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A REVIEW ON THE EFFECTS OF CURING METHODS ON THE STRENGTH OF CONCRETE INTERLOCKING PAVING BLOCKS

[1]Ukala D.C., [2]Akaun I. and [3]Owamah H.I.

[1&3] Department of Civil Engineering, Delta State University, Abraka, Oleh Campus, PMB 1, Nigeria
[2]Department of General Studies, Delta State Polytechnic, Ogwashi-Uku, Delta State

Abstract

The use of concrete in the construction industry is ever increasing as a result of continuous urbanization, industrialization and growing population all over the world. The durability and strength of concrete should however, be of prior importance during construction as the safety of so many lives lies in the strength of the resulting structures. In order to minimize or reduce the rate of structural failures in the nearest future, evaluating the strength of concrete should be of utmost importance. This paper provides a comprehensive overview of existing experimental approaches and investigations to determine the effects of several curing methods on the compressive strength and durability of concrete interlocking paving blocks. The paper reviews the method of curing that produces the strongest and most durable concrete interlocking paving blocks. It reviews different methods of curing, including the open-air method usually used on site, and compares the strength of interlocks before, during and after several curing processes. It was observed that the ponding method of curing produced stronger interlocking blocks.

1. INTRODUCTION

The demand on modern concrete, especially interlocking tiles is increasing day by day around the world as a result of continuous urbanization, especially in developing countries[1]. Interlocking tiles, all over the world, are known mostly for their design, immaculate finesse, and strength gotten from the use of fine and high-quality materials that are able to withstand the toughest daily grind. However, the strength of these interlocking tiles changes during the process of curing, of which most do not pass through after production. Curing is a process that is absolutely necessary for concrete to be able to achieve durability and adequate strength [2]. In Nigeria, interlocking tiles are left to harsh weather conditions like air, moisture, sun and rain immediately after production which eventually tampers with their compressive strength. The main purpose of curing is to keep the concrete as nearly wet or saturated during cement hydration. Concrete tiles exhibit physical and mechanical properties like roughness and rigidity[3]. These properties make them useable for adequate cover and load-bearing. For this singular reason, the compressive strength of interlocking tiles should be highly taken into consideration most especially when they are used for road pavements and required to have very high load-bearing capacity.

Interlocking tile is a type of floor finishing designed in a way that their edges mechanically fit with one another in order to provide a weather seal. The modern interlocking tile is a flat, smooth, single lap interlocking design with a slate-like appearance which is enhanced by a broken bond laying pattern. Interlocking tiles are used mostly for roads, parking lots and walkways. Establishing the highest compressive strength of a particular curing method will help to know what method should be generally accepted and practiced on site which will eventually result in long-lasting use of interlocking tiles and also reduce the span of replacements when used. Interlocks in Nigeria are used mainly for car parks or walk ways. Few months after the interlocks have been arranged by artisans and put to use, some of them begin to crack. Most times, some just totally crumble under the weight of vehicles or people[4]. Looking into this problem, it has been discovered that most producers of interlocking tiles cast and then leave the interlocks outside where it is subjected to rain, sun, wind etc. without carrying out any form of curing process. Replacement of cracked concrete interlocking paving blocks requires a lot of financial resources which puts considerably large burden on the maintenance budget of a project. Aside the strain these costs will put, liability claims are also faced arising from either cracked or uneven pedestrian pavements [5]. This can be avoided if the right curing processes are applied and followed immediately after casting of these interlocks.

It is also good to know that while many manufacturers try to avoid the process of curing after production because of waste of materials and time, recent researches have been carried out on the use of non-destructive test methods that can be carried out on these interlocks on

Corresponding Author**:** Owamah H.I., Email: owamah.hilary@gmail.com, Tel: +2348035705814

site to determine their strength and durability. This review will help shed more light on the most suitable curing method that can be adopted on site to give concrete interlocking paving blocks its highest compressive strength.

2. CONCRETE INTERLOCKING PAVING BLOCKS

Concrete interlocking paving blocks are made from the casting of a mixture made from carefully graded aggregates, cement, and water in a mold. Interlocks are pre-casted solid products made out of cement concrete[6]. They are made up of a surface layer of small-element, solid unreinforced precast concrete, laid on thin compacted bedding materials which is constructed over a profiled base course bounded by edge restraints. The block joints are usually filled using fine materials. There are many advantages and distinct features of concrete interlocking paving blocks. Some of these are:

i. Higher deflections tolerance without structural failure and they are not affected by thermal expansion or contraction.
ii. It can be opened to traffic immediately after construction and curing.
iii. It is labor intensive and thus requires less sophisticated equipment.
iv. The maintenance is easy, simple and it is not affected by oil spillage or fuel.
v. It is restricted to punching loads and horizontal shear force.
vi. There is low cost of maintenance and high salvage value ensures low life cycle cost[7].

There can also be limitations of concrete interlocking paving blocks like the quality control of the materials used at the factory premises and in the process of laying the concrete interlocks[8]. Concrete interlocking paving blocks are presently available throughout Nigeria in more than 25 different shapes and sizes. The standard thickness for interlocks made for light traffic is 60mm while for heavy traffic is 80mm, although [8] has shown that using thicker blocks of 80-100mm thickness will definitely reduce deformations of pavements. There are recommended grades of interlocking paving blocks for different traffic categories with their recommended thickness and compressive strengths after 28 days.

2.1 Concrete

Concrete is the most widely used construction material in the construction industry. Its uses range from built up structures to transportation and even solid waste management [9]. The durability of concrete is a major concern in our recent world as it is related to the safety, economy and sustainability of so many lives. Basically, concrete can be defined as the combination of cement, aggregates and water. Concrete is also the bonding of natural and artificial aggregates to form a strong building material that is durable in the face of normal environmental effect. Concrete should not be mistaken or confused with cement because the term cement refers to the material used to bind materials to form concrete while concrete is the mixture of cement and aggregates.

The reaction gotten from the mixture of water and Portland cement is known as hydration and these are the primary compounds which bind concrete together. Hydration however, is a chemical reaction that is always rapid initially but as time goes on, begins to slow down requiring more water for the process to continue [10]. Some of the tests that can be carried out on concrete include the slump test, flow test, compacting factor test, shrinkage test among many others.

2.2 Aggregates

Aggregates are materials basically used as filters with binding materials in the production of concrete and mortar[3]. Aggregates are derived from the three major types of rocks (igneous rocks, sedimentary rocks and metamorphic rocks) and sometimes from blast furnace slag. They occupy 70% to 80% of the volume and considerable influence on the properties of concrete. Aggregates are classified either based on geological origin (Natural or artificial aggregates), size (coarse or fine aggregates) or shape (rounded, irregular, angular or flaky). Interlocking blocks may use any of these aggregate types or a combination of some. At times they make use of stone dusts.

2.3 Cement

Cement is a binder, a substance that sets and hardens independently and can bind other materials together. It is a powder-like material typically made from a mixture of calcined limestone and clay used with water and sand or gravel to make concrete and mortar. Cement paste plays a very important role in the engineering-scale properties of cementitious materials. There are two types of cement namely:

i. Hydraulic cement: this type of cement hardens due to hydration. It is made by heating limestone and clay in a kiln and pulverizing the result. This cement hardens under water or when exposed to wet weather. The chemical reaction that results when the anhydrous cement powder is mixed with water produces hydrates that are not water soluble. An example of hydraulic cement is the Portland cement.

ii. Non-hydraulic cement: it is mostly kept dry in order to retain its strength. Examples are Elephant cement and Cypson cement.

2.4 Portland Cement

Portland cementis considered to be the most popular type of cement used all around the world. Portland cement is usually considered as the most basic cementitious ingredient of concrete even though other acceptable cementitious ingredients exists. In some countries cementitious materials such as silica fumes, fly ash, GGBS and a few others are gaining more ground in use above Portland cement. Some others have altogether altered the constituents of Portland cement to form other related cement types in order to meet special needs. For example, in Nigeria typical Ordinary Portland Cement has been subliminally replaced by the modified Portland Limestone Cement to meet unique needs of the country [11].

Nevertheless, Portland Cement arguably remains the most used cementitious material in concrete. The first maker of Portland cement, Bricklayer Joseph Aspdin of Leeds, England, laid the foundation of an industry using a crude method of burning powdered limestone and clay in a stove. Each process of production of any Portland cement passes through series of chemical and physical tests in cement plant laboratories where analysis is made on the finished product to make sure that it complies with all industry specifications. Portland cement powder is so fine that one pound of cement contains about 150 billion grains (America's Cement Manufacturers). It is an all-purpose cement suitable for all construction works that has to do with concrete like plastering, casting of reinforced concrete, screeding, rendering and grouting[12].

2.5 Concrete Mix Design

Concrete mix design is defined as the act of obtaining a concrete of desired properties at the lowest cost by a suitable choice and proportion of available materials. Concrete mix proportion can be expressed in terms of either volume or weight.

2.5.1 Design Requirement

i. Minimum and maximum cement content is required for durability.
ii. Type of mixing and curing water to be used, whether potable, fresh, sea or ground water.
iii. Type and size of aggregates to be used.
iv. Type of cement to be used, either hydraulic or non-hydraulic cement.
v. Grade of concrete.
vi. Degree of workability of concrete
vii. Maximum free water-cement ratio by weight which is required for consideration of strength and durability for different exposure and also to meet appearance.
viii. Air content.
ix. Density of the concrete.
x. Maximum and minimum temperature of freshly mixed concrete[13].

2.5.2 Mixing Ratio

Mixing ratio can be defined as the portion of one aggregate to the other. There are principles or conditions to be considered during mixing or in choosing the right mix ratio. These are:

i. Compliancy of the concrete with the specifications of structural strength laid down which is usually stated in terms of compressive strength of standard tests specimens.
ii. Compliancy with the durability requirements to resist environmental factors in which the structure will serve its functional life.
iii. Capability and workability of the concrete being mixed, transported and compacted as efficiently as possible without undue labor.
iv. Economical affordability.

3. CURING OF CONCRETE

It is interesting to know that the hydration of cement continues for years at a very slow but decreasing rate. During the casting of concrete, much water is added to the concrete mix and less water is added for curing after casting which is the most common mistake made during construction. This process is meant to be vice versa. Curing is important because cement hydration is a slow process requiring availability of water. But more than that, the strength of concrete is typically the most important of all other factors that might be considered. Now, curing is often made a low priority in the construction industry. Mostly, curing is not seen as needed because its cost can be put into something else of 'more' benefit or because failure in the structure, mostly due to lack of curing, may not be seen till the later life of the structure and mainly because it is considered a waste of time, material and resources[14].

Curing can be defined as the method of providing concrete with temperature and moisture enough to promote the hydration of cement for a sufficient period of time. It can also be said to be a treatment that prevents the occurrence of excessive drying and makes provision for enough water content to the concrete mass for hydration of its external layers. It plays a vital role on the durability and strength development of concrete[15]. Curing can be a means of opposing the unavoidable effects of environmental actions such as wind, air moisture and sun radiation, which underscores the objectives of this work in comparing types of curing methods.

Researches over the years have studied the compressive strength of concrete before and after curing for different number of days. Proper curing of concrete is vital and very necessary in determination of the strength, durability and most especially the load bearing capacity of interlocks. This is to avoid failure under the weight of load and to also avoid unnecessary cost of replacement here and there after construction and arrangement[16].Factors such as the specified strength, the mixture proportions, completely enveloping weather conditions, future exposure conditions, and the size and shape of the concrete member does affect the length of adequate curing time[17].

3.1 Curing methods

There are different methods of curing concrete but they can all be divided into four categories which are: water curing, membrane curing, application of heat and miscellaneous methods (on-site curing methods). All other methods of curing can be categorized under these four methods stated above. The methods of curing are:

i. Curing of concrete by ponding: Ponding is also another way of water curing. In using this method, a curing tank is needed with clean water of known temperature. The casted concrete is placed inside the curing tank and left for the required number of days before tests are carried out. Ponding method of curing can be used on flat surfaces like pavements, floors and footpaths. The earth around the perimeter of the concrete surface retains a pond of water within the enclosed area which helps to prevent loss of moisture from the concrete. Ponding is also effective for maintaining uniform temperature. This method is mostly used for small jobs[18].

ii. Sprinkling method: Water curing involves the use of water in various ways. Sprinkling of water is a method of water curing but it requires everyday sprinkling using hose preferably till the number of days are complete or the desired strength achieved. Sprinkling method is best for casted concrete of very large volume or mass. Continuous sprinkling is an excellent method of curing because if it is done at intervals, there might be drying up at intervals. Therefore, enough care must be taken in order to avoid loss of moisture during the curing process. A fine spray of water applied continuously using a nozzle helps to provide constant supply of moisture which helps prevent any possibilities of crazing or cracking caused by alternate cycles of drying and wetting. The cost of sprinkling, getting materials, constant supervision and inadequate water supply might be disadvantages of using this method of curing[16].

iii. Membrane methods of curing: the methods of membrane curing are not as efficient as sheet curing (using of polythene sheets) but they have advantages over water curing because they do not need constant supervision once applied. The membrane method mostly used is the method of spraying of compounds. Spray-on of compounds is a process involving the spraying of curing compounds with a hand-held garden spray. The method can be used on both vertical (columns and reinforced walls) and horizontal (slabs) surfaces and it is also very essential to choose the right type of compound to use. The chemical compounds mostly consist of a resin (a class of either solid or semi-solid viscous substance obtained either as exudation from certain plants or by simple molecules polymerization) in a solvent that evaporates after it has been applied, leaving a thin and continuous film that seals in most of sun radiation and wind after weeks. Most of the compounds used for curing come in two grades:

a. A standard grade which has a curing efficiency of 75%

b. A super grade with a curing efficiency of 90%.

These two grades are usually available with either white or aluminized pigment which are for external paved areas because they reflect rays of sun which keeps the concrete cooler. Those compounds with fugitive dye can be checked at a glance that an all-over uniformed layer has been applied before the dye disappears without leaving stains on the concrete as it should not be applied on dry surfaces. For external paving and for areas with tropical climate, a super grade compound with either white or aluminized pigment is always advisable[19].

iv. Curing of concrete by shading: this method is meant to prevent evaporation of water from the surface even before the concrete sets. The method is adopted in cases of large concrete surfaces like road slabs and especially used in dry weather to protect the concrete from heat, direct sunrays and wind.

v. Open-air method of curing: This method of curing has been adopted by most, if not all manufacturers of concrete interlocking paving blocks across Nigeria. In using this particular method, the strength and durability of the interlocking tiles are mostly not tested for.

3.2 Importance of Curing

The following are the importance of curing:

i. Curing helps in the improvement of the durability of concrete.

ii. It enhances the serviceability of the concrete and increases the lifespan.

iii. Curing helps the cement hydration reaction to gradually improve steadily, binding the aggregates strong enough to lead to a rock solid mass making the concrete denser.

iv. It also helps to decrease porosity and then enhances the mechanical and physical properties of the concrete.

v. It helps in preventing scaling, dusting, and surface disintegration of concrete.

vi. Curing, if done properly, makes concrete more impermeable, preventing water-borne chemicals and moisture from entering into the concrete [3].

3.3 Curing models

In a bid to better understand the effect of curing on concrete, some works have looked at developing models that best relates the curing process with desired outputs. It is generally considered that the most basic models of the effects of curing on concrete is one where the hydration degree (ξ), the activation energy of the reaction (Ea), the temperature (T), a constant (R) that allows for ideal gases and a normalized affinity specific for individual hydration reactions ($\tilde{A}$), are related by Equation 1 [20];

$$\xi = \tilde{A}(\xi) \exp [- Ea / RT] \geq 0 \qquad (1)$$

where $\tilde{A}$ is in itself is a function of the chemical affinity between liquid and concrete (A) and the liquid viscosity directly linked with the microdiffusion of the free water through the hydrates represented by η [20] such that;

$$\tilde{A} = A/\eta \qquad (2)$$

Considering the effect of a body undergoing thermal changes as regards thermal equilibrium, and considering the interdependence of ξ on T, equations 1 can be modified under isothermal test conditions as;

$$\xi_n = \Delta t \exp [- Ea / R\check{T}]\sum_{i=1}^{n-1} \tilde{A}(\xi_i) \geq 0 \qquad (3)$$

where, ξ_n is the hydration degree per step in time, Δt is the time spacing between two consecutive time steps and $\check{T}$ is the constant temperature observed throughout the curing process.

Equation 3 derived under isothermal test conditions, suggests that concrete subjected to different thermal conditions will achieve the same maturity irrespective of the temperature history. It adopts the value of the accumulated temperature to describe the influence of temperature on the curing process. However superior arguments have shown through experiments that not only does an accumulated temperature have its effect on a concrete specimen but the temperature change during the process of curing has a separate influence on the specimen. [21] observed that an increase or decrease in curing temperature on the first day after casting leads to accelerated or decelerated hydration process respectively. A feat that is much slowed down on both scenarios if the change in temperature is introduced at a later stage of curing. It had also been argued that an increase in the early curing temperature leads to an increase in early strength development but a decrease in the final strength the concrete would normally have achieved assuming the temperature remained constant [22]underscoring the importance of temperature and age of concrete in the curing process.

3.4 Curing performances

It is generally accepted that ponding makes for the best type of curing of concrete specimen in order to achieve maximum strength. [23] presented findings shown in Fig 1 and Fig 2 that suggests the ponding method of curing produces concrete with the highest compressive strength.

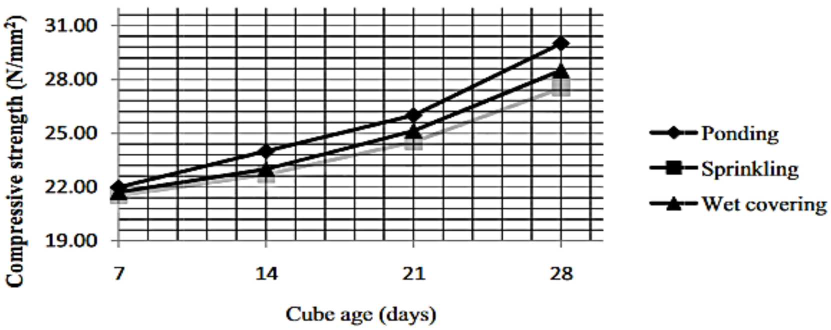

Fig 1: Variation of compressive strength with curing methods [23]

[23] explained that the reason behind ponding curing producing the strongest concrete was as a result of "…improved pore structure and lower porosity resulting from greater degree of cement hydration and pozolanic reaction without any loss of moisture from the concrete cubes". The findings also show that the totally uncured concrete (air dried) led to the weakest concretes while the ones with one sided curing (plastic sheeting covering and wet covering) led to weaker strengths than their ponding and sprinkling counterparts. Other related research works have reported similar results[24,25].

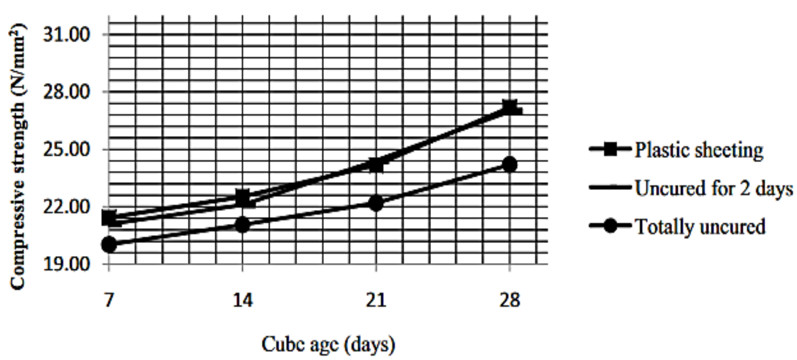

Fig 2: Variation of compressive strength with other curing methods [23]

Its interesting to note that the findings of [23]agree with the models of equations 1 and 3. The behaviour of the specimen uncured for 2 days (fig 2) suggests a change in the degree of hydration (ξ_n) between when it was uncured up until its curing started however it was unable to reach its potential strength of other curing methods despite the same liquid curing temperatures used as used for other curing methods aggreging also with the arguments of [21] and [22].

4. Conclusion

The review concludes that in producing concrete interlocking paving blocks, the ponding method of curing should be considered first for usage in order to achieve the highest potential compressive strength of the paving blocks. In such cases where it may not be feasible to adopt ponding method of curing, the available models like those presented in this work can be used in analyzing the degree of hydration of paving blocks from any potential method of curing. A higher degree of hydration suggests higher strengths. In such cases, methods such as sprinkling methods or spray-on method using curing compounds may be the next best alternative after due analysis. In case sprinkling has been chosenfor use, it is important to note that it requires very close supervision such that moisture is not left to completely dry up before another sprinkling session is carried out however if spray-ons are selected, super grade compounds should be used since it has a higher efficiency of about 90%.

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