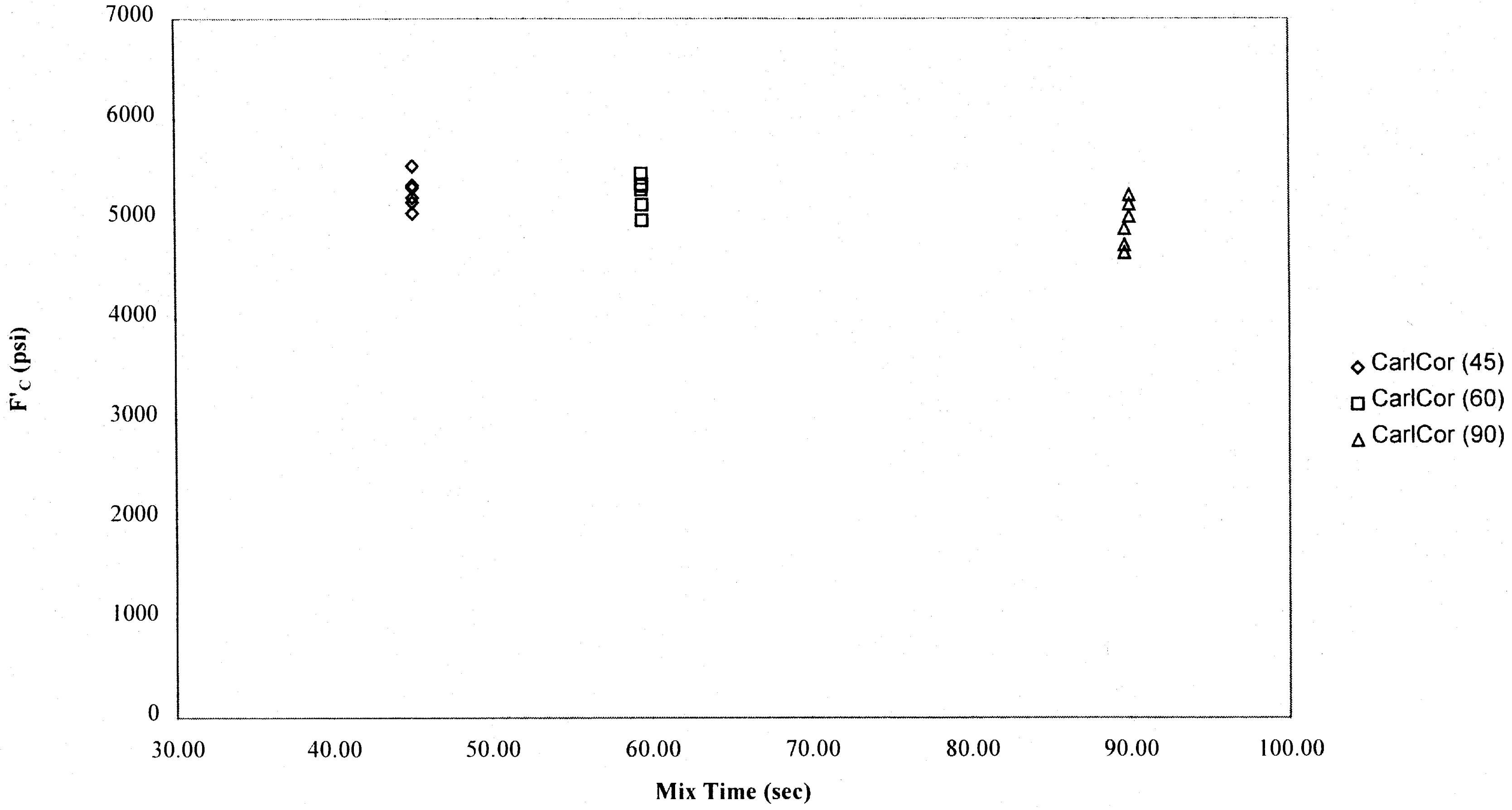


Figure C-5. Mix Time vs Concrete Cylinder Strength - Carlisle Contractor Mix.

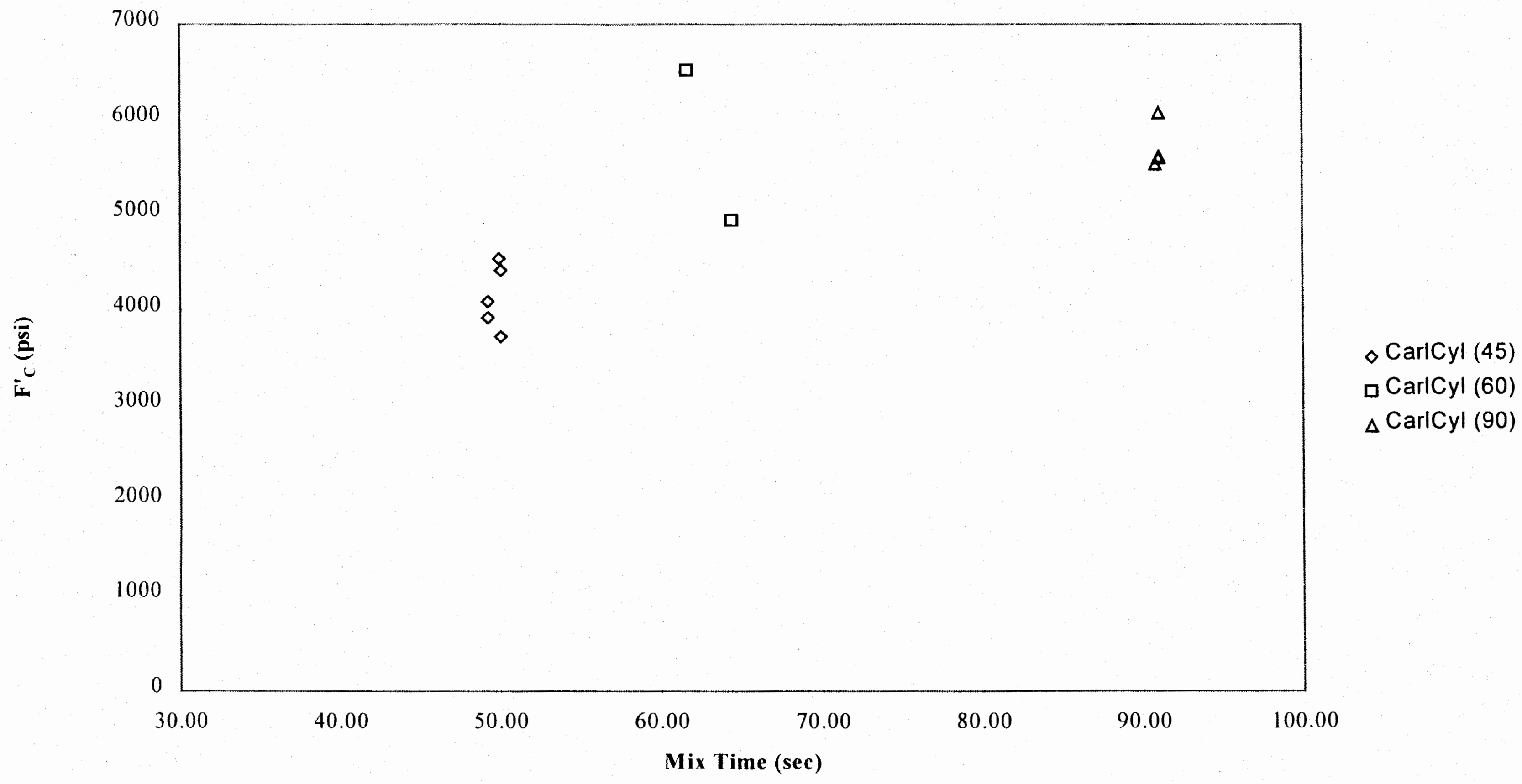


Figure C-6. Mix Time vs Concrete Core Strength - Carlisle Contractor Mix.

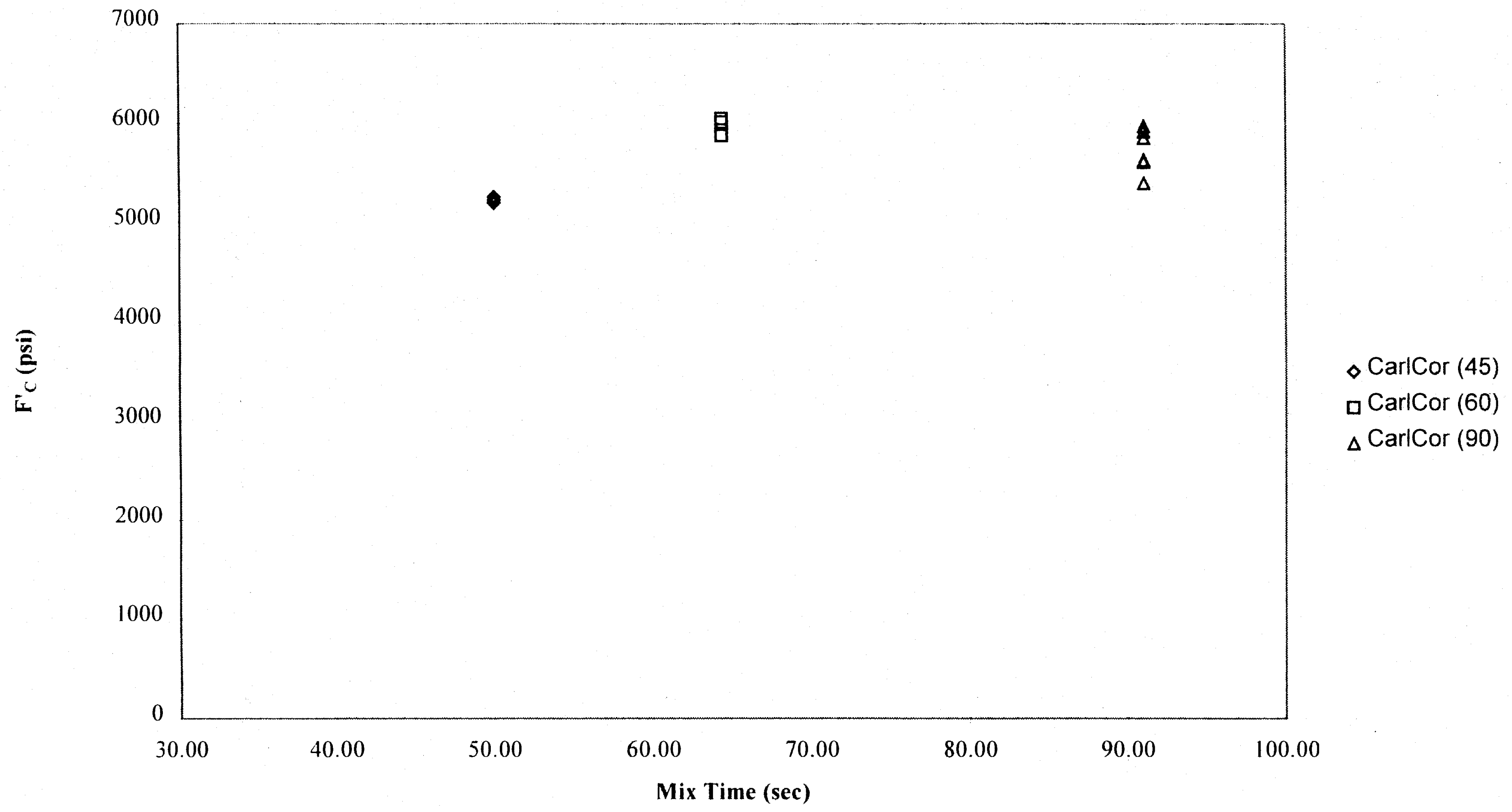


Figure D-1. Mix Times vs Average Air Content for Hardened Concrete Cores - Carroll Iowa Dot Mix

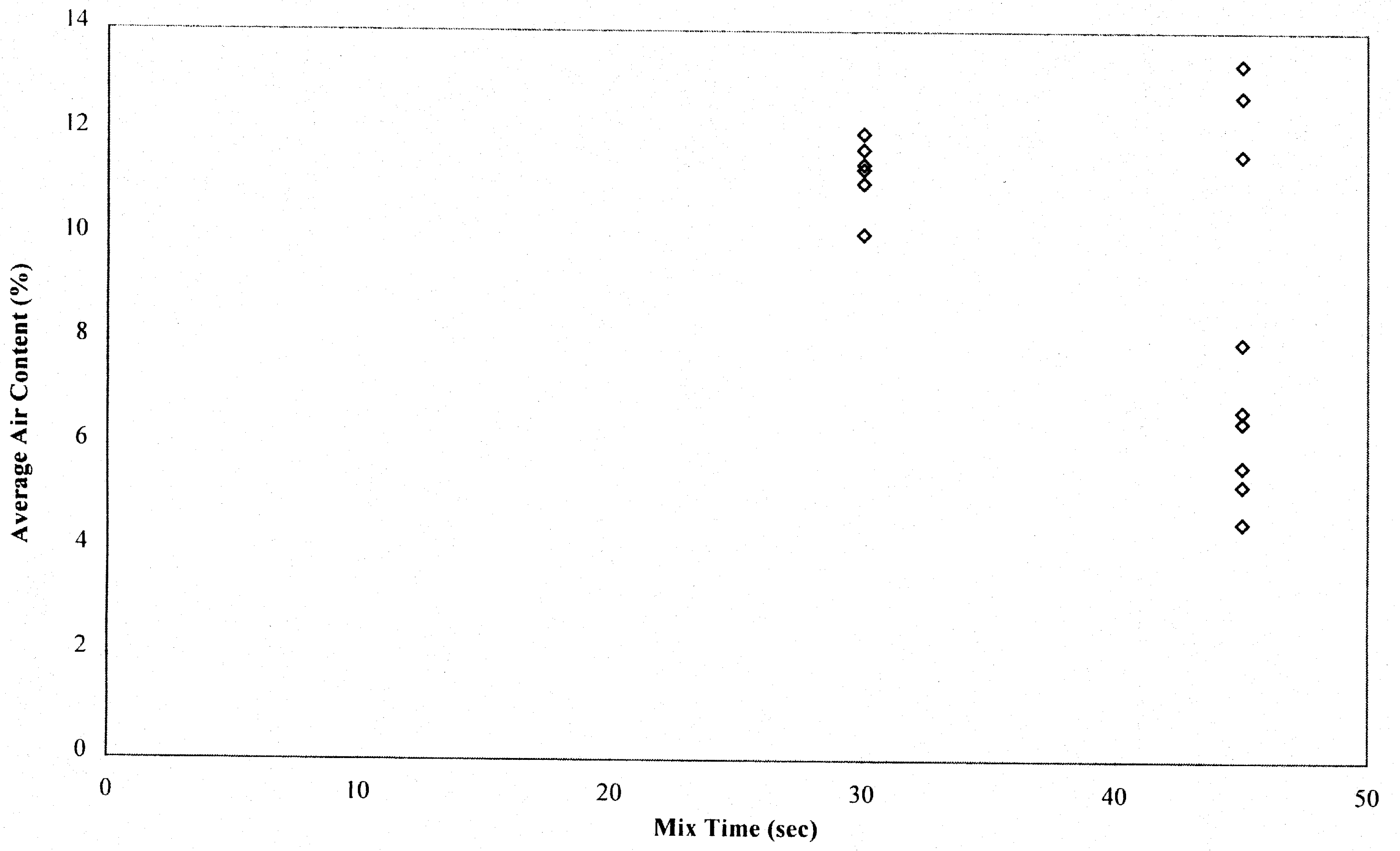


Figure D-2. Mix Times vs Average Air Content for Hardened Concrete Cores - Carlisle Iowa Dot Mix

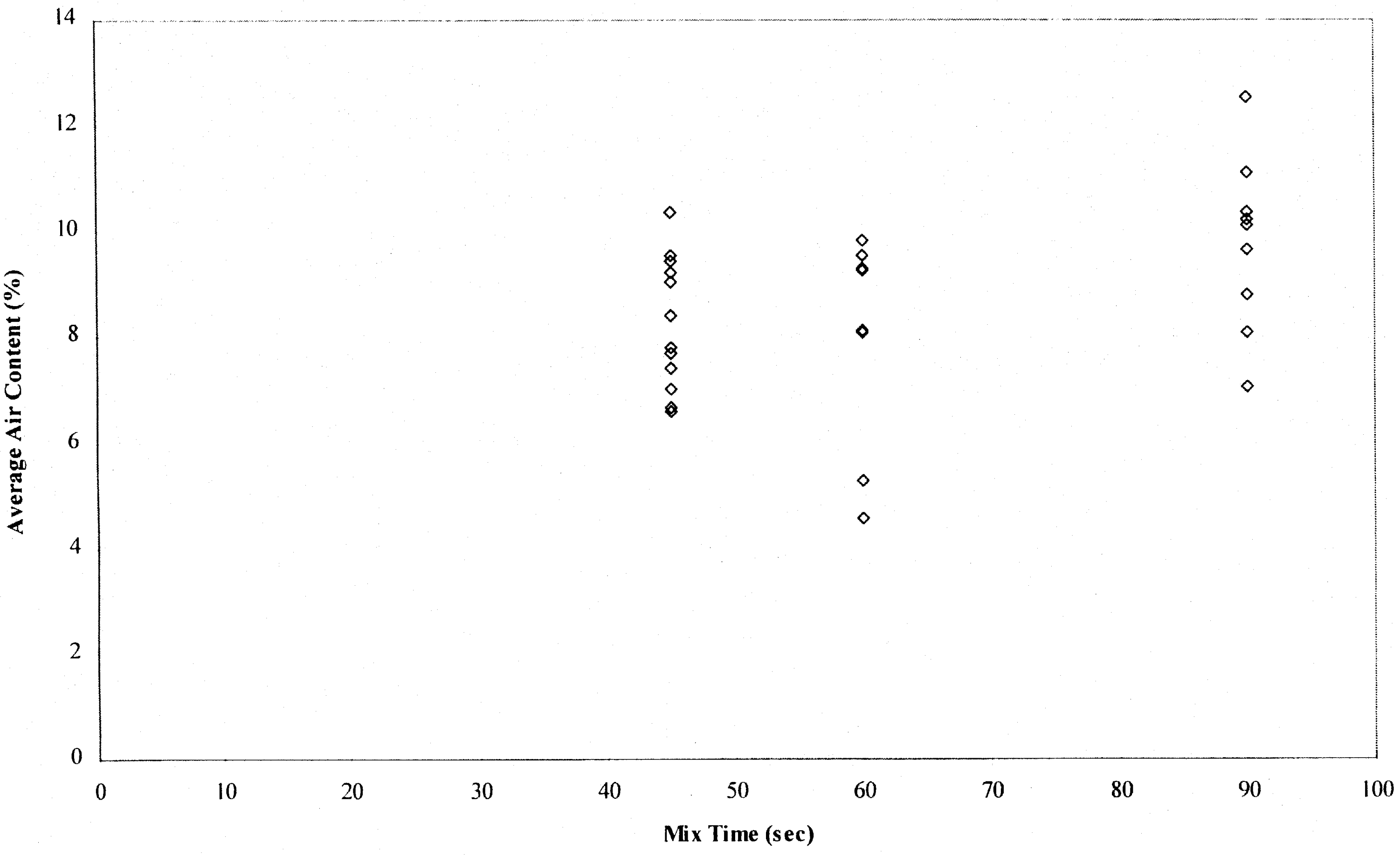


Figure D-3. Mix Time vs Average Air Content for Hardened Concrete Core - Carlisle Contractor Mix.