CHAPTER 1

INTRODUCTION

Concrete has come a long way since its use in building the Roman Coliseum in 70 A.D. New methods of construction as well as improvement in cement formulas, aggregates and admixtures have significantly increased the type of projects for which concrete can be used. The strength and properties of various concrete mixes have led the way for larger buildings, safe and sound bridges and more durable structures. With the invention of reactive powder concrete (RPC), the use of concrete has increased. RPC with trade name 'DUCTAL' was developed in France by researchers Mr.Richard and Mr. Cheyrezy in the early 1990s at Bouygues, laboratory in France. The world's first RPC structure, the Sherbrooke Bridge in Canada, was constructed in July 1997. RPC is an ultra-high-strength and high ductility cementitious composite with advanced mechanical and physical properties. It is a special concrete where the microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. It extensively uses the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce the highest strength hydrates.

RPC was nominated for the 1999 nova awards from the construction innovation forum. RPC has been used successfully, for isolation and containment of nuclear wastes in Europe due to its excellent impermeability.

This new material demonstrates greatly improved strength and durability characteristics compared with traditional or even high-performance concrete. Classified as Ultra-High Performance Concrete (UHPC), or Reactive Powder Concrete (RPC). The improved properties of RPC are obtained by improving the homogeneity of the concrete by eliminating large aggregates, increasing compactness of the mixtures by optimizing packing density of fine particles, and using fine steel fibres to provide ductility.

The HPC used for nuclear waste containment structures of Indian concrete power plants are having moderate compressive strength, moderate E value, uniform density, good workability, and high durability. There is a need to evaluate RPC regarding its strength and durability to suggest its use for nuclear waste containment structures.

1.1 COMPOSITION OF RPC

RPC is composed of similar modulus of elasticity and size increasing homogeneity reducing differential tensile strain. The material having the largest particle size in RPC is sand.

It composed of very fine powders (cement, sand, quartz powder, steel aggregates and silica fume), steel fibres (optimal) and a superplasticizer. The superplasticizers, used at its optimal dosage, decrease the water to cement ratio (w/c) while improving the workability of the concrete. A very dense matrix is achieved by optimizing the granular packing of the dry fine powders. This compactness gives RPC, ultra-high strength and durability. Reactive powder concretes have compressive strengths ranging from 200 MPa to 810 MPa.

Table 1.1 Components and function parameters of RPC

Components	**Function parameters**
sand	Give strength to aggregate
cement	Binding material
Quartz powder	Maximum reactivity during heat-treating
Silica fume	Filling the voids
Steel fiber	Improve ductility
Superplasticizer	Reduce water binding

CHAPTER 2

MATERIAL SELECTION

2.1 SILICA POZZOLAN

A highly reactive silica pozzolan is an essential component of reactive powder concrete, Performing three vital roles for which it needs the following properties:

1. It must be sufficiently fine to pack closely around the cement grains, improving the density of the composite matrix and minimising the potential for voids between the particles.
2. It should possess considerable pozzolanic activity, such that the non-cementing portlandite crystals [Ca (OH)] generated by hydration of the cement react with the silica to form additional C–S–H gel, reinforcing the binding of the composite.
3. The particles should have a basically spherical shape to act as a lubricant within the fresh mix, improving its ability to flow and be cast into moulds.

Conventionally, the reactive silica used for RPC has been silica fume, which is an industrial by- product of the manufacture and purification of silicon, zirconia and ferro-silicon alloys in submerged-arc electric furnaces. Escaping gaseous SiO oxidises and condensates as extremely fine (0.03 – 0.2 µm) spherical particles of amorphous silica, neatly fulfilling the requirements listed above. One of the potential drawbacks of RPC production in New Zealand is the absence of a domestic source of silica fume: importing this material is an expensive proposition, both because of high demand and an inconveniently light bulk density of 200 – 300 kg/m, complicating shipping and handling.

However Microsilica 600, a geothermal silica sinter mined near Rotorua, has been widely used in conventional high performance concrete as a 1:1 replacement for silica fume, and an important part of the study was the evaluation of its suitability for use in locally-produced RPC. According to its producer: "The NZ Standard NZS 3122:1995 'Specification for Portland and Blended Cements' classifies Microsilica 600 as a silica fume" and "Microsilica 600 meets the performance requirements of most international silica fume standards such as the Australian Standard AS358.2 'Silica Fume' and the Canadian Standard CSA-A23.5M86 'Supplementary Cementing Materials for Type U Silica Fume' ".

In addition to Microsilica 600, two alternative silica fumes were sourced for use as control materials from their suppliers, Australian Fused Materials (AFM), Rockingham, Western Australia and Simcoa Operations Pty, Kimerton, Western Australia. The AFM product is a white undensified fume arising from zirconia manufacturing, a variety that the literature suggests is most suited to use in RPC.

The Simcoa silica fume is a more common silicon- smelting by-product and has been densified, i.e. the primary silica particles are agglomerated into micro-pellets by aeration and the application of pressure. This increases the bulk density of the silica fume making transportation a more viable process.

Fig 2.1 Silica pozzolan

2.2 CEMENT

Due to the very high cement factor, the choice of cement can be an important factor in the performance of RPC. Based on published practice, the ideal cement has a high C_3S and C_2S (di- & tri-calcium silicate) content and very little C_3A (tri-calcium aluminate). This is understandable because C_3A has little intrinsic value as a binding agent and is primarily included in cement due to its role as a flux during the calcination process. Consequently, most RPC made with commercially-available cement employs an ASTM Type V 'sulfate-resistant' blend, which is formulated specifically for low C_3A content.

2.3 QUARTZ FINES

For RPC mixes designed to be cured at temperatures exceeding 90ºC, including autoclaving at elevated pressures, additional silica is necessary to modify the CaO/SiO ratio of the binder. In these cases powdered quartz flour with a mean particle size of 10 – 15 μm was employed.

Fig 2.2 Quartz fines

2.4 FINE AGGREGATE

The majority of mixes were produced using high purity silica sand widely used for foundry casting and mould-making with a near mono-sized particle size distribution.

2.5 STEEL FIBERS

To enhance the RPC ductility, some mixes were produced with micro-fibres of straight carbon Steel wire, 13 mm in length and 0.2 mm in diameter, with a minimum on-the-wire tensile strength of 2,000 MPa.

Fig 2.3 Steel fibers

2.6 SUPER-PLASTICISER

The very low w/b (cement + silica fume) ratios used in RPC are only possible because of the fluidizing power of high-quality third generation super-plasticizing agents. ViscoCrete-5 was selected as the most suitable for use. This is described as an aqueous modified carboxylate, designed specifically for ultra-high water reduction applications such as self-compacting concrete. To minimise any air-entrainment effects due to the high-dosage rates necessary, 1% Pronal 753S defoaming agent, was also added to the super-plasticiser before use.

Mr. Richard and Mr. Cheyrezy indicate the following principles for developing RPC.

- Enhancement of homogeneity by elimination of coarser aggregates.
- Enhancement of compacted density by Optimization of the granular mixture.
- Enhancement of the microstructure by Post-set heat-treatment
- Enhancement of ductility by addition of small-sized steel fibres
- Application of pressure before and during setting to improve compaction
- Utilization of the pozzolanic properties of silica fume.
- The optimal usage of superplasticizer to reduce w/c and improve workability.

After selecting a mixture design according to minimum water demand, optimum water content is analyzed using the parameter of relative density (Do / Ds). Here Do and Ds represent the density of the concrete and the compacted density of the mixture (no water or air), respectively. Relative density indicates the level of packing of the concrete and its maximum value is one. For RPC, the mixture design should be such that the packing density is maximized.

Heat curing does microstructure enhancement of RPC. Heat curing is by simply heating (normally at 90 C) the concrete at normal pressure after it has set properly. This considerably accelerates the pozzolanic that have formed. Pre-setting pressurization has also been suggested as a means of achieving high strength. The high strength of RPC makes it highly brittle. Steel micro fibres are generally added to RPC to enhance its ductility. Straight steel fibre used typically are about 13mm long, with a diameter of 0.15mm.The fibre are introduced into the mixture at a ratio of between 1.5 and 3 percent by volume. The cost-effective optimal dosage is equivalent to a ratio of 2 percent by Volume.

CHAPTER 3

PROPERTIES OF RPC

3.1 COMPRESSIVE STRENGTH

Higher compressive strength than HPC It is a factor linked with durability of material. Maximum compressive strength of RPC is approximately 200MPa.

3.2 FLEXTURAL STRENGTH

Plane RPC possess high flextural strength than HPC By introducing steel fibers, RPC can achieve high flextural strength.

3.3 RESISTANCE TO CHLORIDE ION PENETRATION

Increases when heat curing is done in concrete Heat cured RPC show higher value than normal cured RPC.

3.4 HOMOGENEITY

Improved by eliminating all coarse aggregates. Dry components for use in RPC is less than 600 micro meter.

3.5 COMPACTNESS

Application of pressure before and during concrete setting period.

3.6 MICROSTRUCTURE

Microstructure of the cement hydrate can be changed by applying heat treatment during curing.

3.7 MATERIAL DUCTILITY

Material ductility can be improved through the addition of short steel fibres.

Table 3.1 Properties of RPC enhancing its homogeneity and strength

Property of RPC	**Description**	**Recommended Values**	**Types of failure eliminated**
Reduction in aggregate size	Coarse aggregates are replaced by fine sand, with a reduction in the size of the coarsest aggregate by a factor of about 50.	Maximum size of fine sand is 600 µm	Mechanical, Chemical & Thermo-mechanical
Enhanced mechanical properties	Improved mechanical properties of the paste by the addition of silica fume	Young's modulus values in 50 GPa – 75 Gpa range	Disturbance of the mechanical stress field.
Reduction in aggregate to matrix ratio	Limitation of sand content	Volume of the paste is at least 20% greater than the voids index of non-compacted sand.	By any external source (e.g., formwork).

Table 3.2 Oxide composition of Cementations Materials

Oxide Composition, % by Weight	**Portland Cement**	**Silica Fume**	**Fly ash**	**Blast Furnace Slag**
CaO	63.0	4.15	2.5	42.4
SiO2	20.0	93.0	52.5	32.3
AL2O3	6.3	0.2	28.2	13.3
Fe2 O3	3.6	0.05	10.5	0.3
MgO	2.4	0.51	1.6	6.4
SO3	1.5	0.05	0.2	2.1
Na2O	0.15	0.2	0.04	-
K2O	0.5	0.22	0.9	-

CHAPTER 4

TYPES OF REACTIVE POWDER CONCRETE

The RPC family includes two types of concrete, which offer interesting implicational possibilities in different areas they are,

(i) RPC 200

(ii) RPC 800

RPC 200 uses a combination of fine quartz, silica, silica fume and cement to form a cementitious matrix supporting straight and smooth steel fibre reinforcements. These steel fibres are generally 13 mm long and have a diameter of 0.15 mm. The addition of super and hyper-plasticisers allow for the cement to be mixed with approximately the same ease as conventional concrete. Obtaining a compressive strength of 170MPa when curing for 28 days at ambient temperature and 230MPa when curing at 90 degrees Celsius for 6-12 hours after pre-curing at ambient temperature for 2 days. They found that the fracture energies varied from 15,000 J/m2 to 40,000 J/m2 depending on the amount of steel fibre added to the mix. The maximum stress encountered was approximately ten times greater than the displacement at the opening of the first crack.

RPC 800 is restricted in its use to small or medium sized pre-fabricated structural elements such as bridge bearings, security vaults and waste/transportation vessels. The composition of RPC 800 proposes by Richard and Cheyrezy is similar to RPC 200 although steel fibres are replaced by a stainless steel microfiber, less than 3mm long. RPC 800 is cured at 250 degrees Celsius after de-moulding and a compressive force is generally applied while in the mould. Richard and Cheyrezy experimented with the use of steel powder instead of quartz sand and reached compressive strengths of up to 800MPa and fracture energies of 1,500 J/m2.

Table 4.1 Typical Composition of Reactive Powder Concrete 200

Material	**Quantity**
Portland Cement – Type V	1000kg/m3
Fine sand (150-400 microns)	500kg/m3
Ground Quartz (4 microns)	390kg/m3
Silica fume (18m2/g)	230kg/m3
Superplasticiser (Polyacrylate)	18kg/m3
Steel Fibres	630kg/m3
Total water	180kg/m3

Table 4.2 Typical Composition of Reactive Powder Concrete 800

Material	**Quantity**
Portland Cement – Type V	955kg/m3
Fine sand (150-400 microns)	1051kg/m3
Silica fume (18m2/g)	229kg/m3
Precipitated Silica (35m2/g)	10kg/m3
Superplasticiser (Polyacrylate)	13kg/m3
Steel Fibres	191kg/m3
Total water	153kg/m3

In order to achieve the aforementioned properties of RPC 200 the underlying following principles become a major focus:

4.1 IMPROVEMENT OF HOMOGENEITY

RPC relies on the homogeneous nature of its aggregates to enhance its physical properties. Common aggregates and traditional sand found in heterogeneous cement mixes are eliminated and replaced with finely ground quartz. Large aggregates form a rigid skeleton and prevent global shrinkage while smaller aggregates can move relative to the paste decreasing the voids present in the final product. The Young's modulus of the cement paste is also increased in RPC with values ranging from 55 to 75GPa. This eliminates modulus variance between the quartz and the surrounding paste and allows for mechanical properties to be transferred through the two mediums.

4.2 INCREASE OF DRY-COMPACTED DENSITY

Water content can be reduced in a concrete mix by increasing the dry-compacted density of the solids. In traditional concrete an increase in the dry compacted density is achieved by the use of superplasticisers and silica fume. An increase in dry-compact density of up to six percent can be achieved by applying pressure after moulding and during setting. This pressure acts to remove entrapped air and expel excess water. It also partially compensates for chemical shrinkage during the first few hours of setting by inducing micro-cracks in the sample.

4.3 IMPROVEMENT OF MICROSTRUCTURE

Silica fume encourages pozzolanic reactions within the cement paste. These pozzolanic reactions are activated by temperature. Richard and Cheyrezy (1994) observed a 30% resistance gain by curing at 90 degrees Celsius for two days while decreasing the size of pores. They also found that, when using ground quartz, a higher curing temperature of 250 to 400 degrees Celsius resulted in the transformation of amorphous cement hydration products to crystalline products such as xonotlite (C6S6H) resulting in dehydration and a significant decrease in weight. Using high temperature curing alone, RPC samples have been made to withstand up to 524MPa compressive strength.

4.4 ACHIEVEMENT OF DUCTILE BEHAVIOUR

The ductile behaviour of RPC is obtained by the addition of steel fibres, by volume, of up to 3 percent. This results in an increase of flexural strength from 28MPa to approximately 100MPa and fracture energies from 50Jm-2 to 40,000Jm-2 depending on the type of hot curing and amount of fibres added. Fracture energies this high indicate a very ductile behaviour. By confining RPC 200 in steel tubes further enhancement in both ultimate strength and ductility can be achieved.

CHAPTER 5

COMPARISION OF RPC AND HPC

Typical mechanical properties of RPC compared to a conventional HPC of compressive strength 80 MPa[11]. As fracture toughness, which is a measure of energy absorbed per unit volume of material to fracture, is higher for RPC, it exhibits high ductility. Apart from their exceptional mechanical properties, RPCs have an ultra-dense microstructure, giving advantageous waterproofing and durability characteristics. These materials can therefore be used for industrial and nuclear waste storage facilities.

RPC has ultra-high durability characteristics resulting from its extremely low porosity, low permeability, limited shrinkage and increased corrosion resistance. In comparison to HPC, there is no penetration of liquid and/or gas through RPC.

5.1 COMPRESSION STRENGTH

Compression strength is the ability of a material to stand up under applied pressure. RPC compression strength can be as high as 120,000 pounds per square inch (psi) compared to residential strength of 2,500 psi. High-strength concrete has a psi above 6,000, and concrete in high rise buildings may have a compressive strength of 20,000 psi, according to the Portland Cement Association.

5.2 TENSILE STRENGTH AND DUCTILITY

Tensile strength is the ability of a material to hold together as it is pulled from each end. Because of the fine steel fibers distributed throughout RPC, the ductility of the concrete is improved, making it less brittle and less vulnerable to breaking when tension is applied. This feature of RPC will come into play as supporting members of an elevated slab of RPC flex and move, putting tension on the slab longitudinally.

5.3 SHEAR STRENGTH

Regular concrete snaps off easily when pressure is applied, indicating a low shear strength. Low shear strength is a result of a lack of flexibility that makes a material as brittle like a pretzel stick. Steel reinforcement fibers give flexibility to RPC, allowing for greater spans with fewer supports. Because of the ultra-high strength, increased flexibility and tensile strength of RPC, less concrete is used, making for lighter slabs. Lighter, stronger materials are a benefit to architectural and civil engineering construction, as they allow longer, safer bridges and taller buildings.

Table 5.1 Comparison of RPC 200 and RPC 800

Qualities	**RPC 200**	**RPC 800**
Pre-setting pressurization	None	50 MPa
Heat-treating	20 to 90°C	250 to 400°C
Compressive strength (using quartz sand)	170 to 230 MPa	490 to 680 MPa
Compressive strength (using steel aggregate)	--	650 to 810 MPa
Flexural strength	30 to 60 MPa	45 to 141 MPa

Table 5.2 Comparison of HPC (80 MPa) and RPC 200

Property	**HPC (80 MPa)**	**RPC 200**
Compressive strength	80 MPa	200 MPa
Flexural strength	7 MPa	40 MPa
Modulus of Elasticity	40 GPa	60 GPa
Fracture Toughness	$<10^3$ J/m²	$30*10^3$ J/m²

Table 5.3 Durability of RPC Compared to HPC

Abrasive Wear	2.5 times lower
Water Absorption	7 times lower
Rate of Corrosion	8 times lower
Chloride ions diffusion	25 times lower

5.4 MIXTURE DESIGN OF RPC AND HPC

The process of mixture selection of RPC and HPC is given below.

- Considerable numbers of trial mixtures were prepared to obtain good RPC and HPC mixture proportions.
- Particle size optimization software, LISA (Elkem website) was used for the preparation of RPC and HPC trial mixtures.
- The selection of best mixture proportions was on the basis of good workability and ideal mixing time.

Table 5.4 Mixture proportions of RPC and HPC

Materials	Mixture proportions			
	RPC	RPC-FIBRE	HPC	HPC-FIBRE
Cement	1	1	1	1
Silica fume	0.25	0.25	0.12	0.12
Quartz powder	0.31	0.31	-	-
Standard sand grade 2	1.09	1.09	-	-
Standard sand grade 3	0.58	0.58	-	-
River sand	-	-	2.40	2.40
20mm aggregate	-	-	1.40	1.40
10mm aggregate	-	-	1.50	1.50
30mm steel fibre	-	0.20	-	-
36mm steel fibre	-	-	-	0.20
Water	0.25	0.25	0.4	0.4

Workability and density were recorded for the fresh concrete mixtures. Some RPC specimens were heat cured by heating in a water bath at 900 C after setting until the time of testing. Specimens of RPC and HPC were also cured in water at room temperature.

The performance of RPC and HPC were monitored over time with respect to the following parameters.

- Compressive strength (as per IS 516 on 50mm cubes for RPC, 100mm cubes for HPC), flexural strength (as per IS 516 on 40x40x160 mm prisms for RPC, 100x100x500 cm beams for HPC)
- Water absorption (on 150 mm cubes for both RPC and HPC), confirming to BS 1881:122-1983
- Non destructive water permeability test using German instruments (on 150mm cubes for both RPC and HPC),
- Resistance to chloride ions penetration test (on discs of diameter 100mm and 50mm as per ASTM C 1202)

5.5 RESULTS

The laboratory experiment conducted by Mr. Dili and Mr. Santhanam (2004), based on the mix proportions given in table 6 has obtained the following results.

5.5.1 FRESH CONCRETE PROPERTIES

The workability of RPC mixture (with and without fibre) measured using the mortar flow table test as per ASTM C 109 was in the range of 120- 140 mm. On the other hand, the workability of HPC mixture (with and without fibre), measured using the slump test as per ASTM C 231,was in the range of 120-150mm.The density of fresh RPC and HPC mixtures was found to be in the range of 2500-2650 kg/m3.

5.5.2 COMPRESSIVE STRENGTH

The compressive strength test shows that RPC has higher compressive strength than HPC. Compressive strength at early ages is also very high for RPC. Compressive strength is one of the factors linked with the durability of a material. The maximum compressive strength of

RPC obtained from this study is high as 200 MPa, while the maximum strength obtained for HPC is 75 MPa.

The incorporation of fibre and use of heat curing was seen to enhance the compressive strength of RPC by 30 to 50 percent. The incorporation of fibre did not affect the compressive strength of HPC significantly.

5.5.3 FLEXURAL STRENGTH

Plain RPC was found to possess marginally higher flexural strength than HPC. Here the increase of flexural strength of RPC with the addition of fibre is higher than that of HPC. According to Mr. Blais P.Y (1994) literature view RPC should have an approximate flexural strength of 40 MPa. The reasons for low flexural strength is due to the fibre used (30mm) were long and their diameters were relatively very higher. Fibre reinforced RPC (with appropriate fibre) has the potential to be used in structures without any addition of steel reinforcement. This cost reduction in reinforcement can compensate the increase in the cost by the elimination of coarse aggregates in RPC to some extent

5.5.4 WATER ABSORPTION

A common trend of the water absorption with age is seen for both RPC and HPC. The percentage of water absorption of RPC however is very low compared to that of HPC. This quality of RPC is one among the desired properties of nuclear waste containment materials. The incorporation of fibres and use of heat curing are seen to marginally increase the water absorption. The presence of fibre possibly leads to creation of channels at the interface between the fibre and paste that promote the uptake of water. Heat curing, on the other hand, leads to the development of a more open microstructure (compared to normal curing) that could result in an increased absorption.

5.5.5 RESISTANCE TO CHLORIDE ION PENETRATION

Penetration of chloride increases when heat curing is done in concrete. Even though heat cured RPC shows a higher value than normal-cured RPC, it is still extremely low or even negligible (<100 coulombs). This property of RPC enhances its suitability for use in nuclear waste containment structures. The addition of steel fibre leads to an increase in the permeability, possibly due to increase in conductance of the concrete. The HPC mixture also showed very low permeability, although higher compared to RPC.

5.5.6 WATER PERMEABILITY

The non-destructive assessment of water permeability using the German instrument equipment actually only measures the surface permeability and not the bulk permeability like in conventional test methods. A comparison of the surface water permeability of RPC and HPC shows that the water permeability decreases with age. The 28-day water permeability of RPC is negligible when compared to that of HPC (almost 7 times lower). As in the case of water absorption, the use of fibre increases the surface permeability of both types of concrete.

5.6 BENIFITS OF RPC

- RPC is a better alternative to high performance concrete and has the potential to structurally compete with steel.
- Its superior strength combined with higher shear capacity results in significant dead load reduction and limitless structural member shape.
- With its ductile tension failure mechanism, RPC can be used to resist all but direct primary tensile stresses. This eliminates the need for supplemental shear and other auxiliary reinforcing steel.
- RPC provides improve seismic performance by reducing inertia loads with lighter members, allowing larger deflections with reduced cross sections, and providing higher energy absorption.

- Its low and non-interconnected porosity diminishes mass transfer making penetration of liquid/gas or radioactive elements nearly non-existent. Cesium diffusion is non-existent and Tritium diffusion is 45 times lower than conventional containment materials.

5.7 ADVANTAGES OF RPC

- It has the potential to structurally compete with steel.
- Superior strength combined with higher shear capacity result in significant dead load reduction.
- RPC can be used to resist all but direct primary tensile stress..
- Improved seismic performance by reducing inertia load with lighter member.
- Low & non-interconnected porosity diminishes mass transfer, making penetration of liquid/gas non-existent.

5.8 APPLICATIONS OF RPC

- Impact-resistant structures
- Nuclear structures
- Skyscrapers
- Corrosion-proof structures
- Pavements
- Barrier to nuclear radiation.
- Security for banks, computer centers
- An application of RPC can be seen in the Pedestrian Bridge 197m span, 3.3m wide, 3.0m deep, 30mm thick slab, in the city of Sherbrooke, Quebec, Canada.

Fig 5.1 Pedestrian Bridge in the city of Sherbrooke, Quebec, Canada.

- Seonyu foot Bridge 120m span, 4.4m wide, 1.3m deep, 30mm thick slab, in Seoul, Korea
- Sakata Mirai footbridge, in Japan

Fig 5.2 Sakata Mirai footbridge, in Japan

- Sewer, Culvert and pressure pipes in Army engineer waterways experiment station, Viksburg, MS.
- RPC has also been used for isolation and containment of nuclear waste of several projects in Europe.
- This product was nominated for the 1999 Nova Awards from the Construction Innovation Forum.
- Half-canopy in steel form of Shawnessy Light Rail Transit Station, Calgary, Canada

Fig 5.3 Half-canopy Light Rail Transit Station, Calgary, Canada

5.9 LIMITATIONS OF RPC

- The least costly components of conventional concrete are basically eliminated or replaced by more expensive elements.
- The fine sand used in RPC becomes equivalent to the coarse aggregate of conventional concrete
- The Portland cement plays the role of the fine aggregate and the silica fume that of the cement of conventional concrete.

- The mineral component optimization alone results in a substantial increase in cost over and above that of conventional concrete (5 to 10 times higher than HPC)
- Applying pressure to mix and applying heat treatment in the field has got technological difficulties and cost.
- RPC should be used in areas where weight savings can be realized
- Since RPC is in its infancy, the long-term properties are not yet known.

5.10 BARRIERS

In a typical RPC mixture design, the least costly components of conventional concrete have been basic basically eliminated or replaced by more expensive elements. The fine sand used in RPC becomes equivalent to the course aggregate of conventional concrete, the Portland cement fills the role of the fine aggregate and the silica fume that of the cement. The mineral component optimization alone results in a substantial increase in cost over and above that of conventional concrete (5 to 10 times higher than High Performance Concrete.)

RPC should be used in areas where substantial weight savings can be realized and where some of the remarkable characteristics of the material can be fully utilized.

5.11 DISCUSSIONS

- A maximum compressive strength of 198 MPa was obtained by Mr.Dili and Mr.Santhanam. This is in the RPC 200 range (175 MPa -225 MPa)
- The maximum flexural strength of RPC obtained was 22 MPa, by Mr.Dili and Mr.Santhanam is lower than the values quoted 40 MPa. A possible reason for this could be the higher length and the diameter of fibre used in this study.
- A comparison of the measurements of the physical, mechanical and durability properties of RPC and HPC shows that RPC has better strength (both compressive and flexural) and lower permeability compared to HPC
- The extremely low levels of water and chloride ion permeability indicate the potential of RPC as a good material for storage of nuclear waste.

- The elimination of reinforcement, reduction of permanent loads of structure and reduction of concrete quantities, generate major cost savings

- RPC needs to be studied with respect to its resistance to other toxic wastes emanating from nuclear plants (such as Cesium 137 ion in alkaline medium) to qualify for use in nuclear waste containment structures.

CHAPTER 6

CONCLUSIONS

RPC is an emerging technology that lends a new dimension to the term "high performance concrete". It has immense potential in construction due to superior mechanical and durability properties than conventional high performance concrete, and could even replace steel in some applications. The development of RPC is based on the application of some basic principles to achieve enhanced homogeneity, very good workability, high compaction, improved microstructure and high ductility. RPC has an ultra-dense microstructure, giving advantageous waterproofing and durability characteristics. It could, therefore be a suitable choice for industrial and nuclear waste storage facilities.

REFERENCES

- RICHARD P and CHEYREZY M “Composition of Reactive Powder Concrete, Cement and Concrete Research”, 1995, Vol 25
- AICTIN P.C. “Cements of yesterday and today: Concrete of tomorrow, Cement and Concrete Research”, 2000, Vol 30.
- BLAIS P.Y and COUTURE M. “Precast, Prestressed pedestrian bridge- World’s first Reactive Powder Concrete structure, PCI journal” 1999,Vol 44
- DAURAIC C “Special concrete may give steel stiff competition: Building concrete. The seattle Daily Journal of Commerce”, May 9, 1977.
- BASU P.C “Performance requirements of HPC for Indian NPP structure. The Indian
- BONNEAU O, VERNET C, MORANVILLE M. and AITCIN P C “Characterization of granular packing and percolation threshold of Reactive Powder Concrete, Cement and Concrete Research” 2000 ,
- GOLTERMANN P, JOHNSAN V and PALBOL L “Packing of aggregates: An alternate tool to determine the optimal aggregate mix, ACI Materials Journal”, September – October 1997.
- MATTE V and MORANVILLE M “Durability of reactive powder composites: Influence of silica fume on the leaching properties of very low w/b pastes, Cement and Concrete Composites”, 1999, Vol 21.
- STAQUET S and EPISON B “Influence of cement and silica fume type on compressive strength of reactive powder concrete, 6th International Sympoium on HPC,University of Brussels Belgium”, 2000.
- BICKLEY J.A and MITCHELL D “A state of art review of high performance concrete structures built in Canada”, 1990-2000(2001)
- Dili and Santhanam,”The Indian concrete journal”, April 2004
- Website on Reactive powder concrete