EVALUATION OF FLY ASH IN WATER REDUCED PAVING MIXTURES

Final Report
Project No. MLR-84-7

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Highway Division
Iowa Department of Transportation

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by

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ABSTRACT

Fly ash was used to replace 15% of the cement in C3WR and C6WR concrete paving mixes containing ASTM C494 Type A water reducing admixtures. Two Class C ashes and one Class F ash from Iowa approved sources were examined in each mix. When Class C ashes were used they were substituted on the basis of 1 pound of ash added for each pound of cement deleted. When Class F was used it was substituted on the basis of 1.25 pounds of ash added for each pound of cement deleted.

Compressive strengths of the water reduced mixes, with and without fly ash, were determined at 7, 28, and 56 days of age. In every case except one the mixes containing the fly ash exhibited higher strengths than the same concrete mix without the fly ash.

An excellent correlation existed between the C3WR and C6WR mixes both with and without fly ash substitutions.

The freeze-thaw durability of the concrete studied was not affected by presence or absence of fly ash.

The data gathered suggests that the present Class C water reduced concrete paving mixes can be modified to allow the substitution of 15% of the cement with an approved fly ash.

INTRODUCTION:

Current Iowa D.O.T. specifications allow the optional use of fly ash as a partial cement replacement for Class A, B and C concrete paving mixes provided a highly frost resistant coarse aggregate (Class 3 durability) is used. Such an option does not exist for concrete containing water reducing admixtures.

The only concrete mixes routinely used that contain water reducing admixtures are the C-3WR, C-4WR, C-5WR, and C-6WR mixes. These mixes contain 5% less cement than comparable mixes without the water reducers. For example, a C-3 mix contains 604 lbs of cement per cubic yard as compared to a C-3WR mix which contains 574 lbs of cement. A C-4 mix contains 626 pounds of cement as opposed to 595 pounds for a C-4WR mix, etc.

If Class C paving mixes are specified the contractor may elect to choose a corresponding C mix with water reducer. He may not, however, elect to use the water reduced mix and further reduce the cement content by using fly ash.

Information is needed to properly assess the characteristics of water reduced mixes that also contain Iowa fly ashes.

SCOPE:

This study examines the compressive strength and freeze-thaw durability of currently allowed water reduced paving mixtures both with and without fly ash. C-3WR and C-6WR paving mixes (cement factors of 574 and 642 lbs/yd^3 respectively) were studied in combination with three fly ashes currently used in Iowa.

The fly ashes conformed to ASTM C618. One fly ash was a Class F and the other two were Class C. Of the two Class C fly ashes, one was considered to be quite reactive in terms of setting time and heat generation when the pure ash is mixed with water. The other Class C fly ash would be considered less reactive in this regard.

PROCEDURES

A. Materials

The following materials were used in this study:

Cement: Type I Laboratory Blend Lab No. - AC3-350
Air Entraining Agent: Neutralized Vinsol Resin Lab No. - ACA3-16
Coarse Aggregate (Strength Testing): Weaver Const. - Fort Dodge Lab No. - AAC4-3
Coarse Aggregate (Durability Testing): Martin Marietta - Weeping Water, Neb. Lab. No. - AAC4-739
Fine Aggregate(Strength Testing): Hallett - Ames Pit Lab No. - AAS4-296
Fine Aggregate (Durability Testing): Bellvue Sand & Gravel - Bellvue Lab No. - AAS4-290
Water: City of Ames
Water Reducer: Pro-Krete N-3 - Protex Industries dosage---3 oz/100 lbs of cement Lab No. - ACI4-12
Fly Ash:
- Lansing, Iowa - Reactive Class C Lab No. - ACF4-5
- Ottumwa, Iowa - Mildly Reactive Class C Lab No. - ACF4-1
- Clinton, Iowa - Class F Lab No. - ACF4-4

B. Mixes

The following concrete mixes were prepared:

Mix No.	Description
1	C-3WR
2	C-3WR with Lansing fly ash
3	C-3WR with Ottumwa fly ash
4	C-3WR with Clinton fly ash
5	C-6WR
6	C-6WR with Lansing fly ash
7	C-6WR with Ottumwa fly ash
8	C-6WR with Clinton fly ash

C. Fly Ash Substitution Rates

Fly ash was substituted for 15%, by weight, of the Portland cement in all cases. The substitution of Class C fly ash was on a pound-for-pound basis. When Class F fly ash was substituted, it was on the basis of adding 1.25 pounds of fly ash for each pound of cement removed. The change in absolute volumes, due to the fly ash substitution, was applied to each aggregate in its proper ratio. For the C-3WR mix the volumes are 45% fine aggregate, 55% coarse aggregate. For the C-6WR mix the volumes are 60% fine aggregate and 40% coarse aggregate.

D. Aggregate Gradation

The coarse aggregate gradation was:

Sieve No.	% Psg.
1"	100
3/4"	70
1/2"	40
3/8"	10
No. 4	0

The fine aggregate complied with current Iowa D.O.T. specifications.

E. Concrete Controls

All concrete was controlled to a slump of 2" ± 1/2" and an air content of 6.0% ± 0.5%.

F. Concrete Tests

Nine 4 1/2" x 9" horizontal cylinders were cast from each batch of concrete. Three cylinders were tested in compression at each age of 7, 28, and 56 days. All specimens received standard moist room curing.

Three 4"x4"x18" beams were cast from each batch prepared for durability testing. After 2 90-day moist room cure the beams were tested per ASTM C 666 Procedure B "Test Method for Resistance of Concrete to Rapid Freezing and Thawing". The coarse aggregate used in the concrete currently is approved as Class 3 durability aggregate which will produce concrete with an expected maximum service life.

RESULTS

Table Nos. 1 & 2 show the concrete mix characteristics and compressive strength results for the C3WR and C6WR mixes respectively. Each strength value indicated is the average of three cylinders. That data is depicted graphically in Figs. 1-3 to show the relative strengths of the mixes at 7, 28, and 56 days.

In every case except one the concrete containing fly ash exhibited higher compressive strengths than the corresponding control concretes without the fly ash. The lone exception was the 7-day strength of the C3WR mix containing the Class F ash from Clinton.

Figures 4-7 are included to point out the relationship between the C3WR and C6WR mixes with and without the substitution of fly ash for a portion of the cement. The amount of data is limited, however, an excellent correlation between the mixes existed for the control concretes, Class F fly ash concretes, Class C fly ash concretes, and all concretes combined. For all concretes combined the relationship between the mixes can be expressed by the following equation:

$$\text{Comp. Str. (C6WR)} = .91457 \text{ Comp. Str. (C3WR)} + 607 \text{ psi.}$$

Table No. 3 itemizes the freeze-thaw durability characteristics for the concretes studied. There was no significant differences in the frost resistance of any of the concretes studied.

Table No. 1
C-3WR Concrete Mix

Fly Ash Source	Fly Ash Class	Slump Inches	Air Content %	W/C Ratio (1)	Compressive Strength - p.s.i. Age - Days		
					7	28	56
Control	--	2.0	6.0	0.461	4980	6180	6630
Lansing	C	2.0	6.3	0.422	5260	6560	7170
Ottumwa	C	2.0	6.4	0.417	5060	6310	7420
Clinton	F	2.0	6.5	0.412	4530	6270	7070

(1) Fly ash is included in the water - cement ratio calculation as Portland cement.

Table No. 2
C-6WR Concrete Mix

Fly Ash Source	Fly Ash Class	Slump Inches	Air Content %	W/C Ratio (1)	Compressive Strength - p.s.i. Age - Days		
					7	28	56
Control	--	2.0	6.1	0.486	4670	5910	6380
Lansing	C	2.25	6.4	0.416	5260	6660	6990
Ottumwa	C	2.25	6.3	0.416	5390	6900	7360
Clinton	F	2.0	6.1	0.405	5050	6530	7340

(1) Fly ash is included in the water - cement ratio calculation as Portland cement.

Table No. 3
Freeze-Thaw Durability Testing

Concrete Mix	Fly Ash Source	Fly Ash Class	Slump Inches	Air Content %	w/c Ratio(1)	Durability Factor
C-3WR	Control	--	2.0	6.0	0.423	96
C-3WR	Lansing	C	2.0	6.4	0.400	95
C-3WR	Ottumwa	C	2.0	6.1	0.392	95
C-3WR	Clinton	F	2.25	6.1	0.412	94
C-6WR	Control	--	2.0	6.3	0.417	97
C-6WR	Lansing	C	2.25	6.4	0.406	97
C-6WR	Ottumwa	C	2.25	6.3	0.406	97
C-6WR	Clinton	F	2.25	5.8	0.394	96

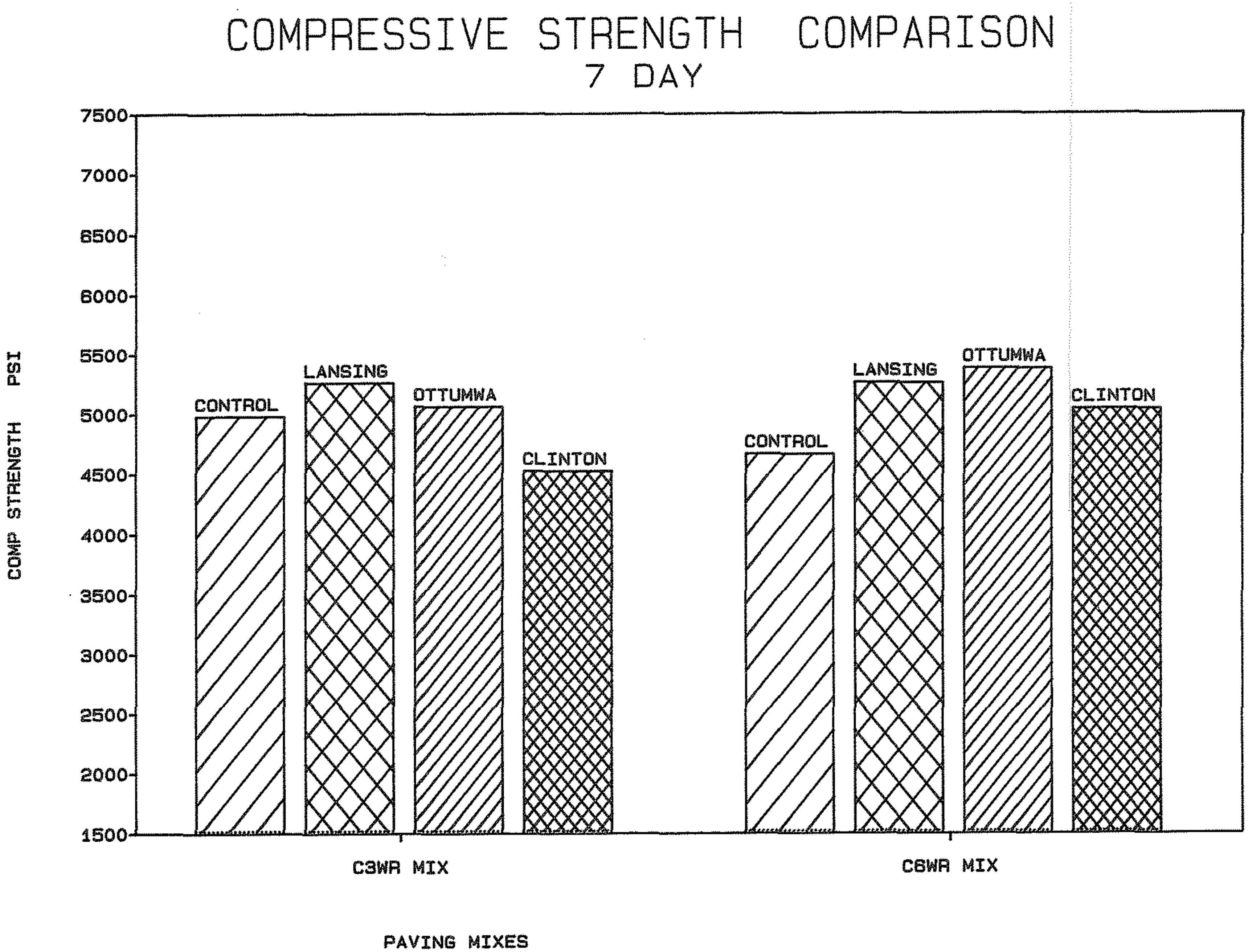
COMPRESSIVE STRENGTH COMPARISON
7 DAY
COMP STRENGTH PSI
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
C3WR MIX
C6WR MIX
PAVING MIXES

Figure No. 1

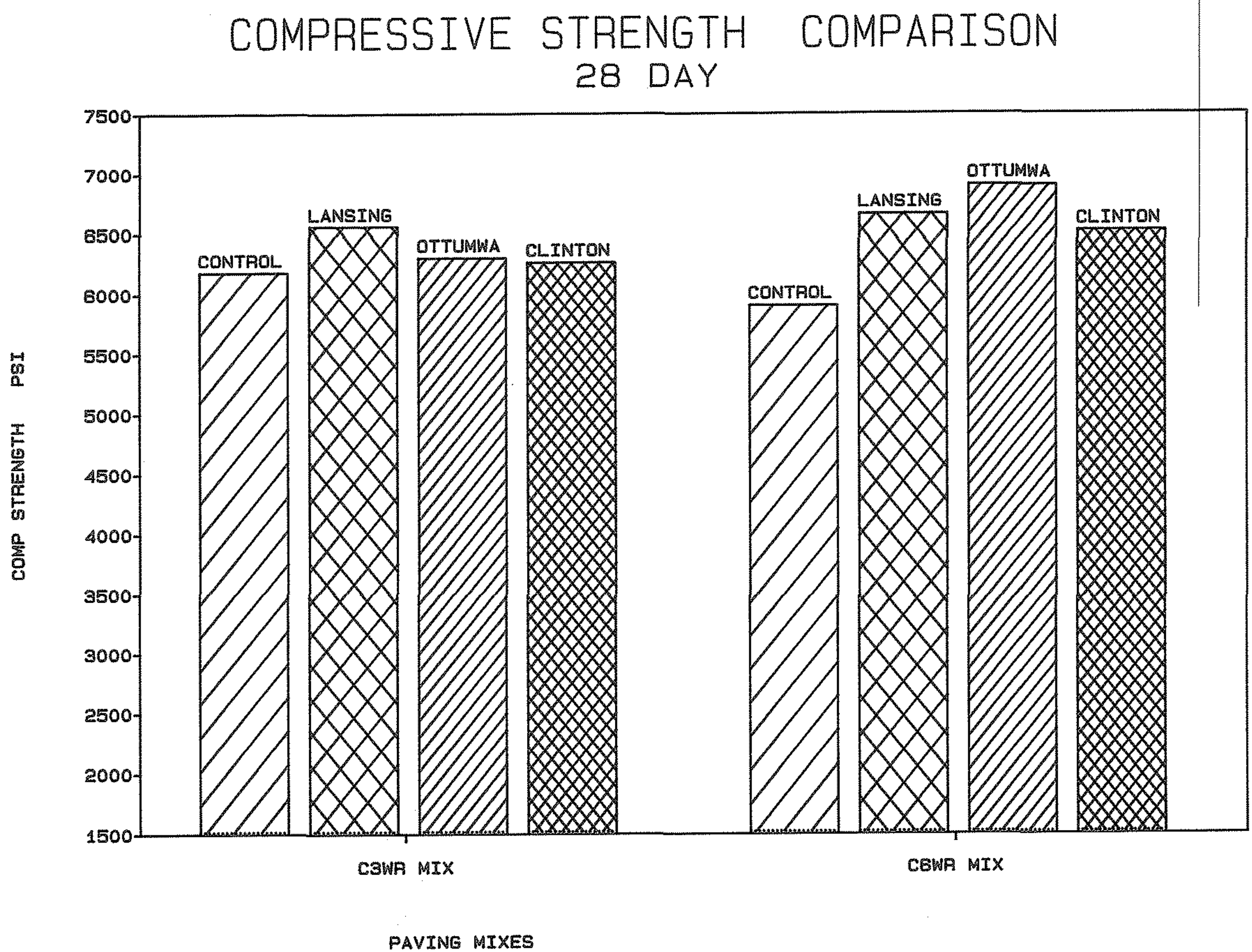
COMPRESSIVE STRENGTH COMPARISON
28 DAY
COMP STRENGTH PSI
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
CONTROL
LANSING
OTTUMWA
CLINTON
C3WR MIX
CONTROL
LANSING
OTTUMWA
CLINTON
C6WR MIX
PAVING MIXES

Figure No. 2

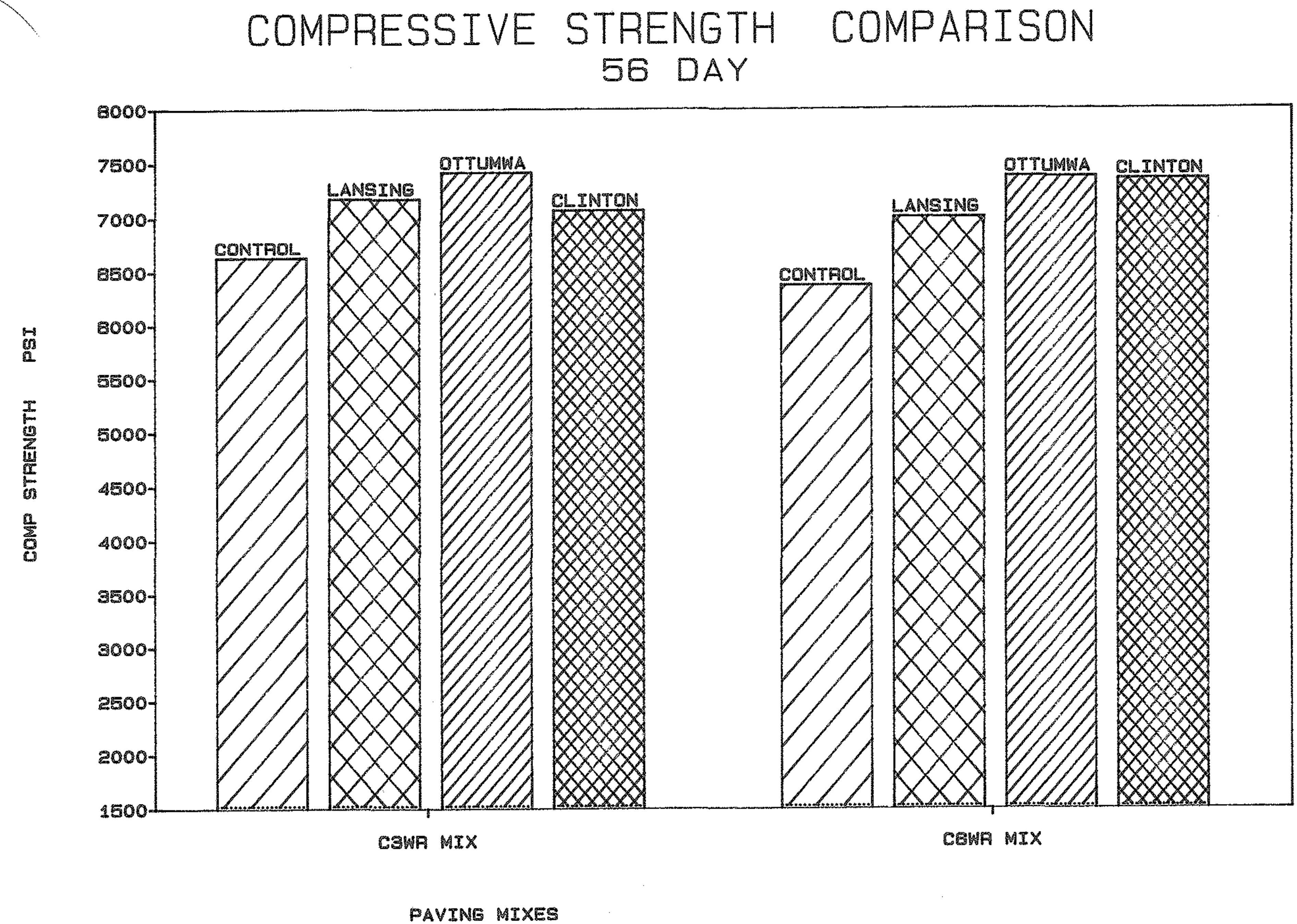
COMPRESSIVE STRENGTH COMPARISON
56 DAY
COMP STRENGTH PSI
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
CONTROL
LANSING
OTTUMWA
CLINTON
C3WR MIX
CONTROL
LANSING
OTTUMWA
CLINTON
C6WR MIX
PAVING MIXES

Figure No. 3

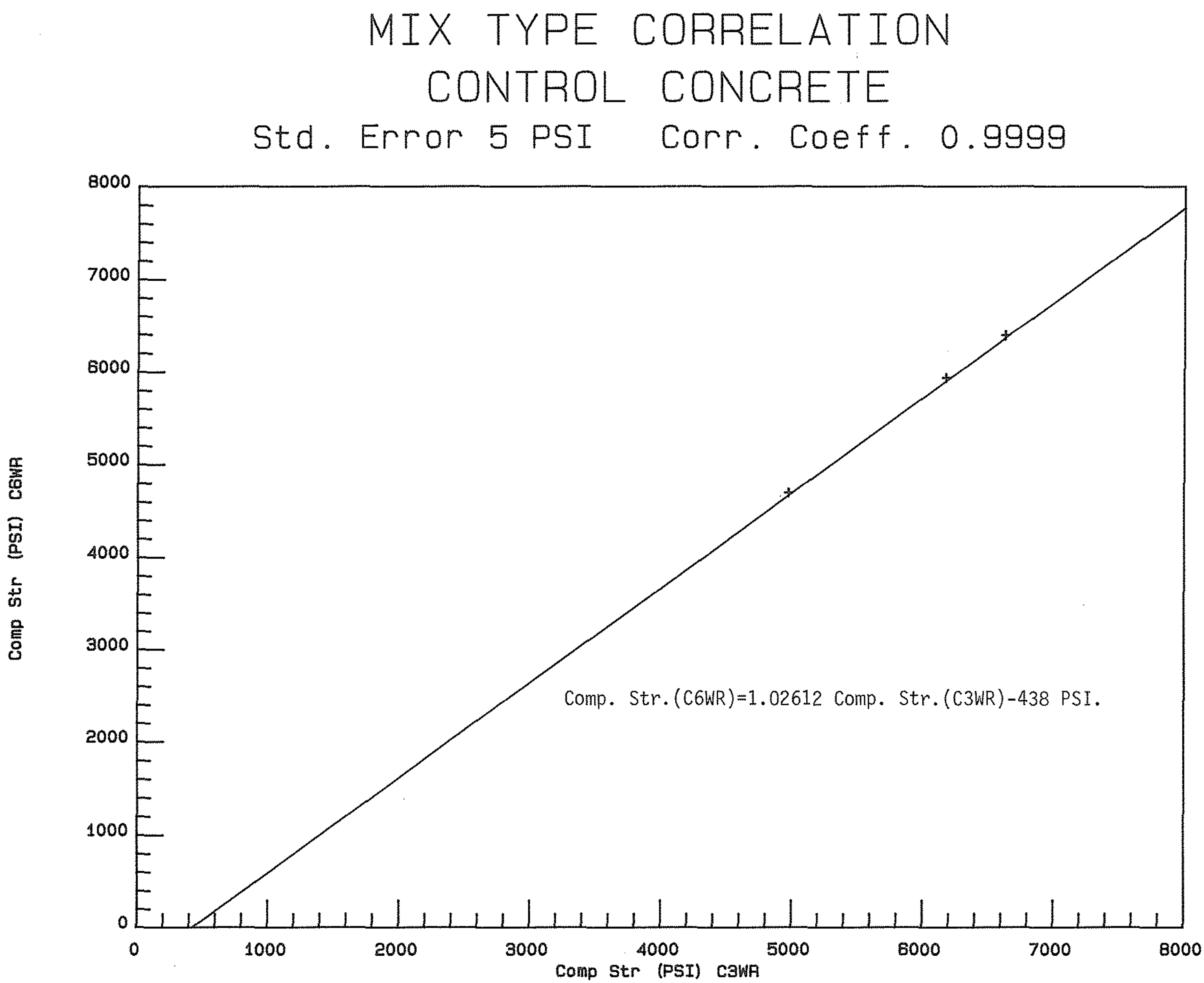
MIX TYPE CORRELATION
CONTROL CONCRETE
Std. Error 5 PSI Corr. Coeff. 0.9999
8000
7000
6000
5000
4000
3000
2000
1000
0
Comp Str (PSI) C6WR
Comp. Str.(C6WR)=1.02612 Comp. Str.(C3WR)-438 PSI.
0
1000
2000
3000
4000
5000
6000
7000
8000
Comp Str (PSI) C3WR

Figure No. 4

MIX TYPE CORRELATION
CLASS F FLY ASH CONCRETE

Std. Error 48 PSI   Corr. Coeff. 0.9989

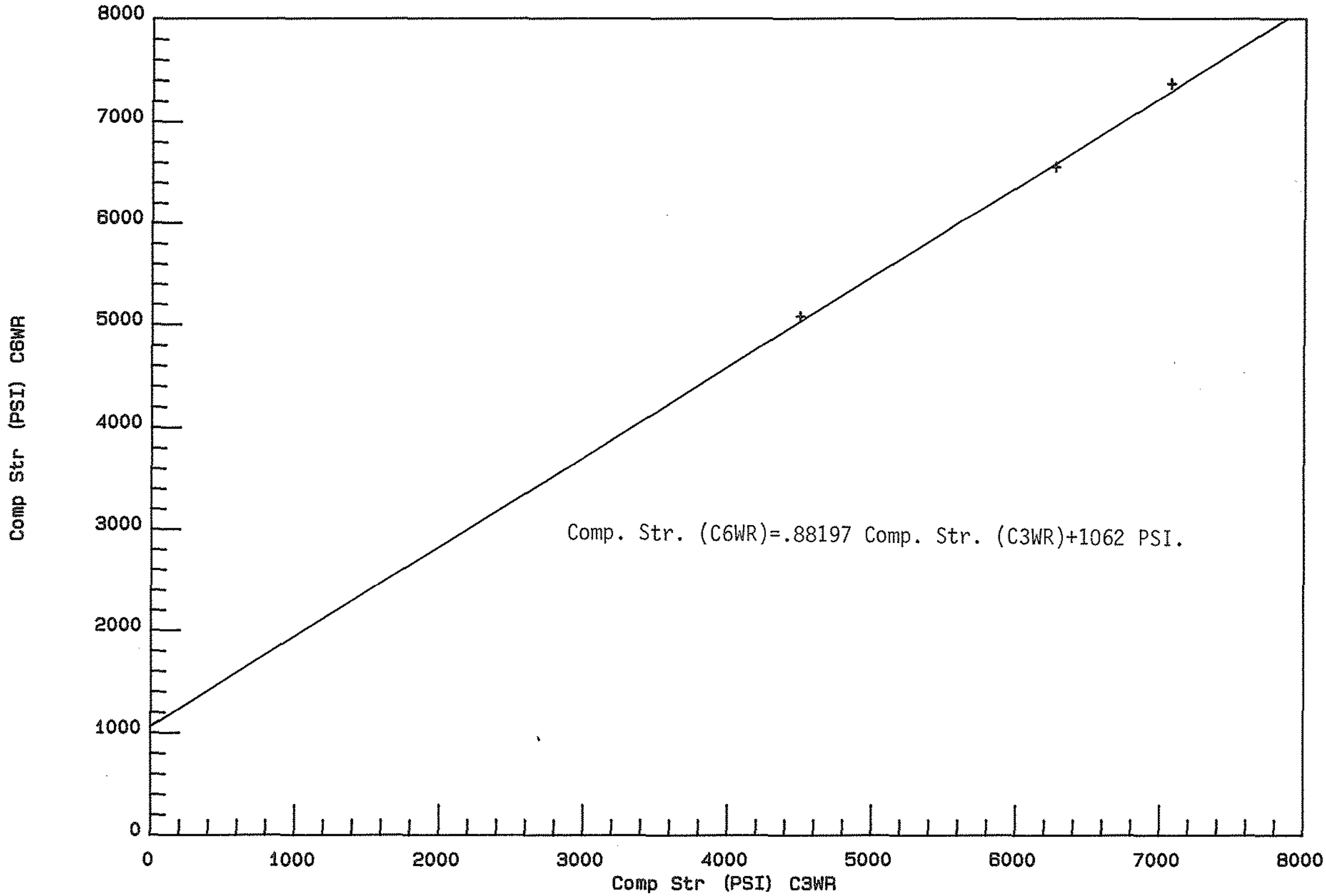

Figure No. 5

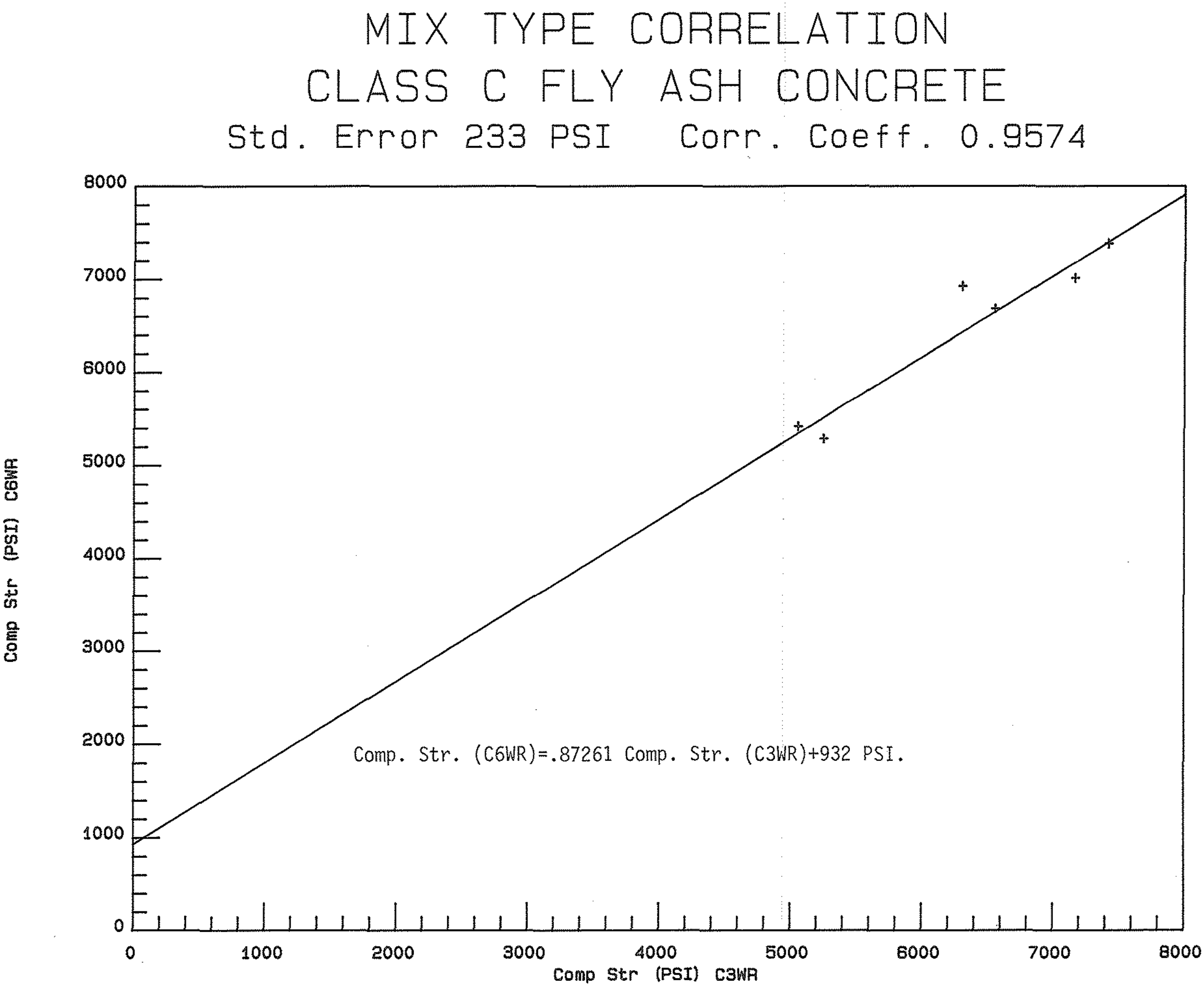
MIX TYPE CORRELATION
CLASS C FLY ASH CONCRETE
Std. Error 233 PSI Corr. Coeff. 0.9574
Comp Str (PSI) C6WR
Comp Str (PSI) C3WR
Comp. Str. (C6WR)=.87261 Comp. Str. (C3WR)+932 PSI.
0
1000
2000
3000
4000
5000
6000
7000
8000

Figure No. 6

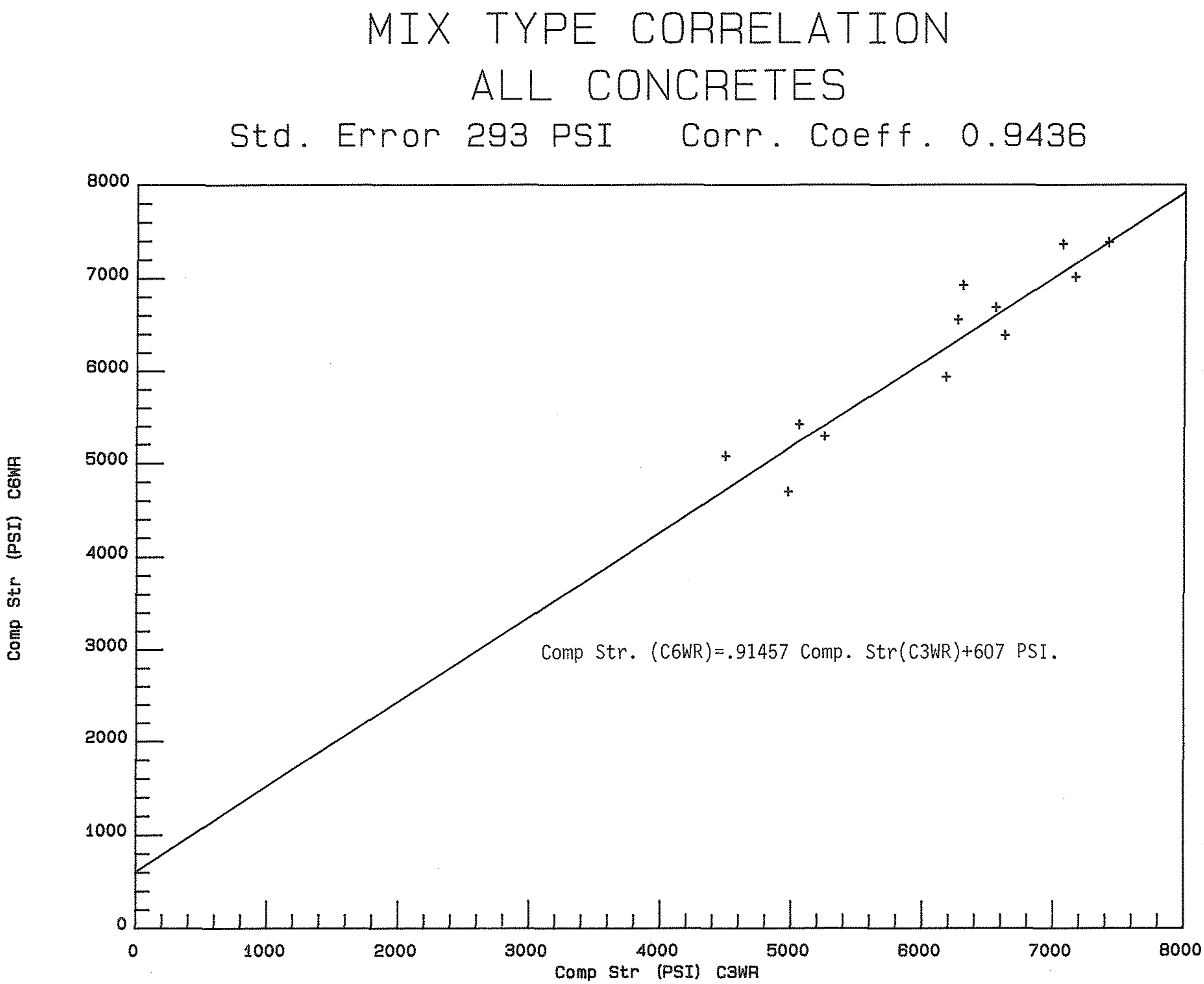
MIX TYPE CORRELATION
ALL CONCRETES
Std. Error 293 PSI Corr. Coeff. 0.9436
Comp Str. (C6WR)=.91457 Comp. Str(C3WR)+607 PSI.
Comp Str (PSI) C6WR
Comp Str (PSI) C3WR
0
1000
2000
3000
4000
5000
6000
7000
8000

Figure No. 7

DISCUSSION AND CONCLUSIONS

The strength data gathered in this study supports the substitution of 15% of the Portland cement in C3WR and C6WR concrete paving mixes with ASTM C-618 Class C fly ash on a pound for pound basis, or with Class F fly ash at a rate of 1.25 pound of ash added for each pound of cement deleted. Since the C3WR and C6WR concrete mixes span the range of the cement contents (574 and 642 lbs/yd^3) and aggregate ratios (45% fine and 55% coarse in the C3WR and 60% fine and 40% coarse in the C6WR) there is every reason to suggest acceptability in the intermediate C4WR and C5WR mixes as well.

Previous studies (1, 2) have shown that the durability of fly-ash concrete can be adversely affected when certain coarse aggregates are used. The reasons for the potential accelerated deterioration are not completely known and more studies are underway to better define the problem and potential solution. In the meantime, the Iowa D.O.T. is currently allowing the use of only very frost resistant coarse aggregates, Class 3, in concrete that contains fly ash. When the Class 3 aggregates are used in concretes with cement contents down to 383 lbs/yd^3 (B3 mix with 20% fly ash) there has been no apparent deterioration that can be attributed to fly ash.[(1)]

This study supports previous investigations regarding freeze-thaw durability of fly ash concretes containing Class 3 aggregates. The durability of all concretes was high regardless of the presence or absence of fly ash. There is no reason to suspect that any reaction between quality fly ash and ASTM C494 Type A water reducers will result in lowered durability.

While it was not the intent of this project to verify or refute the equivalency of C3WR and C6WR concrete paving mixes, the correlation between the two is very good and the relative differences between the mixes is minor, whether or not fly ash is used as a cement replacer. Using the equation: Comp. Str. (C6WR) = .91457 Comp. Str. (C3WR) +607 psi. the following relationships apply:

C3WR Comp. Str. (psi)	C6WR Comp. Str. (psi)
4,500	4,720
5,000	5,180
6,000	6,090
7,000	7,010

SELECTED REFERENCES

(1) Isenberger, Ken Fly Ash Concrete - Compressive Strength and Freeze-Thaw Durability. June 1981, Iowa D.O.T.

(2) Demirel, T. & Pitt, J.M. Characterization of Fly Ash for Use in Concrete. September 1983, Iowa State University.