

コンクリートの強度におよぼす蒸気養生の効果

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The Effects of Steam Curing on the Strength of Concrete

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This paper describes the problems on the effect of various steam curing procedures on the strength of structural concrete. These problems seem to have been thoroughly studied by many investigators, but still now many investigators are studying on optimum steam curing procedures to be compatible with the time requirements of modern prestressing plants or other own particular requirement.

Problems are discussed according to typical steaming schedules, including the summaries of the current knowledge that have been reported by some investigators and that were observed in some additional investigations by the writer.

Steam curing of concrete is commonly used in the manufacture of concrete products to obtain high early strength to expedite the stripping of forms and to shorten the curing period.

Knowledge of the effect of steam curing on the properties of concrete has been increased very substantially by recent publication of E. C. Higginson,¹⁾ J. A. Hanson,²⁾ and ACI Committee 517.³⁾

The strengths developed during the early hours after casting are of particular interest for researchers and producers. In general, however, concrete that has been steam cured and then air dried, is not as good as concrete that has been continuously fog cured or even for cured for 7 days.

Many prestressing plants in Japan require concrete with compressive strength of 300 Kg/cm² at stripping of forms to introduce prestress. Such high strength requirement may be incompatible with early form removal or shortening the curing period.

Many plants operate on a 24-basis, with casting, curing, stripping and clean-up continuing on a daily schedule, in which curing cycle may be within 12 hrs. Producers desire to get more knowledge of the detrimental effect of early steam application and higher temperature of steaming.

Hanson reported compressive strength in excess of 4000 psi in 8 hrs after casting, that was about 65 percent of the 28-day strength of fog-cured specimens, and many other investigators have also reported more than 60 percent of the fog cured 28-day strength may be obtained in 28 hrs. In later age, however, many investigators have found that

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higher initial temperatures reduce the potential strength at later age. With respect to the steam cured normal weight concrete, the 28-day strength amounted to 65 to 95 percent of that obtained with continuous moist curing.

Compressive strength as affected by presteaming period

A Comprehensive laboratory work on this subject is that reported by Hanson.²⁾ He based his investigation of normal weight concrete on a curing cycle appropriate for prestressing or other products plants in which a period of 18 hrs between casting and the end of steam. He used several different maximum temperatures, rate of temperature rise and presteaming periods, showing the effect of respective condition. His 18 hr strength curves show an increase as the presteaming period increase from 1 to 5 hrs and the 7 and 28-day curves reach maximum for 5 to 7 hrs of presteaming period.

The steam curing procedure of his investigation was regulated such that as the presteaming period increased, the total steaming period decreased. The sum of those two periods was held constant at 18 hrs, and this procedure may qualify the reported results. (see Fig. 1)

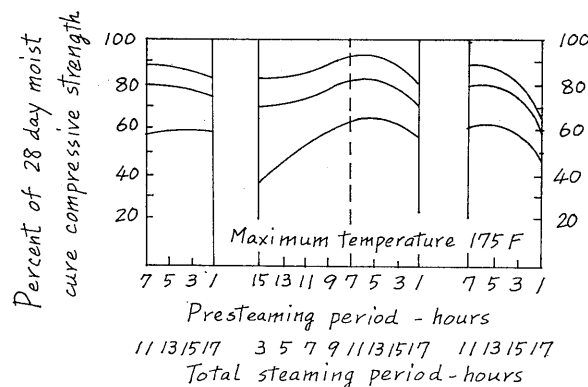


Fig. 1 Relative compressive strength of steam cured concrete.

E. G. W. Bush⁴⁾ discussed in his experience in various prestressing plants, each individual cement requires its own optimum preset time before the application of steam, and if one is allowed to generalize while attempting to stress the importance of particular case, it may be said that the optimum preset time for plane mixes using tipe-III cement appears to be in the region of 3 or 4 hrs for average condition.

K. Kohn, K. Emura and K. Kinoshita⁵⁾ reported the effect of presteaming period on bond and tensile strength of concrete, in which specimens were placed in a 20°C room for four presteaming periods: 0, 3, 6 and 24 hours, and then were put into a curing tank to be cured at high temperature to 65°C by test programs. His conclusions are followings,

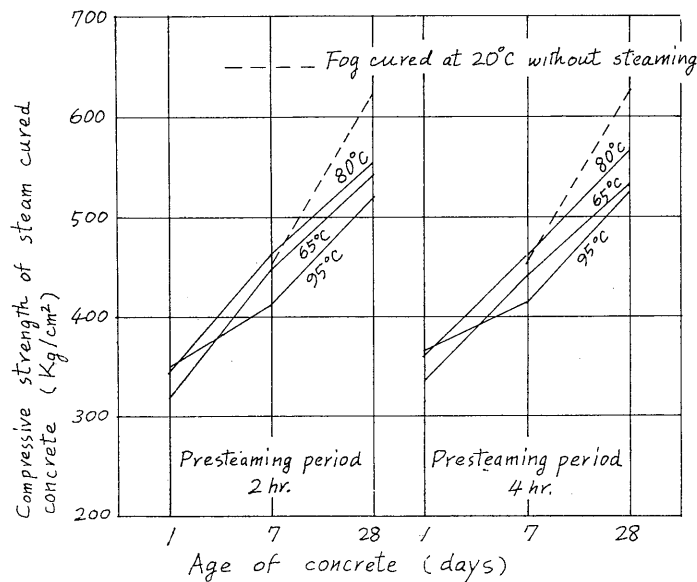


Fig. 2 Relationship between compressive strength and age of steam cured concretes.

1) The optimum presteaming period exists between 3 and 6 hours after casting in general, although the effects of presteaming period on various strengths are different in all cases.

2) The effects of presteaming period on bond strength are not so remarkable as those on compressive and tensile strength while a delay of several hours.

In the recent investigation by T. Mukai⁶⁾, he reported that 2 hours is proper for presteaming period, and the rate of temperature rise is little affect on strength of concrete. The specimens used in his tests were bound the outer surface to restrain swelling of concrete during the curing period. The results of his investigation may not be applicable in all cases of various types of concrete products, because those curing method was not at atmospheric pressure, and different restraining conditions may produce different results.

Rate of temperature rise

Hanson recommends that severe damage may be incurred with rate in excess of 40°F per hour with presteaming period of less than 3 hrs.

R. K. Lewis⁷⁾ discussed that for optimum compressive strength the delay period and rate of temperature rise should be such that the temperature of the concrete did not reach 50°C until about 6 hrs after mixing.

In Japanese Industrial Standard for concrete products as piles, poles, pipes etc. maximum

rate of temperature rise was revised in 1963 from 15°C/hr to 20°C/hr.

For the purpose of shortening of curing cycle, the rate 20°C/hr will be suitable, but it may not in all cases be economical.

Maximum temperature

The maximum temperature between 60°C and 70°C in curing room is generally used in manufactures of concrete product in Japan, because Japanese Industrial Standard for concrete products limits the maximum temperature in curing room to 65°C.

Several investigators have found that the most effective results are obtained when the concrete is cured at a temperature between 150°F and 180°F.

Hanson indicated that a temperature of 175°F gave highest strengths although this provided only a slight advantage over those obtained at 150°F.

Many investigators have found that higher initial temperatures reduce the potential strength at later ages. The poor correlation between strength and "Maturity" has been indicated by several investigators at high temperature.

R. K. Lewis⁷⁾ has showed that the compressive strength increased linearly for concretes given maturity (based on 0°C) between 600 and 1000°C hr, and that above this latter maturity the rate of increase in strength decreased. However, when the steam-cured specimens were given additional fog curing the compressive strength increased by amount depending on the initial maturity given.

K. Kohno, K. Emura, K. Kinoshita⁸⁾ reported their experimental work in Onoda Central Research Laboratory, describing the effects of maximum temperature (65, 80 and 95°C) and presteaming period (2, 4, and 6 hours) on the compressive strength of concretes, and the result of these tests led to the following conclusions.

1) One day strength of steam-cured concretes increases as the maximum temperature during steam curing rises, but at the age of 28 days the concretes steam cured at 95°C yield at the lowest strength.

2) The longer the presteaming period, the higher the strength of steam cured concretes. The presteaming period of concretes made with high-early strength cement can be considerably shortened.

3) High-early strength cement is profitable to gain high required strength at early ages, but effect of maximum temperature on strength of concrete using this cement is not so remarkable as that on other cements.

4) The steam cured concrete using normal Portland cement indicates greater strength

developments at later ages than other concretes.

5) The fly ash replacement in amount of 20 percent and 40 percent of normal portland cement gives much higher rate of strength development at one day, as the maximum temperature rises from 65°C to 95°C.

6) The optimum curing conditions are influenced by type of cement, type and amount of admixture, casting temperature, etc.

Picking up from his test results, effects of maximum temperature and presteaming period on the relative compressive strength of steam cured concretes are shown in Fig.-2. These test results are interesting in steaming method by higher temperature than other former investigations, and obtaining high strength of all specimens. The writer guess the cause of their high strength would be a continuous fog curing after steaming up to the tests, and maximum temperature 80°C will not be detrimental if presteaming period is adequate.

Soaking

Proper soaking procedure are profitable for the purpose of saving steam and slowing down of rate of temperature fall. Common practice of soaking period is adjusted when conditions require an increase or decrease in other portions of the curing cycle, for example the presteaming period is increased during winter operation. The soaking procedure as commonly practices produced satisfactory results if heat loss of concretes is not excessive.

Resaturation

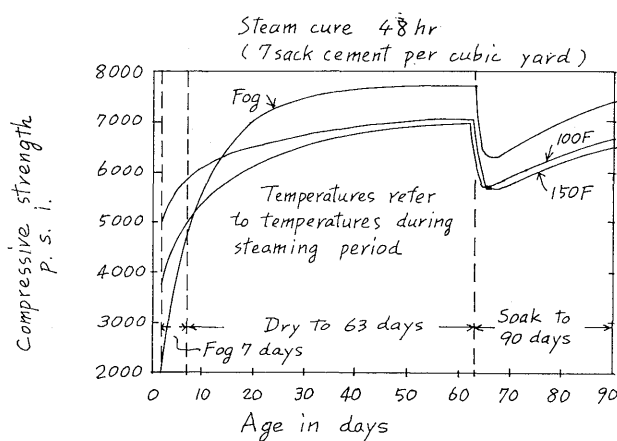


Fig. 3 Compressive strength of resaturated concrete.

Higginson reported that compressive strength of concrete decreases 20 to 25 percent

when the concrete is resaturated from the air-day condition, however, after resaturation, both steam and fog-cured concretes develop additional strength, thus indicating that interrupted curing can be profitably resumed. (see Fig.3)

Whether a soaking or a constant high temperature period is used, concretes remain hotter than the steaming room and continue to lose moisture, and the moisture loss may always become greater during soaking period than during continuous steaming period.

In the case of cast pipes or piles, most of them are made by centrifugation in Japanese plants, are exposed only on the inside surface of fresh concretes, and the mold which forms the outer surface is usually left in place until the end of the curing period.

Humidity of the curing atmosphere is not important to obtain early strength of concrete, but moisture loss due to the large surface area will produce a baneful influence to develop strength in later age. It should be proper treatment to use water curing after initial steam curing.

The writer attempted to evaluate on the effects of water curing period after steam curing for compressive strength of standard concrete specimens.

Normal portland cement was used. Specified mix proportion of concrete and curing condition in test series are shown in Tables 1 and 2, and the result of the tests is shown in Fig.4.

Table 1 Specified Mix Proportion of Concrete

Test Series	Max. Size of Aggregate (mm)	Slump (cm)	Water-Cement Ratio (%)	Cement (Kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)	Note
A	20	6	44.5	401	832	999	CaCl 1.0%
B	20	8	37	408	677	1083	

Table 2 Curing Conditions of Concrete in Test Series

Curing Conditions	A	B
Presteamming Period (hr)	3	2
Rate of Temperature Rise (C°/hr)	10~20	10~20
Max. Temperature (°C)	75	85
Soaking Period (hr)	2 hr Constant T. 10 hr Descending T.	0
Water Curing Period after Stripping (days)	0, 3, 7	0, 1, 2, 3, 4, 5, 6.

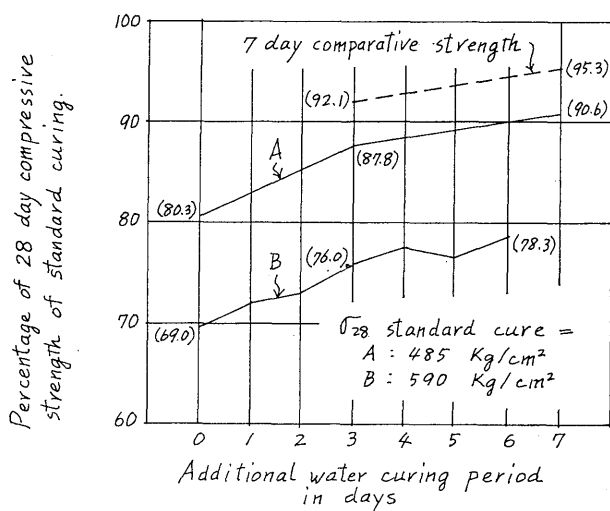


Fig. 4 Effect of additional water curing after steam curing on 28 day compressive strength.

In these investigations, following observations were made on the effect of water curing after steam curing for the compressive strength of concrete. Concrete that had been water cured of 6~7 days after steaming period gains 10% advantage in 28 days compressive strength, and initial 3 days water cured concrete gains 7% advantage over only steam cured one.

Summery

1. Presteamming period should be longer than 3 hrs, and being longer than this allows higher rate of temperature rise without detrimental effect for the strengths of concrete.
2. Maximum temperature excess than 65°C will reduce the potential strength at later ages in general, but it can probably be preventable by establishing some restrictive condition, and otherwise development of strength after steaming will continue to a certain degree by additional fog or water curing.

References.

- 1) Elmo C. Higginson, "Effect of Steam Curing on the Important Properties of Concrete", ACI Journal, Proceedings V. 58, No. 3, Sept. 1961.
- 2) J. A. Hanson, "Optimum Steam Curing Procedure in Precasting Plants", ACI Journal, Proceedings V. 60, No. 1, Jan. 1963.
- 3) ACI Committee 517, "Low Pressure Steam Curing", *Ibidem* V. 60, No. 8, Aug. 1963.
- 4) E. G. W. Bush, "Discussion of a paper by J. A. Hanson: Optimum Steam Curing Procedure in Precasting Plants", *ibid.* V. 60, No. 9, Sept. 1963.

- 5) K. Kohno, K. Emura and K. Kinoshita, "Effect of Precuring Period on Bond and Tensile Strength of Concrete", Reports of Onoda Central Research Laboratory, No. 58, 1963.
- 6) Takeshi Mukai, "Study on Low Pressure Steam Curing Method of Concrete Products", Transactions of the Architectural Institute of Japan, No. 119, Jan. 1966.
- 7) R. K. Lewis, "Discussion of a Paper by J. A. Hanson: Optimum Steam Curing Procedure in Precasting Plants", ACI Journal, Proceedings, V. 60, No. 9, Sept. 1963.
- 8) K. Kohno, K. Emura and K. Kinoshita, "Effect of the Maximum Temperature during Steam Curing on the Compressive Strength of Concrete", Reports of Onoda Central Research Laboratory, No. 65, 1965.