Review Paper on Effect of Curing Conditions and Application Methods on Strength of Concrete

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Abstract : Adequate curing is necessary with proper method of its application for a newly placed concrete to achieve the enviable qualities and accepted durability of the hardened concrete .Curing in the early ages of concrete is more important for concrete structures. Though the exact lab curing practice is not possible on field, up to certain extent the suggested methods can be applied in due consideration of site conditions. Curing may be applied in a number of ways and the most appropriate means of curing may be dictated by the site or the construction method.

***IndexTerms* - Curing, intermittent curing, delayed curing, curing regime**

I. INTRODUCTION

Curing of concrete is the process of maintaining satisfactory Full hydration of the entire quantity of cement is not often achieved, and it takes a few years to achieve complete hydration responsible for strength and durability of concrete. Normal design practice is to take 28-day strength as the basis for design, since it is known that with continuous water moisture and temperature conditions for freshly placed concrete for some specified time for proper hardening of concrete .In this loss of water of evaporation from the capillaries as the hydration can take place only in water filled capillaries. Curing is essential as long as the water filled space is engaged by the product of hydration to the desired extent .Curing may be made possible either allowing the access of water into the concrete or by preventing the loss by sealing the specimens (Tighare & Singh, 2017)

Full hydration of the entire quantity of cement is not often achieved, and it takes a few years to achieve complete hydration responsible for strength and durability of concrete. Normal design practice is to take 28-day strength as the basis for design, since it is known that with continuous water curing at 28 days, strength to the extent of 80 percent of the maximum possible strength is obtained due to fast rate of hydration initially, which produces sufficient cementitious compounds. At construction sites, it is not possible to follow the prescribed curing condition strictly. The reason may be attributed to bad supervision, lack of knowledge, manual or mechanical errors, power failure, accidents, strikes, etc.

Therefore the effect of improper curing , partly in water and the rest in air, or vice versa, need a thorough and careful study before the strength of such concretes at site conditions ,whose design has been done under idealized conditions is assessed and predicted.

II.LITERATURE REVIEW

Ferhat Bingol, IlhanTohumcu (Bingöl & Tohumcu, 2013) studied the effect of air curing, water curing and steam curing on the compressive strength of Self Compacting Concrete. The Self Compacting Concrete is produced with using silica fume (SF) instead of cement by weight, by the ratios of 5%, 10% and 15%, and fly ash (FA) with the ratios of 25%, 40% and 55%. The conclusion is that mineral admixtures have positive effects on the self settlement properties. The concrete specimens with using 15% SF and for 28days water curing condition provide optimum compressive strength while air curing caused compressive strength losses in all groups. The concretes strengths with mineral admixtures were determined relative higher than concretes without admixtures at steam curing conditions.

Li-Cheng Wang et al. (Wang, Cheng, & Bao, 2016) studied the influence of standard curing, natural curing, water curing, and sealed curing, on the capillary absorption of normal concrete.
Compressive strength tests on the cylinder specimens that are core drilled from concrete slabs are carried out. Experimental results show that the curing condition has an important influence on compressive strength, ultrasonic pulse velocity, and porosity of concrete.
The temperature and relative humidity are the key factors to ensure strength development during the curing procedure..
For the same curing conditions, the cumulative water content, sorptivity, and porosity of concrete progressively decrease with the

increase of distance from the surface, but the ultrasonic pulse velocity reverses.
The initial sorptivity of each location for the same curing condition is greater than the corresponding location of second sorptivity , while the curing condition (except sealed condition) has no regular influence on sorptivity.

The paper" Effect of curing conditions on the engineering properties of self-compacting concrete" (Yazicioglu, Caliskan, & Turk, 2006), the experimental study investigates the influence of curing conditions on the engineering properties of self-compacting concretes (SCC). Portland cement (PC) concrete and two types of SCC, i.e., SCC-I with fly ash and SCC-II with silica fume, specimens are prepared and cured in three different curing conditions, namely standard 20°C water, sealed and air cured for the periods of 3, 7, 14 and 28 days. Compressive and tensile strength and ultrasonic pulse velocity (UPV) values are determined at the end of each curing period .The water cured specimens always give the highest values followed by those cured as sealed and in air irrespective of type and age of concrete and test methods. For both compressive and tensile strength tests, the SCC-II gives the highest values followed by SCC-I and then PC concrete for all curing periods and conditions.

The effect of curing condition of five different composition of Portland composite cement (PCC) studied and ordinary Portland cement (OPC) were investigated. (Uddin et al., 2012) Compressive strength development of five different concrete types has been investigated in terms of cement content and curing duration. In experimental observation, it is found that the early age strength of concrete made with PCC is lower than that of concrete made with OPC due to the presence of fly ash in PCC which is responsible for the pozzolanic reaction. Sufficient curing at early ages as well as at later ages is necessary in the strength development of PCC concrete. Drying ambient conditions reduce the strength potential of PCC concrete as the secondary (pozzolanic) reaction fails to contribute to the development of strength.

In the paper the effectiveness of various curing methods on the properties of concrete is presented by Pincy. (Princy K P & Dr. Elson John, 2015) .The study includes various curing period and various curing methods [Dry curing, Immersion technique, Liquid membrane curing, compound, water proofing compound.
Conventional water curing is the most efficient method of curing as compared to Membrane curing, 7days, 14days water curing and dry air curing methods.
Using wax based curing compound and acrylic resin based curing compound can achieve 99% and 96% of compressive strength compared to Conventional Curing method.
Membrane curing compounds are most practical and widely used method and it is most suitable in water scarce area.
As compared with normal water curing, the concrete with water curing water proofing compound attained maximum compressive strength.
As compared with normal water curing, the concrete with waterproofing compound showed 12%, concrete with wax based curing compound showed 21%, and concrete with acrylic resin based curing compound showed 26 % decrease in flexural strength.
As compared with normal water curing, the concrete with waterproofing compound showed 7%, concrete with wax based curing compound showed 10%, and concrete with acrylic resin based curing compound showed 16% decrease in splitting tensile strength.
The study shows that the method and duration of curing significantly affects the strength characteristic of concrete. In situations where curing with water is difficult, curing compounds could be utilized. Among the two curing compounds studied, the performance of wax based curing compound is better than acrylic resin based curing compound.

The effect of steam curing on later-age strength of concrete was studied on mixes having the nominal cement content of 150 to 400 kg/m^3 also studied (Bentur,eta al.). Three series of tests involving the delay period 30 or 60 minutes, the curing period varied from 2 to 5 hours, and the curing temperature from 60° to 80°C was studied. It was investigated that steam-curing affected adversely concrete later-age strength. It was concluded, however that under short curing periods and moderate temperatures this adverse effect was primarily due to the lack of supplementary wet-curing.
The supplementary wet-curing will improve also the strength of concrete which is subjected to more severe curing conditions. Under such conditions, however, due to the irreversible nature of the physical effects, strength losses will persist, and the supplementary wet-curing of the concrete can only reduce the resulting losses.

Effects of different curing methods on the strength development of concrete containing waste glass as substitute for natural aggregate (Akinpelu, Odeyemi, Olafusi, & Muhammed, 2019)(Olofinnade, Ede1, Ndambuki, & Olukanni1, 2017) deals with the influence of curing methods on the mechanical strength development of concrete comprises of waste soda lime glass pulverized into fine and coarse aggregate sizes as partial and complete replacement for natural aggregates in concrete.
Concrete cubes and cylinders were cast and tested after 7, 14 and 28 days of curing using two curing methods; namely total immersion in water and plastic membrane sheet covering .In the first method curing was done by total immersion in potable water

(WC) at mean daily temperature that ranged from 28 – 32°C all through the period of curing with mean relative humidity that ranged from 60 – 85%.
In the second method, curing is done by wrapping the concrete specimens with polythene nylon sheets (PC).
The results obtained clearly indicate that waste glass concrete cured by complete immersion in water showed better performance in strength development than those cured by plastic membrane covering.
Generally, the results indicate that concrete mix produced with 25% glass content exhibit significant strength that compared well with the control at 28 days of curing.

Effect of Curing Age on High-Strength Concrete at Low Temperatures (Hussein & Marzouk, 1995) ,paper investigates the effect of curing age on the strength development of high-strength concrete containing silica fume and fly ash and exposed to cold temperatures. In the experiment three sets of specimens, having initial curing ages of 1, 14, and 28 days at room temperature were tested. The test specimens were exposed to five temperatures varying from −10°C to 20°C for periods over 3 months in cold ocean water. The relationship in compressive and tensile strength with time was found to be directly proportional to the rise in temperature. The highest gain in strength with time was observed at 20°C and the lowest at −10°C for all three sets of specimens.
The reduction in the rate of strength gain was found for the set initially cured for 1 day. However, it was minor for the set cured initially for 14 days, and negligible for the set cured initially for 28 days. The maturity functions gave reasonable agreement with the three sets of specimens at different temperatures except for the specimens cured for 1 day and exposed up to 7 days.

The specimens prepared were from a concrete batch kept in molds for the first 24 hours, then divided into groups. Each group was cured at standard (230 C) temperatures but under different wetness conditions (Popovics, et al..)
Then compressive strength carried out. The procedure was repeated with two more batches of different compositions. Curing methods differed with varying combinations of fog room and air curing. Results shows that concrete specimen provides higher compressive strength in a drying state (when the surface of the concrete is dryer than the inside) than in a rewetting state. The experiment shows that the fluctuations in strength results can be reduced by tightening curing specifications.

The effect of curing period and of delay in carrying out curing by the wet burlap method on some properties of concrete with different mix proportions (cement content, water content) in hot weather was studied. (Al-Ani & Al-Zaiwary, 1988)
The wet burlap curing method used was an effective method for maintaining the moisture content of concrete and its curing in hot weather.
Initial curing was more effective for the higher cement-content concrete; a minimum curing period of 3 days was sufficient for rich mixes in hot weather, while longer curing periods were necessary for concrete with lower cement content; a minimum curing period of 7 days was required for lean mixes.
A large amount of water evaporated from concrete in a short period after stopping curing, therefore the burlap must be left covering the concrete after stopping curing for a sufficient period to protect concrete from rapid moisture loss and temperature change.
Rapid shrinkage resulted due to the large amount of water loss in a short time after stopping curing, but the magnitude of later-age shrinkage was not greatly affected by curing,
Delaying the curing of concrete in hot weather had a harmful effect on compressive strength, for all mix proportions, and the first day of delay caused the largest effect.
Prolonging the curing period from 3 up to 7 days after curing delay increased the compressive strength of concrete, but it did not recover the reduction in strength caused by the curing delay.
The delaying, curing and stopping of curing caused substantial length changes in concrete (shrinkage, expansion, then shrinkage); this behaviour is undesirable because it will increase the cracking tendency especially at early ages.
The results show that a minimum of 3 days curing was sufficient -for rich mixes, while a longer period was required for leaner mixes (min. 7 days).
The delay of curing had a harmful effect on concrete and the first day of delay caused the largest effect. Curing after delaying increased the compressive strength of concrete, but it did not recover the reduction in strength caused by the curing delay.

The effect of cumulative curing sequences (first w_I days in water and rest all days in air) and delayed curing (first a_I days in air and rest w_{II} days in water) have been compared each for six combinations. (N.K. Bairagi, et al.)Typical influencing parameters for the entire range of both the cumulative curing sequences have been suggested and whenever possible, compared with those prescribed by the IS code.
An experimental programme for both curing sequences has been carried out in two phases on M15 and M25 concrete grades.
Phase -I Cube specimens (150mm x 150mm) and cylinder specimens (150mm x 300mm) were prepared for both grades of concretes and cured under both types of curing sequences.

Compressive strength, tensile strength and modulus of elasticity values for these specimens have been planned to be evaluated for the following curing sequences:
Type I: w28a0, w21a7, w14a14, w7a21, w3a25, w0a28
Type II. a28w0, a21w7, a14w14, a3w25, a7w21, a0w28
Phase II Prototype reinforced concrete beams having a c/s area of 80mmx125mm, and span l = 1,200mm have been prepared out of the concrete grades. The beams were cured under identical curing conditions for the curing sequences w7a21, w3a25, a7w21 and a3w25 only, and tested under two-point loading system to evaluate the compressive strength which have been compared with those obtained from laboratory cubes and cylinder specimens.
It is observed that in the improper curing sequence, concrete attains additional strength during air cured state.
Concrete cured under delayed curing sequence shows a decreasing trend in the compressive strength as compared to improper sequence.
The tensile strength of concrete also follows a similar trend as that of the compressive strength.
The ratio of compressive strength to tensile strength has been found to be around 7.0 for M15 mix and around 9.0 for M25 concrete for all curing sequences.
Modulus of elasticity value Ec decreases with the decrease in initial water curing period, but again increases.
The maximum compressive as well as tensile strength have been found to occur at around 18- days initial water-curing. The strength has been found to be 9 to 7 % higher. This perhaps happens because most of the hydration achievable under wet curing is complete within 21 days, after that there is a dominant period when no appreciable hydration reaction takes place. But as soon as the specimen is taken out of water, the additional product of hydration occupies the space then available on drying of the saturated sample.
Results shows that the initial water curing for 7 days is a very practical and economic period of curing when around 92 % of the compressive strength , around 105 to 106 % of the tensile strength , around 84 to 99 % of elastic modulus values are noticed as compared to corresponding strength value of completely water- cured specimens.
M25 concrete mixes are comparatively more adversely affected by improper –curing sequences than M15
The ratios of the compressive strengths obtained from cylinder specimens to those obtained from cube specimens have been observed to vary between 0.78 to 0.79 for improper- curing sequences and between 0.79 to 0.82 for delayed -curing sequence for both types of concrete considered in this study.

Experiments done to find the strength of curing concrete in an absolutely or partially dry state. (T. Waters, et al..)
The work was done in two parts, the first to find the effect of curing concrete in absolutely dry air, and the second in ordinary room atmosphere.
Except in cases where an early development of strength is required, it is not necessary to keep concrete wet after the initial curing period, as the curing can be done at any time.
It is observed that concrete structures out of doors will take advantage of wet weather periods and large solid masses will retain sufficient moisture for curing.
The concrete indoors will not have sufficient moisture to give a reasonable rate of curing, and the concrete must be kept damp until it has cured sufficiently.
These results would not apply to thin slabs of concrete, such as roads and walls. Lack of moisture at an early age may lead to cracking and the concrete should be kept wet until it has developed sufficient strength to resist shrinkage cracks.

Effect of curing methods on density and compressive strength of concrete. studied by researchers. (Raheem, SoyingbeRaheem, A. A., Soyingbe, A. A., & Emenike, A. J. (2013.) In this the effect of different methods of curing on density and compressive strength of concrete is studied.
The cubes were cured using six methods (air curing, water-submerged curing, spray curing, polythene curing, moist sand curing and burlap curing) until testing ages of 3, 7, 14, 21 and 28 days when their densities and compressive strengths were determined.
The specimens of moist sand curing method gives highest compressive strength while air curing specimens the lowest.
All the methods of curing considered, except air curing (the control) produced concrete specimens that met the minimum compressive strength specified by the available code. There exists a weak positive correlation between density and compressive strength of concrete.

The effect of humidity on development of mechanical properties of Portland cement mortars under different curing regimes is determined (Hayri & Baradan, 2011). The curing conditions were selected in order to simulate the seasonal climatic conditions in various regions of Turkey. Mainly under low relative humidity conditions the test data obtained in this paper reveals that; this assumption is no longer valid. Test results also include the comparative data on relation between compressive and flexural strength, compressive strengths of 50 mm cubic and 40×40×160 mm prismatic mortars.

The early strength values were higher at warmer conditions compared to the cooler conditions..

It is observed that flexural strength is more sensitive to curing conditions especially to relative humidity than compressive strength. The lower relative humidity values cause decreases on flexural strengths.

Since the experiments are made on mortar specimens, the determined values and results may not be directly compatible to concrete specimens. Especially penetration of the aggressive chemicals and corrosion of reinforcement is adversely affected by quality of cover.

Critical climatic conditions created in study caused decreases up to 40% in compressive strength and 30% in flexural strength compared to standard curing. This means that poor curing conditions and in proper climatic conditions may create significant undesirable results.

The research shows that the specimens cured in tap water and lime saturated water have approximately equal compressive and flexural strength values separately at all curing ages. The strength of the specimens did not decrease considerably because the tap water was not changed and the pH degrees of the curing waters were same after 12 hour.

Prediction of compressive strength of concrete using accelerated curing is studied by the authors. (N.L. Shelke,et al.)The aim of the study was the short term performance of concrete by using accelerated curing. The increase in strength with increased curing temperature is due to the speeding up of the chemical reactions of hydration which affects only the early strengths without affecting ultimate strengths. In accelerated curing gain of strength of concrete can be expedited by raising the temperature of curing, reducing the curing period. The results show that both the normal compressive strength and accelerated strength achieved the target strength of M40.The compressive strength obtained by using accelerated curing method is higher than normal compressive strength.

"A comparative study on methods of curing concrete " paper illustrates the effectiveness of different curing methods and the influence of climate on the strength properties of concrete (Reddy, et al.) In this paper The curing compounds resulted in strength up to 85 to 90 % of ponding.

The white based curing compounds were found effective than membrane based curing compounds.

The results showed that, there is no necessity of double layer application if a high efficiency index curing compound is uniformly applied with a adequate amount.

Air Curing during February with relative humidity (56%) and temperature (34.80C) resulted in a compressive strength of 38Mpa which is 76.16% of the strength achieved through air curing in December showing relative humidity as prime factor in determining the quality of concrete.

As compared to conventional jute bag curing ,compound curing is found to be cost effective since ponding is not suitable in-situ for all components of the structure.

Effect of curing water availability and composition on cement hydration studied for the effect of sealing the concrete with plastic or formwork, (Siddiqui, Nyberg, Smith, Blackwell, & Riding, 2013), use of a liquid curing compound, wet curing, and internal curing with saturated lightweight aggregates on the cement degree of hydration (DOH) development with time using isothermal calorimetry. The amount, ionic concentration, and sample thickness of curing water were varied. Curing application timing was studied by comparing strength development of concrete cylinders sealed, placed in a moist room after 24 hours sealed, and immersed in a water bath immediately after finishing.

Increasing the height of curing water decreased the height of heat of hydration rate peaks.

Ionic concentration of curing water affects the rate of hydration. Curing compounds provided a increase in hydration to water curing in a sealed environment when compared to sealed specimens without curing compound or water ponding, due to high water content in water-based curing compound.

III. CONCLUSION

Following conclusions can be drawn based on experimentations conducted on curing conditions and the methods application on strength of concrete.

*Efficient uninterrupted curing is the key to quality concrete. Proper curing of concrete is crucial to obtain design strength and maximum durability.

*In the improper curing sequence, concrete attains additional strength during air cured state.

*Concrete cured under delayed curing sequence shows a decreasing trend in the compressive strength as compared to improper sequence.

*Higher grade concrete mixes are comparatively more adversely affected by improper –curing sequences than the lower grade.

*The water cured specimens always give the highest values followed by those cured as sealed and in air irrespective of type and age of concrete and test methods.

*Drying ambient conditions reduce the strength potential of PCC concrete as the secondary (pozzolanic) reaction fails to contribute to the development of strength.

*The temperature and relative humidity are the key factors to ensure strength development during the curing procedure.

*Steam-curing affected adversely concrete later-age strength. Under short curing periods and moderate temperatures this adverse effect was primarily due to the lack of supplementary wet-curing.

* The supplementary wet-curing will improve also the strength of concrete which is subjected to more severe curing conditions.

*It is observed that concrete structures out of doors will take advantage of wet weather periods and large solid masses will retain sufficient moisture for curing. The concrete indoors will not have sufficient moisture to give a reasonable rate of curing, and the concrete must be kept damp until it has cured sufficiently

*The specimens of moist sand curing method gives highest compressive strength while air curing specimens the lowest.

*All the methods of curing considered, except air curing (the control) produced concrete specimens that met the minimum compressive strength specified by the available code.

* There exists a weak positive correlation between density and compressive strength of concrete

*The compressive strength obtained by using accelerated curing method is higher than normal compressive strength.

*Concrete specimen provides higher compressive strength in a drying state (when the surface of the concrete is dryer than the inside) than in a rewetting state. The experiment shows that the fluctuations in strength results can be reduced by tightening curing specifications.

*The outcome of this study shows that initial water curing is essential to assist the density and strength development of POFA Cement Based Aerated Concrete which is a pozzolanic material.

*Curing compounds provided a increase in hydration to water curing in a sealed environment when compared to sealed specimens without curing compound or water ponding, due to high water content in water-based curing compound.

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