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Parametric Study of Internal Curing of Concrete Using Brick Chips: A Review

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Abstract: ***As urban landscapes evolve with taller skyscrapers, the design and safety of high-rise buildings under wind forces have become critical considerations. This study explores the impact of aspect ratios—height-to-width proportions—on the wind behavior of buildings. Tall, Shorter, wider structures are less vulnerable to wind-induced vibrations than slim buildings having high aspect ratios with low aspect ratios face challenges in stability and strength. The research examines how building shape and aspect ratios influence structural behavior under wind loads. Key parameters, including maximum displacements, story drift, shear forces, and bending moments, are analyzed to assess wind effects. The study also compares buildings of varying aspect ratios but equal floor areas to determine optimal designs. By identifying the most suitable aspect ratios for high-rise structures, this research aims to enhance safety, functionality, and aesthetic appeal while addressing the challenges posed by wind forces in urban environments.***

Keywords: High-Performance Concrete (HPC), Internal Curing, Microstructure of Hydrated Cement Paste, Structural behavior, Interface etc.

I. INTRODUCTION

Internally hardened concrete (ICC) has emerged as a promising material in modern construction, offering distinct advantages such as high strength, enhanced durability, and good workability. ICC is characterized by its ability to sustain internal curing, which mitigates issues related to shrinkage and cracking often observed during the cement hydration process. The ability to internally regulate moisture content and humidity during curing makes ICC particularly attractive for large-scale infrastructure projects, where maintaining long-term structural integrity is paramount [1].

Traditional external curing techniques have been widely used to address concrete shrinkage and ensure sufficient hydration. However, these methods are often limited to the surface layers, leaving the interior of the concrete vulnerable to self-drying and shrinkage. Self-drying occurs due to the evaporation of water in the internal pores, leading to a drop in internal humidity. This creates tensile stresses within the concrete matrix, which, if exceeding the local tensile strength, can result in microcracks. Such imperfections can compromise the structural performance and durability of the concrete [2][3].

ICC seeks to overcome these challenges by incorporating internal curing agents that release moisture gradually, ensuring continuous hydration within the matrix. Water-retaining materials, such as lightweight aggregates and superabsorbent polymers, are commonly employed as internal curing agents. These materials regulate moisture variations during the hydration process, reducing capillary pressure and facilitating uniform hydration throughout the concrete. The resulting material demonstrates lower shrinkage, enhanced tensile strength, and improved microstructural density.

The role of internal hardness in influencing the long-term performance of ICC is a key area of interest. While compressive strength has traditionally been a primary measure of concrete performance, studies indicate that internal hardness plays a more significant role in determining tensile and flexural strength at advanced stages of concrete aging. Furthermore, the densification of the interfacial transition zone, achieved through internal solidification, enhances the overall structural integrity of ICC.

This study delves into the behavior of ICC, focusing on its microstructure, density, shrinkage characteristics (self-shrinking and drying), and mechanical characteristics like bending, tensile, and compressive strength. The study also assesses ICC's drawbacks, including the difficulties caused by moisture fluctuations and how well internal curing works to address these problems. This work attempts to give an extensive knowledge about the internal post-remediation techniques that improve the efficiency for high-performing concrete (HPC) by examining previous studies. The findings are critical for optimizing ICC applications in contemporary construction and addressing the persistent challenges associated with its implementation.

II. PROBLEM STATEMENTS

1) *Shrinkage-Induced Stress:*
- Early volume variations in internally hardened concrete (ICC) result from the cement hydration process and self-drying, leading to internal stresses.
- Shrinkage-induced stress can surpass the local tensile strength, causing microcracks and compromising structural integrity.

2) *Limited Effectiveness of External Curing:*
- External curing methods primarily address surface moisture but fail to penetrate deeper layers, leaving the interior prone to self-drying and shrinkage.

3) *Internal Humidity Reduction:*
- Evaporation of water within internal pores lowers relative humidity, resulting in capillary pressure and winding tensions that weaken the concrete matrix.

4) *Challenges in Internal Hardness Development:*
- Achieving uniform internal hardness is critical for improving tensile and flexural strength, but it remains inadequately addressed.

5) *Microstructural Vulnerability:*
- Variations in moisture content during hydration adversely affect the densification of the interfacial transition zone, reducing overall durability and performance.

III. LITERATURE REVIEW

A. Literature Survey

The use of internally hardened concrete (ICC) has been extensively studied to address challenges related to shrinkage and cracking during hydration. The drawbacks of external curing techniques, which prioritize surface layers over the core matrix, have been brought to light by researchers. Research highlights the function of internal cure agents, including superabsorbent polymers and lightweight aggregates, in mitigating shrinkage and maintaining relative humidity during hydration.

One important aspect affecting the long-term viability of ICC, namely in terms of improving tensile and flexural strength, has been shown to be the densification that occurs in the interfacial transition zone. The longevity of aged concrete is more significantly influenced by internal hardness than by compressive strength, according to studies on microstructural behavior. Additionally, the impact of moisture variations on shrinkage-induced stresses and the subsequent formation of microcracks has been a focus of prior research. These findings underscore the need for optimized internal curing techniques to ensure the longevity of ICC.

Duy Dung Khuat, Shota Yamanaka, May Huu Nguyen, Kenichiro Nakarai (2024) [1], This study sought to examine the combined effects of chloride-based accelerator (CA) and internal curing (IC) utilizing roof-tile waste material on the performance of marine salconcrete. When compared to regular concrete, the IC impact raised the compressive force by 40% and both of them increased it by 60%.

Ghasan Fahim Huseien a,b,*, Ruhal Pervez Memon c, Mohammad Hajmo-hammadian Baghban d,*, Iman Faridmehr e, Leong Sing (2024) Wong [2], That 5, 10, 15, 20, or 25% with water replacement are examined in this study. In water and air curing, concrete compositions with 10% water substituted with EM have a greater internal relative humidity than concrete without EM. In air and water curing, the concrete compositions with 10% water substituted with EM had a lower interior temperature than the concrete without EM.

Vu-An Trana, Hoang-Anh Nguyenb,⁎, Bui Le Anh Tuana (2023) [3], This study aims to improve the performance for common super-sulfated cement (SSC) cement made with a ternary mix consisting of 85% ash, 10% Gypsum, and a mere 5% blended Portland cement. (PCB) by using cold-bonded flying ash based artificial light-weight aggregate (ALWA) and obtained unground rice husk ashes (URHA) as the internal curing (IC) agents. Fine aggregate (FA) was partially replaced with ALWA at four different percentages: 25, 50, 75, and 100. Following optimization, URHA was used to partially replace the ALWA quantity at four different levels: 25, 50, 75, and 100 vol.%. According to experimental data, ALWA significantly improved workability and had uncompromiseable effects on the strengths as well as durability of SSC mortars when it replaced FA up to 50% by volume.

Ali Reza Panahi 1, Jamal Ahmadi 1*, Behzad Saeedi Razavi 2 (2023) [4], The purpose of this study was to examine how internal curing affected the mechanical characteristics and autogenous shrinkage of high-performance concrete. This was accomplished by examining the curing capacity of concrete specimens that contained recycled crushed bricks (RCB), superabsorbent polymers (SAP), or pre-saturated synthetic aggregate (LECA) as internal curing agents.

The concrete's tensile strength was raised by 3 to 35% by the specimens that contained crushed bricks and SAP.

The specimens with SAP equivalent to 0.34% in cement weight have the highest rise. When all of the internally curing agents were used, the concrete's 28-day bending strengths increased in comparison to the counter-part study specimen.

Kumar, K. Sundeep and PV Subba Reddy (2022) [5], the process potential, me-chanical features, and durability of S.C.C. assessment were the focus of this study. Ferrosilicon slag was utilized as a coarse aggregate, while paraffin wax was employed as a self-hardening agent. Compared to deeply hardened concrete (i), the paraffin content of M25-grade concrete in this investigation varied from 0% to 1.0%. The ideal amount of F.S.S. could be used to achieve a wide range of doses. It was changed, and the concrete was then given a liquid addition of paraf-fin. The optimal HSE ratio, according to the literature, was 40% light paraffin wax and heavy paraffin wax together, which boosts concrete's compressive and flex-ural strength by 1.0%. The rapid chloride test for penetration (RCPT) and the ultrasonic pulse velocity examination (U.P.V.) were used to increase the durability of concrete.

Faxiang Xie, et al. (2021) [6], The findings showed that the residual power, compression strength, overall shear strength for SAPC increased linearly with axial strain, but the compressible strength, shear force, the friction coefficient associated with stress aggregation decreased as deformation increased. By analyzing the SAPC's compressive and shear strengths, the failure conditions are determined utilizing the theories of dual shear capacity with octahedral stress space. By contrasting them with other particular experimental results that have been reported in the literature, the proposed failure criteria are confirmed. The validation findings validate the validity and usefulness of the recommended failure criteria for SAP applications.

Paul Alvaro, et al. (2021) [7], finding moisture carrying mechanisms in LWA that regulate IC performance was the aim of this investigation. Different air sorption methods exist, as indicated by the results of pre-soaking LWA with various inter-nal structures (natural, artificial), size distributions (fine, coarse), and environ-ments in both pure water and water containing shrinkage reduction agents (SRAS). According to Author, one fled from the chamber's activity, while the other was directed by the air diffusing via the air pores. Making LWA total influ-ence on IC performance related to SRA efficacy the most suitable portion for better LWA ci properties used 3D micro-CT pore action imaging and pore distri-bution. Manufactured with IC applications in consideration.

Alaskar Abdulaziz and Mohammad Alshannag (2021) [8], The impact of natural lightweight aggregates (LWA) internal processing An experimental study was conducted to examine the mechanical characteristics, shrinkage, and durability of high-performance concrete (HPC). At dosages of 5, 10, and 20 volumes, pre-wetted coarse and fine LWA were used in place of some standard aggregates. The HPC mixture's initial autogenous shrinkage and drying shrinkage were observed for a maximum of 180 days. Compressive strength, elastic modulus, tensile strength at 28 days, fast salt penetration, and water absorption were among the characteristics of the HPC mixes that have been investigated. According to the results, the HPC mixture's autogenous shrinkage decreased by roughly 118% after a 28- day period and 65% after 18 days. The rate at which coarse and fine aggregates were replaced was 20%. Seven days after watering, test findings addi-tionally indicated a 75% decrease in autogenic responses between 3 p.m. Shrink-age

Mhaad Balapour a, Weijin Zhao a, E.J. Garboczi b, NayYe Oo a, Sabrina Spatari a, Y.Grace Hsuan a, Pieter Billen c, Yaghoob Farnam a (2020) [9] The potential application of spherical porous responsive aggregate (SPoRA), a novel light-weight aggregate (LWA) made from leftover coal bottom ash, for the internal curing of cement is assessed in this study. The specific gravity, porosity, sphericity, absorption of water, and water desorption of SPoRA—engineering parameters necessary for internal curing of concrete—were evaluated. With a low oven wet specific gravity (between 0.83 and 1.43) and high porosity, SPoRA can hold the volume of water required for internal curing of concrete. Using computed tomography of X-rays (XCT),

Jones Casey, Daniel Goad, and W. Micah Hale (2020) [10], The authors investigated the effects of varying LWA replacement amounts and immersion durations on the mechanical characteristics and capacity to reduce shrinkage of conventional concrete. LWA was added, which resulted in weight reductions of 6.0% for shale content and 6.7% for clay content. Each LWA's elastic modulus dropped by more than 11%, and its compressive strength dropped by over 16%. When LWA shale was utilized, the strength of the clay material increased (4.3%) and slightly decreased (8.5%), according to the modulus of rupture data. At a replacement rate of 178 kg/m3, LWA clay shrank by 7.7% and shale shrank by 8.3%, respectively, in comparison with the controlled concrete mixed.

Balapour Mohammad, et al. (2020) [11], the use of unique spherical reactive aggregates (SPORA), which may be made from clinker waste and have ad-vantages over LWA, can be advantageous for internal concrete treatment. Con-crete internal measures were obtained by evaluating and averaging the following SPORA properties: density, porosity, rigidity, irrigation conductivity, and desorp-tion. Due to its high porosity and low kiln dry density of 0.83 to 1.43, SPORA is able to hold onto the water content that regulates the concrete's hardening. The high porosity (volume 39.6–57.8) of SPORA was determined using X-ray com-puted tomography (XCT), and its accuracy in terms of its impact on contractile function was assessed

A.T.M. Masum, Tanvir Manzur ⇑ (2019) [12], Therefore, it is anticipated that internally cured concrete with the right amount of BC will produce stronger and denser concrete, delaying the onset of corrosion in RC structures. This study examined the extension of the service life of internally formed concrete containing BC under various adverse curing circumstances by delaying the beginning of corrosion. It was discovered that, depending on the harshness of the curing conditions and the concrete cover, the corrosion start time of internally cured cement could be extended by several years in comparison to conventional concrete. The study demonstrates the enormous potential of their internal curing with BC to prolong the service life of slab under unfavorable curing circumstances and prevent premature concrete repair.

Ma Xianwei, Jianhui Liu, and Caijun Shi (2019) [13], in this paper, LWA was studied as a high-performance cementitious material's internal curing agent. The dosage, pretreatment technique, concrete particle size, and distribution all affect how LWA affects IC. Dried LWA had a worse impact than pre-moistened LWA. To obtain a satisfactory IC efficiency, concrete's LWA particle size and LWA dispersion were two key elements. B. concrete's strength and natural shrinkage, for instance. Additional research was required. The impact of LWA on strength is determined by two contradicting facts: the positive effect of internal stiffening on hydration and the repercussions of LWA's porous nature.

Dinghua Zou, Kun Li, Weidong Li, Haiyan Li, Tianlu Cao (2018) [14], The findings of an experimental study on the desorption behaviour and internal cure effectiveness of porous aggregate with varying pore structures and water absorption but the same size fraction (between 2.36 and 4.75 mm) are presented in this paper. In the desorption test, the water flow rate and the equilibrium amount of water left in the aggregates at various relative humidity levels were determined. Measurements were made of the plain and internally cured mortar's compressive and flexural strengths, internal relative humidity, and autogenous deformation.

Shohana Iffat, Tanvir Manzur, Sayedur Rahman, Munaz Ahmed Noor, Nur Yazdani (2017) [15], Six simulated unfavorable curing conditions were applied to internally cured samples that had three different percentage replacements of stone chips by brick chips (15, 20%, and 25%). Masonry chip aggregate was shown to create better-performing internally cured concrete in terms of durability and strength when 20% of the stone chips were replaced.

Dejian Shen, Xudong Wang, Dabao Cheng, Jinyang Zhang, Guoqing Jiang (2016) [16], As the quantity of IC water increased, the internal cured concrete's final AS at fourteen days or AS rate dropped. As the amount of IC fluid in cement increased, SAP's IC efficiency dropped. There was an early-age expanding stage in the development for the AS of mixes containing SAP. The quantity of IC water has an impact on the concrete's expansion.

Shohana Iffat*, Tanvir Manzur**, and Munaz Ahmed Noor*** (2016) [17], An efficient way to create internally cured concrete is to use locally accessible burnt clay chip aggregate, also referred to as Brick Chips (BC). To replicate indoor and outdoor climatic conditions, three widely used water cement ratios—0.4, 0.45, and 0.5—as well as five curing settings were chosen. Three distinct percentage replacements of fragments of stone by BC were chosen: 10%, 20%, and 30%. For comparison, control samples containing chunks of stone were also created. The Rapid Chloride Permeability Test (RCPT) and the Water Permeability Test were conducted. The durability of externally cured concrete covered with polythene sheets is found to be on par with that of control concrete that has not been normally cured. Furthermore, internally cured concrete outperformed control samples under unfavorable curing conditions without an external water supply. As a result, BC can be utilized to create long-lasting concrete in Bangladesh at a reasonable cost.

Dejian Shen a,b,⇑ , Xudong Wang a , Dabao Cheng a , Jinyang Zhang a , Guo-qing Jiang c (2016) [18] In actuality, high-performance concrete, or HPC, is widely utilized. Nevertheless, the low water-to-cement (w/c) percentage in this kind of concrete results in self-desiccation and a relatively significant autogenous shrinkage (AS). When the concrete is prevented from undergoing unrestricted shrinkage at a young age, AS then raises the chance of cracking. Internal curing (IC) is widely employed to lower AS and, as a result, lower the high risk of HPC breaking at an early age. By providing extra IC water for concrete hydration, super absorbent polymeric materials (SAPs) can reduce the impacts of self-desiccation.

Shirish V. Deo1, Arun D. Pofale2 (2015) [19] Correlations are created based on experimental data to forecast cost per N/mm2, compressive strength, and flexural strength for the fraction of sand replaced with fly ash. Table 5 shows the strength under compression on 150 mm cubes after 7 and 28 days. The results show that the concrete's compressive strength is consistently higher than that of the control concrete when fly ash is substituted for sand at 12% and 27%. Results also show that super plasticizer improves concrete strength. 100 mm cubes' compressive strength at 3. Even on the third day, the results show increased strength due to the partial substitution of fly ash for sand. This improvement could be explained by improved concrete component packing because fly ash has a lubricating effect and finer particles reduce voids.

Kong Lijuan1,2, DU Yuanbo1 (2015) [20], hydrates are produced, which leads to a denser ITZ architecture with fewer macropores. Because of its rough texture and increased water absorption, limestone has the tightest connection with cement paste despite having the least activity. The longevity of the concrete is severely harmed by the numerous pores and cracks that are apparent in granite with a smooth surface and decreased water absorption because of its loose bond with cement paste.

Magda I. Mousa a, *, Mohamed G. Mahdy a , Ahmed H. Abdel-Reheem a , Akram Z. Yehia (2014) [21], The purpose of this study is to compare the effects of two distinct curing agents in order to maximize the performance of concrete. First, soaked lightweight gravel (leca) in various ratios (0.0, 10%, 15%, and 20% of sand volume) is employed. Second, a chemical agent percent polyethylene-glycol (Ch.) in various percentages (1%, 2%, and 3% of cement weight) is utilized. Three cement contents (300, 400, and 500 kg/m3), three distinct water-to-cement ratios (0.5, 0.4, and 0.3), and two amounts of silica fume to serve as poz-zolanic addition (0.0 and 15% percent cement weight) were used in the test program carried out in this work. Concrete's physical characteristics were assessed at various ages, for a maximum of 28 days. The ideal values were 15% leca and 2% Ch. in every instance. Concrete's self-curing agents work better when there is a higher proportion of cement and/or a lower water-to-cement ratio. All physical qualities of concrete mixtures are improved when silica fume is added.

Stella Evangeline (2014) [22], Concrete must cure in order to reach its maximum strength and durability. However, when the temperature, humidity, and moisture content of the surrounding air are enough for curing, no action is necessary. For concrete to properly hydrate and achieve the required strength, moisture must be applied for at least 28 days. Concrete's strength and durability will suffer from any sloppy curing. To hydrate all of the cement particles and fill the gel pores, a water/cement ratio of roughly 0.38 would be needed.

Pietro Lura a b, Mateusz Wyrzykowski a c, Clarence Tang d, Eberhard Lehmann e (2014) [23], Concrete shrinkage can cause cracking, which can ultimately shorten the lifespan of concrete structures. Internal curing using porous aggregates is one of the well-known techniques for shrinkage mitigation that has been effectively applied in the past few decades to reduce drying and autogenous shrinkage. The internal curing capabilities of pre-saturated lightweight crushed stone formed from biomass-derived wastes (bio-LWA) were examined in this work.

Jason Weiss b (2014) [24], The research findings that examined the tender age cracking actions of plain and internally cured mortars under restraint are presented in this publication. The development of residual stress, cracking stress, and age of plain and internally cured mortars held back by two rings of varying thickness were all thoroughly examined. Based on the fracture test findings, tensile stress barrier was computed. Also examined was autogenous volume deformation.

Igor De la Varga a,⇑ , Javier Castro b , Dale Bentz c , Jason Weiss a (2012) [25], Class C fly ash is used in this operation to replace a comparatively high percentage of cement (40, 60, or 80% by volume). The water-to-cementitious material ratio (w/cm) by weight has been lowered from a traditional value of 0.42 to 0.30 in order to address issues related to delayed set and early-age development of strength that are frequently raised with large-volume fly ash mixtures (HVFA). In order to mitigate the potential self-desiccation issues caused by low w/cm, internal curing (IC) using prewetted soft aggregate was employed to decrease shrinkage and boost hydration.

B. Gap Identified

Despite extensive research on internally hardened concrete (ICC), significant gaps remain. Although it is known that internal curing chemicals help prevent shrinkage and preserve relative humidity, the long-term effects of varying curing techniques on microstructural behavior and durability are not fully understood. Limited studies address the optimization of internal hardness and its influence on tensile and flexural strength. Additionally, the interaction between moisture variations and the densification of the interfacial transition zone requires further investigation. A comprehensive analysis of alternative materials and waste incorporation for internal curing in ICC is also lacking, presenting opportunities for innovative approaches.

C. Summary of Literature

The literature on internally hardened concrete (ICC) highlights its potential to address shrinkage and cracking during hydration, issues often unresolved by external curing methods. Studies focus on the effectiveness of internal curing agents in preserving relative humidity and lowering capillary pressure, such as superabsorbent polymers and lightweight aggregates. The densification of the interfacial transition zone is identified as critical for enhancing tensile and flexural strength, particularly in aged concrete. However, research also points to challenges in optimizing internal hardness and mitigating shrinkage-induced stresses.

While the importance of microstructural behavior in improving durability is emphasized, gaps remain in exploring long-term effects, alternative materials, and innovative approaches to internal curing techniques in ICC.

IV. COMPARATIVE ANALYSIS

A. Comparison of key studies and findings:

A comparison of key studies highlights significant advancements in internal curing (IC) and material replacement strategies to enhance concrete performance. Khuat et al. (2024) demonstrated a 60% increase in compressive strength with IC with a chloride-based accelerator and roof-tile waste. Similarly, Tran et al. (2023) improved workability and durability by replacing fine aggregates with artificial lightweight aggregates and rice husk ash. Panahi et al. (2023) observed up to a 35% tensile strength increase using superabsorbent polymers and recycled bricks.

Huseien et al. (2024) found enhanced internal humidity and reduced temperatures with 10% water replacement using emulsified modifiers, while Kumar et al. (2022) improved strength and durability by incorporating ferrosilicon slag and paraffin wax. Advanced lightweight aggregates like SPoRA (Balapour et al., 2020) and pre-moistened LWA (Ma et al., 2019) proved effective for IC, offering enhanced hydration and reduced shrinkage. Studies on natural lightweight aggregates (Alaskar & Alshannag, 2021) also highlighted significant shrinkage reduction and durability improvements.

These findings underline the effectiveness of IC agents and alternative materials in enhancing concrete properties, offering diverse strategies for improved performance, durability, and sustainability under various environmental and operational conditions.

B. Evaluation of methodologies used in the reviewed studies

The methodologies employed in the reviewed studies showcase diverse approaches to enhancing concrete performance through internal curing (IC) and material substitutions. The majority of research used experimental setups that combined durability evaluations such water absorption, salt penetration, and shrinkage with mechanical characteristics tests (compressive, tensile, or flexural strength). Cutting-edge methods like X-Ray Diffraction (XRD) and SEM (scanning electron microscopy) were frequently employed to examine hydration mechanisms and microstructural alterations, offering insights into the efficacy of ICs.

Khuat et al. (2024) and Tran et al. (2023) adopted experimental designs integrating natural and artificial lightweight aggregates, evaluating their performance through standardized ASTM and EN test protocols. Panahi et al. (2023) employed superabsorbent polymers, focusing on moisture retention and self-desiccation reduction using thermogravimetric analysis (TGA). Ma et al. (2019) and Balapour et al. (2020) emphasized pre-saturation techniques for lightweight aggregates, meticulously assessing shrinkage and strength development over varying curing durations.

Field simulations by Huseien et al. (2024) and Kumar et al. (2022) evaluated performance under realistic environmental conditions, ensuring practical applicability. While most studies successfully validated their findings, some lacked long-term durability assessments and life-cycle analyses. Overall, the methodologies were robust but could benefit from integrating sustainability metrics to better align with environmental objectives.

C. Highlighting trends, advancements, and challenges

Trends and Advancements:

Recent advancements in concrete technology highlight the increasing use of internal curing (IC) techniques to improve cementitious materials' performance and longevity. A notable trend is the growing reliance on lightweight aggregates (natural and artificial) and superabsorbent polymers (SAPs) as effective IC agents. Studies reveal that these materials optimize water retention, mitigate self-desiccation, and improve long-term hydration, leading to reduced shrinkage and enhanced mechanical properties.

Another emerging trend is the integration of nanotechnology and microstructural analysis, such as SEM and XRD, to investigate hydration processes and IC efficiency at microscopic levels. The use of machine learning and computational modeling for predicting IC outcomes is also gaining traction, enabling researchers to optimize mix designs and curing conditions effectively.

Sustainability is a dominant focus, with many studies exploring eco-friendly materials like recycled aggregates, fly ash, and slag for partial cement replacement, aligning with environmental and cost-effectiveness goals. Real-world applications and field trials have further validated IC methods, proving their practicality in large-scale construction.

However, challenges persist, including variability in IC material availability, cost implications, and the need for standardized testing protocols to evaluate IC performance comprehensively. Addressing these issues is critical for widespread adoption and implementation of IC technologies.

V. DISCUSSION

A. Synthesis of findings from literature

A review of literature on internal curing (IC) in concrete highlights its effectiveness in mitigating autogenous shrinkage, enhancing hydration, and improving durability. Studies consistently show that IC using lightweight aggregates (natural and artificial) or superabsorbent polymers (SAPs) provides a sustained water supply, addressing self-desiccation during cement hydration. High-performance or strong concrete, which is vulnerable to early-age cracking because of low water-to-cement ratios, benefits most from this process.

Type, particle size, frequency capacity to absorb are some of the variables that affect how well IC materials operate. Lightweight aggregates are recognized for their dual role in water retention and strength improvement, while SAPs are lauded for precise dosage control and self-regulating water release. Incorporating IC has demonstrated significant enhancements in compressive strength, tensile strength, and long-term durability.

Microstructural analysis using techniques like SEM and XRD reveals a denser and more homogeneous matrix in IC-treated concrete, contributing to reduced porosity and improved resistance to external environmental effects. Furthermore, sustainability-focused research underscores the potential of recycled aggregates and industrial by-products in IC applications, aligning with eco-friendly construction practices.

Despite these advancements, challenges such as optimizing material proportions, cost-effectiveness, and scalability remain, necessitating further research and standardization for broader implementation.

B. Implications for Study

By reducing life cycle costs, IC's social benefits have extended service life and enhanced economies. the primary benefits of IC. By examining transport characteristics including diffusion and sorptive coefficients, it is discovered that internal curing has been expanded to take longer-term durability into account. In one investigation, the sorptivity of cylindrical paste and mortar specimens without or with internal curing, cured in sealed conditions contained within double plastic bags, was measured using the ASTM C1585 typical testing technique [ASTM C1585, 2004]. Internal sealing of concrete has been found to limit corrosion and decrease the depth of penetrating of chlorine and other ions.

Various experiments were conducted on cement, sand, BC, and stone chips. The aggregate gradation was obtained using sieve analysis. Tests for aggregate's specific gravity, absorption ability, unit weight, or desorption were also conducted. The cement's normal consistency, setting time, and mortar strength were established. The purpose of this investigation was to ascertain the aggregate sample gradation that was utilized in this mixture design. The material's coarseness or fineness is gauged by its Fineness Modulus (FM). The empirical factor is calculated by dividing the total percentage of material retained in a US standard sieve by 100. Using ASTM C136 [2006], each of the aggregate grades were produced independently. The ratio solid aggregate to the weight of an equivalent volume of water with permeable pores yields the bulk specific gravity. The weight of an equivalent volume of water, excluding permeable pores, divided by the oven-dry weight of the aggregate yields the apparent specific gravity. The ASTM C128 [2012] standards was followed in the laboratory to determine the specific gravities of the two types of aggregate utilized in mixtures.

Table 1 :Specific gravity, absorption capacity and FM of materials

Materials	Unit Weight (kg/m^3)	Bulk Specific Gravity (OD)	Bulk Specific Gravity (SSD)	Absorption Capacity %	Fineness modulus
SC	1545	2.05	2.18	6.40	6.90
BC	1210	1.90	2.00	15.80	7.20
Sand	1683	2.20	2.40	7.00	2.72

The test was conducted using Portland Composite Cement (PCC). ASTM C187 [2011] was followed for the normal consistency test, ASTMC150 [2012] for the setting time test, and ASTM C150 [2014] for the mortar's compressive strength test.

Table 2 : Cement test results

Test Title	Results
Normal consistency (%)	29%
Initial setting time (minutes)	60
Final setting time (minutes)	210
28 days Compressive strength of mortar (MPa)	31.61

C. Methodology for future research directions

In order to replicate concreting work under exposed field conditions, seven conditions for curing were used for this study. Table 3 lists the seven conditions for treatment along with their detailed forms.

Table 3 : Curing conditions of cylindrical sample

Concise form of curing Condition	Elaborate of curing condition
NC	Normal curing underwater
WP	With polythene cover
WOP	Without polythene cover
3-WP	Three days normal curing under water then with polythene cover
3-WOP	Three days normal curing under water then without polythene cover
7-WP	Seven days normal curing under water then with polythene cover
7-WOP	Seven days normal curing under water then without polythene cover

Samples were covered with polythene sheets and placed outdoors the lab immediately upon casting in one curing environment (WP). In contrast, samples were left outside the lab without any covering as soon as they were cast under the WOP curing condition. Samples were submerged for three and seven days, respectively, under (3-WP) and (7-WP) treatment conditions before being stored outside the lab under polythene cover. The samples were placed outside without cover after being submerged underwater for three and seven days for the (3-WOP) and (7-WOP) conditions. For comparison, every sample were also exposed to standard exterior curing conditions.

D. Scope and Limitation :

1) Scope:

- The study of internal curing using brick chips explores an innovative approach to enhance concrete performance by leveraging the water-absorbing properties of porous brick aggregates.
- This technique aims to address challenges in curing under adverse conditions, such as limited water availability or extreme climates.
- Assessing how brick chips affect concrete's strength, durability, ability to withstand shrinkage, and long-term performance is part of the scope.
- Additionally, it examines the environmental benefits of utilizing recycled materials and the cost-effectiveness of incorporating brick chips compared to traditional curing methods.

2) Limitation:

- The brick chips' quality, size, & porosity can affect the method's efficacy, necessitating careful selection and uniformity.
- The approach might not be suitable for high-performance or specialized concretes requiring strict control over material properties.
- Furthermore, the long-term effects of using brick chips in aggressive chemical environments remain underexplored, limiting its application in industrial or marine settings.

VI. CONCLUSION

Internal curing using brick chips offers a promising solution to enhance concrete performance, particularly in addressing challenges like shrinkage, cracking, and inadequate curing in water-scarce regions. The water retention capability of porous brick chips aids in prolonged hydration, resulting in improved strength, durability, and dimensional stability of concrete. This approach also promotes sustainability by utilizing recycled materials, reducing the dependency on natural resources.

However, its application requires careful consideration of factors such as brick chip quality, porosity, and mix design compatibility. While the method demonstrates significant potential for conventional and mid-strength concretes, its suitability for high-performance and chemically exposed environments needs further investigation. Overall, internal curing with brick chips represents an innovative and eco-friendly advancement in concrete technology, encouraging further research and optimization for broader industrial adoption and environmental benefits.

VII. ACKNOWLEDGMENT

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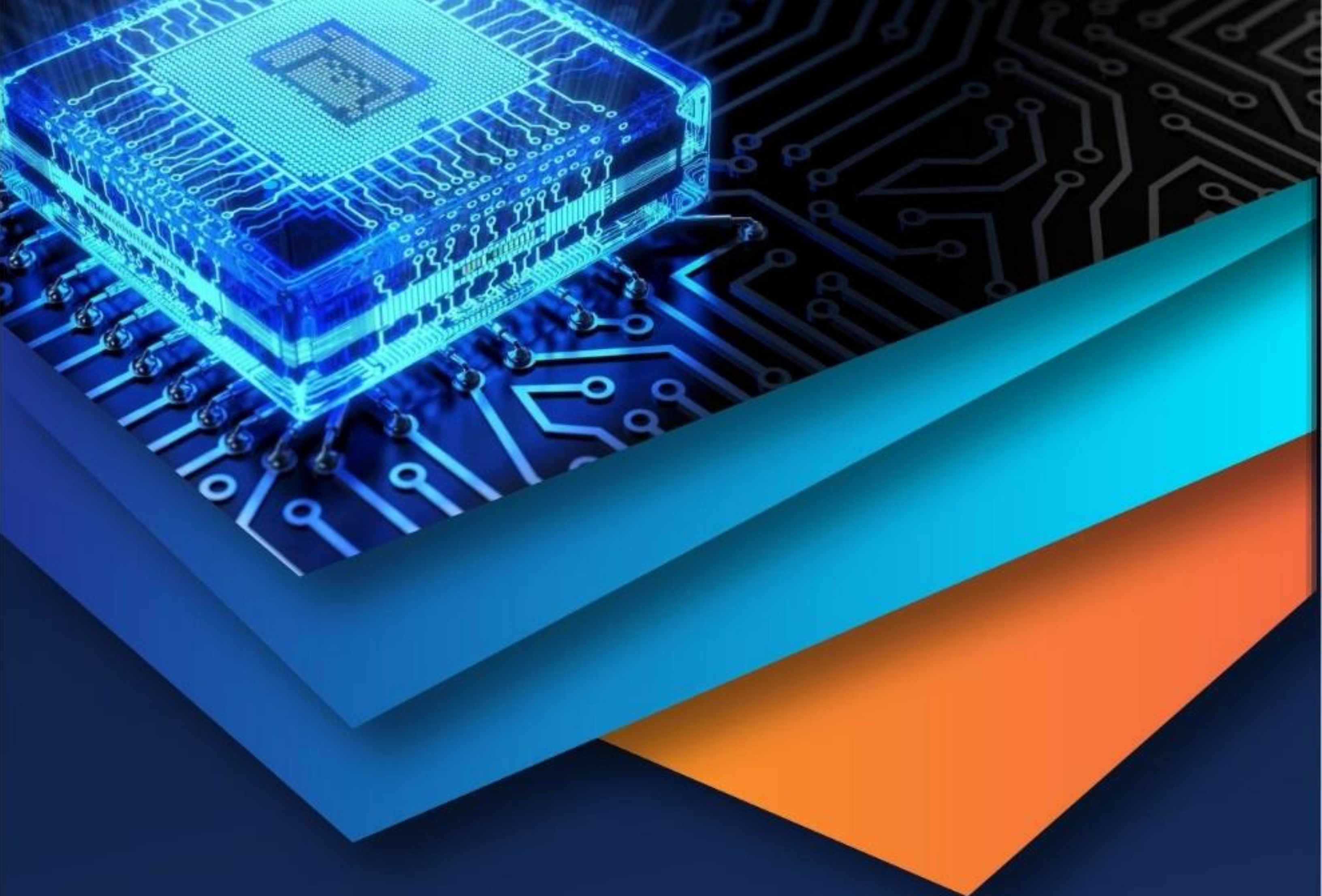

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