



## Reactive Powder Concrete: Composition, Mechanical Properties, and Structural Applications : A Review

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### ABSTRACT

This paper reviews the composition, mechanical properties, and structural applications of Reactive Powder Concrete (RPC), an advanced cementitious material that represents a major leap in concrete technology. Unlike conventional concrete, RPC contains no coarse aggregates. Instead, it relies on a carefully engineered mixture of cement, silica fume, fine sand, superplasticizers, and steel fibers to achieve an ultra-dense microstructure. The result is exceptional mechanical performance, with compressive strengths ranging from 170 to 800 MPa, depending on the curing method and mix design. The review of previous studies reveals that heat treatment significantly enhances strength, with curing at 90°C raising compressive strength from 120 MPa to 180 MPa. Adding steel fibers at volume fractions of 1–2% improves splitting tensile strength by up to 39%, flexural strength by 29%, and impact resistance by nearly 150%. Interestingly, some researchers successfully incorporated crushed coarse aggregate into RPC without reducing compressive strength, contradicting early assumptions that coarse aggregate must be eliminated. Structural applications, including beams, T-beams, and bridge decks, demonstrate superior load capacity, ductility, and crack control. However, RPC remains expensive, requires high cement content, and often needs special curing conditions, limiting its widespread use. This review concludes that while RPC is an outstanding material for high-performance applications, further research is needed to reduce costs and validate long-term durability under real-world conditions.


## 1. Introduction

Reactive powder concrete (RPC) represents one of the most significant in concrete technology since the development of High-Performance Concrete (HPC) [1]. RPC was first developed in France in the early 1990s by Pierre Richard and colleagues at Bouygues, aiming to overcome the limitations of traditional concrete by eliminating coarse aggregates, optimizing particle packing, and enhancing homogeneity and microstructure [2][1][3]. RPC achieves compressive strengths ranging from 150–230 MPa (RPC200) up to 800 MPa (RPC800), far

surpassing HPC[2][1]. The absence of coarse aggregates, use of fine powders (e.g., silica fume, quartz powder), and dense particle packing result in significantly lower porosity and permeability, enhancing resistance to gas, liquid ingress, and corrosion[3], [4]. The addition of fibers (steel, basalt, glass, polypropylene) further improves ductility, crack resistance, and tensile properties[5]. Splicing is essential in reinforced concrete (RC) beams due to bar length limitations and construction needs[6]. However, improper splice design or execution can reduce flexural strength, ductility, and increase failure risk [7], [8], [9]. Modern research shows that

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optimizing splice length, configuration, and strengthening techniques can signify Lap splices (contact and non-contact) are the most common, but their effectiveness depends on lap length, bar diameter, concrete strength, and transverse reinforcement. Insufficient lap length is a primary cause of debonding and premature failure, whereas the bond in splice improved it enhances the performance of RC beams with spliced reinforcement [10][8]. Short or inadequate lap splice lengths reduce both flexural strength and ductility, leading to premature failure at the splice zone and lower load-carrying capacity[11]. Use of ultra-high-performance fiber-reinforced concrete (UHPC), rapid-hardening concrete (RHC), or hybrid fiber mixes can significantly increase the flexural strength of lap-spliced beams, sometimes allowing for reduced splice lengths without compromising performance [12][13].

### 1.1 Application of RPC

RPC used widely in the reinforced concrete structures such as:

- 1- Bridge and footbridges where the high strength of RPC allows for slender, lightweight designs and longer spans; improved durability against harsh environments [14] .
- 2- Composite steel-concrete structures where the RPC enhances joint efficiency, and improves crack resistance in steel girder–concrete slab systems [15].
- 3- For military purpose and low permeability building
- 4- Tunnel and harsh environment, the characteristics of RPC of low permeability and high durability extend service life in aggressive conditions[2].

Figure 1 shows some applications for reactive powder concrete such as seonyu and Sherbrook foot bridges in South Korea and Canada also it used in public concrete benches [13], [16].

### 1.2 Composition of RPC

RPC contain high cement content, silica fume, fine sand (grain size distribution of 150-

600  $\mu\text{m}$  as a replacement of natural coarse and fine aggregates), in other way, RPC consists from only fine materials and special water reducer (superplasticizer) should be used so that it makes possible to adopt water-cement ratio less than 0.20, and special fine fibers[7] [17].



Figure 1 Application of RPC [18][19]

Each component of RPC supports a special idea allowing for increasing the strength, ductility, and durability of the material. With its superior properties, the use of RPC has a number of advantages when compared with currently used conventional and high performance concretes.



Figure 2. Constituents of RPC [20]

### 1.3 Mechanical properties

RPC has superior behavior than normal concrete in all aspects. In compressive strength, RPC typically achieves compressive strengths ranging from 170–680 MPa, significantly higher than conventional and high-performance concretes [2]. Industrial-scale mixes can reach 200 MPa, and optimized lab mixes have reported up to 134 MPa with specific additives [2]. Flexural

strength ranges from 25–102 MPa, and axial tensile strength is usually 4–12 MPa, with splitting tensile and flexural strengths higher than axial tensile strength. Fiber reinforcement in mix (steel, basalt, glass, or carbon fibers) can further enhance these values and improve ductility [2][21].

RPC is inherently brittle at high strength, but the addition of fibers (steel, basalt, glass, or carbon) significantly increases toughness, energy absorption, and resistance to crack propagation [2]. The elastic modulus is high and relatively stable across temperature variations, with only minor changes even at ultra-low or elevated temperatures [2][22].

The RPC structural elements such as beams, slabs, corbels, and composite decks demonstrate high load-bearing capacity, excellent ductility, and reduced crack widths even without increasing slab thickness. Also, high fiber content enhances ultimate load and deflection capacity, while reinforcement ratio has a lesser but still positive effect [14].

## 2. Previous Researches on RPC

**Richard and Cheyrezy (1995)** [1] aimed to develop RPC, an ultra-high- by eliminating coarse aggregates and optimizing particle packing. Their methodology involved creating two mixes: RPC 200, cured at 20-90°C, and RPC 800, which required pre-setting pressurization (50 MPa) and high-temperature curing (250-400°C). The mixtures used Portland cement, silica fume, fine sand, and crushed quartz, with compressive strengths reaching 170-230 MPa for RPC 200 and an exceptional 490-810 MPa for RPC 800. Ductility was provided by incorporating small, straight steel fibers (0.15mm diameter, 13mm long). This approach produced a composite with metal-like strength and high fracture energy (up to 40,000 J/m<sup>2</sup>). This study highlighted and comprehensively demonstrated of how microstructure design can revolutionize concrete performance. However, a significant weakness is the complex manufacturing process for RPC 800, involving pressure and heat treatment, which limits its

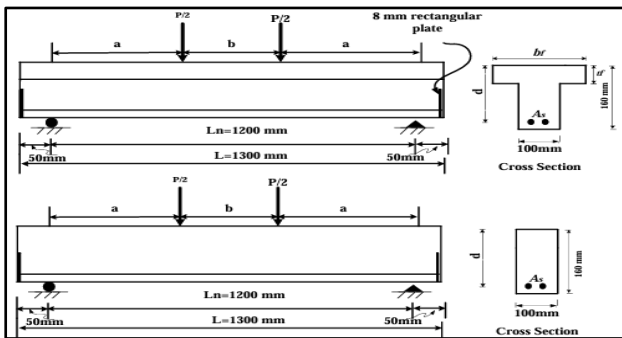
practical, large-scale application to precast elements.

**Jungwirth (2002)** [23] studied the effect of heat treatment of RPC samples at 90o C, in comparison with the samples moist cured at 20o C, on their compressive and splitting tensile strength. The RPC mix was containing 638 kg of cement, 231 kg of crushed furnace slag, 239 kg of silica fume, 1085 kg of furnace slag sand, 23.7 kg of superplasticizer, 116 kg of metallic fibers (with a length of 25 mm and a diameter of 160 µm), and 173 liters of water. The results indicated that the heat treatment at 90o C caused an increase in compressive strength from 120 to 180 MPa, and in flexural strength from 25 to 35 MPa.

**Kadri (2012)** [24] investigated the compressive strength of concrete containing silica fume at low water-cementitious materials ratios with a naphthalene sulphonate superplasticizer. It was found that the increase of the compressive strength of concrete depends much more on the decrease of the water/cementitious materials ratio than on the replacement of silica fume with cement. It was also shown that the compressive strength increases with the silica fume content up to 20% and reaches a maximum value for a 10 to 15% SF level.

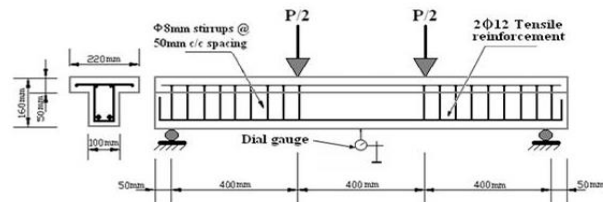
In 2012, **Khalil** [25] aimed to modify RPC by adding crushed coarse aggregate (12.5 mm max size) and evaluate its mechanical properties. The methodology used a mix with 900 kg/m<sup>3</sup> cement, 0.23 water-cement ratio, 3% superplasticizer, 20% silica fume, and hooked or crimped steel fibers (0–1% volume). Specimens were hot-water cured at 60°C for 3 days, achieving 139–150 MPa compressive strength. The findings showed that crushed coarse aggregate did not reduce strength, contradicting earlier models, and 1% hooked steel fibers increased splitting tensile strength by 39%, flexural strength by 29%, and impact resistance by up to 148%. Strengths include systematic testing of multiple mechanical properties and practical fiber recommendations. The conclusion need further researches for the validation of the finding concluded in this study.

**Al-shafii (2013)** [26] investigated the shear behavior of RPC T-beams without stirrups. The research evaluated the effect of various parameters like steel fiber volume, flange dimensions, and shear span-depth ratio affect shear capacity. The experimental program involved testing sixteen beams as shown in Figure 3 made of RPC (101-149 MPa) with varying fiber content (0-2%) and longitudinal reinforcement, all designed to fail in shear. The findings showed that a 2% steel fiber volume increased ultimate shear strength by over 170%, and the presence of a flange significantly enhanced load capacity and ductility compared to rectangular sections. The study's strength is its systematic analysis of multiple influential variables on a novel material. Also, based on this study, the high steel fiber ratio can compensate the stirrup entirely for the shear strength.



**Figure 3.** Specimen Details by Researched [26]

The research by **Al-Hassani et al. (2014)** [27] examined the flexural behavior of RPC T-beams, focusing on the impact of steel fibers (0%, 1%, and 2%) and silica fume (15%, 20%, and 25%) on their mechanical properties. The beams were tested for first crack load, ultimate load, and deflection and related structural aspects under two points of loading as shown in Figure 4. The results indicated that increasing steel fiber content significantly improved both the load-bearing capacity and ductility of the beams, with a 57.32% increase in ultimate load at 2% fiber volume. Silica fume, however, had a lesser effect, showing only modest improvements in load capacity. The study's strengths lie in its detailed experimental approach, while the limited silica fume range and lack of dynamic loading tests are potential weaknesses



**Figure 4.** Details of the tested beams [27]

**Al-Mohsen (2018)** [28] investigated the structural performance RPC non-prismatic beams (tapered beams). The study aimed to analyse how concrete type, tapering ratio, and reinforcement details influence structural behavior of tapered RPC beams. The study involving tested nine beams, with RPC's exceptional 80 MPa compressive strength compared directly to standard 25 MPa normal concrete. The experimental variables included the ratio of tensile and shear reinforcement, alongside the geometry defined by the tapering ratio and its direction. Figure 5 shows the effect of superplasticizer on the mix workability.

The findings were significant, demonstrating that RPC dramatically enhances performance. In tapered beams, it increased the cracking and ultimate loads by 70% and 57%, respectively, compared to normal concrete. The research also revealed that a higher tapering ratio improves load capacity, a crucial finding as it achieves this even with a reduced concrete volume. Perhaps the most striking result was the 60% increase in ultimate load when the beam was tapered towards the top, compared to a standard prismatic beam.



**Figure 5** Effectiveness of superplasticizer [28]

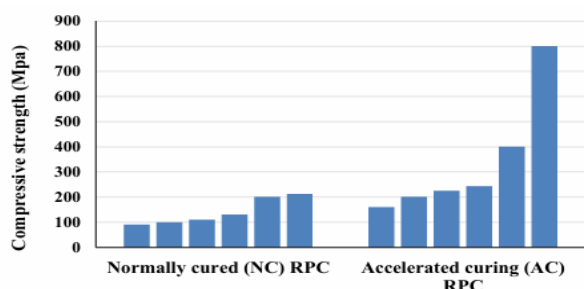
**Velichko and Vatin (2022)** [29] conducted a study aimed at optimizing the dispersed composition of reactive powder concrete to minimize interparticle voids and enhance both the solid phase concentration and compressive strength. The research focused on developing a

high-performance, self-compacting concrete mixture without coarse aggregate, utilizing a multicomponent binder that included Portland cement, finely ground granulated blast furnace slag, microsilica, and a highly dispersed cement fraction. The mixture also incorporated a polycarboxylate-based superplasticizer and a high-valence hardening accelerator. Specimens were designed with varying cement contents—650, 700, and 750 kg/m<sup>3</sup>—and were tested for compressive strength at 2 and 28 days, revealing impressive results of 52–74 MPa and 128–163 MPa, respectively. No traditional reinforcement was used, as the study emphasized dense particle packing and microstructural refinement. The findings highlighted the critical role of optimized particle size distribution, where mineral additives like slag and microsilica filled voids between larger clinker particles, reducing void content by 12–14% and more than doubling concrete strength. The most significant outcome was the effectiveness of a bimodal clinker component and the synergistic use of superplasticizers with hardening accelerators, which allowed a 20% reduction in water content. The study's strengths lie in its comprehensive microstructural analysis using SEM, TGA, and XRD, supported by empirical data that validate the proposed physical model of particle packing. However, a limitation is the lack of long-term durability data and real-scale application trials, which are essential for practical validation. Additionally, the high cement content may raise concerns about heat release and economic feasibility, though the partial use of industrial by-products like slag offers an eco-friendly advantage.

**Delphi (2024)** [30] investigated the behavior of reinforced reactive powder concrete beams under the combined effects of torsional and bending moments, aiming to understand how this high-performance material performs under such complex loading and to develop predictive models. The methodology involved testing sixteen simply supported beams measuring 1500 mm in length, 200 mm in depth, and 150 mm in width, with variables including concrete type (normal concrete with 33 MPa compressive

strength versus reactive powder concrete with 110 MPa compressive strength), longitudinal reinforcement ratios (0.009 and 0.016), transverse reinforcement ratios (0.0042 and 0.0075), and torsion-to-bending moment ratios (0, 0.5, 1, and infinity). The findings revealed that using reactive powder concrete instead of normal concrete significantly improved cracking capacity by up to 136 percent and ultimate capacity by up to 118 percent, particularly at a torsion-to-bending ratio of one, while also producing stiffer moment-deflection and torque-rotation responses with substantially reduced deformations. A significant strength of this research lies in its comprehensive experimental program examining combined loading on an advanced material with limited prior investigation in this area. A notable weakness is the relatively small number of specimens per variable group, which limits the statistical robustness of the conclusions, and the use of only one reactive powder concrete mix design, preventing generalization across different compositions.

In their review **Algburi and Alghazali (2025)** [31] on RPC, the researchers highlighted RPC's composition, which includes cement, fine aggregates, silica fume, superplasticizers, and steel fibers, achieving compressive strengths between 170 MPa and 800 MPa, depending on curing techniques. The research emphasizes RPC's enhanced properties like high compressive strength, low porosity, and resistance to freeze-thaw cycles and abrasion. The findings show RPC's effectiveness in infrastructure projects, such as bridges and high-rise buildings, improving durability and performance. They stated that based on researches review, the accelerated curing can affect significantly on the compressive strength of RPC as shown in Figure 6



**Figure 6.** Compressive strength of RPC in Normal and Accelerated Curing Condition [31]

### 3. Conclusion

This study reviewing a several previous studies and scientific on reactive powder concrete, here is what we can conclude:

- RPC is way stronger than normal concrete, with compressive strength reaching 170–800 MPa, mainly because it has no coarse aggregates and uses very fine powders instead.
- Heat curing makes a big difference, it can boost compressive strength from around 120 MPa to 180 MPa.
- Adding steel fibers (about 1–2% by volume) significantly improves tensile strength, flexural strength, and impact resistance. In some cases, fibers can even replace traditional stirrups in beams.
- Surprisingly, adding crushed coarse aggregate to RPC does not reduce its strength, which goes against what early researchers believed.
- RPC performs excellently in structural elements like beams, T-beams, and bridges, offering higher load capacity, better ductility, and smaller cracks.
- RPC is still expensive, uses a lot of cement, and often needs special curing conditions. This makes it hard to use widely in everyday construction projects.

More research is still needed, especially on long-term durability, cost reduction, and real-world large-scale applications.

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