

CONCRETE CASE STUDY NUMBER 31

Effect of Long Steam Curing Durations on the Strength
of A5 Concrete

by

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Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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INTRODUCTION

In response to a request from D. A. Traynham of the Department's Materials Division, the Research Council has investigated the effect of long steam curing times on the strength of A5 concrete.

For prestressed work, the Department usually specifies A5 concrete having a minimum 28-day compressive strength of 5,000 psi. In much of the prestressed work, a compressive strength of 4,000 psi is required before the pretensioning is released. Generally, steam cured class A5 concrete attains this strength within a day, thus fulfilling the Department's specifications which restrict the steaming time to 12-24 hours. However, provisions are made in the specifications whereby a change in steaming duration can be authorized by the engineer. In a current project, pretensioned prestressed concrete beams with a minimum 28-day compressive strength of 6,000 psi and a release strength of 4,800 psi are needed. The fabrication of these elements has been contracted to the Bayshore Concrete Products Corporation. To attain the high strengths needed, they have considered the use of a Type II cement with a high C_3S content and a high cement content in the mixture, and steam curing for long durations. The latter consideration prompted this study. Two series of tests utilizing both the job and the laboratory aggregates were performed.

BACKGROUND

For economy and convenience, it is desirable to accelerate the concrete strength development at the prestressing plant to expedite form removal, early handling, and the release of pretensioning preferably on a daily basis.^(1,2) Utilization of atmospheric pressure (low pressure) steam curing and the proper cement requirements generally enables the achievement of early strengths within 18 hours of casting and allows some time for stripping and cleaning the forms and releasing the prestress in a 24-hour period. For a length of steam curing from 6 to 48 hours Higginson, has observed an increase in compressive strength with an increase in steaming duration.⁽³⁾

Similarly, the compressive strengths of specimens steam cured for different time intervals and then air cured have increased along with an increase in the length of the steam curing time. Schmid and Schutz have reported that for steam curing at temperatures over 140° F very little is gained by curing longer than 24 hours.⁽⁴⁾ They have also stated that through the use of proper atmospheric steam pressure, compressive strength values similar to those for moist cured specimens can be achieved at 28 days. On the other hand, ACI Committee 517 has acknowledged that the ultimate compressive strength of steam cured concrete is not as great as that of continuously moist cured concrete.⁽²⁾ However, the committee also mentions the advantage of steam curing over the limited moist curing usually experienced in practice.⁽²⁾ Researchers also have excluded the possibility of adverse effects on the resistance to freezing and thawing by increasing the steam curing durations.^(3,5)

The prestressing industry is capable of manufacturing quality concrete within 24 hours by utilizing proper curing procedures. The Department's specification acknowledges this fact and restricts the steaming duration from 12 to 24 hours to ensure quality of production and to avoid problems related to the inadequacy of curing operations. However, this time limit does not necessarily indicate that long steam curing durations are harmful to concrete.

LABORATORY STUDY AND RESULTS

Test Series 1

Materials and Mixture Proportioning

The laboratory study conducted by the Council utilized the mix proportions and aggregate sources to be used by the fabricator. Samples of the cement to be used by the fabricator were obtained from the Universal Atlas Cement Company. (The laboratory test report of the cement is attached.) The coarse aggregate was siliceous gravel and was graded to eliminate material larger than that retained on the 1" sieve, since small cylinders (3" x 6") were to be used in the testing. The mix proportions per cubic yard as furnished by the fabricator were as follows:

Cement	7-1/2 bags
Sand	956 lb.
#5 stone	1157 lb.
#7 stone	768 lb.

Air entraining agent	6 oz.
Plastiment	30 oz.
Water	289 lb.

A slump of 3-1/2" to 4" and an air content of 5% were intended by the producer. These values are within the limits of the Department's specification which requires a slump of 0-4" and an air content of $4 \pm 2\%$ for A5 concrete. The initial batch of 1-1/2 ft.³ was prepared by using a water content of 262 lb./yd.³. This mixture yielded an air content of 7.5% and a slump of 6.4", both of which values were higher than desired. In the next mixture, the air entraining agent was reduced to 3 oz./yd.³ and the water content was kept at 262 lb./yd.³. This batch yielded an air content of 3.3% and a slump of 3.9". Consequently, this mixture was considered satisfactory for preparation of the specimens.

Testing and Results

Forty-five 3" x 6" cylinders were fabricated from the acceptable batch within an hour after the addition of mixing water. Five of the specimens were moist cured. The remaining specimens were put in the steam chest and kept at 90° F until the time of initial set. Then the temperature in the chest was increased to 130° F in 1 hour. During the next 1/2 hour a final temperature of 160° F was attained. After reaching 130° F, the samples were steam cured for different durations; namely, 8, 12, 16, 24, 30, 36, 48 and 72 hours. At the end of each duration, 5 specimens were removed from the chest; 3 were tested within 1 hour after removal. The compressive strength values were found to increase rapidly during the first 16 hours, to level off until the 36th hour, when they again increased as shown in Figure 1*(solid line). After each duration period, 2 of the cylinders were air cured at a relative humidity of $50 \pm 5\%$ for a combined curing of 28 days and tested. The results, plotted in Figure 2, show that beyond 24 hours of steam curing (after reaching 130° F) the 28-day moist cured average cylinder strengths of 7,220 psi were maintained.

Test Series 2

Materials and Proportioning

To investigate the leveling off of strength values observed in

*Figures are appended.

the first specimens and to assure that at durations up to 72 hours strength loss did not occur, another batch of concrete was prepared. In this mixture, because of the depletion of the laboratory's limited supply of Bayshore aggregates, locally available crushed stone and siliceous fine aggregates were used and the amount of Plastiment was decreased to 15 oz./yd.³, since in the former batch the time of set was 11-1/2 hours. With this reduction in admixture the time of set was 5-1/4 hours. An air content of 5.5% and a slump of 3.5" were obtained in this mixture. Meeting the specifications, it was used for the preparation of specimens.

Testing and Results

As for the first batch, 45 specimens were prepared and the same curing and testing were applied, except that the 12 hour duration of steam curing was omitted for convenience. The compressive strength results after each duration are shown in Figure 1 by the broken line. As can be seen, there was a continuous increase in strength even though the rate of gain gradually decreased. The strength values for the specimens that were cured for 28 days under the steam and air curing combined are shown in Figure 2. After almost a day of steam curing, strength values similar to those of moist-cured specimens exhibiting 7,780 psi compressive strength were obtained.

CONCLUSION

Based on the results of this investigation in which the longest steam curing time was 72 hours, it is concluded that increasing the curing times did not adversely affect the strength of the concrete tested after each duration. However, at the later stages of steam curing, gains in strength were smaller than at the earlier stages. Specimens steam cured for durations beyond 24 hours and then air cured for a combined curing of 28 days attained strength values in the range achieved by moist curing at 28 days.

1. Hanson, J. A., "Optimum Steam Curing Procedure in Precasting Plants," ACI Journal, January 1963.
2. ACI Committee 517, "Low Pressure Steam Curing," ACI Journal, August 1963.
3. Higginson, E. C., "Effect of Steam Curing on the Important Properties of Concrete," ACI Journal, September 1961.
4. Schmid, E., and R. J. Schutz, "Steam Curing," PCI Journal, September 1957.
5. Klieger, P., "Some Aspects of Durability and Volume Change of Concrete for Prestressing," Journal of the Research and Development Laboratories, PCA, V 2, September 1960.



2313

Universal Atlas Cement

Division of United States Steel Corporation

Date Shipped _____

Cement T-11 Portland

Shipped From _____

Laboratory Test Report

To: _____

Consigned To _____

Car/Truck No. _____

Bbl. _____

The data given below is average of bin from which cement was shipped.

CHEMICAL %

SiO ₂	<u>22.0</u>
Al ₂ O ₃	<u>4.49</u>
Fe ₂ O ₃	<u>3.61</u>
CaO	<u>64.7</u>
MgO	<u>0.55</u>
SO ₃	<u>2.6</u>
Loss On Ignition	<u>1.4</u>
Insoluble Residue	<u>0.36</u>
C ₃ S	<u>53.2</u>
C ₃ A	<u>5.8</u>

PHYSICAL

Fineness	
Specific Surface -- Sq. Cm./g	
Wagner	<u>2115</u>
Blaine	<u>4050</u>
Soundness, Autoclave Exp. %	<u>0.04</u>
Time Of Setting, Hr.: Min. -- Initial	_____
Final	_____
Air Content -- %	<u>8.8</u>
Compressive Strength, psi -- 1 Day	<u>1520</u>
3 Day	<u>3160</u>
7 Day	<u>4410</u>

This cement complies with applicable ASTM and Federal Specifications.

By myc

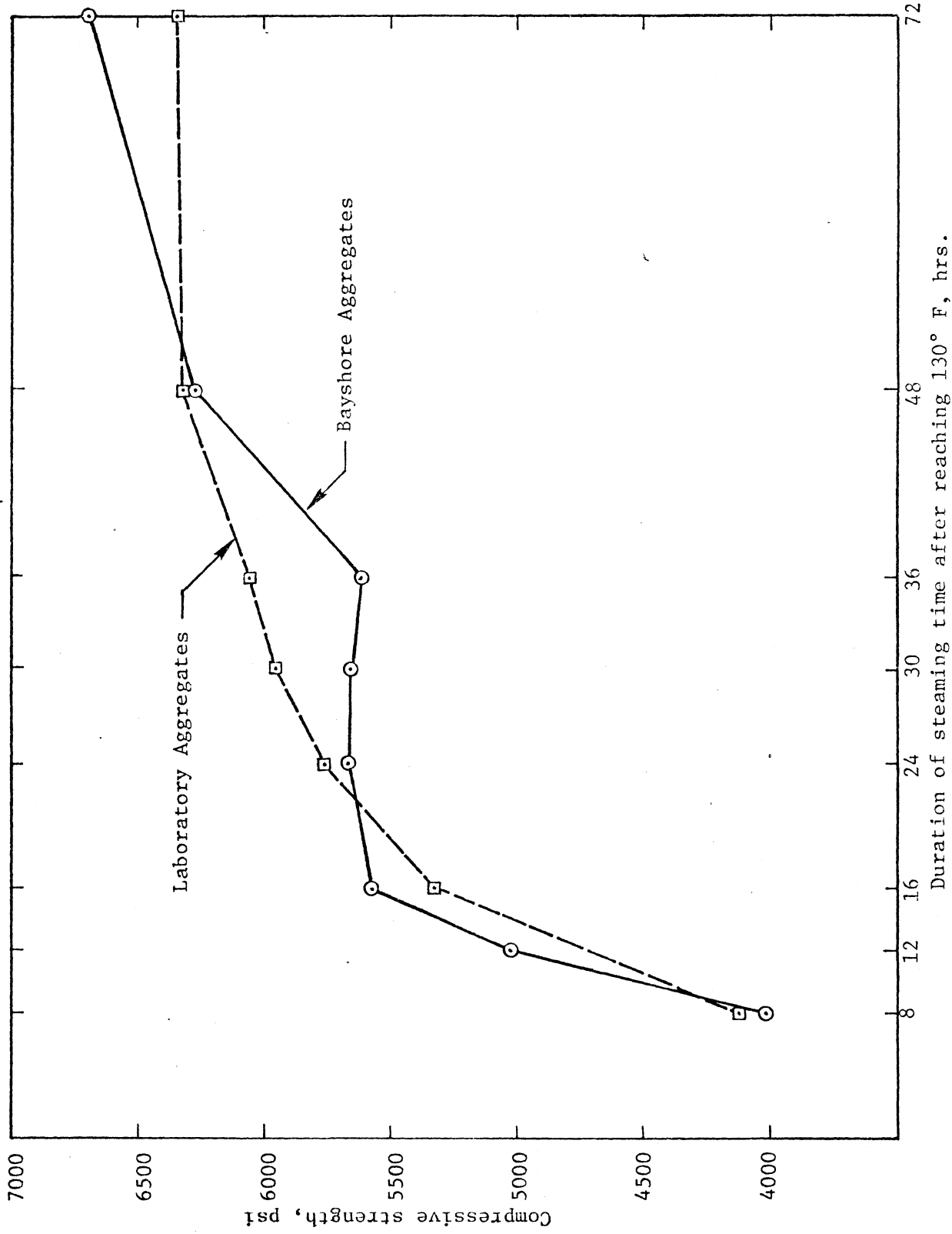


Figure 1. Compressive strength of 3" x 6" cylinders tested after different durations of steaming time.

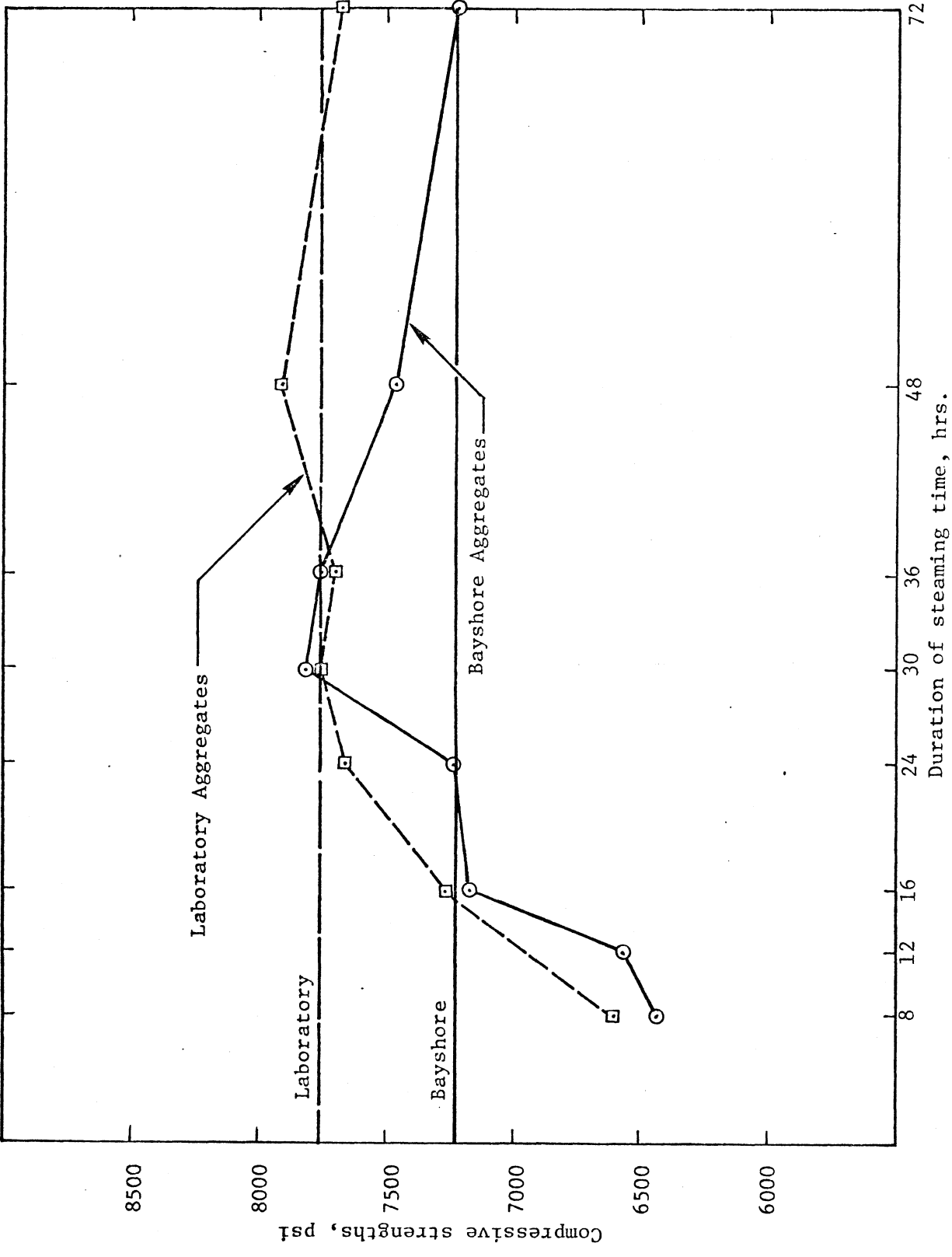


Figure 2. Compressive strength of 3" x 6" cylinders steam cured for different durations and then air cured for a combined curing period of 28 days. The 28-day compressive strengths of the moist-cured specimens are shown by the horizontal lines.

