Lecture 12. Non-conventional and advanced building materials

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Lecture contents

- Foamed glass aggregates
- Self-healing (bacterial) concrete
- Cellulose insulation material
- Fiber Reinforced Polymer (FRP) composites rebar
- Quick review of some innovative building materials
1. **Knowledge:**
   - will be able to learn basic theory about main building- and construction materials:
     - material composition / Properties
     - applications in buildings and structures.

2. **Skills:**
   - be able to make right and well-founded choice of materials

3. **General competence:**
   - Learn about non-conventional and innovative building materials
Introduction

Foamed glass aggregates:
- Obtained from recycled glass
- 1980's ‡ production was started in Switzerland and Germany
- 1990's ‡ for use as a thermal barrier in road construction in Scandinavia

Production process - video

1. Waste glass crushing ‡ 6mm
2. Grinding of the crushed glass (Cullet Mill)
3. Sieving of the glass powder
4. Mixing the glass powder with the foaming materials (silica carbide)
5. Baking of the glass mixture ‡ 950°C
6. Rapid cooling: the foamed glass breaks up into gravel size pieces

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http://www.foamit.fi/
## Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Variations recorded in technical literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular size</td>
<td>10...60 mm</td>
</tr>
<tr>
<td>Density (dry bulk)</td>
<td>180...230 kg/m³</td>
</tr>
<tr>
<td>Density (dry compacted)</td>
<td>225...290 kg/m³</td>
</tr>
<tr>
<td>Density (moist. in a long-term road structure)</td>
<td>270...530 kg/m³</td>
</tr>
<tr>
<td>Density, long-term underwater (&lt;1 year)</td>
<td>600 kg/m³</td>
</tr>
<tr>
<td>Density, permanently underwater</td>
<td>1000 kg/m³</td>
</tr>
<tr>
<td>pH value</td>
<td>10</td>
</tr>
<tr>
<td>Water absorption</td>
<td></td>
</tr>
<tr>
<td>Short-term (4 weeks)</td>
<td>30...60 weight-%</td>
</tr>
<tr>
<td>Long-term (1 year)</td>
<td>40...116 weight-%</td>
</tr>
<tr>
<td>Compression strength</td>
<td>0.3...0.4 MPa</td>
</tr>
<tr>
<td>10 % amount of compression</td>
<td></td>
</tr>
<tr>
<td>20 % amount of compression</td>
<td>0.77...0.92 MPa</td>
</tr>
</tbody>
</table>

http://www.foamit.fi/DowebEasyCMS/?Page=FoamitBrochure
Applications

Structural engineering
- Insulation under ground slabs
- Around insulation of basement walls
- Drainages
- Swimming pool insulation
- Terrace insulation
- Light loose fill
- Industrial roofs
- Green roofs and flat roofs
- High load bearing roof constructions
- Floor constructions

Civil engineering
- Light loose fill
- Road construction – load bearing and frost proof
- Frost free foundations of paths and building sites
- Soil stabilization
- Slope stabilization
- Drainage
- Water and sewage line construction
- Thermal insulation of district heating lines
Advantages

- 10 times lighter than stone aggregates
- Highly thermal insulation from the ground
- No capillary formation
- Excellent drainage
- Repose angle of up to 45 degrees possible
- Thermal insulation prevents frost damage

Disadvantages

- Inorganic material
- Not combustible
- Expensive about 60 € / m³
SELF-HEALING (BACTERIAL) CONCRETE

What is S.H.B.C?
- A new concrete technology that autonomously repairs cracks.

How does it work?
- Alkaliphilic bacteria added to concrete matrix.
- Bacteria react to the water and metabolize crystals, which close the crack and protect the steel within.
Bacteria used

- Fresh concrete pH up to 13
- Most organisms die in a pH value of 10 or above.
- There are some bacteria that survive in alkaline environments
- These bacteria can be found, for example:
  - alkali lakes in Russia,
  - carbonate-rich soils in desert areas of Spain
  - soda lakes in Egypt.

Preparations of bacterial concrete

Self healing bacterial concrete can be prepared in two ways.

1. **By the method of direct application**
   - bacterial spores and calcium lactate are added directly while making the concrete and mixed.
   - Here when the crack occurs in the concrete bacterial spores broke and bacteria comes to life and feed on the calcium lactate and limestone is produced which fill the cracks.
Preparation of bacterial concrete

2. By encapsulation method
   - the bacteria and its food, calcium lactate, are placed inside treated clay pellets and concrete is made
   - About 6% of the clay pellets are added for making bacterial concrete
   - When concrete structures are made with bacterial concrete, when the crack occurs in the structure and clay pellets are broken and bacterial treatment occurs and hence the concrete is healed.
   - Minor cracks about 0.5mm width can be treated by using bacterial concrete

   • Among theses two methods encapsulation method is commonly used, even though it’s costlier than direct application. Bacillus bacteria are harmless to human life and hence it can be used effectively.

Mechanism

1. The cracks are formed on the surface of concrete due to many reasons like shrinkage, Inadequate water for hydration ...etc.

2. The water is forced into the crack and the bacteria is activated
The activated bacteria result in metabolic conversion of calcium lactate $[\text{Ca(C}_3\text{H}_5\text{O}_2)_2]$ into calcium carbonate $[\text{CaCO}_3]$, limestone:

$$\text{Ca(C}_3\text{H}_5\text{O}_2)_2 + 7\text{O}_2 \rightarrow \text{CaCO}_3 + 5\text{CO}_2 + 5\text{H}_2\text{O}$$

The self healing bacterial concrete helps in reduced maintenance and repair costs of steel reinforced concrete structures.

- Oxygen is an agent that can induce corrosion, as bacteria feeds on oxygen tendency for the corrosion of reinforcement can be reduced.
- Self healing bacteria can be used in places where humans find it difficult to reach for the maintenance of the structures. Hence it reduces risking of human life in dangerous areas and also increases the durability of the structure.
- Formation of crack will be healed in the initial stage itself thereby increasing the service life of the structure than expected life.
Disadvantages

- If the volume of self healing agents (bacteria and calcium lactate) mixed becomes greater than 20%, the strength of the concrete is reduced.

- Preparation of self healing concrete needs bacteria and calcium lactate.
  - Preparation of calcium lactate from milk is costlier.
  - Hence preparation of self healing concrete costs double than conventional concrete.

Applications

Self healing bacterial concrete can be used for sectors such as:
- tunnel-lining,
- structural basement walls,
- highway bridges,
- concrete floors
- marine structures.
Cellulose insulation is made by hammer milling waste paper and cardboards. The paper and cardboards are treated with chemicals, such as boric acid, to retard the spread of fire.
introduction

- Roughly 85% of the insulation by weight is recycled wood pulp (newspapers)
- 15% of the cellulose insulation by weight is fire retardant (hidastin):
  - Ammonium sulfate,
  - Borates
  - Boric acid

Cellulose insulation

Installation Methods

1. **Loose Fill**
   - either manually pouring in place, or compressed air blowing in place
   - insulation into wall or ceiling cavities.

2. **Spray-On**
   - involves compressed air blowing of cellulose materials that are impregnated with adhesives material to the exposed interior horizontal and vertical surfaces of walls and ceilings

Loose Fill

Spray-On
Installation Methods

3. Board stock
   - involves cellulosic materials that are compressed and formed into rigid boards or panels.
   - The panels may be manufactured with or without surface coatings, facings, or decorative finishes.

Properties of cellulose insulation

<table>
<thead>
<tr>
<th>Property</th>
<th>Cellulose Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity, $\lambda$ [W/m·K]</td>
<td>0.035 in ceiling cavities 0.038 - 0.040 in walls</td>
</tr>
<tr>
<td>Thermal resistance at 100mm [K·m²/W]</td>
<td>2.632</td>
</tr>
<tr>
<td>Specific Heat Capacity [J/(kg·K)]</td>
<td>2020</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>27 to 65</td>
</tr>
<tr>
<td>Embodied energy [MJ/kg]</td>
<td>0.45</td>
</tr>
<tr>
<td>Vapour permeable</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Cellulose insulation is used in:

- **Attics**: blown to whatever depth (with proper ventilation) and there is no joints to allow heat loss.

- **Packed into walls**
  - allows little air infiltration
  - fire and insect resistant.

  • **NOT** recommended for basements due to its sensitivity to moisture.

### Applications

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**Applications**

**Cellulose insulation is used in:**

- **Attics**: blown to whatever depth (with proper ventilation) and there is no joints to allow heat loss.

- **Packed into walls**
  - allows little air infiltration
  - fire and insect resistant.

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**Advantages**

- Helps reducing the discarded paper and cardboard
- Cellulose is treated with boric acid, which increases fire resistance, resists mold and insects.
- Cellulose is generally cheaper than fiberglass insulation (up to 25% cheaper, in some cases)
- Higher R-value of cellulose (2.6 per 100 mm)
- The health risks are fewer than those from fiberglass.

**Disadvantages**

- Cellulose insulation creates an enormous amount of dust when it is installed, so a certified breathing mask is absolutely essential
- Dry-blown cellulose sags and settles, reducing its R-value over time
- Cellulose insulation absorbs moisture easily, cause the insulation to mold and rot
- Both dry- and wet-blown cellulose need a vapor barrier.

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**http://www.solar365.com/green-homes/insulation/cellulose-insulation-pros-cons**
FIBER REINFORCED POLYMER (FRP) COMPOSITES REBAR

What is FRP rebar?

- A structural reinforcing bar made from filaments or fibers held in a polymeric resin matrix binder.

a) Fibers such as Glass (GFRP) or Carbon (CFRP).

b) Matrix: Polyester, Epoxy, Vinyl Ester

Fibers

Provide strength and stiffness

Matrix

Protects and transfers load between fibers

- Creates a material with attributes superior to either component alone!
- Fibers and matrix both play critical roles in the composites material

What is FRP rebar?

Materials
- Glass/ vinylester
- Carbon/ vinylester

Forms
- Solid

Surface
- Ribbed
- Sand Coated
- Wrapped and Sand Coated
- Deformed and Helical

Bar sizes
- 6 – 32 mm

Manufacturing process

The Pultrusion Process:
a process where composite parts are manufactured by:
- pulling layers of fibers/fabrics
- impregnated with resin through a heated die
- thus forming the desired cross-sectional shape with no part length limitation

Resin types in pultrusion including:
- polyester,
- polyurethane,
- *vinylester* for rebar
- epoxy
Factors Affecting Material Characteristics

- Type of fiber
- Fiber volume
- Type of resin
- Fiber orientation
- Quality control procedures during manufacturing
- Rate of curing
- Void content
- Service temperature

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength (MPa)</th>
<th>Elastic Modulus (GPa)</th>
<th>Strain at Break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass FRP</td>
<td>480-1600</td>
<td>35-51</td>
<td>1.2-3.1</td>
</tr>
<tr>
<td>Carbon FRP</td>
<td>1720-3690</td>
<td>120-580</td>
<td>0.5-1.9</td>
</tr>
</tbody>
</table>
Tensile Stress-Strain Characteristics

- Linear elastic behavior to failure
- No yielding
- Higher Ultimate Strength
- Lower Strain at Failure

Standards & Specifications
### Where should FRP rebar be used?

- Any concrete member susceptible to corrosion by chloride ions or chemicals
- Any concrete member requiring non-ferrous reinforcement due to Electro-magnetic considerations
- As an alternative to epoxy, galvanized, or stainless steel rebars
- Where machinery will "consume" the reinforced member i.e. Mining and tunneling
- Applications requiring Thermal non-conductivity

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### FRP rebar applications

- **Sierrita de la Cruz Creek Bridge**
  - USA
- **Taylor Bridge**
  - Manitoba, Canada
- **Pierce Street Bridge, Lima**
  - OH, USA
- **Wotton, Quebec**
  - Canada

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FRP rebar applications

Seawalls


INNOVATIVE BUILDING MATERIALS
Translucent concrete

- Concrete based building material with light transmissive properties due to embedded light optical elements (optical fibers).

Solar Panel Roofing Tiles

- Transform the solar energy into useable electricity.
Nanomaterials

- When combined with ultra-high-strength concrete, nanomaterials such as Carbon Nanotubes (CNTs) create a material so strong in both tension and compression that steel rebar is no longer needed in construction, therefore expediting the building process.

http://architizer.com/blog/material-trends-for-2014-and-beyond/

Concrete Canvas

- A flexible cement impregnated fabric that hardens on hydration to form a thin, durable water proof and fire proof concrete layer.
- Essentially, it’s concrete on a roll Just Add Water.

http://voices.nationalgeographic.com/2013/03/20/concrete-canvas-goes-beyond-fast-deploying-shelters/
Thank you for attending the CIV-E1010 course