LABORATORY STUDY OF COMPRESSIVE STRENGTH VS MIXING TIME USING SILICA FUME MORTAR

REPORT 95-5
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REPORTING ON WORK PLAN 94-R-15

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS AND RESEARCH DIVISION

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TABLE OF CONTENTS

<u>Note:</u> Values shown in the text are presented in SI (International System) units, with US customary units shown in parentheses. Generally, SI units are direct conversions and should not be considered as the standard, in referenced specifications.

EXECUTIVE SUMMARY

During a recently completed Materials and Research Division testing program, lower than anticipated strengths were encountered in concrete batches containing a densified silica fume admixture. Information obtained as part of the investigation indicated that mixing times or mixing energy may have influenced the results, citing incomplete dispersion of the silica fume as a possible cause.

This investigation was organized in an attempt to develop a relatively quick and easy test to assess the need for increased mixing energy when silica fume products are used. If successful, the test would permit samples of silica fume products to be obtained and evaluated in one to three days to determine if there was a need for extended mixing.

However, the equipment and materials used in this evaluation provided no clear indication that extended mixing resulted in greater compressive strengths. The mixing energy of the paddle mixer combined with the angularity of the standard sand appeared to adequately disperse the silica fume at all mixing intervals and mixing speeds.

This report recommends that the Agency continue using the currently specified extended mixing intervals with silica fume concrete.

INTRODUCTION

Condensed silica fume (microsilica) is available in many forms as a concrete additive. Suppliers may furnish the material as a slurry; as a dry product in densified, compacted or pelletized form; or as a component of blended silica fume cement.

During a recently completed testing program, conducted at the Materials and Research Division, concrete batches containing blended silica fume cement, a densified silica fume admixture and a high range water reducing admixture (HRWR) were compared with a reference concrete to examine their performance. Lower than anticipated strengths encountered with the densified silica fume product raised questions regarding batching and mixing procedures and how those procedures affected the performance of various silica fume products.

Information obtained as part of the overall program substantiated concerns about dispersion of silica fume particles and indicated that normal concrete mixing procedures may not be adequate when densified, compacted or pelletized products are used. Increased mixing energy (additional drum revolutions) was recommended and adopted as a specification change, in an effort to resolve the problem.

This investigation was organized in an attempt to develop a laboratory test to assess the need for increased mixing energy when silica fume products are used. If successful, the test would permit samples of silica fume products to be obtained and evaluated in one to three days to determine if there was a need for extended mixing. The three days was considered a reasonable maximum period for use with field operations.

Mortar batches were prepared using blended cement and combinations of type II cement and silica fume admixtures. The blended silica fume cement and Type II cement were obtained from two manufacturers. Silica fume admixtures consisted of two dry products and one slurry and were obtained from two admixture suppliers. The two blended cements each contained about 7 1/2% to 8% silica fume. The dry and slurry silica fume products were used at an addition rate of 7 1/2%. Graded standard sand meeting the requirements of ASTM C-778, Specification for Standard Sand, was used as the fine aggregate in the mortar.

The quantities of materials selected for making nine, 50.8 mm (2") cubes were roughly equivalent to those outlined in AASHTO T 106, Compressive Strength of Hydraulic Cement Mortar (using 2 in. or 50 mm cube specimens). Compressive strengths were determined at one day, two days and three days. A water/(cement + silica fume) ratio of 0.50 was used throughout the evaluation.

A paddle type mixer was used which met the requirements outlined in AASHTO T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. Initially, mixing followed the general procedures outlined in AASHTO T 162, with final mixing intervals modified to examine the possible effects of extended mixing on the dispersion of silica fume particles. When approximately equal strengths were encountered early in the program, it was believed the mixing energy of the paddle type mixer and angularity of the standard sand were sufficient to provide complete dispersion of the silica fume products. The investigation was then expanded to examine mixing speed, as well as mixing interval.

During the initial part of the program, identified as **Part 1**, the paddle type mixer was operated at medium speed (285 $\pm$ 10 rpm). Mixing in **Part 2** was accomplished with the mixer operating at slow speed (140 $\pm$ 5 rpm). Final mixing intervals ranged from two to eight minutes.

MATERIALS

The cement and silica fume admixtures selected for use in this evaluation represent products commonly available to ready mix producers in this region. Materials used were as follows:

Fine Aggregate: (ASTM C-778 Graded Standard Sand)

ACCUSAND
Unimin Corporation
Ottawa, Illinois

Cement:

1. Type II

   a. Lafarge Corporation, Northeast Cement
      St. Constant, Quebec

   b. Ciment Quebec
      St. Basile, Quebec

2. Blended Silica Fume Cement

   a. Lafarge Corporation, Northeast Cement
      St. Constant, Quebec

   b. Ciment Quebec
      St. Basile, Quebec

Silica Fume Admixture:

1. Force 10,000 (Slurry)
   W. R. Grace & Co.-Conn.
   Cambridge, Massachusetts

2. Force 10,000 (Dry)
   W. R. Grace & Co.-Conn.
   Cambridge, Massachusetts

3. MB-SF (Dry)
   Master Builders, Inc.
   Cleveland, Ohio

PROCEDURES

Batch quantities selected for this program were roughly equivalent to those outlined in AASHTO T 106 for making nine, 50.8 mm (2") cubes. An approximate water/(cement + silica fume) ratio of 0.50 was used throughout the evaluation. Batch quantities are shown in Table 1, Appendix A.

The paddle type mixer used in this evaluation complied with requirements outlined in AASHTO T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. Mixing procedures also followed the general procedures outlined in AASHTO T 162. The final mixing intervals and speeds were modified to examine the possible effects of different levels of mixing energy on the dispersion of silica fume particles.

In the early part of the investigation, it became apparent that all selected mixing periods were providing approximately equal strengths. The mixing energy of the paddle type mixer and angularity of the standard sand were believed to be sufficient to provide complete dispersion of the silica fume products.

When the initial phase of the program was completed, the study was expanded to include another complete round of tests, but using reduced mixing energy. The initial phase of the evaluation is identified as **PART 1**. The second phase of the evaluation, conducted using reduced mixing energy, is identified as **PART 2**.

Mixing procedures were as follows:

PART 1:

1. Place the dry paddle and the dry bowl in the mixing position in the mixer. Place all the mixing water in the bowl.

2. Add the cement to the water. Start the mixer and mix at the slow speed (140 $\pm$5 rpm) for 30 seconds.

3. Add the entire quantity of sand slowly over a 30 second period, while mixing at slow speed.

4. Stop the mixer, change to medium speed (285 $\pm$ 10 rpm), and mix for 30 seconds.

5. Stop the mixer and let the mortar stand for 1 1/2 minutes. During the first 15 seconds of this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl. Then, for the remainder of this interval, cover the bowl with the lid.

6. Finish by mixing at medium speed (285 $\pm$ 10 rpm) for intervals of 2 minutes, 4 minutes, 6 minutes, and 8 minutes.

PART 2:

1. & 2. Follow same procedures as in **PART 1**.

3. Add the entire quantity of sand slowly over a 30 second period, while mixing at slow speed. Continue mixing at the slow speed (140 ±5 rpm) for an additional 30 seconds.

4. Stop the mixer and let the mortar stand for 1 1/2 minutes. During the first 15 seconds of this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl. Then, for the remainder of this interval, cover the bowl with the lid.

5. Finish by mixing at slow speed (140 ±5 rpm) for intervals of 2 minutes, 4 minutes, 6 minutes, and 8 minutes.

Following mixing, nine 50.8 mm (2") cubes were prepared from each batch and compressive strengths determined at one day, two days and three days. Cubes were prepared and tested in accordance with AASHTO T 106. Compressive strengths at the various mixing intervals were compared for each age of test.

RESULTS & DISCUSSION

Figures 1-SI and 1-US, in Appendix B, display the average results of **PART** 1 tests using cements from Lafarge Corporation, Northeast Cement. Figures 2-SI and 2-US, also in Appendix B, display the average results of **PART** 1 tests using cements from Ciment Quebec. Average results of **PART** 2 tests using cements from Lafarge Corporation, Northeast Cement are shown in Figures 3-SI and 3-US, in Appendix C. **PART** 2 average results using cements from Ciment Quebec are shown in Figures 4-SI and 4-US, also in Appendix C.

With the equipment and materials used in this evaluation, no clear indication was provided that extended mixing resulted in greater compressive strengths. The mixing energy of the paddle mixer combined with the angularity of the standard sand appeared to adequately disperse the silica fume at all mixing intervals and at both mixing speeds.

Compressive strengths using blended cements, were generally equal to or less than other mixtures cured for one day. However, the strengths with blended cements appeared to increase more rapidly and were predominantly greater than those obtained with other mixtures cured for three days.

Although many of the changes were minor, **PART** 2 compressive strengths were greater than **PART** 1 strengths in 66% of the tests. Results were pretty much scattered with no pattern established related to age of test or mixing interval.

Results of tests obtained in this evaluation should not be regarded as being indicative of field operations, which involve central mixers or transit mixers to blend concrete ingredients.

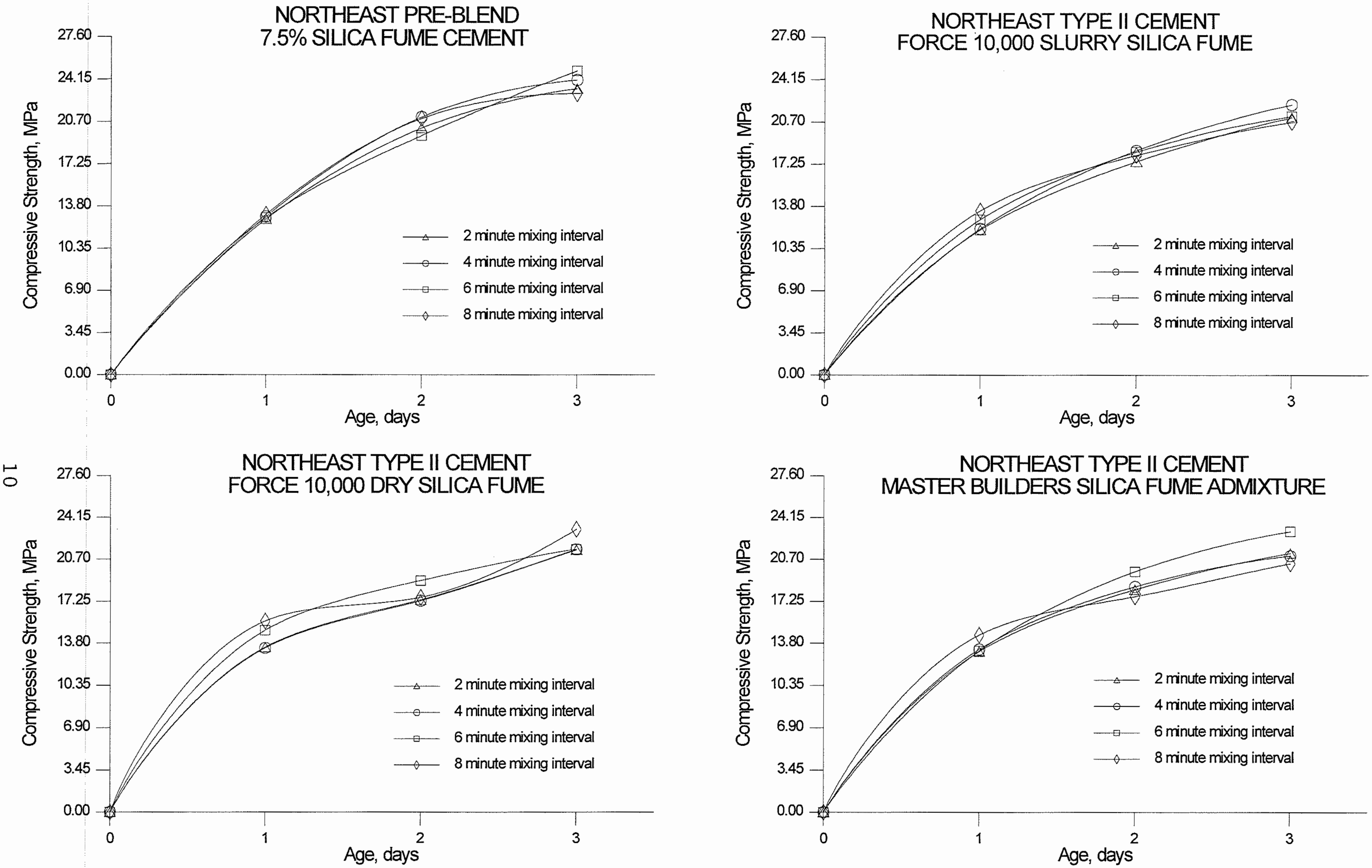
RECOMMENDATIONS

Although this evaluation provided no clear evidence that extended mixing results in increased compressive strengths, it is recommended that the Agency continue using current extended mixing intervals with silica fume concrete. The angularity of the standard sand and aggressive mixing action of the paddle type mixer may have sufficiently dispersed the silica fume products to cause the similarity in compressive strengths at the various mixing intervals and mixing speeds.

TABLE 1

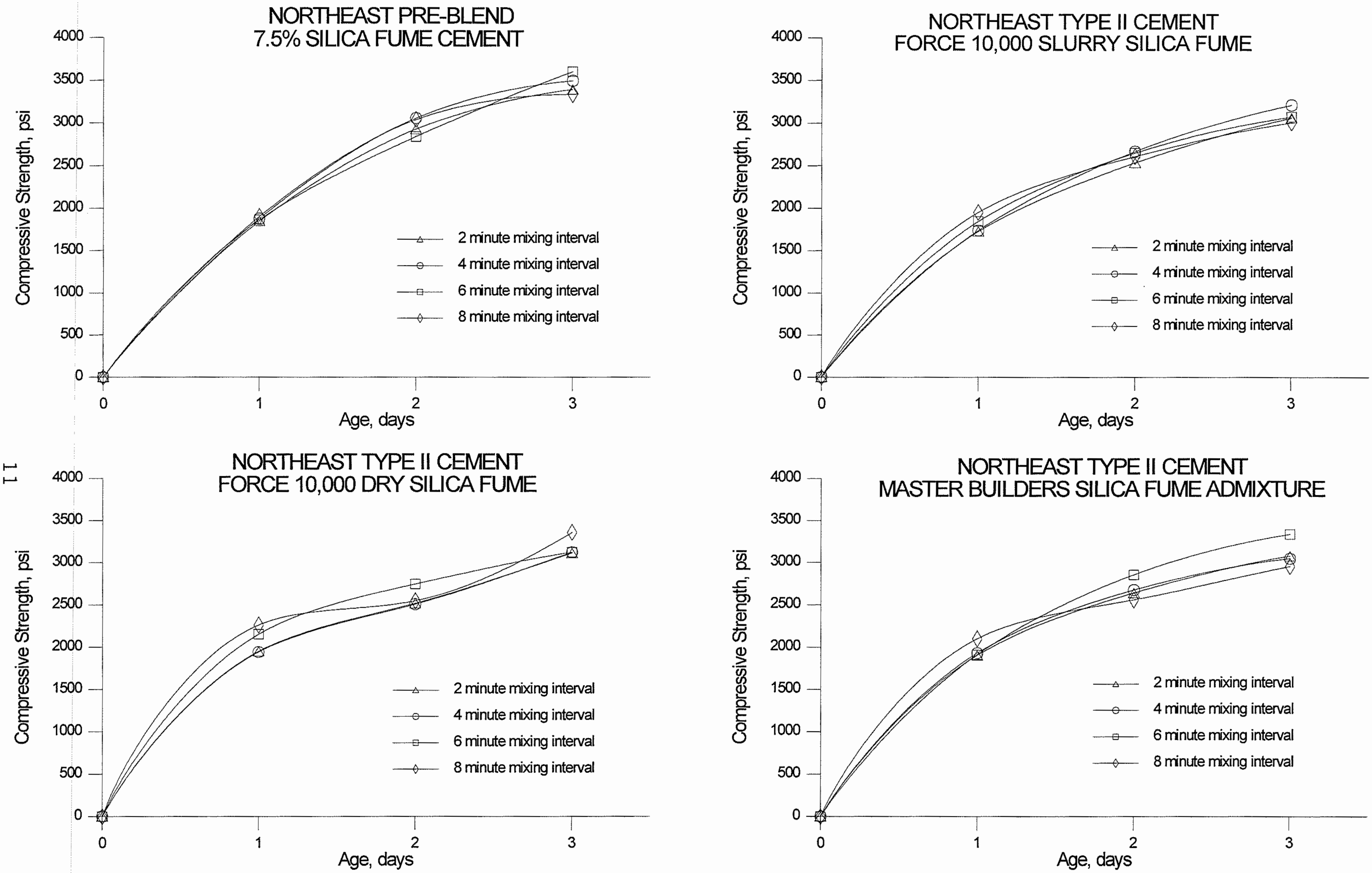
BATCH QUANTITIES - SILICA FUME MORTAR

	Batch Quantities		
	Dry Silica Fume	Slurry Silica Fume	Blended Cement
Graded Standard Sand, g	2069	2069	2069
Type II Cement, g	700	700	
Blended Silica Fume Cement, g			752.5
Dry Silica Fume, g	52.5		
Slurry Silica Fume, g		108	
Water, mL	376	321	376



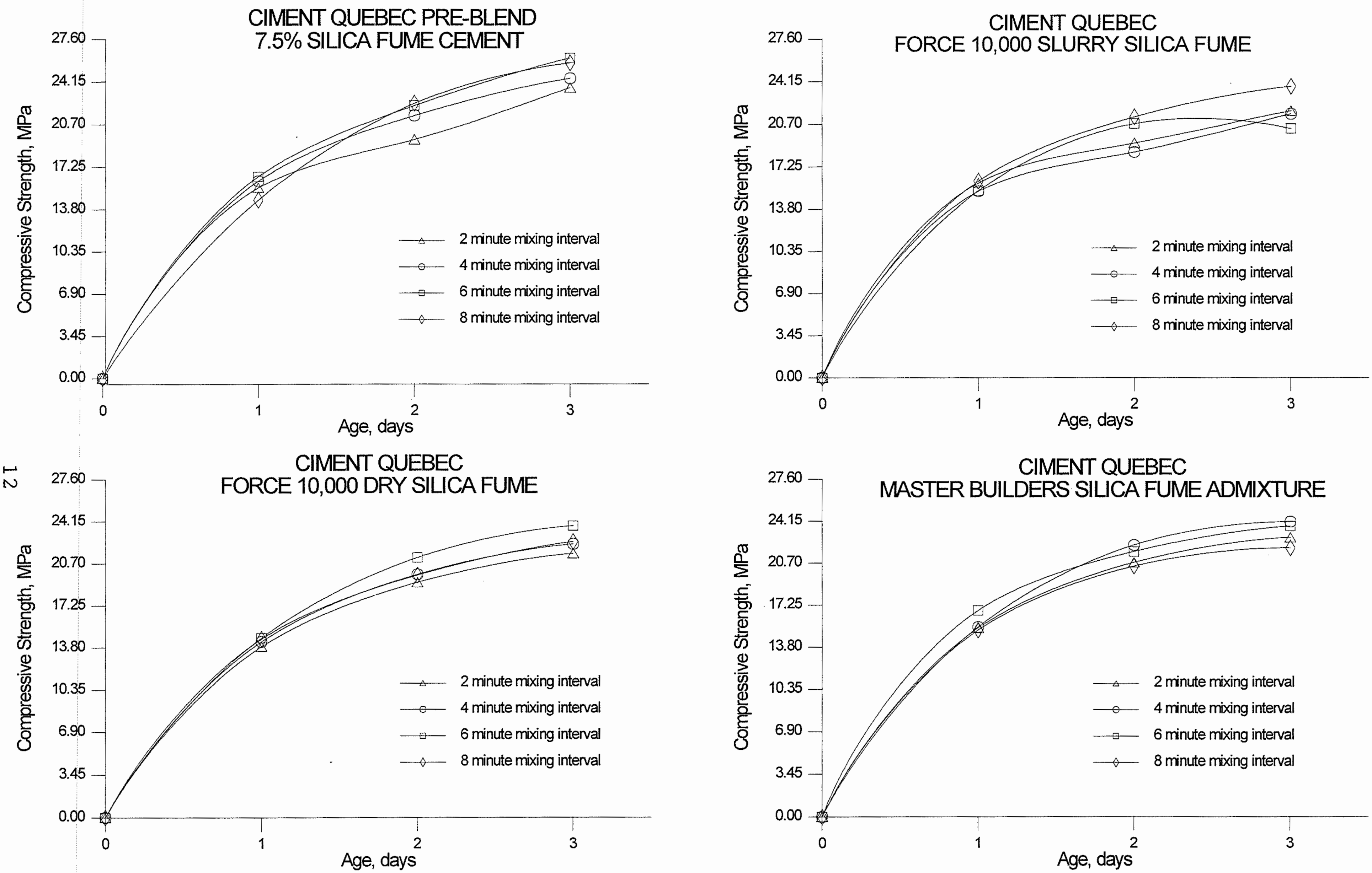
COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 1 - Mixed At Medium Speed - Northeast Cement

FIGURE 1 - SI



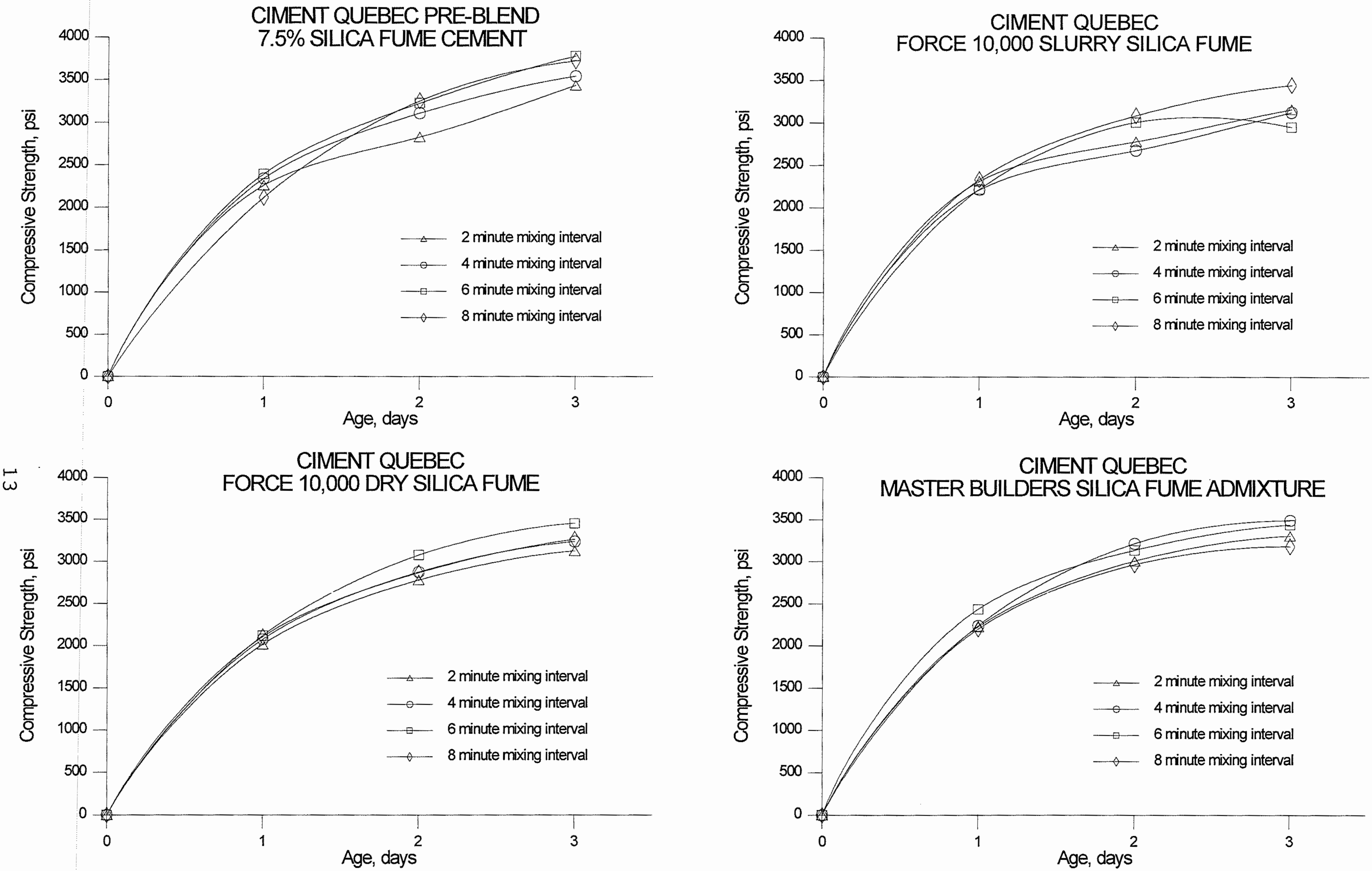
COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 1 - Mixed At Medium Speed - Northeast Cement

FIGURE 1 - US



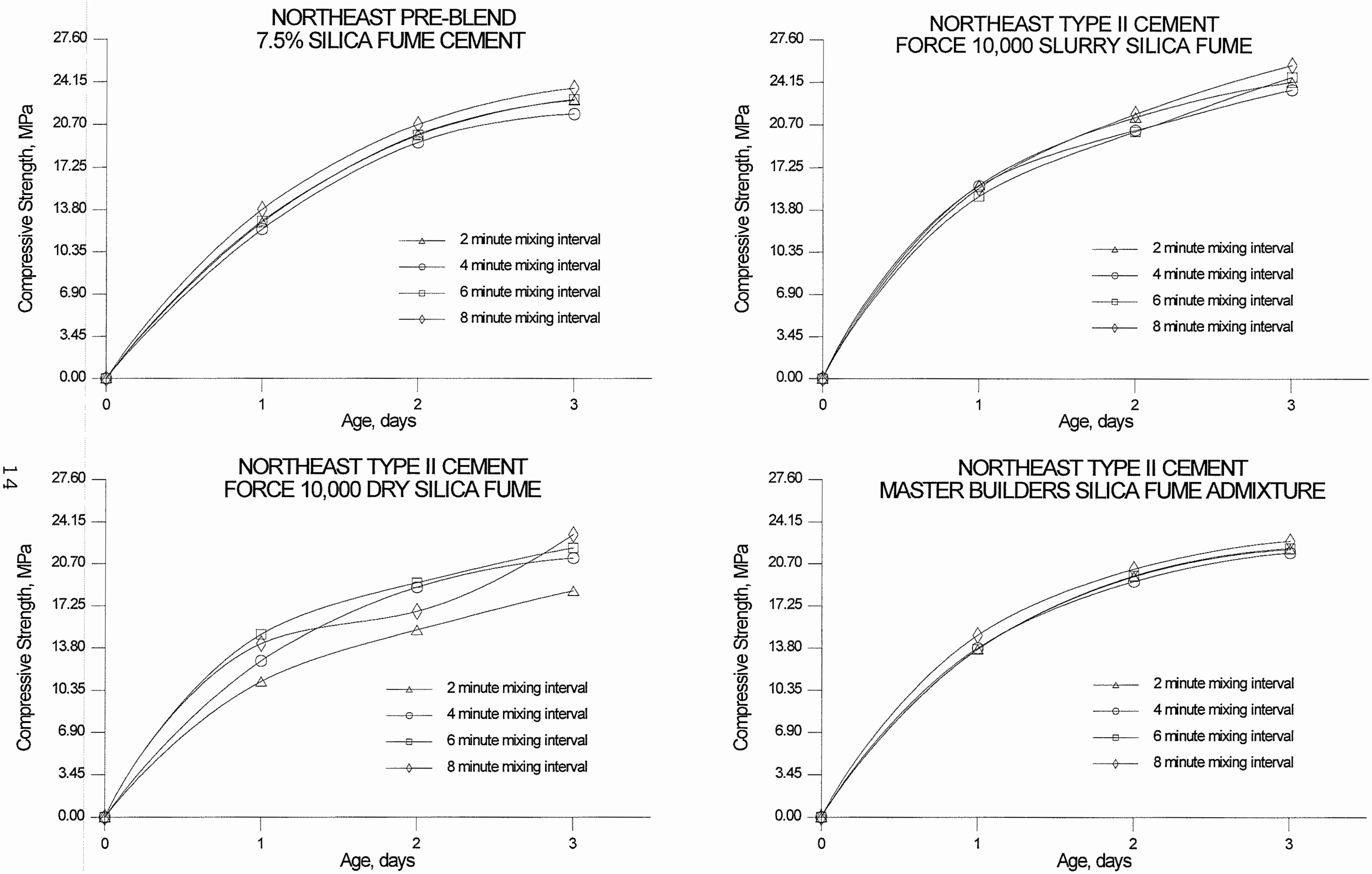
COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 1 - Mixed At Medium Speed - Ciment Quebec

FIGURE 2 - SI



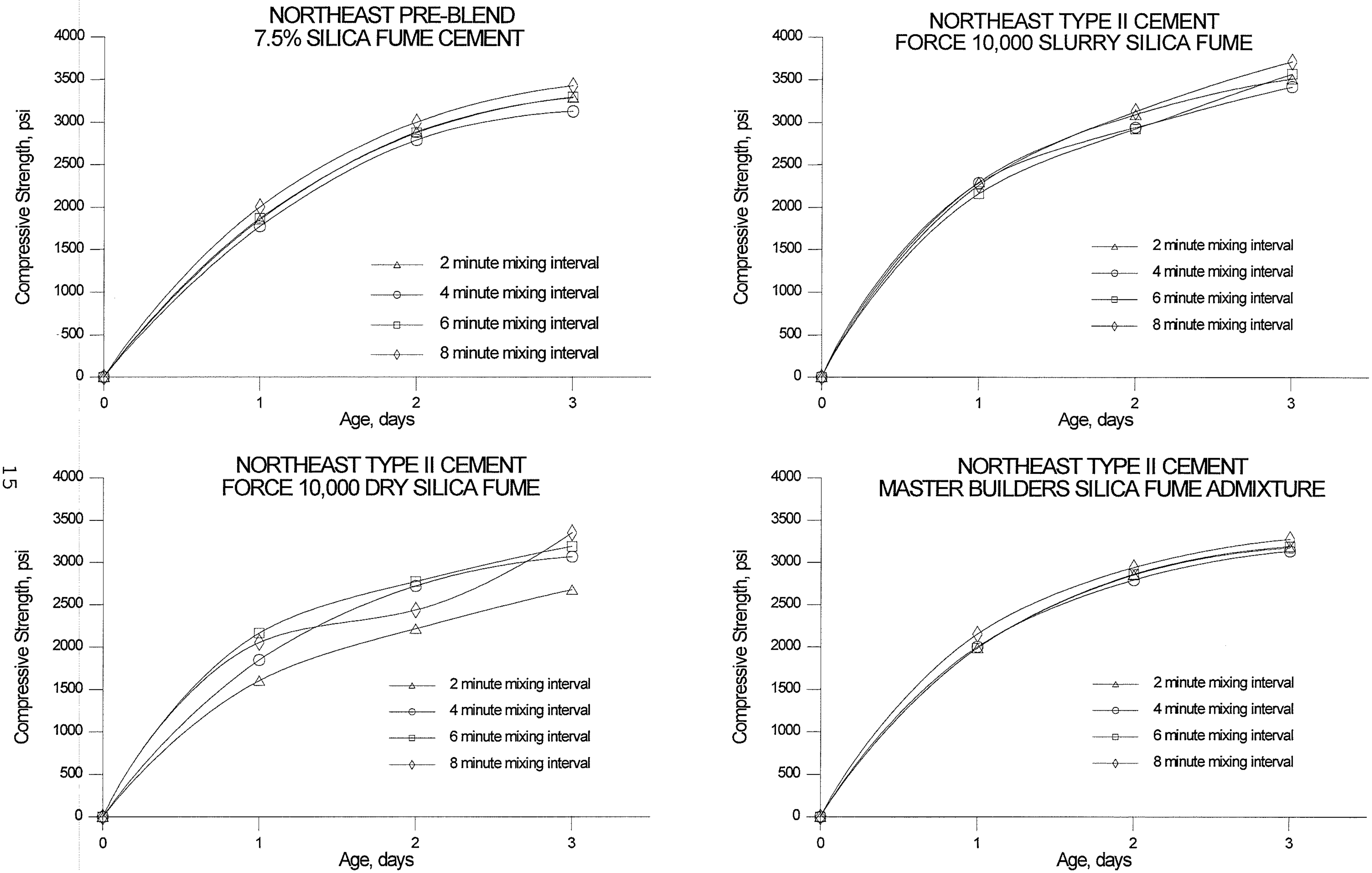
COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 1 - Mixed At Medium Speed - Ciment Quebec

FIGURE 2 - US



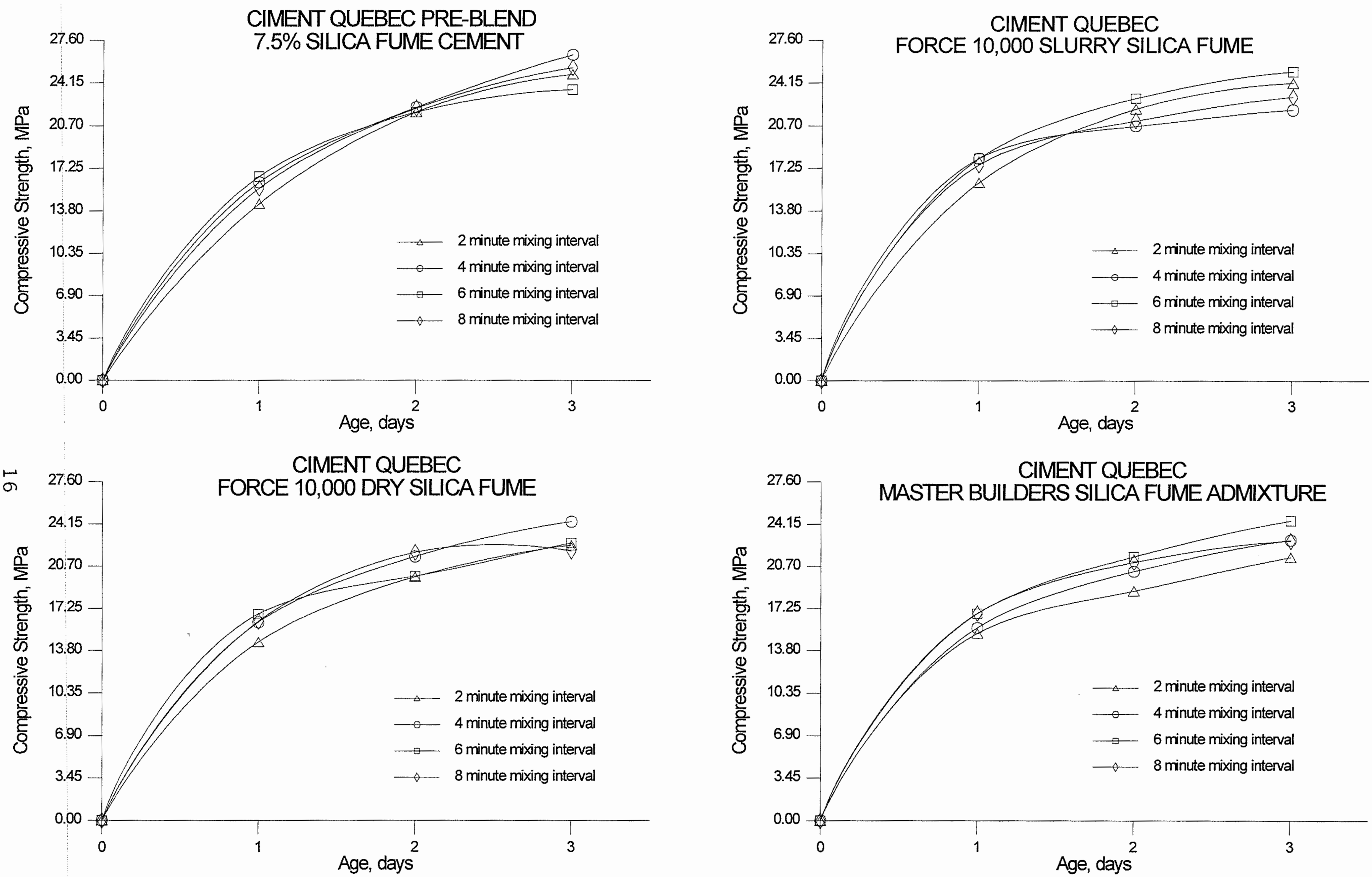
COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 2 - Mixed At Slow Speed - Northeast Cement

FIGURE 3 - SI



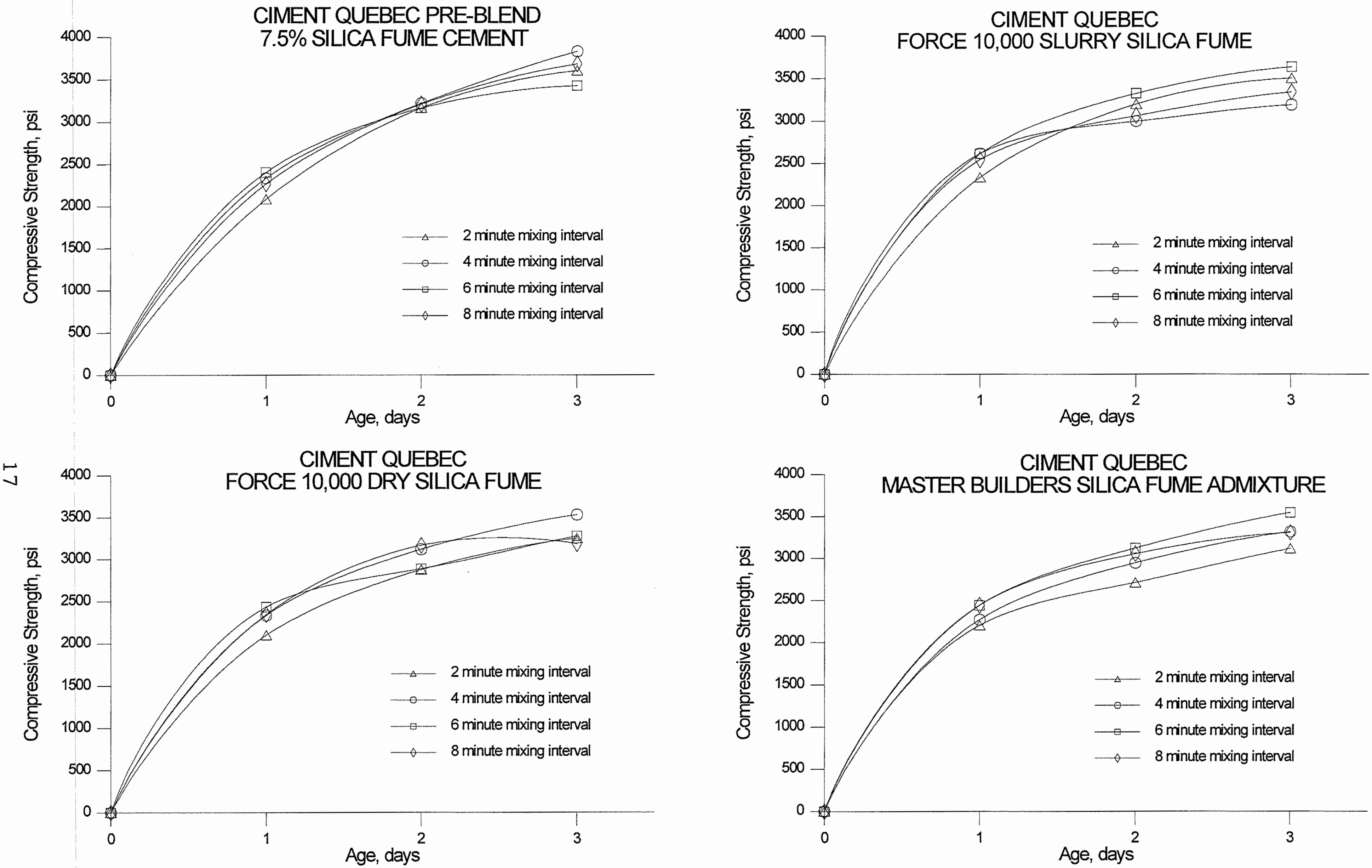
COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 2 - Mixed At Slow Speed - Northeast Cement

FIGURE 3 - US



COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 1 - Mixed At Slow Speed - Ciment Quebec

FIGURE 4 - SI



COMPRESSIVE STRENGTH vs AGE FOR FOUR MIXING INTERVALS
Part 1 - Mixed At Slow Speed - Ciment Quebec

FIGURE 4 - US

TA 565 Rev. 4/79

Prepared By: W. Meyer
Date: 5/19/94
Sheet 1 of 3

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH

RESEARCH INVESTIGATION

Work Plan No. 94-R-15

Subject: Evaluating the need for extended mixing times with silica fume concrete.

Investigation Requested By: Structural Concrete Section Date: N/A

Date Information Required: A.S.A.P.

Purpose of Investigation: This investigation will work towards development of laboratory tests for assessing adequacy of mixing times when silica fume is incorporated into concrete mixtures, as recommended in Report 94-4.

Proposed Tests or Evaluation Procedure: This evaluation will be conducted using blends of cement, Ottawa sand, silica fume, blended silica fume cement and water, as follows:

(see attached sheet)

Proposal Discussed With: R. Hale & L. Willey Projected Mnpr. Requirements: 30 mandays

Investigation To Be Conducted By: Structural Concrete Section

Proposed Starting Date: A.S.A.P. Estimated Completion Date: Sept.15, 1994

Approval/~~Disapproval~~ by Materials & Research Engineer: [signature]

Comments by Materials & Research Engineer:

Materials & Research Division
Agency of Transportation
Date Typed:

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH

RESEARCH INVESTIGATION

Work Plan No. 94-R-15

Proposed Tests or Evaluation Procedure (cont.)

1. All mortars will be blended in a laboratory mixer meeting the requirements of AASHTO T162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency.

2. Materials will be mixed in accordance with "Procedure for Mixing Mortar", as outlined in AASHTO T162, with the finish mixing period extended as necessary to achieve two, four, six and eight minute total mixing times.

3. Prepare nine, two inch cubes for each material, in accordance with AASHTO T106, Compressive Strength of Hydraulic Cement Mortar (Using 2 inch, or 50 mm Cube Specimens).

4. Determine compressive strength in accordance with AASHTO T106, by testing three cubes each at one, two and three days. Compressive strength shall be determined at the required age using a permissable tolerance of $\pm$ 1/2 hour.

5. Proposed Materials:

Portland Cement - Ciment Quebec
Northeast Cement Co.

Blended SF Cement - Ciment Quebec
Northeast Cement Co.

Silica Fume - Master Builders, MB-SF (dry compacted)
W.R. Grace & Co., Force 10,000
(slurry & dry densified)

Fine Aggregate - Standard Ottawa Sand

6. Recommended Quantities:
AASHTO T106 quantities for nine cubes.

Cement	740g
Sand (Ottawa)	2035g (2.75 x mass of cement)
Water (0.485 w/c)	359ml
Total mass	3134g

6. Recommended Quantities (cont.):

Recommended quantities for Silica Fume mortar batches.

Cement	700 g	(752.5g total cement-
*Silica Fume @7.5%	52.5 g	itious material)
Sand (Ottawa)	2069 g	(2.75 x mass of cement-
*Water (0.500 w/c)	376 ml	itious material)
Total mass	3197.5 g	

*Note: The mass shown represents the dry or solid silica fume quantity. When a slurry product is used, the quantities of the product and water must be adjusted to reflect the solids vs liquids portions of the material. the total cementitious material mass (752.5g) is to be used when a blended sf cement is being examined.