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A REVIEW ON THE CURING OF CONCRETE USING DIFFERENT METHODS

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ABSTRACT: *The hardened properties and durability of concrete are dependent on the moisture and temperature condition of the concrete during its hydration process. This review explores various methods of curing concrete focusing on their effectiveness in improving the performance and sustainability of concrete structures. Traditional methods of curing (such as ponding, sprinkling) and the modern curing techniques (such as curing compounds, self-curing agents and steam curing) are compared. The advantages and disadvantages of these methods are highlighted and water curing is found to be the most effective method of concrete curing, for it allows for the maintenance of adequate moisture and temperature, and it does not change the macro and microscopic structure of the concrete. The research methodology includes extensive literature, experimental studies and performance evaluations. The review aimed at providing a comprehensive understanding of the best curing practices for different projects and working conditions.*

KEYWORDS: Concrete curing, hydration process, curing compounds, steam curing, self-curing agents, concrete performance.

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INTRODUCTION

Curing is an innovative approach through which the potential for performance and sustainability of concrete structures can be improved (Agustin, 2023).

Conventionally, curing concrete means creating conditions that will prevent water from evaporating. This evaporation takes place at the surface of the concrete, i.e., curing occurs from the outside to the inside of the concrete. Internal curing simply means those concrete that are self-curing (Viswam & Murali, 2018).

Concrete has high sensitivity to moisture losses and so the strength is proportional to the presence of moisture within and at the surface (C09 Committee, 2020b).

The presence of moisture within a certain temperature for maturity and development of the hardened properties of concrete due to the hydration of cement is referred to as curing.

Quality concrete requires an uninterrupted curing and that is the preservation of a satisfactory moisture content and temperature in concrete for a period of time. Curing is a strong influencer of the properties of hardened concrete; it requires that water be retained in the concrete during this period; this is achieved by preventing evaporation or substantially reducing it. All desirable properties are improved with curing, though the curing period may vary but it should be as long as practical. The minimum should be 7 days or until 70% of the specimen's compressive or flexural strength is attained. The period can be reduced to 3 days if high early strength concrete is used and the temperature is above 10º C (50ºF) (A.s et al., 2017).

Curing begins from the time fresh concrete is placed and finished to when it reaches its desired strength. Meanwhile, it should be maintained to when its surface drying will have no damage effect on the concrete. The moisture and temperature sources might be from an external source (C09 Committee, 2020b).

Water-cement ratio of a mix should be the smallest possible to fill the pore space and to allow for proper hydration. The hydration is later supported by externally applying curing water to promote the maximum possible degree of hydration or devising a means to stop the loss of concrete moisture (C09 Committee, 2020b).

Curing is a process that typically follows consolidation and finishing processes in the order of operations for the production of concrete. Two main categories of methods for curing concrete are: those that maintain availability of water and those that minimize the loss of mixing water from concrete by sealing its exposed surfaces (Akinwumi, 2014).

Several methods and procedures are provided to control and maintain adequate moisture in concrete. These are classed into three stages: the first is the initial stage curing which involves fogging, use of evaporation reducers, etc. The intermediate curing includes applying liquid membrane forming compound sand. Then, the final curing includes ponding, wet covering and application of liquid membrane forming compounds, etc. (C09 Committee, 2020b).

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The most common curing method in the concrete construction industry involves the application of water all over the freshly cast structural element continuously from the time it is set to three days, seven days or more (Mohamed & Najm, 2019).

Those properties of hardened concrete that are improved by curing include compressive strength, permeability, abrasion resistance and resistance to freezing and thawing (C09 Committee, 2020b).

For proper selection of curing methods, economic and logistical issues are not the only factors to be considered; their effectiveness on the concrete properties is also an important factor.

The two basic methods of curing are by water application on concrete through ponding, fogging, steam or by saturated cover materials such as burlap, cotton mats, rugs, sand, straw, hay or by minimization of water loss by using moisture retaining materials placed over the exposed surface or by application of membrane forming compounds (C09 Committee, 2020b).

An improper curing of concrete is uneconomical, because remedying insufficiently cured concrete may cost about 200 dollars while one dollar could have been enough for proper curing at the initial stage (Lee, 2000).

The quantity of moisture retained and temperature controlled in concrete are the basic factors of curing that determine how shrinkage forces are adjusted, minimizing the possibility of cracks, though these are dependent on water availability, materials used for curing, workforce available and the environmental weather (Agustin, 2023).

Construction and chemical industry have brought many advancements that have paved the way for more development in new curing techniques and production of construction chemicals such as Membrane curing compounds, Self-curing agents, Wrapped curing, Accelerators, Water proofing compounds, etc. Conventional curing methods have proven to be economically costly as there are many practical issues and that have made it to be replaced by Membrane curing compounds and Self-curing agents up to some extent, as they can be used in inaccessible areas, Vertical structures, Water scarce areas, etc. (Pawar & Shrikant Rajendra Kate, 2020).

Direct exposure of concrete to the environment leads to evaporation of water, and the loss of moisture reduces the initial water cement ratio, which results in the partial hydration of the cement, hence lowering the quality of the concrete (Pawar & Shrikant Rajendra Kate, 2020).

Curing compounds are membrane-forming chemicals that facilitate the curing of concrete during the initial stages of the hydration process by preventing water loss from the concrete’s surface (Ślusarek et al., 2022).

Chemical compounds that when applied on a concrete surface will form a membrane and prevent the loss of moisture through evaporation and facilitate the hydration process are known as curing compounds (C09 Committee, 2020b).

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The curing compounds are divided into two: first are those identified as with or without dyes, and the second are white pigmented compounds which can be applied on concrete by spraying, brushing or rolling (C09 Committee, 2020a).

To accelerate curing, various methods have been used in the production of prefabricated concrete units, such as steam curing, electric thermal curing, microwave curing, infrared curing, etc. Among these, steam curing is the most widely used owing to its ease of operation (Yazıcı et al., 2009).

The effectiveness of a curing method depends on its ability to support the continuation of cement hydration and prevent concrete from drying (Soroka, 1979).

One of the good curing methods is ponding. This is related to its ability to improve pore structure and reduce pore volume in concrete resulting from high degrees of cement hydration and pozzolanic reaction without any loss of moisture from the concrete cubes (James et al., 2011).

However, for ponding curing, it requires considerable labor and supervision; this method is generally used only for small jobs. The higher dosage of the self-cure chemical provided a greater improvement in surface characteristics, but at both concentrations, the chemical decreases the rate of absorption at the surface (A.s et al., 2017).

The process through which concrete is cured under heating and at atmospheric steam pressure to rapidly improve the strength of concrete at early stages and improve the efficiency of a template turnover is referred to as steam curing. This curing method is mostly used for precast structural element and foam concrete (T. Wang et al., 2024).

The effects of temperature in concrete are numerous and it has also been reported that fly ash activity can be increased under high temperature to prevent it from deterioration (Wu et al., 2021).

The curing temperature of concrete is to be controlled in a relatively low range to allow for the development of long-term strength (T. Wang et al., 2024).

To improve the early age strength of concrete steam curing is used, but it has a drawback compared with normally cured concrete: steam-cured concrete displays some macroscopic and microscopic faults such as a non-uniform hydration distribution (Patel et al., 1995), delayed ettringite formation, decreased strength, low durability, enlarged porosity and brittleness. Experimental work proves that all these drawbacks result from the steam-cured process and put great side effects on concrete (Ma et al., 2017).

The total pore volume and porosity of concrete is increased after steam curing; a high temperature during curing enlarges the pores further. Samples treated with steam have a more porous and weak adhesion area; as the gel loosens, the deterioration of the concrete is more obvious after the steam temperature rises. Further, the long-term effects of steam-curing concrete will be deteriorated due to these cracks. Curing concrete at temperatures higher than 65°C does harm to the early-age and long-term strengths of the concrete (Erdoğdu & Kurbetci, 1998)

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Generally, the molding strength of concrete is increased due to a longer preheating duration (Baoju et al., 2001). To improve the pore structure and alkali content of a concrete to be cured using steam, minerals such as fly ash and slags can be incorporated into it (L. Wang et al., 2023).

Similarity is observed in the relative compressive strength development of concrete cubes cured in water and those cured by plastic sheet covering. Also, the relative compressive strength development of concrete cubes cured by air-drying and those cured by covering with wet rug show similarity. For curing methods, immersion in lime water, covering with wet rug, covering with plastic sheets, and immersion in water should be limited to the 28-day curing period. After a 28 day curing period, the increase in compressive strength is not significant except for air-dried concrete cubes (Akinwumi, 2014).

LITERATURE REVIEW

Pawar and Shrikant Rajendra Kate (2020) in his review discussed the various curing techniques which include Shading concrete work, Covering concrete surfaces with hessian or gunny bags, Sprinkling of water, Ponding method, Membrane curing, Immersion curing and Steam curing. And the time length of concrete curing depends on the following factors: Mixture proportions, Specified strength, Size and shape of concrete member, ambient weather condition and Future exposure conditions, coupled with the fact that the curing temperatures do not affect the water penetration of concrete, but affect the chloride penetration and compressive strength of concrete significantly.

Wang et al. (2024) in their experiment on an orthogonal experimental study on the influence of steam curing on mechanical properties of foam concrete with fly ash results shows that the pore size distributions for the steam curing process enlarge the porosity of foam concrete, similar to the microstructure of normal-density concrete being also deteriorated by steam curing. Besides, the experiment was conducted on groups of concrete under different steam curing, label S0, S1, S2. And the mean pore sizes of S0, S1, and S2 are 40.34 nm, 62.56 nm, and 77.06 nm, which indicate that the steam curing process enlarges the porosity of foam concrete, which means that the higher the curing temperature, the higher the deterioration and coarsening of the pore structure. The higher the steam curing temperature, the lower the long-age strength we observe.

Agustin (2023), in his experiment on the Effect of Different Curing Methods in Flexural Strength of Concrete, performed a tensile strength test on the concrete specimen cured using immersion in water, rice husk, rice straw and curing compounds at the curing 14 days; the water curing has a higher tensile strength than rice husk, rice straw and curing compounds with 9.6, 9.9 and 15.9 % respectively. Similarly, at the 7th day, the water-cured specimens have higher tensile strength than those cured with rice husk, rice straw and curing compounds with 17.7, 11.4 and 19.4% respectively.

James et al. (2011) did an experiment to study the effect of curing methods on the compressive strength of concrete, which was conducted on concrete cubes and cured using ponding, sprinkling, wet covering, plastic sheeting, some uncured for two days and some totally not cured. Specimens cured using the ponding curing had the highest compressive strength greater than those cured using sprinkling, wet covering, plastic sheeting, some

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uncured for two days and some totally not cured with 4.2, 8.8, 8.8, 12.9 and 23.1 respectively at the 28 curing days.

Akinwumi (2014), in his experiment on Effects of Curing Condition and Curing Period on the Compressive Strength Development of Plain Concrete, cured concrete cubes using lime water, plastic sheet, water, air dried and wet rug and found that only concrete cured by immersion in lime and those covered with plastic sheet had their compressive strength meeting the minimum required 28 days strength. Of this set of curing methods, the highest compressive strength was obtained using the lime water, and then followed by plastic sheet, water cured, air dried and wet rug with their compressive strength less than that cured by lime water in 28 days with 7, 15, 18 and 19% respectively. Meanwhile, the least compressive strength was obtained for concrete cured by covering with wet rug. This result may be attributed to the outdoor (exposure) conditions that this curing method was subjected to.

Mohamed and Najm (2019) conducted an experiment on the Effect of Curing Methods on Compressive Strength of Sustainable Self-Consolidated Concrete. In this study, three curing methods were used to examine their effect on the 28-day compressive strength; the curing methods include submerging the samples in water bath under room temperature for 28 days, submerging the samples for 3 days in water and then placing them for 25 days under direct exposure to sun until the age of 28 days, and applying acrylic chemical curing compound to concrete samples until the test day. The experiment comprises a mix with water to binder ratio of 0.33 and 0.36. For both experiments, the sun curing specimens at the 28th day has the highest compressive strength with 6.4 and 19.2% above water bath curing and chemical compound curing respectively for w/b = 0.36. Similarly, for w/b = 0.36, the percentage difference values are 19.2 and 5.97% for water bath curing and chemical compound curing respectively.

Su le and Petr (2021) in their experiment on Research of Curing Time and Temperature-Dependent Strengths and Fire Resistance of Geopolymer Foam Coated on an Aluminum Plate found that the compressive strength of concrete cured at 70, 85 and 105°C exhibited a rapid strength development; meanwhile, they achieved their target strength values three days after mixing.

Pawar and Shrikant Rajendra Kate (2020) in their experiment on Curing of Concrete performed a compressive strength test on concrete cubes specimens at 7, 21, and 28 days. Some of the specimens were cured by immersion in water, wet gunny bag curing and an accelerated warm water curing (for one day at 55°C). For the results with target strength of $20N/mm^2$ at 28 days of curing, the concrete immersed in water for curing has a compressive strength with 5.7 and 6.7% above those cured with wet gunny bag curing and accelerated curing respectively. Similar to that with target strength of 40 N/mm^2, the difference is also 5.3 and 6.75% respectively.

Rahimi et al. (2023), in their research on the influence of curing strategies on the compressive strength and hardening behavior of concrete prepared with Ordinary Portland Cement, cured concrete cubes samples using water and curing compounds for 7, 14, 21 and 28 days. The compressive strength of samples cured with water is higher than those with curing compounds at all ages. Hence, the increments of strength for 7, 14, 21 and 28 days are 6.50, 12.77, 11.84 and 18.57% respectively.

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EVALUATION AND COMPARISON OF VARIOUS CURING METHODS: EFFICACY AND PERFORMANCE INSIGHTS FROM RECENT RESEARCH STUDIES

RESEARCH STUDY	CURING METHOD	RESULT/MEASURE	DIFFERENCE FROM HIGHEST (%)
Agustin (2023)	Water curing	Tensile strength	0% (Highest)
	Rice husk	Tensile strength	-9.6% (14 days), -17.7% (7 days
	Rice straw	Tensile strength	-9.9% (14 days), -11.4% (7 days
	Curing compounds	Tensile strength	-15.9% (14 days), -19.4% (7 days)
James et al. (2011)	Ponding curing	Compressive strength	0% (Highest)
	Sprinkling	Compressive strength	-4.2%
	Wet covering	Compressive strength	-8.8%
	Plastic sheeting	Compressive strength	-8.8%
	Uncured for 2 days	Compressive strength	-12.9%
	Not cured	Compressive strength	-23.1%
Akinwumi (2014)	Lime water	Compressive strength	0% (Highest)
	Plastic sheet	Compressive strength	-7%
	Water cured	Compressive strength	-15%
	Air dried	Compressive strength	-18%
	Wet rug	Compressive strength	-19%
Mohamed & Najm (2019)	(w/b=0.36)		
	Sun curing	Compressive strength	0% (Highest)
	Water bath curing	Compressive strength	-19.2%
	Chemical compound curing	Compressive strength	-5.97%
	(w/b=0.33)		
	Sun curing		0% (Highest)
	Water bath curing		-6.4%
	Chemical compound curing		-19.2%
Pawar & Shrikant Rajendra Kate (2020	**Grade M20**		
	Immersion in water	Compressive strength	0% (Highest)
	Wet gunny bag curing	Compressive strength	-5.7%
	Accelerated warm water curing	Compressive strength	-6.7%
	Grade M40		
	Immersion in water	Compressive strength	0% (Highest)
	Wet gunny bag curing	Compressive strength	-5.3%
	Accelerated warm water curing	Compressive strength	-6.75%
Rahimi et al.	Water curing (7 day	Compressive strength	0% (Highest)

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(2023)	Curing compounds (7 days)	Compressive strength	-6.5%
	Water curing (14 days)	Compressive strength	0% (Highest)
	Curing compounds (14 days)		-12.77%
	Water curing (21 days)	Compressive strength	0% (Highest)
	Curing compounds (21 days	Compressive strength	-11.84%
	Water curing (28 days)	Compressive strength	0% (Highest)
	Curing compounds (28 days)	Compressive strength	-18.57%

CONCLUSION

The review consistently shows that curing with water is the most effective method to achieve the best result in compressive and tensile strength. But this is not practicable all the time. Therefore, in light of the situation and condition of the working place or weather, other methods may be used, such as wet covering, plastic sheeting, and accelerated curing (e.g., steam curing, chemical compound curing, etc.) which are available and can be used based on effectiveness considering the project requirements and working condition.

1. Advantages of steam curing include improving the productivity of steam precast concrete products while its drawback include causing drying shrinkage and micro cracks (Katsuoka et al., 2023).

2. Advantages of ponding curing include preventing moisture loss in concrete and maintaining a uniform temperature in concrete; hence, it is used for proper curing of concrete specimens in the laboratory. Its disadvantages include requiring considerable labor and supervision and it is only used for small jobs (Katsuoka et al., 2023).

3. Sprinkling method of curing is effectively used to prevent the concrete surface from drying out and it is found to increase the compressive strength of concrete by about 10% above that of curing under air (Katsuoka et al., 2023).

4. There is a need for determining the strength of concrete even at insitu using the different non destructible methods to correlate the laboratory and insitu properties, (A. I. et al., 2024) . This will help in not just assessing curing methods in laboratory but also at site.

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RECOMMENDATIONS

1. Curing with water should be prioritized due to its superior performance on the compressive and tensile strength of concrete.
2. Lime water has less tendency to evaporate compared to pure water and it is capable of maintaining the concrete moisture; this makes it a good curing method with a result more effective than pure water.
3. The effect of curing concrete with curing compounds is more effective during the early stage and reduces with the concrete age when compared to the strength gained with water curing.
4. Totally not cured samples give the less compressive strength and it should be avoided by using one of the possible curing methods to improve the concrete strength.
5. Though steam curing aids in producing high early strength in concrete, it has some negative impacts on its long-term properties; hence, it should be used with caution.
6. Sprinkling should be applicable to areas with availability of water.
7. Wet covering should be applicable to structural elements, e.g., columns, beams, etc.
8. Curing compounds offer a practical and efficient alternative to the traditional curing methods and can be used where the traditional means is not practicable e.gin high rise structures, water scarce areas. In these circumstances, the chemical compounds should be used as guided by the manufacturer to achieve good result.
9. Other curing methods, such as electrical curing, microwave or infrared curing should be more experimentally assessed to know their effectiveness compared to the traditional curing methods and to know which situation is more favorable for its application.

DECLARATION OF CONFLICT OT INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper. This research was conducted independently, and no funding or financial support was received from any commercial entity that could influence the content or outcomes of this review. All conclusions drawn in this paper are based solely on the authors' analysis and interpretation of the reviewed literature and experimental results.

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