STRENGTH-TEMPERATURE STUDY OF FLY ASH CONCRETE

Project No. MLR-84-6

by

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August 1984

ABSTRACT

Class A, B, and C concrete paving mixes were tested for compressive strength at 40°F and 73°F, both with and without fly ash substitution for 15% of the portland cement. Two Class C ashes and one Class F ash from Iowa approved sources were examined in each mix.

The purpose of the study was to provide data on cool weather strength development of concrete paving mixes utilizing Iowa materials.

In all cases except one, the fly ash concretes exhibited lower 7 and 28-day compressive strengths at 40°F than control mixes.

The continuation of the October 15 cut-off date for the use of fly ash concrete is recommended.

INTRODUCTION

Traditionally fly ash concretes have been known to exhibit somewhat slower strength development than standard concrete. This is especially true when ASTM C-618 Class F fly ash was used. Because of this, specifications for fly ash concrete generally require fly ash concrete not be used for late season work. Data is needed to establish whether strength development is delayed when using Iowa fly ashes in cooler weather.

SCOPE

This study examines concrete compressive strengths with and without fly ash at 40°F. (the minimum allowable paving temperature by specification) and 73°F. Paving concretes of the A, B, & C classes (cement factors of 551, 479 and 604 lbs/yd^3 respectively) were studied in combination with three ashes.

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 the 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 - AC3-350
Air Entraining Agent: Neutralized Vinsol Resin - ACA3-16
Coarse Aggregate: Weaver Const. - Fort Dodge - AAC4-3
Fine Aggregate: Hallett - Ames Pit - AAS4-296
Water: City of Ames
Fly Ash:
- Lansing, Iowa - Reactive Class C - ACF4-5
- Ottumwa, Iowa - Mildly Reactive Class C - ACF4-1
- Clinton, Iowa - Class F - ACF4-4

B. Mixes

The following concrete mixes were prepared:

Mix No.	Description
1	A-3
2	A-3 with Lansing fly ash
3	A-3 with Ottumwa fly ash
4	A-3 with Clinton fly ash
5	B-3
6	B-3 with Lansing fly ash
7	B-3 with Ottumwa fly ash
8	B-3 with Clinton fly ash
9	C-3
10	C-3 with Lansing fly ash
11	C-3 with Ottumwa fly ash
12	C-3 with Clinton fly ash

C. Fly Ash Substitution Rates

Fly ash was substituted for 15%, by weight, of the 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 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 (45% fine aggr., 55% coarse aggr.).

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

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

Twelve 4-1/2" x 9" horizontal cylinders were cast from each batch of concrete. Six (6) cylinders from each batch were cured at 40°F. After casting, these cyclinders were immediately placed in a cooler maintained at 40°F. They were covered with damp cloths while in the cooler to prevent moisture loss from the cylinders. These cylinders remained in the cooler until time for testing. The remaining six (6) cylinders received the standard moist room cure at 73°F until testing.

Half of the cylinders from each curing condition were tested for compressive strength at 7 days. The other half were tested at 28 days.

RESULTS

Compressive strength values for the various combinations of materials and curing conditions are shown in Table No. 1 and graphically presented in Figures 1-6.

In every case, the fly ash concrete cured at 40°F exhibited lower 7-day compressive strengths than the corresponding control concrete. This was also true at 28 days with the exception of the B-3 mix containing the Ottumwa fly ash having a slightly higher strength than the control mix. At the standard moist room cure of 73°F, fly ash mixes were neither consistently higher nor lower in strength than their corresponding controls.

Figures 7-12 establish the relationships between the 40°F and 73°F curing temperatures for all the concretes examined in this study. These relationships are based upon a very limited amount of data, however, and should not be used as the basis of predictions without further verification.

Table No. 1

STRENGTH-TEMPERATURE RELATIONSHIP
OF
FLY ASH CONCRETE

Concrete Mix	Fly Ash Source	Fly Ash Class	7-Day Compr. Str. (PSI) Curing Temp. (°F) 40	73	28-Day Compr. Str. (PSI) Curing Temp. (°F) 40	73
A-3			3540	4810	4490	6020
A-3	Lansing	C	3490	4870	4480	5930
A-3	Ottumwa	C	3430	4830	4220	6450
A-3	Clinton	F	3280	4540	4030	6020
B-3			3060	4150	4420	5540
B-3	Lansing	C	2820	4080	4180	5510
B-3	Ottumwa	C	3000	4050	4520	6020
B-3	Clinton	F	2750	3450	3860	5010
C-3			4280	4760	5050	5750
C-3	Lansing	C	4090	4340	4650	6040
C-3	Ottumwa	C	3700	4690	4680	6220
C-3	Clinton	F	3610	4410	4660	5700

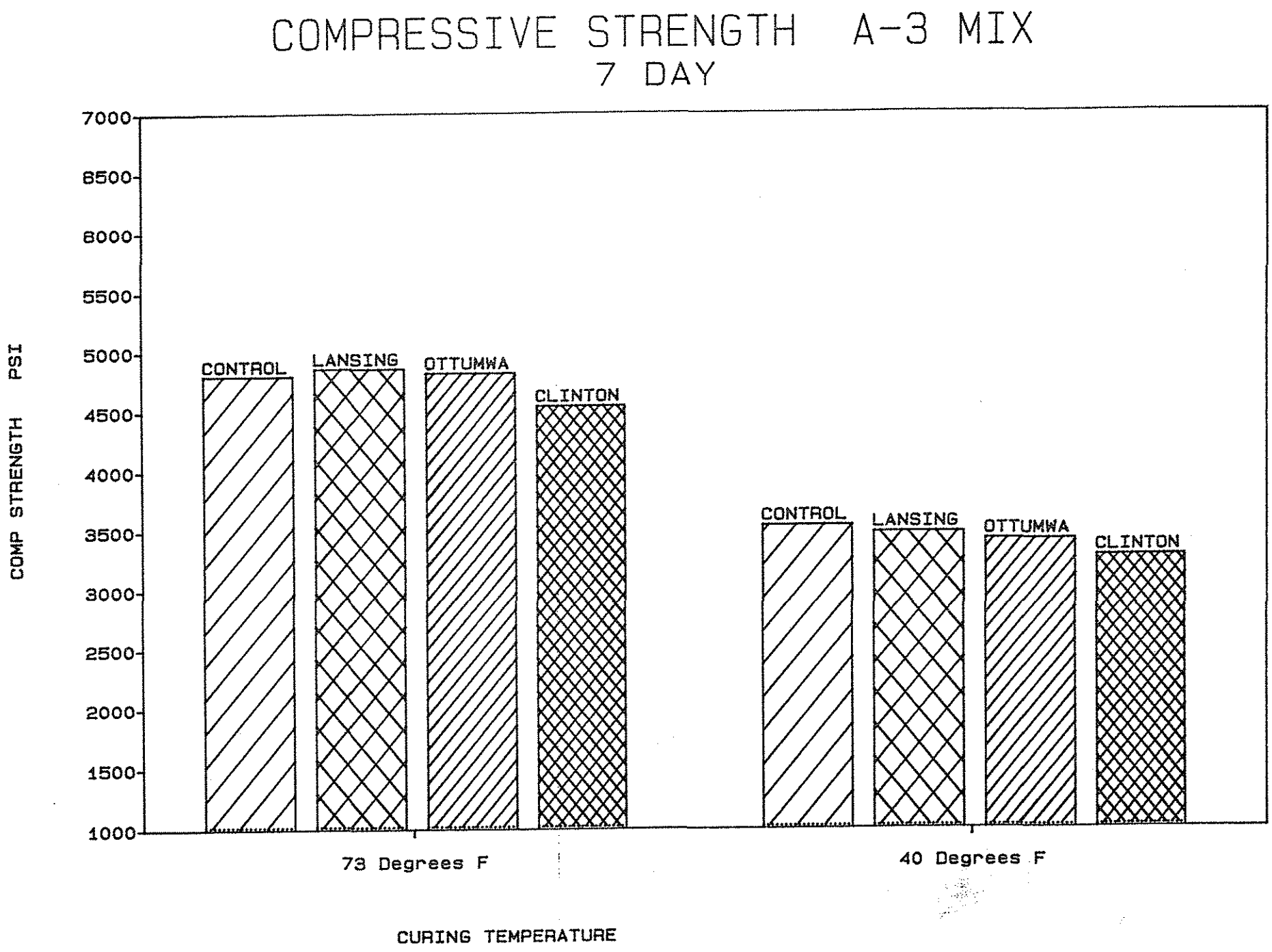
COMPRESSIVE STRENGTH A-3 MIX
7 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 1

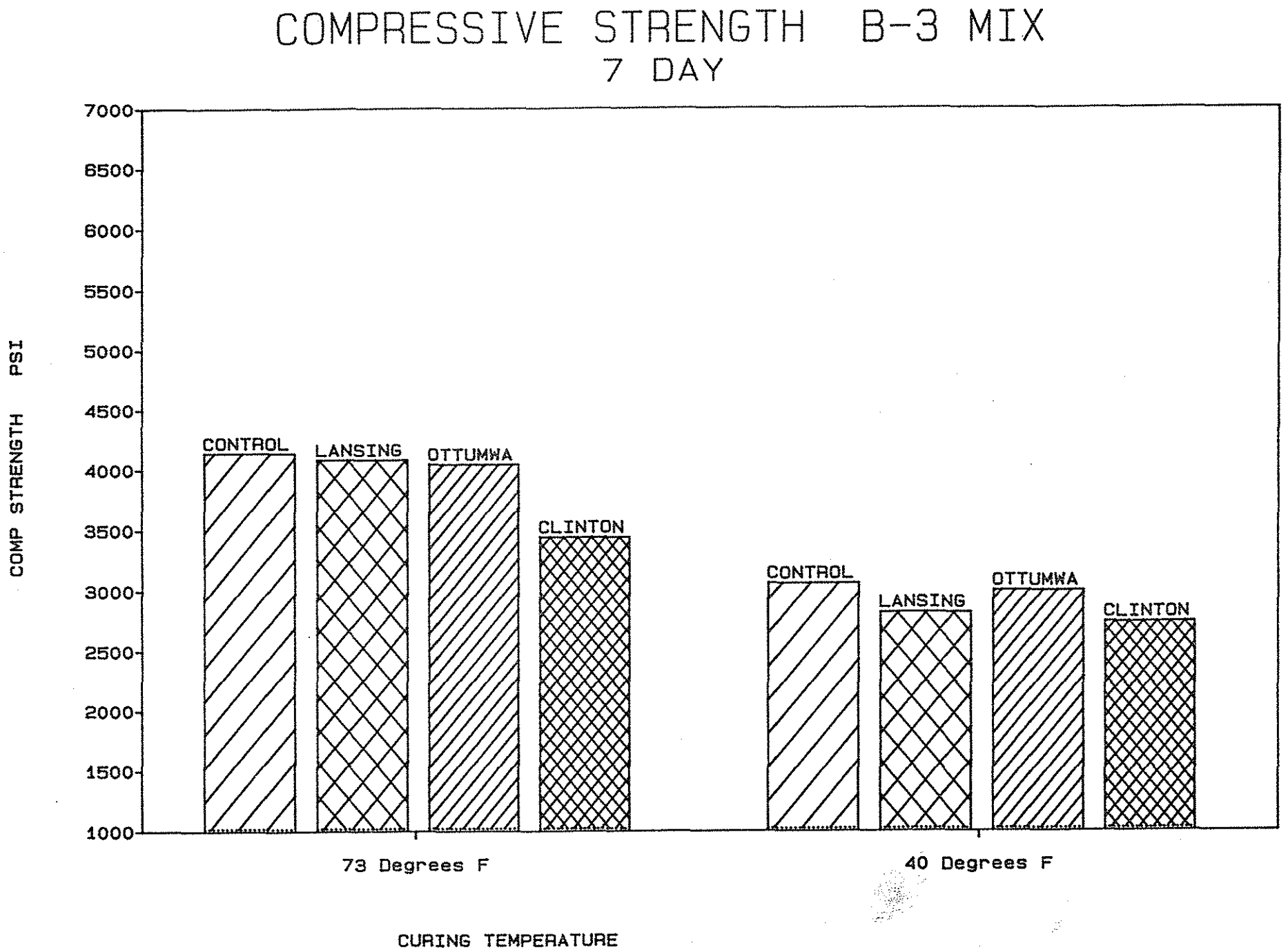
COMPRESSIVE STRENGTH B-3 MIX
7 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 2

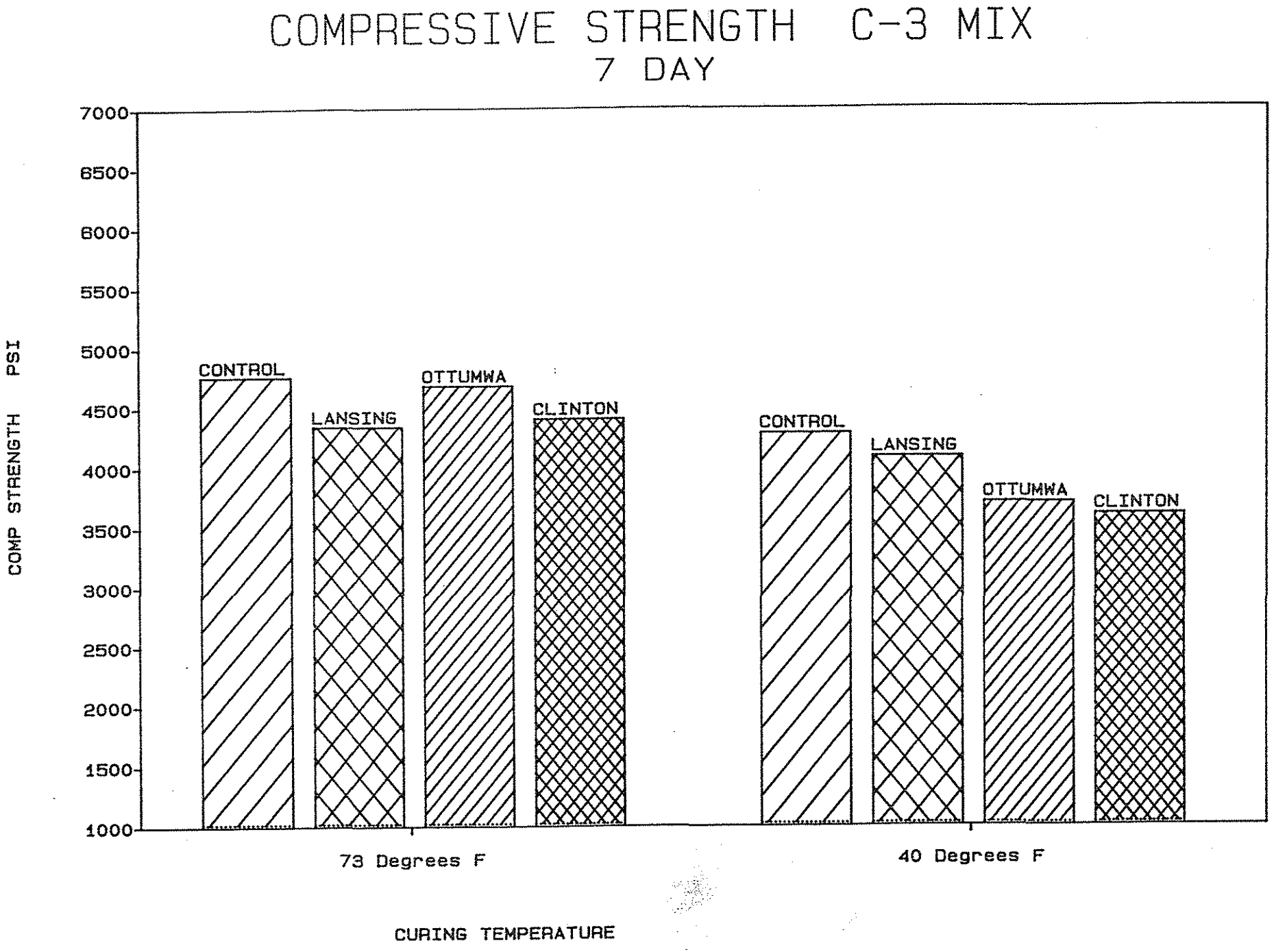
COMPRESSIVE STRENGTH C-3 MIX
7 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 3

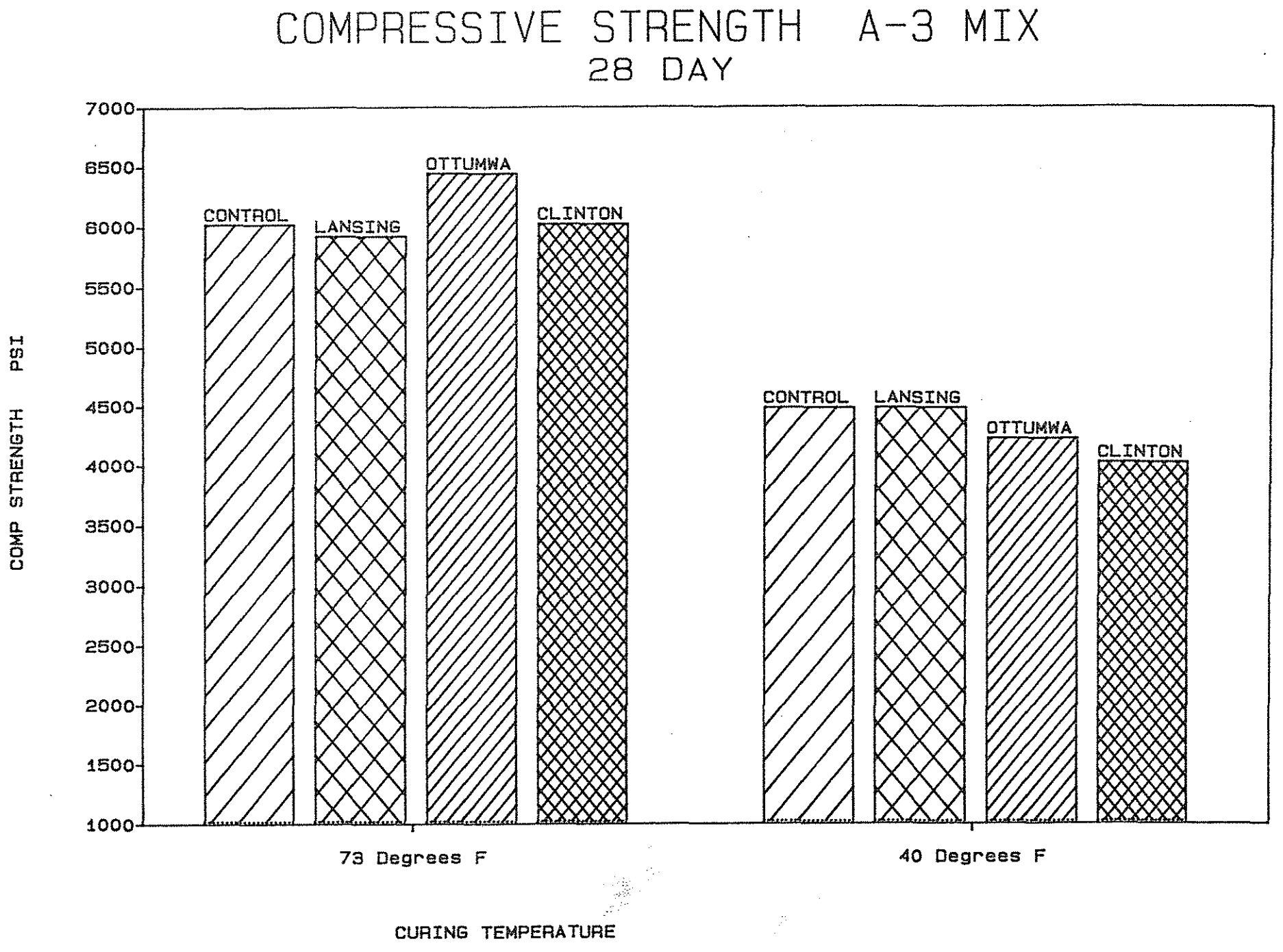
COMPRESSIVE STRENGTH A-3 MIX
28 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 4

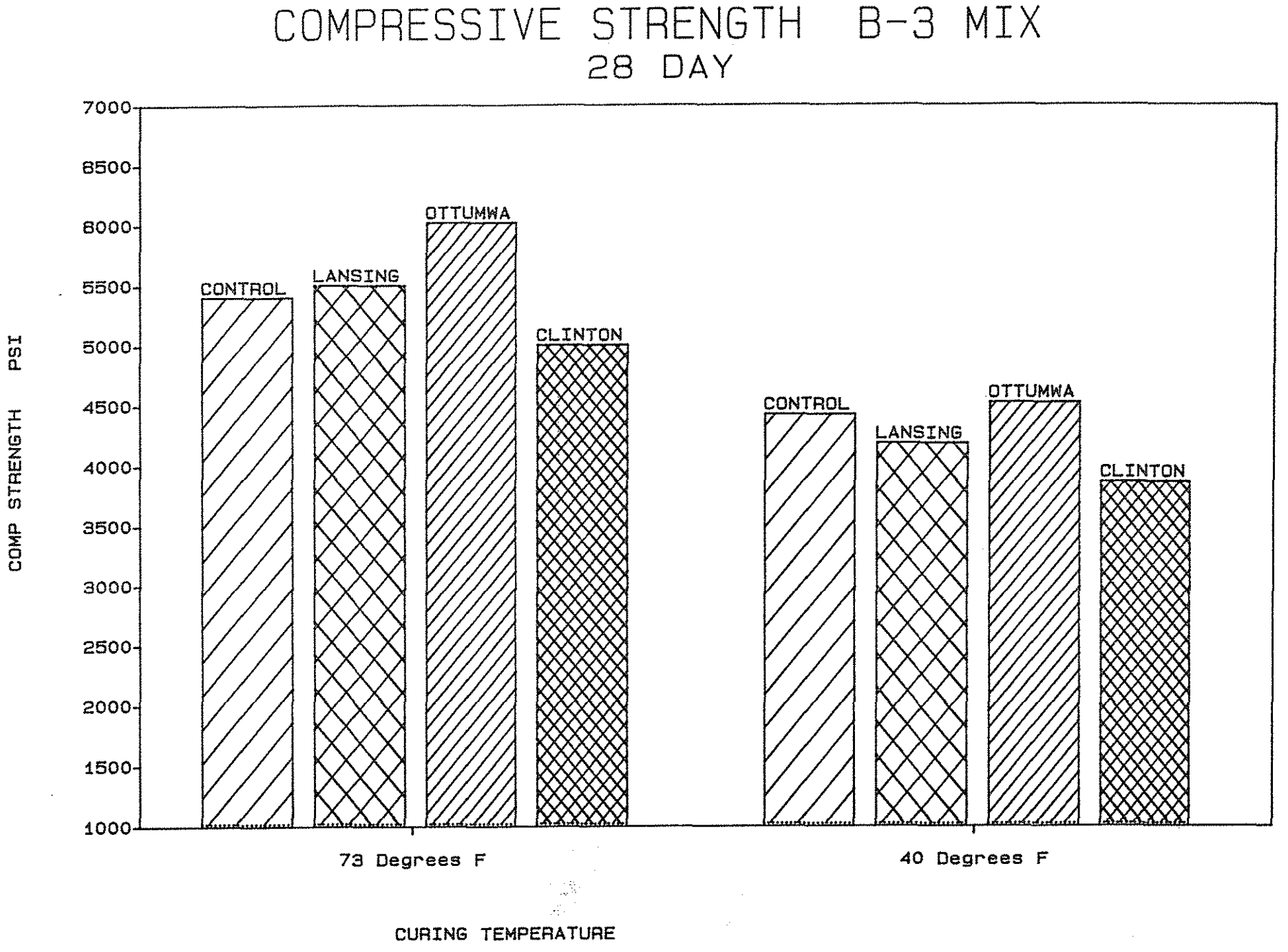
COMPRESSIVE STRENGTH B-3 MIX
28 DAY
COMP STRENGTH PSI
7000
8500
8000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 5

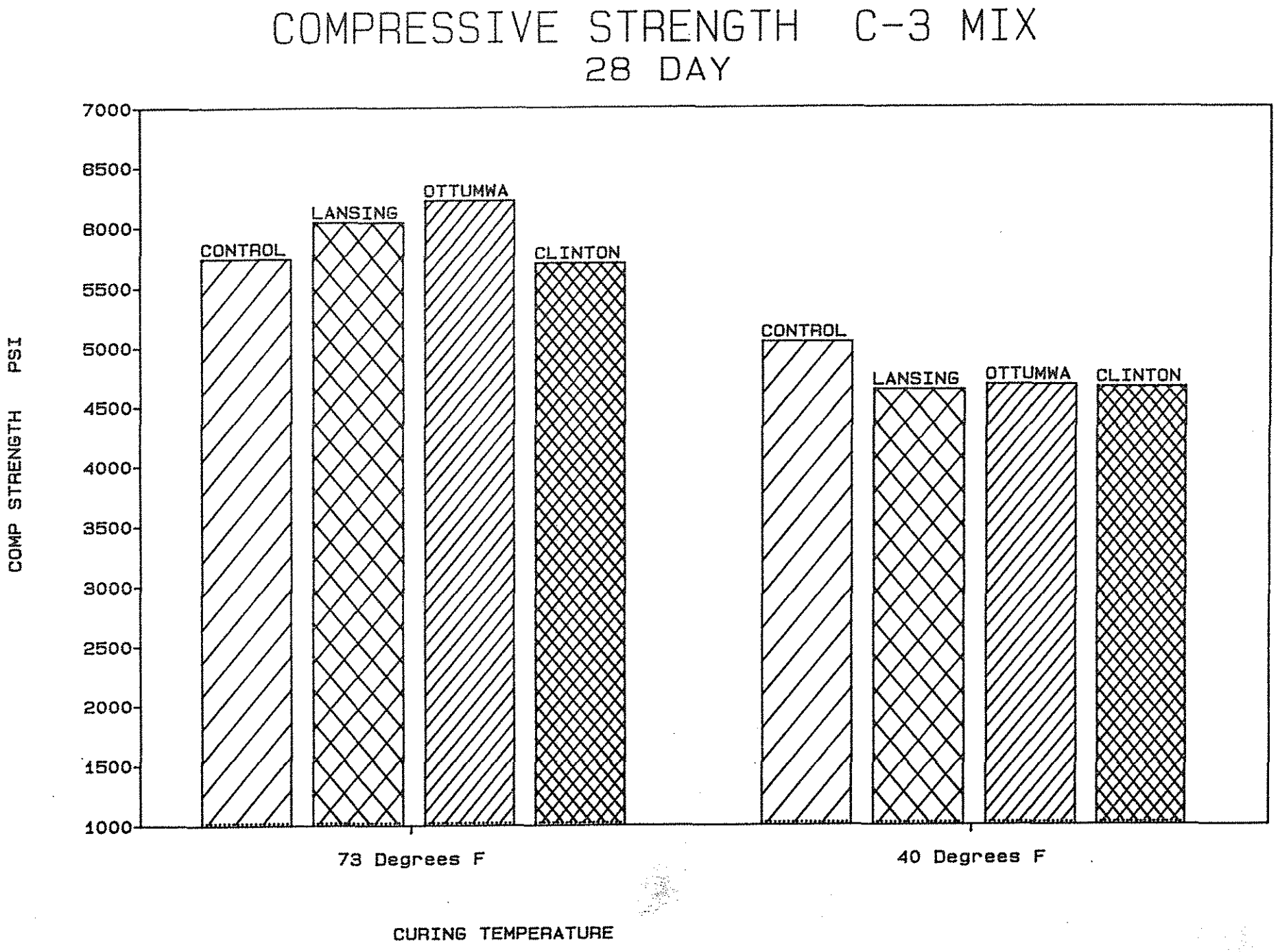
COMPRESSIVE STRENGTH C-3 MIX
28 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 6

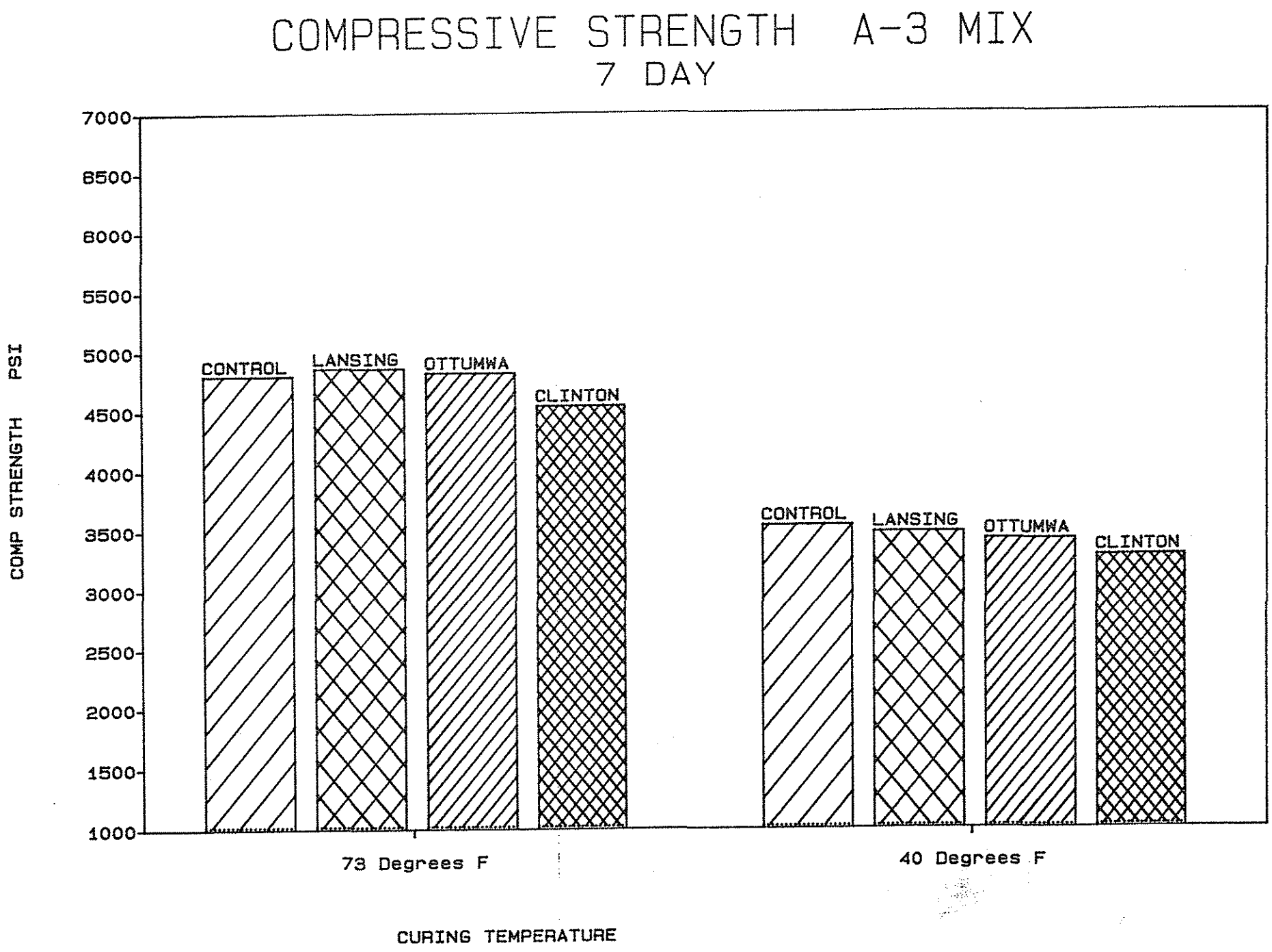
COMPRESSIVE STRENGTH A-3 MIX
7 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 1

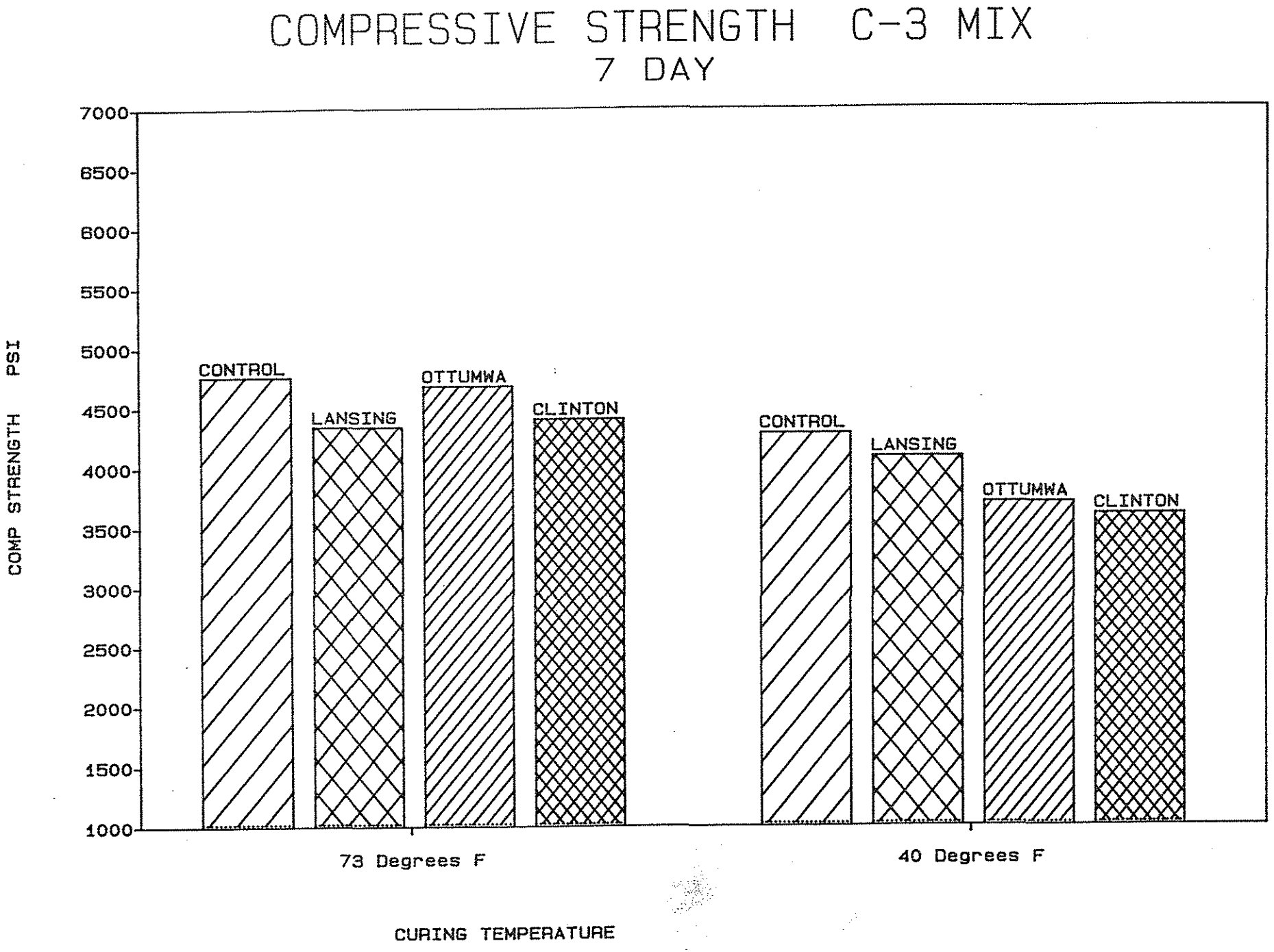
COMPRESSIVE STRENGTH C-3 MIX
7 DAY
COMP STRENGTH PSI
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 3

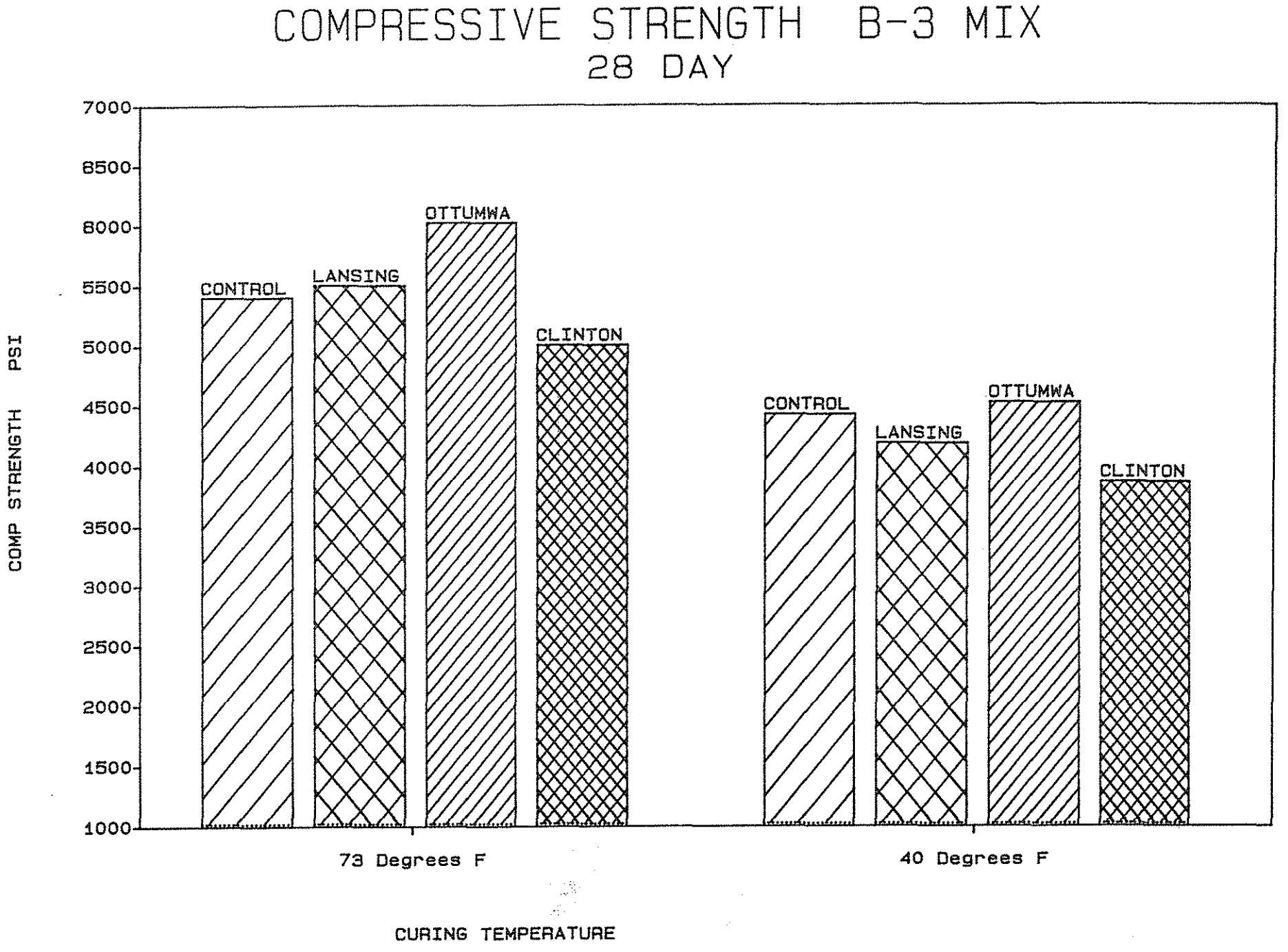
COMPRESSIVE STRENGTH B-3 MIX
28 DAY
COMP STRENGTH PSI
7000
8500
8000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
CONTROL
LANSING
OTTUMWA
CLINTON
CONTROL
LANSING
OTTUMWA
CLINTON
73 Degrees F
40 Degrees F
CURING TEMPERATURE

FIGURE 5

7 Day Temperature Correlation
Control Concrete

Std. Error 197 PSI Corr. Coeff. 0.7557

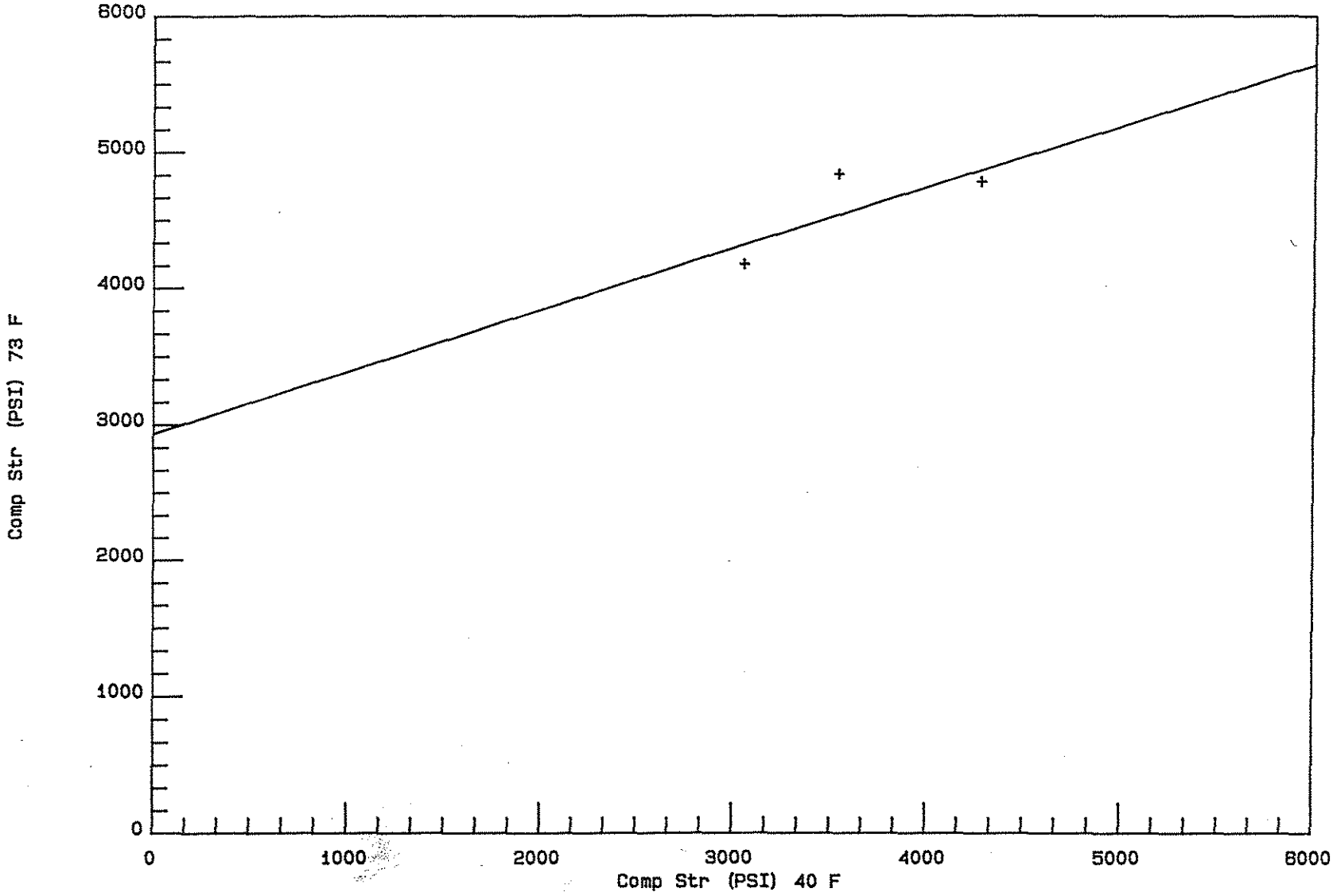

FIGURE 7

7 Day Temperature Correlation
Control Concrete

Std. Error 197 PSI Corr. Coeff. 0.7557

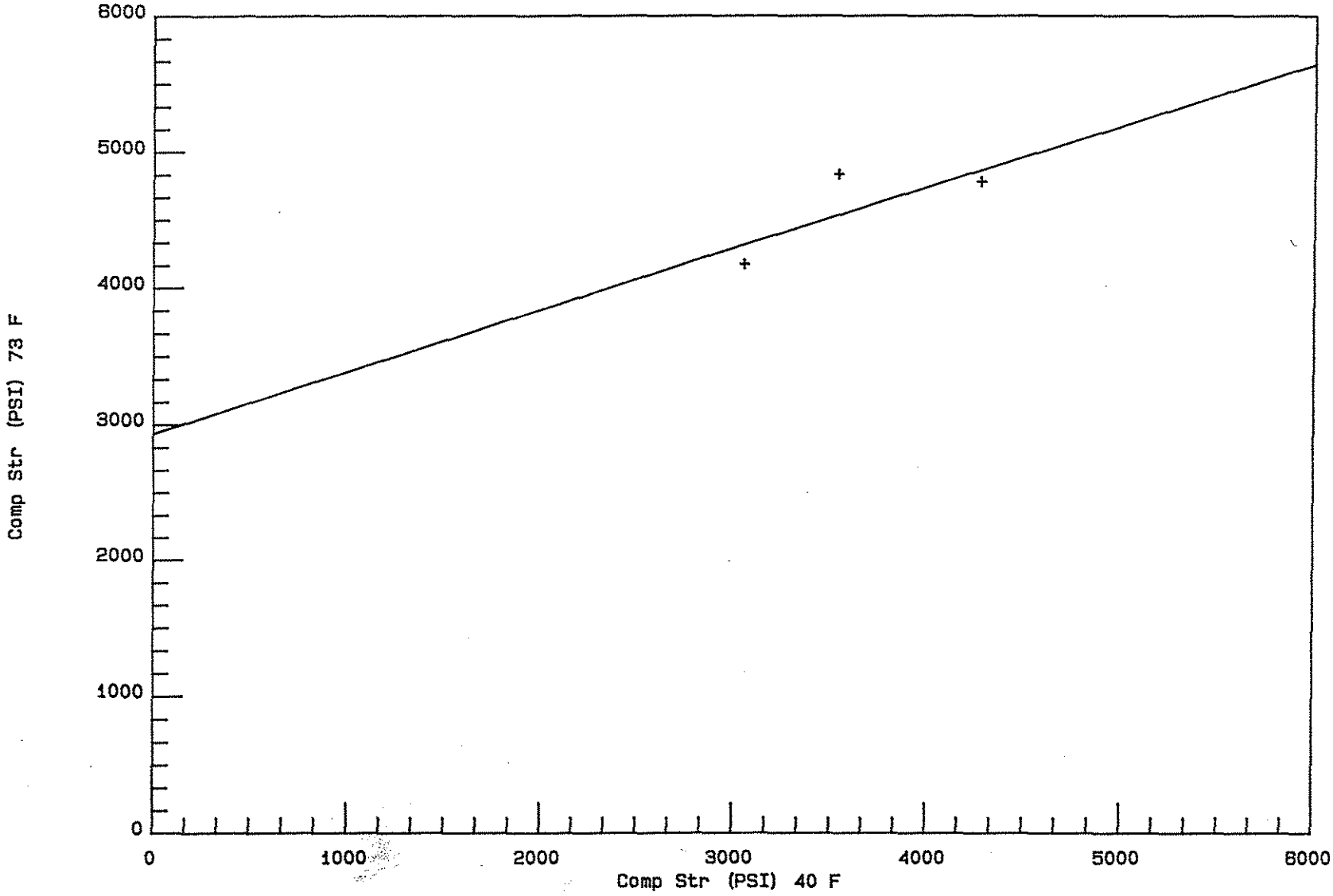

FIGURE 7

7 Day Temperature Correlation
Class F Fly Ash

Std. Error 233 PSI Corr. Coeff. 0.8778

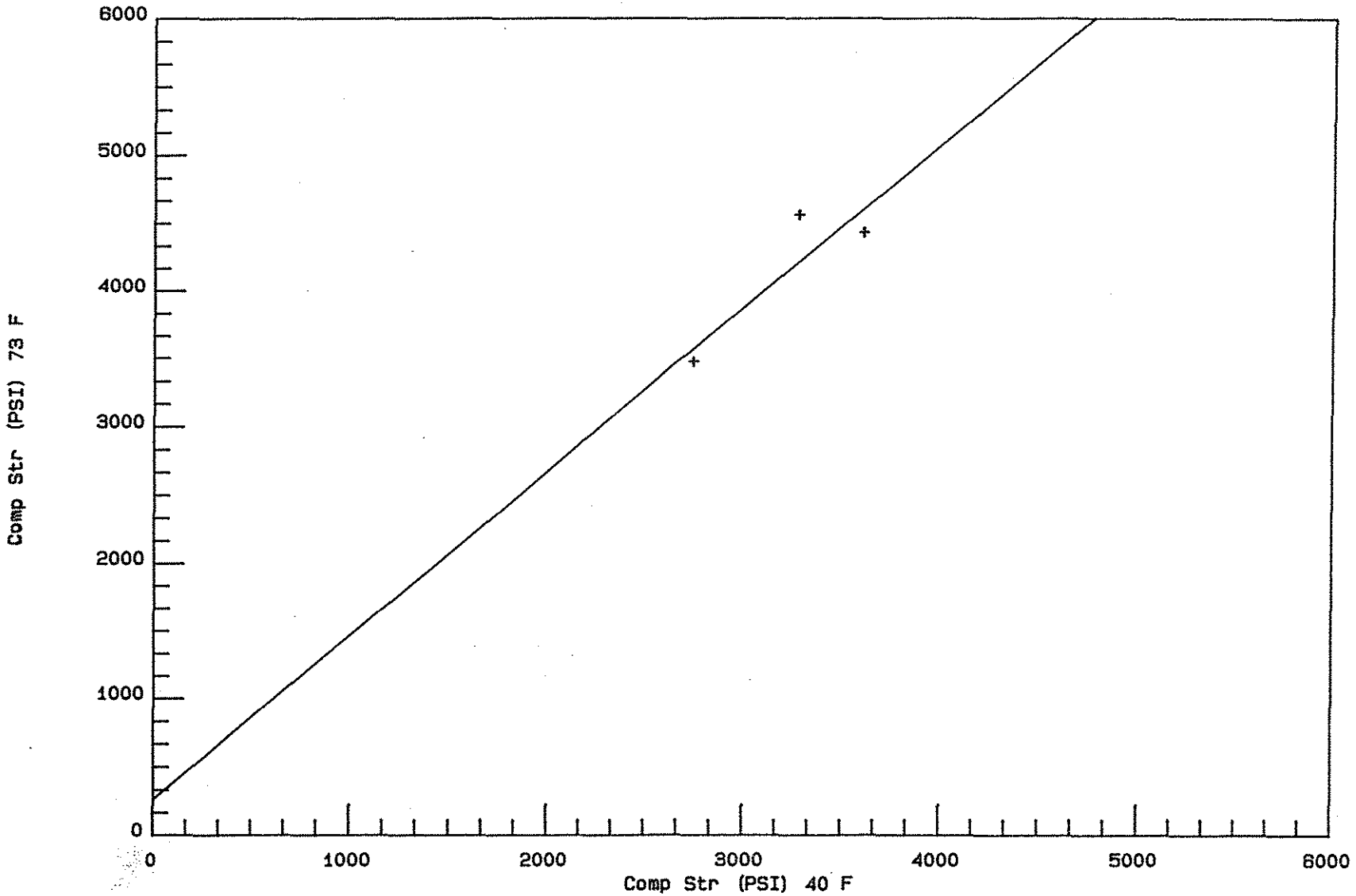

FIGURE 8

7 Day Temperature Correlation
Class C Fly Ash

Std. Error 295 PSI Corr. Coeff. 0.4874

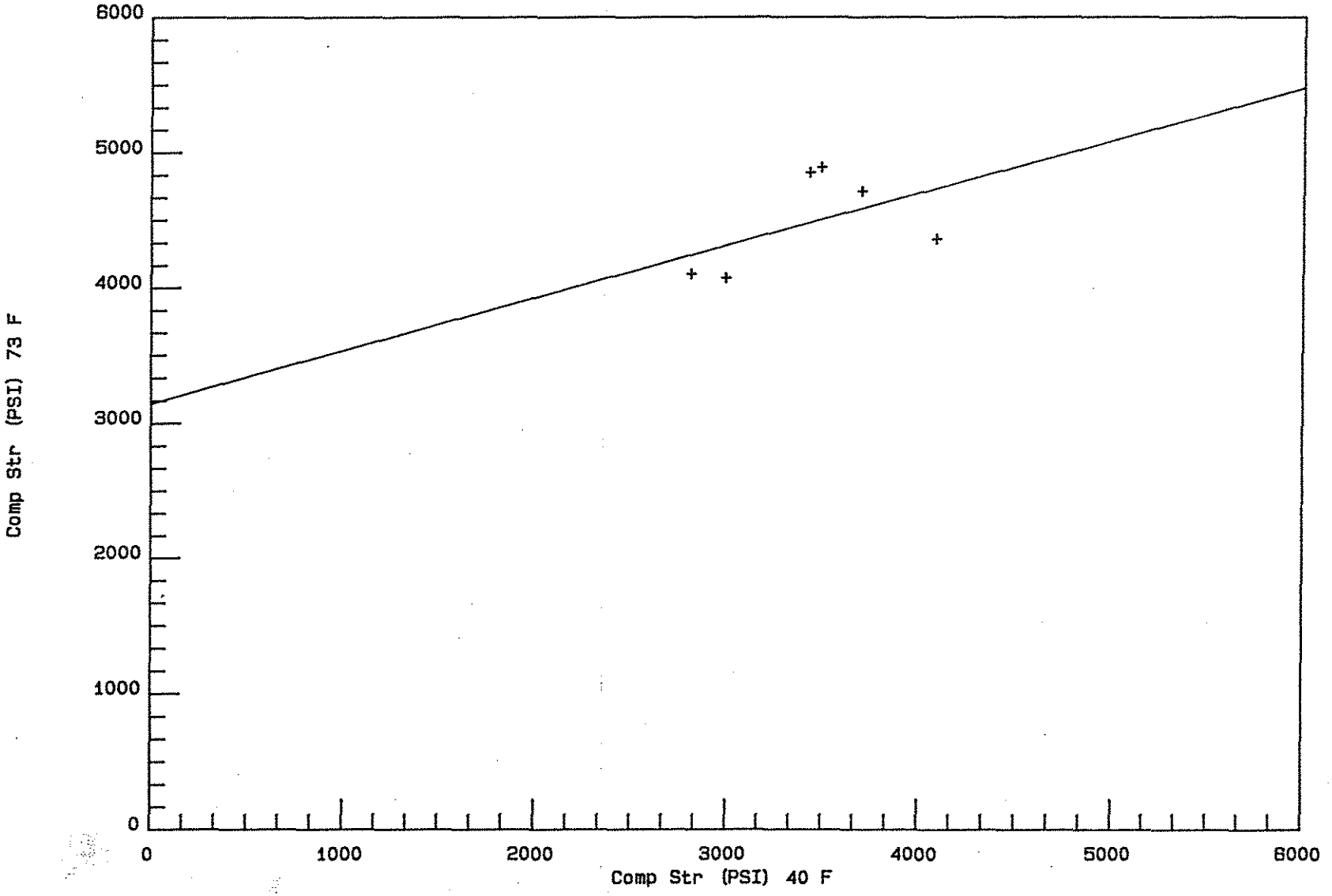

FIGURE 9

28 Day Temperature Correlation
Control Concrete

Std. Error 250 PSI Corr. Coeff. 0.175

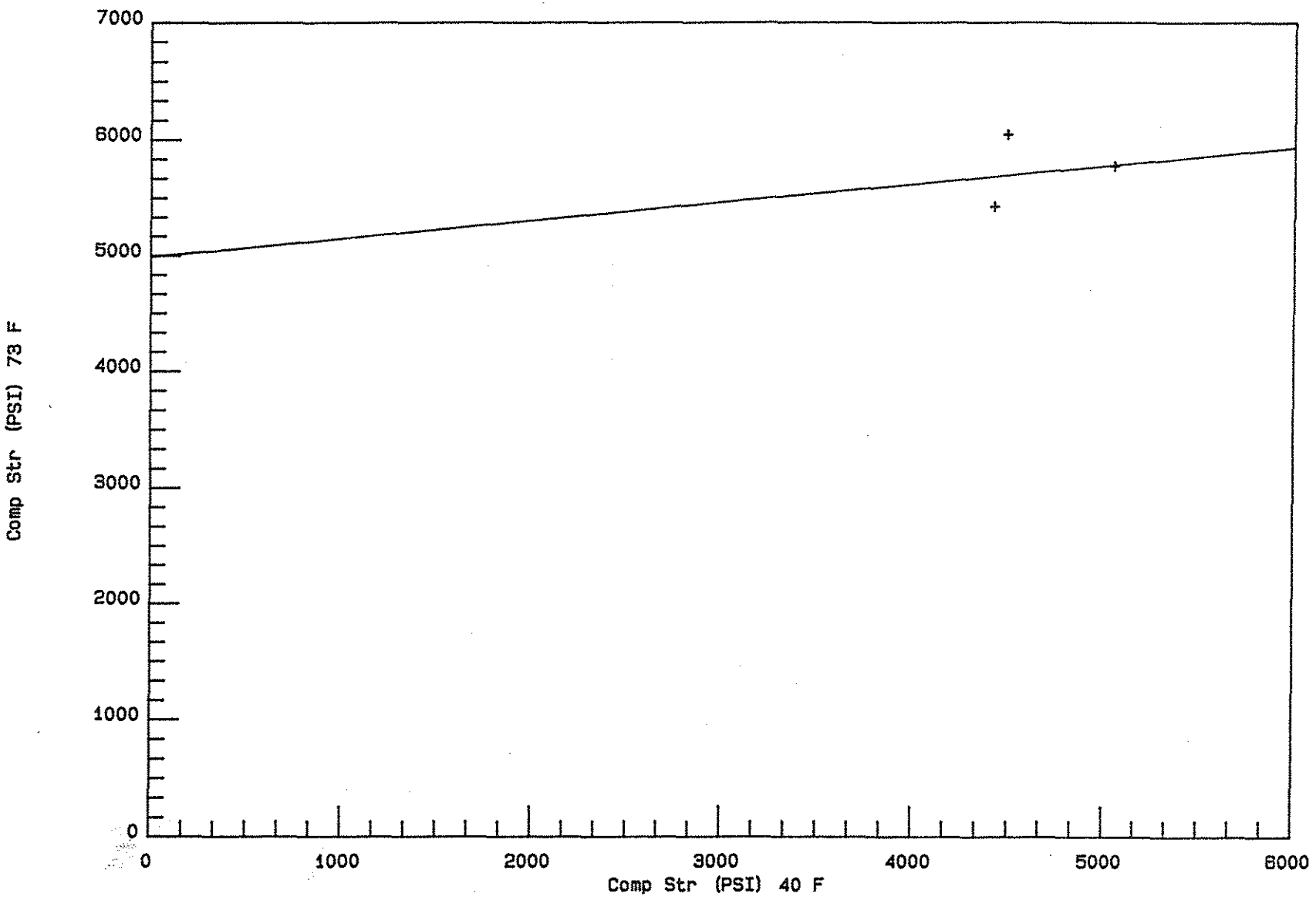

FIGURE 10

28 Day Temperature Correlation
Class F Fly Ash

Std. Error 409 PSI Corr. Coeff. 0.367

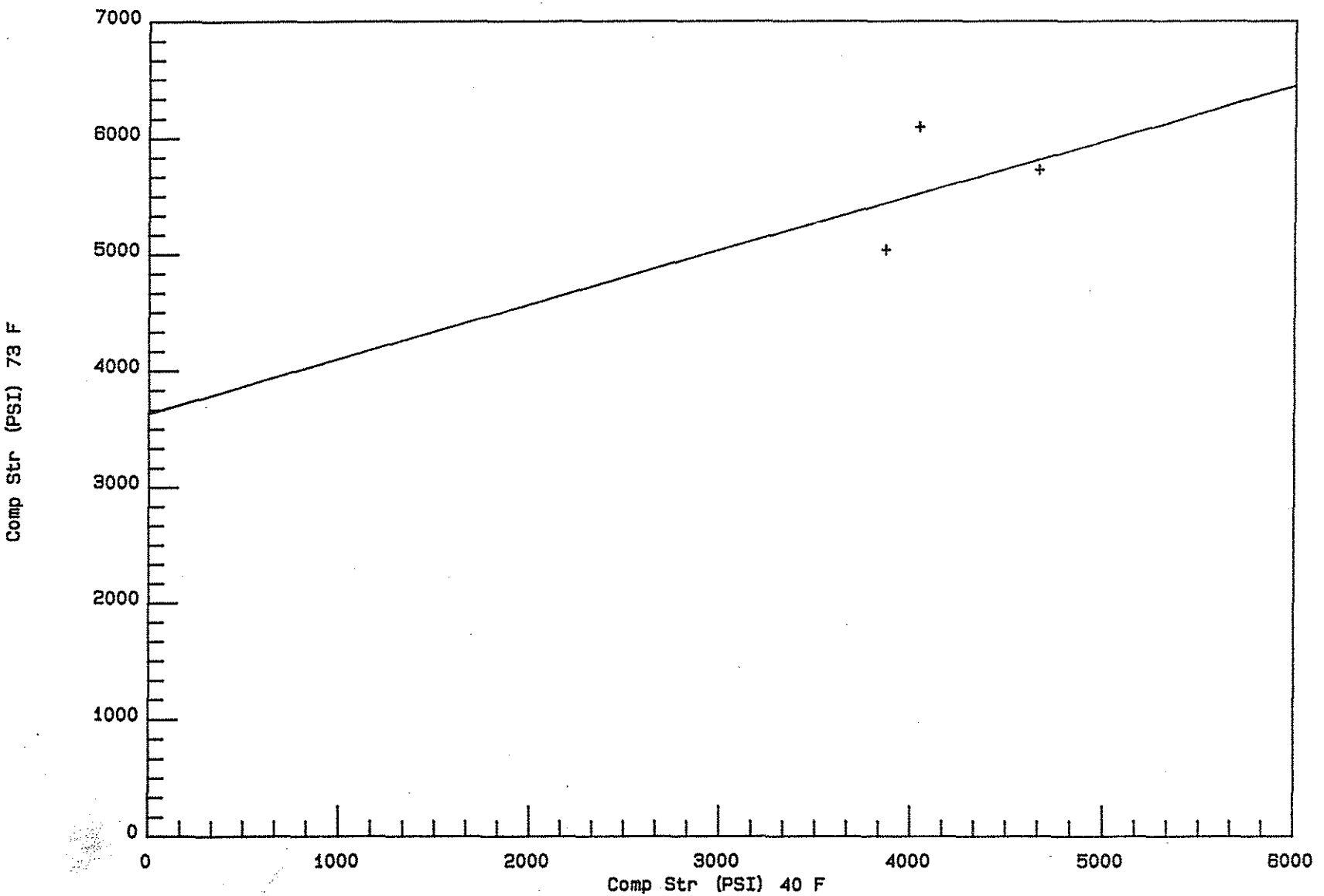

FIGURE 11

28 Day Temperature Correlation
Class C Fly Ash

Std. Error 277 PSI Corr. Coeff. 0.258

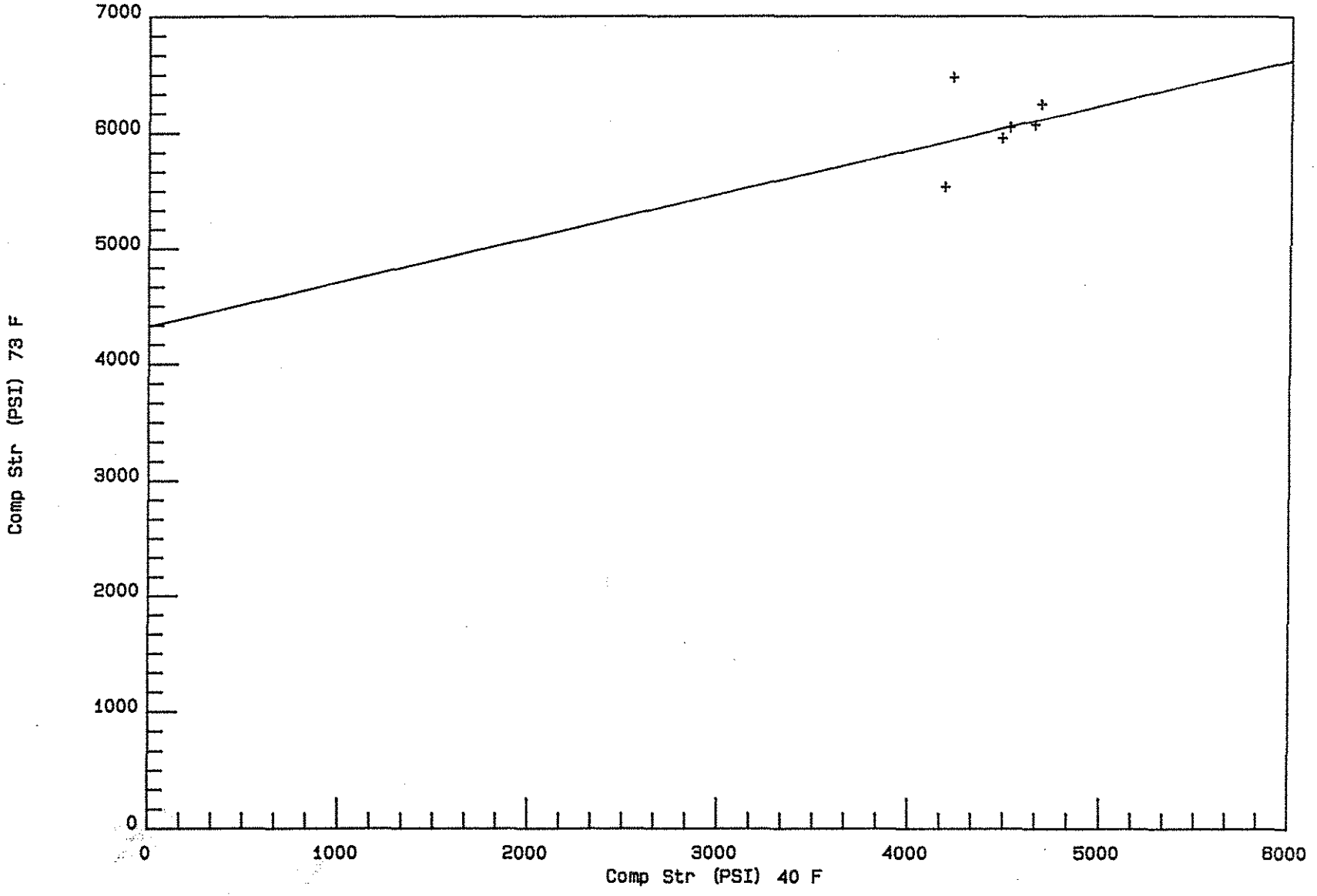

FIGURE 12

CONCLUSIONS & RECOMMENDATIONS

Standard specifications for the Iowa DOT prohibit the use of fly ash as a substitute for portland cement after October 15. Average minimum temperatures in Iowa for October generally fall in the low forties, and would consistently be in 40°F minimum temperature range by the middle of the month for the normal year.

The data collected in this study establishes the slower strength development in cool weather for paving concretes incorporating typical Iowa fly ashes. Based upon this data, the reasonableness of the currently specified October 15 cut-off date is verified and should be continued.