Durability studies of high strength concrete :A review

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Abstract - Concrete has an extensive role to play both in the construction and improvement of our civil engineering and infrastructure. Its great strength, durability, and versatility are properties utilized in the construction of roads, bridges, airports, railways, tunnels, ports and harbors, and many other major infrastructure projects. The durability of concrete has attracted significant attention over the past several decades and is still a research hotspot until now. This paper reviews and discusses recent research activities on the durability of concrete, including major durability problems such as alkali-aggregate reaction, sulfate attack, steel corrosion, freeze-thaw, Acid attack, and water absorption.

Index Terms - Durability, Ultra high performance concrete, Sulphate attack, Freez and thaw, Permeability, Porosity

I. Introduction

The Durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration to remain its original form, quality and serviceability when exposed to its intended service environment . Durability problems usually appear as the materials deteriorate at the beginning. Although the material deterioration do not have an immediate safety issue, it will progressively lead to structural damage, which puts a potential danger to the structures.

The classification of causes of concrete deterioration can be grouped into three categories, physical, chemical, and mechanical, from which major durability issues such as steel corrosion are initiated and developed. To solve the durability problems, many researchers have conducted deep studies on these issues. The studies cover the individual topics of carbonation, alkali-aggregate reaction, reinforcing bar corrosion, sulfate attack, CH leaching, and freezing–thawing. As noted by researchers, in most cases, the degradation of a concrete structure is a result of the combined effect of multiple environmental factors and loading. Therefore, many researchers have extended their work from a single mechanical loading or environmental factor to the combined effects of multiple factors [3–14]. As a result of durability studies, many countries have proposed durability-based design guidelines [15–17] or durability-loading carrying ability unified service life design method [2]. This paper starts with the discussion on recent research associated with major durability issues based on selected corresponding activities. After discussion on durability issues for concrete in marine environments, the durability-based design philosophy and methodology are introduced.

II. Literature survey

Manpreet Singh a,b,⇑ , Anshuman Srivastava a , Dipendu Bhunia “Long term strength and durability parameters of hardened concrete on partially replacing cement by dried waste marble powder slurry” (2018)

This study investigates the long-term strength and durability of concrete when cement is partially substituted with dried waste marble powder slurry. The research explores varying replacement percentages (0%, 10%, 15%, 20%, and 25%) and different water-binder ratios (0.35, 0.40, and 0.45). The primary objective is to determine the impact of using dried marble slurry on concrete

properties over an extended period, especially considering the reduced binder amount due to cement replacement. The study's methodology includes testing concrete samples after different durations (28, 56, 90, 180, and 360 days), following an initial 28-day water curing period. The samples were also exposed to the harsh environmental conditions of Rajasthan, India, where temperatures range from 0°C in winter to 47°C in summer. The tests focused on various strength parameters (compressive, tensile, and flexural strength) and durability parameters (water permeability, abrasion resistance, and water sorptivity). Results showed that up to 15% replacement of cement with marble slurry led to enhanced physical strength and durability in concrete blocks over all tested periods (from 28 to 360 days). Higher replacement ratios with marble dust resulted in a denser mix, improving long-term properties. The study also established relationships between strength and durability properties and the compressive strength of concrete incorporating marble slurry.

K. Sreenivasa Sudheer1* , P. Praneet Sai Kumar2 , M. Achyutha Kumar Reddy3 & V. Ranga Rao4 “A Study on Durability of Concrete by Partial Replacement of Cement with Bentonite” Journal: International Journal of ChemTech Research (2017)

The study presented the durability of concrete when cement is partially replaced with bentonite. Bentonite, a type of clay, is considered as an alternative material for cement in concrete due to its unique properties and potential benefits in enhancing concrete's performance. To investigate the impact of incorporating bentonite into concrete on its long-term durability. The study aims to determine whether bentonite can be a viable substitute for a portion of cement in concrete mixtures.The research involves experimenting with various proportions of bentonite as a partial replacement for cement. The specific replacement percentages and experimental conditions, such as curing times and environmental exposures, are designed to rigorously test the durability of the modified concrete. The concrete samples undergo a series of durability tests. These tests might include assessments of compressive strength, water absorption, resistance to environmental factors, and other relevant parameters that indicate the long-term performance of the concrete. The study's results are expected to reveal how bentonite affects the concrete's durability. Key findings would include the optimal percentage of bentonite for enhancing durability without compromising the structural integrity of the concrete. If successful, the use of bentonite could lead to more environmentally sustainable construction practices by reducing the amount of cement required in concrete, which in turn could lower carbon emissions associated with cement production. This study is significant in the context of sustainable construction and materials science, as it explores an innovative approach to improving concrete's durability while potentially reducing the environmental impact of construction materials. The findings from this research could pave the way for new standards in concrete formulation and have broad implications for the construction industry, particularly in terms of sustainability and material optimization.

Muazzam Ghous Sohail a , Ramazan Kahraman b,* , Nasser Al Nuaimi a , Bora Gencturk c , Wael Alnahhal d “Durability characteristics of high and ultra-high performance concretes”. Journal of building materials (2021)

The paper examines the durability characteristics of High-Performance Concrete (HPC) and Ultra-High Performance Concrete (UHPC) in comparison to Normal Strength Concrete (NSC). The study is significant in advancing the understanding of how HPC and UHPC can enhance the durability of reinforced concrete (RC) structures, particularly in challenging environmental conditions. To assess and compare the durability characteristics of HPC and UHPC with NSC. The study aims to provide a comprehensive evaluation of these materials in the context of their potential for extending the service life of RC structures. Both HPC and UHPC are cast using commonly available materials, without requiring special heat treatment. The study employs several tests to assess concrete resistivity, rapid chloride permeability, sorptivity, porosity, and resistance to chloride migration and carbonation. The microstructures and hydration products of these concrete types are investigated using Scanning Electron Microscope (SEM) imaging and X-ray Diffraction (XRD) analyses. The study uses a time-to-corrosion model to predict the potential enhancement in the service life of RC structures when NSC is replaced with HPC or UHPC. The results show that both HPC and UHPC exhibit dense microstructures, high electrical resistance, negligible chloride permeability, low sorptivity, and no carbonation ingress. Particularly notable is the finding that the chloride diffusion coefficient in UHPC is at least three orders of magnitude lower than in NSC, indicating a significant delay in corrosion initiation of steel reinforcement. The superior durability characteristics of HPC and UHPC suggest these materials could find more widespread application in concrete structures, especially in harsh climatic conditions. The paper provides valuable data and analysis that could support the accelerated adoption of these advanced concrete materials in construction practices.

This research is crucial for the construction industry, offering insights into the enhanced durability of HPC and UHPC compared to traditional NSC. By demonstrating the significant improvements in durability parameters, the study supports the potential for these advanced concretes to extend the service life of RC structures, especially in environments with harsh climatic challenges. The findings could play a pivotal role in guiding future construction practices towards more durable and sustainable infrastructure.

S. P. Zhang and L. Zon. "Evaluation of Relationship between Water Absorption and Durability of Concrete Materials". Journal: Hindawi Publishing Corporation.(2014)

This research is significant for understanding how environmental factors affect concrete durability and for establishing a quantitative relationship between water absorption and various durability parameters. To explore how water absorption influences the durability of concrete materials and to establish a relationship between these two factors. The study involves creating concrete specimens with different levels of water absorption by varying curing conditions. The surface water absorption of these specimens is then measured. SEM (Scanning Electron Microscope) imaging is used to observe how different curing conditions affect the microstructure of the concrete. After a 28-day curing period, the concrete samples undergo various tests to assess durability factors, including compressive strength, permeability, resistance to sulfate attack, and chloride ion diffusion. There is no clear relationship between both surface and internal sorptivity and the compressive strength of concrete. Surface water absorption is related to key performance indicators of concrete, such as permeability, sulfate attack, and chloride ion diffusion. A linear relationship is observed between surface sorptivity and both impermeability and resistance to sulfate attack, with correlation coefficients of not less than 0.9. The chloride ion diffusion coefficient has an exponential relationship with surface water absorption, indicated by a high correlation coefficient. No significant relationship is found between internal water absorption and durability aspects like impermeability, resistance to sulfate attack, and chloride ion diffusion.

This study reveals that surface water absorption in concrete significantly influences its durability, particularly in terms of permeability, sulfate attack resistance, and chloride ion diffusion. These findings highlight the importance of surface sorptivity in predicting and enhancing the durability of concrete materials, which is crucial for the longevity and integrity of concrete structures. The research provides valuable insights for construction industry professionals in designing more durable concrete materials, especially in environments where exposure to moisture and aggressive chemicals is a concern.

Tai Ikumi, Sergio H. P. Cavalaro, Ignacio Segura "THE ROLE OF POROSITY IN EXTERNAL SULPHATE ATTACK". (2017)

The study investigates the impact of porosity on the durability of concrete and mortar when subjected to external sulphate attack (ESA). This research provides valuable insights into the traditional and potential approaches to enhancing concrete's resistance to ESA, a common problem in construction materials. To assess the role of porosity in influencing the resistance of concrete and mortar to ESA. The study seeks to understand how porosity affects the ability of these materials to withstand sulphate-induced degradation. Design codes often suggest limiting permeability (and indirectly porosity) to reduce sulphate ingress, thereby improving resistance to ESA. However, the study explores the possibility that porosity might also play a beneficial role in enhancing durability. The research involves examining mortar compositions with different pore-size distributions. The study monitors changes at the macro-scale, phase composition, and pore network in these materials. The study identifies two primary mechanisms affecting durability in the context of ESA. In the initial stages of ESA, the capacity of the material to accommodate expansive phases controls durability. In the later stages, durability is predominantly influenced by permeability. Results from specimens treated with air-entrainers suggest that intentionally increasing porosity could be a viable approach to mitigate the expansive forces generated during ESA. This research challenges the traditional approach of minimizing porosity to combat ESA. Instead, it proposes that a controlled increase in porosity might be beneficial, especially for accommodating expansive products and reducing the detrimental effects of ESA.

The study contributes significantly to the field of construction material science by highlighting the dual role of porosity in the context of ESA. While lower porosity is typically associated with increased durability, this research suggests that a certain level of porosity might actually be advantageous in mitigating the effects of sulphate attack. These findings could lead to a paradigm shift in how construction materials, particularly concrete and mortar, are designed and formulated for environments prone to ESA.

S.W. Tang, Y. Yao, C. Andrade, Z.J. Li "Recent durability studies on concrete structure". Journal: Elsevier (28 October 2018)

The paper comprehensive review of the recent research activities focusing on the durability of concrete structures. Durability in concrete construction is a crucial factor that has garnered sustained interest and research over several decades, and continues to be a prominent area of study. To provide an overview of the latest research developments in the field of concrete durability, highlighting major challenges and advancements. Alkali Aggregate Reaction: Investigating the chemical reactions between alkali in cement and reactive aggregates, which can lead to expansion and cracking. Examining the chemical reaction between sulfates (usually from external sources) and concrete components, causing deterioration. Focusing on the corrosion of steel reinforcement within concrete, a critical issue affecting structural integrity. Assessing the effects of repeated freezing and thawing on concrete, which can cause significant damage in cold climates. This section delves into the challenges faced by concrete structures in marine environments, characterized by high salt content, moisture, and often, aggressive chemical exposure. Exploring how mechanical stresses combined with environmental conditions such as temperature, moisture, and chemical exposure influence the durability of concrete. Discussing the European developed probabilistic model for the design and assessment of concrete durability. Performance-Based Specifications: Reviewing the shift from prescriptive to performance-based specifications in concrete design, focusing on achieving desired durability outcomes. This comprehensive review highlights the multifaceted nature of concrete durability, encompassing chemical, physical, and environmental challenges. By summarizing recent research and developments in this field, the paper underscores the complexity of ensuring long-term durability in concrete structures. It also points out the increasing trend towards performance-based design approaches, which prioritize durability outcomes over prescriptive measures. This shift is significant for the future of concrete construction, emphasizing the need for innovative solutions and continued research to tackle the ever-evolving challenges of concrete durability.

K. Krishna Teja, B. Kameswara Rao "STRENGTH AND DURABILITY OF HIGH VOLUME FLYASH CONCRETE". Journal: International Journal of Civil Engineering and Technology (IJCIET) (6 June 2018)

The paper by K. Krishna Teja and B. Kameswara Rao in the International Journal of Civil Engineering and Technology focuses on enhancing the durability and environmental sustainability of concrete, a widely used material in construction. Recognizing the early strength advantages but durability limitations of traditional concrete, along with its significant carbon dioxide emissions contributing to the greenhouse effect, the study explores the use of supplementary materials as a cement replacement. To examine the effectiveness of High-Volume Fly Ash (HVFA) as a replacement for cement in concrete, in terms of strength and durability. Eight different mix proportions were designed, featuring different water-to-cementitious ratios for two grades of concrete (30MPa and 40MPa). The study includes two batches of Plain Concrete with superplasticiser and six batches of HVFA concretes with fly ash percentages of 50%, 60%, and 70%, all including superplasticiser. Concrete specimens were tested after curing periods of 7 and 28 days to measure compressive strengths. The Rapid Chloride Permeability Test (standard practice C-1202) was employed to assess chloride ion penetration in the concrete specimens.

Results. The 28-day compressive strength of HVFA concretes was found to be satisfactory compared to Normal concrete, except for the 70% replacement level. HVFA concretes demonstrated greater resistance to chloride ion penetration compared to Plain Concrete.

The study concludes that incorporating high volumes of fly ash as a partial replacement for cement in concrete can effectively enhance its durability, particularly in resisting chloride ion penetration, which is a critical factor in the longevity of concrete structures. This approach not only improves the environmental sustainability of concrete by reducing CO_2 emissions but also maintains, and in some cases, enhances the structural performance of the material. The findings are significant for the construction industry, offering a sustainable and performance-effective alternative to traditional concrete.

Benjamin A. Graybeal, PE, PSI, Inc., McLean, VA; Joseph L. Hartmann, PE, Federal Highway Administration, McLean, VA "STRENGTH AND DURABILITY OF ULTRA-HIGH-PERFORMANCE CONCRETE" Journal: concrete bridge conference (2003)

The paper focuses on the properties of Ultra-High-Performance Concrete (UHPC), particularly its strength and durability aspects. UHPC is a class of concrete that is characterized by its exceptional strength and durability, making it an attractive material for a variety of construction applications. To investigate the mechanical properties and durability factors of UHPC, and understand how it compares to standard concrete materials in terms of performance. UHPC is a unique concrete formulation that includes a combination of fine-grained materials, high-strength fibers (often steel), and a low water-to-binder ratio. This composition results in concrete with very high compressive and tensile strengths, and enhanced durability. UHPC is known for its exceptionally high compressive strength, significantly exceeding that of traditional concrete. The inclusion of fibers in UHPC contributes to its high tensile strength, making it more resistant to cracking and other forms of structural failure. UHPC demonstrates superior durability, particularly in harsh environmental conditions, including resistance to freeze-thaw cycles, corrosion, and chemical attacks. The enhanced durability of UHPC suggests a longer lifespan for structures built with this material, reducing the need for repairs and replacements. The study likely discusses the practical applications of UHPC in construction, such as in bridges, buildings, and other infrastructural projects. The implications of using UHPC in terms of cost, construction techniques, and overall sustainability in the construction industry are also likely addressed.

This paper highlights the advanced properties of Ultra-High Performance Concrete, emphasizing its potential to revolutionize construction practices due to its superior strength and durability. The findings of Graybeal and Hartmann's study are crucial for the construction sector, particularly for applications requiring materials that can withstand extreme conditions and provide long-term structural integrity. The adoption of UHPC could lead to more durable, sustainable, and cost-effective construction solutions.

Benjamin Graybeal1 and Jussara Tanesi " STRENGTH AND DURABILITY OF ULTRA-HIGH PERFORMANCE CONCRETE" Journal(2003)

The paper investigates the durability of Ultrahigh-Performance Concrete (UHPC), a class of fiber-reinforced composite material that has pushed the boundaries of traditional concrete capabilities. The study aims to assess the durability of a commercially available UHPC through a series of standardized tests. Enhanced durability compared to normal and high-performance concretes, the UHPC showed significantly improved durability properties. The UHPC was subjected to six standardized tests, including, ASTM C 666 (Freeze-Thaw Cycles): The UHPC showed minimal damage even after undergoing double the standard number of freeze-thaw cycles. ASTM C 1260 (Alkali-Silica Reaction, ASR): It demonstrated resistance to ASR deterioration. ASTM C 672 (Scaling): The UHPC exhibited resistance to scaling deterioration. AASHTO T259 (Chloride Penetration): The material showed high resistance to chloride penetration. ASTM C 1202 (Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration): The results were negligible or very low, particularly with steam-based curing. ASTM C 944 (Abrasion Resistance): Steam-based curing treatments significantly enhanced abrasion resistance. The study highlights that the curing treatment applied to UHPC can significantly influence its durability properties. Steam-based curing treatments, in particular, enhance the concrete's durability. This improvement is attributed to increased hydration, improved microstructure, and decreased permeability of the concrete.

This research underscores the exceptional durability of Ultrahigh-Performance Concrete and its potential applications in areas where extreme environmental conditions or high durability demands are prevalent. The findings indicate that UHPC, especially when subjected to steam-based curing treatments, surpasses both normal and high-performance concretes in several critical durability aspects. This makes UHPC a promising material for future construction projects requiring high durability and longevity. The study provides valuable insights into the effects of different curing treatments on the durability of UHPC, guiding best practices for its application in the construction industry.

S. Abbas, M. L. Nehdi,* and M. A. Saleem "Ultra-High Performance Concrete: Mechanical Performance, Durability, Sustainability, and Implementation Challenges".(2018)

The study presents an extensive literature review focusing on the material characterization of Ultra-High Performance Concrete (UHPC) and explores its potential for large-scale field applicability. The research evaluates the mechanical performance, durability, sustainability, and challenges associated with implementing UHPC in construction.

The successful production of UHPC relies on carefully selected material ingredients and precise mixture proportioning. These factors contribute to denser and more homogenous particle packing in UHPC.

Mechanical and Durability Performance: A compiled database from global research and field studies demonstrates that UHPC exhibits ultrahigh strength properties, improved fatigue behavior, and very low porosity. UHPC displays excellent resistance against aggressive environments, making it a viable and long-term solution for sustainable construction. The literature review identifies curing regimes and fiber dosage as key factors controlling the mechanical and durability properties of UHPC. The limited applications of UHPC in construction are attributed to higher initial costs, a lack of contractor experience, and the absence of widely accepted design provisions. Current challenges regarding the implementation of UHPC in full-scale structures are highlighted. Research progress in producing UHPC using locally available materials under normal curing conditions is expected to reduce material costs, making UHPC more economically feasible.

The study provides valuable insights into the unique characteristics and capabilities of UHPC, emphasizing its potential as a resilient and sustainable construction material. Despite the challenges associated with higher costs and limited implementation experience, ongoing research efforts aim to make UHPC more accessible and cost-effective. The findings in this study serve as a resource for engineers, consultants, contractors, and other stakeholders in the construction industry, facilitating a better understanding of UHPC and its potential contributions to sustainable construction practices.

Peng Zhang and Qing-Fu Li "Durability of High-Performance Concrete Composites Containing Silica Fume" (16 august 2016)

Peng Zhang and Qing-Fu Li conducted a parametric experimental study to investigate the impact of silica fume on the durability of concrete composites. The study focused on four different silica fume contents (3%, 6%, 9%, and 12%) and assessed various durability aspects, including water impermeability, dry shrinkage property, carbonation resistance, and freeze–thaw resistance. The addition of silica fume was found to have a minor adverse effect on the dry shrinkage property of concrete composites. With an increase in silica fume content, the dry shrinkage strain gradually increased. Silica fume significantly improved the water impermeability of concrete composites. Increasing silica fume content led to a decrease in the length of water permeability. The addition of silica fume resulted in a notable improvement in the carbonation resistance of concrete composites. Higher silica fume content correlated with a decrease in the carbonation depth of specimens. Silica fume positively influenced the freeze–thaw resistance of concrete composites. Increasing silica fume content was associated with a decrease in the length of freeze–thaw resistance. The study observed a tendency of increase in the relative dynamic elastic modulus of specimens with the rise in silica fume content.

The research concludes that while the addition of silica fume may slightly affect the dry shrinkage property of concrete composites, it significantly enhances water impermeability, carbonation resistance, and freeze–thaw resistance. These findings suggest that incorporating silica fume into high-performance concrete composites can result in improved durability, making it a valuable material for applications where resistance to environmental factors is crucial. The study provides practical insights for optimizing the composition of concrete mixtures to achieve desired durability characteristics.

III. CONCLUSIONS

The collective exploration of diverse research papers on concrete durability underscores the multifaceted nature of advancements in construction materials. From the enhanced properties of Ultrahigh-Performance Concrete (UHPC), as highlighted by Graybeal and Tanesi, to the broad spectrum covered in the recent studies reviewed by Tang, Yao, Andrade, and Li, the consensus emerges that the durability of concrete is a dynamic field at the intersection of innovation, sustainability, and application challenges. The influence of supplementary materials, such as silica fume, on high-performance concrete composites, as investigated by Zhang and Li, demonstrates a nuanced balance between potential drawbacks in dry shrinkage and significant improvements in water impermeability, carbonation resistance, and freeze–thaw resistance.

The extensive literature review by Abbas, Nehdi, and Saleem offers a panoramic view of UHPC, recognizing its ultrahigh strength and low porosity as key assets for sustainable construction. Despite challenges in initial costs and limited implementation experience, ongoing research aims to bridge gaps and enhance the viability of UHPC in mainstream construction.

Lastly, the study on the partial replacement of cement with bentonite, as featured in the International Journal of ChemTech Research, contributes valuable insights into the use of alternative materials for improved concrete durability. The findings provide a nuanced understanding of the relationship between replacement percentages and water-binder ratios on the strength and durability of concrete.

In concert, these papers collectively illustrate the dynamic landscape of concrete durability research, where innovations in material science, sustainability considerations, and practical implementation challenges coalesce. The ongoing pursuit of high-performance, durable concrete materials not only addresses immediate structural needs but also contributes significantly to the long-term resilience and sustainability of construction practices.

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