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Impact of fiber usage, high heat, and fire resistance on the mechanical properties of reactive powder concrete (RPC)

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Reactive Powder Concrete (RPC); High-Performance Concrete; Steel Fibers; Heat Treatment; Durability; Mechanical Properties; Thermal Resistance

Abstract:

The object of research is to investigate the composition, processing methods, and mechanical behavior of reactive Powder Concrete (RPC), highlighting its superior durability, impermeability, and resistance to environmental degradation. Reactive Powder Concrete (RPC) is an advanced high-performance construction material developed to overcome the limitations of conventional concrete, such as low strength, poor durability, and susceptibility to chloride and sulfate attacks. RPC achieves exceptional mechanical properties with compressive strengths ranging from 170–800 MPa and flexural strengths up to 250 times that of ordinary concrete through ultra-dense particle packing, elimination of coarse aggregates, and the incorporation of steel fibers. **Methods.** The mechanical properties and processing techniques of powdered concrete are compared with the characteristics of different kinds of concrete currently in use. This study emphasizes RPC's revolutionary potential in contemporary building by combining research on mix designs, curing regimes, and fiber reinforcing. It addresses robustness in harsh environments as well as sustainability (by utilizing industrial byproducts). **Results.** Key findings indicate that heat treatment (90°C–250°C) and pre-setting pressure significantly enhance compressive strength, while steel fibers improve flexural toughness and ductility. Additionally, RPC exhibits remarkable thermal stability, with minimal weight loss and retained strength at high temperatures (up to 800°C), making it suitable for extreme environments. Comparative analyses with ordinary and high-performance concrete demonstrate RPC's advantages, including reduced porosity (2–6%), enhanced resistance to chloride penetration, and superior performance under fire exposure. However, optimal fiber reinforcement and curing conditions are critical to mitigating brittleness and ensuring structural reliability.

1 Introduction

Concrete is one of the most widely used construction materials globally, but conventional concrete suffers from inherent weaknesses such as low tensile strength, porosity, and susceptibility to chemical attacks from chlorides and sulfates. These limitations reduce its durability, particularly in harsh environments, necessitating the development of advanced alternatives. High-performance concrete (HPC) emerged as an improvement, offering enhanced strength and durability. However, the pursuit of even greater performance led to the innovation of Reactive Powder Concrete (RPC), a revolutionary material first patented in 1994 by a French company. RPC distinguishes itself through its ultra-high compressive strength (ranging from 170–800 MPa), exceptional flexural capacity, and near-impermeability. Unlike conventional concrete, RPC eliminates coarse aggregates, optimizing particle packing density to minimize the weak interfacial transition zone (ITZ) responsible for microcracking and reduced durability. Additionally, the incorporation of steel fibers enhances ductility, eliminating the need for traditional reinforcement in some applications. Supplementary cementitious materials like silica fume, fly ash, and slag further improve resistance to chemical degradation while refining the microstructure. The superior mechanical and durability properties of RPC have enabled its use in landmark infrastructure projects, such as the Sherbrooke Footbridge in Canada and France's Saint-Pierre-la-Cour Bridge, demonstrating its potential for long-span, lightweight, and low-maintenance structures. Beyond structural applications, RPC's resistance to extreme temperatures, radiation, and corrosion makes it suitable for nuclear containment, military installations, and seismic-resistant designs.

The composition, processing techniques, and mechanical behavior of RPC are investigated in this research, with an emphasis on:

1. Microstructural advantages over ordinary concrete, including the elimination of ITZ weaknesses.
2. Optimized curing techniques (e.g., heat treatment, autoclaving, and pressure application) to achieve strengths exceeding 200 MPa.
3. The role of fibers (steel, polypropylene, carbon) in enhancing flexural toughness and fire resistance.
4. Comparative performance under high-temperature exposure, showcasing RPC's stability at up to 800°C.

By synthesizing research on mix designs, curing regimes, and fiber reinforcement, this study highlights RPC's transformative potential in modern construction, addressing both sustainability (through industrial byproduct utilization) and resilience in extreme conditions. Reactive powdered concrete is a new type of high-strength concrete that was registered in 1994 by a French company. There were two grades for RPC design. The first, known as RPC200, had a tensile strength of 20–50 MPa and a compressive strength of 170–230 MPa. The second one, called RPC800, has tensile and compressive strengths of 45–140 MPa and 500–800 MPa, respectively [1]. When utilized in high-performance concrete, some industrial by-products, such as fly ash, silica fume, and ground granulated blast-furnace slag, offer strong defense against sulfate assault and chloride penetration [2]. Additionally, a low chloride diffusion coefficient is provided by various concrete compositions that are binary and ternary based [3]. For example, Ting et al. investigated how the durability and compressive strength of high-strength concrete were affected by the addition of 10% and 15% ultra-fine slag or silica fume. While the chloride ion penetration resistance of concretes made with ultra-fine slag and silica fume is very similar, cement paste containing ultra-fine slag demonstrated superior fluidity and dispensability compared to that containing silica fume [4]. Reactive powder concrete has a compressive strength of around 200 MPa, four times that of high-performance concrete, and a flexural strength and ductility of almost 250 times that of regular concrete. Because steel fibers are included in this form of concrete, it offers additional benefits above other standard concretes, including ductility and high flexural strength. In comparison to other concretes, it also has a high tensile strength to compressive strength ratio. By packing with particle gradation of all the concrete ingredients to achieve the greatest density, reactive powder concrete eliminates such coarse particles and improves the microstructure [5]. Because of its superior mechanical and long-lasting qualities, reactive powder concrete has been used effectively in several civil engineering projects. For example, the world's first RPC200 footbridge was constructed in Sherbrook, Canada [6]. This concrete has a homogenous microscopic structure, low porosity, and very good durability thanks to the removal of coarse particles and the addition of fine aggregates. Concrete of this kind is referred to as self-compacting concrete. In locations where compaction is not feasible because of excessive reinforcement or access to the concreting site, self-compacting concrete reduces the quantity of unintentional air in the concrete and enables concreting to proceed without the requirement for compaction. The first bridge constructed in France using this kind of concrete was the Saint-Pierre-la-Cour. Ten precast girders were used in its construction, and pre-tensioned strands were used to pre-stress them. These components all turned out to be incredibly resilient and low-maintenance [7]. Furthermore, Liu et al. documented many uses of reactive powder concrete in bridge engineering [8] and proposed that it may take the role of reinforcing steel bars [9].

2 Materials and Methods

2.1 Transmission area in ordinary concrete and reactive powder concrete

Microscopic studies on the texture of concrete revealed the fact that concrete has three different phases of aggregate, cement paste, and transfer zone, and the properties of these three phases alone are very influential on the final properties of concrete. The weakest phase in concrete is the transition zone, and many weaknesses of concrete, such as low tensile strength, are due to the effect of this phase. Cement paste crystals are difficult to form at the transfer site or at the junction of cement paste and aggregate. This is due to the presence of a large surface of aggregate and its prevention of the growth of cement crystals. On the other hand, due to the accumulation of local water around coarse aggregates, the ratio of water to cement in these areas is high, and the formed crystals are weaker. As a result, this area has very high porosity and permeability. The removal of coarse aggregates in reactive powder concrete has eliminated the weaknesses caused by the connection of these aggregates to the cement paste and has practically turned the reactive powder concrete into an impermeable concrete with very high compressive strength. Reactive powdered concrete expanded dramatically in the 1990s. Before that, high-performance concrete was the most important and suitable option for high-strength and high - performance concretes. This concrete is almost impermeable, which is why it does not have many of the weaknesses of conventional concrete, such as weakness against frost cycles, corrosion of reinforcement, and attack of harmful ions. Also, the major weakness of concrete, i.e., low tensile strength, has greatly increased so that in one type of reactive powder concrete using steel fibers, there is no need to use reinforcement in concrete. Among the notable characteristics of this particular type of concrete are:

1. Reactive powdered concrete is a suitable alternative to high-performance concrete and has the necessary structural potential to combine with steel.
2. Much higher strength and higher shear capacity significantly reduce dead loads, and no restrictions on the shape of structural members.
3. Unlike ductile concrete, its ductile tensile failure mechanism makes it resistant to all initial tensile stresses, even directly, and eliminates the need for shear clamps and axial steel reinforcements.
4. Reactive powder concrete improves the seismic properties of the structure by reducing the critical loads with lighter members, larger deformations of the span at the same time as the smaller cross-section of the member, and increasing energy absorption.
5. Lack of porosity, or to a very small extent, prevents the penetration of liquid or gas or the penetration of radioactive radiation. For example, there is no possibility of leakage and scattering of cesium rays in it, and the possibility of leakage of tritium in it is 45 times less than that of other types used in the nuclear industry.

In prestressed concrete, the use of reactive powder concrete can significantly increase the tensile strength. In this way, it is possible to make much larger openings, especially for stairs. Increasing the span means reducing the number of required piers on the stairs, which increases safety in the case of stairs under which traffic passes, and in the case of bridges that are built on the river. Reducing the number of foundations that are exposed to water flow and the resulting damage means increasing life expectancy and reducing maintenance costs. Undoubtedly, the main advantage of reactive powder concrete is to improve the durability of concrete structures. Expanding the use of concrete in different environments with different conditions and the presence of environmental factors such as glacial cycles, attack of sulfates, chlorides, and other problems has caused today's durability, along with the compressive strength of concrete, to be considered one of the main design parameters. The excellent durability of powdered concrete, reactive against various factors, has made it an ideal material for the execution of long-lasting structures. Figure 1 and Table 1 show a comparison of the mechanical behavior of reactive powdered concrete in different conditions compared to other existing concretes. Table 2 shows some of the durability parameters of reactive powder concrete compared to ordinary concrete and high-performance concrete.

Table 1. Mechanical characteristics of reactive powdered concrete compared to high-performance concrete and ordinary concrete

	Reactive powder concrete	High-performance concrete	Ordinary concrete
pushing resistance (MPA)	150-200	40-100	20-40
Creep coefficient (Cu)	0.2-0.8	1.6-1.9	2.35
Porosity (%)	2-6	10-15	20-25
Tensile strength (Kg/cm3)	70-250	-	25-32
Young’s Module (Mpa)	56000-63000	32000-56000	14000-42000

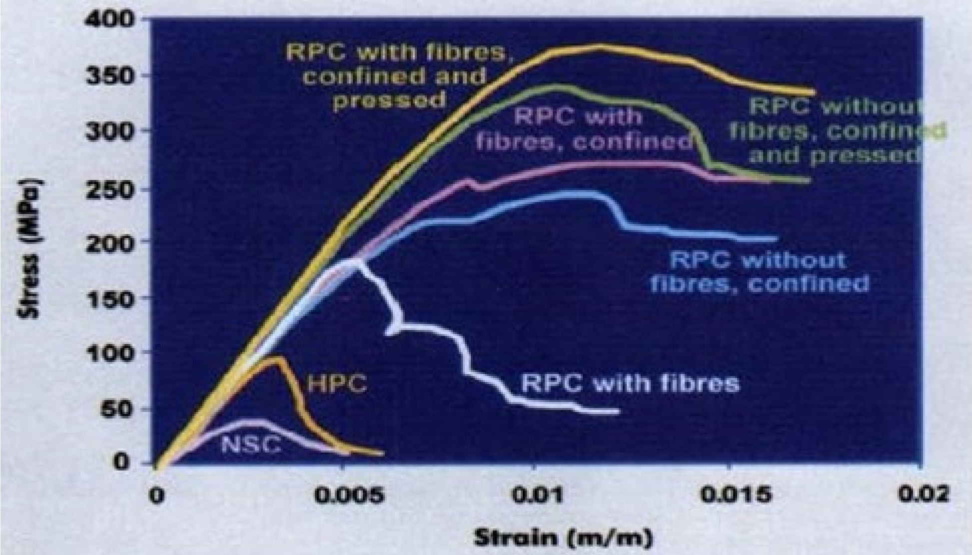

Fig. 1 - Comparison of mechanical performance of powder concrete with other existing concretes
Image by the author of the article

Table 2. Parameters related to durability

	Ordinary concrete	HPC	UHPC
Deep carbonization (after 3 years)	7	4	1.5
Chlorine ion diffusion depth penetration (mm)	23	8	1
Frost cycle resistance (g/m2)	1500	150	20-25
Water absorption factor	60	11	1

2.2 Comparison of processing methods

Heat plays an important role in the processing of reactive powder concrete. Research has shown that high-temperature curing improves many of the properties of this type of concrete. Samples can also be pressed before setting and during setting, which is effective in improving its properties for a variety of reasons, including increasing density. Curing at temperatures between 20 ° C and 90 °C gives concrete with a compressive strength of 200 MPa. The production of reactive powder concrete with a compressive strength above 800 MPa requires pre-setting pressure and curing at 250 ° C. Pressing the sample removes trapped air and increases the density of the reactive powder concrete. This type of concrete can only be used in prefabricated elements. It also has excellent impact resistance and can be used for military structures and equipment. In this research, the possibility of producing reactive powder concrete with a compressive strength of at least 150 MPa and also the use of steel fibers was investigated. For this purpose, some materials required in the preparation of this concrete, including superplasticizers, siliceous sand and silica powder (broken quartz) were prepared. In this study, parameters such as selecting the appropriate number of materials from the mentioned materials by examining their effect on compressive and psychological strength of concrete and then investigating the effect of various processing methods on the properties and finally determining the appropriate mixing plan and use of steel fibers to achieve the compressive and flexural strengths were further examined with acceptable fluency. ASTM C 230 / C230M [10] method was used for psychological evaluation of concretes and ASTM C 1609 / C 1609M [11] method was used to determine their flexural strength. In this study, after removing the samples from the mold after 48 hours, four methods were used to process the concrete.

- days in 90 °C water and 24 days in 20 °C water
- days in 90 °C water and 23 days in 20 °C water
- 5 days in 90 °C water and 21 days in 20 °C water
- 26 days in 20 °C water

By comparing the aforementioned techniques and using Figure 2, it can be inferred that while high temperature curing makes reactive powder concrete stronger, three days of curing in water at 90 °C is enough to finish the hydration processes of this kind of concrete.

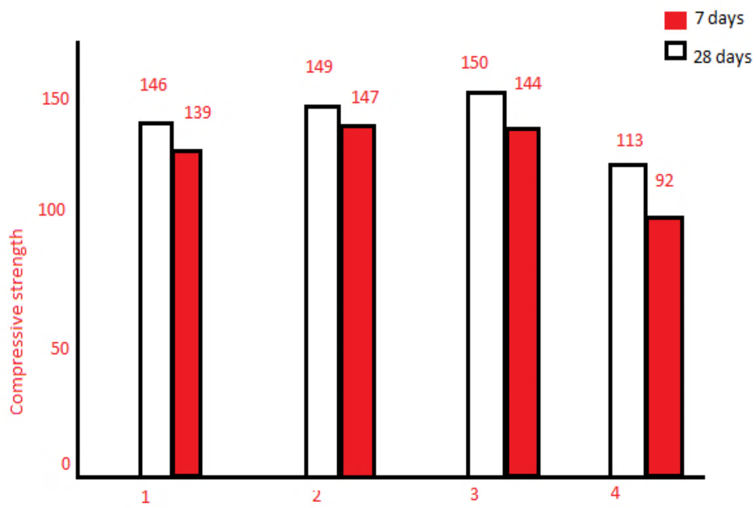

Fig. 2 - Effect of various processing methods on compressive strength of 7-day and 28-day tests
Image by the author of the article

Taking into account how different processing techniques affect compressive strength among this specific type of concrete's noteworthy attributes are:

1. Using the available materials and the appropriate mixing scheme, reactive powder concrete with a compressive strength of at least 160 MPa can be achieved.
2. It is suitable to process this type of concrete at a temperature of 90 C° for at least three days
3. In the case of heat treatment, this type of concrete can be used for immediate repair work such as repairing bridges and other vital arteries.
4. Fibers must be used in this form of concrete in order to provide the appropriate flexural strength.

A laboratory investigation on the impact of silica fume on the functionality of reactive powder concrete was carried out in 2012 by Khaloo et al. [12] They looked at a few of this kind of concrete's characteristics in their essay.

After obtaining the optimum amount of superplasticizer by the marsh cone, calculating and obtaining six suitable mixing designs with different percentages and performing rheological tests by evaluating the flowability of reactive powder concrete by small slump flow, the samples were poured into molds. And after one day, they were taken out of the mold and processed in three different ways.

1. Normal curing 7 days in 20 °C water
2. Normal curing 28 days in 20 °C water
3. Processing in hot water 90 °C

3 Results and Discussion

The microstructure study performed by two scanning electron microscopy (SEM) and energy dissociation analysis (EDS) tests states that the main reason for improving the microstructure and strength of heat-treated concrete specimens is to create a suitable environment for the pozzolanic reaction. These tests showed that heat treatment in water at 90 °C led to the production of higher amounts of hydrated calcium silicate gel (C H S), which led to improved hydration conditions. When large amounts of silica fume are used in the matrix, a significant proportion of these particles only act as fillers and not only do not produce the highly resistant calcium silicate hydrate (CHS) gel, but clump together. The presence of weak and low-strength areas in the matrix of reactive powdered concrete also occurs, for this reason, excessive amounts of silica fume reduce the strength of reactive powder concrete. Figures 3 and 4 are the results of scanning electron microscopy tests and energy dissociation analysis and are magnified 500 times. Portlandite crystals are clearly visible in the left corner of Figure 3, which was prepared at 28 days of age using conventional processing. Figure 4 also shows that heat treatment results in a dense structure and the production of more calcium hydrate calcium silicate gel in reactive powder concrete.

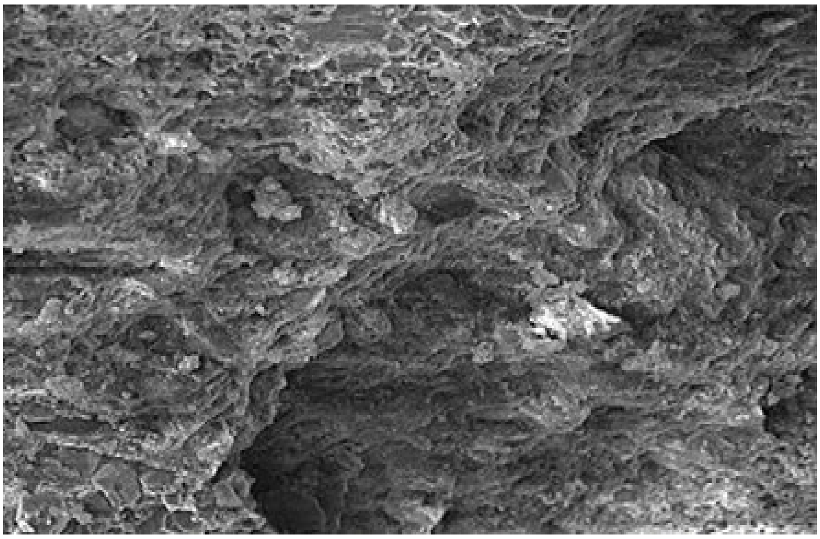

Fig. 3 - shows the basic design's microstructure after 28 days of typical processing
Image by the author of the article

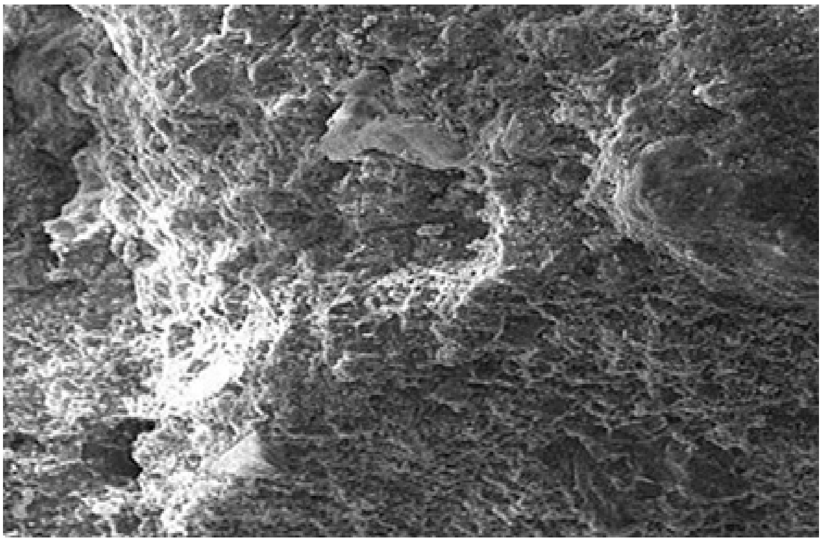

Fig. 4 -. The basic design's microstructure after heat treatment
Image by the author of the article

Based on the studies of this research, the following results can be inferred:

1. By increasing the replacement rate of silica fume, the diameter of the flow opening in the small slump test decreases.
2. The highest compressive strength among the studied designs has the Micro silica obtained is equal to 109.1 MPa in 28 days by heat treatment.
3. Designs with values 10% And 20% silica fume in heat treatment mode have close results
4. The strength of reactive powder concrete has decreased by increasing the amount of silica fume, more than 15% of adhesives, in conventional and thermal processing.
5. Reactive powder concrete has a substantially greater modulus of elasticity than regular concrete. Also, reactive powder concrete has a very high brittleness, which in order to solve this problem, it is necessary to use steel fibers in making this type of concrete.
6. The microstructural study shows that heat treatment improves the porosity structure and also improves the pozzolanic reaction conditions by activating silica particles with saturated surface bonds.

In a 2013, Yazichi et al [13] Investigated the mechanical properties (compressive and flexural strength) of reactive powdered concrete under curing methods. They used two processing methods.

- Conventional water treatment
- Autoclave processing

In autoclave processing, their effect was examined by varying pressure, temperature and time. In this research, the performance of silica foam and steel fibers has been evaluated under these two processing methods. For this purpose, four mixing designs were prepared without silica foam and steel fibers, with silica foam and without steel fibers, with silica foam and with steel fibers, and finally without silica foam and with steel fibers. In autoclave processing, 1MPa ,2MPa and 3Mpa pressures were applied at 0, 4, 6, 8, 10, 12 and 24 hours. Based on the study's findings, it can be said that autoclave curing may boost reactive powdered concrete's flexural and compressive strengths, resulting in a concrete's compressive strength exceeding 200 MPa. This concrete type's strength was further enhanced by the addition of steel fibers and silica foam. The impact of various mineral additions on the mechanical characteristics of reactive powdered concrete (compressive strength, flexural strength, and concrete hardness) under various processing techniques was examined by Yazichi et al. [14] in 2009. Class C fly ash and kiln slag (GGBFS) were among the materials used in this investigation. Six mixing schemes were employed for this purpose, and they are shown in Table 3.

Table 3. Powder concrete mixing plan

Material	CTRL	G10F10	G10F20	G10F30	F20	G40
Cement (kg/m^3)	830.00	664.00	581.00	498.00	664.00	498.00
SF (kg/m^3)	291.00	205.00	157.00	141.00	195.00	173.00
GGBFS (kg/m^3)	–	83.00	83.00	83.00	–	332.00
FA (kg/m^3)	–	83.00	166.00	249.00	166.00	–
1 - 3 mm Quartz (kg/m^3)	489.00	521.00	534.00	530.00	516.00	541.00
0.5 - 1 mm Quartz (kg/m^3)	244.00	260.00	266.00	264.00	257.00	269.00
0 - 0.4 mm Quartz (kg/m^3)	244.00	260.00	266.00	264.00	257.00	269.00
Water (kg/m^3)	151.00	151.00	151.00	151.00	151.00	151.00
SP (L/ m^3)	55.00	35.00	34.00	33.00	38.00	35.00
Water from SP	33.00	21.00	20.00	20.00	23.00	21.00
Water/cement	0.18	0.23	0.26	0.30	0.23	0.30
Water/powder	0.13	0.15	0.15	0.16	0.15	0.15
Water/powder	0.16	0.17	0.17	0.18	0.17	0.17
CaO (Mol)	9.40	8.38	7.82	7.27	8.29	7.55
SiO_2 (Mol)	7.22	6.43	6.00	6.06	6.36	6.29
Steel fiber (kg/m^3)	234	234	234	234	234	234
Flow table (mm)	115	115	113	113	114	117
Molar CaO/SiO_2	1.30	1.30	1.30	1.20	1.30	1.20

Processing methods are:

1. Two days in the water
2. 28 days in water
3. Autoclave processing
4. Steam curing

The results of the compressive strength test under the four processing methods can be seen in Figure 5 The results show that steam and autoclave treatment has significantly increased the compressive strength.

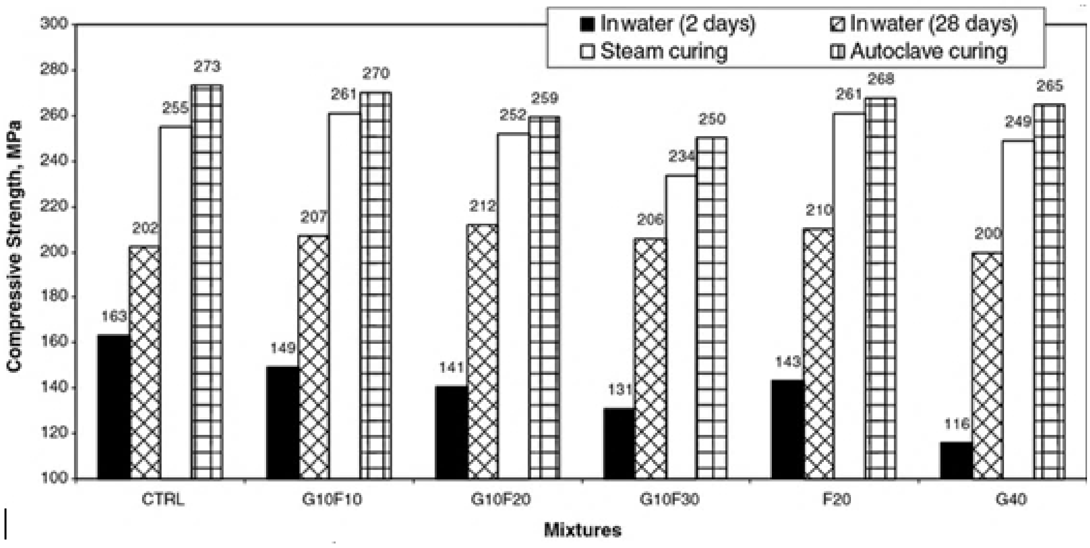

Fig. 5 - Compressive strength under four processing methods
Image by the author of the article

The flexural strength of the six designs under the four processing methods can be seen in Figure 6.

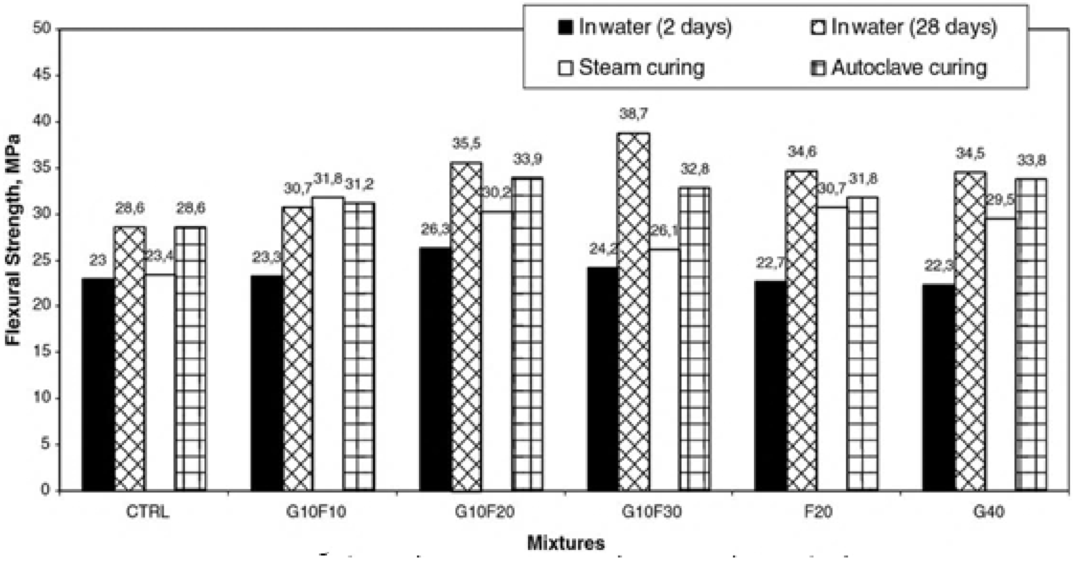

Fig. 6 - Flexural strength under four processing methods
Image by the author of the article

As can be seen, not only has steam and autoclave treatment not increased flexural strength, but in some cases, it has reduced it. Also, the displacement load diagram of four designs under four processing methods is drawn in the diagrams of Figures 7, 8, 9 and 10.

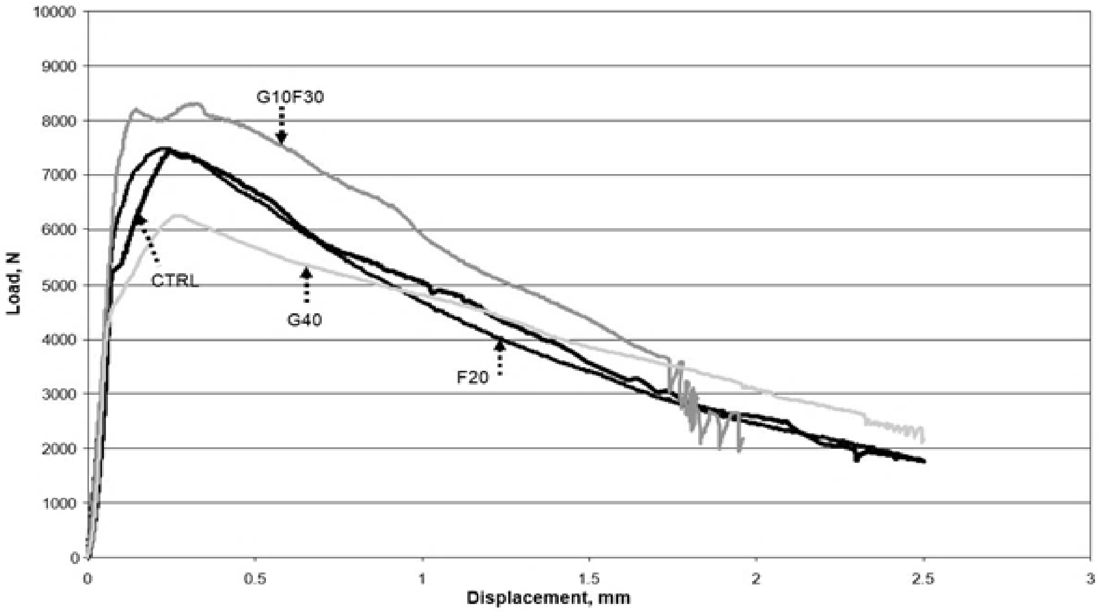

Fig. 7 - Load diagram of the relocation of four designs under water treatment for 2 days
Image by the author of the article

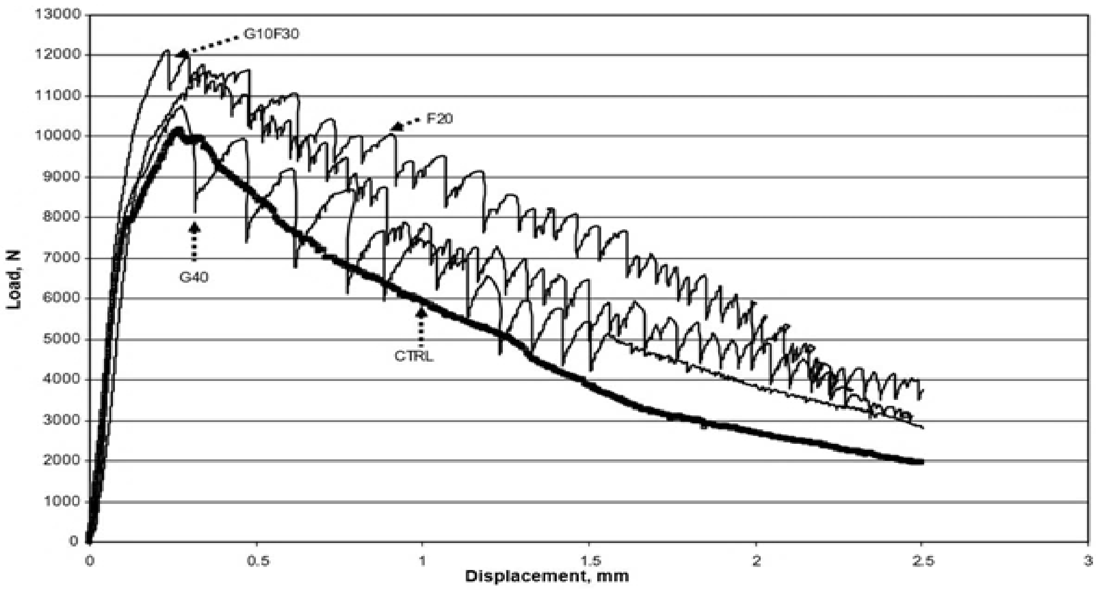

Fig. 8 - Load diagram of the displacement of four designs under water treatment for 28 days
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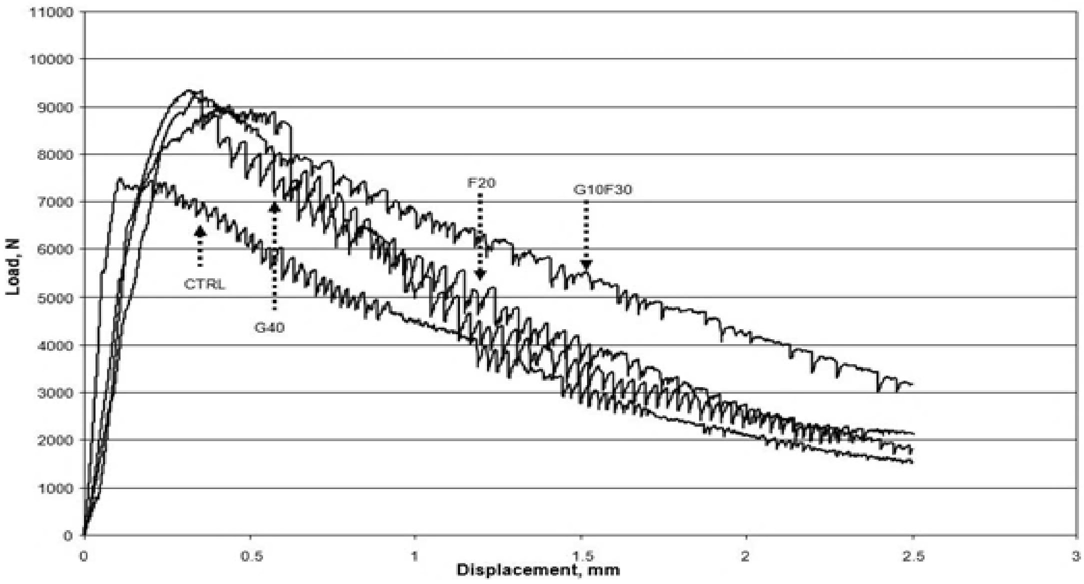

Fig. 9 - Load diagram of the displacement of four designs under steam processing for 28 days
Image by the author of the article

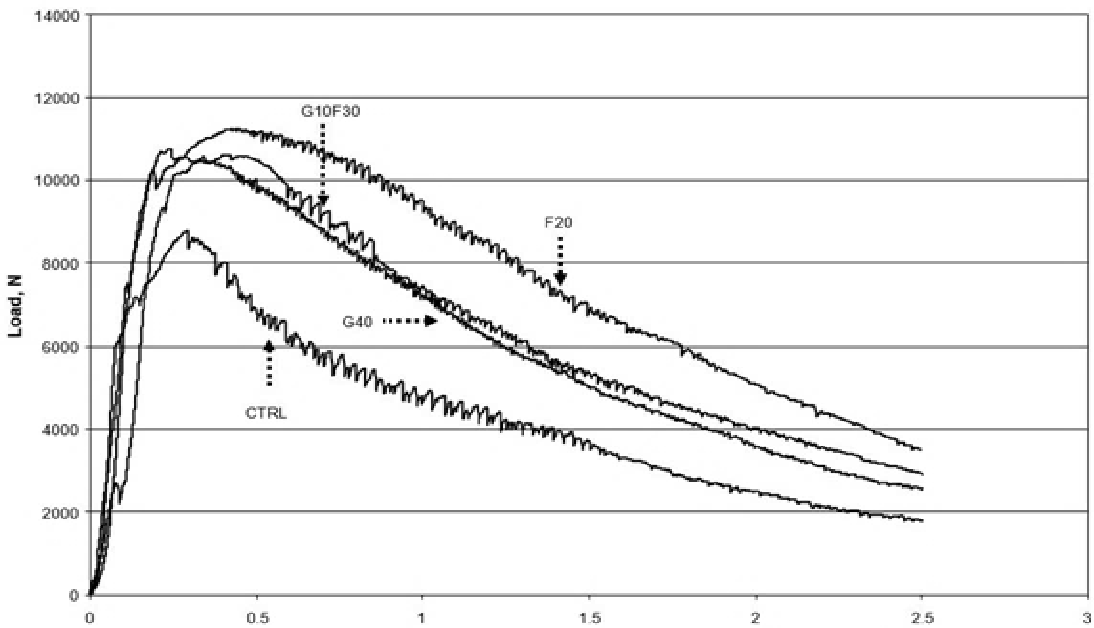

Fig. 10 - Displacement load diagram of four designs under autoclave processing for 28 days
Image by the author of the article

Looking at the diagram in Figure 11, it can be concluded that the addition of fly ash and kiln overhead with a percentage of cement increases the hardness of reactive powder concrete in all four processing methods. Of course, in the processing method, using water retention for 28 days, the maximum hardness of this type of concrete can be achieved.

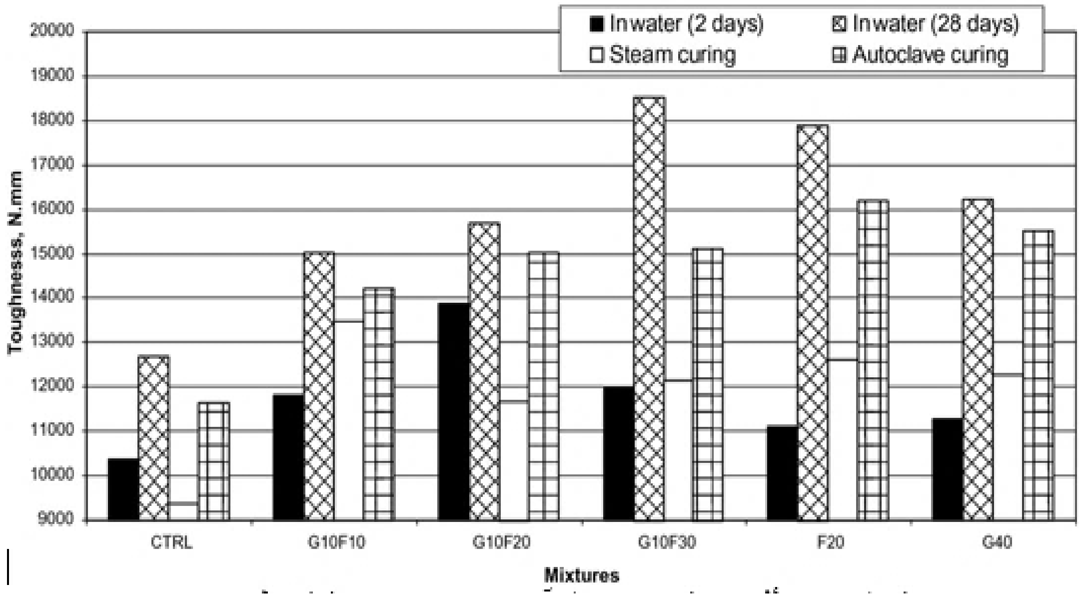

Fig. 11 - The effect of processing methods on the rigidity of six designs
Image by the author of the article

- Compressive strength after steam curing and autoclaving has increased significantly compared to conventional curing and accelerates and improves the hydration reaction. But it has reduced flexural strength and stiffness.
- Addition of fly ash and kiln slag has increased the mechanical properties of reactive powder concrete under various treatments. Consumption of these materials in the concrete industry will also bring environmental benefits, and their replacement instead of cement will reduce the negative effect of steam and autoclave curing on the flexural strength and hardness of reactive powdered concrete.
- The advantages of using minerals such as fly ash and kiln overhead include economic efficiency, reduction of hydration heat and concrete drop, as well as reducing the use of superplasticizers. But on the other hand, the addition of this type of material reduced the modulus of elasticity.

Another study by Ipak et al. [15]. In 2012 examined the effect of pressurized curing on the flexural strength and hardness of reactive powdered concrete. For this purpose, fresh concrete is poured into special molds (according to Figure 13) which are processed under six different pressures (0, 5, 10, 15, 20, and 25 MPa).

Flexural strength improved by 34% due to 5 MPa pressure processing. According to the diagram in Figure 12, the maximum flexural strength obtained is 36.4 MPa. Also, the hardness of concrete has increased almost more than three times and it should be noted that the maximum hardness of 116.96 Nm is under pressure of 25 MPa. Due to the pressure, the volume of the samples decreased by about 7.9% and caused the removal of empty space and free water in the concrete and as a result, its components came closer to each other, which increased the weight per unit volume of reactive powder concrete. Its hardness and strength increased.

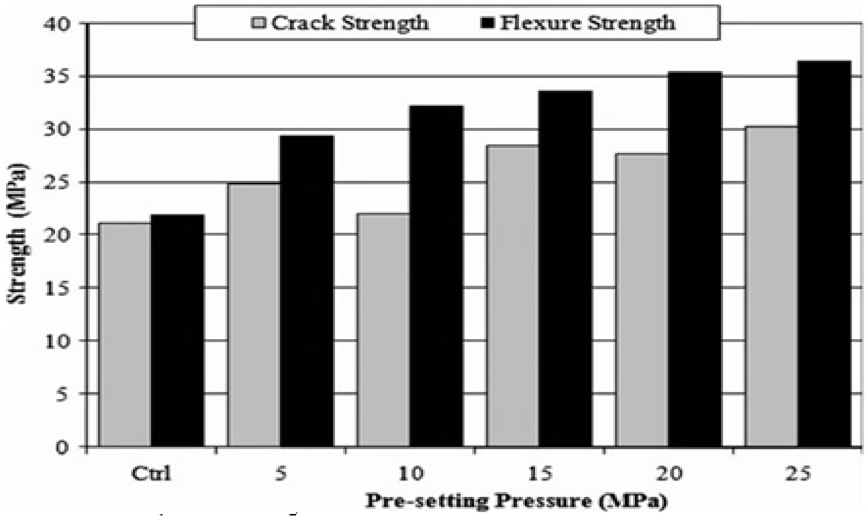

Fig. 12 - Flexural strength and first crack with pressure processing
Image by the author of the article

Other important materials used in reactive powdered concrete are fibers with high tensile strength, which significantly increase the flexural strength, ductility and energy absorption of concrete. For this reason, experts in the concrete industry have taken into consideration the study of how various fibers affect the properties of reactive powdered concrete. For this purpose, various fibers such as steel fibers, polypropylene fibers, carbon fibers, glass fibers and other fibers have been used in this type of concrete. Recently, due to the advancement of nanoscience, a type of fiber called carbon nanotubes has been produced, which has several times the tensile strength of steel and can be used in reactive powdered concrete and significantly increase its characteristics.

In their 2013 study, Mearaji et al. [16] examined how the characteristics of reactive powder concrete were affected by the use of various fibers. For this purpose, a type of short straight steel fibers and a type of fine-grained carbon fibers were used. The amount of steel fibers was considered to be about 2.5% by volume and the amount of carbon fibers was about 2.5% by weight of cement used. Cube samples of compressive strength and prismatic samples of flexural strength of this type of concrete were made using different fibers in the laboratory and the effect of these fibers on its properties, including compressive strength, flexural strength and toughness were investigated. In this research, after removing the samples from the impermeable mold after 48 hours, two methods have been used to process the concrete.

- 3 days in 90 °C water and 23 days in 20 °C water (heat treatment)
- 26 days in water 20 °C (normal processing)

Figure 13 shows the compressive strength of fibrous and non-fibrous specimens. It is observed that, contrary to expectations, the addition of carbon fibers to reactive powder concrete does not have a positive effect on compressive strength. This may be due to the difficulty of working with carbon fibers during mixing and therefore the heterogeneity of the samples made with it. An addition, which was not utilized in this study, is occasionally employed to make it easier to combine carbon fibers with concrete when making concrete using carbon fibers. In contrast to the sample without fibers, the samples' compressive strength rose by around 10% in both processing procedures when steel fibers were added at a volumetric rate of roughly 2.5%. The greatest result in terms of compressive strength (160 MPa) is obtained from a reactive powdered concrete sample that has been heated and contains steel fibers. Additionally, heat treatment greatly increased the specimens' compressive strength and accelerated the pozzolanic reaction in the initial days, as was predicted for all three forms of concrete.

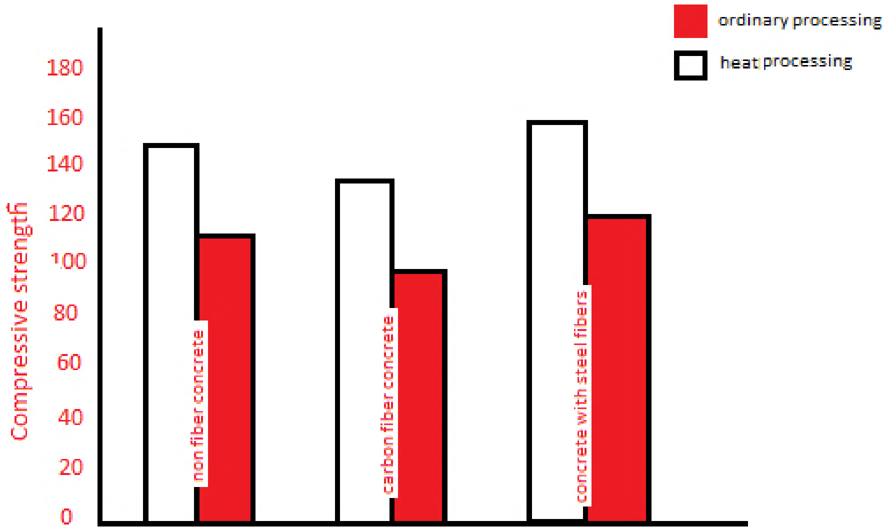

Fig. 13 - Compressive strength of fibrous and non-fibrous specimens
Image by the author of the article

To evaluate the flexural behavior, the specimens were subjected to four-point bending test. The results of bending experiments showed that the bending behavior of the samples is not much different from normal heat treatment. In fibrous specimens, crack propagation was instantaneous and rapid, and failure occurred immediately after the first crack, but in fibrous specimens, the fibers in the reactive powder concrete prevented it from spreading and by bridging between the two sides of the crack, they have delayed its expansion and increased the flexural strength or toughness of the concrete. This problem has been especially evident in samples with steel fibers. The flexural strength of fiber-free and fiber-free specimens is compared in Figure 13. It can be seen that despite the expectation; the addition of carbon fiber did not have a positive effect on flexural strength. As mentioned earlier, this may be due to the heterogeneity of the specimens made with these fibers. However, it can be seen that by adding about 2.5% of steel fibers, the flexural strength of 7 MPa in the fiber-free sample has reached 25 MPa and this shows the significant effect of steel fibers on the flexural strength of concrete.

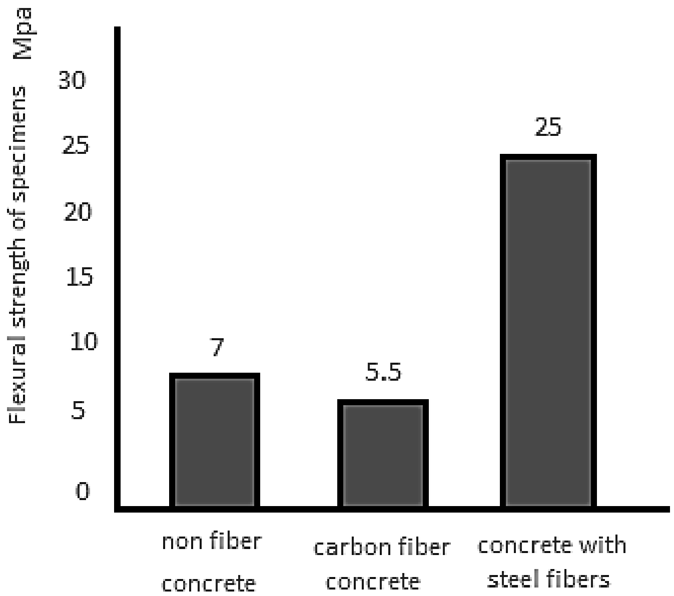

Fig. 14 - Flexural strength of fiber-less and fibrous specimens
Image by the author of the article

The displacement load diagrams of the specimens are shown in Figure 15. The area below these graphs indicates the amount of energy absorption or toughness. As expected, the addition of fibers increased the toughness.

The area under the displacement load curve in the sample with steel fibers is approximately 79 Nm, in the sample with carbon fibers about 3 Nm m and in the sample without fibers about 0.71 Nm, which indicates the significant effect of steel fibers on toughness. Concrete powder is reactive. Consequently, it can be said that steel fibers greatly improve the concrete's flexural strength and toughness while having minimal influence on its compressive strength. Additionally, carbon fiber specimens' toughness increased even though their flexural strength did not rise in comparison to non-fibrous specimens' flexural strength (Figure 14).

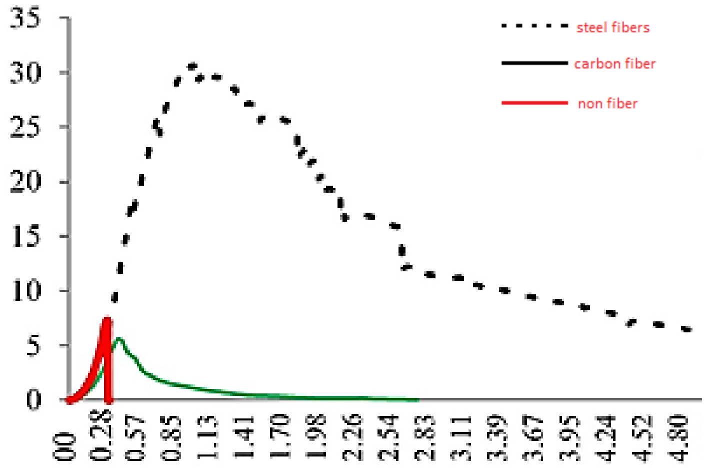

Fig. 13 - Displacement load diagrams of fiber-free specimens with fibers under bending test
Image by the author of the article

Reactive powdered concrete samples prepared with steel fibers showed the best performance in terms of compressive strength and flexural behavior. The compressive strength in samples with 2.5% steel fibers and under heat treatment reached 160 MPa by about 10% compared to the sample without fibers. The effect of this type of fibers on flexural behavior was much more dramatic so that the flexural strength was about 25 MPa and the area below the displacement load diagram (toughness) increased significantly.

Contrary to expectations, the addition of carbon fibers to reactive powdered concrete not only did not improve the compressive and flexural strength of concrete, but also caused a slight decrease in these strengths, probably due to problems in mixing this type of fiber with concrete and thus heterogeneous Being samples are prepared. However, these fibers improved the toughness and energy absorption of concrete specimens. It is expected that more acceptable results can be achieved by using adequate measures in the preparation of this type of concrete with carbon fibers (such as the use of certain additives to facilitate and optimize the mixing of carbon fibers with concrete).

The impact of combining steel and polypropylene fibers on the characteristics of reactive powder concrete was examined by Zeng et al. in 2012 [17]. Following the concrete mixing and sample creation, the samples were subjected to a range of temperatures, from 20 °C to 900 °C. The samples' compressive strength was next examined.

The study's findings demonstrated that steel fibers may be used to enhance reactive powdered concrete's compressive qualities. When concrete is subjected to extremely high temperatures, the inclusion of polypropylene fibers strengthens the concrete's strength, but it has the opposite effect when it is exposed to low temperatures. Because the concrete contains fibers, there are no explosions during the heating process.

As the temperature rises, the initial compressive strength rises but falls; the critical temperature is 400 °C and 300 °C, respectively. Compared to conventional concrete and high strength concrete, reactive powder concrete reinforced with hybrid steel and polypropylene fibers has a very high capacity to withstand very high temperatures. Based on the experimental results in this study, acceptable experimental mathematical relationships between compressive strength and temperature were also obtained.

In 2015, Beglerigale and Yazici [18] stated the main findings of their research that the bonding properties of the fiber matrix increase with increasing fiber length. This behavior is more pronounced for smooth fibers. The low water-to-cement ratio, which promotes bond strength, reduces the importance of fake end-length fiber embedding. The fine and dense structure and low water to cement ratio led to better bonding properties between the steel fibers and the reactive powder matrix compared to other mixtures.

In 2014, Canbaz [19] came to the conclusion that reactive powder concrete would achieve a compressive strength of over 200 MPa following three days of water processing at 90 °C and the application of a specified pressure of 80 MPa. While adding polypropylene fibers lowers the maximum strength of 140 MPa, a 1% fiber ratio results in a strength of 165 MPa. Reactive powder concrete's compressive strength decreases as the fiber ratio is altered. Ordinary concrete weighs 2.4 kilogram per cubic meter, whereas reactive powdered concrete typically weighs 2.75 kg per cubic meter. The processing of reactive powdered concrete under pressure, which decreases the spaces in the concrete and raises its density, is undoubtedly one of the causes of the high density.

3.1 Heat and fire resistance behavior of reactive powder concrete

Research on reactive powder concrete has shown that this type of concrete has a very high resistance to high heat compared to ordinary concrete and high-performance concrete can show that one of the reasons is the use of suitable fibers. The fibers can act as bridges to prevent cracking and explosion. Another reason for the high strength of reactive powder concrete compared to other types of concrete is that the weight loss of this type of concrete is exposed to very low temperatures, which increases its strength.

Liu and Huang found in 2009 [20] based on experimental results that the fire temperature of reactive powdered concrete is higher than that of reinforced concrete or HPC and ordinary concrete or OC. Concurrently, thermal gravity analysis measurements and analyses on samples of conventional concrete, reinforced concrete, and reactive powder concrete exposed to the same fire temperature show that the reactive powder concrete samples lose less weight overall than the other types, increasing their compressive strength. Figure 16 shows the compressive strength of reactive powder concrete, aerated concrete and ordinary concrete under fire at a temperature of 500 °C, at the similar times.

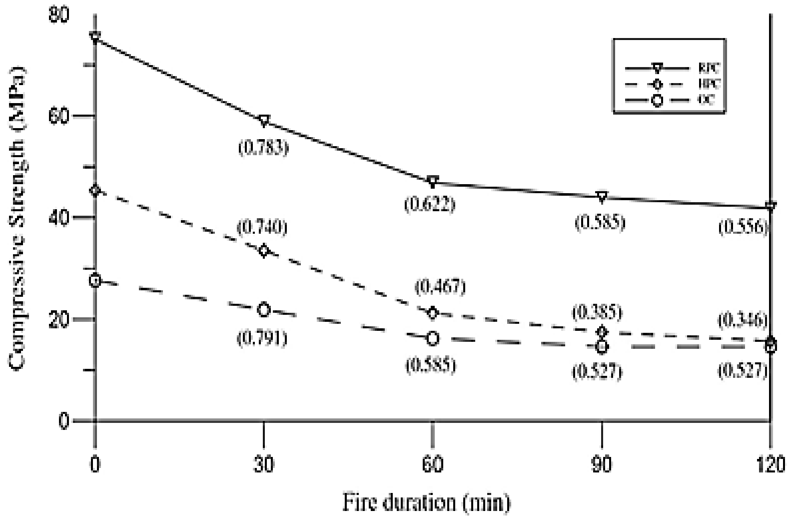

Fig. 16- Compressive strength of reactive powder concrete, reinforced concrete and ordinary concrete under fire of 500 °C
Image by the author of the article

Figure 17 shows the weight loss of reactive powder concrete, aerated concrete and ordinary concrete under fire at a temperature of 500 °C, at similar times, where the weight loss of reactive powder concrete is much lower than other types of concrete.

under fire of 500 °C

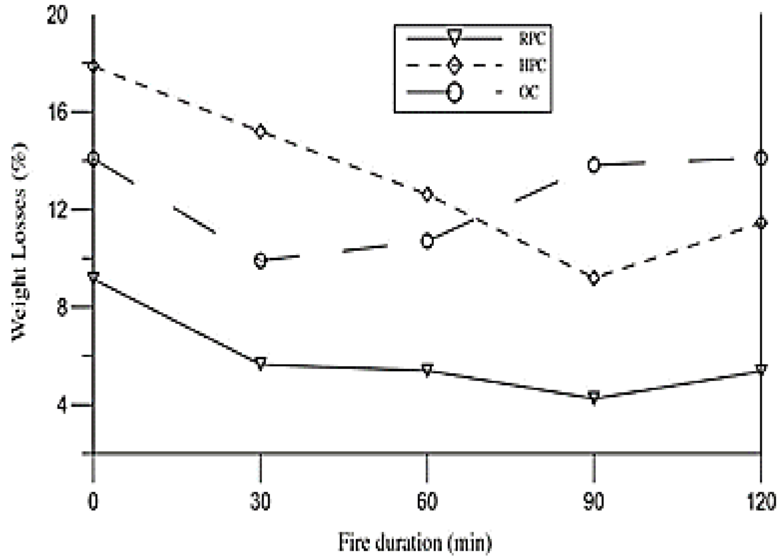

Fig. 17- percentage weight reduction of reactive powder concrete, reinforced concrete and ordinary concrete
Image by the author of the article

In a 2011 study, Thai et al. [21]. Conducted a series of experiments to investigate the mechanical properties of reactive powdered concrete after exposure to high temperatures (up to 800 °C). The results showed that the slope of the ascending part of the strain stress curve decreases with increasing temperature. The anterior part of the strain stress curves is concave upwards and the descending part gradually becomes smoother. In addition, increasing the temperature decreases the stress peak index but increases the strain peak. Additionally, heating the samples from 200 °C to 300 °C gradually enhances the strength of reactive powder concrete. At temperatures between 200 °C and 400 °C, samples with 1% steel fibers are stronger than those at room temperature. If the temperature rises beyond 500 °C, they start to lose strength. As the temperature rises over 400 °C, specimens containing 2% and 3% steel fibers rapidly lose strength. This kind of concrete's modulus of elasticity rapidly drops as the temperature rises and then slows down after the temperature reaches 600 °C. The impact of varying fiber percentages and temperatures on the modulus of elasticity and compressive strength of reactive powdered concrete is depicted in Figure 18.

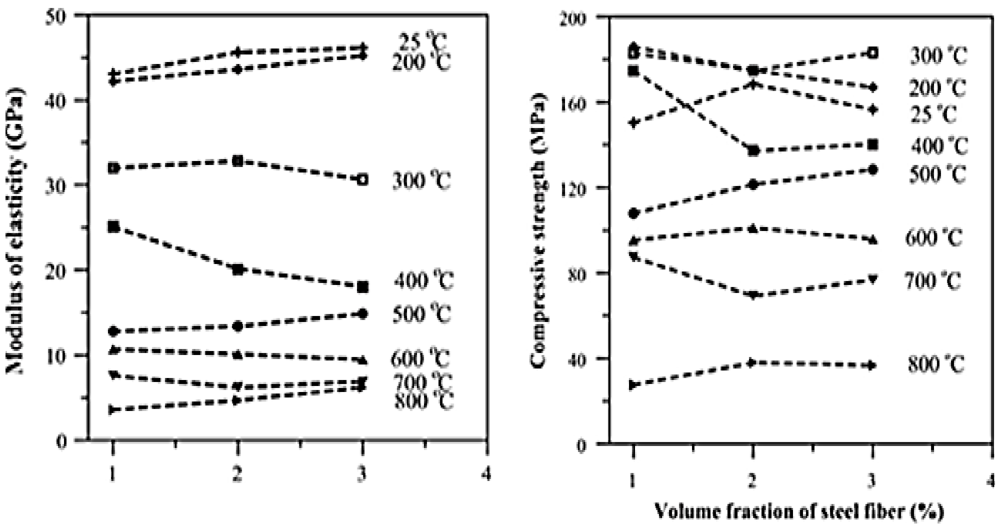

Fig. 18- Effect of different percentages of fibers at different temperatures
Image by the author of the article

A laboratory investigation on the impact of high temperatures on the tensile and compressive strengths of reactive powdered concrete was carried out in 2013 by Zeng et al. [22]. In their research, they concluded that the risk of explosive inflation increases with increasing size. At high temperatures, the fracture state of reactive powder concrete improves with the increase of steel fibers. Explosive attack occurs at temperatures between 602 °C and 520 °C. 2% of steel fibers effectively prevent explosive attack, reduce or delay crack propagation and crack propagation, and significantly increase the tensile and compressive strength of reactive powder concrete. The compressive strength of this type of concrete with steel fibers decreases at 100 °C and increases from 200 °C to 500 °C and decreases above 600 °C. At temperatures below 300 °C, the compressive strength of reactive powdered concrete cubes increases with increasing steel fibers, but at temperatures between 400 °C and 600 °C, this strength decreases with increasing steel fibers. Figure 19 shows the mold form of tensile specimens.

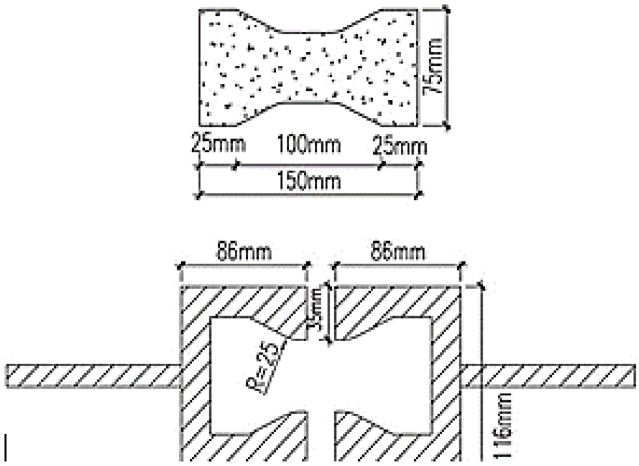

Fig. 19- Form of tensile specimens
Image by the author of the article

4 Conclusions

Reactive Powder Concrete (RPC) represents a transformative advancement in construction materials, addressing the critical limitations of conventional concrete—low tensile strength, high porosity, and susceptibility to chemical and environmental degradation. Through the elimination of coarse aggregates, optimized particle packing, and the incorporation of steel fibers and supplementary cementitious materials (e.g., silica fume, fly ash), RPC achieves unparalleled mechanical properties, including compressive strengths of 170–800 MPa and flexural strengths 250 times greater than ordinary concrete. Its near-impermeable microstructure (porosity of 2–6%) and exceptional durability against chloride, sulfate, and freeze-thaw cycles make it ideal for demanding environments, from marine infrastructure to nuclear containment.

1. Microstructural Superiority: By eliminating the weak interfacial transition zone (ITZ), RPC minimizes microcracking and enhances impermeability, translating to longer service life and reduced maintenance.
2. Processing Optimization: Heat treatment (90–250°C) and pre-setting pressure are critical for achieving ultra-high strengths (>200 MPa), while autoclaving and steam curing further refine hydration kinetics.
3. Fiber Reinforcement: Steel fibers (2.5% by volume) significantly improve flexural strength (up to 25 MPa) and toughness, though challenges remain with carbon fiber dispersion and brittleness mitigation.
4. Thermal Resilience: RPC retains structural integrity at temperatures up to 800°C, with <5% weight loss at 500°C, outperforming conventional and high-performance concretes in fire resistance.

Applications and Future Directions: RPC's success in projects like the Sherbrooke Footbridge and Saint-Pierre-la-Cour Bridge underscores its potential for lightweight, long-span, and seismic-resistant structures. Future research should prioritize: Cost-Effective Production: Scaling RPC through optimized mix designs (e.g., higher slag/fly ash content) and reduced reliance on high-temperature curing. Fiber Hybridization: Combining steel with polypropylene or carbon nanotubes to enhance workability and high-temperature performance.

Sustainability: Leveraging industrial byproducts to reduce carbon footprint while maintaining performance. In conclusion, RPC redefines the boundaries of concrete technology, offering a synergistic blend of strength, durability, and versatility. As advancements in processing and material science continue, RPC is poised to become a cornerstone of next-generation infrastructure, resilient to both mechanical stresses and environmental extremes. Its adoption will hinge on overcoming economic and practical barriers, but the long-term benefits extended lifespan, reduced maintenance, and enhanced safety—make it a compelling choice for the future of construction.

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