Irradiation Effects on Concrete Strength

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NRA: Nuclear Regulation Authority, Japan
* NOTE: The content of this report does not represent official NRA positions.

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1. Background
2. Objectives

➢ To investigate the effects on strength reduction of concrete by neutron irradiation.

➢ To investigate the technical basis based on the scientific method when there are the effects on strength reduction.
3. Key Points

- α-quartz in aggregate expands 16 to 18% in volume by neutron irradiation.
- The crystal structure inside α-quartz changes due to metamictization in a process of expansion of aggregate by neutron irradiation.

**Focusing on percentage of α-quartz content in coarse aggregate**

Focusing on percentage of α-quartz content in coarse aggregate

Metamictization*: A state in which a crystal lattice is destroyed by radiation and is regarded as amorphous like glass for both X-rays and visible light.

4. Tests on Coarse Aggregate
Specification on Coarse Aggregate Specimens

- Specimen Size: $\Phi 10\text{mm} \times 10\text{mm}$
- Neutron Fluence ($E>0.1\text{Mev}$): 4 Levels
  - 0.701, 1.28, 4.12, 8.25 ($\times 10^{19} \text{n/cm}^2$)
- Quartz Content: 5 Levels

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Quartz Content (mass %)</th>
<th>$\text{SiO}_2$ Content (%)</th>
<th>Grain Size (mm)</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>91.9</td>
<td>87.0</td>
<td>0.1 - 0.3</td>
<td>Tuff (Crushed Stone)</td>
</tr>
<tr>
<td>GB</td>
<td>47.1</td>
<td>74.7</td>
<td>1.0 - 3.0</td>
<td>Sandstone (Crushed)</td>
</tr>
<tr>
<td>GC</td>
<td>39.7</td>
<td>70.8</td>
<td>2.0 - 5.0</td>
<td>Sandstone (Crushed)</td>
</tr>
<tr>
<td>GD</td>
<td>40.1</td>
<td>74.1</td>
<td>1.0 - 3.0</td>
<td>Sandstone (Crushed)</td>
</tr>
<tr>
<td>GE</td>
<td>23.5</td>
<td>52.6</td>
<td>0.5 - 1.5</td>
<td>Sandstone (Crushed)</td>
</tr>
</tbody>
</table>

The expansion on height was proportional to the square of the neutron fluence.

The quartz content of 23.5 to 47.1% showed no significant difference in height expansion.

Relationship Between Neutron Fluence and Expansion

- The larger the $\alpha$-quartz content, the greater the expansion.
- The larger the neutron fluence, the greater the expansion.
5. Tests on Concrete

Specification on Concrete Specimens

- Specimen Size: Φ40mm × 60mm
- Neutron Fluence (E>0.1Mev): 3 Levels 0.778, 1.41, 4.58 (×10^{19} n/cm^{2})
- Quartz Content: 2 Levels

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Coarse Aggregate</th>
<th>Quartz Content (%)</th>
<th>Size (mm)</th>
<th>Water-Cement Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Con-A</td>
<td>GA</td>
<td>91.9</td>
<td>5 - 13</td>
<td>0.50</td>
</tr>
<tr>
<td>Con-B</td>
<td>GB</td>
<td>47.1</td>
<td>5 - 13</td>
<td>0.50</td>
</tr>
</tbody>
</table>

- Cement: High-Early-Strength Portland Cement
- Fine Aggregate: Pit Sand (SiO_{2} \simeq 76%)

Relationship Between Neutron Fluence and Expansion

- The larger the α-quartz content of aggregate in concrete, the greater the expansion.
- The amount of height expansion of concrete is less than that of aggregate.
Compressive strength of concrete decreased linearly with neutron fluence.

The larger the α-quartz content is, the more rapid the decrease in concrete strength is.

6. Discussion

Result of X-Ray Diffraction in Coarse Aggregate

- Peak position angles shifted to the low angle. → Increase in the spacing of lattice planes ⇒ Expansion
- Peaks of α-quartz decrease due to increase in neutron fluence.
- X-ray diffraction pattern of α-quartz became not being observed. ⇒ Change of the crystal structure
There is almost no change in the peaks on cement paste due to the increase in neutron fluence. 
⇒ Cement paste has high resistance to neutron fluence.

The effect of heat on concrete is not as large as the effect of neutron irradiation. 
⇒ The reduction in compressive strength is dominated by neutron irradiation.

7. Conclusion
The Effects of Concrete by Neutron Irradiation

- Concrete expands by neutron irradiation.
  → The larger the α-quartz content in the coarse aggregate, the greater the expansion of concrete.
- Compressive strength of concrete is decreased by neutron irradiation.
  → The larger the α-quartz content in the coarse aggregate is, the more rapid the decrease in concrete strength is.

Mechanism: increase in the spacing of lattice planes and disappearance of X-ray diffraction pattern on α-quartz in the coarse aggregate of concrete by neutron irradiation.

Thank you very much.