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PERFORMANCE OF INTERNAL CURING CONCRETE USING SAP AS AN INTERNAL CURING AGENT

Li HongYuan[1,2] & Norul Wahida Kamaruzaman[1]
[1]*Infrastructure University Kuala Lumpur, MALAYSIA*
[2]*Guangzhou City Construction College, Guangzhou, Guangdong, CHINA*

ABSTRACT

This study investigates the performance of internal curing concrete (C-S) incorporating superabsorbent polymers (SAP), compared to ordinary concrete (C). Standard specimens —150 mm cubes for compressive strength and 150 × 150 × 550 mm prisms for flexural strength— were tested in accordance with GB/T 50081-2019. The internal curing concrete (C-S) exhibited superior compressive strength, increasing by 6.1 N/mm² from 7 to 14 days and by 1.9 N/mm² from 14 to 28 days, compared to increases of 4.1 N/mm² and 2.3 N/mm² for the, respectively, for ordinary concrete (C). At 28 days, the flexural strength of internal curing concrete (C-S) exceeded that of ordinary concrete (C) by 0.6 N/mm² (17.6%). These improvements are attributed to the sustained moisture supply provided by the SAP, which promotes calcium silicate hydrate formation and reduces microcracks caused by autogenous shrinkage. Internal curing concrete shows potential for use in high-temperature or low-humidity environments, enhancing durability under challenging conditions. However, only one type of SAP was tested, limiting the generalizability of the findings. Future research should examine various SAP types and assess long-term durability. This study highlights SAP-based internal curing as a sustainable approach for producing high-performance concrete, contributing to advancements in civil engineering applications

Keywords:
internal curing concrete, superabsorbent polymer (SAP), compressive strength, flexural strength

INTRODUCTION

Concrete remains the most widely used construction material in modern infrastructure (Xie et al., 2021). Concrete structures have gained unparalleled prominence in the construction industry, becoming one of the primary choices for various construction projects. Effective curing is critical to achieving optimal mechanical properties and long-term durability in concrete structures by facilitating cement hydration, which forms strength-giving compounds like calcium silicate hydrate (C-S-H). Various curing methods exist, including water curing, steam curing, and internal curing, each influencing hydration kinetics and microstructure development differently (Bentz & Weiss, 2011).

The proposed research work on self-curing concrete offers several advantages compared to normal conventional concrete, such as enhanced early-stage strength, reduced shrinkage cracks, and a flowable mix without bleeding or segregation. Additionally, incorporating self-curing agents reduces the water content in the concrete, contributing to a healthier and more sustainable environment (Saravanakumar et al., 2023).

There are currently two prevailing categories of internal curing materials for concrete: inorganic porous materials and chemical polymers (Ma et al., 2015). Porous ceramics and superabsorbent polymers (SAPs) stand as exemplary representatives of inorganic porous and synthetic polymer internal curing materials, respectively.

The exceptional water retention capacity of SAPs has driven extensive research into their application for internal curing of concrete to mitigate early-age shrinkage (Mechtcherine, 2016). Numerous studies have investigated the influence of SAPs on the physical and mechanical properties of internally cured concrete (Zheng et al., 2021; Xie et al., 2020, 2021). The incorporation of SAPs

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into cement pastes results in a marginal reduction in compressive strength after 28 days. However, in concrete mixtures, naturally occurring pores counteract the adverse effects of SAP-induced pores, leading to a notable improvement in compressive strength, particularly when using SAPs with a particle size of 400 µm (Niu et al., 2024).

The addition of preabsorbed water to SAPs delays the initial cement hydration process, accelerates the rate of later-stage hydration, and increases the ultimate degree of hydration, thereby enhancing the compressive strength of concrete. Moreover, pre-wetted SAPs significantly reduce concrete shrinkage, exhibiting a more pronounced shrinkage mitigation effect compared to the dry SAP addition (Huang et al., 2022). Larger SAP particle sizes have been shown to more effectively reduce autogenous shrinkage in early-age concrete (Lura et al., 2006), while SAP particles approximately 100 µm in size demonstrate superior water absorption efficiency (Jensen & Hansen, 2001, 2002). Additionally, SAPs enhance concrete durability under freeze-thaw cycles (Zheng et al., 2021).

The inclusion of SAPs also modifies the microstructural properties of concrete, increasing the density of the binding gel while introducing capillary pores. These alterations contribute to improved abrasion resistance and reduced chloride ion permeability (Kazemian & Shafei, 2024). However, existing studies have predominantly explored higher SAP dosages (0.2–0.5% by cement mass) and varying water-cement ratios in high-strength concrete, leaving a research gap concerning the performance of low-dosage (0.1%) pre-wetted SAPs in standard-cured, ordinary concrete.

Despite these advancements, challenges remain in the field of internal curing, particularly in determining the optimal dosage of internal curing agents and their compatibility with diverse concrete mix designs, which warrant further investigation (Kiran et al., 2025; Li & Kamaruzaman, 2025).

This study addresses this gap by investigating the performance of internal curing concrete (C-S) with 0.1% pre-wetted SAP (150 µm, 64.37 g/g absorption capacity) under standard curing conditions, in accordance with GB/T 50081-2019 (Chinese Standard, 2019). Unlike prior work, this research focuses on the low-dosage SAP’s impact on compressive and flexural strength, offering insights into its practical applicability and sustainability benefits. Despite progress, further research is needed to optimize SAP particle sizes, dosages, and long-term durability across diverse concrete grades. This study contributes to the field by providing experimental data on low-dosage SAP’s effects, advancing internal curing technology for sustainable, high-performance concrete applications in civil engineering.

EXPERIMENTAL PROGRAMS

Materials

The cement employed was of P·C42.5-grade composite Portland cement, boasting a density of 3180 kg/m³. The fine aggregate utilized was Zone II medium sand, characterized by a fineness modulus of 2.5 and an apparent density of 2670 kg/m³. For the coarse aggregate, continuously graded crushed stone within the size range of 5–25 mm was selected, sharing the same apparent density of 2670 kg/m³. The mixing water (W) was sourced from tap water. A polycarboxylate superplasticizer served as the water reducer, capable of achieving a water reduction rate of 28%.

The superabsorbent polymer (SAP) used in this study is a cross-linked acrylic acid/sodium acrylate copolymer with a particle size of 150 µm. Based on prior water absorption tests, the SAP exhibits a saturated water absorption capacity of 64.37 g/g, meaning it can absorb water equivalent to 64.37 times its own mass when fully saturated. For the dilution water experiments, 5 grams of SAP were weighed and saturated with water. The subsequent water release process was monitored, and the resulting water release curves are presented in Figure 1. The superabsorbent polymer (SAP) is incorporated into the concrete mixture in a pre-saturated state to ensure optimal water absorption. The SAP dosage is 0.1% of the cement mass. The choice of this low dosage aligns with prior research indicating that SAP dosages of 0.1–0.2% by cement mass provide sufficient internal curing water to enhance cement hydration without introducing excessive free water, which could compromise early-age strength (Snoeck et al., 2020).

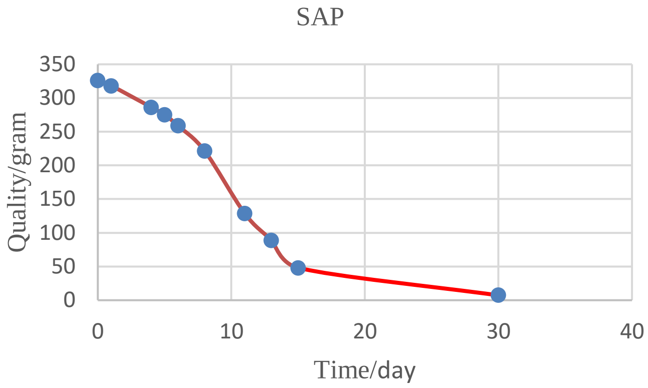


Figure 1: SAP water release process curve

According to the Chinese standard “Design Specification for Ordinary Concrete Mix Proportion” (JGJ55-2011) (Ministry of Housing and Urban-Rural Development of the People’s Republic of China, 2011), the design strength grade of concrete was C35. The mix proportions for ordinary concrete (C) and internal curing concrete (C-S), with SAP as the internal curing agent, are presented in Table 1.

Table 1: Mix proportions of concrete kg/m^3

Sample No.	Cement	Sand	Stone	Water	Water reducing agent	SAP	Pre absorption water
C	359	809	1117	155	14.4	-	-
C-S	359	809	1117	155	14.4	0.359	23.1

DESCRIPTION OF MIX PROPORTIONS AND PREPARATION METHODS

Control Group Concrete (C)

The control group concrete, designated as “C,” was formulated without superabsorbent polymer (SAP) to serve as a baseline for evaluating the performance of internal curing concrete. The mix proportion consisted of 359 kg/m³ of cement, 809 kg/m³ of sand, 1117 kg/m³ of coarse aggregate (stone), 155 kg/m³ of water, and 14.4 kg/m³ of water-reducing agent. These proportions were designed to produce a standard concrete grade suitable for assessing mechanical properties and hydration behaviour under conventional curing conditions.

The preparation of the control group concrete followed a standardized mixing procedure to ensure uniformity. Cement, sand, and coarse aggregate were dry-mixed in a laboratory mixer for 1 minute to achieve a homogeneous blend. Water and the water-reducing agent were then gradually added over 30 seconds while mixing continued. The mixture was mixed for an additional 2 minutes to ensure thorough dispersion and uniform consistency. The fresh concrete was cast into moulds, compacted using a vibrating table to eliminate air voids, and cured under standard conditions (20 ±

2 °C, 95% relative humidity) for 24 hours before demoulding. The specimens were subsequently cured according to the experimental protocol to evaluate compressive and flexural strengths.

Internal Curing Concrete (C-S)

The internal curing concrete, designated as "C-S," incorporated SAP to facilitate internal curing through controlled water release. The preparation of the internal curing concrete (C-S) differs from the control group concrete primarily in the incorporation of superabsorbent polymer (SAP) and its associated pre-absorption water. Specifically, 0.359 kg/m³ of SAP (a cross-linked acrylic acid/sodium acrylate copolymer with a particle size of 150 μm) and 23.1 kg/m³ of pre-absorption water were added to the mix to facilitate internal curing through controlled water release. Prior to mixing, the SAP was pre-saturated with the pre-absorption water in a separate container until fully absorbed, as determined by the SAP's saturated water absorption capacity of 64.37 g/g. During the mixing process, the pre-saturated SAP was added alongside the water and water-reducing agent over 30 seconds, while all other steps—dry mixing of cement, sand, and coarse aggregate for 1 minute, final mixing for 2 minutes, casting, compaction using a vibrating table, and curing under standard conditions (20 ± 2 °C, 95% relative humidity) for 24 hours before demoulding—remained identical to those for the control group concrete.

EXPERIMENTAL PROGRAMS

Testing method for compressive strength of concrete

Compressive strength tests were conducted on 150 mm × 150 mm × 150 mm cubic specimens in accordance with the Standard for Test Methods of Concrete Physical and Mechanical Properties (GB/T 50081-2019) (Ministry of Housing and Urban-Rural Development of the People's Republic of China & General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2019). Each test group comprised three specimens. The loading rate was maintained between 0.5 MPa/s and 0.8 MPa/s during testing. The compressive strength of the concrete was determined using Equation (1).

$$f_{\mathrm{cc}} = \frac{F}{A} \tag{1}$$

where F is the failure load (N) of the specimen, A is the bearing area (mm²), and fcc is the compressive strength (N/mm²). The arithmetic mean of the compressive strength measurements from the three specimens was calculated to represent the compressive strength of the group, and reported to a precision of 0.1 N/mm².

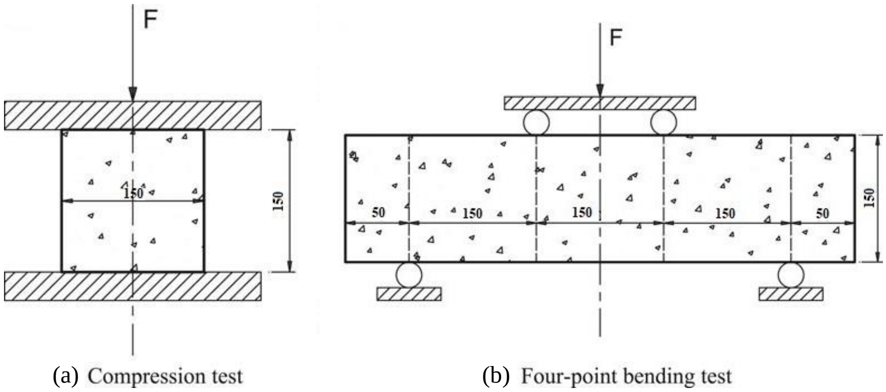
Testing method for flexural strength of concrete

Flexural strength tests were conducted on standard prismatic specimens measuring 150 mm × 150 mm × 550 mm, in accordance with the Standard for Test Methods of Concrete Physical and Mechanical Properties (GB/T 50081-2019) (Ministry of Housing and Urban-Rural Development of the People's Republic of China & General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2019). Each test group consisted of three specimens. During testing, the loading rate was maintained between 0.05 MPa/s and 0.08 MPa/s. The flexural strength of the concrete was calculated using Equation (2).

$$f_{\mathrm{f}} = \frac{Fl}{bh^2} \tag{2}$$

where F is the failure load (N) of the sample, l is the span between the supports (mm), b is the section width (mm), h is the section height of the sample, and ff is the flexural strength of the concrete

(N/mm²). The arithmetic mean of the flexural strength measurements from the three specimens was calculated to represent the flexural strength of the group, and reported to a precision of 0.1 N/mm². The loading schematic diagram of the experiments for ordinary concrete and internal curing concrete specimens is shown in Figure 2.



(a) Compression test (b) Four-point bending test

Figure 2: Loading schematic diagram of experiments

RESULTS AND ANALYSIS

Analysis of compressive strength of concrete

The compressive strength of the ordinary concrete (C) and the internal curing concrete (C-S) incorporating superabsorbent polymers (SAP) are is presented in Figure 3. For ordinary concrete, compressive strength increased by 4.1 N/mm² from day 7 to day 14, followed by a further rise of 2.3 N/mm² from day 14 to day 28, reflecting the typical pattern of strength development, where early gains are rapid but subsequently slow. In contrast, the internal curing concrete exhibited a more robust strength development, with an increase of 6.1 N/mm² from day 7 to day 14 and an additional 1.9 N/mm² from day 14 to day 28. This enhanced performance underscores the superior early and sustained strength growth of the internal curing concrete (C-S), attributed to the internal curing mechanism facilitated by SAP.

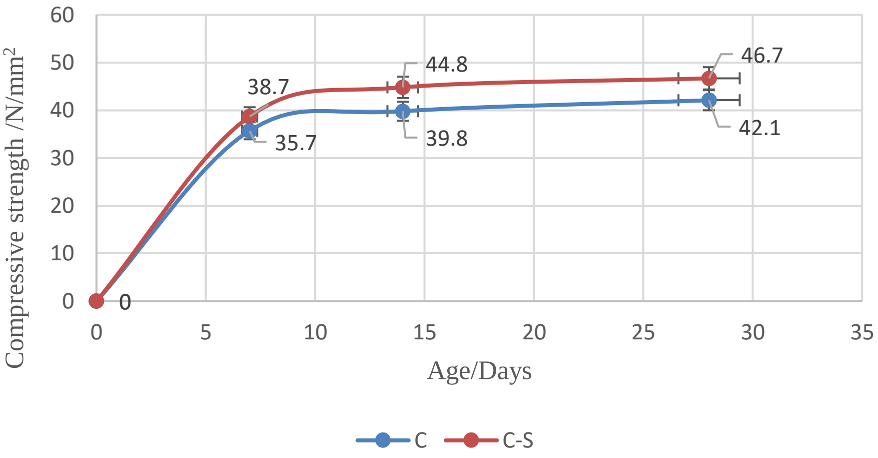


Figure 3: Concrete compressive strength under different ages

The improved compressive strength of the internal curing concrete (C-S) is primarily due to the SAP's ability to absorb and gradually release water during the hardening process, ensuring a sustained moisture supply for cement hydration. This prolonged hydration promotes the formation of additional calcium silicate hydrate (C-S-H) gel, the primary strength-contributing phase in cement paste, resulting in a denser and more uniform microstructure. Furthermore, SAP mitigates autogenous shrinkage by reducing internal stresses, thereby minimizing microcrack formation. This dual effect of enhanced hydration and reduced microcracking significantly enhances the compressive strength of the internal curing concrete (C-S) compared to the ordinary concrete (C) across all tested ages, highlighting the efficacy of SAP-based internal curing in improving concrete durability and performance in civil engineering applications.

Analysis of flexural strength of concrete

The flexural strength of the ordinary concrete(C) and the internal curing concrete (CS) are depicted in Figure 4.

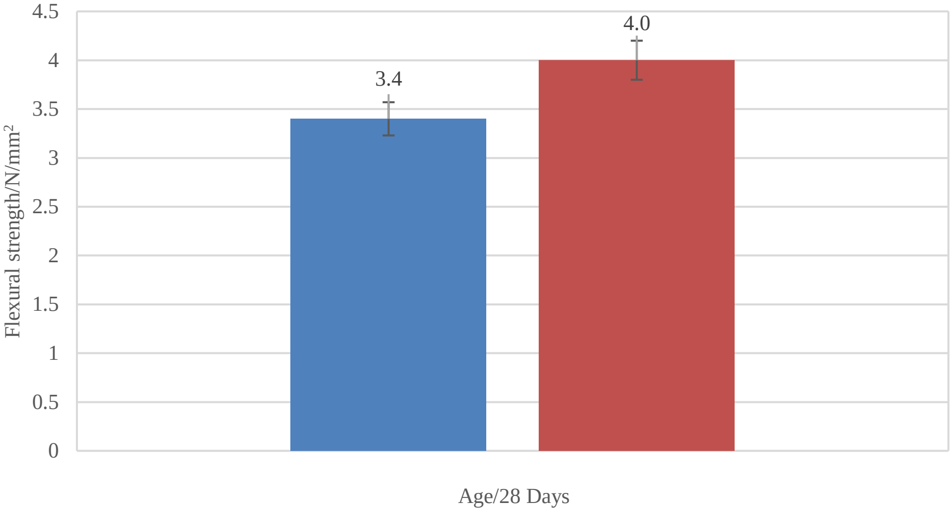


Figure 4: Flexural Strength of Concrete at the age of 28 days

At 28 days, the flexural strength of the internal curing concrete (C-S) exceeded that of ordinary concrete (C) by approximately 0.6 N/mm², representing an improvement of about 17.6%. This significant enhancement demonstrates the superior resistance of internal curing concrete to flexural stresses, attributed to the internal curing action of superabsorbent polymers (SAPs).

The enhanced flexural strength of the internal curing concrete (C-S) results from the SAPs' capacity to maintain a high internal relative humidity, facilitating more complete cement hydration. This leads to the formation of a robust cementitious matrix with increased calcium silicate hydrate (C-S-H) content, which enhances the concrete's tensile capacity. Additionally, SAPs reduce self-shrinkage by releasing stored water to counteract moisture loss, thereby limiting the development of microcracks caused by shrinkage stresses. This improved microstructural integrity not only bolsters the concrete's ability to withstand flexural loads but also enhances its overall durability. These findings validate the effectiveness of SAP-based internal curing strategies in optimizing the mechanical performance of concrete in civil engineering applications.

CONCLUSIONS

Section A: Demographic Information

This study investigated the performance of internal curing concrete (C-S) incorporating superabsorbent polymers (SAPs) compared to ordinary concrete (C), focusing on compressive and flexural strength development. The results demonstrate that SAP-based internal curing significantly enhances both compressive and flexural strengths. Specifically, the internal curing concrete (C-S) exhibited a more pronounced strength gain, with a 6.1 N/mm² increase from 7 to 14 days and 1.9 N/mm² from 14 to 28 days in compressive strength, compared to 4.1 N/mm² and 2.3 N/mm² for ordinary concrete. Similarly, at 28 days, the internal curing concrete (C-S) achieved a 17.6% higher flexural strength (approximately 0.6 N/mm² greater) than the ordinary concrete (C). These improvements are attributed to SAPs' ability to sustain cement hydration by releasing absorbed water, promoting the formation of additional calcium silicate hydrate (C-S-H) gel, and mitigating autogenous shrinkage to reduce microcrack formation, thereby enhancing microstructural integrity.

The findings have significant implications for civil engineering practice, particularly in optimizing concrete performance under challenging conditions. The sustained moisture supply provided by SAPs makes internal curing concrete particularly suitable for high-temperature or low-humidity environments, where conventional curing methods may be inadequate, such as in arid regions or in precast concrete production. By improving early and long-term strength, SAP-based internal curing can enhance the durability and service life of concrete structures, reduce maintenance costs and improve structural reliability.

However, this study has limitations. Only one type of SAP was tested, which may limit the generalizability of the results, as different SAP compositions or particle sizes could yield varying performance. Additionally, the study focused on mechanical properties at 7, 14, and 28 days, without exploring long-term behavior. Future research should investigate the durability of internal curing concrete, including resistance to freeze-thaw cycles, chemical attack, and long-term shrinkage behavior. Exploring different SAP types, dosages, and their impact on hydration kinetics and pore structure could further optimize internal curing strategies. Long-term studies on the performance of internal curing concrete under real-world environmental conditions are also recommended to validate its practical applicability.

This research underscores the potential of SAP-based internal curing to advance concrete technology, offering a sustainable solution for high-performance concrete in demanding construction scenarios. These findings contribute to the growing body of knowledge on internal curing and provide a foundation for developing innovative concrete mixtures tailored to specific engineering applications.

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AUTHOR BIOGRAPHY

Li HongYuan, is a Doctor of Philosophy in Civil Engineering (by Research) in the Faculty Of Engineering and Technology Infrastructure of Infrastructure University Kuala Lumpur, currently works at the Faculty of Architectural Engineering, Guangzhou City Construction College, Guangzhou, Guangdong, China. His doctoral supervisor was Norul Wahida Kamaruzaman, Ts., PhD. *Email: 94221994@qq.com*

Norul Wahida Kamaruzaman, Ts., PhD is an Associate Professor in the Civil Engineering & Construction Department of Infrastructure University Kuala Lumpur. She received her M.Eng in Construction from the University Malaysia Pahang in 2013 and her PhD in Engineering Technology in 2019 from the same university. *Email: wahida@iukl.edu.my*

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