IMPROVED AGGREGATE GRADATION FOR PORTLAND CEMENT CONCRETE MIXES

Final Report
for
Project HR-563

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Project Development Division

Iowa Department of Transportation

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Research Project HR-563

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TECHNICAL REPORT TITLE PAGE

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8. ABSTRACT

Improving the aggregate gradation for a portland cement concrete mix may result in higher compressive strengths. With an improved gradation, the cement factor may be reduced to achieve a more economical concrete mix since cement is the most expensive component in a portland cement concrete mix. This project located on I-80 westbound in Scott County, Iowa examined three different mixes.

1. Standard Class C mix with project aggregates.
2. Standard Class C mix with an improved aggregate gradation.
3. Standard Class C mix with an improved aggregate gradation and 10% cementitious reduction.

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TABLE OF CONTENTS

DISCLAIMER

Introduction

This research examined the addition of 9.5 mm (3/8") chips to the aggregate in a portland cement concrete mix to achieve an improved gradation. Concrete mixes produced with an improved gradation of aggregates should have greater compressive strengths and improved workability. Three different mixes were placed on this project as follows:

Std. Mix- Standard Iowa D.O.T. "C" mix with project aggregates

Mix 1 - Standard Iowa D.O.T. mix with 35% of the coarse aggregate replaced with 9.5 mm (3/8") chips

Mix 2 - Standard Iowa D.O.T. mix with 35% of the coarse aggregate replaced with 9.5 mm (3/8") chips and 10% cementitious reduction.

Objective

The objective of the research was to evaluate the feasibility of reducing the cement factor in a portland cement concrete mix with an improved gradation and still achieve comparable compressive strengths.

Project Description

The project was located on I-80 from just west of the Stockton Interchange (MP 280.78) to west of the Walcott Interchange (MP 283.23) and at the I-280 Interchange (MP 289.06) in Scott County. (Figure 1) The work involved replacing 4.687 miles of 4-lane interstate highway at two locations. A 305 mm (12 inch) plain doweled and jointed PCC pavement was designed to replace the 35 year old pavement.

The test sections were placed between September 13 and September 15, 1995. The sections are located on the westbound roadway of I-80 at the following locations:

Std. Mix- Station 213+81 to 236+66, and the remainder of project

Mix 1 - Station 190+44 to 213+81

Mix 2 - Station 190+44 to 179+62 and 159+60 to 147+41.

Materials

The following materials were used:

Cement -	LaFarge, Davenport Type I
Fly Ash -	Louisa Class C
Coarse Aggregate -	Linwood Quarry, Scott County (A82008)
Fine Aggregate -	Milan-Big Island, Illinois (AIL504)
Air Entraining -	Daravair 1000, W.R. Grace
Water Reducer -	WRDA-82, W.R. Grace

Refer to Figures 2 and 3 for the concrete absolute volumes and mix proportions.

Scope

The research examined the standard Iowa Department of Transportation Class C concrete mix versus a Class C mix with the gradation modified by the addition of 9.5 mm (3/8") chips and a

Class C mix with the gradation modified by the addition of 9.5 mm (3/8") chips and a 10% cementitious reduction. Two test sections were placed with the modified gradation mixes while the remainder of the project used the standard Class C mix. Nine beams and nine cylinders were cast from each mix type.

Construction

McCarthy Improvement was the successful bidder for the 4.687 mile inlay at two locations. The research sections were placed between September 13th and 15th, 1995. Temperatures during the construction of the research sections ranged from daytime highs of 24 to 29°C (76 to 85°F) and overnight lows of 13 to 16°C (55 to 60°F). Nine beams and nine cylinders were fabricated at the plant from each of the three concrete mixes for 7, 14, and 28 day strengths, air content, and slump were determined for each mix (Figure 4). The plastic air content at the plant was approximately 5% higher than that at the grade due to air loss during transport. All beams and cylinders were covered with plastic and placed in a wet sand pit until they were transferred to the central laboratory in Ames. During transporting to the central lab, the beams and cylinders were covered with wet burlap.

For convenience, the beams and cylinders were fabricated on September 13th from the plant mixed standard Class C concrete mix. The concrete mix exhibited fairly good workability and finishability in the slab.

Mix 1 was placed on September 14th from station 190 + 44 to 213 + 81 westbound. The beams and cylinders were fabricated from the concrete mix with 35% of the coarse aggregate replaced with 9.5 mm (3/8") chips. While fabricating the beams, it was noted that the mix seemed to be harder to move around than the standard concrete mix. This phenomenon may be due to the particle shape, cubical vs. rounded, of the 9.5 mm (3/8") chips or the extra mortar content. It was noted that the finishers had a slight amount of trouble with finishing if they got too far behind the paver, but otherwise the mix was fairly workable in the slab.

Mix 2 was placed on September 15th from station 179 + 62 to 190 + 44 westbound. The conveyor belt that introduced the 9.5 mm (3/8") chips into the plant broke down and paving with this mix was suspended. An additional section of Mix 2 was placed on September 16th from 147 + 41 to 159 + 60 until the 9.5 mm (3/8") chips stockpile was used up. This mix exhibited fairly good workability and finishability.

Strength Testing

Three cylinders and three beams were tested for compression and modulus of rupture from each mix at each of the following times: 7 days, 14 days, and 28 days. The results of the tests are shown in Figure 5. The data is shown in Figure 6 as modulus of rupture versus time and in Figure 7 as compressive strength versus time. Mix 1, with the improved gradation, showed a marked increase in strength over the standard mix with approximately a 34% increase in modulus of rupture and approximately a 30% increase in compressive strength.

Mix 2 with the improved gradation and 10% cementitious reduction exhibited strengths similar to those achieved by the standard mix with the standard gradation. Lowering the cement factor and using a more uniform gradation will allow a more economical concrete mix, since cement is the most expensive component in a concrete mix.

Gradation

The standard mix used in this project was a C3WRC20. The C3 mix uses 55% coarse aggregate and 45% fine aggregate. For mixes 1 and 2, 35% of the coarse aggregate was replaced with 9.5 mm (3/8") chips. The combined gradations for both aggregate blends are shown in Figure 8. The combined aggregate gradation was plotted as percent passing (Figure 9). The plot indicates that the addition of the 9.5 mm (3/8") chips provides a more uniform gradation than the standard aggregate gradation.

Increasing the amount retained on the 9.5 mm (3/8") to 1.18 mm (#16) sieves provides a more uniform aggregate gradation. The percent retained on each sieve was plotted as shown in Figure 10. The plot indicates an increase in material retained on the 4.75 mm (#4) and 2.36 mm (#8) sieves over the standard project aggregates. Using the plot of percent retained on individual sieves is a useful tool in evaluating the combined aggregate particle distribution.

Discussion of Results

The improvement towards a more uniform gradation produces a mix capable of higher compressive and flexural strengths. Reducing the cementitious content of a concrete mix with an improved gradation of aggregates will tend to produce concretes with compressive strengths similar to those achieved by concrete mixes with a more gap graded aggregate structure. This field research verifies research performed in the laboratory[1].

Improving the aggregate gradation of concrete mixes is sometimes difficult due to availability of a aggregate in the 9.5 mm (3/8") and lower sizes. Aggregate producers tend to remove the 9.5 mm (3/8") and lower portions of concrete stone for other purposes. During this project, there was some difficulty acquiring the 9.5 mm (3/8") chips due to the aggregate producer needing the chips at their asphalt plant. The aggregate producers need to be made aware of changes needed in production of concrete stone.

The workability of Mix 1 was somewhat stiff compared to Mix 2, perhaps due to particle shape of the 9.5 mm (3.8") chips or maybe due to excess mortar content. Using a mix design program, such as Shilstone, could help to determine proper aggregate proportions for optimum workability.

Summary and Conclusions

Based on the results of this project, the following is concluded:

1. Higher compressive strengths may be achieved with a more uniform combined gradation of aggregates.

2. Reducing the cement factor in concrete mixes with a more uniform combined gradation of

[1]Ouyang, C., "Coarse Aggregate Gradations for P.C. Concrete", Iowa Department of Transportation, MLR-94-8, 1995, 11 pp

aggregates produces a concrete with compressive and flexural strengths similar to those achieved by concrete mixes with a more gap graded combined gradation of aggregates.

3. Providing a more uniform gradation of combined aggregates does not necessarily achieve a concrete mix with improved workability.

Acknowledgments

The author wishes to extend appreciation to the East Central Iowa Transportation Center Materials personnel for their efforts in this project. We also would like to thank McCarthy Improvement Inc. for their cooperation during this project.

Figure Captions

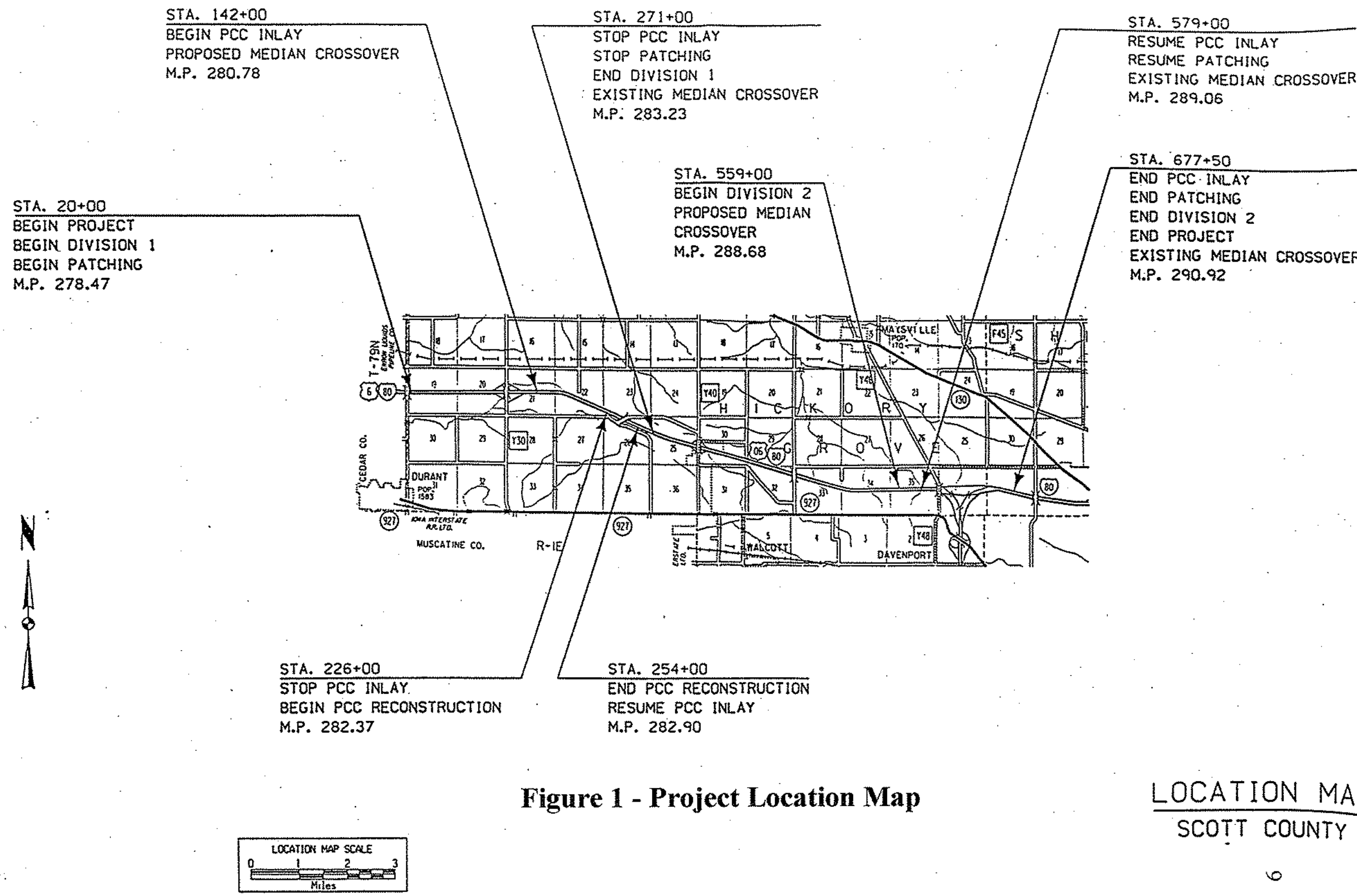


Figure 1 - Project Location Map

LOCATION MAP
SCOTT COUNTY

OFFICE OF DESIGN • CADD • PRODUCED	STATE OF IOWA	FHWA REGION 7	FISCAL YEAR	SCOTT COUNTY	PROJECT NUMBER IM-80-8(160)279--13-82

Figure 2 - Basic Absolute Volumes - IM-80-8(160)279--13-82

	Standard Mix	Mix 1	Mix 2
Cement	0.086	0.086	0.078
Fly Ash	0.025	0.025	0.022
Water	0.146	0.146	0.131
Fine Aggregate	0.307	0.307	0.319
Coarse Aggregate	0.376	0.244	0.2535
3/8" Chips	-	0.132	0.1365
Air	0.06	0.06	0.06

Figure 3 - Mix Proportions (lbs./cu. yd.) - IM-80-8(160)279--13-82

Mix	Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	3/8" Chips Aggregate	Water
Standard	457	114	1381	1698	-	218
Mix 1	457	114	1381	1104	594	218
Mix 2	411	103	1435	1145	616	210

Figure 4 - Mix Locations and Concrete Test Results
IM-80-8(160)279--13-82

Mix	Locations	Slump (in.)	% Air*** at Plant	% Air at Grade
Standard	213+81 to 236+66*	2 1/4"	12.0	7.6
Mix 1	190+44 to 213+81	1/2"	11.5	7.8
Mix 2	190+44 to 179+62 & 159+60 to 147+41**	1 3/4"	12.5	7.6

* Standard mix used throughout project.

** Gap due to conveyor belt break.

*** Lost approxiamtely 5% air on transport.

Figure 5 - Compressive Strength and Flexural Strength

Compressive Strength, psi, 4 1/2" X 9" Cylinders

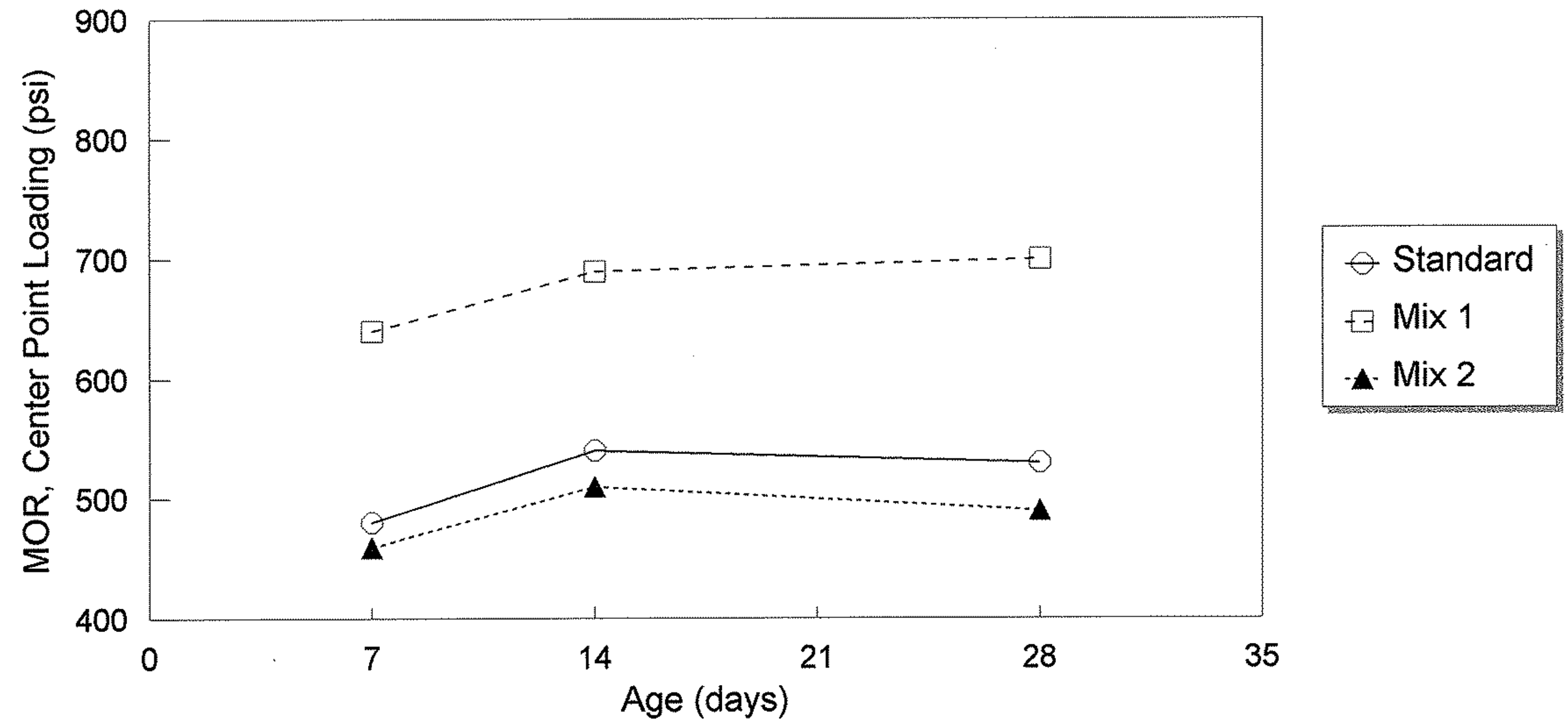
Mix	7 Day	14 Day	28 Day
Standard	3440	4200	4160
Mix 1	4650	5120	5420
Mix 2	3430	3520	4480

Modulus of Rupture, psi, 6" X 6" X 20" Beams

Mix	7 Day	14 Day	28 Day
Standard	480	540	530
Mix 1	640	690	700
Mix 2	460	510	490

Figure 6 - Modulus of Rupture vs. Age

IM-80-8(160)279--13-82



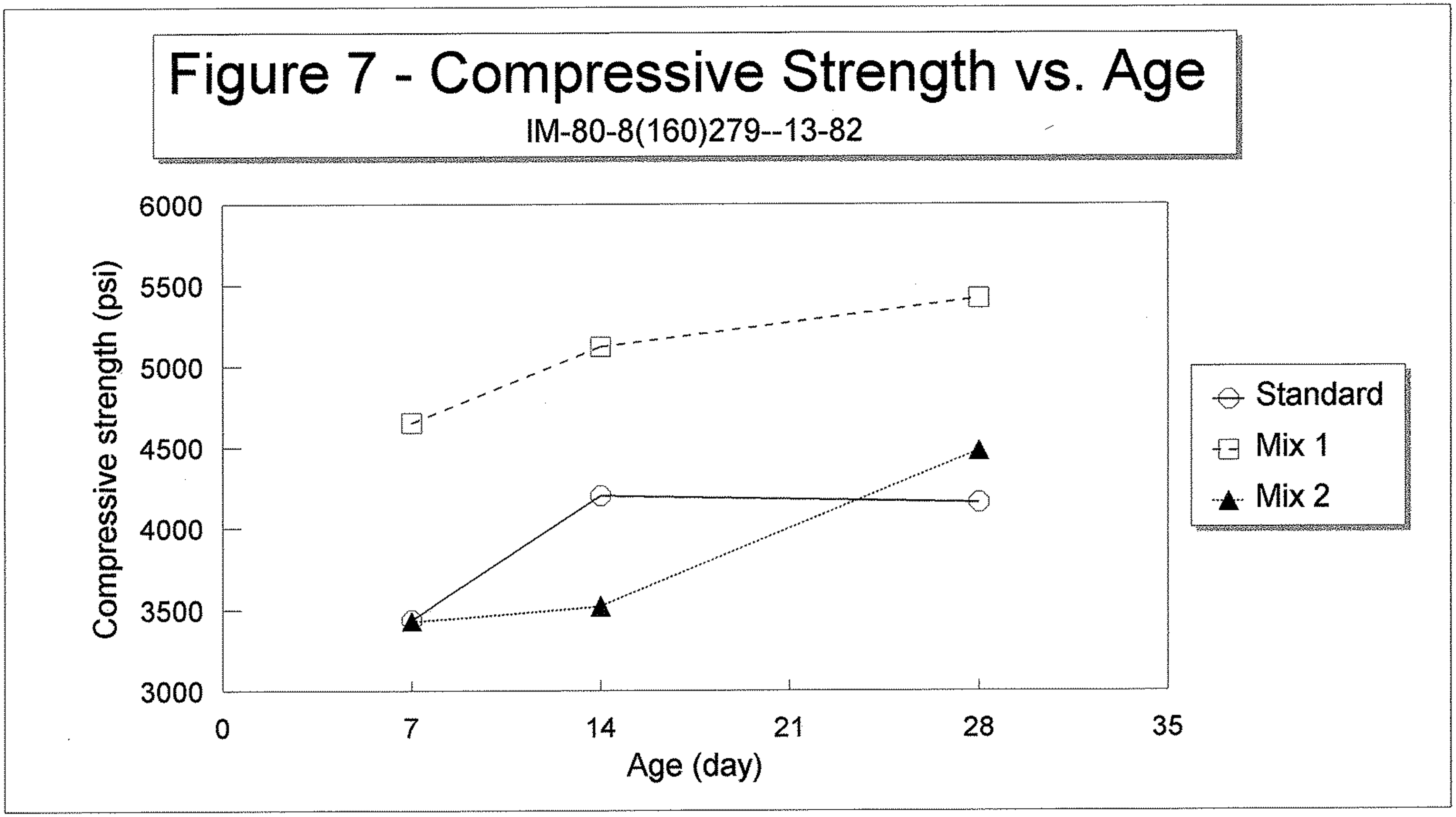


Figure 7 - Compressive Strength vs. Age
IM-80-8(160)279--13-82
Compressive strength (psi)
6000
5500
5000
4500
4000
3500
3000
0
7
14
21
28
35
Age (day)
Standard
Mix 1
Mix 2

Figure 8 - Combined Aggregate Gradations

Standard Mix - Project Aggregates
IM-80-8(160)279--13-82

Sieve Size	Coarse Aggregate	Fine Aggregate	Combined Gradation
26.4 mm (1")	100		100.0
19 mm (3/4")	70		83.5
13 mm (1/2")	36		64.8
9.5 mm (3/8")	13	100	52.2
4.75 mm (#4)	3.1	94	44.0
2.36 mm (#8)	2.2	87	40.4
1.18 mm (#16)		74	34.5
600 µm (#30)		44	21.0
300 µm (#50)		8.2	4.9
150 µm (#100)		0.5	1.4
75 µm (#200)	1.6	0.1	1.3

Mix 1 & Mix 2 - 35% Coarse Aggregate Replaced with Chips
IM-80-8(160)279--13-82

Sieve Size	Coarse Aggregate	9.5 mm Chips	Fine Aggregate	Combined Gradation
26.4 mm (1")	100			100.0
19 mm (3/4")	70			89.3
13 mm (1/2")	33	100		76.0
9.5 mm (3/8")	6	92	100	64.9
4.75 mm (#4)	1.2	32	95	49.3
2.36 mm (#8)	1	8.2	88	41.5
1.18 mm (#16)			75	35.7
600 µm (#30)			42	20.8
300 µm (#50)			6.1	4.7
150 µm (#100)			0.2	2.0
75 µm (#200)	0.6	0.7	0.1	0.4

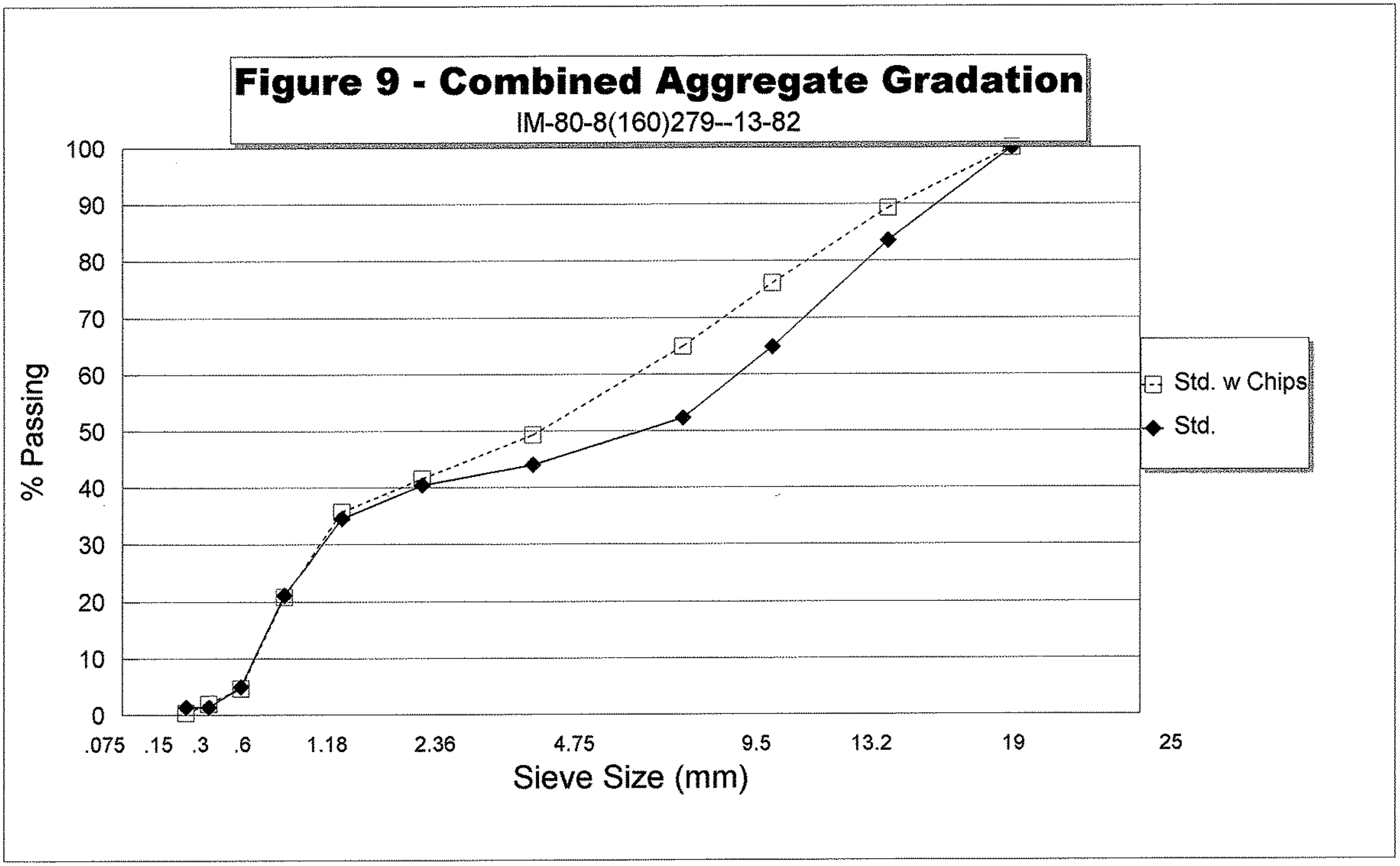


Figure 9 - Combined Aggregate Gradation
IM-80-8(160)279--13-82
% Passing
100
90
80
70
60
50
40
30
20
10
0
.075
.15
.3
.6
1.18
2.36
4.75
9.5
13.2
19
25
Sieve Size (mm)
Std. w Chips
Std.

Figure 10 - Combined Aggregate Gradation, % Retained

IM-80-8(160)279--13-82