New Insulating Precast Concrete Panels

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Concrete

Conventional concrete is a poor insulating material but has good thermal mass.

Lightweight concrete provides good insulation at the price of thermal mass.

Precast concrete walls systems provide poor thermal and acoustic performance. Precast concrete can however provide high quality products which are easy to construct.
The Variable Density Concrete Panel

- Lightweight material moves towards top of panel
- Insulating layer to prevent heat loss from panel
- Dense, structural used for heat storage
- Under vibration:
  - 170mm
  - 80 mm
  - Welded mesh
  - Heavy material settles during vibration
- In service
## Technical Objectives

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Top Layer</th>
<th>Bottom Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness [$\text{mm}$]</td>
<td>170</td>
<td>80</td>
</tr>
<tr>
<td>Density [$\text{kg/m}^3$]</td>
<td>1000</td>
<td>2250</td>
</tr>
<tr>
<td>Compressive Strength [$\text{MPa}$]</td>
<td>2-5</td>
<td>25-35</td>
</tr>
<tr>
<td>Thermal Conductivity [$\text{W/mK}$]</td>
<td>&lt;0.25</td>
<td>1.00-1.25</td>
</tr>
<tr>
<td>Specific Heat [$\text{MJ/m}^3\text{K}$]</td>
<td>0.75-1.25</td>
<td>2.00-3.00</td>
</tr>
<tr>
<td>R-value panel [$\text{m}^2\text{K/W}$]</td>
<td>0.8-1.0</td>
<td></td>
</tr>
</tbody>
</table>
Recycled Materials & By-products

Aggregate materials:
• Expanded glass beads & perlite, slag
• Pumice, perlite & greywacke chips
• Two grades expanded glass beads & slag

Binders:
• Portland cement (PC)
• Inorganic polymer cement (IPC) – Fly ash & slag (GGBS) activated with alkali & sodium silicate solutions
Recycled Materials & By-products

Aggregates

Expanded glass beads – made from recycled glass that cannot be used by the glass industry to manufacture new glass products (Poraver)

Slag – by-product from smelting iron ore (air cooled) (Steelworks)

Pumice, perlite (Inpro) and greywacke chips (Yaldhurst) – natural materials found in New Zealand
Recycled Materials & By-products

Binders

Portland cement – high energy process

- Embodied energy 1110-1470 kWhr/tonne
- Embodied CO₂ 870-1090 kg/tonne

Embodied energy – total energy used in production
Embodied CO₂ – total amount of carbon dioxide produced

Inorganic polymers – by-products

- Fly ash – mineral residue from coal combustion in electric generating plants
- Slag – ground granulated blast-furnace slag
Stratification

Decreased stickiness

Increased stratification

Rheological properties

Duration of vibration

Intensity of vibration

3000rpm 3500rpm

3000rpm 2500rpm
**Fresh Properties**

- **Moderate flow & high viscosity**
  concrete is too stiff (sticky) to stratify adequately

- **Good flow & low viscosity**
  concrete segregates during handling and produces uneven (delaminated) layers during vibration

- **Good flow & moderate viscosity**
  concrete is relatively homogenous (mixing & handling) and stratifies under vibration
## Hardened Properties

<table>
<thead>
<tr>
<th>Material Property</th>
<th>PC</th>
<th>IPC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>Density ([kg/m^3])</td>
<td>1020</td>
<td>2460</td>
</tr>
<tr>
<td>Compressive Strength ([MPa])</td>
<td>5.0</td>
<td>24.1</td>
</tr>
<tr>
<td>Modulus of Elasticity ([GPa])</td>
<td>7.5</td>
<td>29.5</td>
</tr>
<tr>
<td>Drying shrinkage ([microstrain])</td>
<td>945</td>
<td>570</td>
</tr>
</tbody>
</table>

- Compression strength \(5-19MPa\)
- Cracking flexural strength \(1.4-4.5MPa\)
- Ultimate flexural strength \(4.2-4.9MPa\)
Hardened Properties

- Degree of stratification
- Relative strength and thickness of layers
- Curing, age & environment
Shrinkage and warping

**Insulating layer** - low strength & stiffness, high shrinkage and creep

**Structural layer** - moderate strength & stiffness, low shrinkage & creep

Different shrinkage can be caused because of various reasons; different temperature, moisture, stiffness or strength.

Potential for warping in service is increased even further by the fact that the outside layer is exposed to more severe drying than the interior layer.
Increased stratification → more stress relieve in LW layer → LW layer weaker and less stiff → creeps to follow structural layer
Thermal performance

Thermal conductivity is the ability of a material to conduct heat

Specific heat is the amount of heat per unit mass required to change the temperature by one degree

Thermal mass is the ability of material to absorb and store thermal energy with its mass

Total thermal resistance (R-value) is a measure of products insulating ability (R-value = thickness/thermal conductivity)

Non steady state method - Hot Disk Thermal Constants Analyser (Gustafsson, S. 2005)
Thermal performance

High density conductivity specific heat

Low density, conductivity specific heat

TC [W/mK]

Density [kg/m³]
Degree of stratification

R-value = 0.47

R-value = 0.65

TC = 0.3529
SH = 1.137
TC = 0.4091
SH = 0.8636
TC = 0.5215
SH = 1.380
TC = 0.6258
SH = 0.9579
TC = 1.183
SH = 1.904

TC = 0.2428
SH = 0.6586
TC = 0.3146
SH = 0.8538
TC = 0.6201
SH = 1.644
TC = 1.335
SH = 1.698
R-values for walls

Different R-value requirements in New Zealand, for a wall in a solid construction the minimum requirements (NZS4218, 2004):

- South Island and Central North Island > 1 m²K/W
- Remainder of the North Island > 0.6 m²K/W

Typical R-values achieved for concrete:
- Structural concrete < 0.20
- PC stratified concrete 0.6 – 0.80
- IPC stratified concrete ~ 1.00
Variable density panels

• These mixes were not designed optimising the thermal performance of the variable density concrete
• Only limited range of aggregate types were used
• Factors such as surface resistance have not been examined or included but these could potentially increase the R-value by 0.1-0.2$m^2K/W$
Conclusions

Stratified concrete is relatively easy to make under laboratory conditions:
• Uses recycled material or by-products
• Produces consistent fresh properties
• Has adequate hardened properties
• Produces reasonable serviceability
• Has good thermal performance

Further development will continue under precast yard conditions to assess practical feasibility
Conclusions

Getting closer to sustainability:

• Energy is saved by using less energy in heating
• Using the concrete as insulating material → improving the use of the material
• Using recycled materials or by-products
• Portland cement production is a high energy process that could be replaced by using inorganic polymer binder
Acknowledgements

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Questions