Challenges of Fibre Recovery from Thermoset Composites Materials

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Presentation content

• Composite waste streams
• Fibre recovery technologies for thermoset composites.
• Issues and opportunities for re-use of recovered fibre as reinforcement.
Carbon/Glass Fibre Waste

- Dry fibre waste – from weaving, preforming, prepreg manufacture.
- Waste prepreg (CF)/moulding compounds (GF) (thermoset)
- Cured thermoset composite waste from manufacture
- End of life thermoset composite waste
- Waste thermoplastic CFRP
Typical fibre recovery (separation) process

- Most processes use heat to breakdown resin and allow fibre separation
- Preparation of waste (size reduction)
- Post treatment operations (packaging)
- Few processes yet developed to commercial scale
Recycling Processes for CFRP

Pyrolysis processes

- Heating in absence of air
- Potential for low fibre oxidation
- Need to avoid char on fibres:
  - Controlled atmosphere (O₂)
- Operating commercially
  (ELG CF UK/ Carbon Conversions USA/ CFK Valley, Germany/Karborek Italy.....)

Key Issues:
- Controlled removal of pyrolytic char to ensure quality – thick parts?
- Fibre length control: before or after pyrolysis?

Recovery of clean carbon fibres

Energy recovery from polymer

Separates carbon fibre from contaminated and mixed materials e.g. end-of-life waste

Robust process

Key Issues:

- Requires source of hot air (*heat recovery*)
- Removal of contaminants from fluidised bed.

Microwave pyrolysis

- Heating from microwave radiation
- Heating in absence of air
- No pyrolytic char formed on fibres
- No fibre oxidation damage
- Waste must be shredded and fragments dispersed.

**Key Issues:**

- Difficult to control energy input and ensure full polymer removal
- Difficult to control process temperature

EH Lester et al, Mat Res Bulletin, 39, 2004
Thermal-fluid processes (Solvolysis)

- Heating in presence of a fluid to breakdown and extract polymer
- Supercritical fluids (propanol/water)
- Clean/ high grade fibres recovered
- Useful chemical products recovered
- Some lower temperature catalytic processes (Adherent Technologies USA)

Key Issues:
- High pressure/temperatures – expensive equipment

Thermal Recycling Processes

Pyrolysis Processes
Waste is heated in low oxygen conditions and pyrolytic char remains on fibres. Oxygen is introduced to oxidise char. Care needed to ensure all char is removed without oxidising rCF. (Microwave pyrolysis avoids char production.)

Fluidised Bed Process
As char is oxidised, fibres are released and elutriated from fluidised bed. This avoids excess oxidation of fibres after char removal, and only clean fibres are elutriated.
Properties of Recycled Fibre

- Good mechanical properties - modulus largely unchanged, some loss in strength.
- Good surface chemistry properties – functional groups for bonding to epoxy resins.
- Clean fibres generally produced.
- Physical form – filamentised, discontinuous fibres in a fluffy form with a length distribution, *unlike commercial grades of virgin fibre*

**Challenge:**

Using fluffy discontinuous recycled carbon fibre in high grade applications.

Large quantities of end-of-life glass thermoset composite waste need recycling (e.g. wind turbine, marine and construction industries)

- Cement kiln recycling established in Europe.
- Mechanical recycling
  - Shredding/milling – cheap processes.
  - Filler or coarse reinforcement
  - Alternative materials are very cheap
- Thermal fibre recovery
  - Clean fibres can be recovered (fluidised bed)
  - Poor strength of recovered glass fibre
  - Strength recovery technology available

*Development of recycling hampered by very low cost of alternative virgin materials*
Reuse of Recovered Carbon Fibre

Structural Reinforcement - Processing Routes

- **Discontinuous recovered fibres**
  - Random
    - BMC / low value
      - Low volume fraction ~10-15%
        (Direct utilisation)
    - Non-woven random mat
      - Compression moulding TS/TP
        - Intermediate volume fraction 10-30%
          (Intermediate material)
      - Intermediate volume fraction 10-40%
        (Intermediate material - pellets)
    - Thermoplastic Injection Moulding
      - Intermediate volume fraction 10-40%
        (Intermediate material - pellets)
  - Aligned
    - Aligned fibre material
      - Wet processing?
      - Dry processing?
  - High volume fraction 30-60%
High fibre volume fraction (~60%) composites don’t compete with other cheaper materials.
Composites from random non-woven mat

- High moulding pressure required for high fibre volume fraction.
- Increasing moulding pressure does not achieve required mechanical properties.
- High moulding pressure reduces fibre length through breakage.

**Moulding pressure required for random mat**

**Composite mechanical properties**

(Epoxy/recovered carbon fibre)

**Mean fibre length in moulded composite**

(Epoxy/recovered carbon fibre)

KH Wong et al, SAMPE Conference, May 2009, Baltimore
Fibre alignment process

- Convergent flow fibre alignment processes developed by MoD in 1960’s/70’s.
- Suspension of fibres in viscous liquid fed through convergent nozzle onto rotating drum with mesh screen.

Composite manufacture from aligned mat

- Autoclaved T700 3mm fibre 2mm thick laminates
- Volume Fraction achieved = 46%
- Modulus expected from perfectly aligned continuous fibres ~107 GPa
- Little fibre length degradation during moulding.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Strength (MPa)</th>
<th>Modulus (GPa)</th>
<th>Areal density (gsm/layer)</th>
<th>Fibre vf (%)</th>
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<td>877.2</td>
<td>96.4</td>
<td>151.5</td>
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<td>775.5</td>
<td>96.1</td>
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</table>

- 49% fibre volume fraction was achieved at 7bar (autoclave pressure)
- 3mm fibres
High value composites

- Aligned rCF fibre
- Random rCF fibre
Summary

- A range of carbon fibre recovery processes are proposed and commercial exploitation is developing.
- Recovered carbon fibre can be processed into non-woven fabric using wet lay technology, but random non-wovens cannot be processed into highest value composites.
- Alignment processes under development show promise to allow recovered carbon fibre to reach high value applications.
- Glass fibre composites recycling still remains a challenge.