Lightweight Cement Boards Reinforced with Fibers from Post Consumer Carpet

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Outline

- Carpet waste
- The need for diversified approaches in carpet recycling
- Light-weight cement board
- Bending and impact properties
- Applications
Carpet recycling

- Carpet structure
  - About 85% tufted
  - Other: woven, nonwoven, etc

[Diagram showing the structure of a carpet with layers labeled as Face yarn (nylon etc), Primary backing (PP), Adhesive (CaCO$_3$/latex), and Secondary backing (PP).]
Components in a carpet

Typical Carpet (g/m²)

- Face Yarn: 1291
- Backing: 170
- SBR: 238
- CaCO₃: 713

Used Carpet (%)

- Face Yarn: 40.0%
- Backing: 5.0%
- SBR/CaCO₃ adhesive: 30.0%
- Dirt: 25.0%
Processes to recover polymers

- Recovery of “pure” resins (e.g., nylon)
  - High value of products
  - Sort carpet then separate its components by chemical or mechanical means
  - Complicated & costly processes

- Processes to convert entire carpet of a given type into products (e.g., glass fiber reinforced composites)
  - Need to sort carpet, but no need to separate components

- Processes independent of carpet type
  - Converting any type of carpet into products (e.g., wood-like composites)
  - No sorting & component separation. Lower cost

- They should all play a role in carpet recycling
Commercial products

- Pads
- Decking
- Marine Timbers
- Shingles
- Rail Road Crossties
- Stones
Synergy of recycling activities

- The need for maximum use of all-types of carpet collected
- Each approach may not be the “best”, but contributes to the overall success

Need Various Outlets for Waste Carpet Collected

- Post consumer carpet
- Mats, pads, geotextiles
- Fiber for concrete
- Glass fiber composites
- Nylon 6 carpet
- Nylon 6 depolymerization
- Resins
- Plastic lumber
- Chemicals
- Etc.
- Cement kiln
Cement boards & concrete

- Use of carpet waste
  - Requires low cost processing
  - No need for fiber ID & separation
  - Low cost products
  - Large potential market

- An ideal outlet for carpet waste collected but not suitable for high value processes such as nylon 6 depolymerization
Fiber reinforced concrete

- Concrete: most widely used structural material. Brittle, weak in tension
- Fibers: may improve toughness & reduce shrinkage cracking
- Recycled fibers are also effective in concrete: Shredded nylon & PP carpet
- Typical fiber content: 0.1-1% (volume or mass)
Fiber bridging in flexural test
Development of cement board

- High fiber content, up to 20 wt. %
- Very light in weight, porous structure
  - Carpet fiber cement board: 0.7-1.0 g/cm³
  - (Typical concrete density: 2.4 g/cm³; lightweight concrete density: 1.7 g/cm³)
- Can be easily cut with ordinary tools
- Work well with nails and screws
Preparation of cement boards

- Mixes: varying (fiber):(cement):(water) ratios
  - Fiber: 185 g
  - Cement: 925-1850 g
  - Water: 800-1100 g

- Fibers
  - Post consumer carpet (nylon & PP)
  - Coarse shredding, fiber length 50-70 mm (2-3”)

- Portland cement
  - (G) gray, and (W) white
Sample preparation

- Cement, fibers and water are mixed in a container
- Placed in a mold by hand
- Allowed to cure for 7 days
- Cut with ordinary saw for testing
Cement board samples

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Fiber</th>
<th>Water</th>
<th>Cement</th>
<th>Density (g/cm³)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200</td>
<td>1.081</td>
<td>1 (Gray)</td>
<td>0.678</td>
</tr>
<tr>
<td>2</td>
<td>0.159</td>
<td>0.690</td>
<td>1 (Gray)</td>
<td>0.841</td>
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<tr>
<td>3</td>
<td>0.150</td>
<td>0.608</td>
<td>1 (Gray)</td>
<td>0.848</td>
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<tr>
<td>4</td>
<td>0.128</td>
<td>0.690</td>
<td>1 (Gray)</td>
<td>0.953</td>
</tr>
<tr>
<td>5</td>
<td>0.200</td>
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<td>1 (white)</td>
<td>0.729</td>
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<tr>
<td>6</td>
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<td>1 (white)</td>
<td>0.943</td>
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<td>7</td>
<td>0.100</td>
<td>0.595</td>
<td>1 (white)</td>
<td>1.001</td>
</tr>
</tbody>
</table>
Density vs fiber/cement ratio

- Density decreases with increase in fiber content
- Density increases with increase in cement content
Flexural test

- Three-point bending on an Instron machine
- Specimen: about 30 mm in height
- 5 specimens
Flexural test specimens

- Gray (top) & white (bottom) cement
- Ductile, non-brittle failure
Flexural test curves

MIX: Fiber 0.15, Water 0.618, Cement 1.0, Density 0.848
Typical flexural test curves

Ductile failure (gray cement specimens)

Fiber/cement ratio

0.13
0.15
0.20
0.16
Flexural Toughness index

\[ TI_5 = \frac{A + B}{A} \]

Brittle material
TI = 1

Elastic-plastic material
TI = 9

Strain-softening mat'l
1 < TI < 9
**Flexural Toughness index**

<table>
<thead>
<tr>
<th>Sample No.</th>
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<th>Water</th>
<th>Cement</th>
<th>$T_{I5}$</th>
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</thead>
<tbody>
<tr>
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<td>0.100</td>
<td>0.595</td>
<td>1 (white)</td>
<td>7.50</td>
</tr>
</tbody>
</table>

Similar toughness index values. Behavior close to “elastic-plastic”
Flexural test results

- Strength and modulus decrease with fiber/cement ratio

![Graph showing flexural test results with fiber to cement ratio on the x-axis and strength on the y-axis. The graph indicates a decrease in strength as the fiber to cement ratio increases.]
Flexural test results

- Strength and modulus increase with density

**Graphs:**

- **Flexural Test**
  - Strength (MPa) vs. Density (g/cc)
  - Modulus (GPa) vs. Density (g/cc)
Impact test

- On Dynatub tester
- Drop weight
- Impact velocity
  - 2.15 m/sec
- Specimens
  - 100 x 100 mm
  - 28.3 mm thickness
- Test data
  - Energy absorption
  - Maximum force
Impact test: Impact energy

- Impact energy is not sensitive to fiber ratio
Impact test: Impact energy

- Impact energy is not sensitive to fiber ratio
- Due to total absorption of impact energy at the test level
- Most damages are not visible from the back side
Impact test: Maximum force

- Maximum force decreases with fiber/cement ratio
- Maximum force increases with density
Potential applications

- Characteristics
  - Lightweight, tough, easy to handle & install
  - Moisture, mold, termite resistant

- Applications
  - Underlayment board for tiles
  - Wall panels replacing dry wall for wet locations
  - Outdoor patio tiles & stones
Summary

- Large amount of fibrous waste: a resource
- Overall success of post consumer carpet recycling requires
  - High value added technologies, e.g., nylon 6 depolymerization, nylon 66 resins
  - Other technologies to use all carpet collected (low cost, large volume, any fiber type)
- Very light cement boards are made using post consumer carpet fibers
  - Have adequate properties: bending, impact, compressive
  - Other desirable attributes: moisture, mold, termite resistance
  - Suitable for in-door & out uses