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Impact of Curing on Mechanical Properties of Concrete – an Environmental Approach

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ABSTRACT

The advancement in the construction industry has resulted in a new way of environmental pollution. These industries produce almost 7% of the worldwide production of total carbon dioxide emissions. Apart from producing carbon dioxide, these industries also consume a tremendous amount of energy and produce dust, heavy metals, hydrogen chloride, hydrogen fluoride, etc., which are hazardous. This paper is aimed at studying the environmental impact of different curing regimes as well as the effects of curing conditions on the durability (permeability, abrasion resistance and sulphate attack) and mechanical properties (compressive strength) of concrete. Improved durability is important for the environmental sustainability of concrete. Curing is mainly intended to keep concrete moist by avoiding moisture removal from the concrete during the strength-building process. Curing generally promotes the hydration of cement as a consequence of which hydrated products fill the pores of the concrete and produces a more compact structure whose permeability is less. As a consequence of reduced permeability, water and other harmful chemicals do not enter the concrete, thus improving its durability. Durable concrete can reduce the total annual concrete production, thus reducing the total environmental pollution caused by the concrete industry. The most appropriate method of curing depends on the site conditions and materials used.

Keywords: Abrasion resistance; Curing; Durability; Environmental impact; Permeability; Sulphate attack.

1. INTRODUCTION

Curing is maintaining sufficient moisture content as well as adequate temperature in concrete for a particular period of time immediately after placing and finishing operations. Curing has a great influence on the properties of hardened concrete. In order to attain good quality concrete, a suitable concrete mix must be cured in a suitable environment during the early stages of concrete. Durability, volume, consistency, weight, water tightness, abrasion resistance and resistance to freezing and thawing will be the benefits of proper curing. Exposed slab surfaces are particularly vulnerable to curing, as curing in faulty conditions can minimize strength development and freeze-thaw resistance of the slab's top surface (Abalaka and Okoli, 2013).

As cement is combined with water, a chemical reaction known as hydration occurs. The strength and resilience of concrete are affected by the magnitude of this reaction. In freshly mixed concrete, the amount of water is much more than that required for hydration, but due to excessive water evaporation, the process of hydration may be delayed or stopped. The surface of concrete dries first, so it is more susceptible to insufficient hydration.

Curing not only influences the strength but also influences the durability properties of concrete. The concrete industries contribute 7.8% of total carbon dioxide emissions in the atmosphere. The concrete production industry is the third-ranking producer of anthropogenic carbon dioxide in the world. If we improve the durability properties of concrete, we can reduce the over-consumption of concrete and also reduce the carbon footprints in the environment. Durable concrete experiences a long service life in most natural environments without deterioration. Inadequate curing results in a porous and weak structure near the surface of the concrete that allows the entrance of various harmful substances from the environment.

The curing compounds used in this experiment reduced the water loss compared with no curing. Under hot weather conditions, the effect of curing compound application on moisture retention became much clearer (Wang *et al.* 2011). There was no difference in permeability between the middle and bottom portions of cores for varying curing conditions. For the top portion of the concrete core, the concrete cured with a water-based curing compound and wet curing had almost the same values of permeability (Behera *et al.* 2014). All curing compounds decreased the moisture loss when compared to no curing, but none of the compounds retained the same or more moisture than plastic sheeting (Whiting and Snyder, 2003). Relative humidity is a prime factor in the determination of the curing effect of concrete. Compound curing is found to be more effective in complex structures. Researchers have found that conventional water curing is the most efficient method. It was reported that the use of curing compounds resulted in strength up to 85 to 95% by the ponding method**.** In an acute shortage of water, membrane curing is more useful. It was evaluated that a double-layer membrane curing compound is more effective than a single layer. It was also found that the double layer of wet jute shows improvement in compressive strength. Pack curing shows 16% improvement in compressive strength than that of air drying.

Curing improves physical (freezing and thawing action, permeability and temperature stresses) as well as chemical (sulphate and chloride attacks) durability. Since the curing of concrete improves the process of hydration, more hydrated products will form that will fill the voids in concrete, reducing the permeability of concrete. Less permeable concrete means the entrance of chemicals and water from the outer environment is hindered. As a consequence, chemical attacks and corrosion of reinforcements are reduced.

2. METHODS OF CURING

Ponding and Immersion: Ponding can be done on the flat surface of small concrete soil or sand dikes are made around the periphery of the concrete surface, and water is filled. It is an excellent tool for preventing concrete moisture depletion and keeping a constant temperature in the concrete. To prevent thermal pressures that might cause cracking, the temperature of the curing water should not be more than 11 °C lower than the temperature of the concrete. Ponding necessitates a lot of monitoring and labor, so it is best for small workers.

Immersion is a popular technique for curing research specimens in the laboratory. In this method, test specimens are completely immersed in water. Although ponding and immersion is the most efficient method, it requires a considerable amount of potable water for curing concrete which leads to severe pollution of freshwater; hence, in the context of short-term environmental pollution, this method is not appropriate, but in the long-term perspective, since this method produces durable concrete, it is convenient to adopt. In the short term, it only pollutes the water, but it also helps to reduce the production of carbon footprints by increasing the durability of concrete in the long-term perspective.

Fogging and Sprinkling: When the ambient temperature is well above freezing and humidity is low, fogging and sprinkling is an excellent method of curing. A system of nozzles or sprayers is used to create a fog mist to raise the relative humidity of the air. Fogging is used to minimize plastic shrinkage cracking. Proper water supply and careful supervision are a must for this method. If sprinkling is done at intervals, concrete must be prevented from drying by using some water-absorbing materials such as burlaps.

In this method, energy consumption is involved in operating nozzles and sprayers. For energy production, the burning of fuels comes into the picture, which leads to air pollution. Apart from polluting air up to a minor extent, this method causes a tremendous water runoff which leads to the wastage of water.

Wet Covering: Fabrics saturated with water are used for curing - burlaps, cotton mats, rugs, etc. For vertical surfaces, wet gunny bags, hessian cloth, jute ratting, etc., are used to keep concrete in wet condition. For horizontal surfaces, sawdust, earth or sand is used for wetting the concrete. Care must be taken to avoid drying these coverings; otherwise, they will suck the moisture from concrete by capillary action.

Since there is no surface runoff of water in this method, so it is convenient for minimizing water pollution. This method also gives good results in terms of durability.

Impervious Paper: It is an efficient means of curing horizontal surfaces and simple-shaped concrete. The periodic addition of water is not required in this method. The impervious paper retains the internal moisture of concrete and thus promotes hydration. When concrete is sufficiently hardened to resist surface damage, it is thoroughly wetted and impervious paper is applied. The edges of these papers should be properly sealed and adjacent sheets are to be sufficiently overlapped (about 150 mm).

Directly use of impervious paper does not cause any kind of environmental pollution, but the production units of these papers are a potential source of environmental pollution. In the production unit, heavy water pollution, huge energy consumption and emission of harmful gases are very prominent factors which can cause heavy pollution.

Plastic sheets: Plastic sheets such as polythene films can be used for curing purposes. They are lightweight, effective moisture retarders and they can be easily applied flat on a complex surface. Curing with plastic sheets may cause patchy discoloration. Plastic sheet is a major source of environmental pollution as they are not decomposable after their use. It is effective in reducing water pollution, but on the other hand, they cause many serious environmental problems.

Membrane-forming Curing Compound: Liquid membrane-forming compounds can be used as evaporation retarders from concrete. These compounds may contain waxes, resins, chlorinated rubber, etc. Curing compounds are able to maintain the relative humidity of concrete surfaces above 80% for seven days to promote cement hydration. These compounds should be applied by hand-operated or power-driven spray immediately after the final finishing of the concrete. Normally only one smooth coat is applied at the rate of 3 to 4 m² per liter or as per the manufacturer's instructions.

These compounds are used to eliminate the compulsion of water for curing. They form a protective layer over the surface to skip the evaporation of water inside the concrete. Since these compounds are sprayed in the air, they contribute to air pollution up to some extent.

Steam Curing at Ordinary Pressure: During the early strength gain of the concrete, additional heat is required to accomplish hydration; steam curing can be used. This method is generally used for pre-fabricated members. This method is quite difficult to apply on-site. Hydration reaction is accelerated at a higher temperature and concrete attains the 28-day strength in only 3 days.

Steam Curing at High Pressure: Concrete is exposed to a mean temperature of about 175 °C in this process of curing, resulting in a steam pressure of about 8.5 kg/cm^2. Crushed stone dust makes up 20 to 30% of the pozzolanic content in concrete which has been exposed to high steam curing. Concrete with a higher water/cement ratio has been shown to be more durable. One of the most significant benefits of steam-cured concrete is its increased resistance to sulphate attack, freezing and thawing and chemical action. It also has a lower level of efflorescence.

Steam curing at high pressure as well as ordinary pressure requires a tremendous amount of energy to produce steam and create pressure; hence it could be said that certain environmental pollution might be seen. But whenever the early strength of concrete is required, these methods are most convenient.

Electrical Curing: This method of curing is generally used in very cold climatic regions. For economic reasons, this method is not used in normal conditions. Concrete is cured electrically by passing an alternating current through the concrete between two electrodes either buried in concrete or applied to the surface of the concrete.

This method of curing requires electricity of high voltage. Hence, on construction sites, there is zero environmental pollution but the electricity generation point is an effective environmental polluting site.

Forms Left in Place: If the top exposed surface is continuously wet, then forms provide satisfactory protection against the loss of moisture. The forms should be left on the concrete as long as possible. If wooden forms are used, they should be kept moist by sprinkling water during hot weather. If it is not possible, they should be removed as soon as possible to avoid moisture suction from concrete.

This method generally causes zero environmental pollution, since there is no burning of fossil fuels; only a minimal amount of water is needed for the purpose of curing.

2.1 Effect of Curing on Compressive Strength

The cement needs a certain level of relative humidity to continue to hydrate. Even though different values are reported for the cement hydration to continue, 80% is the widely accepted relative humidity value (Krishna Rao *et al*. 2010). If the relative humidity in concrete pores falls below this value, the hydration of cement virtually stops and further improvement of concrete properties owing to continued cement hydration and pore-filling by hydration products is not achieved. The compressive strength of concrete is a function of various parameters, one of which is the length of time for which it is cured. Various studies show that concrete without curing achieves only 40 to 45% of the compressive strength of the cured concrete. Even 3 days of water curing increases this figure to 60 to 65%, while 28 days of curing increases it up to 95 to 98%. Concrete allowed to dry out quickly also undergoes considerable early-age drying shrinkage.

2.2 Effect of Curing on Abrasion Resistance

Concrete roadways, industrial flooring and other publicly accessible areas are subjected to high abrasion conditions. Hence, it is important to improve the abrasion resistance of such types of surfaces. Since curing improves the surface characteristics, abrasion resistance may be an effective parameter to evaluate curing effectiveness. Abrasion resistance of hydrated cement is lower than that of aggregates, particularly porous cement matrix. The porosity of the concrete can be reduced by providing effective curing by an efficient method. Abrasion resistance is substantially high for cured concrete than that of uncured concrete. Studies show that ponding is the most convenient method to improve abrasion resistance, since it reduces the porosity of concrete by promoting the process of hydration. Inadequate or insufficient curing is one of the main factors contributing to weak, powdery surfaces with low abrasion resistance.

2.3 Effect of Curing on the Durability of Concrete

Durability can be defined as the capability of concrete to resist weathering action, chemical attack and abrasion, while maintaining its desired engineering properties. Durability can be classified into two categories: physical durability and chemical durability. Curing of concrete promotes the hydration reaction of Portland cement and enhances the quality of hydrated products. These hydrated products fill the pores of the concrete and improve its strength and durability. The durability of concrete is affected by a number of factors such as porosity, permeability and absorptivity. Cured concrete can minimize thermal, plastic and drying shrinkage cracks, making concrete more water-tight, thus preventing the entry of moisture and water-borne chemicals into the concrete and thereby increasing its durability (Zain et al. 2007).

Curing promotes the steady hydration reaction to produce calcium silicate hydrated gel, which binds the aggregate, increases the density, decreases the porosity and enhances the chemical and physical durability of concrete.

2.4 Water Permeability

Permeability of concrete is defined as the rate of flow of fluid into a porous solid. The permeability of concrete is a major factor that affects the long-term durability of concrete as it controls the movement of water and entry of aggressive liquids. Curing improves the process of hydration as a consequence of which pores of the concrete are filled with hydrated products. The filling of pores and disturbing the capillary fringes in the concrete improves the permeability. Studies show that the coefficient of permeability continues to reduce with concrete age. This is because of the hydration of cement particles over a long span of time. It is generally not the porosity, but the pore structure and the presence of micro-cracks are crucial in the determination of the permeability of concrete. These micro-cracks will propagate on the application of load and reduce the durability of concrete.

2.5 Sulphate Attack

Sulphate attack may cause excessive expansion, cracking and loss of strength. The degree of sulphate attack depends on water penetration, the sulphate salt and its concentration and the type of salt (e.g., Calcium or Magnesium). In the presence of calcium hydroxide, formed as a hydrated product, sulphate ions will react to produce ettringite. These ettringite crystals expand or swell and cause volumetric changes in concrete mass. Due to these volumetric changes, concrete that are subjected to sulphate attack has some cracks, which reduce the durability of concrete. By proper means of curing, more compact and dense structure can be produced, which reduces the penetration of sulphate salt. The compressive strength of concrete is reduced when it is subjected to sulphate attack because of the presence of cracks.

3. CONCLUSION

Ponding and immersion is the most efficient method for curing concrete as they attain almost 95 to 98% strength, but their water demand is more. Membrane-curing compound is an effective tool where water is in scarcity. In a very cold climate, electrical curing is effective, but in normal weather, it is not used because of its high-cost nature. Curing with a wet covering is the most appropriate method from the perspective of reducing environmental pollution because these bags are biodegradable and require comparatively less water and produce more durable concrete. It was observed in this study that uncured concrete produces only 40 to 45% of compressive strength than that of continuously cured concrete. It is also noted that uncured concrete is more vulnerable to sulphate attacks which produce cracks and reduce the concrete strength. Curing generally improves the surface behavior of concrete; it is noted that the abrasion resistance of cured concrete is much more than that of cured concrete.

The permeability of concrete is also dependent on the curing of concrete. The coefficient of permeability is reduced with an increase in the curing period. This is because of the formation of good quality hydrated products that fill the voids of concrete and discontinue the capillaries in the concrete. Precisely, curing methods cause environmental pollution in a short time span, but in long term, curing improves not only durability but also reduces the pollution caused by concrete industries.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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