Review of research on effects of steam curing on concrete properties

Abstract: Steam curing is a method used to increase the strength of concrete at an early stage. Steam curing is based on applying hot water vapor at a certain temperature. The constant temperature time and maximum temperature are determined according to the characteristics, cost and production cycle of the target concrete. This paper reviews the effect of steam curing on the performance of concrete, especially on the performance of fly ash based concrete. Steam curing has a negative effect on the microstructure of concrete, which will increase with the increase of temperature. In addition to the cooling period, the curing period and pre-curing period also affect the performance and strength of concrete. Concrete exposed to steam curing at low temperatures of 45°C to 80°C and for longer periods of time within a 24-hour cycle can achieve better concrete performance.

Key words: Steam curing　concrete strength　fly ash based material

1 Introduction

Concrete is a kind of building material composed of cement, sand, stone and other materials. There are many factors affecting the raw materials. At present, it is very difficult for relevant personnel to accurately judge concrete strength through prediction models [1][2]. Through standard curing, concrete strength can be directly determined, and concrete design and production personnel can quickly grasp the potential activity of the admixture and adjust and determine the concrete mix ratio in time [3][4]. The strength of natural curing is closely related to age, curing time, curing method and curing temperature, and the curing method directly affects the strength. The most important process after concrete placement is maintenance. Whether the curing is proper and sufficient directly affects the strength development, deformation, size, cracking, and durability of the concrete. Therefore, the curing determines whether the performance of the concrete in the actual structure is consistent with the performance of the laboratory standard conditioned concrete, and whether the design performance of the concrete can be achieved. Therefore, studying the growth law, characteristics and interrelations of concrete strength under different curing methods is conducive to more accurate determination of concrete strength.

2. Influence of steam curing on concrete performance

2.1 Curing method of concrete

The curing of concrete refers to the necessary measures (including the humidity and temperature required for hydration) taken for the continuous hydration reaction of cementing materials (including cement and mineral admixtures) in concrete. The curing methods adopted for concrete after pouring are different. In actual construction, water coating is generally used for curing, while in the laboratory, humidity above 95% is usually used. The standard curing temperature of 20 ±2℃, in order to improve production efficiency and improve the early strength of concrete in the prefab plant, steam curing is generally used.

Osama Mohamed[5] studied the curing technology involving compounds, and conducted a comparative study on the influence of three curing methods: soaking in water, high-temperature air curing and compound curing on the compressive strength of concrete. A total of 20 mixtures were tested. For all mixtures, the sample cured in air at 45 ° C produced the highest 28-day compressive strength compared to other curing methods. Similarly, concrete samples cured with the compound yielded higher compressive strength compared to conventional curing methods.

Commented [DMF1]: If possible, give examples of negative effects.

Commented [DMF2]: Lack of background on steam curing.

Commented [DMF3]: Can the author explain why predictive models are unreliable?
Provide brief examples of common model limitations.

Commented [DMF4]: The author tries to present research significance at the end of introduction, but its very defective and lacks.

Commented [DMF5]: Limited discussion of different curing methods and comparison of methods.

Commented [DMF6]: Any references?

Commented [DMF7]: Which standard does the author refer to? Please cited.
Format, should be 45°C .

Commented [DMF8]: The author needs to provide more details of the mechanism behind why this happens.

UNDER PEER REVIEW

2.2 Influence of steam curing on concrete performance

Steam curing is based on the application of hot water vapor at temperatures ranging from 40°C to 100°C within a limited time. The maximum temperature and the longest curing time are determined according to the characteristics, cost and production cycle of the target concrete. The application of steam curing in precast structural components is beneficial and economical. One of its purposes is to accelerate the construction speed and achieve superior mechanical properties at an early stage.

Abdullah M. Zeyad and Bassam A. Tayeh [6] reviewed the previous literature on the impact of steam curing systems on the performance of concrete. Steam curing has a negative effect on the microstructure of concrete, and this effect increases with rising temperature. Besides the cooling period, the curing period and pre-curing period also have an impact on the performance and strength of concrete. Previous studies have confirmed that concrete exposed to low temperatures ranging from 45°C to 80°C for a longer period within a 24-hour cycle can achieve better concrete performance.

Yun Duan[7] experimentally analyzed the hydration heat, temperature changes and microstructure under different steam curing temperatures, and studied the influence of steam curing temperature and curing time on the compressive strength of concrete in the constant temperature stage to determine an economical and practical steam curing scheme. The results show that the higher the steam curing temperature and the longer the curing time, the greater the loss of later strength of concrete. If the duration of the constant steam curing temperature stage is too short, the hydration products only cover a small area, and most of the cement remains unhydrated. This is more obvious at lower steam curing temperatures.

Liu Baoju and Xie Youjun [8] used UFA and slag to replace cement, and accelerated the hydration of cement and fly ash with steam curing and chemical activators, and compared it with standard curing. The influence of steam curing on the compressive strength of UFA concrete with and without slag was studied. The test results show that the early strength of UFA concrete is relatively low after steam curing for 13 hours, and the 28-day compressive strength of the concrete after steam curing for 13 hours is significantly different from that of the standard curing concrete. However, the early strength of the concrete is relatively high after UFA is mixed with CaSO4 or Ca(OH)2, which accelerates the reactivity of fly ash. Concrete containing UFA and ground slag was prepared, and the compressive strength of the concrete was improved. The compressive strength of UFA concrete after demolding and steam curing is relatively low, and the 28-day compressive strength is also relatively low, indicating that the steam curing adaptability of UFA is poor.

Cement type, curing time and curing temperature are important parameters in the steam curing process. Selcuk Tqrkela [9] prepared concrete cubes with a water-cement ratio (W/C) of 0.44 and conducted steam curing for 4, 8, 16, 24 and 36 hours at curing temperatures of 65°C and 85°C. The aim of the study was to compare the performance of the new binder with traditional PC42.5 under steam curing. The compressive strength values and maturity changes under each condition were compared. The test results show that Portland composite cement (PKC/A42.5) can replace PC42.5 for normal pressure steam curing in precast concrete production. However, if early demolding and early high strength requirements are present for PKC/A42.5 cement concrete, the curing temperature should be increased to 85.8°C.

A.A. Ramezanianpour [10] investigated the influence of 36 different steam curing regimes on the compressive strength and permeability of self-compacting concrete mixtures, which were used

Commented [DMF9]: In some discussions, there is no critical parameter (temperature range). If possible, prepare a comparison table that summarizing the main findings.

Commented [DMF10]: Check the format of writing a citation.

Commented [DMF11]: The author typed "UFA" this is the first time this acronym appears in the manuscript but it is not defined. Please define the acronym.

UNDER PEER REVIEW

for the prefabricated concrete elements of the Sadar Elevated Highway. Compressive strength tests indicated that within a certain total time, an increase in pre-temperature exposure time would lead to a decrease in immediate compressive strength. On the other hand, increasing the treatment temperature and total cycle time (which implies higher energy and time consumption) resulted in higher immediate compressive strength. Moreover, the durability test results showed that applying a cycle with a maximum temperature of 70°C had a negative impact on the durability performance of the reference SCC, such as surface resistivity and capillary absorption. Finally, based on three indicators of compressive strength, permeability, and energy consumption of the steam curing cycle, the optimal steam curing cycle was proposed and applied to the prefabricated concrete factory. The influence of steam curing on the compressive strength and permeability of aggregate-filled SCC was studied.

At present, the HDE problem of steam-cured concrete has not been well solved. Jinyan Shi, Baoju Liu [11] adopted two steam curing methods and four subsequent curing methods to cure the concrete. Through long-term compressive strength, surface permeability and microstructure tests, the influence of curing conditions on the performance of steam-cured concrete was analyzed. The results showed that stepwise curing was beneficial to the formation of pre-structure, thereby improving the long-term mechanical properties and impermeability of steam-cured concrete. Among the four subsequent curing conditions, saturated limestone soaking was the most favorable for the long-term performance of steam-cured concrete, while water soaking was the most unfavorable. Through a series of experimental analyses, the influence of staged curing, variable-rate curing and subsequent curing on the evolution of HDE was studied.

Shashi Kant Sharma [12] initially produced plain cement concrete with a 28-day compressive strength of 70 MPa and conducted tests on this concrete, while changing the binder composition, aggregate ratio, and application of on-site curing methods, thereby achieving the same strength with less binder content. Ground granulated blast furnace slag (GGBS), fly ash (FA), and silica fume (SF) were used under normal water (23°C) and hot water (40°C) for 24 hours, and steam (60°C) curing for 2 hours in a 6-hour cycle (four cycles of 24 hours) to achieve early strength and reduced shrinkage of pavement quality self-compacting concrete (PQSCC). The results showed that steam curing could achieve good results even without CaCl2, while hot water curing must be supplemented with CaCl2 to achieve high strength.

2.3 Effects of Steam Curing on the Properties of Fly Ash-Based Concrete

Commented [DMF12]: The effect of variation on fly ash content is not clearly explained.

A detailed discussion of the mechanisms behind these effects is lacking

Gou Yu [13] conducted experiments to investigate the influence of steam curing temperature and fly ash on the properties of steam-cured concrete. The compressive strength of concrete with fly ash at a temperature of 60°C was tested. The results showed that at the studied temperature, the compressive strength of concrete with fly ash replacing the benchmark cement in equal amounts was lower than that of the benchmark concrete within the age range of 1 to 90 days. With the increase in steam curing temperature, the compressive strength of each concrete after 7 days of age showed a decreasing trend.

She Liang [14] prepared high-activity multi-component supplementary cementitious materials by using a combined activation method with fly ash microspheres, granulated blast furnace slag, and silica fume. The effects of different activation methods on the activity index of mortar and hydration products were studied. The influence of adding multi-component supplementary cementitious materials on the compressive strength and sulfate resistance of concrete was also explored. When 30% of the multi-component supplementary cementitious materials were added to

UNDER PEER REVIEW

replace cement, and after static curing for 7.5 hours and steam curing at 90°C for 4.5 hours, the compressive strength of the concrete was significantly improved, and its sulfate resistance was enhanced. This indicates that the multi-component supplementary cementitious materials made from slag, fly ash microspheres, and silica fume, after mechanical-chemical combined activation, can partially replace cement to prepare high-performance steam-cured concrete.

Zhao Xingli[15] prepared SCC with a high fly ash replacement rate and cured it in a standard curing box for 24 hours or in a steam curing machine at 60°C and 90°C for 24 hours, and then placed it in tap water for curing. The effects of different early curing conditions on the mechanical properties of fly ash-based SCC were analyzed, and the relationship between the mechanical properties of fly ash-based self-compacting concrete was discussed. The conclusion was drawn that an increase in the fly ash content had a significant negative effect on the early compressive strength, splitting tensile strength, and elastic modulus of SCC. However, early high-temperature curing could significantly improve the early mechanical properties of fly ash-based SCC. Considering the actual engineering requirements, the application of fly ash-based SCC in the production of prefabricated components is feasible.

In order to understand the brittleness characteristics of steam-cured concrete, Li Guang et al. [16] used the brittleness coefficient and impact toughness as evaluation indicators to study the effects of curing temperature (20, 45, 55, 65, 75°C) and mineral admixtures on the brittleness of concrete. The results showed that as the curing temperature increased or the curing age prolonged, the brittleness coefficient of concrete increased, and steam curing reduced the impact toughness of concrete. The combined addition of fly ash and slag powder admixtures could improve the brittleness and impact resistance of steam-cured concrete. Higher curing temperatures led to coarser crystallization of hydration products, the formation of microcracks in the interfacial transition zone, and an increase in the porosity of the matrix, thereby increasing the brittleness of steam-cured concrete. The combined addition of fly ash and slag powder admixtures improved the pore structure and microstructure of the interfacial transition zone of steam-cured concrete.

Zhang Yao et al. [17] studied the mechanical properties, chloride ion permeability, and volume stability of high-volume fly ash and slag steam-cured concrete under 60°C and 80°C steam curing conditions, and analyzed the reaction degree of fly ash and slag. The results showed that under 60°C steam curing conditions, when the slag content was high, the early strength of concrete slightly increased, while when the fly ash content was high, it significantly decreased. The later strength of both was only slightly lower than that of pure cement concrete. Under 80°C steam curing conditions, the early strength of high-volume fly ash specimens improved, while that of high-volume slag specimens decreased. The later strength of all three types of concrete decreased, but the strength degradation of fly ash and slag concrete was less than that of pure cement concrete. This was mainly because fly ash and slag could alleviate the delayed formation of ettringite, improve the chloride ion permeability and volume stability of concrete, and enhance the durability of steam-cured concrete.

3 Conclusion

Commented [DMF13]: Too general, does not clearly restate main findings.

This report investigated the effects of steam curing on the behavior of concrete. The following conclusions can be drawn:

(1) Concrete exposed to steam curing at low temperatures ranging from 45°C to 80°C and for longer periods within a 24-hour cycle can achieve better performance. Additionally, raising the steam curing temperature above 80°C can have negative impacts on the microstructure and other

properties of concrete.

(2) The addition of pozzolanic or complementary cementitious materials can help reduce the damage caused by applying steam curing regimes to concrete at later stages. Such verification is needed to clarify the behavior of concrete under the influence of steam curing systems, understand their impact on concrete performance, and find ways to minimize the damage caused by the application of steam curing regimes.

UNDER PEER REVIEW

UNDER PEER REVIEW

Reference

[1] Si Xiuyong, Hu Weihua, Pan Huimin. Carbonation resistance and prediction model of concrete with mineral admixtures [J]. Concrete, 2024 (1): 17-20, 27.

[2] Wang Xu. Analysis of influencing factors and optimization measures for testing concrete strength by rebound method [J]. Foshan Ceramics, 2023, 33 (7): 87-89.

[3] Zhang Xuhui, Liu Bowen, Yang Ling, et al. Experimental study on carbonation performance of concrete under different temperatures and strengths [J]. Building Structure, 2020, 50(24): 110-115.

[4] Fan Yaohu, He Zhen, Cai Xinhua, et al. Study on the effects of fly ash dosage and curing conditions on mechanical properties and carbonation resistance of concrete [J]. Guangdong Building Materials, 2021, 37 (7): 4-6, 3.

[5] Osama Mohamed, Omar Najm. Effect of Curing Methods on Compressive Strength of Sustainable Self-Consolidated Concrete[J]. Materials Science and Engineering, 2019.

[6] Abdullah M. Zeyad, Bassam A. Tayeh, Adeyemi Adesina. Review on effect of steam curing on behavior of concrete[J]. Cleaner Materials, 2022, 3, 100042.

[7] Yun Duan , Qicai Wang , Zijiang Yang. Research on the effect of steam curing temperature and duration on the strength of manufactured sand concrete and strength estimation model considering thermal damage[J]. Construction and Building Materials, 2022, 315, 125531.

[8] Baoju Liu, Youjun Xie, Jian Li. Influence of steam curing on the compressive strength of concrete containing supplementary cementing materials[J]. Cement and Concrete Research, 2005, 35, 994-998.

[9] Selcuk Tqrkela, V olkan Alabas. The effect of excessive steam curing on Portland composite cement concrete[J]. Cement and Concrete Research, 2005, 35, 405-411.

[10] A.A. Ramezanianpour, M.H. Khazali, P. Vosoughi. Effect of steam curing cycles on strength and durability of SCC: A case study in precast concrete[J]. Construction and Building Materials, 2013, 49, 807-813.

[11] Jinyan Shi, Baoju Liu, Shuai Shen. Effect of curing regime on long-term mechanical strength and transport properties of steam-cured concrete[J]. Construction and Building Materials, 2022, 255, 119407.

[12] Shashi Kant Sharma, Kanish Kapoor, Mohit Kumar. Evaluating the effect of different mix compositions and site curing methods on the drying shrinkage and early strength of pavement quality self-compacting concrete [J]. International Journal of Pavement Research and Technology. 2022, (15): 10-28.

[13] Gou Yu. Effect of fly ash on compressive strength of steam-cured concrete [J]. Concrete. 2021, 07: 86-89.

[14] She Liang, Fu Pingfeng, Deng Wei. Effect of combined activated multi-component auxiliary cementitious materials on the performance of steam-cured concrete [J]. Chinese Journal of the Chinese Ceramic Society. 2022, 41 (9): 3059-3067.

[15] Zhao Xingli, Dong Pengcheng, Luo Yuanbin. Effect of early high temperature curing on the performance of fly ash-based self-compacting concrete [J]. Chinese Journal of the Chinese Ceramic Society. 2020, 39 (09): 2821-2829.

[16] Li Guang, Li Beixing, Huang An. Effects of curing temperature and mineral admixtures on the brittleness of steam-cured concrete[J].Bulletin of the Chinese Silicate Society. 2023, 42(02):

487-495.
[17] Zhang Yao, Zou Guangqiang, Hu Yizhang. Effects of curing temperature on the properties of steam-cured concrete with fly ash and slag alone[J]. Concrete. 2022, (11): 32-35.

UNDER PEER REVIEW