Reactive Powder Concrete
A New Type of Concrete

RPC
or
UHPFRC
Reactive Powder Concrete

- What is it?
- What does it do?
- What is its applicability?
- Why should we care?
- Where is it headed?
Introduction:

- Reactive-powder concrete (RPC) was first patented by a French construction company in 1994. It is characterized by high strength and very low porosity, which is obtained by optimized particle packing and low water content.

- The compressive strength of reactive-powder concrete is typically around 200 MPa (29,000 psi), but can be produced with compressive strengths up to 800 Mpa (118,000 psi).
مقایسه منحنی‌های تنش–کرنش برای انواع بتن ها
The properties of RPC are achieved by:

1. Eliminating the coarse aggregates;

using very fine powders such as:

- Sand
- Crushed quartz
- Silica fume

particle sizes between 0.02 and 600 μm
The properties of RPC are achieved by:

2. Optimizing the grain size distribution
densify the mixture

3. Post-set heat-treatment to
improve the microstructure
The properties of RPC are achieved by:

4. Addition of steel fibers (about 2% by volume) - high ductility and energy absorption

5. Use of superplasticizers - decrease the water to cement ratio-usually to less than 0.2—while improving the rheology of the paste
The properties of RPC:

- Low permeability
- Limited shrinkage
- High corrosion and abrasion resistance
- High durability
- Reacting all of the powders during or after the hydration reaction at ambient temperature
The properties of RPC:

- RPC can also be considered as a mortar with:
  - a very high paste content
  - high silica fume content
  - low water/cement ratio
Typical Mechanical Properties of RPC Compared to an 80-MPa Concrete

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>80 MPa</th>
<th>RPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>MPa (psi)</td>
<td>80 (11,600)</td>
<td>200 (29,000)</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>MPa (psi)</td>
<td>7 (1000)</td>
<td>40 (5800)</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>MPa (psi)</td>
<td>8 (1160)</td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>GPa (psi)</td>
<td>40 (5.8 x 10^6)</td>
<td>60 (8.7 x 10^6)</td>
</tr>
</tbody>
</table>
Fig. 3: Surface Water Permeability of RPC and HPC
RPC Composition:

1. Portland cement (type II and type V)

   - Cements with low C₃A content give better results

   - Cements with a high Blaine fineness are not satisfactory, due to their high water demand.

   - Cement should have a moderate fineness and a C₃A content significantly lower than 8% to reduce the demand for water, which influences compressive strength.
RPC Composition:

2. Fine quartz sand (150-600μm)

- Advantages of quartz sand
  - Highly angular sand
  - Natural quarry sand, where the grains are more spherical
  - Very hard material
  - Excellent paste/aggregate interfaces
3. Crushed quartz
   Maximum reactivity during heat-treating is obtained for a mean particle size of between 5 and 25 μm (The mean particle size = 10 μm)(is the same granular class as the cement).

4. Silica fume
   ➢ The optimum amount: 25% of the cement by weight
5. Small size steel fibers

- **Dimension of fibers**: 13 mm long, 0.2 mm diameter
- **Strength**: high-strength (tensile strength of 2600 MPa)
- **Ratio of the fibers into the mix**: between 1.5 and 3% by volume (The economic optimum ratio 2% by volume)
- **Effect of fibers**: improving the mechanical properties of the composite, particularly in terms of tensile strength and ductility.
RPC Composition:

6. High dosages of superplasticizer

   A superplasticizer based on polycarboxylate ether was found to be very effective.

7. Low \( w/c \) ratio: 0.16 to 0.27

   The optimum value: approximately 0.22
Mix Compositions (by weight)

mix design which is based on some published recommended compositions:

<table>
<thead>
<tr>
<th>Materials</th>
<th>Cement</th>
<th>Silica fume</th>
<th>Silica sand</th>
<th>Silica powder</th>
<th>Superplasticizer</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportions</td>
<td>1</td>
<td>0.25</td>
<td>1.4</td>
<td>0.25</td>
<td>0.065</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Advantages of RPC compared to the conventional concrete:

- Superior strengths with very high compressive strength of 200 MPa (approximately four times the strengths of conventional Concrete)
- RPC structures may weigh only one-third or one-half of the corresponding conventional concrete structures.
- Weight reduction is good in producing more slender transportation structures, reducing overall costs and increasing usable floor space in high-rise buildings.
Advantages of RPC:

- Superior durability which leads to long service life with reduced maintenance.

- Elimination of steel reinforcement bars reduces high labour costs and provides greater architectural freedom, allowing nearly limitless structural member shapes and forms for architects and designers.

- Reduction of thickness of concrete elements results in material and cost savings.
Weakness of RPC:

- Cement content as high as 800–1000 kg/m³ so it has negative effects on the environment.
In RPC, the number of ingredients is higher and the fineness of the particles is smaller compared to normal-strength concretes. Therefore, it is important that all particles, especially the very fine ones, are uniformly distributed. Because very fine particles tend to form chunks, and the minimal shear force for breaking these chunks can be reduced by keeping the particles dry, it is recommended to mix all dry particles first before adding the water and HRWR.
curing

- Heat-curing

  - Heat-treating at 90°C substantially accelerates the pozzolanic reaction, while modifying the microstructure of the hydrates which have formed.

  - High temperature heat-treating (at between 250 and 400°C), only applicable to fibered RPC.
curing

• Application of pressure

Compressive strength increases with density. An effective way of increasing density is to apply a pressure force to the fresh concrete.

Effects of application of pressure:
- Reduction of entrapped air
- Excess water removal
- Improving the density
curing

Mechanical properties for the two types of RPC:

<table>
<thead>
<tr>
<th>Pre-setting pressurization</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat-treating</td>
<td>20 to 90°C</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>170 to 230MPa</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>30 to 60MPa</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>50 to 60GPa</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pre-setting pressurization</th>
<th>50MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat-treating</td>
<td>250 to 400°C</td>
</tr>
<tr>
<td>Compressive strength</td>
<td></td>
</tr>
<tr>
<td>using quartz sand</td>
<td>490 to 680MPa</td>
</tr>
<tr>
<td>using steel aggregate</td>
<td>650 to 810MPa</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>45 to 141MPa</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>65 to 75GPa</td>
</tr>
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</table>
RPC Applications:

<table>
<thead>
<tr>
<th>Material</th>
<th>Depth</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHPC</td>
<td>14 in</td>
<td>94 lb/ft (355 mm, 140 kg/m)</td>
</tr>
<tr>
<td>STEEL</td>
<td>14 in</td>
<td>75 lb/ft (355 mm, 110 kg/m)</td>
</tr>
<tr>
<td>PRESTRESSED CONCRETE</td>
<td>28 in</td>
<td>313 lb/ft (710 mm, 465 kg/m)</td>
</tr>
<tr>
<td>REINFORCED CONCRETE</td>
<td>28 in</td>
<td>355 lb/ft (710 mm, 530 kg/m)</td>
</tr>
</tbody>
</table>
RPC Applications:

Ultra-High Strength
Beams of Equal Load Carrying Capacity

Mass (weight) of Beams:

- Steel: 313 kg/linear meter, 355 lbs/linear foot
- Reinforced Concrete: 467 kg/linear meter, 530 lbs/linear foot
- Pre-stressed: 112 kg/linear meter, 75 lbs/linear foot

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RPC Applications:

1. First structure that used RPC was a pedestrian bridge in Sherbrooke, Quebec, **Canada**. span: 60 m, **1997**

2. **Seonyu Footbridge on the Han River. Seoul, South Korea.** span: 120 m, **2002**

3. Qinghai-Tibet Railway Bridge, **China**, (160 Mpa)

4. Shawnessy Light Rail Transit Station, **Canada**, 2003

5. An ongoing project: a highway traffic bridge at the Shepherd’s Gully Greek at NSW, **Australia**.
   - four traffic lanes
   - 16 precast pretensioned FR-RPC beams without any conventional stirrup in the web
Future application of RPC

- This material also has excellent impact resistance properties, and can be employed for hardening military structures or equipment.

- Apart from their exceptional mechanical properties, RPC concretes have an ultra-dense microstructure, giving advantageous waterproofing and durability characteristics. These materials can therefore be used for industrial and nuclear waste storage facilities.
<table>
<thead>
<tr>
<th>مصالح</th>
<th>kg/m³</th>
</tr>
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<tbody>
<tr>
<td>سیمان</td>
<td>840</td>
</tr>
<tr>
<td>ماسه سیلیسی</td>
<td>930</td>
</tr>
<tr>
<td>پودر سیلیس</td>
<td>180</td>
</tr>
<tr>
<td>میکروسیلیس</td>
<td>210</td>
</tr>
<tr>
<td>فوق روان کتنده</td>
<td>40</td>
</tr>
<tr>
<td>آب</td>
<td>190</td>
</tr>
</tbody>
</table>

وزن مخصوص بتن تازه: 2400 kg/m³

عمل آوری: 5 روز در آب و سپس در هوا 90°C و سپس گذاشتن در هواي محيط 28 روز ازمايش
 مقاومت 28 روزه: 1600 kg/cm²
Thanks for Your Attention