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A REVIEW OF SHRINKAGE AND CRACK RESISTANCE OF INTERNAL CURED CONCRETE USING SAP AS AN INTERNAL CURING AGENT

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ABSTRACT
Concrete is the most widely used construction material globally, but its production requires substantial amounts of water for casting and curing. With water scarcity becoming a pressing concern, alternative methods to reduce water consumption while maintaining or enhancing concrete properties are vital. Internal curing using superabsorbent polymers (SAPs) has emerged as a promising solution to address this challenge. This paper explores the mechanisms, benefits, and applications of internal curing concrete, with a particular focus on the role of SAPs. SAPs function by absorbing and retaining water, which is gradually released during the hydration process. This mechanism helps mitigate autogenous shrinkage, a common cause of cracking in concrete, thereby improving the material's crack resistance and overall durability. The review highlights the advantages of SAPs in enhancing the performance and sustainability of concrete, positioning them as a viable alternative to traditional curing methods. However, it also underscores the need for further research to optimize the use of SAPs and validate their long-term benefits across various construction applications. By providing insights into the potential of internal curing with SAPs, this study contributes to the ongoing efforts to develop more sustainable and durable concrete solutions. Future studies should focus on refining the application of SAPs and exploring their effectiveness in diverse environmental and structural conditions.

Keywords:
Internal curing concrete, superabsorbent polymers, shrinkage, crack resistance, construction

INTRODUCTION

Concrete stands as the most extensively utilized building material worldwide, making it an integral component of modern construction practices (Xie et al, 2021). Concrete structures have gained unparalleled prominence in the construction industry, becoming one of the primary choices for various construction projects (Kiran et al., 2021). Water, as a natural resource, holds significant importance in the construction industry and is extensively utilized for casting and curing purposes. Considering the escalating global demand for water and its widespread scarcity, it has become crucial to explore strategies to minimize water consumption in construction processes (Lokeshwari et al, 2021). For the construction of every 1 m^3 of concrete, approximately 3 m^3 of water is needed, with the majority of it allocated to the curing process (A.S. El-Dieb, 2007). Curing of concrete plays a vital role in achieving optimal strength and significantly contributes to enhancing its durability properties. Primarily, curing facilitates the essential hydration process of cement. Several curing methods are available, including water curing, steam curing, self-curing, curing by infrared radiation, electrical curing, among others. However, the extensive use of these methods results in a significant water demand, potentially leading to water scarcity concerns. Exterior and interior curing represent the two fundamental approaches for concrete curing. In the case of conventional concrete, the external curing process takes place after the mixing, placing, and finishing stages. However, in regions facing water scarcity issues, extended curing becomes impractical. When concrete surfaces are exposed to the environment, water within the concrete evaporates, leading to a reduction in the water content used during the concreting process. This, in turn, impacts the cement hydration process, potentially compromising the quality of the concrete (Kiran et al., 2021). Internal curing concrete, a novel approach to enhancing the curing of high-strength concrete, has been gaining increasing attention in the construction industry. As an innovative maintenance technology, internal curing concrete has significant significance in the context of concrete application and water resource scarcity. It provides strong support for solving the problem of concrete maintenance, improving concrete performance, and promoting sustainable development of the construction industry. Therefore, the research and application of internal curing concrete is worth further exploration and promotion in the field of construction engineering.

MECHANISMS

Philleo pioneering proposal in 1991 utilized lightweight aggregate to supply additional moisture during the curing process (R. Philleo, 1991). Subsequently, the American Concrete Institute (ACI,2001) (Institute AC. Standard Practice for Curing Concrete, 2001) officially defined internal curing in 2001, followed by the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM,2012) providing a more comprehensive explanation of the concept (V. Mechtcherine and H. Reinhardt, 2012). The fundamental concept behind self-curing concrete or mortar is to mitigate water evaporation within the concrete and enhance its water retention capacity. To achieve this, water-filled internal curing agents, acting as reservoirs, are introduced into the concrete mixture (Hamzah et al, 2022). The American Concrete Institute, ACI-308 (2013) code states that self-curing is a process where hydration of cement occurs due to avail-ability of the additional internal water which is usually not part of mixing water.

The difference between internal curing and external curing was illustrated in Figure 1 (Bentz ,et al, 2010). The self-curing concrete mechanism was explained. Initially, the conditions between the internal curing agent and the fresh cement paste were uniform, with no movement of absorbed water. As the humidity conditions changed, particularly in a dry environment, the absorbed water in the internal curing agent began to migrate into the hardened cement paste. This migration facilitated the ongoing hydration process around the aggregate's surface. Eventually, the water migration ceased, and the hydration process stopped. The water in the internal curing agent provided a continuous supply for cement hydration (Sampebulu, 2012). Water is transported from the curing agent to the un-hydrated cement through capillary suction, vapor diffusion, and capillary condensation, facilitating continuous hydration. As a result, chemical shrinkage and self-desiccation, caused by low water-to-binder ratio, can be significantly reduced (Namsone et al, 2016).

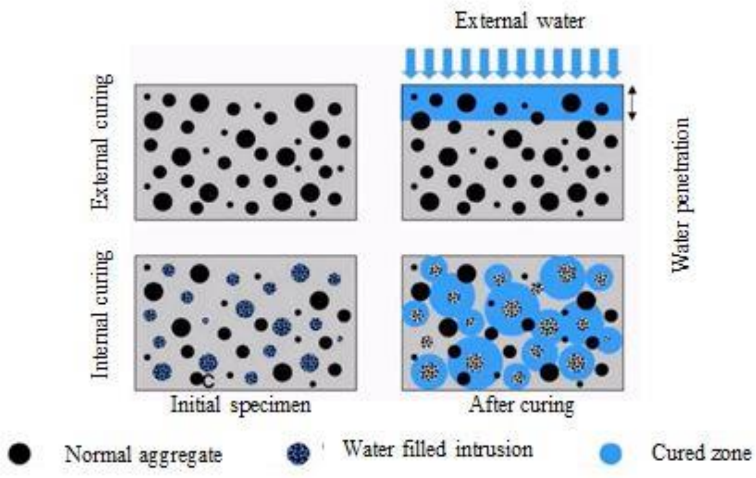

Figure 1 The difference between internal curing and external curing

There are currently two prevailing categories of internal curing materials for concrete: inorganic porous materials and chemical polymers (Ma Xianwei et al, 2015). Porous ceramics and Superabsorbent Polymers (SAP) stand as exemplary representatives of inorganic porous and synthetic polymer internal curing materials, respectively. The excellent water retention property of SAP has spurred numerous studies exploring its application for internal curing of concrete to mitigate early shrinkage (V. Mechtcherine, 2014). SAP with larger particle sizes exhibited a more pronounced effect in mitigating the autogenous shrinkage of early-age concrete (P. Lura et al, 2006), whereas SAP particles of approximately 100 μm in size demonstrated the highest water absorption efficiency (O.M. Jensen, 2001; O.M. Jensen, 2002). In summary, the main mechanism of internal curing agents is to promote the cement hydration reaction in concrete by continuously releasing water, thereby improving the performance and durability of concrete. The application of internal curing agents can effectively solve the problems caused by self-drying and self-shrinkage of concrete, improve the mechanical and overall performance of concrete, and contribute to the sustainable development of construction projects.

BENEFITS AND APPLICATIONS

Internal curing technology, as an innovative concrete curing method, has made significant progress in the field of construction materials. Its unique advantages and wide-ranging applications have made it a highly regarded research direction in the construction industry. Internal curing offers several benefits, including improved hydration, reduced chloride ingress, and minimized early-age cracking, thereby enabling concrete to achieve its maximum potential as a sustainable building material and extending its service life. The utilization of self-curing concrete with the incorporation of Superabsorbent polymers (SAP) as an admixture in different grades of concrete has demonstrated significant positive effects on concrete structures. The key advantages of internal curing are the production of more durable and less permeable concrete. Providing a congenial atmosphere aids in the hydration of cement, making concrete curing essential until a major portion of the hydration process is completed. The proposed research work on self-curing concrete offers several advantages compared to normal concrete, such as enhanced early-stage strength, reduced shrinkage cracks, and a flowable mix without bleeding and segregation. Additionally, incorporating self-curing agents reduces the water content in the concrete, contributing to a healthier and more sustainable environment (Saravanakumar,R. 2023). The addition of SAP reduces early-stage autogenous shrinkage of concrete, mitigating shrinkage stress during the initial curing period and effectively contributing to the reduction of early-age cracks in concrete (O.M. Jensen and P.F. Hansen, 2002; Saravanakumar et al, 2023; O.M. Jensen et al, 2001; V. Mechtcherine et al, 2008; Kong Xiangmin et al, 2014; X.M. Kong et al, 2015; D. Shen et al, 2016). Internal curing technology holds significant promise in the field of concrete curing, offering advantages in mitigating early-age shrinkage, enhancing concrete strength, improving durability, and conserving water resources. Future research and engineering practices will further drive the development and implementation of internal curing technology.

SHRINKAGE BEHAVIOR AND CRACK RESISTANCE

Cracks in structures can result from various factors, including shrinkage, freeze/thaw cycles, and structural stresses, among others. While several solutions exist, the use of superabsorbent polymers (SAPs) appears to be a promising approach to counteract these problems. The significant concern of cracking in building applications was addressed. During the early stages, SAPs can absorb water, which can effectively mitigate autogenous and plastic shrinkage. Moreover, the formation of macro pores can enhance the freeze/thaw resistance of the concrete. Additionally, when water enters, the swelling of SAPs can seal cracks and prevent the intrusion of fluids, thereby improving overall water-tightness. Furthermore, the absorbed water may facilitate autogenous healing. These various mechanisms make the utilization of superabsorbent polymers highly appealing in addressing the cracking issues in concrete structures (Mignon,A et al, 2017).

High-performance concrete (HPC) is widely used in practical applications. However, due to its low water-to-cement (w/c) ratio, HPC is susceptible to self-desiccation, leading to significant autogenous shrinkage (AS). This high AS increases the risk of early-age cracking, especially when the concrete is restrained from freely shrinking. To address this issue, internal curing (IC) has been extensively employed to reduce AS and mitigate the risk of early-age cracking in HPC. Super absorbent polymers (SAPs) are capable of providing additional internal curing water for concrete hydration, effectively counteracting the effects of self-desiccation. The influence of internal curing (IC) on early-age expansion, autogenous shrinkage (AS) development, AS rate, and IC efficiency of concrete with superabsorbent polymer (SAP) was studied experimentally. Early-age expansion in the internal curing concrete was evident even before the first day, and the maximum expansion increased with higher IC water content. The ultimate AS at 28 days and AS rate in internal curing concrete decreased as the amount of IC water increased. The internal curing (IC) efficiency of SAPs decreased with the increase in IC water content in concrete (Shen,D, 2016).

Past investigations into the restrained shrinkage traits of internal curing concrete centered on SAP incorporation strategies, taking into account the temporal dynamics of water uptake during the mixing phase. Researchers aimed to probe the differential impacts of various SAP integration methods on the ring shrinkage strain of internal curing concrete. It was found that SAP inclusion markedly enhanced concrete's shrinkage performance, notably curtailing shrinkage strain. Notably, concrete amalgamated with pre-absorbed SAP displayed the most pronounced shrinkage strain diminution, with no evidence of cracking surfacing until the conclusion of the testing period. In contrast, the shrinkage-mitigation efficacy of dry SAP was constrained, with cracking persisting in the concrete. Concrete specimens devoid of SAP bore a heightened risk of early-age cracking, fracturing well before reaching the 28-day milestone. To promote sustained hydration, SAPs retained water in the initial stages and progressively discharged it, thereby augmenting concrete's crack resistance and structural integrity. Pre-absorbed SAPs surpassed dry SAPs in terms of shrinkage reduction potency. The pre-water absorption ratio, indicative of SAP's peak water retention capacity, underscored the advisability of the pre-water absorption technique (Huang,X, 2022), highlighting its efficacy in optimizing concrete's performance.

The use of superabsorbent polymers (SAP) for internal curing of ultra-high performance concrete (UHPC) can help reduce autogenous shrinkage and self-desiccation, which can cause early-age cracking. Testing on the autogenous shrinkage can be successfully decreased while preserving the extremely high strength of UHPC was the primary objective of this work. The pore fluid absorption of SAP was investigated using a novel method based on image analysis on polished cross sections of cement pastes, revealing an approximate value of 16 gpore fluid/g SAP.When a small amount of SAP (＜63 μm in the dry state) was added to a UHPC mixture with a basic w/c of 0.15, autogenous shrinkage could be reduced from over 600 μm/m to approximately 120 μm/m after 30 days. This is most likely because the extra space provided by the SAP allows hydration to continue rather than stopping because there isn't enough free capillary pore space for the precipitation of hydration products (Justs,J, 2015).

The lifecycle crack resistance of internal curing concrete, enriched with superabsorbent polymers (SAPs), underwent scrutiny. Methodically, plate induction tests gauged the plastic stage, ring restraint tests evaluated the curing phase, and three-point fracture tests appraised service life performance—all pinpointing temporal shifts in crack behavior. Plate induction outcomes during the plastic phase revealed that SAP inclusion deferred the emergence of initial cracks and maintained widths between 0.1 and 0.3 mm, with crack propagation largely mitigated within a day. Optimal crack suppression was observed with 40–80 mesh and 100–120 mesh SAP particles, as cracking areas shrank in tandem with augmented water content. Ring restraint trials corroborated extended crack latency periods and diminished steel ring strain. Thermogravimetric analysis (TGA) disclosed that SAPs extended the water release timeline, orchestrating hydration for sustained and homogeneous cementitious material hydration. This investigation underscored the enhancement of concrete's crack resistance through SAP augmentation (Lyu,Z, 2020), encapsulating a comprehensive approach to concrete durability optimization.

The use of low water cement ratio (w/c) in high-strength concrete (HSC) can lead to an increase in autogenous shrinkage caused by self-desiccation, thereby reducing the crack resistance of the concrete. To address this issue, researchers employed internal curing (IC) of superabsorbent polymers (SAP) to reduce autogenous shrinkage and improve the crack resistance of HSCs. The early behavior and tensile creep of ICHSC with different SAPs contents (0%, 0.57%, 0.86%, and 1.14% of cement weight) were studied using a temperature stress testing machine at a constant initial s/s ratio. The mechanical properties of ICHSCs with the same basic w/c ratio decrease with increasing SAPs content. As the content of SAPs increases, the autogenous shrinkage rate of ICHSC decreases. With the increase of SAPs content, the basic tensile creep, basic tensile creep coefficient, and bi tensile creep of ICHSC show a nonlinear increase, which is attributed to the increase of total w/c ratio (Shen,D, 2019).

In recent decades, internal curing has developed into a method of reducing shrinkage in low water cement ratio (w/c) concrete by introducing additional water into the concrete. The restrained ring test was conducted to investigate the crack resistance of concrete containing different amounts of SAP (0%, 0.05%, 0.16%, and 0.26% by weight of cement). The strain in the constrained steel ring decreases with the increase of SAP amount. The residual stress of the concrete ring decreased with the increase of SAPs dosage. The stress rate decreased with the increase of SAPs dosage. After the start of drying, the relaxation stress increased with the increase of SAP content. The cracking time of concrete increased with the increase of SAPs dosage. These findings highlighted the positive impact of SAP in improving the crack resistance of internal curing concrete and provided valuable insights for further understanding the stress relaxation behavior of SAP mixed concrete (Shen,D, 2016).

The effects of SAPs as IC agents on the temperature, autogenous shrinkage, restrained stress, basic tensile creep, and cracking potential of high performance concrete (HPC) were simultaneously studied using the Temperature Stress Test Machine. The adiabatic temperature rise of HPC increased with the amount of SAP, reaching 27.6 °C, 29.3 °C, 31.0 °C, and 34.9 °C, respectively. The restrained tensile stress rates of high-performance concrete decreased with the increase of SAPs content, which are 1.7, 1.5, 1.4, and 1.2 MPa/day, respectively. The specific basic tensile creep of HPC decreased with the increase of SAPs content when the mixed SAP-0 constrained specimen cracks, which are 45, 23, 13, and 7 μ ε/MPa, respectively. According to the comprehensive standard, the cracking potential of HPC decreased with the increase of SAPs content. These findings revealed the beneficial role of SAP as an IC reagent for HPC, helping to better understand its potential in mitigating cracking and improving the overall performance of HPC structures (Shen,D, 2018).

To explore the impact of superabsorbent polymer (SAP) dosage on the mechanical attributes and tensile creep characteristics of Internal Curing High-Strength Concrete (ICHSC), an experimental study was conducted. Employing a Temperature Stress Test Machine, we scrutinized the performance of ICHSC specimens prepared with SAP contents ranging from 0% to 1.14% by weight of cement, while maintaining a consistent solid-to-solid (s/s) ratio at the outset. The investigation revealed that, under identical baseline water-to-cement (w/c) ratios, the mechanical robustness of ICHSC diminished in response to escalating SAP concentrations. Conversely, there was a noted reduction in autogenous shrinkage with higher SAP content. Intriguingly, both the fundamental tensile creep and its coefficient, alongside the specific tensile creep of ICHSC, displayed a non-linear escalation as the SAP proportion grew. This phenomenon could be ascribed to the augmented effective w/c ratio resulting from the SAPs' water-retaining capability. These outcomes offer significant perspectives on how SAP incorporation affects the mechanical integrity and self-shrinkage dynamics of ICHSC. They contribute to a deeper comprehension of SAPs' potential role in enhancing crack prevention and the comprehensive quality of high-strength concrete formulations (Shen,D, 2020).

The microarchitectural properties of an innovative hybrid concrete were scrutinized, with a focus on the effects of polymer particle dimensions and volume fraction on its mechanical resilience and durability. Complementary insights were gleaned through advanced scanning electron microscopy (SEM) analysis. Findings indicated a negative correlation between the superabsorbent polymer (SAP) content and the extent of concrete shrinkage. Notably, the concrete's volumetric stability showcased a biphasic response to SAP particle size, initially improving before declining. The strategic addition of SAP notably curtailed drying shrinkage by 16.09% and autogenous shrinkage by 30.62%, bolstering the material's overall volumetric consistency (Zheng,X, 2021). Concrete's hydration progression under distinct SAP integration techniques was probed via scanning electron microscopy, elucidating the internal hydration dynamics pertinent to SAP-enhanced internal curing strategies. Our findings underscore that SAP adeptly sequesters moisture in the early hydration phase, subsequently liberating it over time, thus sustaining the hydration process. This continuous hydration fosters a denser microstructure, significantly augmenting the concrete's resilience to cracking. Remarkably, pre-saturated SAP outperforms its dry counterpart in mitigating shrinkage, advocating for a pre-absorption methodology where the saturation ratio aligns with SAP's peak water retention capacity. This revelation underscores the pivotal role of pre-hydration in fine-tuning the performance of SAP-integrated internal curing concrete. SAP-modified cementitious composites have emerged as a focal point in global research due to their exceptional resistance to cracking, robust durability, broad accessibility, and economic viability (Huang,X, 2022), highlighting the transformative potential of SAPs in concrete engineering.

An exhaustive analysis of superabsorbent polymer (SAP)-enhanced cementitious composites was undertaken, zeroing in on fabrication techniques, microstructural evolution (including hydration kinetics and porosity), and the SAP's influence on rheological, mechanical, shrinkage, self-repair, and endurance attributes of these materials. Incorporating SAPs injects supplemental moisture, boosting the blend's fluidity, with a negligible sway on the mechanical robustness relative to SAP-free counterparts. Strikingly, SAPs markedly curb autogenous shrinkage, fortifying crack resistance and elevating longevity, manifested through heightened impermeability, bolstered carbonation defense, and superior frost resilience. It bears emphasis that SAP's precise impact hinges on a constellation of variables encompassing particle dimensions, dosage, and the mode of admixture (He,Z, 2019), underscoring the complexity of optimizing SAP-modified cement-based systems.

CONCLUSIONS AND RECOMMENDATIONS

The use of internal curing (IC) technology addresses water scarcity issues in concrete curing, promoting sustainable construction practices. Internal curing (IC) using SAPs significantly enhances concrete performance by providing sustained hydration, reducing autogenous shrinkage, and improving crack resistance. SAPs effectively mitigate early-age shrinkage and cracking in high-performance and ultra-high performance concrete. Pre-absorbent SAPs are more efficient in reducing shrinkage and enhancing crack resistance compared to dry SAPs. Further research is needed to optimize the use of SAPs in various concrete mixtures, particularly in terms of particle size and pre-water absorption ratios. Standardized guidelines should be developed for the application of IC technology using SAPs in different concrete grades and construction environments.

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