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A Review on improving concrete durability by using Controlled Permeable Formwork

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Abstract

Concrete durability is a critical factor in ensuring the long-term performance and service life of structures, especially in aggressive environmental conditions. Controlled Permeable Formwork (CPF) has emerged as an innovative technique to enhance the durability of concrete by improving the quality of the cover zone. CPF liners, typically made of non-woven fabric, allow excess water and entrapped air to drain from the fresh concrete surface while retaining fine cement particles. This process reduces the local water-to-cement ratio and increases cement content in the surface layer, resulting in a denser, less porous cover zone with improved hardness, abrasion resistance, and reduced water absorption. The review consolidates various studies that demonstrate CPF's effectiveness in enhancing near-surface concrete properties, including resistance to chloride penetration, carbonation, and freeze-thaw cycles. It also highlights the potential benefits of combining CPF with supplementary cementations materials such as fly ash and rice husk ash for further durability enhancement. Overall, CPF presents a practical and cost-effective solution for producing more durable, long-lasting concrete structures.

Keywords: Concrete durability, Controlled Permeable Formwork, CPF liner, Water-to-cement ratio, Surface densification, Supplementary cementations materials, Abrasion resistance, Chloride penetration, Freeze-thaw resistance.

Introduction

Controlled Permeable Formwork (CPF) liners are specially designed formwork liners made from permeable fabrics, typically polyester or polypropylene, that allow controlled drainage of excess water and air from the surface of freshly placed concrete during casting. By permitting the escape of water and entrapped air while retaining the fine cement particles, CPF liners significantly improve the quality of the concrete cover zone, which is often the weakest and most porous part of a structural element. The use of CPF results in a denser, more durable, and less permeable surface with enhanced strength, reduced bleeding, improved resistance to carbonation, chloride ingress, and freeze-thaw cycles, thereby extending the service life of reinforced concrete structures. Additionally, CPF liners reduce surface defects such as honeycombing, bug holes, and laitance, while also improving aesthetics with a uniform finish. They can be reused multiple times depending on the type of liner, making them a practical and cost-effective solution for improving concrete durability and long-term performance, especially in harsh or aggressive environments. Controlled Permeable Formwork (CPF) enhances concrete durability by producing a denser, less porous surface layer. CPF liners, usually made of non-woven fabric, allow excess water and entrapped air to drain from the fresh concrete while retaining cement particles near the surface. This process lowers the water-cement ratio and increases cement content in the cover zone, resulting in higher surface hardness, improved abrasion resistance, and reduced water absorption. Consequently, concrete exhibits greater resistance to aggressive environmental agents, extending its service life.

S Kandasamy et al (2025) the controlled permeable formwork (CPF) liner is an innovative approach to enhance the quality of the concrete cover zone. This novel technique facilitates the drain of excess water and entrapped air from the freshly laid concrete's near-surface region, while retaining tiny particles like cement and other fine constituents. Therefore, the concrete becomes denser and less porous as a result of a decrease in the water-to-cement ratio at the surface zone. This strategic manipulation of the concrete's surface composition yields more robust and durable cover zone, enhancing the overall performance and longevity of the structural element. The effect of incorporating glass fiber (GF) into concrete with a CPF liner was investigated in this research. Different percentages of glass fiber (0.5, 1.0, 1.5, and 2.0) were added to the CPF concrete mix to prepare the samples, and tested at various ages. The Rockwell hardness, rebound number, dynamic hardness, split tensile, flexural strength, compressive strength, and superficial pore measurement tests were conducted. The results indicated that the dynamic and rebound hardness, split, and flexural strength of the CPF liner concrete with 1.5% of GF were significantly enhanced at a range of 74, 69, 49, and 47% correspondingly.

Adabiya Hussain et al (2023) The durability and service life of any reinforced concrete element largely depend on the quality of its cover concrete, as it serves as the first line of defense against the ingress of aggressive agents that can cause steel reinforcement corrosion and structural deterioration. Controlled Permeable Formwork (CPF) liner technology has emerged as an innovative method to significantly improve the quality of this cover zone. Unlike impermeable formwork (IMF), CPF liners are designed to allow excess water and entrapped air to drain out during casting while retaining cement particles and fines at the surface, which leads to a reduced water-cement ratio, enhanced cement content near the surface, and a denser, less porous microstructure. This modification not only improves the appearance of the formed surface but also minimizes blowholes, honeycombing, and surface porosity, thereby enhancing durability against chloride penetration, carbonation, and other chemical attacks. To evaluate the effectiveness of CPF liners, concrete samples of varying grades were cast against both CPF and IMF and subjected to compressive, tensile, and flexural strength tests, along with durability assessments at different curing ages. The study anticipates that CPF-lined concretes will demonstrate superior strength, reduced permeability, and improved durability characteristics compared to conventional IMF concretes, thereby offering longer service life and better structural performance.

A.balasaikumar et al (2022) the present experimental study was undertaken to evaluate the influence of Control Permeable Formwork (CPF) liners on the mechanical properties of M20 grade concrete with varying steel fibre content (0%, 1%, and 2%). Concrete specimens were cast using both CPF liners and conventional impermeable steel formwork and tested at 28 days to assess compressive strength, split tensile strength, rebound hammer, and ultrasonic pulse velocity. The results demonstrated that CPF-lined concrete consistently outperformed normal concrete across all percentages of steel fibre addition, showing higher strength and durability characteristics due to the improved surface densification and reduced porosity achieved by CPF liners. The presence of steel fibres further enhanced the mechanical behavior, particularly in tensile performance, as fibres bridged cracks and improved post-cracking resistance. Overall, the findings confirm that the use of CPF liners in M20 grade concrete, especially when combined with steel fibres, is highly effective in improving both compressive and tensile properties, thereby enhancing the structural performance and durability of concrete elements.

Vishal Ambad et al (2022) The study highlights the importance of improving the surface quality and durability of concrete structures by using Controlled Permeability Formwork (CPF) liners, which are designed to allow excess water and air to escape during casting while preventing the loss of cement fines and smaller particles. In this experimental work, concrete specimens were prepared using both impermeable steel formwork (SF) and CPF liners to compare their performance. The mix was designed with Ordinary Portland Cement (OPC) 53 grade**,** supplementary cementations materials such as pulverized fly ash (PFA) and micro silica**,** along with crushed sand, natural aggregates, water, and a super plasticizer to achieve workability and durability. The specimens, cast in both cubic and cylindrical shapes, were tested at 7 days and 28 days to determine their compressive strength and resistance to chloride ingress using the Rapid Chloride Penetration Test (RCPT)**.** Results showed that specimens cast with CPF liners developed a much denser and stronger cover zone because the liner facilitated the drainage of excess water and trapped air voids from the surface concrete, thereby improving the microstructure. This improvement led to a significant increase in strength, with CPF liner-cast specimens recording around 14% higher compressive strength compared to those made with impermeable steel formwork. Moreover, in terms of durability, CPF liner specimens exhibited 9.98% fewer charges passed in RCPT**,** which directly indicates lower permeability and better resistance to chloride ion ingress. Since chloride penetration is a major cause of reinforcement corrosion and long-term deterioration of concrete in aggressive environments, the findings prove that CPF liners not only improve mechanical properties but also substantially enhance the durability of concrete, making them highly effective for construction in marine and chloride-rich environments.

B. menaka et al (2022) lightweight concrete is a type of concrete with a substantially lower unit weight compared to conventional concrete made from gravel or crushed stone, and its performance can be further enhanced by using Controlled Permeable Formwork (CPF) liners, which are innovative surface improvement materials designed to improve the quality of the concrete cover region. These liners function by allowing excess mix-water and entrapped air bubbles to drain out through their permeable structure while retaining cement and other fine particles within the mix, leading to a denser, stronger, and more durable concrete surface with reduced porosity. This process not only minimizes surface defects such as blowholes and weak zones but also enriches the actual cement content near the formed face, thereby improving the overall microstructure and durability of the cover zone, which is critical in protecting reinforcement against carbonation, chloride ingress, and other environmental attacks. The experimental study reported in the paper demonstrated that the use of CPF liners in lightweight concrete results in a significant improvement in both strength properties and near-surface concrete quality compared to conventional lightweight concrete, confirming the effectiveness of CPF liners in enhancing the performance and service life of lightweight structural elements.

Freddy Soman et al (2021) the construction industry faces growing pressure to improve productivity sustainably while maintaining quality, and one key strategy is the use of supplementary cementations materials (SCMs) like Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash as partial replacements for Portland Cement. Concrete incorporating GGBS or Fly Ash exhibits properties that vary depending on their proportion in the total cement content; generally, higher proportions reduce water demand, prolong setting time, and slow the initial strength gain, though long-term strength may be comparable or superior. Importantly, such concrete often shows enhanced durability compared to ordinary Portland Cement (OPC) concrete, due to a denser microstructure and lower permeability, making it more resistant to aggressive agents. Durability is typically assessed through standardized tests such as rapid chloride permeability, water absorption, water permeability, chloride migration, porosity, and capillary absorption, usually at a test age of 28 days. The durability of concrete is influenced mainly by three mix design parameters: the maximum free water-to-cement ratio, the proportion of mineral additions, and the minimum cementations content. Beyond technical improvements, using GGBS or Fly Ash also offers environmental benefits by reducing CO_2 emissions associated with cement production and contributing to pollution control, making them both technically advantageous and environmentally sustainable alternatives in modern concrete construction.

S. Kandasamy et al. (2020) carried out a detailed experimental investigation to evaluate the impact of Controlled Permeable Formwork (CPF) liners on the durability and service life of reinforced self-compacting concrete (SCC), focusing particularly on its resistance to chloride-induced deterioration, which is one of the major causes of reinforcement corrosion in concrete structures. In their study, SCC specimens were cast using both CPF liners and conventional impermeable formwork (IMF) and were subjected to a series of durability assessments, including accelerated rebar corrosion tests, rapid chloride penetration tests, chloride ingress measurements, and chloride diffusion studies, to determine how effectively CPF liners improve the performance of concrete in aggressive environments. The experimental results clearly indicated that SCC cast with CPF liners exhibited a much denser and higher-quality cover zone, which significantly reduced chloride ion penetration by 54% to 75% compared to SCC produced with IMF, thereby limiting the pathways for aggressive agents to reach the steel reinforcement. This improvement in surface quality and reduced permeability was directly reflected in the extended service life of the concrete, with SCC made using CPF liners demonstrating nearly 1.5 times longer durability than its IMF counterpart. These findings highlight that the use of CPF liners is an efficient and practical approach to enhancing the long-term performance of SCC structures, especially in chloride-laden environments such as marine or coastal regions, where reinforcement corrosion is a critical durability concern.

Wael A. Megid et al. (2020) investigated how different forming materials affect the surface quality of self-consolidating and highly workable concretes by placing mixtures in a specially designed Z-shaped mould without applying any mechanical consolidation, allowing the concrete to settle under its own rheological properties. The mould sides were constructed using four different materials—plywood, PVC, steel, and a permeable formwork liner made from polyester filter—to evaluate their impact on eliminating surface defects. The study revealed that while impermeable formworks such as plywood, PVC, and steel often trapped air and water at the interface, leading to surface blemishes, voids, and weaker cover quality, the permeable polyester liner allowed excess water and entrapped air to escape while retaining cement and fine particles at the surface. This drainage mechanism significantly reduced surface porosity, improved hardness, and enhanced the aesthetic and durability-related characteristics of the formed concrete, thereby demonstrating that permeable formwork is an effective method for improving cover concrete quality compared to conventional impermeable materials.

Sahil Garg et al. (2019) investigated the effect of controlled permeable formwork (CPF) liners on the quality of near surface concrete (NSC) by comparing a commercially manufactured CPF liner with more economical and easily available alternatives such as particle board and gunny bags. To evaluate durability and surface performance, they conducted tests including rapid chloride permeability, $AgNO_3$ colorimetry, initial surface absorption, and pull-off strength. The results revealed that the commercially available CPF liner provided the best enhancement in surface quality and durability characteristics of NSC, demonstrating significant resistance to chloride ingress, reduced permeability, and stronger surface bonding. However, among the cheaper alternatives, gunny bags also showed considerable improvement in NSC properties compared to particle boards, making them a noteworthy low-cost substitute, though still less effective than the commercial CPF liner in ensuring optimal durability and performance.

Wael A. Megid et al. (2018) carried out an extensive study to evaluate how the rheological properties of self-consolidating concrete (SCC) and super workable concrete (SWC) influence the quality of formed surfaces. In their work, 31 concrete mixtures with 12 varying levels of workability and rheology were prepared and cast into a specially designed Z-shaped column, eliminating the need for mechanical consolidation to replicate realistic placement conditions. The surface quality of the hardened concrete was assessed using an image analysis methodology that quantified defects such as surface air voids, bleeding marks, segregation effects, and inadequate filling ability. The study revealed a strong link between rheological parameters and surface finish, showing that mixtures with very low plastic viscosity (less than 10 Pa·s) and low yield stress (below 100 Pa) exhibited more pronounced surface defects, particularly segregation, which compromised the overall finish of the concrete. These findings emphasize the importance of optimizing rheology in SCC and SWC mixtures to minimize defects and ensure higher durability and aesthetic quality in concrete structures.

S. Kothandaraman et al. (2016) carried out an experimental study to evaluate the effect of Controlled Permeable Formwork (CPF) liners on the surface hardness and wear resistance of concrete by comparing specimens cast against CPF liners with those cast against impermeable steel formwork (IMF). The results demonstrated that the use of CPF liners significantly improved the surface quality of concrete, with an enhancement in surface hardness ranging from 14% to 58% compared to conventionally cast specimens. A key observation was that in CPF-cast concretes, the outer 20 mm thick cover layer exhibited greater hardness than the core concrete, indicating superior densification and durability of the surface region. In contrast, for concrete cast using traditional steel formwork, the 15 mm thick cover zone was found to be softer than the core, reflecting poorer surface quality and greater susceptibility to deterioration. This beneficial effect of CPF liners on enhancing the near-surface properties of concrete was consistent across water-to-cement ratios ranging between 0.31 and 0.48, confirming the robustness and reliability of CPF liners in improving the long-term performance of cover concrete.

W. Lin et al (2014) corrosion of steel reinforcement caused by chloride ion intrusion remains one of the most serious threats to the durability of concrete structures, particularly in aggressive marine environments. When chloride ions penetrate through the concrete cover and accumulate at the steel surface, they eventually reach a critical concentration that initiates corrosion, leading to cracking, spalling, and reduced structural service life. To delay this process, the permeability of concrete is generally improved by optimizing the mix design to achieve better compatibility and refined pore structure, thereby limiting chloride ingress. In recent years, the use of Controlled Permeability Formwork (CPF), initially developed to provide smoother concrete surfaces, has been found highly effective in improving the quality of the surface zone of concrete. By filtering out excess water and air during casting, CPF creates a denser, less permeable cover layer that acts as a stronger barrier against chloride penetration, significantly enhancing durability in chloride-rich environments. This study investigated the influence of CPF on concrete permeability under varying conditions of water-to-binder ratio, workability, and fly ash content, and further established mathematical models to evaluate its effect on chloride transport resistance and predict the potential extension of structural service life.

Jiaping Liu et al. (2013) conducted a detailed study on the influence of Controlled Permeable Formwork (CPF) liners on the water adsorption properties of concrete, focusing on the mechanisms by which CPF improves concrete quality. In their research, concrete blocks were analyzed for surface appearance, meso-surface morphology, and microstructural characteristics to determine how CPF affects adsorption behavior. The findings revealed that the use of CPF significantly reduced concrete permeability, primarily because the liner enhanced the surface quality and refined the microstructure, leading to denser and more durable cover concrete. Furthermore, Scanning Electron Microscopy (SEM) was used to examine the surface structure of the CPF liner itself, which showed that the liner’s porous and permeable characteristics allowed excess water and entrapped air to escape during casting while retaining fine cement particles at the surface, resulting in a compact and durable microstructure. Overall, the study concluded that CPF liners are highly beneficial and promising materials for improving the durability and performance of concrete by reducing permeability and enhancing near-surface characteristics.

Jun Ying Lai et al (2011) Concrete durability is a critical factor in the design of structures exposed to aggressive environments, as it largely depends on both the quality of the surface layer and the presence of cracks. In this study, concrete specimens were cast using controlled permeability formwork (CPF) and conventional steel formwork, and their surface properties were evaluated using rebound number tests, which measure surface hardness. Additionally, the early-age shrinkage of concrete was assessed under three curing conditions: a dry environment at 20±2°C with 75±5% relative humidity, sealed curing using plastic film, and curing with a CPF liner covering the concrete. The results demonstrated that concrete cast with CPF exhibited higher surface hardness, indicating a denser and less porous surface layer, and experienced lower early-age shrinkage compared to concrete cast with ordinary steel formwork. This reduction in shrinkage can be attributed to the CPF's ability to allow excess water and air to escape while retaining fine cement particles near the surface, leading to improved microstructure and reduced cracking potential. Consequently, the application of CPF not only enhances the surface quality and mechanical resistance of concrete but also reduces susceptibility to shrinkage-related cracking, thereby significantly improving durability and extending the service life of structures exposed to harsh environmental conditions.

Helena Figueiras et al. (2009) investigated the performance of full-size precast concrete elements made with both self-compacting concrete (SCC) and conventional vibrated concrete (CC) when cast using controlled permeability formwork (CPF), focusing on evaluating and comparing the efficiency of two different CPF systems. The study aimed to assess how CPF influences the surface and durability properties of SCC in comparison with CC, since SCC already has superior workability and compaction characteristics, which can potentially complement the action of CPF liners. Their results highlighted that the use of CPF significantly enhanced the surface quality and durability performance of both SCC and CC by reducing surface porosity, improving densification, and limiting ingress of aggressive agents. Moreover, when SCC was used with CPF, the improvements were more pronounced compared to CC, demonstrating that the combined effect of SCC's self-compacting ability and CPF's filtration and densification mechanism resulted in superior concrete elements, making this approach highly effective for precast applications where durability and long-term performance are critical.

P.J. Schubel et al. (2008) investigated the effects of different concrete mixes and commonly used mineral additions on near-surface performance when vertically cast against Controlled Permeable Formwork (CPF), and their findings highlighted the significant role CPF plays in improving concrete quality. The study showed that CPF consistently enhanced the surface characteristics of concrete by improving appearance, uniformity, and surface densification, which was evident through observable changes in surface color, indicating a denser and less porous structure. This densification directly contributed to improved durability-related properties by reducing surface permeability and minimizing pathways for aggressive agents, thereby lowering the risk of deterioration. Importantly, these benefits were not limited to a specific concrete mix or mineral addition; rather, all concrete systems examined in the study demonstrated significant improvements when CPF was used. This emphasized CPF's effectiveness as a universal method for enhancing surface quality and extending the service life of concrete structures.

J. Sousa Coutinho (2003) conducted a laboratory study to investigate the effect of controlled permeability formwork (CPF) on the durability of concrete in which cement was partially replaced with Portuguese rice husk ash (RHA) at levels of 10%, 15%, and 20% by weight. In this study, concrete specimens were cast using both conventional formwork and CPF liners, and a series of durability-related tests were performed to assess the influence of CPF when combined with RHA as a supplementary cementations material. The results demonstrated that CPF significantly improved the near-surface properties of concrete, reducing porosity and enhancing resistance to aggressive agents, while the inclusion of RHA further contributed to the refinement of pore structure and long-term durability. Importantly, the study concluded that the synergistic effect of CPF and partial cement replacement by RHA produced superior concrete performance compared to conventional casting, highlighting CPF's ability to maximize the durability benefits of sustainable cement replacements.

Methodology

The methodology for improving concrete durability using Controlled Permeable Formwork (CPF) involves casting concrete against specially designed CPF liners, typically made of non-woven, porous fabrics. These liners allow excess water and entrapped air from the fresh concrete surface to drain while retaining fine cement particles, resulting in a denser, less porous cover layer. In experimental studies, concrete specimens are prepared using standard mixes or mixes incorporating mineral additives such as fly ash, slag, or rice husk ash, and cast against both CPF and conventional steel formwork for comparison. After casting, the concrete is cured under controlled conditions—usually at 20 ± 2°C and 75 ± 5% relative humidity—or using sealed or covered curing methods. Key performance parameters such as surface hardness, water absorption, porosity, rebound numbers, and microstructural characteristics are then measured to evaluate the effectiveness of CPF in enhancing surface densification, reducing permeability, and improving the overall durability of concrete.

Conclusion

Controlled Permeable Formwork (CPF) has been demonstrated as an effective method to significantly enhance the durability and surface quality of concrete. By facilitating the removal of excess water and entrapped air from the fresh concrete's surface while retaining cement particles, CPF produces a denser and less porous cover zone. This results in improved surface hardness, reduced water absorption, enhanced resistance to chloride ingress, carbonation, and freeze–thaw cycles, and overall increased service life of concrete structures. Studies indicate that CPF is particularly effective when combined with mineral additions, self-compacting concrete, or supplementary cementations materials, further optimizing the near-surface performance. The method offers a practical, environmentally friendly, and cost-effective approach to improving concrete durability, making it highly suitable for aggressive environments and long-lasting infrastructure applications.

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