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# **EVALUATION OF FLY ASH IN WATER REDUCED PAVING MIXTURES**

**Final Report  
Project No. MLR-84-7**

**October 1984**

**Highway Division**



**Iowa Department  
of Transportation**



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EVALUATION OF FLY ASH IN  
WATER REDUCED PAVING MIXTURES

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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 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 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<sup>3</sup> 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: Weaver Const. - Fort Dodge Lab No. - AAC4-3

Fine Aggregate: Hallett - Ames Pit Lab No. - AAS4-296

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:

| <u>Mix No.</u> | <u>Description</u>         |
|----------------|----------------------------|
| 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:

| <u>Sieve No.</u> | <u>% Psg.</u> |
|------------------|---------------|
| 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  $2" \pm 1/2"$  and an air content of  $6.0\% \pm 0.5\%$ .

#### F. Concrete Tests

Nine  $4 \frac{1}{2}" \times 9"$  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.

### 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. 1  
C-3WR Concrete Mix

| Fly Ash<br>Source | Fly Ash<br>Class | Slump<br>Inches | Air Content<br>% | W/C<br>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<br>Source | Fly Ash<br>Class | Slump<br>Inches | Air Content<br>% | W/C<br>Ratio (1) | Compressive Strength - p.s.i. |                  |      |
|-------------------|------------------|-----------------|------------------|------------------|-------------------------------|------------------|------|
|                   |                  |                 |                  |                  | 7                             | Age - Days<br>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.

# COMPRESSIVE STRENGTH COMPARISON 7 DAY

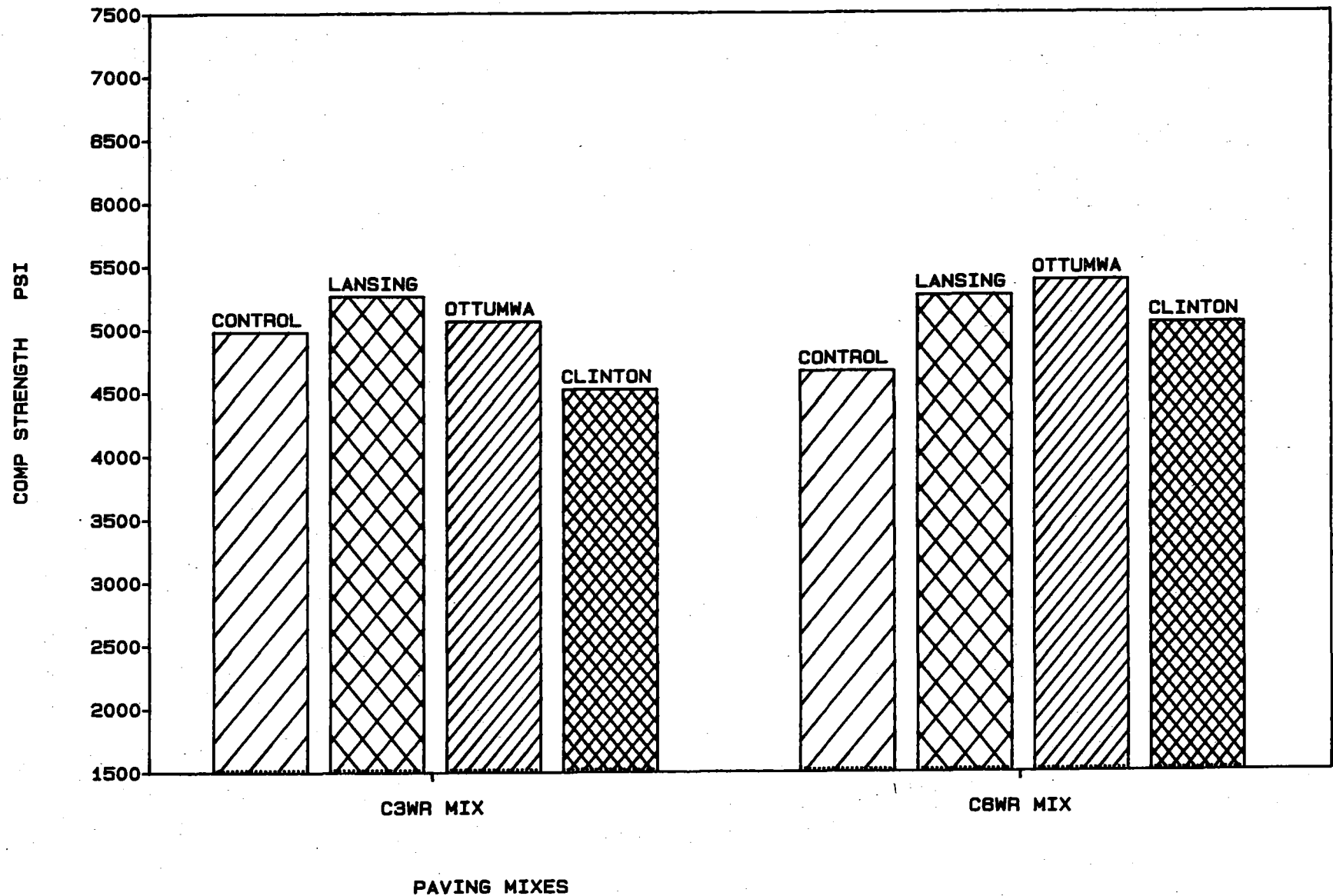
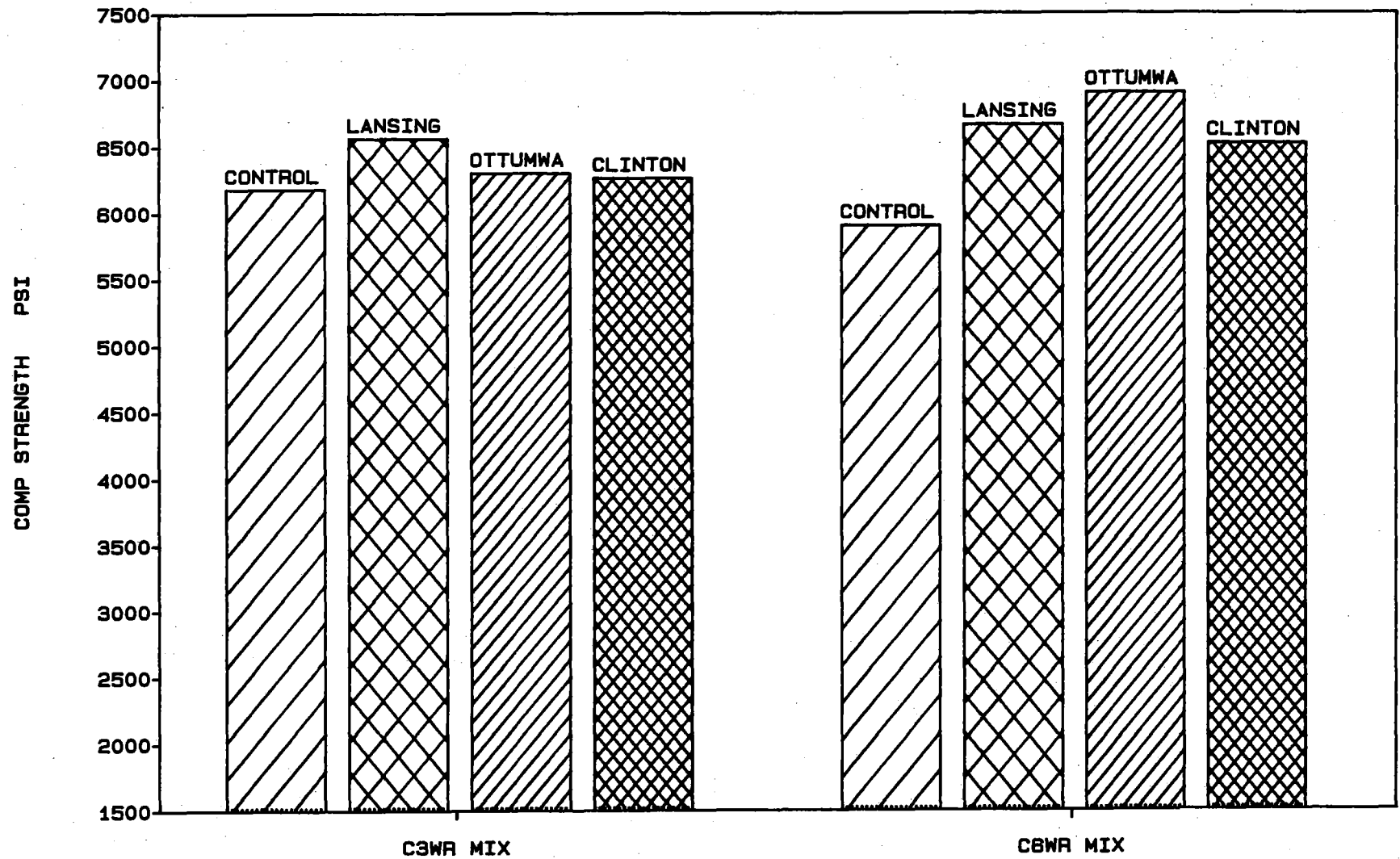


Figure No. 1



# COMPRESSIVE STRENGTH COMPARISON 28 DAY



PAVING MIXES

Figure No. 2

# COMPRESSIVE STRENGTH COMPARISON 56 DAY

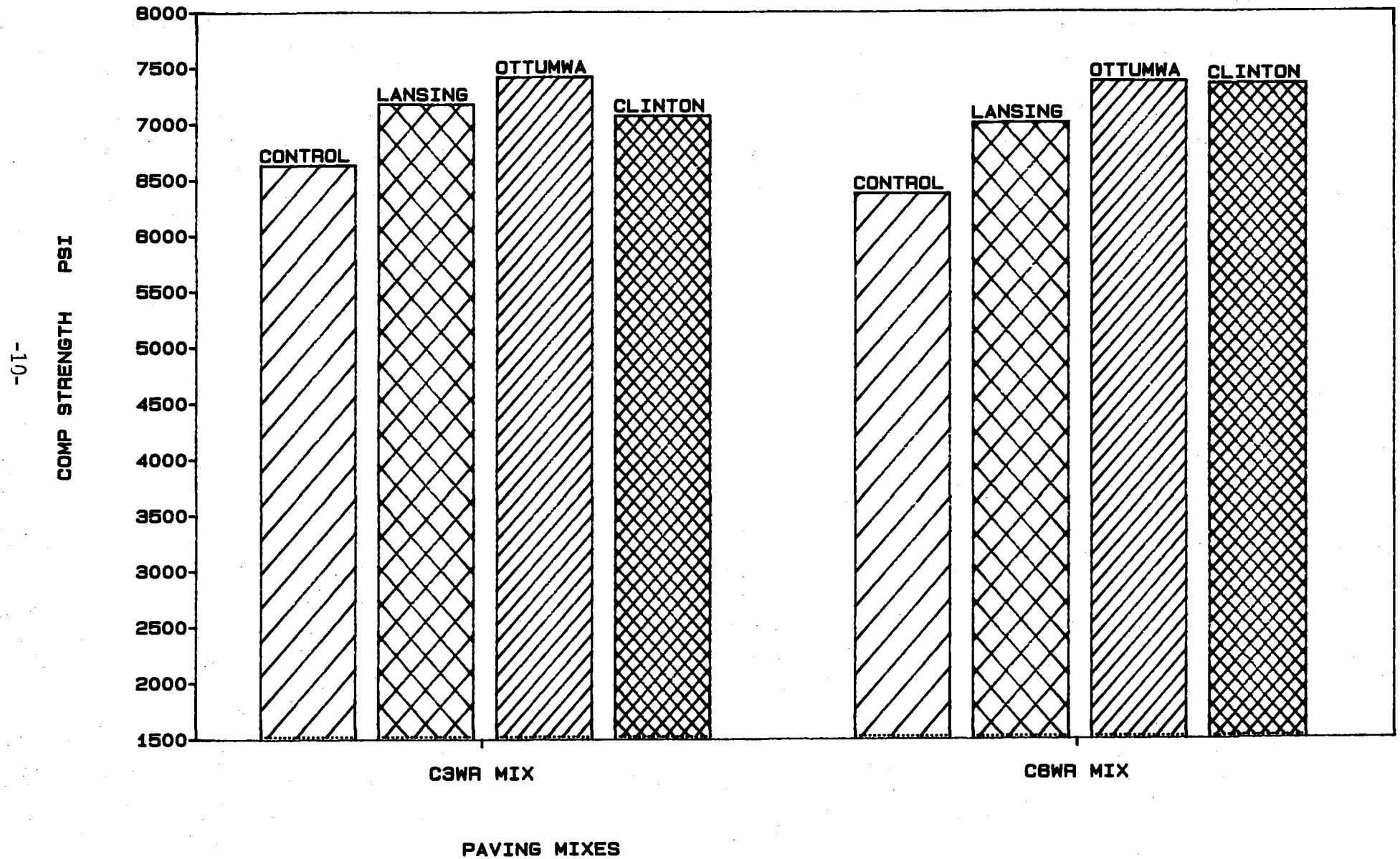


Figure No. 3

# MIX TYPE CORRELATION CONTROL CONCRETE

Std. Error 5 PSI    Corr. Coeff. 0.9999

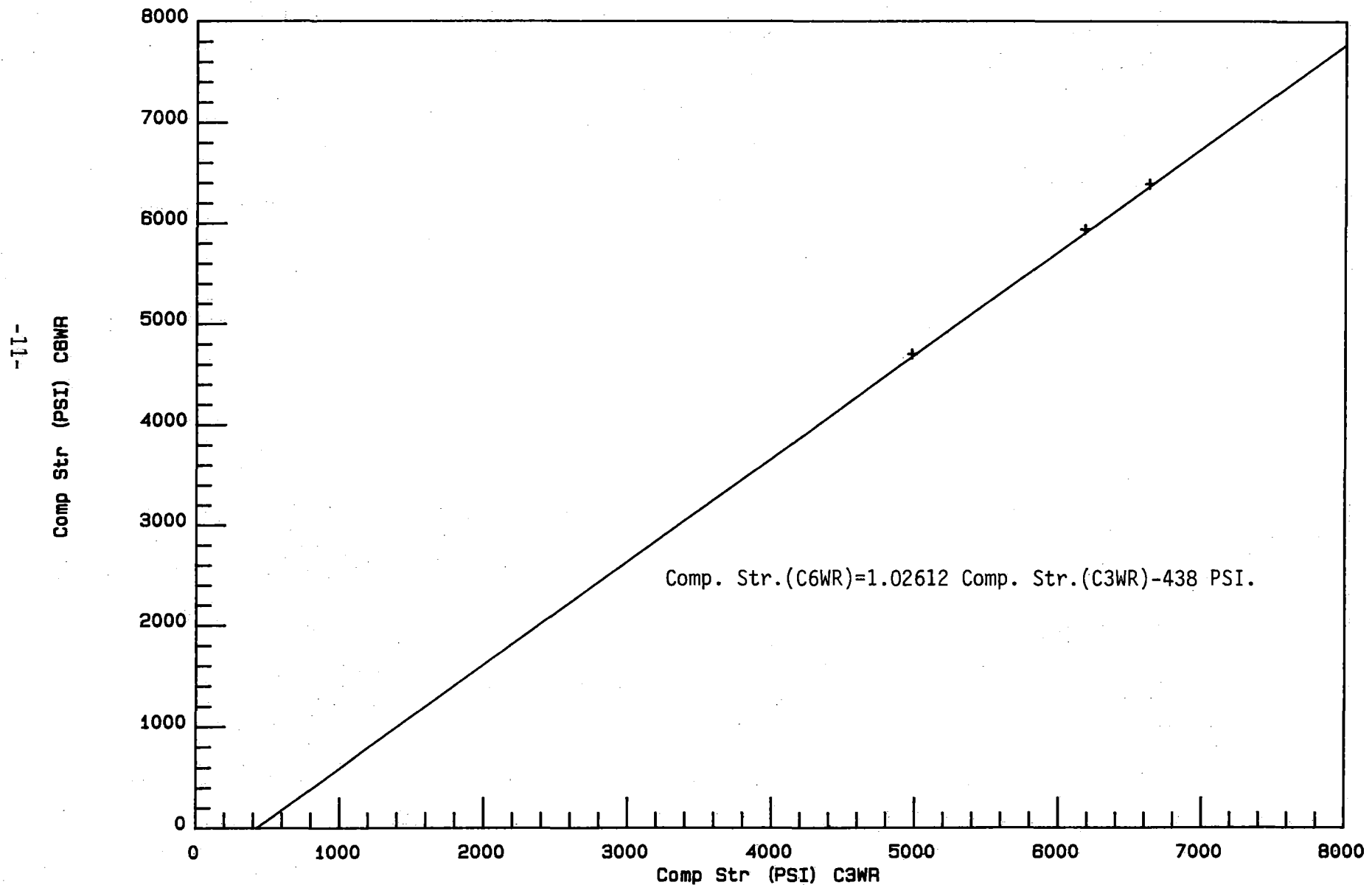


Figure No. 4

MIX TYPE CORRELATION  
CLASS F FLY ASH CONCRETE  
Std. Error 48 PSI    Corr. Coeff. 0.9989

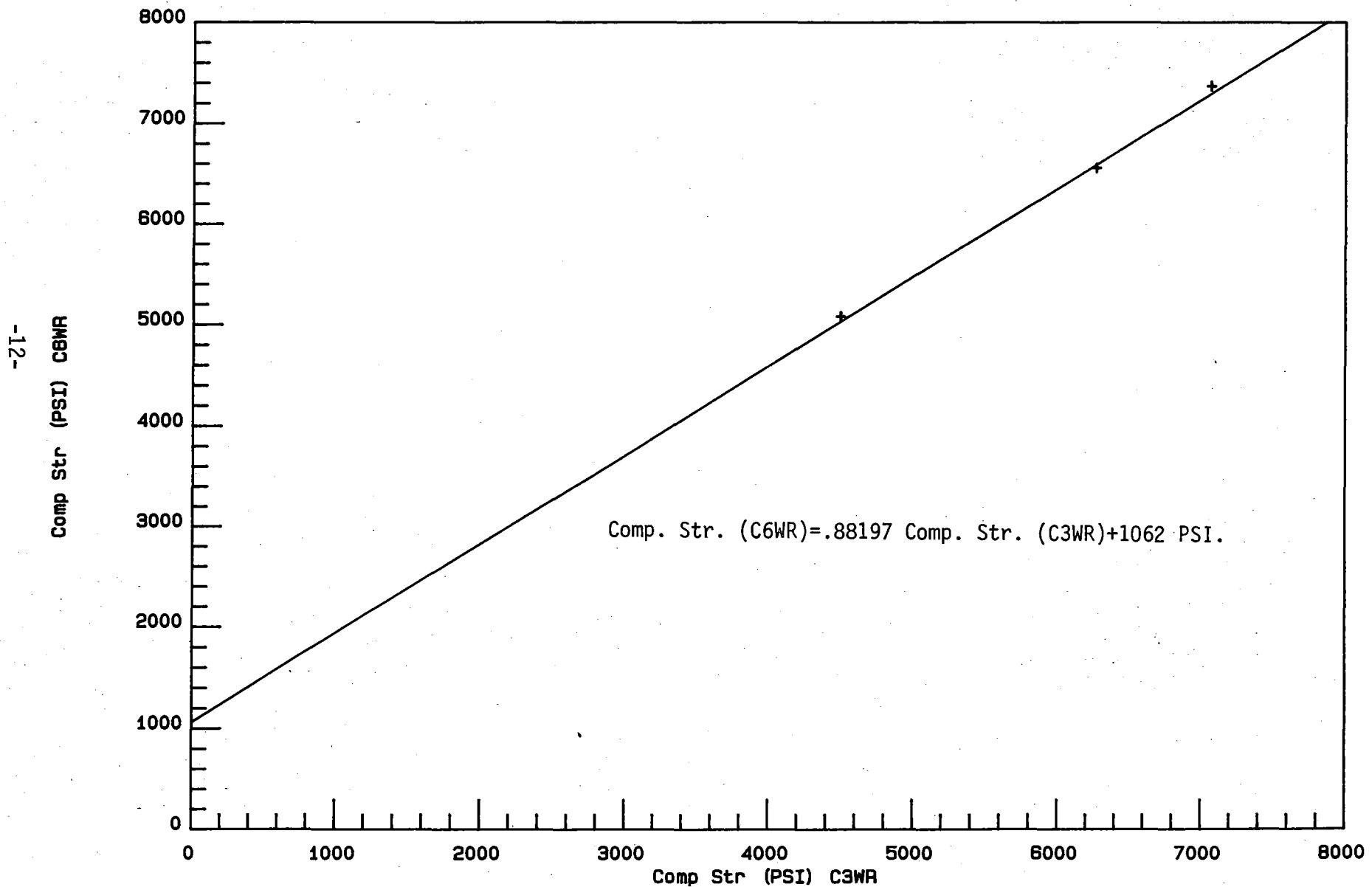


Figure No. 5

MIX TYPE CORRELATION  
CLASS C FLY ASH CONCRETE  
Std. Error 233 PSI    Corr. Coeff. 0.9574

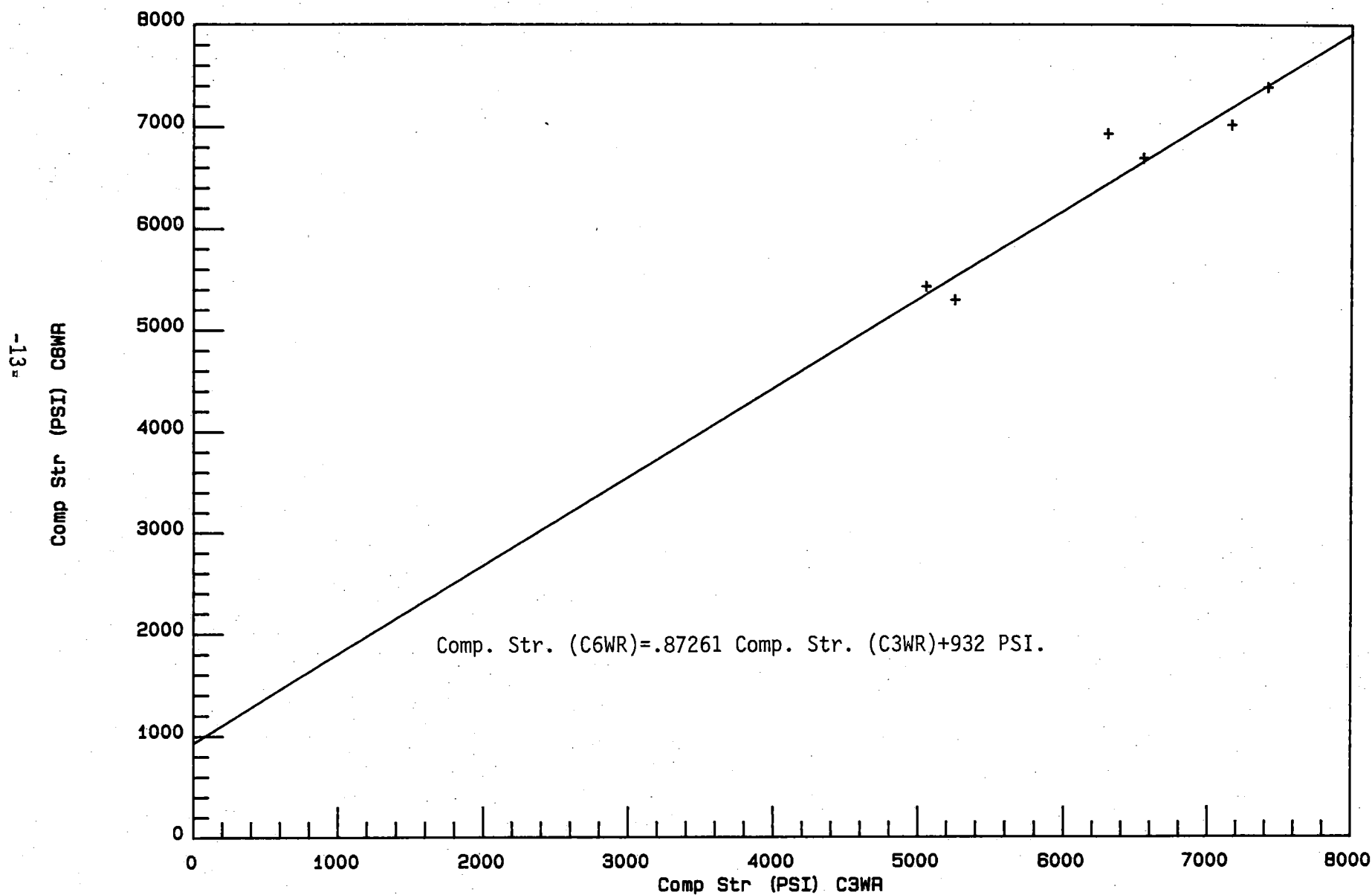


Figure No. 6



# MIX TYPE CORRELATION ALL CONCRETES

Std. Error 293 PSI    Corr. Coeff. 0.9436

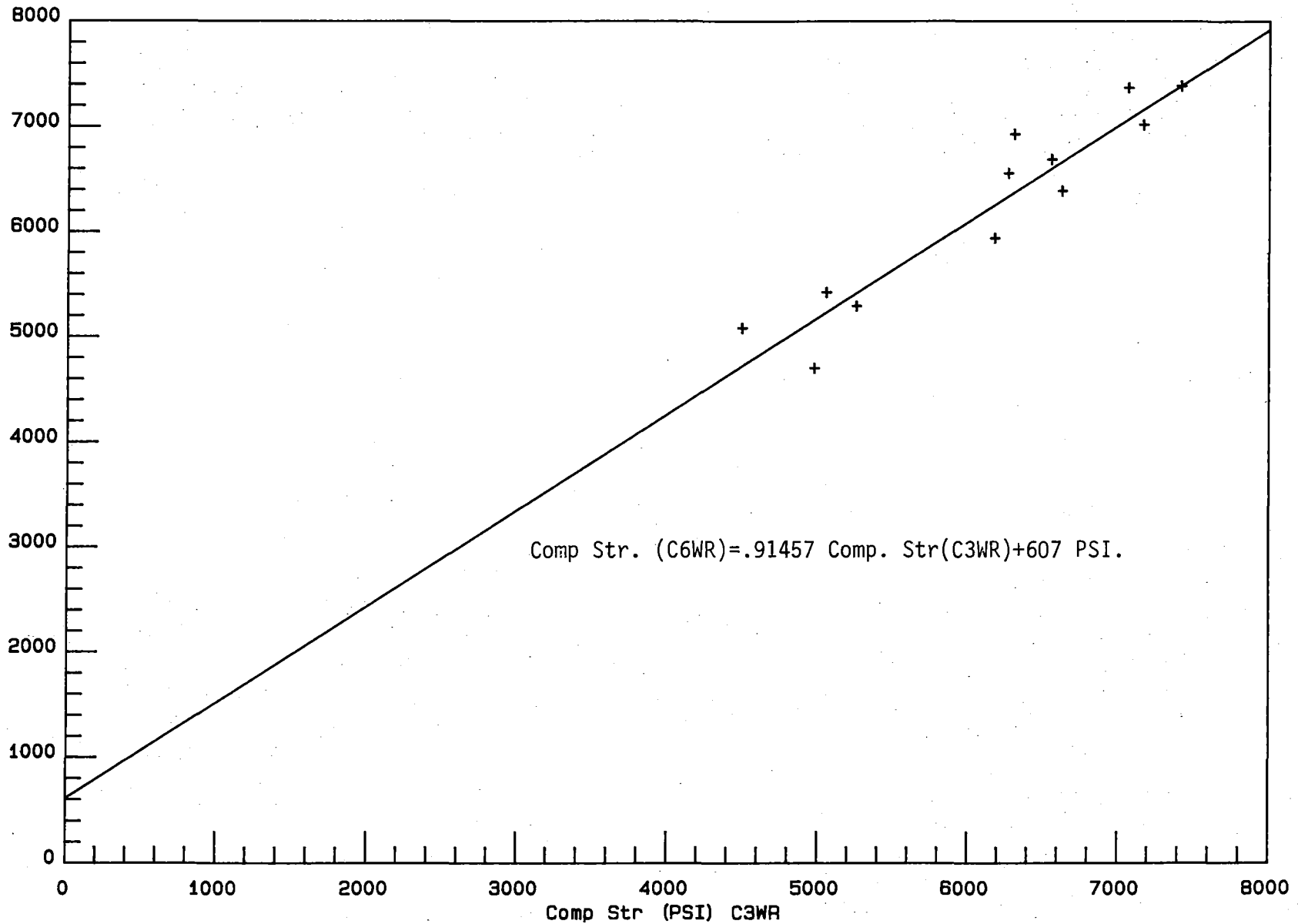


Figure No. 7

## 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<sup>3</sup>) 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.

Freeze-thaw durability testing was not included in this study because the test apparatus was being used for higher priority studies, and the possibility of water reducer - fly ash combinations causing reduced frost resistance was extremely remote.

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<sup>3</sup> (B3 mix with 20% fly ash) there has been no apparent deterioration that can be attributed to fly ash.<sup>(1)</sup>

Prior to allowing the routine use of concrete water reducers in 1975, freeze-thaw durability tests per ASTM C666 Procedure B with an initial 90 day moist room curing period were run to establish the effects of the

admixtures. It was concluded that the admixtures which conformed to ASTM C494, Type A did not affect the freeze-thaw durability of concrete in any significant way.

In light of these previous investigations, it is logical to conclude that the use of approved fly ashes in the water reduced concrete mixes studied would have acceptable durability provided Class 3 coarse aggregate is specified. It is not uncommon to encounter standards that require the use of approved water reducers in fly ash concrete mixes.

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:  $\text{Comp. Str. (C6WR)} = .91457 \text{ Comp. Str. (C3WR)} + 607 \text{ psi}$ , the following relationships apply:

| <u>C3WR</u><br><u>Comp. Str. (psi)</u> | <u>C6WR</u><br><u>Comp. Str. (psi)</u> |
|--|--|
| 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.





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