

Experimental Investigation on Reactive Powder Concrete

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Abstract—Reactive Powder Concrete (RPC) is an ultra-high-performance cementitious composite developed to achieve exceptional strength, durability, and ductility through the elimination of coarse aggregates and optimization of particle packing density. This study presents an experimental investigation on the mechanical and durability performance of RPC prepared using carefully selected fine materials and advanced chemical admixtures. The experimental program focuses on optimizing mix proportions by varying key parameters such as water-to-binder ratio, cement and supplementary cementitious material content, fine aggregate grading, and fiber reinforcement. Laboratory tests including compressive strength, flexural strength, split tensile strength, workability, and water absorption were conducted to evaluate the performance of RPC mixtures. The results demonstrate that RPC exhibits significantly higher strength and superior durability characteristics compared to conventional and high-performance concretes. The study also highlights the potential of incorporating industrial by-products to develop cost-effective and sustainable RPC mixes. The findings of this research contribute to a better understanding of RPC behavior and support its application in high-strength, durable, and advanced structural systems.

Index Terms—Reactive Powder Concrete (RPC); Advanced Cementitious Composites; Experimental Study; High-Strength Concrete; Durability Performance; Fiber-Reinforced Concrete; Sustainable Mix Design; Structural Applications

I. INTRODUCTION

Reactive Powder Concrete (RPC) represents a new generation of cement-based composites designed to deliver extremely high strength and durability compared to conventional and high-performance concretes. The concept of RPC is based on the elimination of coarse aggregates and the optimization

of granular packing using very fine powders, which results in a dense and homogeneous microstructure [11]. This refined internal structure significantly improves mechanical performance and resistance to environmental deterioration.

Previous research has established that the performance of RPC is strongly influenced by its mix composition. Parameters such as water-to-binder ratio, cement content, mineral additives, and particle size distribution play a crucial role in determining both fresh and hardened properties [1]. Lower water-to-binder ratios combined with fine reactive materials enhance strength development while maintaining workable consistency through the use of advanced superplasticizers [6].

The inclusion of fibers is a defining feature of RPC technology, as it substantially improves tensile strength, ductility, and crack resistance. Studies have shown that steel, glass, and hybrid fibers contribute to enhanced load-carrying capacity and energy absorption, making RPC suitable for structural applications subjected to high stress levels [4]. The use of recycled and waste fibers has also been explored, offering a sustainable approach without compromising mechanical performance [5,17].

RPC has also gained considerable attention in structural strengthening and rehabilitation works. Experimental investigations have demonstrated that RPC jackets can effectively improve the axial and flexural behavior of reinforced concrete columns, especially when combined with fiber-reinforced polymer confinement techniques [3,15]. Such strengthening systems provide increased stiffness, delayed failure, and improved deformation capacity under loading conditions [16].

Durability is one of the most significant advantages of RPC. Due to its extremely low permeability and

refined pore structure, RPC exhibits excellent resistance to sulfate attack, chemical exposure, and aggressive environments [7,14]. Furthermore, RPC has demonstrated improved performance under elevated temperatures compared to traditional concrete materials, highlighting its potential for use in structures exposed to fire or thermal loading [9]. The role of curing methods in enhancing RPC performance has also been emphasized, with heat curing shown to accelerate strength gain and durability [10].

Owing to these superior characteristics, RPC has been increasingly adopted in infrastructure projects such as bridges, precast elements, pressure pipes, and high-security facilities where long-term performance is critical [2,8]. Despite its advantages, the broader application of RPC is still constrained by high material costs and limited practical guidelines for mix design and implementation.

In this context, the present research aims to experimentally investigate Reactive Powder Concrete by optimizing mix proportions, evaluating mechanical and durability properties, and exploring sustainable material alternatives. The outcomes of this study are expected to support the practical application of RPC in advanced structural and infrastructure engineering projects.

II. LITERATURE REVIEW

Ahmad et al. (2015) investigated the influence of key mixture parameters on the fresh and hardened properties of reactive powder concrete. The study focused on variables such as water-to-binder ratio, silica fume content, and superplasticizer dosage. The authors reported that a lower water-to-binder ratio significantly improves compressive and flexural strength but adversely affects workability unless compensated by chemical admixtures. Increased silica fume content enhanced matrix densification and strength due to improved particle packing and pozzolanic activity. Flow characteristics were found to be highly sensitive to admixture dosage, emphasizing the need for optimized mix design. The study concluded that RPC performance is strongly governed by mixture proportioning, and small variations in parameters can lead to significant changes in mechanical behavior.

Akhnoukh and Soares (2018) reviewed the application of reactive powder concrete in the construction industry of the United States. Their work highlighted

the advantages of RPC, including ultra-high compressive strength, superior durability, and reduced structural member dimensions. The authors discussed successful applications in bridges, precast elements, and protective structures. However, challenges such as high material cost, limited availability of fine powders, and lack of standardized design guidelines were also identified. The study emphasized the need for improved construction practices and greater industry awareness to facilitate widespread adoption of RPC in large-scale infrastructure projects.

Algburi et al. (2019a) proposed an innovative strengthening technique for square reinforced concrete columns by circularizing them using reactive powder concrete and wrapping with fiber-reinforced polymer. Experimental results demonstrated a substantial increase in axial load capacity and ductility compared to unstrengthened columns. The RPC jacket improved stress distribution, while FRP wrapping provided effective confinement. The study confirmed that combining RPC with FRP systems is an efficient retrofitting solution for deficient structural members.

Algburi, A.H., Sheikh, M.N. and Hadi, M.N.S. (2019b)

This study examined the mechanical properties of RPC reinforced with steel fibers, glass fibers, and hybrid fiber combinations. Algburi et al. (2019b) reported that steel fibers significantly enhanced compressive and flexural strength, while glass fibers improved crack control and post-cracking behavior. Hybrid fiber systems showed superior performance by combining strength enhancement and toughness. The research highlighted the importance of fiber type and synergy in achieving balanced mechanical properties in RPC.

Al-Tikrite and Hadi (2017) investigated the use of industrial and waste steel fibers in RPC under compressive loading. The results showed that incorporating steel fibers enhanced compressive strength and ductility, with waste fibers performing comparably to industrial fibers. The study demonstrated the feasibility of using waste steel fibers in RPC as a sustainable and cost-effective alternative without compromising structural performance.

Aydin et al. (2010) studied the effect of aggregate type on the mechanical properties of reactive powder concrete. The authors reported that aggregate mineralogy, strength, and surface texture significantly influence compressive strength, flexural strength, and

fracture energy. Rough and strong aggregates enhanced crack resistance and energy absorption, while smooth aggregates limited flexural performance. The study emphasized that aggregate selection is critical in RPC due to its high-strength matrix.

Bakhbergen et al. (2022) evaluated the durability of RPC subjected to different sodium sulfate concentrations. The study assessed compressive strength, water absorption, porosity, and microstructural changes. Results indicated that RPC exhibits excellent sulfate resistance due to its dense microstructure and low permeability. Minimal strength degradation and stable hydration products were observed even at high sulfate exposure levels.

Campbell et al. (1998) presented one of the earliest large-scale applications of reactive powder concrete for sewer, culvert, and pressure pipes. The study demonstrated that RPC pipes exhibit superior strength, durability, and resistance to aggressive environments compared to conventional concrete pipes. The authors highlighted the suitability of RPC for infrastructure applications requiring long service life and minimal maintenance.

Canbaz (2014) investigated the effect of high temperature exposure on the mechanical properties of reactive powder concrete. The results showed that RPC retains higher residual strength than conventional concrete when subjected to elevated temperatures. However, significant strength loss occurred beyond critical temperature levels due to microcracking and dehydration of hydration products. The study emphasized the fire resistance potential of RPC.

Chang et al. (2009) studied the performance of RPC under different curing conditions and its effectiveness in retrofitting concrete members. The authors reported that steam and heat curing significantly enhance compressive strength and improve bonding between RPC overlays and existing concrete. The study confirmed that curing regime plays a vital role in determining RPC performance in repair applications.

Cheyrezy et al. (1995) conducted a detailed microstructural analysis of reactive powder concrete. The study revealed that RPC possesses a highly dense microstructure with minimal porosity due to optimized particle packing and high silica fume content. The authors concluded that microstructural refinement is the primary reason for the exceptional mechanical and durability properties of RPC.

DAAX Construction (2022) documented the use of reactive powder concrete in the Central Bank of Iraq project. The project demonstrated the practical feasibility of RPC in complex architectural and structural applications. The use of RPC enabled reduced member dimensions, improved durability, and enhanced aesthetic performance, showcasing its potential for landmark infrastructure projects.

Denisiewicz and Kuczma (2013) proposed a two-scale numerical modeling approach for reactive powder concrete. The study developed a representative volume element to simulate RPC behavior at the micro-scale and link it to macro-scale structural response. The model provided accurate predictions of stress-strain behavior, contributing to improved understanding of RPC mechanics.

Fojtik and Hubacek (2006) investigated the resistance of RPC to corrosive environments. Their findings showed that RPC exhibits superior durability compared to conventional high-performance concrete due to its low permeability and dense microstructure. The study confirmed the suitability of RPC for aggressive environmental conditions.

Hadi et al. (2018a) examined the axial and flexural behavior of circular reinforced concrete columns strengthened with RPC jackets and FRP wrapping. The results demonstrated significant improvements in load-carrying capacity, stiffness, and ductility. The combined use of RPC and FRP was shown to be an effective strengthening technique.

This study focused on CFRP-confined hollow-core RPC columns. Hadi et al. (2018b) reported substantial enhancements in axial strength and confinement efficiency. The results confirmed that CFRP confinement is highly effective when used with RPC due to its high compressive strength and compatibility. Hasan (2024) studied the effect of waste fibers on the strength properties of sustainable reactive powder concrete. The research demonstrated that waste fibers significantly improve compressive and flexural strength while promoting sustainability through material reuse. The study supports the development of eco-friendly RPC formulations without compromising mechanical performance.

III. SPECIMEN AND MATERIAL

The compressive strength of conventional concrete commonly used in Egypt generally ranges between 25

and 30 MPa, with values of 35–40 MPa being relatively frequent, 50 MPa achieved only in limited cases, and strengths of 60–70 MPa considered rare. Even under controlled laboratory conditions, compressive strength levels typically do not exceed 90–100 MPa in most research studies. In contrast, significantly higher strength values have been successfully achieved in several countries worldwide. The feasibility of attaining compressive strengths in the range of 150–200 MPa using locally available construction materials, even after careful selection and optimization, remains uncertain. Consequently, this study focuses on Reactive Powder Concrete (RPC) as a promising alternative. The report presents a comprehensive review of RPC, covering its fundamental principles, performance potential, practical applications, and future prospects. Key research questions addressed include the possibility of producing RPC using locally sourced materials, identifying optimal mix proportions, and determining the maximum achievable strength levels. The findings of this study aim to establish a foundational framework for the potential adoption and implementation of RPC technology in Egypt.

In the present investigation, experimental studies were carried out to evaluate the mechanical and durability performance of the proposed concrete mixtures. Standard cube specimens of size $150 \times 150 \times 150$ mm and cylindrical specimens of 150 mm diameter and 300 mm height were cast. The concrete mixes were prepared using cement, fine aggregate, coarse aggregate, and selected supplementary materials such as bottom ash and fibers, in proportions corresponding to the designed grade. All ingredients were thoroughly mixed to ensure uniformity, and the fresh concrete was properly placed and compacted in moulds. After demoulding, the specimens were subjected to controlled curing conditions for the specified duration. Various tests were conducted on the hardened specimens, including compressive strength, split tensile strength, and flexural strength tests, to assess the mechanical behavior of the concrete. Additionally, selected specimens were examined for crack development and post-cracking performance. Previous studies reported that micro-cracks within a limited width range significantly influence strength and durability characteristics. Based on this understanding, controlled cracking techniques were adopted to study crack behavior. The experimental

procedure involved (i) casting specimens with predefined parameters, (ii) monitoring crack initiation and propagation over time, (iii) evaluating performance based on strength recovery and crack control, and (iv) analyzing test results using statistical methods. The results indicated that strength development and crack control behavior were significantly influenced by material composition and curing duration, with notable improvements observed after 21 to 28 days.

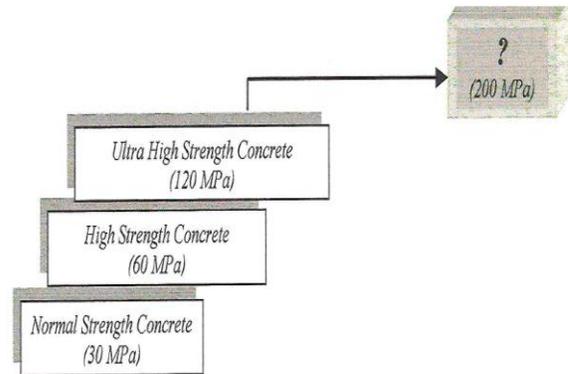


Fig. 1. Typical trend in advancements in the technology of concrete production.[2] Akhnoukh, A.K. and Soares, R. (2018)

State of the art RPC : Reactive Powder Concrete (RPC) was originally developed in the early 1990s by a research group working at the laboratory of HDR's predecessor organization in Paris. The earliest formally reported study on RPC was published in 1994 by Richard and Cheyrezy, which laid the foundation for the development of this advanced cementitious material. Following this pioneering work, the concept of RPC attracted global attention, and similar research directions were gradually adopted in different parts of the world. Nevertheless, despite its recognized potential and superior performance characteristics, the number of comprehensive and well-documented studies on RPC has remained relatively limited.

What is Reactive Powder Concrete (RPC) ?

Reactive Powder Concrete (RPC) is an advanced cement-based composite material composed primarily of fine sand, a very high cement content, silica fume, finely ground quartz powder, and a high-range water-reducing admixture (superplasticizer) [1,6,11]. In many applications, fine steel, glass, or hybrid fibers are incorporated to improve ductility, tensile strength, and post-cracking behavior [4,5]. The fundamental

concept of RPC is based on achieving an extremely dense and homogeneous microstructure by minimizing internal voids, which significantly enhances its load-bearing capacity and overall mechanical performance [11,13].

One of the defining characteristics of RPC is the complete elimination of coarse aggregate. This approach reduces material heterogeneity between the cementitious matrix and aggregate particles, thereby limiting stress concentrations and delaying crack initiation and propagation [6,14]. In RPC mixtures, conventional concrete constituents are functionally replaced by finer and more reactive materials. Fine sand effectively substitutes coarse aggregate, Portland cement assumes the role of fine aggregate, and silica fume acts as a highly reactive cementitious filler, leading to optimized particle packing and superior matrix densification [11,16].

Owing to these optimized material proportions and microstructural improvements, RPC has been reported to achieve compressive strength values typically ranging from 170 to 230 MPa, along with flexural strength levels between 30 and 60 MPa [1,4,11]. Further enhancement in mechanical performance, with compressive strengths exceeding 200 MPa, can be obtained through optional production techniques such as post-setting heat treatment and the application of external pressure during or prior to setting [9,10,15].

RPC is generally characterized by the following key parameters [1,11,15]:

1. A very low water-to-cement ratio, usually between 0.15 and 0.18, which is insufficient for complete cement hydration; the unhydrated cement particles function as micro-fillers, contributing to matrix densification.
2. Elimination of coarse aggregate, with the maximum particle size limited to approximately 400–600 μm .
3. A high Portland cement content, often close to 1000 kg/m^3 .
4. Silica fume content typically around 230 kg/m^3 .
5. Finely ground quartz powder with an average particle size ranging from 4 to 10 μm .
6. Combined content of fine sand and quartz powder generally in the range of 900–1000 kg/m^3 .
7. Use of a high dosage of efficient superplasticizer to maintain workability at very low water content.

Benefits of Reactive Powder Concrete (RPC)

Reactive Powder Concrete (RPC) offers several significant advantages over conventional and high-performance concretes due to its optimized particle packing, dense microstructure, and advanced material composition. One of the most notable benefits of RPC is its exceptionally high compressive and flexural strength. Studies have reported compressive strength values exceeding 170 MPa and, in some cases, reaching beyond 200 MPa, making RPC suitable for heavily loaded and slender structural elements [1,4,11]. This superior strength enables a reduction in member size and self-weight, leading to more efficient structural designs [2,15].

Another major advantage of RPC is its enhanced durability performance. The elimination of coarse aggregates and the use of ultra-fine particles significantly reduce porosity and permeability, resulting in excellent resistance to water ingress, chemical attack, and aggressive environmental conditions [7,14]. Bakhbergen et al. [7] demonstrated that RPC exhibits low absorption and high resistance when exposed to sulfate environments, while Fojtik and Hubacek [14] confirmed its superior performance in corrosive conditions compared to conventional concrete.

RPC also exhibits improved ductility and crack control when reinforced with fibers. The inclusion of steel, glass, or hybrid fibers enhances tensile strength, post-cracking behavior, and energy absorption capacity, thereby improving structural safety and serviceability [4,5]. Algburi et al. [4] reported that fiber-reinforced RPC shows delayed crack propagation and improved toughness, making it particularly effective for strengthening and retrofitting applications.

From a structural application perspective, RPC has proven highly effective in repair, rehabilitation, and strengthening of existing reinforced concrete members. Experimental studies have shown that RPC jacketing significantly improves the axial and flexural capacity of columns and enhances confinement efficiency when combined with fiber-reinforced polymer (FRP) wrapping [3,15,16]. These properties make RPC an ideal material for extending the service life of aging infrastructure.

RPC also demonstrates excellent performance under extreme conditions. Canbaz [9] reported that RPC retains a considerable portion of its mechanical strength even after exposure to elevated temperatures. Additionally, heat curing and controlled post-

treatment methods further enhance the microstructure and strength of RPC, allowing it to perform reliably under demanding service conditions [10].

In terms of constructability and long-term efficiency, RPC allows for the production of precast and thin-section elements with high dimensional accuracy and extended durability. Applications in sewer pipes, culverts, and pressure pipelines have shown reduced maintenance requirements and longer service life due to RPC's low permeability and high strength [8]. Although RPC involves higher material costs due to increased cement and silica fume content, the overall life-cycle cost can be reduced through improved durability, reduced repair needs, and extended service life [2].

Recent research has also highlighted the potential sustainability benefits of RPC through the incorporation of waste and industrial by-products. Hasan [17] demonstrated that the use of waste fibers in RPC can enhance mechanical performance while contributing to environmental sustainability. Such developments support the growing interest in optimizing RPC mixtures using alternative materials without compromising performance.

Comparison of Reactive Powder Concrete (RPC) with High-Performance Concrete (HPC) and Structural Steel

Reactive Powder Concrete (RPC) differs significantly from High-Performance Concrete (HPC) and structural steel in terms of composition, mechanical performance, durability, and structural efficiency. While HPC was developed to improve the strength and durability of conventional concrete through optimized mix design and supplementary cementitious materials, RPC represents a further advancement by eliminating coarse aggregates and achieving an ultra-dense microstructure through optimized particle packing [1,6,11].

In comparison with HPC, RPC exhibits substantially higher compressive and flexural strength. Typical compressive strength values for HPC generally range between 60 and 100 MPa, whereas RPC consistently achieves strength levels exceeding 170 MPa and may surpass 200 MPa under optimized curing conditions [1,11]. The enhanced strength of RPC is primarily attributed to its extremely low water-to-cement ratio, high cement and silica fume content, and refined granular composition, which collectively result in

reduced porosity and improved homogeneity compared to HPC [6,13].

Durability performance of RPC also exceeds that of HPC. Although HPC provides improved resistance to permeability and chemical attack relative to conventional concrete, RPC demonstrates superior resistance due to its nearly impermeable microstructure [7,14]. Studies have shown that RPC exhibits lower water absorption, reduced porosity, and enhanced resistance to sulfate and corrosive environments when compared with HPC, making it particularly suitable for aggressive exposure conditions and long-term infrastructure applications [7,8].

When compared with structural steel, RPC offers several distinctive advantages, particularly in terms of durability and maintenance. While steel exhibits very high tensile strength and ductility, it is susceptible to corrosion, especially in marine and industrial environments, leading to increased maintenance and protection costs. In contrast, RPC possesses excellent resistance to corrosion and environmental degradation due to its dense matrix and low permeability [14,15]. Additionally, fiber-reinforced RPC exhibits improved tensile behavior and crack control, reducing brittleness and enhancing post-cracking performance [4,5].

From a structural efficiency perspective, RPC bridges the gap between concrete and steel. Although steel generally exhibits higher tensile strength, RPC provides high compressive strength combined with adequate tensile capacity when reinforced with fibers or confined using external reinforcement systems such as FRP [3,15,16]. Experimental studies on RPC-jacketed reinforced concrete columns demonstrated performance comparable to steel confinement systems, with significant improvements in load-carrying capacity and deformation behavior [3,15].

In terms of fire and thermal resistance, RPC shows superior performance compared to steel. Structural steel rapidly loses strength at elevated temperatures, whereas RPC retains a significant portion of its mechanical properties under high-temperature exposure, particularly when appropriate curing and mix optimization techniques are employed [9,10]. This characteristic enhances the fire resistance and safety of RPC-based structural systems.

Despite its advantages, RPC involves higher material costs compared to HPC and conventional concrete due to increased cement, silica fume, and admixture

content. However, when compared to steel structures, RPC can offer cost efficiency over the structure's life cycle due to reduced maintenance, improved durability, and longer service life [2,8]. The use of waste fibers and alternative materials in RPC mixtures has further improved its sustainability and economic feasibility [5,17].

Overall, RPC combines the beneficial attributes of both HPC and structural steel by offering ultra-high strength, excellent durability, and improved structural efficiency. These characteristics make RPC a promising material for advanced structural applications, strengthening works, and next-generation infrastructure systems.

Applications of Reactive Powder Concrete (RPC)

Reactive Powder Concrete (RPC) is not intended to replace conventional concrete in general construction; rather, it is best suited for specialized applications where exceptional mechanical performance, durability, and significant reduction in structural weight are required. Owing to its ultra-high strength and dense microstructure, RPC is particularly advantageous in situations where strict performance criteria govern structural design. Its superior characteristics make it especially suitable for precast concrete elements, where precision, durability, and reduced section thickness are critical.

RPC has been recommended for several high-performance and safety-critical applications, including high-pressure pipelines, blast-resistant structures, security and protective enclosures, and facilities requiring isolation and containment of hazardous or nuclear waste. In such applications, the low permeability, high compressive strength, and enhanced durability of RPC provide long-term structural reliability and reduced maintenance requirements. Early implementations of RPC in the United States included precast products such as

concrete utility poles, railway sleepers, and grade-crossing planks, demonstrating its feasibility for infrastructure applications requiring high strength and durability.

One of the earliest and most notable structural applications of RPC was the Sherbrooke Pedestrian and Bikeway Bridge in Sherbrooke, Quebec, Canada. This landmark project represents the first full-scale structure constructed using RPC. The bridge was designed as a post-tensioned open-web space truss and notably contained no conventional steel reinforcement. Instead, the structure was composed of six prefabricated, match-cast RPC segments, highlighting the material's suitability for advanced precast construction techniques.

In the top and bottom chord members of the Sherbrooke bridge, RPC achieved a compressive strength of approximately 200 MPa. The diagonal web members were constructed using RPC confined within stainless steel tubes, which significantly enhanced ductility and enabled compressive strength levels of up to 350 MPa. Steel fibers were incorporated into the RPC mix to further improve tensile performance and crack resistance. The effective structural thickness of the bridge deck was limited to only 15.2 cm, demonstrating the remarkable material efficiency of RPC. Comparative studies indicated that if the same structure had been constructed using high-performance concrete (HPC), a thickness of approximately 38.1 cm would have been required, nearly 2.5 times greater than that achieved with RPC. These applications clearly demonstrate the potential of RPC to enable innovative structural forms, reduce material consumption, and achieve superior performance in demanding engineering applications. As research and field experience continue to expand, RPC is expected to play an increasingly important role in advanced infrastructure, precast construction, and high-performance structural systems.

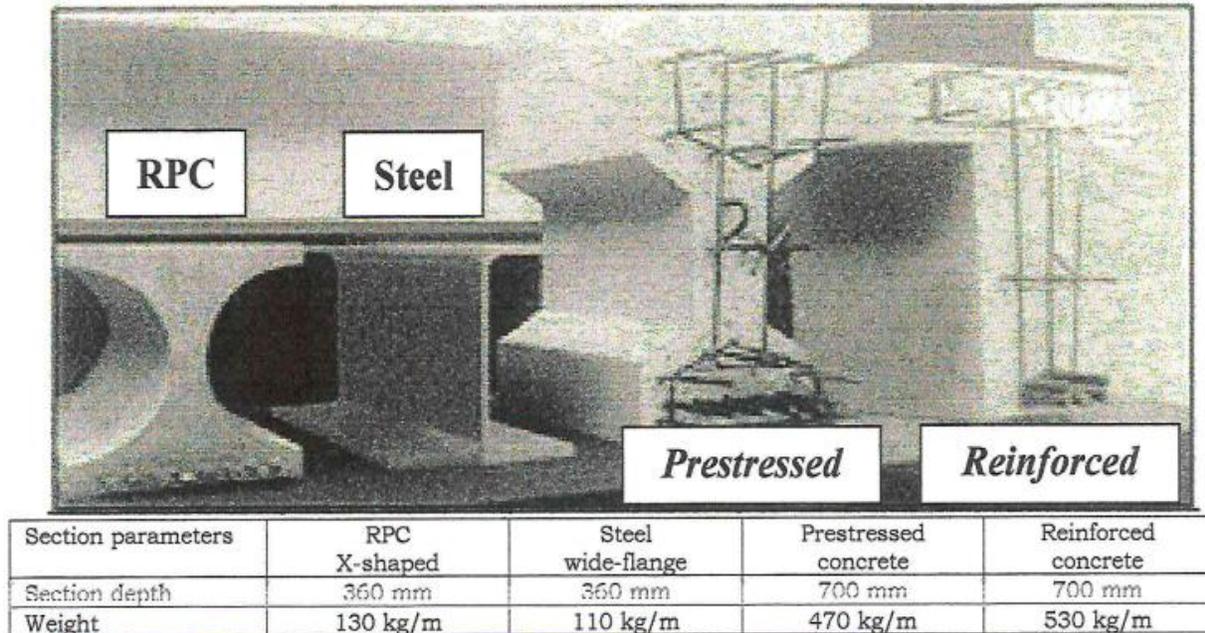


Fig. 2. Comparison of beam cross sections of equal moment capacity [18] C. Dauriac, “Special concrete may give steel stiff competition,” Seattle Daily Journal of Commerce (DJC), Special Issue, May 1997.

Table 1: Enhanced Physical Characteristics of Reactive Powder Concrete (RPC) Compared to High-Performance Concrete (HPC)

Sr. No.	Physical Property	Performance of RPC Compared to HPC
1.	Abrasive wear	3.6 times lower
2.	Water absorption	2.5 times lower
3.	Corrosion rate	7 times lower
4.	Chloride ion diffusion	25 times lower

Table 1 presents a comparative evaluation of the key physical performance characteristics of Reactive Powder Concrete (RPC) relative to High-Performance Concrete (HPC). The data clearly indicate that RPC exhibits significantly superior durability-related properties due to its dense and refined microstructure. The abrasive wear resistance of RPC is approximately 3.6 times higher than that of HPC, indicating its excellent ability to withstand surface degradation under repeated mechanical actions such as traffic loading and abrasion. This makes RPC particularly suitable for applications like industrial floors, bridge decks, and precast elements exposed to heavy wear

Water absorption in RPC is reported to be 2.5 times lower than that of HPC. This reduction is mainly attributed to the elimination of coarse aggregates and the use of ultra-fine particles, which minimize capillary pores within the concrete matrix. Lower water absorption directly contributes to improved durability and long-term performance by restricting the ingress of harmful agents.

The corrosion rate of reinforcement in RPC is found to be 7 times lower compared to HPC. The dense and nearly impermeable microstructure of RPC significantly limits moisture and oxygen penetration, which are essential for corrosion processes. As a result, RPC offers enhanced protection to embedded steel reinforcement, increasing the service life of reinforced concrete structures.

Furthermore, RPC demonstrates an exceptional resistance to chloride ion diffusion, with values approximately 25 times lower than those observed in HPC. This property is particularly important for structures exposed to marine environments, de-icing salts, and industrial chemicals. The reduced chloride penetration delays reinforcement corrosion and significantly enhances structural durability.

Overall, the comparative data presented in Table 1 highlight the superior durability and resistance characteristics of RPC over HPC. These enhanced

properties justify the use of RPC in critical infrastructure applications where long service life, minimal maintenance, and high performance under aggressive environmental conditions are required

IV. RESEARCH GAP

Concrete structures designed using Reactive Powder Concrete (RPC) exhibit exceptional compressive strength, dense microstructure, and superior durability compared to conventional concretes. Owing to its ultra-low porosity, high cementitious content, and optimized particle packing, RPC has been increasingly adopted in high-performance and specialized structural applications. However, despite these advantages, RPC is not entirely immune to long-term degradation, particularly when exposed to aggressive environmental conditions. The majority of existing studies emphasize short-term mechanical performance under controlled laboratory environments, while the long-term behavior of RPC under sustained exposure to chlorides, elevated temperatures, and harsh service conditions remains insufficiently understood. This knowledge gap limits the confident application of RPC in marine, industrial, and high-temperature environments where durability is critical.

Furthermore, steel fibers are predominantly used to enhance the tensile strength, ductility, and crack resistance of RPC. Although effective, reliance on steel fibers raises concerns related to corrosion, cost, and sustainability. Limited research has explored the feasibility of alternative fiber reinforcements such as synthetic fibers, basalt fibers, and hybrid fiber systems. The influence of fiber type, dosage, aspect ratio, and orientation on mechanical performance, post-cracking behavior, and failure mechanisms of RPC has not yet been systematically optimized, making it difficult to achieve an ideal balance between strength, ductility, and economic efficiency.

In addition, the sustainability of RPC remains a major concern due to its high cement content, which contributes significantly to carbon emissions. Research on incorporating supplementary cementitious materials such as fly ash, rice husk ash, and ground granulated blast furnace slag as partial cement replacements in RPC is still limited. Further investigations are required to develop environmentally friendly RPC mixtures that maintain high mechanical strength and durability while reducing environmental

impact.

- Limited understanding of the long-term performance of RPC under sustained environmental exposure, particularly chloride attack and high-temperature conditions.
- Insufficient research on the effectiveness of alternative fiber reinforcements such as synthetic and basalt fibers in enhancing tensile strength, ductility, and crack resistance of RPC.
- Lack of systematic optimization of fiber parameters including type, dosage, aspect ratio, and orientation to balance mechanical performance and cost-effectiveness.
- Inadequate exploration of sustainable RPC mixtures incorporating supplementary cementitious materials such as fly ash, rice husk ash, and slag while maintaining desired mechanical and durability properties.

V. CONCLUSION

Reactive Powder Concrete (RPC) has emerged as a promising ultra-high-performance cementitious material capable of delivering exceptional mechanical strength, durability, and structural efficiency. Based on the comprehensive review of previous studies and the experimental insights discussed in this work, it is evident that the superior performance of RPC is primarily attributed to its dense microstructure, optimized particle packing, low water-to-binder ratio, and effective use of fiber reinforcement. Compared to conventional and high-performance concretes, RPC demonstrates significantly enhanced compressive, tensile, and flexural strength, along with excellent resistance to aggressive environmental conditions.

The reviewed literature confirms that mix design parameters such as cement content, supplementary cementitious materials, fine aggregate grading, curing regime, and fiber type play a critical role in governing the fresh and hardened properties of RPC. The inclusion of fibers, particularly steel, glass, and hybrid fibers, has been shown to substantially improve ductility, crack resistance, and energy absorption capacity. Moreover, the use of waste and recycled fibers presents a sustainable and cost-effective alternative without compromising mechanical performance. Durability studies further indicate that RPC exhibits superior resistance to sulfate attack, corrosion, and elevated temperatures due to its

extremely low permeability and refined pore structure. Despite these advantages, the broader application of RPC is still constrained by high material cost, limited long-term durability data under combined environmental exposures, and the lack of standardized mix design and design guidelines. The findings of this study highlight the need for further experimental and analytical research focusing on long-term performance, alternative fiber systems, and sustainable material incorporation. Overall, this research contributes to a deeper understanding of RPC behavior and supports its potential application in advanced, durable, and sustainable structural engineering systems.

REFERENCE

- [1] Ahmad, S., Zubair, A. and Maslehuddin, M. (2015) Effect of key mixture parameters on flow and mechanical properties of reactive powder concrete. *Construction and Building Materials*, 99, pp. 73–81.
- [2] Akhnouk, A.K. and Soares, R. (2018) Reactive powder concrete application in the construction industry in the United States. In: *Proceedings of the Tenth International Conference on Construction in the 21st Century*, Colombo, Sri Lanka, pp. 195–202.
- [3] Algburi, A.H., Sheikh, M.N. and Hadi, M.N.S. (2019a) New technique for strengthening square reinforced concrete columns by circularisation with reactive powder concrete and wrapping with fiber-reinforced polymer. *Structure and Infrastructure Engineering*, 15(10), pp. 1392–1403.
- [4] Algburi, A.H., Sheikh, M.N. and Hadi, M.N.S. (2019b) Mechanical properties of steel, glass, and hybrid fiber-reinforced reactive powder concrete. *Frontiers of Structural and Civil Engineering*, 13(1), pp. 998–1006.
- [5] Al-Tikrite, A. and Hadi, M.N.S. (2017) Mechanical properties of reactive powder concrete containing industrial and waste steel fibers at different ratios under compression. *Construction and Building Materials*, 154, pp. 1024–1034.
- [6] Aydin, S., Yazici, H., Yardimci, M.Y. and Yiğiter, H. (2010) Effect of aggregate type on mechanical properties of reactive powder concrete. *ACI Materials Journal*, 107(5), pp. 441–449.
- [7] Bakhbergen, U., Shon, C.S., Zhang, D., Kryzhanovskiy, K. and Kim, J.R. (2022) Assessment of reactive powder concrete subjected to different sodium sulfate concentrations: Compressive strength, absorption, porosity, microstructure, and durability. *Construction and Building Materials*, 325, 126804.
- [8] Campbell, R.L., O'Neil, E.F., Dowd, W.M. and Dauriac, C.E. (1998) Reactive Powder Concrete for Producing Sewer, Culvert and Pressure Pipes. *Construction Productivity Advancement Research Program*, pp. 1–88.
- [9] Canbaz, M. (2014) The effect of high temperature on reactive powder concrete. *Construction and Building Materials*, 70, pp. 508–513.
- [10] Chang, T.B., Chen, B.T., Wang, J.J. and Wu, C.S. (2009) Performance of reactive powder concrete with different curing conditions and its retrofitting effects on concrete members. In: *Concrete Repair, Rehabilitation and Retrofitting II*. London: Taylor & Francis Group, pp. 1203–1208.
- [11] Cheyrezy, M., Maret, V. and Frouin, L. (1995) Microstructural analysis of reactive powder concrete. *Cement and Concrete Research*, 25(7), pp. 1491–1500.
- [12] DAAX Construction (2022) Central Bank of Iraq Project. Available at: <https://www.daaxconstruction.com/projects/central-bank-of-iraq> (Accessed: 3 March 2022).
- [13] Denisiewicz, A. and Kuczma, M. (2013) Two-scale modelling of reactive powder concrete. Part I: Representative volume element and solution of the corresponding boundary value problem. *Civil and Environmental Engineering Reports*, 10, pp. 41–61.
- [14] Fojtik, T. and Hubacek, A. (2006) Resistance of high-performance concrete (reactive powder concrete) to the effects of a corrosive environment. *Center for Integrated Design of*

- Advanced Structures, Czech Republic, Project No. 1M0579, pp. 1–2.
- [15] Hadi, M.N.S., Algburi, A.H., Sheikh, M.N. and Carrigan, A.T. (2018a) Axial and flexural behavior of circular reinforced concrete columns strengthened with reactive powder concrete jacket and fiber-reinforced polymer wrapping. *Construction and Building Materials*, 172, pp. 717–727.
- [16] Hadi, M.N.S., Goaiz, H.A. and Yu, T. (2018b) Experimental investigation of CFRP-confined hollow-core reactive powder concrete columns. *Construction and Building Materials*, 174, pp. 343–355.
- [17] Hasan, S. (2024) Effect of using waste fibers on the strength properties of sustainable reactive powder concrete. *Kufa Journal of Engineering*, 15(1), pp. 95–107.
- [18] C. Dauriac, "Special Concrete may Give Steel Stiff Competition", Downloaded from the web site of "The Seattle Daily Journal of Commerce" (DJC) at <http://www.djc.com>, special issue, May (1997).