Composite Products from
Post-Consumer Carpet

John Muzzy, Georgia Tech
Richard Simmons, Georgia Composites & Eleison Composites

CARE Conference
May 10, 2005
Callaway Gardens
Outline

- Georgia Tech and Georgia Composites
- Glass Fiber Composites
- Wood Fiber Composites
- Bracket Demonstration Product
- Additional Products
- Conclusions
- Future work
Georgia Tech’s Role

• CCACI project:
  – Products from Post-consumer carpet
    • Focus on reinforced composites
    • Determine properties and processing routes
    • Identify and assess applications
  – Use processing and testing facilities in the Center for Polymer Processing
Georgia Composite’s Role

• CARE Project:
  – Molded Products containing Post-Consumer Carpet
    • Screen applications (presented last year)
    • Demonstrate molding of viable candidates
    • Commercialize molded products
Georgia Composites Background

- Georgia Tech start-up
  - Initial technology from Muzzy in 1997
- Eleison Composites, LLC has majority stake
  - As of April, 2005
- Primary product is GcompR
  - Mostly glass mat reinforced recycled polypropylene
SUV Load Floor

Decorative Carpet (PP)

Top Reinforcing Skin (Gcomp)

Internal Core Layer (PP)

Bottom Reinforcing Skin (Gcomp)

Molded by Venture Industries
Load Floor in SUV
Jeep Grand Cherokee
Challenges & opportunities

- 4 billion lbs per year of carpet waste is landfilled
- Industry initiative, CARE, set a goal to divert 40%, or recycle 1.5 billion lbs per year in 7 years (2012)
- What’s needed
  - Diversified technologies, products & commercial activities
  - Large volume, cost-effective applications
Why Reinforce PCC?

Fibers dominate properties (99 %) (GPa)

<table>
<thead>
<tr>
<th></th>
<th>Thermoplastic</th>
<th>Glass Fiber</th>
<th>Composite 60 vol %, unidirectional</th>
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</thead>
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<tr>
<td>Tensile Strength</td>
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<tr>
<td>Modulus</td>
<td>2</td>
<td>70</td>
<td>40</td>
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Why Long Fiber?

- Impact Strength increases with fiber length
- Avoid fiber breakage
  - Requires use of low shear extruders

![Graph showing impact strength vs fiber length]
Approach: Do only easy separation

• Sort carpet by face fiber
  => process entire carpet
  => pellets with mixed polymers
  – Suitable for low cost, high volume processing
  – Low properties due to incompatibility between nylon & PP?
  – May improve properties by using compatibilizers AND/OR fiber reinforcement
Pelletizing Shredded Carpet

- Shredded carpet (separated by face fiber)
  - Courtesy of Wellman, Inc.
- Pelletized using NGR A-Class Type 55 Repelletizing System
  - Some provided by Wellman, Inc.

![Diagram of pelletizing process]

- 260°C
High Face Fiber Contents in NGR pellets from shredded PCC

Weight % via DSC

<table>
<thead>
<tr>
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<th>PP</th>
<th>N6</th>
<th>N66</th>
<th>Remainder</th>
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<tr>
<td>PP PCC</td>
<td>84</td>
<td>9</td>
<td>0</td>
<td>7</td>
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<tr>
<td>N6 PCC</td>
<td>11</td>
<td>77</td>
<td>0</td>
<td>12</td>
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<tr>
<td>N66 PCC</td>
<td>8</td>
<td>0</td>
<td>81</td>
<td>11</td>
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- Significant loss of SBR, calcium carbonate and dirt in shredded PCC
- N6 in PP PCC is an artifact from changeover
- DSC analytical technique quick and effective
Properties of Compression Molded Pellets of PCC Close to Neat Resins

<table>
<thead>
<tr>
<th>PCC</th>
<th>Flexural Strength (MPa)</th>
<th>CV (%)</th>
<th>Flexural Modulus (GPa)</th>
<th>CV (%)</th>
<th>Drop Impact Strength (J@4.0 mm th)</th>
<th>CV (%)</th>
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<td>PP</td>
<td>42</td>
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<td>2.3</td>
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<td>4</td>
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<td>70</td>
<td>16.2</td>
<td>2.7</td>
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<tr>
<td>N66</td>
<td>63</td>
<td>2.7</td>
<td>2.0</td>
<td>14.5</td>
<td>1.7</td>
<td>6.6</td>
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- Impact strengths low
- Note: 1 MPa = 145 psi, 1 GPa = 145,000 psi
Glass Fiber Mat Composite Preparation

- E-Glass mat from Eleison Composites, Brighton, MI
  - Weight=115 g/m², with about 10 wt% TP binder
- Shredded PCC debulked into thin mats
- PCC Pellets ground to coarse powder, OR
- Powder or debulked mats interleaved with mats in 30 x 30 cm mold
- Mold heated above PCC melt temperature at 0.1 MPa
- Pressure increased to 1.5 MPa during cooling
Flex Strength of Glass Mat PCC Composites Close to Commercial GMT

- Commercial GMT:
  - Azdel
    - 32 %: 104 MPa
    - 40 %: 146 MPa
- Nylon PCC better
- PP PCC probably needs an adhesion promoter
- Pellets better than Debulked
Flex Modulus of GMT from PCC similar to Commercial GMT

- Commercial GMT:
  - Azdel
    - 32%: 4.6 GPa
    - 40%: 5.5 GPa
- Nylon 66 PCC better
- Other PCC comparable
- Pellets > Debulked
Drop Impact Strength of GMT from PCC similar to Commercial GMT, J @ 4 mm thickness

- Commercial GMT:
  - Azdel
    - 32%: 22.7 J @ 4 mm
    - 40%: 23.7 J @ 4 mm
- PP and Nylon 6 PCC comparable
- N66 low (degradation)
- Debulking close to pellets
Glass Fiber Reinforced PCC status

- Glass mat reinforced PCC has good mechanical properties
- Evaluating extrusion compounding
- Demonstrating coupling extrusion compounding with compression molding
Wood Fiber vs Glass Fiber Composites

- **Advantages**
  - Cheaper
  - Renewable
  - Lower density
  - Less abrasive
  - More durable

- **Disadvantages**
  - Lower strength
  - Lower modulus
  - Hard to disperse
  - Low aspect ratio
  - Degradation
Wood Fiber Processing

- Heat treatment of wood fibers
  - 1 hour, above matrix melt temp, N₂ purge
- Sizing of fibers
  - Polyurethane emulsion from Hydrosize Technologies
- Dry fibers and matrix
- Compounding and molding
  1. Batch mixer and compression mold
  2. Double injection mold
     - Dry blend, injection mold, grind, mold again
     - Less time at high temperature than # 1
# PCC / Wood Flour Properties

*(60 / 40 wt %)*

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<tr>
<th>Face Fiber</th>
<th>Heat treat</th>
<th>Sizing*</th>
<th>Flex Str.</th>
<th>Flex Mod.</th>
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<th>Ten. Mod.</th>
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<td>GPa</td>
<td>MPa</td>
<td>GPa</td>
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* Polyurethane emulsion
# Nylon 6 PCC/Pulp Properties

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<td>Flour</td>
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* Polyurethane emulsion
Wood Pulp Composite Status/Plans

• PP and N6 composites promising
• N66 needs work (less time at high temp.)
• Scale up to 30 mm twin screw
• Couple extrusion and molding (less time at high temp.)
• Find feeders for pulps and shredded carpets
Integrated Process Scheme

PC Carpet

Sort → Shred → Compact

Melt → Devolutilize → Compound → Extrude

Adsorb → Compression Mold → Molded Products

Dirt and CaCO₃

Additives and Reinforcements

Extruded Products
Lab Demonstration

Cross-section of twin screw

25 mm rod die

NFM Welding Engineers
30 mm twin screw design

Hopper
Vent
Glass Feed Vent

Home of the 1996 Olympic Village
Georgia Institute of Technology

Georgia Composites
Glass Feeding
Chopper Feed

- Glass Roving
- Chopper Gun (motorized)
- Hopper
Extruded Charge
Molding Z Base Bracket

Hot Log from Extruder
Brackets from PCC / Chopped Glass

PP PCC + 20 wt % 1/2” GF

N6 PCC + 20 wt % 1” GF
Bracket Outside, PET/Wood Flour
Bracket Economics

- Raw materials: $0.30/lb or $0.50/bracket set
- Need 4 presses and molds for one 30 mm extruder
- Make 450,000 bracket sets/yr (760,000 lb/yr)
- Break-even selling price $2.10/bracket set
- Assessment:
  - Feasible
  - Try wood fibers instead of glass fibers
  - Look for bigger products
    - Better for larger extruders and larger parts
Composite applications

- Brackets (just covered)
  - Everything that follows is > than 10 lbs/part
  - Truck accessories
    - Tool boxes
  - Manhole covers
  - Car components
    - Bumpers

- Shipping
  - Pallets
  - Containers

- Building Elements
  - Structural lumber
  - Ramps
Conclusions

• PP, N6 and N66 PCC successfully reprocessed and tested
  – Shredded carpet repelletized
  – Pellets injection molded with good properties
  – Glass mat composites compression molded with commercially attractive properties

• Wood fiber reinforcement feasible for PP and N6 PCC
  – Need better equipment to gain benefits of fiber length, improve dispersion and to process N66 PCC
Conclusions

• Integrated extrusion-molding demonstrated with Z base garment rack bracket
• High volume applications identified
  – Pallets, structural lumber, bumpers, truck accessories
  – Large parts preferable for integrated process
• Commercialization feasible
Work in progress

• Further demonstration of bracket molding
  – Field testing of brackets
• Integrated extrusion-compression molding of test plaques
  – Wood and glass fibers
  – Fiber lengths and distributions
  – Properties
• Candidate Products
• Exploring Commercialization
Acknowledgements

• Project support
  – Funding from Georgia TIP - CCACTI program and GT IPST Exploratory Grant
  – Wellman, Inc (Shredded PCC carpet, pellets)
  – Georgia Composites/ Eleison Composites, LLC (glass mat)
  – CARE support for Georgia Composites (Bracket mold)
  – Shaw Industries
  – Invista