Recycling and Disposal of Thermoset Composites

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Presentation Outline

• Need to Recycle
• Problems in recycling FRP
• Recycling Processes
  – mechanical recycling
  – thermal processing
• Use of Recyclate
• Current and future activities
Need to Recycle

Pressure from legislation

• EU Directives
  • Landfill
  • End-of-Life Vehicles
  • Waste Electrical and Electronic Equipment

Reduce Environmental Impact

Make money!
Recycling Heirarchy

- **Prevent** waste
- **Reuse** product
- **Recycle** material

**Incineration**
- with material and energy recovery
- with energy recovery
- without recovery

**Landfill**

Does not measure recycling quality (environmental benefit)
Problems in Recycling FRP (thermosets)

- Technical Problems
  - Thermosetting polymers can’t be remoulded
  - Long fibres
  - Mixtures of materials (different compositions)
  - Contamination
- Costs
- Collection and Separation
Recycling Processes for Thermoset Composites

- Mechanical Recycling (comminution)
  - Powdered fillers
  - Fibrous products (potential reinforcement)

- Thermal Processes
  - Combustion with energy recovery (and material utilisation)
    - Fluidised Bed process
    - Pyrolysis processes
    - Thermal Fluid processes

- Fibres & energy recovery
- Fibres & energy/chemical products
- Fibres & chemical products
Mechanical Recycling

Size reduction

- Coarse primary crushing
- Hammer milling followed by grading to give:
  - Powder
  - Coarser fractions (*reinforcement rich*)

*All scrap material is contained in recyclate (incl. different polymers, contamination, paint....)*
Mechanical Recycling

Recyclate

- Powdered recyclate \((\text{resin rich})\)
  
  \((\text{particle sizes } < \sim 100 \text{ microns})\)

- Coarser fibrous recyclate \((\text{fibre rich})\)
  
  \((\text{fibre length up to } \sim 20 \text{mm})\)

Most research has been done on glass fibre
Thermal Recycling

- Aim is to recover clean fibres (glass or carbon)
- Energy recovery or chemical products from polymer
- Prepare scrap by shredding before thermal process or by chopping fibre after thermal process.
- Most research has been done on carbon fibre
Combustion with material and energy recovery in *cement kilns*

- GFRP can be disposed of in cement kilns
- Polymer contributes to kiln energy demand
- Glass fibre and fillers contribute to minerals to make cement.
- Accepted as a material/energy recycling route within EU.

[www.compocycle.com](http://www.compocycle.com)  *(EuCIA/ECRC)*
Pyrolysis Processes

- Heating in absence of air
- Potential for low fibre oxidation
- Need to avoid char on fibres:
  - Controlled atmosphere (O2)
  - Operating commercially

Key Issues:
- Controlled removal of pyrolytic char to ensure quality.
- Fibre length control: before or after pyrolysis?
Fluidised Bed Process

- Carbon fibre recovery and energy recovery from polymer
- Separates carbon fibre from contaminated and mixed materials e.g. end-of-life waste
- Robust process
Thermal-Fluid Processes

- Heating in presence of a fluid to breakdown and extract polymer
- Catalytic process
- Supercritical fluid (propanol)
- Clean/ high grade fibres
- Useful chemical products
Thermal Recycling

Recyclate

- Short individual filaments in fluffy form with a length distribution.
- Some retention of fibre architecture possible in continuous pyrolysis processes.
- Clean fibres; modulus unchanged, some loss of tensile strength – particularly with glass fibre.
Mechanical Recycling

Recycling into new composites

• Powdered recyclate useful as a filler
  
  \((\text{up to 25\% incorporated in new composite})\)

• Coarser recyclate has reinforcement properties
  
  \((\text{up to 50\% substitution of glass fibre})\)

Issues:

• Fibres covered by damaged polymer (may limit strength and toughness of composite)

• Recyclate is unlike conventional forms of glass fibre/filler and gives processing difficulties
Mechanical Recycling

Recycling into other products

- Compounding with thermoplastics (*issue of bonding of recyclate to thermoplastic*)
- Reinforce recycled thermoplastics for plastic timber
- Production of reinforcement with recyclate core to allow resin flow during impregnation
- Using recyclate to provide damping (noise insulation)
- Alternative to wood fibre
- Asphalt/concrete

Bespoke applications need to be developed with specific waste available.
Thermal Processing

Uses for Recycled Fibre

- Surfacing veil (glass and carbon)
- Structural Reinforcement (glass and carbon)
- Electro-Magnetic Shielding Materials (carbon fibre)
  - Tissue/Veil
  - Milled fibre - compounding
Thermal Processing

**Non-Woven Random Mat**

- Use paper making type processes to form recycled fibre into a non-woven mat.
- Disperse fibres in liquid and form mat on wire mesh.
- Existing commercial process are suitable.
Reuse of **Recycled Carbon Fibre**

**Structural Reinforcement - Processing Routes**

- **Random**
  - BMC / low value
  - Compression moulding TS/TP
  - Low volume fraction $\sim 10-15\%$
    - (Direct utilisation)
- **Discontinuous Recycled fibres**
  - Intermediate volume fraction $10-30\%$
    - (Intermediate material)
- **Aligned**
  - Thermoplastic Injection Moulding
  - Intermediate volume fraction $10-40\%$
    - (Intermediate material - pellets)
  - Aligned fibre material
  - Wet processing?
  - Dry processing?
  - High volume fraction $30-60\%$
The Quest for High Grade Structural Properties
– fibre volume fraction and fibre alignment

• High fibre volume fraction needed for best structural properties.

• Aligning fibres gives better uni-axial properties.

• Aligning fibres allows higher volume fractions at lower moulding pressures with lower fibre damage.

Fibres need to be almost perfectly aligned to give highest volume fractions.

Less perfect alignment still gives good mechanical properties.
Alignment Issues

- Random mat needs high pressure to achieve high volume fraction – this causes fibre damage.

- Alignment techniques for short fibres currently under development.
<table>
<thead>
<tr>
<th>Flexural property</th>
<th>Aligned direction, 0°</th>
<th>Transverse direction, 90°</th>
<th>0°/90° ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>1247.92 ± 68.48 MPa</td>
<td>107.36 ± 2.07 MPa</td>
<td>11.6</td>
</tr>
<tr>
<td>Stiffness</td>
<td>81.84 ± 5.02 GPa</td>
<td>7.23 ± 0.16 GPa</td>
<td>11.3</td>
</tr>
</tbody>
</table>

**Recycled Carbon Fibre**
- 62.5% fibre volume fraction
- Precompacted at 100 bar
- Moulded at 80 bar

**Image:**
- **Highly packed region**
- **Loosely packed regions**
- **CF content: 62.5vol%**
Market Enabling – fibre alignment for rCF

Added value of aligned products

High alignment needed to compete with high value CFRP
Summary

• Some early ventures were **not successful** – viable levels of operation not achieved

• Recyclates were **too expensive** to compete in available markets

• Glass fibre composites can be disposed of in **cement kilns**.

• Composites can be **recycled mechanically** into new products – but current activities generally limited to **manufacturing scrap** by some manufacturers.
Summary contd....

- Several commercial carbon fibre recycling companies in operation.
- Processes suitable for manufacturing scrap and some end-of-life materials.
- Recyclate sold as milled fibre, and chopped fibre pelletised for injection moulding and preforms for liquid moulding processes.
Future Prospects

• Need to **reduce recycling cost** AND/OR

• Need to develop **higher grade aligned recyclates** for more valuable markets (carbon fibre)

• Need to develop processes for **end-of-life** composites.

• Need for **Life Cycle Analysis** to identify best environmental options.
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Driving Innovation

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RECYCLED CARBON FIBRE

Vestas