Super Structural Plastics Continue to Push the Frontier of Metal Replacement

Hyundai Fair
June 27 - 29, 2006
Super Structural Plastics Continue to Push the Frontier of Metal Replacement

AGENDA

- Brief history → Current State of Technology
- Focus on high productivity manufacture
  - Injection Molding
- Structural, load-bearing applications
- Future Technology Trends/Challenges
## Reinforced Engineering Thermoplastics

### Brief history

<table>
<thead>
<tr>
<th>1930’s</th>
<th>1940’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymers: Nylon, Polystyrene, Polyethylene, Acrylics</td>
<td>Military: Glass fiber reinforced resins for Aircraft parts</td>
</tr>
<tr>
<td>Glass Fibers: Commercial manufacturing process</td>
<td>Reinforced plastic boat hulls</td>
</tr>
<tr>
<td>Consumer: Fishing rods, Serving trays, Pleasure boats (All Thermosets)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1950’s</th>
<th>1960’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection molding process</td>
<td>Introduction and growth of reinforced thermoplastics</td>
</tr>
<tr>
<td>Corvette fiberglass body</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1970’s</th>
<th>1980’s</th>
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<tbody>
<tr>
<td>Optimization of manufacturing and molding processes</td>
<td>Commercial carbon fibers developed</td>
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</table>
Reinforced Engineering Thermoplastics

Reinforced vs. Unreinforced

- **Tensile Strength, MPa**
  - PA66
  - PA66 30% GF
  - PA66 40% MR
  - PBT
  - PBT 30% GF

- **Modulus, MPa**
  - PA66
  - PA66 30% GF
  - PA66 40% MR
  - PBT
  - PBT 30% GF
Glass fiber reinforcement

Coupling agent – Bonding fibers to polymer
Current state of technology

Primary Reinforcements

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Platelet</th>
<th>Spherical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>Glass</td>
<td>Glass (solid, hollow)</td>
</tr>
<tr>
<td>Carbon</td>
<td>Mineral</td>
<td>Mineral</td>
</tr>
<tr>
<td>Mineral</td>
<td>Aramide</td>
<td></td>
</tr>
<tr>
<td>Aramide</td>
<td>Metals</td>
<td></td>
</tr>
</tbody>
</table>

Current technical advances

- Better coupling agents – Chemical Resistance
- Long glass fiber reinforcements
- Nanocomposites
- Combinations of reinforcements
- High performance polymers
- In-line compounding/molding
Metal Replacement - How close are we?

- Unreinforced Tensile Strength
- Standard Reinforced Engineering Polymers
- Structural Reinforced Engineering Polymers
- Future Materials
- Steel
Benefits Through Light Weight Strength

Specific Tensile Strength (MPa/s.g.)

- Superstructural Polymers: up to 163
- Magnesium Alloy: 133
- Aluminum Alloy: 95
- Mild Steel: 52
- Zinc: 34

versus Aluminum = >40% weight savings with comparable strength!
Metal / PPS Replacement

with Zytel® HTN
**Thermal Management**

**Thermostat Housing**

- **End User:** Honda / Accord
- **Grade:** Zytel® HTN51G

**Requirements:**
- High heat resistance
- LLC resistance
- Creep resistance

**Electric Water Pump & Valve Housing**

- **End User:** Toyota / Prius
- **Grade:** Zytel® HTN51G

**Requirements:**
- LLC resistance
- Easy assembly with vibration welding
Fuel System

Fuel Integrated Valve

- End-user: Honda
- Grade: Zytel® HTN (GR/MR40%)
- Model: Accord (US model)

Requirements:
- Dimensional Stability
- Ultrasonic welding
- Fuel resistance
- High temp. resistance

Fuel Injector

- End User: Honda
- Grade: HTN51G

Requirements:
- Cost Reduction
- Low SG
- Recycle-ability
- Process-ability (No flash)
- Faster cycle time
Fuel System

FUEL CUT OFF VALVE

♦ Grade: Zytel ® HTN 51G
♦ Model: Camry 4WD, Estima, etc.

Requirements:
• Dimensional stability
• Ultrasonic welding
• Chemical resistance (Gasoline)
• High temp. resistance
**Chasis / Powertrain**

**Brake Guide Piston**

End User: Toyota  
Grade: HTN 51G  
Requirements:  
- Chemical resistance (Brake oil) at elevated temp.  
- Weld line strength  
- Good quality for product liability

**Throttle Valve Gear**

End User: Honda  
Model: Civic  
Grade: HTNWF51G  
Requirements:  
- Dimensional stability / Low moisture pick up  
- Low wear / low friction  
- High temp. resistance
**Auto E/E / Exterior**

**Motor Brush Holder**

- **End User:** Honda
- **Grade:** HTN 51G

**Requirements:**
- Heat resistance at an elevated temp.
- Dimensional stability / low moisture pick up
- Cost Reduction
- Recycle-ability

**Sunroof Guide Bracket**

- **End User:** Toyota, GM
- **Grade:** HTN GR/MR50%

**Requirements:**
- Low wear / low abrasion
- Dimensional stability / low moisture pick up
- Part strength during roll over
- Weight reduction
- Cost down
Summary

• There is still significant opportunity for metal-replacement by using our SuperStructural resins in monolithic parts - and where they work, they will almost always be the most cost-effective solutions v.s. hybrid structures.
DuPont Engineering Polymers

Rynite® PET Polyester Polymers
Zytel® Nylon Polymers
Zytel® HTN PPA Polymers
Crastin® PBT Polyester Polymers
Delrin® Acetal Polymers
Hytrel® Thermoplastic Polyester Elastomers
Back Up Charts
Extending Properties for Reinforced Engineering Polymers

**Polymer Matrix Materials**

**Primary function:**
- Stabilize fibers
- Transfer stress between fibers
- Provide a barrier against adverse environmental effects

**Important Properties:**
- Modulus
- Strength
- Chemical Resistance
- Resistance to end use environment (Tg, thermal stability)
Extending Properties for Reinforced Engineering Polymers

**Materials:**

- PPA high performance polyamide technology
- Long glass fiber reinforced PPA and PA66 resins
- Glass-reinforced polyester

**Properties:**

- High, consistent stiffness and strength capability
- Impact performance
- Creep resistance
- Structural performance at elevated temperatures
# Superstructural Key Grades

<table>
<thead>
<tr>
<th>Reinforcement Type</th>
<th>Filler Level</th>
<th>Zytel® HTN51</th>
<th>Zytel® HTN52</th>
<th>Zytel® HTN53</th>
<th>Zytel® HTN54</th>
<th>Zytel® PA66</th>
<th>Rynite® PET</th>
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</thead>
<tbody>
<tr>
<td>Standard Fiber Length</td>
<td>45</td>
<td>51G45HSL</td>
<td>52G45HSL</td>
<td></td>
<td></td>
<td></td>
<td>Rynite® 545</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td>53G50HSLR</td>
<td>54G50HSLR</td>
<td></td>
<td>Rynite® 555 (55% glass)</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70G60HSL</td>
</tr>
<tr>
<td>Long Length</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75LG40HSL</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>51LG50HSL</td>
<td></td>
<td></td>
<td></td>
<td>75LG50HSL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75LG60HSL</td>
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</table>
Key Features of the Zytel® HTN Product Families

Superstructural
- Ultra Stiff
- High Strength
- Excellent Creep Resistance

<table>
<thead>
<tr>
<th>HTN51 Series</th>
<th>HTN52 Series</th>
<th>HTN53 Series</th>
<th>HTN54 Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Outstanding retention of properties with moisture</td>
<td>- Highest melting point and deflection temperature</td>
<td>- Highest stiffness/strength at ambient temperatures</td>
<td>- Good toughness</td>
</tr>
<tr>
<td>- Improved dimensional stability</td>
<td>- Moldable in water heated tools</td>
<td>- Good toughness</td>
<td>- High burst pressure and knit line strength</td>
</tr>
<tr>
<td>- Retains high level of stiffness up to 140°C</td>
<td>- PPA resin</td>
<td>- Outstanding surface finish</td>
<td>- Retention of properties with moisture</td>
</tr>
<tr>
<td>- PPA resin</td>
<td></td>
<td>- Water heated tools</td>
<td>- Retains high level of stiffness up to 110°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Water heated tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- PPA resin</td>
</tr>
</tbody>
</table>
High Strength and Stiffness

<table>
<thead>
<tr>
<th>Material</th>
<th>Stress at Break (MPa)</th>
<th>Tensile Modulus DAM (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA66 43% GF</td>
<td>160</td>
<td>ISO 527</td>
</tr>
<tr>
<td>PPS 40% GF</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>PA6 50% GF</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>PBT 50% GF</td>
<td>220</td>
<td></td>
</tr>
</tbody>
</table>

Short Glass fiber reinforced engineering polymers

Polyamides conditioned to 50% RH
High Strength and Stiffness

![Graph showing stress at break and tensile modulus for various polymers.](image)

- **Short Glass fiber reinforced engineering polymers**
- **Higher Performance short glass fiber reinforced**

**Polyamides conditioned to 50% RH**

- PA46 50% GF
- PA66 43% GF
- PPS 40% GF
- PBT 50% GF
- PET 45% GF
- PET 55% GF
- PPA1 45% GF
- PPA2 45% GF
- PPA3 50% GF
- PPA4 50% GF

**Tensile Modulus DAM (GPa)**

ISO 527
High Strength and Stiffness

ISO 527

Stress at Break (MPa)

Tensile Modulus DAM (GPa)

Polyamides conditioned to 50% RH

Short Glass fiber reinforced engineering polymers
Higher Performance short glass fiber reinforced
Long glass fiber reinforced

PA46 50% GF
PA66 43% GF
PPS 40% GF
PBT 50% GF
PP 50% LFRT

PA66 50% LFRT
PA66 60% GF
PPA4 50% GF
PET 55% GF
PPA5 50% GF

PPA1 45% GF
PPA3 50% GF
PPA1 50% LFRT
PA66 60% LFRT
PPA1 50% LFRT
High Notched Impact Strength and Modulus

Polyamides conditioned to 50% RH

- PA46 50% GF
- PA66 43% GF
- PPS 40% GF

Tensile Modulus (GPa) ISO 527
Notched Charpy Impact Strength (kJ/m²) ISO 179

Short Glass fiber reinforced engineering polymers
High Notched Impact Strength and Modulus

Polyamides conditioned to 50% RH

PA46 50% GF
PA66 43% GF
PPS 40% GF
PPA1 45% GF
PPA3 50% GF
PPA4 50% GF
PET 45% GF
PET 55% GF
PA66 60% GF
PA6 60% GF

Short Glass fiber reinforced engineering polymers
Higher Performance short glass fiber reinforced

Tensile Modulus (GPa) ISO 527
Notched Charpy Impact Strength (kJ/m²) ISO 179
High Notched Impact Strength and Modulus

- Glass fiber reinforced engineering polymers
- DuPont EP Superstructural standard glass fiber reinforced products
- DuPont EP Superstructural long glass fiber reinforced products

Polyamides conditioned to 50% RH

- PA46 50% GF
- PA66 43% GF
- PP 50% Long glass
- Zytel® 70G60HSL
- PPS 40%GF
- Zytel® HTN 75LG40HSL
- Zytel® HTN 75LG50HSL
- Zytel® HTN 75LG60HSL
- Zytel® HTN 54G50HSL
- Rynite® 545
- Zytel® HTN 51G45HSL
- Rynite® 555
**LFRT - Long Fiber Reinforced Thermoplastics**

**Pellet Dimensions: Standard vs. LFRT pellets**

- Fiber length in granules 8-12 mm
- Fiber length in molded parts are typically 3–4 mm versus 0.3 mm for standard glass fiber resins
- Component design plus processing conditions govern average fiber length and therefore part performance
LFRT - Increased Multiaxial Impact Performance

Energy to max load vs Total energy for PA66 50% GF and PA66 50% LFRT.

DAM
ISO 663
3 mm Disc

PA66 50% GF
PA66 50% LFRT
Properties of PPA 50% LFRT vs. PPA 45% GF

- **Stress at Break, MPa**
  - DAM 50% RH vs. 45% GF

- **Flexural Modulus, MPa**
  - DAM 50% RH vs. 45% GF

- **Notched Charpy Impact, kJ/m^2**
  - DAM 50% RH vs. 45% GF

**Long Glass vs. Short Glass PPA:**
- 5% Higher Tensile Strength
- 10-20% Higher Modulus
- 4-7X Higher Notched Impact Strength
Creep Resistance at High Temperatures
PPA 50% LFRT vs. PPA 45% GF

DMA Accelerated Flexural Creep
at 28 MPa, 150C
PPA 50% LFRT vs. PPA 45% GF

Long Glass vs. Short Glass PPA:
- Better Creep resistance at load and temperature extremes
Modulus vs Temperature
PPA 50% LFRT vs. PPA 45% GF

Long Glass vs. Short Glass PPA:
- Higher Stiffness throughout temperature range
- Similar retention of properties at 50%RH conditions
Reinforced Engineering Thermoplastics

Current and Future Technology Trends

- High performance matrix polymers
- Longer glass fiber length
- Expanded use of carbon fiber
- Thermoplastic nanocomposites
- Polymeric fibers and self-reinforced polymers
- High strength, reinforced polymer fibers
- Combined multi-material reinforcements
- Metal–plastic hybrid systems
- Engineered fiber/fabric composites, laminates and hybrids
- Bio-derived polymer matrices
- Natural fiber composites
Reinforced Engineering Thermoplastics

Current and Future Challenges

- High volume, consistent supply of advanced reinforcements
- Polymer manufacture/compounding
- Optimum molding processes
- High productivity molding/forming processes
- Recycle-ability
- Painting and finishing
- Joining multi-materials systems
- Material property databases and end-user materials knowledge
- Fire and low temperature performance
- Part repair strategies