Comparative study between the Cost of Normal Concrete and Reactive Powder Concrete

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Abstract. Concrete is an important, widely used material in modern-day construction. Structural planners steadily attempt different strategies and designs that will advance their constructions further aesthetically agreeable, functionally practical, and cost saving. Historically, the development in constructions depended greatly upon the properties of engineering substances. A different set of material with superior characteristics regularly results in a revolution in constructions; this is true for steel structures and concrete structures as well. However, the design of structures with innovative materials, such as RPC, cannot hold out with traditional design certificates that do not hold well with nontraditional materials. Ultra-High-Performance Concrete is considered with concern to its cost-effectiveness and sustainability. In several countries, concrete having a compressive strength of higher than 80MPa cannot be employed because current codes limit the additional strength. Accordingly, considerable performance on introducing an innovative design of standards and codes for RPC constructions necessity be managed to get used of the substances possibly. Further cost improvements with RPC superior traditional concrete involve controlled building times and extended usable floor space or overhead clearance predicted extended service life and lower maintenance cost advantages. This investigation pointed to describe the variation within the cost of traditional concrete material and Reactive Powder Concrete material.

Keywords: RPC, Concrete, cost, Material, Steel Fiber, Silica Fume.

1. Introduction
Economic Efficiency of RPC

In the strategy, design, and establishment of constructions, the principle of cost-effectiveness has preceded continued one of the principal conditions granted by civil designers. Regarding the 1990s this concern has been maintained considerably and notably to precede the regularly expanded social requirement of sustainability. While the cost-effectiveness determinant is considered significantly with manufacturing optimization, the main consequence of sustainability including adopts environmental and social conditions [1]. Cost-effectiveness and sustainability are by no substance generally special. Contrary, cost-effectiveness is a fundamental component of the principles of sustainability. Consequently, the arrangement as to which elements are to be utilized for the development design is especially significant. RPC is a cementitious substance that exhibits high-performance properties such as restrained shrinkage and creep, low permeability, ultra-high strength and enhanced protection versus corrosion [2]. Concrete is described by exceptional mechanical characteristics (high compressive and tensile strength, large E-modulus) and has superior durability characteristics concerning corrosion of concrete and reinforcement (low permeability toward liquids and gases, therefore high resistance to freeze-thaw and penetration of ions) [3,4]. The characteristics of RPC perform it an innovative element in the range of concrete technology with potentialities for application
in a broad variety of structural and nonstructural utilization [2]. One of the principal advantages of this kind of concrete is that it can display notable tensile strength and toughness. Much of such characteristics improvement is given to the concrete by the joining of short, discontinuous fibers throughout the mixing system [5-8]. The expression "concrete" is applied preferably than "mortar" to define RPC because of the mechanical performance of RPC during fine steel fibers is attached for improved ductility. If RPC, whose highest particle size is 0.6 mm, as compared to concrete produced with 25 mm maximum coarse aggregate, the scale is 25 to 0.6 mm. Joining a steel fiber that measures (0.2x25mm) to the RPC is like adding (8mmx1m) reinforcing bar to regular reinforced concrete made with (25mm) course aggregate [9-11]. Compressive strength in about of 150MPa, the flexural strength of within 20 and 50MPa, and Elastic modulus in the variety of 45-65Gpa can be achieved. This is commonly performed by microstructural engineering strategy, including the removal of the coarse aggregates, lowering of the water to cementitious material, lowering of the CaO/SiO2 ratio by including the silica elements, and the establishment of steel fiber reinforcement [12-14]. Use of RPC preferably of conventional weight concrete depends on the applicable cost savings and the implied economies that can produce by the application of the material. RPC is valuable than traditional concrete, conservation can be accomplished by the reduction in dead load substance and other elements and structure costs. There is the potent for even higher cost decreases if complete life values are carried into account due to enhanced durability and lower maintenance costs. RPC is lighter than traditional concrete in dead load [15-18].

2. Advantages of Materials
The application of steel fiber in the mixture can develop its several characteristics. The advantages of utilizing steel fibers in the mixture are as results [9-11]:

➢ Steel Fibers are commonly spread completely in the mixture and the whole parts of the structures whereas reinforcing bars are installed just where expected.
➢ Steel fibers are comparatively small and approximately spaced as associated with connected reinforcing bars.
➢ It is frequently not achievable to perform the equivalent reinforcement area to the area of the mixture using steel fibers as correlated to utilizing a network of reinforcing bars.
➢ Steel Fibers are commonly added to the mixture in low volume rate (regularly <1%) and have been explained to be efficient in decreasing cracking of plastic shrinkage.
➢ Steel Fibers regularly do not significantly modify free shrinkage of the mixture, though, at large sufficient values they can, improve the cracking resistance and reduce the width of the crack. Steel fibers in the mixture can develop:
   • Fatigue Resistance, cracking and Impact.
   • Reducing shrinkage.
   • Change micro-cracks to macro-cracks and obstructing/delaying crack propagation and an increase of toughness.

3. Advantages of SFRC (Steel Fiber reinforced concrete) [6]
   • SFRC spreads localized stresses.
   • A decrease in preservation and rehabilitation cost.
   • Produces strong and permanent surfaces.
   • Decreases surface permeability, wear, and dusting.
   • Price conservation.
   • Crack reducer.
   • Develops toughness and tensile strength
   • Impact resistance.
   • Thawing and freezing resistance.

4. Advantages of Silica Fume
The use of intensive materials with cementitious properties, such as silica fume, and natural pozzolan appears in a significant lowering in the cost of cement production and mixture industry. The use of
silica fume is a comparatively modern strategy. It responds immediately with the calcium hydroxide in the cement adhesive, transforming it toward durable cementitious mixtures. Thus improving the microstructure of compound and decreasing its infiltration. The managed particle measurement of silica fume works as an effective micro-packing additive; it will assist to supply the interstitial areas within cement grains, therefore physically binding the particle organization. In appreciation, the optimized reactivity of silica fume works to chemically consolidate with calcium hydroxide. The modification of lime is in a way change by replacement response, where calcium hydroxide crystals respond with silica fume, in the appearance of humidity, to produce enduring binding manufacture like as calcium silicate and calcium aluminate hydrates [6]. The increase of silica fume effects in:

- Developed compressive, tensile and flexural strengths.
- Decreased permeability (like permeability of chloride). The mixture including silica fume produces limited bleed water, which decreases permeability.
- Decreased efflorescence scope, which happens when calcium oxide is brought by water to the exterior where it unites with carbon dioxide of the environment to produce calcium carbonate, which accelerates on the outside as a white deposit.
- Enhanced protection to chemical attack and extended durability.
- Decreased (ASR) alkali-silica reactivity consequences.
- Developed appearance by changing the color of mixture obtaining it reasonable to be tinted with moderate component appearance.
- The mixture including silica fume has a soft construction that improves workability and texture of a concrete surface.

5. Benefits and Usages of (RPC)

5.1. The Benefits

Benefits and advantages of RPC can be summarized according to [7,8,9]as follows:

- RPC is an excellent choice to the high-performance mixture and has the effort structurally towards the steel.
- Its preferred strength connected with greater shear capability issues in important total load decrease and fewer restricted configurations of architectural segments.
- RPC can be employed to maintain but through principal tensile stresses, this reduces the demand for further shear and additional supplemental reinforcing steel associated with conventional concrete.
- RPC presents enhanced seismic appearance by overcoming inertia loads with moderate segments, permitting higher elastic deflections by decreasing cross-sections, presenting larger energy consumption and enhanced confinement.
- It has almost very low shrinkage or creep, and then it can be a perfect selection for prestressed applications.
- Although the cost of one cubic meter or RPC is higher than conventional concrete, the smaller section size, maintenance free and absence of steel bars reinforcement in most cases lead to low overall cost.
- Enhanced abrasion protection produces lengthened life for bridge decks and manufacturing platforms.
- Excellent corrosion protection produces stability from chemicals and damp conditions.
- Self-healing potential following cracking situations produced from a significant amount of unhydrated Portland cement in the finished product.
- Progress in fracture energy, consequent development of ductility.
- Improvement in concrete fresh and hardened properties.
- A decrease in the inclination for cracking.

5.2. The Usage

RPC will be capable to settle a lot of shortcomings problems of last century mixture; i.e. extremely
weak flexural performance, cracks, shrinkage and creep. For certain objects, RPC will be fitting for [9-11]:

- Constructions expecting lightning and thin elements like roofs of stadiums, bridges with long spans, ground supported and pile supported slabs.
- Constructions expecting dependable stability like protection cases, protection of banks and high-pressure pipes.
- A suitable element for the storage of nuclear waste related to its low porosity which gives excellent durability properties.
- RPC should be adopted in structures where fundamental weight conservation can be achieved and where exceptional properties of the substance can be completely employed.
- Casting facility and high workability during the installation of mass quantity, extremely complicated, extremely light precast constructions to an amount eternally prior attained with traditional concrete. Fair face sections can be very perfect making the finishing simpler and less costly.
- Finally, due to its high capacity of energy absorption, then it is suitable to be used in panels and components or structures subjected to explosions such as shelters, government buildings and for military purposes.

The above characteristics open a door to a variety of innovative applications in civil engineering such as structural elements, contemporary architectural works and design as finishing materials or in interior design works, protective elements, in demand for military buildings, a liquid containing structures or even in nuclear structures.

6. Descriptions of Materials and Material Properties

The materials include a description of the cement, aggregate, mineral and chemical admixtures, and steel fibers used in this research.

6.1. Cement

Conventional (ASTM Type I) Portland cement from Iraqi factory having (Al-Jesser) trademark, was employed in molding all units throughout the investigation operation and all the cement supply saved beneath proper situations to avoid display to humidity and to support normal condition. After testing of the adopted cement, results are within the demands of the [Iraqi specification No.5/1984] and verified to the ASTM standard specification for Portland cement [ASTM C150-89].

6.2. Fine Aggregate

Silica sand known as glass sand is the only kind of fine aggregate employed for RPC investigation. It is a crushed Iraqi silica rock brought from Al-Ramadi Glass Factory. It is extremely fine sand with a highest measurement of 600µm (0.6 mm). The sieve analysis of this sand is presented in Figure 1. Its grading satisfies the fine grading in accordance with the [B.S. specificationNo.882/1992 and Iraqi Specification No.45/1984]. To obviate several variations among various batches, the total amount of silica sand was transported from the factory from a single batch and deposited in a proper situation. The silica sand, which was adopted within this work, approved to the chemical and physical specifications of ASTM C 618 class N Pozzolan.

![Figure 1. Grading curve of sieve analysis for glass sand (silica sand).](image)
6.3. Coarse Aggregate
For MRPC mixtures, a well-graded natural aggregate of maximum size (8mm) was employed to ensure acceptable workability and uniform distribution of steel fibers in the mix. Figure 2 show the grading of coarse aggregate, sieve analysis test results of the coarse aggregate used throughout this work confirming to the [Iraqi specification No.45/1984, and B.S.882/1992 specification] and the particle size distribution of the fine silica sand and coarse aggregate used in the RPC and MRPC. The coarse aggregates were washed, then put in the air to dry the surface, and then kept in containers in a dry situation before being used.

![Figure 2. Grading curve for coarse aggregate used in MRPC.](image)

6.4. Mineral Admixture Silica Fume (SF)
A densified silica fume from (Basif Materials Company) has been used as a mineral admixture combined to the compounds of the research. The used percentages are (15%, 20%, and 25%) of cement weight (as an addition to cement). The chemical composition of silica fume employed in this investigation conforms to the chemical and physical conditions of [ASTM C1240-04]. Figure 3 shows silica fume powder used in research work. Densified Silica Fume is a mineral admixture which was finely ground solid pozzolanic substance which has a great amount of amorphous silicon dioxide and having of fine round particles. It responds with calcium hydroxide Ca(OH)2, providing calcium silicate hydrate gel. Silica fume is an extremely effective pozzolanic mineral and is a by-product of the production of Silicon or Ferro-silicon element. It is obtained from the chimney fumes of electric arc kilns. It is a remarkably granular particle, including particles regarding 100 times less than a common cement grain. Those compounds develop mixture workability, engineering characteristics, and strength. The word pozzolan points to a siliceous mineral, which, in a finely distributed manner and in the proximity of water, will respond chemically with calcium hydroxide (CH) to produce cementitious mixtures.

![Figure 3. Silica fume powder used in research work.](image)

6.5. Chemical Admixture High Range Water Reducing Agent (Superplasticizer)
Hardening accelerator, Aqueous solution of modified polycarboxylates based polymer co-polymers, HRWRA High Range Water Reduction Agent, which increases compressive, tensile and flexural strength, as an advantage of its water decreasing characteristics. The superplasticizer (Sika ViscoCrete-PC20) was provided and supplied by SIKAL® which was used in preparing all the specimens in this study as a high range water-reducing admixture. It has three functions, i.e. superplasticizer, viscosity modifying agent, and retarder. This is better than using the three admixtures
individually which might be incompatible and cause complicity in the mixture. It is the third generation of ultra-high range superplasticizer admixture for concrete and mortar, it has been principally produced for designing high-performance concrete and mortar, and for concrete composition in high temperature and humid weather with extensive workability time by reducing the w/c while maintaining equal workability to the mixtures containing no HRWRA. It is almost free from chlorides and complies with the requirements of concrete admixtures Type D and G at [ASTM C494-99/C 494M]. Figure 4 shows Superplasticizer used in the present research. This mechanism implements flowable concrete with considerably decreased water need. The water content for any dosage of HRWRA is subtracted from the original mixing water. The optimum dosage was found to be (4.8% by weight of binder) beyond it; the w/c ratio does not drop. Thus, increasing the dosage of superplasticizer above (4.8%) is considered uneconomical, according to [ASTM C494-99/C 494M].

The most important factor influencing the setting time is the superplasticizer type and quantity which cause some delay of setting when used in high percentages.

6.6. Steel Fibers

The implementation of fibers rely on both the quantity and the parameters of fiber (tensile strengths, aspect ratio, diameter, and Anchorage). A fundamental agent for property fiber is the relationship within the length and the diameter of the fibers: the greater the l/d proportion, the excellent the achievement [19, 20]. RPC includes short steel fibers preferably than high aggregates. Steel fibers manufactured by (Hebei Yusen Metal Wire Mesh Company Ltd. Company, China), were used. Steel fibers were straight steel fibers (13mm) long and diameter of (0.25mm) giving an aspect ratio of (52) was used. Figure 5 shows the ultra-fine steel fibers employed completely in this research and tensile stress-strain curves for steel fiber. The steel fiber employed during this investigation adapted to the requirements of [ASTM A820/A 820M-04] for Type II (Cut Sheet Fibers). A coating of thin brass was implemented to the fibers through the design manufacturing. This coating dissolves throughout the mixing method and clearly not obvious throughout the casting of concrete. According to [19], the steel fibers usually range from 0.25 to 2 percent by volume. The proposed employment of these fibers within RPC demands that the fibers have a very high tensile strength. The manufacturer's designated 2600MPa as a minimum tensile strength and the tension analyses were conducted in the manufacturer's laboratories as a mechanism of quality restriction on the fiber composition. The sequences from three characteristic instrument analyses were employed to manage the average yield strength of 3150 MPa as determined by the 0.2% offset classification. The Elastic modulus with an average of 210GPa and the average ultimate strength was 3250MPa. The conclusions apparently explain that these high-strength steel fibers have limited reserve toughness or ductility capability exceeding yield.

![Steel Fiber Stress-Strain](image)

**Figure 4.** Superplasticizer used in the present research.

**Figure 5.** Tensile stress-strain curves for steel fiber with (l/d=13/0.25mm).
Within the above limits and according to previous researches various proportions mix were proposed in this examination to capture maximum compressive strength and flow of 90%. Seven types of RPC mixes were used in the present research. The variables used in these mixes were the ratio of silica fume (three ratios of silica fume as additives were studied 10, 20 and 25%) and the volume ratio of steel fibers (five volume ratios were considered 0, 0.5, 1, 1.5 and 2%) table 1. The best final mix which gave the highest values is 1: cement, 1: sand, 0.25: silica fume with water cement ratio 0.2 whose w/b ratio is 0.18 plus 4.8% by weight of the binder of SikaViscoCrete-PC20 admixture and max concrete compressive strength was 114 MPa at 28 days. It was observed that the adopted mixture provides high-grade workability and uniform mixing of materials without segregation.

### Table 1. Mix proportion of normal and RPC mixtures.

| Mix  | Cement kg/m³ | Sand kg/m³ | Silica fume by weight of cement | Steel fiber by volume | Superplastisizer 4.8% by binder cement+silica fume | w/c Coarse Aggregate kg/m³ |
|------|--------------|------------|--------------------------------|-----------------------|---------------------------------------------------|---------------------------|
| Mix 1 | 1000         | 1000       | 25%                            | 0%                    | 4.8%                                              | 0.2                      |
| Mix 2 | 1000         | 1000       | 25%                            | 0.5%                  | 4.8%                                              | 0.2                      |
| Mix 3 | 1000         | 1000       | 25%                            | 1.0%                  | 4.8%                                              | 0.2                      |
| Mix 4 | 1000         | 1000       | 25%                            | 1.5%                  | 4.8%                                              | 0.2                      |
| Mix 5 | 1000         | 1000       | 25%                            | 2.0%                  | 4.8%                                              | 0.2                      |
| Mix 6 | 1000         | 1000       | 25%                            | 2.0%                  | 4.8%                                              | 0.2                      |
| Mix 7 | 1000         | 1000       | 20%                            | 2.0%                  | 4.8%                                              | 0.2                      |
| 8 normal Concrete | 450         | 640        | Gives                          | 0.4                   | 1133 max strength=28Mpa                           | 4 size 10 mm             |

### 7. Concrete Tests Strength and Mechanical Properties of Hardened Concrete

Mix plan is the process conducted to select the most proper components of concrete and managing their relative quantities to achieve the desired strength. Different types of tests for hardened concrete were made which compression test and indirect tension (split test), flexure, density, and weight change. A series of tests were conducted for RPC mixes at the duration of 28 days. Table 2 displays properties of hardened concrete. Table 3 shows specifications of the control specimens. The compressive strength is the common essential characteristics of the hardened mixture in worldwide and is the natural element benefit for the classification of concrete in international codes. The compressive strength test was determined satisfying to [B.S-1881; part 116] and with [ASTM C39-2005]. (100x200 mm cylindrical units were employed to determine the compressive strength of RPC and normal concrete. Average of three specimens was applied to achieve the mean compressive strength as expected by [ACI 318M Code].

### Table 2. Properties of hardened concrete.

| specimens Designation | Vf % | Silica Fume % | Compressive Strength $f_{ct}'$ (MPa) | Splitting Tensile Strength $f_{spl}'$ (MPa) | Modulus of Rupture $f_{rt}'$ (MPa) | Modulus of Elasticity $E_c$ (GPa) | Density (kg/m³) | Weight Change |
|-----------------------|------|--------------|--------------------------------------|-------------------------------------------|-----------------------------------|----------------------------------|----------------|--------------|
| Mix 1                 | 0.0  | 25%          | 72                                   | 6                                         | 5                                 | 36.1                             | 2240.67        | 0.402        |
| Mix 2                 | 0.5  | 25%          | 85                                   | 8.5                                       | 8                                 | 40.7                             | 2334           | 0.405        |
| Mix 3                 | 1.0  | 25%          | 93                                   | 11                                        | 11                                | 43.1                             | 2352.33        | 0.412        |
| Mix 4                 | 1.5  | 25%          | 105                                  | 13.5                                      | 14                                | 46.8                             | 2396           | 0.415        |
| Mix 5                 | 2.0  | 25%          | 114                                  | 15.8                                      | 18                                | 50.1                             | 2502.33        | 0.42         |
| Mix 6                 | 2.0  | 15%          | 95                                   | 13.8                                      | 15                                | 44                               | 2446           | 0.4          |
| Mix 7                 | 2.0  | 20%          | 109                                  | 15                                        | 17                                | 48.7                             | 2464           | 0.415        |
| 9 Normal Concrete     | ---  | ---          | 28                                   | ---                                       | ---                               | ---                              | ---            | ---          |


Table 3. Specifications of the control specimens.

| Type of test          | Number and Type of specimen | Specimen dimension (mm) |
|-----------------------|-----------------------------|-------------------------|
| Compression From compression test | 3 cylinders for each mix | 100 diam x 200 long |

8. Cost Analysis
RPC is extremely further costly than traditional concrete. Countless of the expense arises from its steel fiber, so the value of the element is principally conditional on the value of this ingredient. The advantages of RPC superior conventional concrete comprise:

1. Shortened installation times and expanded valuable floor expanse or overhead extent.
2. The application of longer spans with RPC segments could decrease the amount of expected piers and pier support for remarkable bridge employment.
3. The predicted longer assistance period and moderate preservation costs of RPC could manage to even further cost advantages.
4. Developing head times needed for steel structural may direct to cost improvements for RPC in expanding to the reasonable cost per unit weight advantage.

The strength (S) of RPC is taken as a parameter, and the price (P) of RPC is taken as the other parameter. The relationship of R (the cost-performance ratio), S and P is presented in Eq. (1).

\[ R(cost - performanceratio) = \frac{S(Strength)}{P(Price)} \]  

Many factors have an effect on RPC prices, such as raw materials price, preparation, and curing costs, equipment costs, transport costs, labor wages and so on. According to experiment situation, the raw materials prices have been acquired from the current market. Costs for RPC cylinder are calculated and presented in tables. When steel fiber content is (0%), the price of RPC is the lowest. The price grows with the increase of steel fiber. In addition, the failure mode of RPC without steel fiber is likely explosive, so it is not proper for the application. It is indicated that the cost-performance ratio increase with the increase of steel fiber. When steel fiber is (0, 0.5, 1.0, 1.5 and 2%) the cost performance ratio is (0.016035, 0.017498, 0.017799, 0.018776 and 0.019128) while when silica fume increase from (15, 20 and 25%) the cost-performance ratio is (0.01899, 0.019886 and 0.019128) and for normal concrete is (0.120032%) that mean the RPC is better for economy. Table 4 shows the difference between the materials of normal concrete mix and RPC mix No.5 with 2.0% steel fiber and 25% silica fume. Table 5 show the difference between normal concrete and RPC concrete prices. Table 6 shows the difference between the normal concrete cylinder and RPC concrete cylinder. Table 7 shows the effect of steel fiber and silica fume content on RPC price of (100x200mm) cylinder reactive powder concrete. Table 8 shows the cost performance ratio between normal concrete and RPC reactive powder concrete mixes. Figure 9 shows the cost of construction materials in Iraq 2012, 2015, 2016 and 2018 according to central bureau of statistics directorate building and construction statistics. Figure 6 show the effect of steel fiber on cost performance ratio of RPC cylinder and Figure 7 show the effect of silica fume on cost performance ratio of RPC cylinder.
### Table 4. The difference between the materials of normal concrete mix and RPC mix No.5 with 2.0% steel fiber and 25% silica fume.

| Concrete Type        | Cement kg/m³ | Sand kg/m³ | Silica Fume kg/m³ | Steel Fiber | Superplasticizer | w/c | Coarse aggregate kg/m³ | Compressive strength (MPa) |
|----------------------|--------------|------------|------------------|-------------|-------------------|-----|------------------------|---------------------------|
| Normal concrete Mix  | 450          | 640        | ---              | ---         | ---               | 0.44| 1133                   | 28                        |
| Reactive Powder Concrete Mix 5 | 1000         | 1000       | 250              | 2%          | 4.8% of cement weight | 0.2 | ---                    | 114                       |

### Table 5. The difference between normal concrete and RPC concrete prices.

| Concrete Type        | Cement kg/m³ | Sand kg/m³ | Silica Fume kg/m³ | Steel Fiber | Superplasticizer | w/c | Coarse aggregate kg/m³ | Price for 50 kg | Price for 1 kg | Price for 1000 kg | Price for 1 kg |
|----------------------|--------------|------------|------------------|-------------|-------------------|-----|------------------------|-----------------|---------------|------------------|----------------|
| Normal concrete Mix  | 450          | 640        | ---              | ---         | ---               | 0.44| 1133                   | 12000 Dinar     | 28 Dinar      | 2000 Dinar        | 1000 Dinar     |
| Reactive Powder Concrete Mix 5 | 1000         | 1000       | 250              | 2%          | 4.8% of cement weight | 0.2 | ---                    | 12000 Dinar     | 1000 Dinar    | 6000 Dinar        | 6000 Dinar     |

### Table 6. Difference between normal concrete cylinder and RPC concrete cylinder.

| Concrete Type        | Cement kg/m³ | Sand kg/m³ | Silica Fume kg/m³ | Steel Fiber | Superplasticizer | w/c | Coarse aggregate kg/m³ | Price for 50 kg | Price for 1 kg | Price for 1000 kg | Price for 1 kg |
|----------------------|--------------|------------|------------------|-------------|-------------------|-----|------------------------|-----------------|---------------|------------------|----------------|
| (100x200mm 7 m³ Cylinder) | 0.00157      | 0.00157    | ---              | ---         | ---               | 0.4 | 0.00157                | 169.56 Dinar    | 28.1344       | 881 kg           | 20 Dinar       |
| Normal Concrete Price | 7065 kg      | 240        | 28 Dinar         | ---         | ---               | 0.4 | *1133=1.77             | 7065 kg        | 28 Dinar      | 7065 kg          | 28 Dinar       |

**Total Price for Normal Concrete**: 233.2706 Dinar
Total Price for
RPC Reactive powder 5959.72 Dinar
Concrete
R=S/P Normal 0.1200322
R=S/P RPC 0.019128

| Concrete Type | Cement | Sand | Silica Fume | Steel Fiber | Superplasticizer | w/c | Total Price |
|---------------|--------|------|-------------|-------------|------------------|-----|-------------|
| Mix 1         | 0.00157 | 0.00157 | 0.00157* | 0 kg         | 1.9625*0.048=0   | 0.2 | ---         |
|               | 1.57kg  | 1.57kg  | 25 kg      |              |                  |     |             |
| Price for 1 kg | 240 Dinar | 1000 Dinar | 6000 Dinar | 0 Dinar      | 2000 Dinar for 1 kg |     |             |
| Price*Weight  | 376.8 Dinar | 1570 Dinar | 2355 Dinar for 1 kg | 0 | 188.4 Dinar | --- | 4490.2 Dinar |
| Mix 2         | 0.00157 | 0.00157 | 0.00157* | 0.00157*    | 1.9625*0.048=0   | 0.2 | ---         |
|               | 1.57kg  | 1.57kg  | 25 kg      | 0.005*      |                  |     |             |
| Price for 1 kg | 240 Dinar | 1000 Dinar | 6000 Dinar | 0 Dinar      | 2000 Dinar for 1 kg |     |             |
| Price*Weight  | 376.8 Dinar | 1570 Dinar | 2355 Dinar for 1 kg | 0 | 188.4 Dinar | --- | 4857.58 Dinar |
| Mix 3         | 0.00157 | 0.00157 | 0.00157* | 0.00157*    | 1.9625*0.048=0   | 0.2 | ---         |
|               | 1.57kg  | 1.57kg  | 25 kg      | 0.01*7      |                  |     |             |
| Price for 1 kg | 240 Dinar | 1000 Dinar | 6000 Dinar | 0 Dinar      | 2000 Dinar for 1 kg |     |             |
| Price*Weight  | 376.8 Dinar | 1570 Dinar | 2355 Dinar for 1 kg | 0 | 188.4 Dinar | --- | 5224.96 Dinar |
| Mix 4         | 0.00157 | 0.00157 | 0.00157* | 0.00157*    | 1.9625*0.048=0   | 0.2 | ---         |
|               | 1.57kg  | 1.57kg  | 25 kg      | 0.015*      |                  |     |             |
| Price for 1 kg | 240 Dinar | 1000 Dinar | 6000 Dinar | 0 Dinar      | 2000 Dinar for 1 kg |     |             |
| Price*Weight  | 376.8 Dinar | 1570 Dinar | 2355 Dinar for 1 kg | 0 | 188.4 Dinar | --- | 5592.34 Dinar |
| Mix 5         | 0.00157 | 0.00157 | 0.00157* | 0.00157*    | 1.9625*0.048=0   | 0.2 | ---         |
|               | 1.57kg  | 1.57kg  | 25 kg      | 0.02*7      |                  |     |             |
| Price for 1 kg | 240 Dinar | 1000 Dinar | 6000 Dinar | 0 Dinar      | 2000 Dinar for 1 kg |     |             |
| Price*Weight  | 376.8 Dinar | 1570 Dinar | 2355 Dinar for 1 kg | 0 | 188.4 Dinar | --- | ---         |

Table 7. Effect of steel fiber and silica fume content on RPC price of (100x200mm) cylinder.
| Mix 6 | Price*Weight | Price*Weight | Mix 7 | Price*Weight | Price*Weight | Compressive Strength (MPa) | R=Strength/Price (S/P) RPC |
|-------|--------------|--------------|-------|--------------|--------------|-----------------------------|-----------------------------|
| Dinar | 376.8        | 1570         | Dinar | 1469.52      | 188.4        | 72                          | 0.01603                     |
| Dinar | 1.57kg       | 1570         | Dinar | 1988.28      | 2000 Dinar   | 85                          | 0.01749                     |
| Dinar | 55 kg        | 1413         | Dinar | 1469.52      | 173.328      | 93                          | 0.017799                    |
| Dinar | 150 kg       | 1469.52      | Dinar | 1884         | 180.864      | 105                         | 0.01877                     |
| Dinar | *1000=1.57kg | *1000=150    | Dinar | *1000=150    | *0.02*7      | 6                           | 0.019128                    |
|lob of Dinar | 0.31 kg       | 0.60 kg     | Dinar | 0.01988      | 0.6          | 9                           | 0.01988                     |

Price for 1 kg

| Price | 240 Dinar | 1000 Dinar | 6000 Dinar | 2000 Dinar for 1 kg |
|-------|-----------|------------|------------|---------------------|
| Price | 0.00157   | 0.00157    | 0.00157*   | 1.8055*Dinar.048=0 |
| Price | 0.00157   | 0.00157    | 0.00157*   | 1.884*Dinar.048=0  |
| Price | 0.00157*  | 200=0.31   | 800=0.2    |                     |
| Price | 0.00157*  | 200=0.31   | 800=0.2    |                     |

Compressive Strength (MPa)

R=Strength/Price (S/P)

**Figure 6.** Effect of steel fiber on cost performance ratio of RPC cylinder.

**Figure 7.** Effect of silica fume on cost performance ratio of RPC cylinder.
Table 8. Cost performance ratio between normal concrete and RPC mixes.

| Mix Type     | Mix | Price (Dinars) | Strength (MPa) | cost performance ratio |
|--------------|-----|----------------|----------------|------------------------|
| RPC          | 1   | 4490.2         | 72             | 0.016035               |
| Concrete     | 2   | 4857.58        | 85             | 0.017498               |
|              | 3   | 5224.96        | 93             | 0.017799               |
|              | 4   | 5592.34        | 105            | 0.018776               |
|              | 5   | 5959.72        | 114            | 0.019128               |
|              | 6   | 5002.648       | 95             | 0.01899                |
|              | 7   | 5481.184       | 109            | 0.019886               |
| Normal Concrete | 8 | 233.2706       | 28             | 0.120032               |

Figure 8. Cost of construction materials in Iraq according to central bureau of statistics directorate building and construction statistics.

9. Economic aspects with respect to the life-cycle costs of a structure
Following an investigation of the environmental matters, the economic advantages of the application of UHPC will be performed. If one analyzes the clear composition costs, the greater values per m³ of concrete with developing compressive strength, including the price on supplementary condition promise measures, prepared statements and appropriate licenses required by the application of non-standard concrete, are balanced by lower costs in regard of the subsequent states:

- Decrease volume of the mixture.
- Decrease volume of reinforcement.
- Decrease volume of formwork.
These result in a modification of substances, payments, transportation charges, and the significant transforming and moving functions (cranes, concrete pumps) on the construction position. Because of the decreased composite assembly computations, the load accepting for the design of the foundation are lessened. Quantitative identification of generation values in particular states necessity demand into account modern demand values. UHPC shows to be economically advantageous in terms of both production costs and the utilization condition. The smaller cross-section required with the corresponding load capability improves the rentable floor space. On the evidence of this conclusion, the economic benefit of UHPC as associated with normal strength concrete is definitely shown, in the concept of the writer, by the case presented.

In an attachment to the composition costs, the costs acquired throughout the life-cycle of construction further have to be estimated in terms of cost-effectiveness. These involve the replacement and maintenance costs to maintain the construction purposes as well as the costs acquired by destruction at the peak of the life-cycle of the construction. Concurrently with the generation costs, they present up to the sum entirety of the life-cycle values. Examinations conducted out in Austria expose that the common replacement values for the raw frame construction of a bridge that had approached the end of its life-cycle with a sufficient span of up to 40 m were approx. 640 €/m² of bridge area [5]. The values for improvement of the bearing construction consequently amount to 28% of this cost. In sequence to be prepared to estimate alternative building designs including respect to their life-cycle values for a cost-effectiveness measurement, the application has to be presented of the existing cost arrangement [6]. By means of this approach, all values to be acquired in the expectation are reduced to the modern time of the study. The immediate advantage thus designates the quantity which has to be advanced at the moment of consideration and then has to generate earnings in order to be able to achieve all expected costs. The above-mentioned cost examination benefits to explain how large the existing value is in terms of extra construction costs, in sequence to explain its significance for a cost-effectiveness evaluation of structure design.

10. Comparison with other researchers
UHPC is extremely further expensive than traditional concrete. Extremely of the cost of UHPC proceeds from its steel fiber reinforcement, so the expense of the substance is principally probable on the price of this ingredient. Bonneau et al. 1996 [6] concluded the amount of UHPC with fibers in Europe as ($1400/m³). Aitcin [24] summarized a profound 1996 price of UHPC in Europe at ($1000/m³). Aitcin stated the price had declined to ($750/m³) by the year 2000, which conforms reasonably similarly to Blais and Couture (1999) [6] that published the value of $250/ton or ($750/m³) in 1999. As a practice of UHPC displays further general, the cost per cubic yard is required to reduce significantly. Aitcin [24] predicts the cost of UHPC will presently decrease to ($600/m³ to $650/m³) in Europe. The value of UHPC in North America as of the year 2007 was similarly large at roughly ($2620/m³) but is likewise presumed to decrease with improved utilization in North America.

Correspondence to the (ENR) Engineering News-Record (2008), the ordinary cost of (35 MPa) (0.76 m³) in January 2008 of concrete in the United States (20 cities) was $99. If ($750/m³) is employed as the value for UHPC. UHPC in term of 5.8 further expensive than traditional concrete on volumetric support. Multiple present, though, that the capacity to manage a lower volume of UHPC and the preferred production of the substance explain a comparison not volumetrically with traditional concrete but by weight with steel. In November 2007 ENR reports the average cost of (45 kg) of fundamental steel as $41. Considering a (2400 kg/m³) unit weight for traditional concrete. (2480 kg/m³) for UHPC, and 490 (7850 kg/m³) for steel, the amounts of various material per ton (1.02 tons) can be associated, as recorded in Table 9.

| Material         | Cost          | Ratio to UHPC |
|------------------|---------------|---------------|
| Normal concrete  | $49/ton ($48/tonne) | 1:5.6        |
| UHPC             | $270/ton ($270/tonne) | 1:1          |
| Structural Steel | $810/ton ($800/tonne) | 3:0:1        |
Supplementary cost improvements with UHPC above traditional concrete involve decreased construction period and improved available floor space or overhead clearance. The application of longer spans with UHPC segments could decrease the estimate of expected piers and pier foundations for some bridge applications. The prophesied longer service life and economical maintenance costs of UHPC could reach to even more cost advantages of UHPC. Furthermore, improving lead times expected for structural steel may lead to 10 cost advantages for UHPC in appreciation to the reasonable cost per unit weight advantage described earlier. Interestingly, [24] describes that the Quebec Ministry of Transportation concluded that the original cost of a (55 MPa) bridge was 8.0% less than that of an equal (35 MPa) bridge without exerting enhanced service life into the description. Accordingly, it is rational to assume a cost saving when using ultra high-performance substances like UHPC.

11. Conclusion
1. The production of RPC was undertaken by using very fine sand as aggregate instead of ordinary aggregate, densified silica fume as highly active pozzolan, and (Sika ViscoCrete-PC20) as superplasticizer as a high performance high range water reducing agent plus stabilizing agent, and ultra-fine micro steel fibers with very low water/cement ratio (w/c).
2. The use of fine sand with grain size of (<600µm) and low (w/c=0.2) and silica fume improves the mechanical properties due to more dense microstructure of the cement matrix.
3. Eight mixes were used in this research with silica fume content increases from (15, 20 and 25%) and steel fiber increases from (0, 0.5, 1.0, 1.5 and 2.0%) (7 mixes of RPC concrete and one normal concrete mix).
4. When silica fume content increases from (15, 20 and 25%) compressive strength are (95, 109 and 114MPa) an increase in average compressive strength of RPC concrete mixes at 28-day age (0, 14.73684 and 20%) and results show that there is a significant improvement in the compressive strength of RPC due to the addition of steel fibers. When steel fiber content increase from is (0, 0.5, 1.0, 1.5 and 2.0%) compressive strength is (72, 85, 93, 95, 105, 109 and 114MPa) an increase of (0, 18.05556, 29.167, 45.83 and 58.33%). When water binder is (0.1739, 0.166 and 0.16%) average compressive strength are (95, 109 and 114) that means when the water binder decreases the compressive strength increases.
5. Cost-performance ratio increase with the increase of steel fiber content. When steel fiber is (0, 0.5, 1.0, 1.5 and 2%) the cost performance ratio is (0.016035, 0.017498, 0.017799, 0.018776 and 0.019128) while when silica fume content increase from (15, 20 and 25%) the cost-performance ratio is (0.019, 0.0198 and 0.019) and for normal concrete is (0.120).
6. Most of the researchers agree with that, UHPC is extremely further expensive than traditional concrete. Greatly of the cost of UHPC develops from its steel fiber reinforcement, so the price of the substance is largely provisional on the cost of this ingredient

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