READY MIXED CONCRETE MANUFACTURERS' ASSOCIATION – (RMCMA)

(Bulletin No. 9)

CURING OF CONCRETE

PRESIDENT'S MESSAGE

Dear Readers,

It is with great pleasure and a sense of accomplishment that I welcome you to the 9th Bulletin of the RMCMA. As the President of the Ready Mixed Concrete Manufacturer's Association (RMCMA), I am truly honoured to introduce this edition, which is dedicated to one of the fundamental aspects of our industry - the curing of concrete.

Concrete has been an integral part of human civilization for centuries, providing the foundations upon which we build our homes, roads, bridges, and cities. It is a testament to human innovation and engineering prowess. However, the true potential of concrete can only be harnessed when it is cured effectively and with precision.

In this Bulletin, we delve deep into the art and science of concrete curing. We explore the do's and don'ts, the advantages, and the latest methodologies that ensure the longevity and durability of concrete structures. Concrete curing is not merely a process; it is a commitment to the future. Proper curing enhances the strength, durability, and resistance of concrete against various environmental factors, and it is imperative for ensuring the safety and sustainability of our infrastructure.

Our association, RMCMA, has always been at the forefront of disseminating knowledge and best practices within the ready mixed concrete industry. We believe that sharing knowledge is the key to progress, and this Bulletin is a testament to our commitment to this belief. It is a result of the collective efforts of our members, experts, and contributors who have dedicated their time and expertise to produce a comprehensive resource on concrete curing.

As we navigate an ever-changing world with evolving construction technologies and sustainability challenges, understanding the nuances of concrete curing becomes even more critical. This Bulletin aims to serve as a guide, not only for our members but for all stakeholders in the construction industry, including engineers, architects, contractors, and students who are aspiring to join this dynamic field.

I would like to express my heartfelt gratitude to all those who have contributed to this Bulletin. Your dedication to advancing the knowledge and practices in the ready mixed concrete sector is commendable, and your work will undoubtedly benefit the industry for years to come.

I invite you all to immerse yourselves in the wealth of information presented within these pages. Let this Bulletin be your companion in the journey towards achieving excellence in concrete curing. Together, we can continue to build a stronger, safer, and more sustainable future.

Thank you for your unwavering support to RMCMA, and I look forward to our collective growth and success.

Warm regards,

Er. Anil Banchhor
(President, RMCMA)

Published By: Ready Mixed Concrete Manufacturers' Association
Mobile No. +91 93241 11122, Email: info@rmcmaindia.org, Website: http://rmcmaindia.org

1 Introduction

Curing is essential for newly placed concrete to maintain adequate moisture and suitable temperature conditions, so that freshly placed concrete develops designed properties of strength and durability. Curing should begin immediately after placement and finishing and should be continued for sufficient period of time typically from 7 to 14 days. The objective of curing is to prevent loss of moisture and maintain a favourable temperature to support continued hydration. Temperature control is an important aspect of curing. The rate of hydration and consequent strength development is faster at higher temperature. Temperature of placed concrete should be maintained above 10°C. In thicker sections curing procedures should minimise temperature differential between core and surface to avoid thermal cracking. Curing can also regulate the cooling rate to prevent thermal shock. When finishing minimise the rate of moisture loss from the concrete surface to prevent plastic shrinkage cracking.

Curing will increase the strength of concrete and decrease the permeability of hardened concrete. Curing also helps in mitigating plastic and drying shrinkage cracks, which can severely impact the durability of concrete. It is important to make sure uninterrupted hydration to achieve desired strength and durability. Alternate wetting and drying of concrete members during early age will damage micro-structure and may lead to interconnected pores within the body of concrete and impair its long-term durability. Uniform temperature ought to be maintained throughout the concrete section's depth to avoid thermal shrinkage cracks. In short curing of concrete is a process designed primarily to keep the concrete moist till the end of hydration by monitoring loss of moisture and water from the body of concrete, during the given period in which it gains desired strength.

Internal curing involves the use of absorptive materials such as soaked lightweight sand and super absorbent polymers or nano silica particles in suspension in concrete that releases moisture with time. The internal curing system is described in subsequent paragraphs.

2 Purpose of Curing

2.1 Predictable Strength Gain.

Hydration process of calcium silicates in cement is critically dependent on quality of curing, especially in structural elements of large surface area like floor slabs, concrete pavements, etc, where evaporation loss can exceed more than 1kg/sqm per hour. Deficiency of mixed water at surface may seriously hamper hydration process and consequently adversely affect the strength gain. It is therefore essential that adequate water is replenished to make good the loss of water due to evaporation continuously during the hydration process, therefore, to achieve the target strength of concrete, water curing is critically important.

2.2 Improved Durability -

Well-cured concrete has better surface hardness to withstand surface wear and impact. Curing minimises cracking and makes concrete more water-tight, thereby reducing the ingress of water and water-borne chemicals resulting in improved durability and service life. The permeability of well cured concrete is far lesser than improperly cured concrete. The capillary forces are intersected or partially or completely filled by the products of hydration, rendering concrete more impermeable and durable. The refinement in pore structure of concrete is greatly affected by the quality and degree of water curing. For durable concrete, it is essential that it shall be well cured. Improperly cured concretes as well as mortar remain permeable and ingress of rain water results in appearance of unsightly wet patches on vertical walls and surface finish and present very unaesthetic appearance. In addition due to inadequate strength and cyclic wetting and drying, micro-cracks appear over a period which widens and become deeper with age and reaches up to steel reinforcement resulting in its corrosion. The serviceability of concrete is greatly reduced due to improper curing including subsequent likelihood of corrosion of reinforcement.

2.3 Better serviceability and appearance -

Lack of curing will result in a concrete surface with poor resistance to wear and abrasion. Proper curing reduces the potential for crazing, dusting and scaling during the service life of the structure.

3 Methods of Curing

3.1 Maintaining Moisture

Concrete should be protected from losing moisture until final finishing by fogging or evaporation retarders. Fogging or light sprinkling of water should immediately start after finishing. The gap between placing and finishing of concrete shall be minimum preferably not exceeding 30 minutes.

Subsequent to finishing, moist curing methods can involve application of additional water and retention of water in the concrete. Deficiency of curing causes micro-cracks within the body of concrete due to plastic and drying shrinkage at various periods of its life after placing and finishing. These micro-cracks widen over a period reducing the service life of the structure manifold. The corrosion of reinforcing steel when started leaves its telltale marks on the surface of concrete in the form of coloured patches, cracks and spalling. The service life and appearance of concrete surfaces are greatly affected due to improper curing.

3.1.1 Methods of Application of Water

(i) Continuous fogging or sprinkling of water is an excellent method of curing. Soaker hoses can be used on vertical surfaces. Alternate wetting and drying is not an acceptable curing practice.

(ii) Ponding is most thorough method of water curing. A dyke is created along the edge of the slab to pond water on the slab surface and it is kept continuously wet for the given period of curing.

(iii) Use of absorbent materials like burlap or cotton mats can be used to hold water on horizontal or vertical surfaces applied by a soaker hose or sprinkler. The materials should be kept wet and weighted down to keep from blowing away. Materials should not stain the concrete surface.

(iv) Damp earth, sand or sawdust can be used to cure flatwork, especially floors. Materials should be clean or free from organic matter and iron staining contaminants.

3.2 Methods Using Retention of Water

Methods reduce evaporative water loss from the surface. They can be applied earlier than water curing methods.

3.2.1 Covering with Plastic Sheet

Covering with plastic sheets either clear white (reflective), or black. Plastic sheet should be at least 0.1mm thick. Films reinforced with fibers are more desirable. Clear and dark sheets absorbs solar radiation and are recommended in cool weather or on shaded areas. Reflective sheets minimise heat gain and should be used in warm weather. Plastic should be laid in direct contact with concrete as soon as possible after finishing without marring the surface. Edges should overlap, be taped and weighted down Sheets should extend beyond the edge of slab at least twice the slab thickness. Wrinkles will cause dark streak or a mottled appearance due to variation of moisture or temperature. Plastic should not be used on concrete surfaces where appearance is important. Plastic is sometimes used over wet-burlap to retain moisture.

(fig - 1 Spreading of plastic sheet on concrete surface immediately after finishing)

3.2.2 Use of Curing Compound

Liquid Membrane-forming Curing Compounds. These are wax or resin based materials that form a surface film and minimise evaporation. The curing compounds are applied to the concrete surface, at the recommended rate, immediately after disappearance of water sheen on the surface after final finishing. Delayed application after surface has dried prevents the formation of the film. While a clear liquid may be used, a white pigment provides reflective properties and coverage is visible. Two coats applied at right angles is desirable for even coverage. Curing materials that are wax-free are recommended for concrete surfaces that will be painted or if a surface covering has to be bonded to the concrete.

(fig-2 Application of curing compound after finishing)

3.2.3 Waterproof Paper

Consists of two layers of Kraft paper connected together and reinforced with fiber. Paper is used like plastic sheeting and is less likely to mar the surface. This method is used where concrete surfaces of high aesthetic value are required.

(fig - 3 Covering concrete surface with kraft paper)

3.2.4 Evaporation Retarders

Evaporation retardants are used to reduce evaporation from concrete surfaces before it sets to prevent plastic shrinkage cracking. These should not be used for final curing. These are used immediately after finishing and before application of water.

Fig - 4 Use of evaporative retarders

4 Control of Temperature

In cold weather do not allow concrete to cool faster than a rate of 3°C per hour. Concrete shall be protected from freezing until it achieves a strength of 3.5 MPa, using insulating materials. Curing methods that retain moisture, rather than wet curing, shall be used when freezing temperatures are anticipated. Wet curing is avoided in cold climate and curing methods which help in retaining water are more effective.

In hot weather high initial curing temperature will result in rapid strength gain but lower ultimate strength. Water curing and sprinkling can be used to get lower curing temperature in summer. Precautions should be used to protect against heating faster than 3°C per hour due to temperature extremes.

(fig-5 Monitoring of concrete temperature)

5 Other Methods of Curing of Concrete

There are curing systems of concrete other than water also. Some popular methods in this category are described below.

5.1 **Steam Curing** - Steam curing at atmosphere pressure is a method used to raise concrete strength at early ages. The steam curing method is based on the application of water vapour at a temperature between 40°C and 100°C for a limited period. Steam curing has some negative effect on micro-structure of concrete and it increases at higher temperature above 80°C. Concrete exposed to steam curing regime at low temperature 45°C to 65°C and a longer period within a 24 hour cycle achieve better concrete properties. The curing period and the pre-curing period in addition to the cooling period influence the properties and the strength of concrete. Some of the important aspects of steam curing are given below.

(fig-6 Method of steam curing)

a) Steam curing is very effective for curing of pre-cast structural elements, where one of the objectives is to increase early strength to increase production.

b) The application of atmospheric pressure steam curing systems greatly increases the hydration rate of cement to raise the early strength of concrete, achieving the designed strength within 3 days of casting.

c) The application of lower steam curing temperatures from 45°C to 65°C for a longer period (24 h), yields positive results in the early and later ages compared with higher curing temperatures and shorter periods.

d) The curing steam temperatures of 80°C and above has negative effect on micro-structure and the strength of concrete at a later ages due to delayed ettringite formation and the porous structure.

e) To avoid thermal stresses, a sufficient delay period should be provided before steam curing is carried out, which shall not be less than the initial setting time of concrete.

f) The addition of pozzolanic materials plays an important role in reducing the negative effects of steam curing on the strength of concrete at later ages because the pozzolanic materials improves the micro-structure and reduces the permeability of concrete.

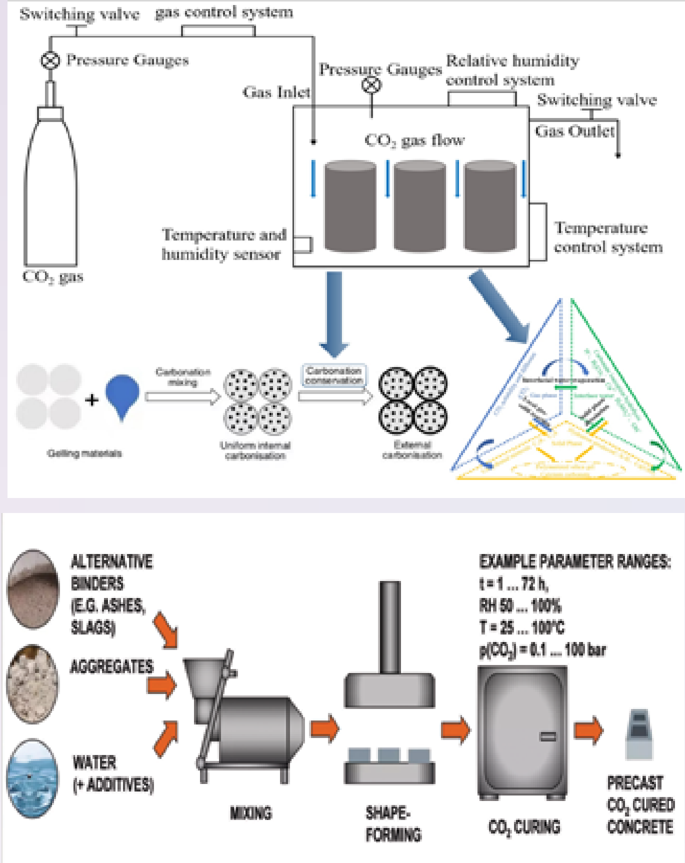
5.2 Curing of Concrete by Carbon-di-oxide (CO_2)

The curing of concrete elements by diffusing Carbon-di-oxide into it under controlled pressure and temperature is one of the methods of accelerate curing. This method is more suitable for precast concrete-elements in a factory. The process permits the CO_2 to diffuse into the concrete and undergo carbonation. The carbonation finally results in thermodynamically stable calcium carbonate products. The carbonation process is performed under control conditions in a chamber at the early stages of concrete for strength gain. Under Carbonation curing process, the Carbon-di-oxide is injected into the vessel where the concrete elements are stored. The CO_2 is diffused into the fresh concrete under low pressure. During this process, the cement compounds C_3S and C_2S and the by-products of hydration calcium hydroxide $Ca(OH)_2$ reacts with CO_2 producing solid calcium carbonate ($CaCO_3$) at ambient temperature.

$Ca(OH)_2 + CO_2 = CaCo_3 + H_2O$

$C_3S + 3CO_2 + H_2O = C\text{-}S\text{-}H + 3CaCO_3$

$C_2S + 2CO_2 + H_2O = C\text{-}S\text{-}H + 2CaCO_3$



(fig-7 Process of CO_2 curing system)

The hydration products form at an accelerated rate and the curing facilitates accelerated strength gain. This process is widely used by “Carbon Cure” a company in Canada and this method is becoming popular in other parts of the world.

The CO_2 emitted by industrial units is reused for curing that finally embeds CO_2 within concrete permanently and future emission of CO_2 is blocked. It is green technology, which enhances sustainability and reduces carbon footprints.

The concrete cured by Carbon-di-oxide does not bring any harmful effect to the concrete compared to conventionally cured concrete. It has following advantages and disadvantages.

5.2.1 Advantages

a) Rapid strength gain

b) The carbonation process due to curing produces solid stable products.

c) Carbon-di-oxide being a significant green house gas, its consumption for curing reduces the carbon content in the atmosphere.

d) It saves water and the process in general is very environment friendly.

5.2.2 Disadvantages

a) The Carbon-di-oxide reaction with concrete units lower the pH. Hence the steel enforcement in the concrete elements is subjected to corrosion. It is therefore not used for steel reinforced structures.

b) It is used only for precast units like concrete solid, hollow blocks, pavers, tiles etc., and not applicable to RCC structures.

5.3 Internal Curing of Concrete

Internal curing provides an improved method of curing by encapsulating water within the cementitious matrix after setting. The water encapsulation is achieved either through light-weight aggregate, super absorbent polymers, cellulose fibers, recycled concrete, nano-silicon particles or any other suitable materials. These materials are mixed as additives in the concrete mix, which releases water after concrete is set to compensate the loss of water due to evaporation and to meet the requirement of water for continued hydration.

Internal curing improves the performance of concrete by uniformly progressing the reaction of cementitious materials within throughout the mass of concrete. Conventional curing supplies water from the surface of concrete, while internal curing provides the water within the concrete. This is very beneficial since the depth that external water can penetrate is very limited for any concrete, while the internal curing water is dispensed through out the depth of concrete uniformly.

The water that is absorbed/adsorbed to the internal curing additives does not contribute to the water-cement ratio. The water to cement is a descriptor of structure of matrix and pores that develops in fluid concrete system. Once the concrete sets, the structure and pores have been established, and water can only aid in hydration. The water in internal cure additives desorb (leave) as the negative pressure in the pore fluid develops with setting and increases thereafter.

Internal curing can reduce autogenous shrinkage, since water released by additives will work to fill pores that otherwise can lead to autogenous shrinkage. Internal curing can also reduce permeability, diffusion and sorption of concrete through increased hydration of the interfacial transition zone. Internal curing is especially beneficial for mixtures containing high volumes of supplementary cementitious materials that may require longer time to hydrate. Internal curing can also make concrete less susceptable to thermal cracking, as the built in stress caused due to autogeneous shrinkage is subsentially reduced. Other advantages of internal curing are being investigated.

Internal curing system is very eco-friendly technology. In USA and many other countries, it is widely used especially for pavements and bridge decks but in India it is still in nascent stage. In view of numerous advantages internal cure provides, it will soon be widely adopted in India also.

6 Recommendations of RMCMA to BIS

RMCMA has recommended to BIS to modify curing clauses no. 13.5.3 in IS:456 -2000 as under

13.5 Curing

Curing is the process of preventing the loss of moisture from the freshly placed concrete whilst maintaining a satisfactory temperature regime, so that freshly placed concrete develops targeted properties of strength and durability. Curing should begin immediately after placement and finishing and should be continued for a sufficient period of time to support continued hydration. The prevention of moisture loss from the concrete is particularly important if the water cement ratio is low, if the cement has a high rate of strength development, if the concrete contains granulated blast furnace slag or pulverised fuel ash. The curing regime should also prevent the development of high temperature gradients within the concrete.

The rate of strength development at early ages of concrete made with supersulphated cement is significantly reduced at lower temperatures. Supersulphated cement concrete is seriously affected by inadequate curing and the surface has to be kept moist for at least seven days.

13.5.1 Methods of Curing

Concrete should be protected from losing moisture until final finishing by fogging or evaporative retardants or other methods. Subsequent to finishing moist curing methods shall be applied.

13.5.2 **Membrane Curing**

Membrane curing reduces evaporative water loss from concrete surface. Membrane curing can be applied earlier than water curing method.

Plastic sheets either clear white (reflective) or black shall be at least 0.1 mm (100 micron) thick. Black sheets absorb solar radiation and should be used in cool weather or on shaded areas. Reflective sheets minimise heat gain and should be used in warm weather. Plastic sheets should be laid in direct contact with concrete as soon as possible to prevent plastic shrinkage cracking. Edges should overlap, be tapped and should extend beyond the edge of slab at least twice the thickness of slab.

Liquid forming membrane of approved curing compound may be used. These are wax or resin-based materials that form a surface film and minimise evaporation. These should be applied immediately after disappearance of water sheen on the surface after final finishing. Delayed application after surface has dried prevents the formation of the film. Two coats applied at right angles is desirable for even coverage. Curing materials that are wax free are suitable for concrete surface that will be painted or, if a surface covering has to be bonded to concrete surface.

13.5.3 **Moist Curing**

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of absorbent materials like sacking, canvas, hessian or similar materials and kept constantly wet for at least seven days from the date of placing concrete in case of ordinary Portland Cement and at least 10 days where mineral admixtures or blended cements are used. Alternate wetting and drying is not an acceptable curing practice. The period of curing shall not be less than 10 days for concrete exposed to dry and hot weather conditions. In the case of concrete where mineral admixtures or blended cements are used, it is recommended that above minimum periods may be extended to 14 days.

13.5.4 For the concrete containing Portland Pozzolana Cement, Portland slag cement, Composite Cement or mineral admixture, period of curing may be increased, after considering climatic and environmental conditions.

7 Termination of Curing:

Curing shall be terminated as required by the specification, or for at least 7 to 10 days. Termination of curing shall allow for gradual drying of concrete and to prevent large temperature differentials in the concrete member. The use of embedded temperature and relative humidity monitoring devices can be useful in critical application.

8 Conclusions

Curing of concrete is very important operation in any type of concrete construction. Proper curing of concrete and preventing loss of water in initial stages immediately after placing has significant effect on its micro-structure, permeability and development of plastic and shrinkage cracks. Curing of concrete for sufficient duration is very essential for hydration of cement and development of strength of concrete.

Various methods of curing of concrete have been developed over a period. Water curing remains the most popular methods, but presently use of other methods like curing compounds, membrane curing, steam curing and internal cure additives is increasing. All these methods have advantages when judiciously applied either in combination of water curing or all alone. Curing becomes more critical in tropical country like India, where ambient temperatures are high, most of the time during the year and loss of water due to evaporation is significant.

Considering the importance of curing, RMCMA has recommended revision of curing clauses 13.5 to 13.5.3 of IS:456 - 2000 to BIS. The recommendations made by RMCMA to BIS have been included in this bulletin for the information of the readers. RMCMA is endeavoring to get proper provisions of curing included in revised IS:456, which is under draft stage at present.

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- SCHWING Stetter (India) Pvt. Ltd

Written & Edited by Er. A. K. Jain, Principal Consultant - RMCMA