Curing of Concrete

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INTRODUCTION

The author of this paper would like to draw the attention of readers that unless concrete is properly cured it loses many of its qualities. On the other hand it is not his intention to present something new. The author has observed that concrete in this country is usually mishandled and very few people seem to see the advantages of proper curing of concrete at construction sites.

Concrete being, at present, the main construction material in Ethiopia, it would be wise to be familiar with its properties so as to be able to use it economically.

Curing of concrete involves the retention of sufficient free water in the cement paste so that the process of cement hydration may readily proceed. It also involves favorable temperature, humidity, and wind speed.

No part of the process of making good concrete is more important than thorough curing. It is also one of the operations most frequently neglected in this country. Dusty floors, loose surface coats, weak concrete blocks, leaky conduits and pipes illustrate defects frequently caused by improper curing. Proper curing is of the utmost importance if the impermeability of concrete or mortar is to be secured.

THEORETICAL CONSIDERATION

Theoretical considerations show that the net amount of water required for total hydration of cement is about 37 per cent *[(1,2)] by weight of the cement. This is the same as saying that it corresponds to a water-cement ratio of 0.37 by weight. This means that if the actual water-cement ratio of the mix, allowing for bleeding, is less than 0.37 by weight, complete hydration is not possible as the volume available is insufficient to accomodate all the products of hydration. For instance, if we have a mix of 100g. of cement and 30g. of water, the water would suffice to hydrate x grams of cement as given by the following equation:-

Contraction in volume

$$=0.23x^{*2)} \times 0.254^{*3)} = 0.0585x$$

Volume occupied by the solid products of

$$\text{hydration} = \frac{x}{3.15} + 0.23x - 0.0585x = 0.489x$$

$$\text{Porosity} = \frac{Wg}{0.489x + Wg} = 0.28$$

where Wg is the volume of gel water and 0.28 an approximate value of prosity of cement paste.

and total water $= 0.23x + Wg = 30$
Hence, $x = 71.5g = 22.7\ cm^3$
and $Wg = 13.5\ cm^3$
Thus, the volume of hydrated cement $=$
$0.489 \times 71.5 + 13.5 = 48.5\ cm^3$

The volume of unhydrated cement
$= 31.8 - 22.7 = 9.1\ cm^3$

Therefore, the volume of empty capillaries $=$
$(31.8 + 30) - (48.5 + 9.1) = 4.2\ cm^3$

If water was available from outside some further cement could have hydrated, its quantity being such that the products of hydration occupy 4.2 cm^3 more than the volume of dry cement. We found that 22.7 cm^3 of cement hydrates to occupy 48.5 cm^3, i.e., the products of hydration of 1 cm^3 of cement occupy $\frac{48.5}{22.7} = 2.13\ cm.^3$

Thus 4.2 cm^3 would be filled by the hydration of y cm^3 of cement such that $\frac{4.2 + y}{y} = 2.13$; hence $y = 3.7\ cm^3$ Thus volume of still unhydrated cement is $31.8 - (22.7 + 3.7) = 5.4 cm^3 = 17g$. In other words 17 per cent of the original weight of cement has remained unhydrated and can never hydrate since the gel already occupies all the space available.

It may be added that unhydrated cement is not detrimental to strength and in fact, among pastes all those with a higher proportion of unhydrated cement have a higher strength, possibily because in such pastes the layers of hydrated paste surrounding the unhydrated grains are thinner[(3)]. Abrams obtained strengths of the order of 2,800 kg/cm^2 using mixes with a water-

*(1,2) Numbers relate to the References, page 20.

*2) $0.23x$ = amount of water combined (non-evapourable water)

*3) When cement hydrates the solid products occupy a volume equal to the sum of volumes of anhydrous cement and watr less by 0.254 of the volume of non-evapourable water.

cement ratio of 0.08 by weight, but it is clear that a considerable pressure is necessary to obtain a properly consolidated mix of such proportions.

GEL-SPACE RATIO

Recent investigation results have shown that the compressive strength of concrete depends on the degree of hydration of cement, and its physical and chemical properties; the temperature at which hydration takes place; the air content of the concrete and also the change in the effective water-cement ratio rather than only on the water-cement ratio.

Therefore, it is reasonable to relate the strength of concrete to the concentration of the solid (gel) products of hydration of cement in the space available for these products. The gel-space ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of the volumes of the hydrated cement and of the capillary pores.

Powers[2] tested concrete for compressive strength and found the compressive strength of concrete to be about $2400x^3$ kg/cm^2 where x is the gel-space ratio and this is independent of the age of the concrete or its mix proportions. The relation between the compressive strength of concrete and the gel-space ratio is shown in Fig. 1.

EFFECT OF CURING CONDITIONS.

The curing conditions with respect to moisture and temperature, through their effects on hydration of the cement, excercise an important influence on the strength as indicated in Fig. 2[4]. The diagram indicates that the development of strength stops at an early age if the concrete specimen is exposed to dry air with no previous curing. Concrete exposed to dry air from the time it is placed is about 50 per cent as strong at 6 months as concrete moist cured 14 days before being exposed to dry air.

Exposure to air, with consequent drying, arrests hydration of cement, the rate and extent of drying depends on the mass of the concrete relative to the area of exposed surface as well as on the humidity of the surrounding air. The necessity of curing arises from the fact that hydration of cement can take place only in water filled capillaries. For this reason, a loss of water by evaporation from the capillaries must be prevented. Furthermore, water lost internally by self desiccation has to be replaced by water from outside, i.e., ingress of water into the concrete must be made possible.

Hydration of sealed specimens can proceed only if the amount of water present in the paste is at least twice that of the water already combined. Self desiccation is thus of importance in concrete mixes with water-cement ratios below 0.5 by weight; for higher water-cement ratios the rate of curing of sealed specimens is the same as that of saturated specimens.[5]

Evaporation of water from concrete depends on the temperature and relative humidity of the surrounding air and on the velocity of wind which effects a change of air over the surface of the concrete. An indication of the influence of these three factors can be seen from Figs. 3, 4 and 5 based on Lerch's[6] results.

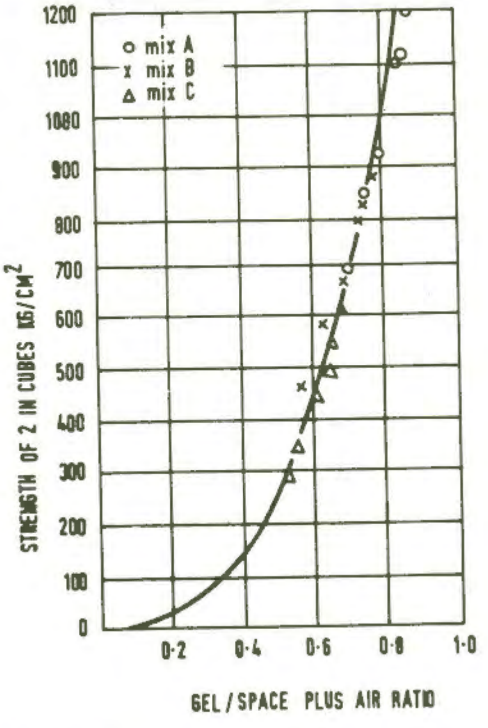

Fig. 1 Relation between the compressive strength of mortar and gel/space ratio.

METHODS OF CURING[7]

A common method of preventing loss of moisture from an exposed surface of concrete is to keep the surface continually damp by frequent sprinkling, ponding with water, or covering with continuously wetted sand, burlap or its equivalent. Other methods for preventing loss of moisture involve the use of liquid seal coat, or tight covers such as waterproof paper.

Too rapid drying of exposed surfaces before they have hardened sufficiently to stand sprinkling with water or covering with damp burlap may result in serious checking and crazing of the concrete. To prevent such rapid drying some specifications require that concrete be protected from drying winds and direct rays of the sun from the first day after placement, until adequate curing is begun.

Forms, if used on structure in which the concrete will not be cured after removal of the forms, should be left in place as long as possible to protect the surface and aid in delaying the loss of moisture in the concrete. Such protection is desirable, as other types of curing are not always applicable to structures using forms. wetting wooden forms periodically serves to prevent their shrinkage and opening of cracks between boards, and thus further aids the retention of moisture in the concrete. Ordinarily, buildings are not kept wet after removal of the forms because of the difficulty involved and the inconvenience to workers, although the quality of the concrete is

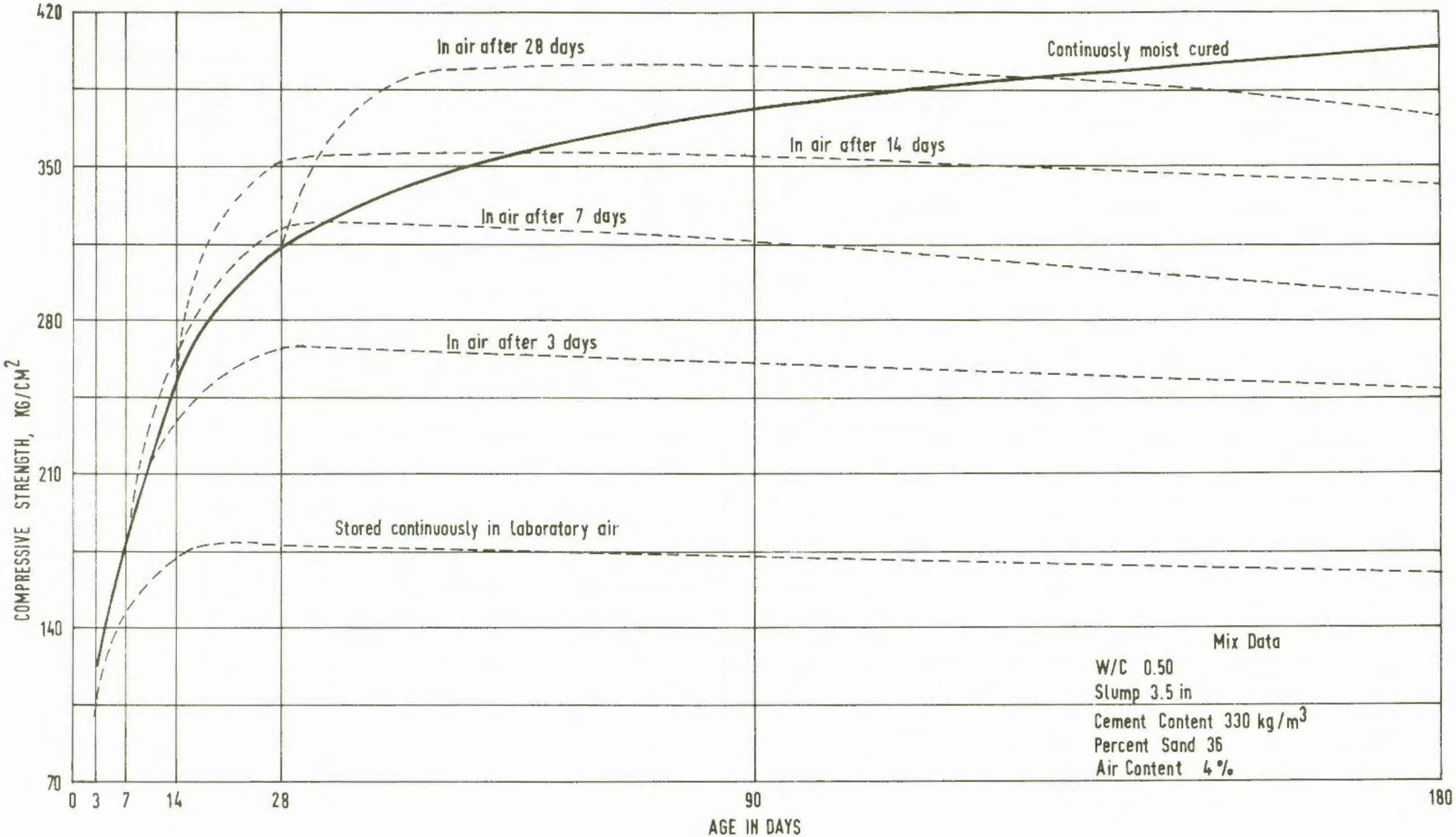

FIG. 2. THE INFLUENCE OF MOIST CURING ON THE STRENGTH OF CONCRETE WITH A WATER/CEMENT RATIO OF 0.50

unquestionably lower than it might otherwise be, because of the resulting lack of moisture.

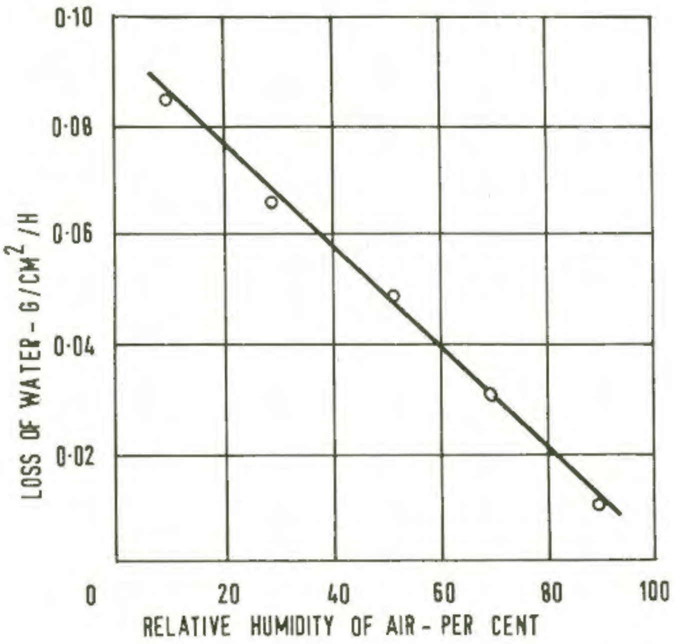

Fig. 3 Influence of relative humidity on the loss of water from concrete (air temperature 22°c, wind velocity 10 mph)

If the concrete surface can be cured properly after the removal of the forms, then it is desirable to remove them as soon as possible, as forms made of these boards are not fully effective in preventing loss of moisture from the concrete. Furthermore, early form removal permits better repairs, if any patching or other repairs are necessary, as then the concrete is still green, i.e., in the early stage of hydration, so that repairs bond to it more readily.

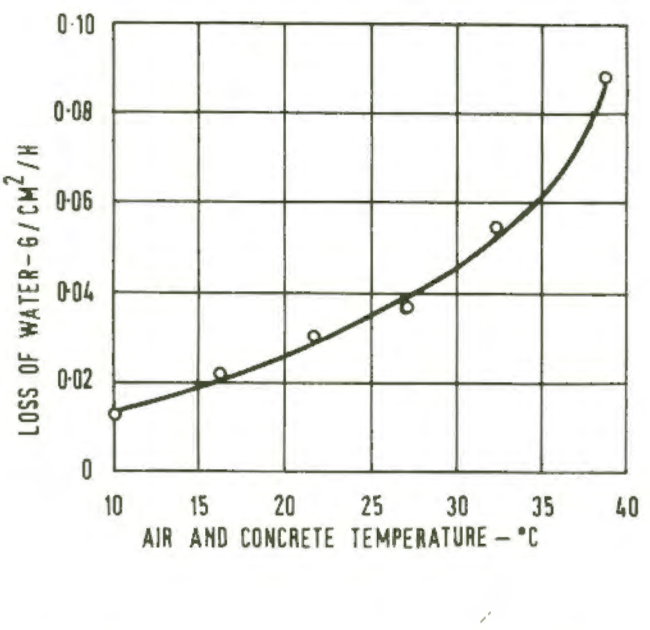

Fig. 4 Influence of temperature of air and concrete on the loss of water from concrete (relative humidity of air 70 per cent, wind velocity 10 mph)

The period of curing cannot be prescribed simply but it is usual to specify a minimum of seven days for oridinary Portland Cement concrete. With slower-hardening cement a longer curing period is desirable.

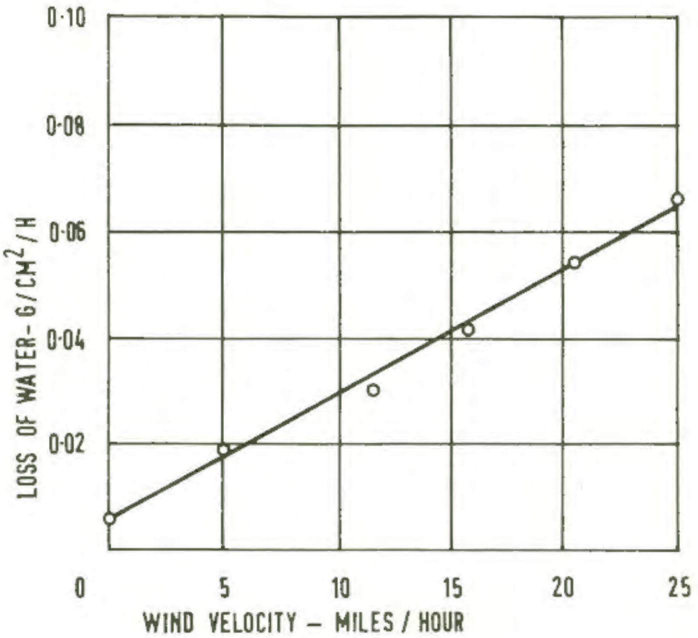

Fig. 5 Influence of wind velocity on the loss of water from concrete (relative humidity of air 70 per cent, temperature 22°c)

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