ENGINEERED PLASTICS WORKSHOP
Learn About Thermoplastics | Connect with Experts

2016 TENNESSEE / NORTH CAROLINA

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
PDF copies of the presentations from today’s workshop can be downloaded from our website at
www.rtpcompany.com/workshoppresentations
Introduction to RTP Company: Your Global Compounder of Custom Engineered Thermoplastics

Kevin Jennings  |  Regional Sales Manager
kjennings@rtpcompany.com
(864) 723-9162

8:45 a.m.
RTP Company
Your Global Compounder of Custom Engineered Thermoplastics

RTP Company is an independent, privately owned thermoplastics compounder with global manufacturing, engineering support, and sales representation.

- 1,500+ employees
- $500+ million annual sales

High-Tech Compounds to Unfilled Resins
- 60+ resins
- 100s of modifiers
- Brodest range of competitive compounds (From talc polypropylene to nanotube PEEK)

Annual Production
- 6,000+ commercial products
- 1,750+ new products per year
High-Tech Compounds to Unfilled Resins

- 60+ resins
- 100s of modifiers
- Broadest range of competitive compounds
  (From talc polypropylene to nanotube PEEK)

Annual Production
- 6,000+ commercial products
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Introduction to RTP Company: Your Global Compounder of Custom Engineered Thermoplastics - Kevin Jennings

Engineered Plastics Workshop
RTP Company operates 18 production plants and has sales offices in major commerce centers around the world.

RTP Company is a global compoundinger of custom engineered thermoplastics.

Alloy Polymers, a division of RTP Company, provides contract manufacturing and high volume processes.

Wiman Corporation, a wholly-owned subsidiary of RTP Company, produces customized, high quality plastic films and film laminates.
Engineered Sheet Products™ (ESP™), a division of RTP Company, manufactures specialty engineered sheet.

RTP Company partners with ResMart, a distributor of off-the-shelf, unfilled resins.

Our goal is to satisfy our customers with solutions, providing...

- Technology
- Flexibility
- Speed

RTP Company offers the most competitive lead times in the industry.
Our culture can be described as…

- A close-knit organization
- Generational/long term thinkers
- Entrepreneurial
- High spirited with a sense of urgency
- "Bureaucracy-less"

Our independence allows us to be objective in…

- Raw materials
- Formulations
- Solutions

RTP Company has 100+ sales & support employees worldwide:

- Americas – Canada, United States, Mexico, Brazil
- Asia/Pacific Rim – China, Korea, Singapore, Japan, Taiwan, India
- Europe – Austria, Netherlands, France, Germany, United Kingdom

RTP Company has 50+ development engineers worldwide, including regional engineers for local support.

At RTP Company, our development engineers:

- Apply the most current research
- Aggressively seek new resins and additives
- Have a passion for creating the best solution for you
Our development services are available in each region of the world, and include:

- Application development
- Product development
- Process development
- CAE support
- Pilot Plant production

RTP Company has 20+ Technical Service Engineers and Specialists worldwide, that provide:

- Plastic processing trials
  - Injection, extrusion, compression, film, and blow molding trials
- Process optimization
- Problem resolution
- Customer trials and samples

RTP Company has 30+ Customer Service Representatives worldwide, who are dedicated to serving you.

- Regionally located, experienced representatives for real-time service
- Deliver personalized attention to each order
- Dedicated to your account, serving as an extension of your team

Each year, RTP Company measures how satisfied customers are with the accessibility and helpfulness of their RTP Company Customer Service Representative. In 2015, 96% of respondents indicated that they were satisfied with the service they received.

We develop it anywhere…
make it anywhere…
and support it everywhere!

- Scalability: Develop your solution on a small scale and produce your solution in large quantities
- Plant-to-plant consistency
- ISO: 9001:2008 registered facilities
Compounds formulated to meet performance requirements, from one property to multiple technologies

- Color
- Conductive
- Flame Retardant
- Thermoplastic Elastomers
- Structural
- Wear Resistant
- Film - Wiman
- Sheet - ESP™

ResMart Resins:
- Ultra, Plus, and Utility grades:
  - Polypropylene
  - Nylon 6, 6/6
  - Clear Nylon (Amorphous Nylon)
  - Polycarbonate
  - SAN
  - ABS
  - Polystyrene
  - Clear ABS (MABS)
  - ACETAL
  - PBT
  - Polypropylene
  - ASA
  - Black Masterbatch
  - TPU
- Specialty grades:
  - Solvay Udel® PSU
  - Solvay Radel® PPSU
  - Solvay Ketaspire® PEEK

RTP Company is your global compounder of custom engineered thermoplastics… and much more!
Thank You!
An Engineer’s Guide to Specifying the Right Thermoplastics

Steve Maki  |  VP of Technology
smaki@rtpcompany.com
(507) 474-5371

9:00 a.m.
An Engineer’s Guide to Specify the Right Thermoplastic

Steve Maki
Vice President Technology
smaki@rtpcompany.com

AGENDA

1. Define Compounding
2. Plastic Resin Selection Process
3. Application Case Studies
4. Compounding To Enhance Performance
5. New RTP Technologies

INDEPENDENT SPECIALTY COMPOUNDER

Compounder → We blend thermoplastic resins with fillers, additives, and modifiers

Specialty → We create engineered formulations

Independent → We are unbiased in our selection of raw materials

COMPOUNDING PROCESS

Raw Materials → Finished Product

- Blender
- Extruder
- Cooling
- Pelletizer
- Classifier
COMPOUNDING OBJECTIVES

Mixing

- Dispersive
- Distributive

Agglomerates → Dispersion → Distribution

COMPOUNDING EXTRUDERS

- Single Screw
- Twin Screw
- Co-Kneader

PUTTING COMPOUNDING INTO PERSPECTIVE

- Conductive carbon black surface area = 130 m²/gram
- 34 grams carbon black = surface area of football field (4460 m²)
- Dispersing a 20% carbon black compound is similar to evenly coating a football field with 136 grams of plastic!

Resin Selection
THE DILEMMA

60 thermoplastic resins + 100 additives = 1000's of potential compounds

Which ONE Do I Choose For My Application???

PLASTIC SELECTION

PROCESS

Step 1: Use Resin Morphology

Step 2: Use Thermal & Cost Requirements

Step 3: Fine Tune & Special Features

MORPHOLOGY

The form and structure the molecules of a polymer take upon solidification

Amorphous

Semi-Crystalline

Compare

- Molecular packing (shrinkage)
- Resistance to molecular disentanglement (chemical/abrasion resistance)
- Melting characteristics (flow)
- Light refraction (opacity)
### Morphology Characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>Amorphous</th>
<th>Semi-Crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Shrinkage</td>
<td>X</td>
<td></td>
</tr>
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<td>X</td>
<td></td>
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<td>Transparency</td>
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<td></td>
</tr>
<tr>
<td>Mold Flow Ease</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Wear Resistance</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

### Morphology of Thermoplastics

- **Amorphous**: Polyetherimide (PEI), Polyethersulfone (PES), Polysulfone (PSU), Amorphous Nylon, Polycarbonate (PC), Acrylic (PMMA), Acrylonitrile Butadiene Styrene (ABS), Styrene Acrylonitrile (SAN), High Impact Polystyrene (HIPS), Polystyrene (PS)
- **Semi-Crystalline**: Polyetheretherketone (PEEK), Polyphenylene Sulfide (PPS), Polyphthalamide (PPA), Polyamide (PA/Nylons), Polybutylene Terephthalate (PBT), Polyethylene Terephthalate (PET), Acetal (POM), Polyactic Acid (PLA), Polypropylene (PP), Polyethylene (HDPE, LDPE, LLDPE)

### Plastic Selection Process

1. **Step 1**: Use Resin Morphology
2. **Step 2**: Use Thermal & Cost Requirements
3. **Step 3**: Fine Tune & Special Features
### MORPHOLOGY VS. THERMAL/COST

<table>
<thead>
<tr>
<th>Amorphous</th>
<th>Semi-Crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyetherimide (PEI)</td>
<td>Polyetheretherketone (PEEK)</td>
</tr>
<tr>
<td>Polysulfone (PES)</td>
<td>Polyphenylene Sulfide (PPS)</td>
</tr>
<tr>
<td>Polysulfone (PSU)</td>
<td>Polyphthalamide (PPA)</td>
</tr>
<tr>
<td>Amorphous Nylon</td>
<td>Polyamide (PA/Nylons)</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>Polybutylene Terephthalate (PBT)</td>
</tr>
<tr>
<td>Acrylic (PMMA)</td>
<td>Polyethylene Terephthalate (PET)</td>
</tr>
<tr>
<td>Acrylonitrile Butadiene Styrene (ABS)</td>
<td>Acetal (POM)</td>
</tr>
<tr>
<td>Styrene Acrylonitrile (SAN)</td>
<td>Polylactic Acid (PLA)</td>
</tr>
<tr>
<td>High Impact Polystyrene (HIPS)</td>
<td>Polypropylene (PP)</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Polyethylene (HDPE, LDPE, LLDPE)</td>
</tr>
</tbody>
</table>

- Commodity (<$1.50)
- Engineered ($1.50-$4.00)
- High Performance (>$4.00)

### PLASTIC SELECTION PROCESS

#### Step 1: Use Resin Morphology

#### Step 2: Use Thermal & Cost Requirements

#### Step 3: Fine Tune & Special Features

### ENGINEERED & COMMODITY RESINS

<table>
<thead>
<tr>
<th>Amorphous</th>
<th>Semi-Crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amorphous Nylon</td>
<td>Polyamide (PA/Nylons)</td>
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- Commodity (<$1.50)
- Engineering ($1.50-$4.00)

### AMORPHOUS RESINS

- **Morphology Features** -- Low Shrink, Low Warp, Tight Dimensional Tolerances, Transparent (except HIPS & ABS), Poor Chemical & Abrasion, Poor Flow in Thin Mold Sections

<table>
<thead>
<tr>
<th>Amorphous</th>
<th>Special Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amorphous Nylon</td>
<td>Transparent/good chem. resistance</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>Optical transparency/high impact</td>
</tr>
<tr>
<td>Acrylic (PMMA)</td>
<td>Optical transparency/UV stable</td>
</tr>
<tr>
<td>Acrylonitrile Butadiene Styrene (ABS)</td>
<td>High impact/high gloss/opaque</td>
</tr>
<tr>
<td>Styrene Acrylonitrile (SAN)</td>
<td>Transparent/mod. chem. resistance</td>
</tr>
<tr>
<td>High Impact Polystyrene (HIPS)</td>
<td>Moderate impact/opaque</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Transparent/brittle</td>
</tr>
</tbody>
</table>

- Commodity (<$1.50)
- Engineering ($1.50-$4.00)
# SEMI-CRYSTALLINE RESIN

**Morphology Features** – Excellent Chemical Resistance, Excellent Abrasion Resistance, Good Flow in Thin Mold Sections, Poor Dimensions, Opaque

<table>
<thead>
<tr>
<th>Semi-Crystalline</th>
<th>Special Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon 6/12</td>
<td>Less Sensitive to humidity vs. 6/6/6</td>
</tr>
<tr>
<td>Nylon 6/6</td>
<td>Better thermal vs. 6/humidity Dep</td>
</tr>
<tr>
<td>Nylon 6</td>
<td>Hides GF/strong but humidity Dep</td>
</tr>
<tr>
<td>Polybutylene Terephthalate (PBT)</td>
<td>Good electricals/easier to mold</td>
</tr>
<tr>
<td>Polyethylene Terephthalate (PET)</td>
<td>Good electricals/difficult to mold</td>
</tr>
<tr>
<td>Acetal (POM)</td>
<td>Low wear &amp; friction/high fatigue</td>
</tr>
<tr>
<td>Polylactic Acid (PLA)</td>
<td>Green/Low impact &amp; thermal</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Poor low temp impact/mod thermal</td>
</tr>
<tr>
<td>Polyethylene (HDPE, LDPE, LLDPE)</td>
<td>Good low temp impact</td>
</tr>
</tbody>
</table>

Commodity (<$1.50) • Engineering ($1.50-$4.00)

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# PUTTING IT ALL TOGETHER

**Step 1:** Use Resin Morphology

**Step 2:** Use Thermal & Cost Requirements

**Step 3:** Fine Tune & Special Features

Test Your Knowledge With Application Examples

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# CASE STUDY

**CD Jewel Case**
- Transparent
- Flat & Dimensionally Stable
- Low Cost

**Gas Tank**
- Good chemical resistance
- Good low temperature impact
- Low cost

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An Engineer’s Guide to Specifying the Right Thermoplastics - Steve Maki
**CASE STUDY**

**Auto Tail Lamp Cover**
- Transparent Colors
- Dimensionally Stable
- Excellent UV
- Low Cost

PMMA

**Plastic Glass Tumblers**
- Transparent
- Reasonable Thermal & Chemical Resistance (Dishwasher Cycles)
- Low Cost

SAN

**CASE STUDY**

**Sump Pump Housing**
- Chemical resistance
- Reasonable thermal resistance
- Low cost

PP + GF

**CASE STUDY**

**Safety Glasses**
- Optical transparency
- High impact
- Moderate cost OK

PC
CASE STUDY

Hub Odometer Lens
• Transparent
• Good Chemical Resistance
• Moderate-High Cost OK

Amorphous Nylon

CASE STUDY

Chemical Beakers
• Excellent chemical resistance
• Low Cost
• Transparent

CASE STUDY

Nail Gun Housing
• Good chemical resistance
• Excellent strength, stiffness & impact
• Good surface finish when reinforced
• Moderate cost OK

Nylon 6 + GF

CASE STUDY

Automotive Intake Manifold
• Chemical resistance
• Excellent strength, stiffness & impact
• Moderate heat resistance
• Moderate cost OK

Nylon 66 + GF
CASE STUDY

Oil Pan
- Chemical resistance
- Excellent strength, stiffness & impact
- Moderate heat resistance
- Moderate cost OK
- Extremely tight dimensions & flat

CASE STUDY

Electrical Connectors
- Good flow in thin walls
- Excellent electrical properties
- Dimensionally stable in humidity
- Moderate cost OK

PBT (PET) + GF + FR

CASE STUDY

Conveyor Rollers
Good abrasion resistance
Low wear & friction
Moderate cost OK

Acetal

CASE STUDY

Printer Gears
- Extremely tight dimensions
- Moderate cost OK
- Good abrasion resistance
- Low wear & friction

???

???
CASE STUDY

Lawn Tractor Hood
• Tight dimensions & low warp
• Moderate cost OK
• Chemical resistance
• Good mold flow

Overcoming Resin Deficiencies Via Compounding

MORPHOLOGY DEFICIENCIES

<table>
<thead>
<tr>
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<td>D</td>
</tr>
<tr>
<td>Wear Resistance</td>
<td>D</td>
</tr>
</tbody>
</table>

DIMENSIONAL STABILITY

Can We Reduce Shrink Rate & Improve Dimensional Stability of Semi-Crystalline Resins?
**FIBER REDUCES SHRINK**

Shrink Rate X ≠ Shrink Rate Y ➔ Warp

**WARP CONTROL**

Shrink Rate X = Shrink Rate Y ➔ Flat Part

*But Low Strength!*

**STRENGTH & WARP CONTROL**

Common Loading = 15% Glass Fiber & 25% Mineral or Beads

**CASE STUDY**

**Oil Pan**

- Chemical resistance
- Excellent strength, stiffness & impact
- Moderate heat resistance
- Moderate cost OK
- Extremely tight dimensions & flat

**Nylon 66 + 15% GF + 25% Mineral**
Can We Make A Semi-Crystalline Resin Transparent?

Compounding nucleator into PP or PE controls crystal size to less than wavelength of light = Transparency

CASE STUDY

Chemical Beakers
• Excellent chemical resistance
• Low Cost
• Transparent

PP + Nucleator

Can We Improve Chemical Resistance & Mold Flow of Amorphous Resins?
### Alloying

#### Alloy PC with ABS
**RTP 2500 A Series**

<table>
<thead>
<tr>
<th>Property</th>
<th>PC</th>
<th>PC/ABS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength, psi</td>
<td>9000</td>
<td>8900</td>
</tr>
<tr>
<td>Flexural Mod, E6 psi</td>
<td>0.34</td>
<td>0.40</td>
</tr>
<tr>
<td>Izod Impact, ft lb/in</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>HDT @ 264 psi, °F</td>
<td>270</td>
<td>210</td>
</tr>
<tr>
<td>Fuel Resistance</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Melt Flow, gm/10 min</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Clarity</td>
<td>Transparent</td>
<td>Opaque</td>
</tr>
</tbody>
</table>

#### Alloy PC With Polyester (PBT or PET)
**RTP 2099 X 63578 B**

<table>
<thead>
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<td>8700</td>
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<td>HDT @ 264 psi, °F</td>
<td>270</td>
<td>250</td>
</tr>
<tr>
<td>Fuel Resistance</td>
<td>Poor</td>
<td>Fair</td>
</tr>
<tr>
<td>Melt Flow, gm/10 min</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Clarity</td>
<td>Transparent</td>
<td>Opaque</td>
</tr>
</tbody>
</table>

### Case Study

**Lawn Tractor Hood**
- Tight dimensions & low warp
- Moderate cost OK
- Chemical resistance
- Good mold flow

**PC/PBT Alloy**

### Wear Resistance

**Can We Make An Amorphous Resin Wear Resistant?**
PTFE LUBRICATED

Compound PTFE Into PC
RTP 300 TFE 15

<table>
<thead>
<tr>
<th></th>
<th>PC</th>
<th>PC/15 PTFE</th>
<th>Acetal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear Factor</td>
<td>560</td>
<td>130</td>
<td>90</td>
</tr>
<tr>
<td>Dynamic Coef. of Friction</td>
<td>0.60</td>
<td>0.33</td>
<td>0.40</td>
</tr>
</tbody>
</table>

CASE STUDY

Printer Gears
- Extremely tight dimensions
- Moderate cost OK
- Good abrasion resistance
- Low wear & friction

New Technologies

NEW TECH (HEALTHCARE)

RTP 2000 HC Series
- Increased chemical resistance to healthcare cleaners vs PC, ABS, PC/ABS
- Good dimensional stability with shrinkage similar to above resins
- Flame retardant grade for electronic housings
  - RTP 2000 HC FR A
**NEW TECHNOLOGIES (COLOR)**

**IR Reflecting Colors**
Allows Dark Colored Plastics To Remain Cool When Exposed To Sunlight

- Patio Furniture
- Decking/Pavers
- Roofs/Siding
- Auto Interiors

---

**NEW TECHNOLOGIES (FR)**

**FR Compounds for Plenum Applications (UL 2043)**

**Low Heat/Smoke Release Grades**
- FR PP Grades (Glass Fiber, Mineral, Unfilled)
- FR Nylon (Glass Fiber)

**Opportunities**
- Wireless Access Points
- Speaker Housings
- Vent Diffusers
- Cable Racks
- Light Housings

---

**NEW TECHNOLOGIES (WEAR)**

**Abrasion Resistant Compounds**
To Compete With UHMWPE (Not Moldable)

- Injection Moldable Polyolefin Alloy
- Similar Abrasion Resistance To UHMWPE
  - Gears
  - Cam Follower
  - Slides
  - Wear Liners

---

**NEW TECH (HIGH TEMPERATURE)**

**Specialty Torlon Compounds**
RTP has a license agreement with Solvay Specialty Polymers to manufacture specialty compounds based on Torlon polyamide-imide

- Custom Fiber Reinforced
- Custom Wear Formulas
  - Automotive
  - Aerospace
  - Industrial
Intro To Compounding
The Dilemma
Resin Selection Procedure
- Resin Morphology
- Resin Cost & Thermal Performance
- Unique Resin Features

Application Case Studies
Compounding in Performance
- Overcoming Resin Deficiencies

Introduction To New Technologies
Tough or Strong? Short or Long? Dialing in Mechanical Properties

Karl Hoppe  |  Senior Product Development Engineer
khoppe@rtpcompany.com
(507) 474-5367

10:00 a.m.
Tough or Strong? Short or Long? Dialing in Mechanical Performance

Karl Hoppe
Senior Product Development Engineer

Engineered Plastics Workshop
THE FORMULA

Resin + Additives = Change in Properties

THE FOUNDATION

THE ADDITIVES TOOLBOX

Modifiers | Fillers

MODIFIERS

Polymer blends
Impact modifiers

Tough or Strong? Short or Long? Dialing in Mechanical Properties - Karl Hoppe 
PC/ABS
- ABS brings
  - Improved flow
  - Chemical resistance
  - Cost reduction

Nylon/PP
- PP brings
  - Improved flow
  - Chemical resistance
  - Cost reduction

PC/PBT
- PBT brings
  - Improved flow
  - Chemical Resistance

ABS/PC
- PC brings
  - Toughness
  - Strength

PP/Nylon
- Nylon brings
  - Strength
  - Stiffness

PBT/PC
- PC brings
  - Toughness
  - Dimensional stability

<table>
<thead>
<tr>
<th></th>
<th>PC</th>
<th>PC/ABS (RTP 2500 A)</th>
<th>ABS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.19</td>
<td>1.15</td>
<td>1.05</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>59</td>
<td>59</td>
<td>45</td>
</tr>
<tr>
<td>Notched Izod Impact (J/m)</td>
<td>850</td>
<td>740</td>
<td>250</td>
</tr>
</tbody>
</table>
### Impact Properties

- **Strength/stiffness**

### Impact Modifiers

#### ATV Wheel Bead Lock Ring

**Problem:** Low ductility

**Solution:** Impact Modified Nylon 6/6 with fiber reinforcement

**Benefits:**
- Retain some stiffness of reinforced Nylon
- Improved ductility for high strain rate loads

#### Limitations

- Base resin
- Environment
  - Lose Performance
  - Temperature
  - Chemical Resistance
  - UV Resistance

### Table: Impact Properties Comparison

<table>
<thead>
<tr>
<th>Property</th>
<th>PA 6/6</th>
<th>Impact Modified PA 6/6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.14</td>
<td>1.08</td>
</tr>
<tr>
<td>Notched Izod Impact (J/m)</td>
<td>55</td>
<td>900</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>80</td>
<td>45</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>2.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

**Engineered Plastics Workshop**

**Tough or Strong? Short or Long? Dialing in Mechanical Properties - Karl Hoppe**

39
THE ADDITIVES TOOLBOX

Modifiers

Fillers

FILLERS

Beads
(Glass)

Minerals
(Talc)

Fibers
(Glass)

ASPECT RATIO

Property change determined by:
Aspect Ratio = L/D

LOW ASPECT RATIO

<table>
<thead>
<tr>
<th></th>
<th>PC</th>
<th>PC + 10% Glass Beads</th>
<th>PC + 30% Glass Beads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.19</td>
<td>1.27</td>
<td>1.42</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>59</td>
<td>55</td>
<td>48</td>
</tr>
<tr>
<td>Notched Izod Impact (J/m)</td>
<td>850</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>2.4</td>
<td>2.6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Engineered Plastics Workshop

Tough or Strong? Short or Long? Dialing in Mechanical Properties - Karl Hoppe
**LOW ASPECT RATIO**

<table>
<thead>
<tr>
<th>Minerals (Talc)</th>
<th>PC</th>
<th>PC + 20% Talc</th>
<th>PC + 40% Talc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>0.91</td>
<td>1.05</td>
<td>1.25</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>32</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>Notched Izod Impact (J/m)</td>
<td>47</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>1.5</td>
<td>2.5</td>
<td>3.8</td>
</tr>
</tbody>
</table>

**LOW ASPECT RATIO**

Shrink Rate X = Shrink Rate Y — Flat Part

**LOW ASPECT RATIO**

Reusable Handling Container

**Problem:** Warpage prevented smooth operation

**Solution:** Mineral filled Polypropylene

**Benefits:**
- Reduced warpage
- Improved functionality

**HIGH ASPECT RATIO**

<table>
<thead>
<tr>
<th>Fibers (Glass)</th>
<th>PC</th>
<th>PC + 30% Glass Beads</th>
<th>PC + 30% Glass Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.19</td>
<td>1.42</td>
<td>1.42</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>59</td>
<td>48</td>
<td>124</td>
</tr>
<tr>
<td>Notched Izod Impact (J/m)</td>
<td>850</td>
<td>80</td>
<td>160</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>2.4</td>
<td>3.4</td>
<td>7.6</td>
</tr>
</tbody>
</table>
**Surgery Drill Guide**

**Problem:** Stiffness and dimensional stability

**Solution:** Glass fiber reinforced Polycarbonate

**Benefits:**
- Rigidity
- Tight tolerances

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>PP</th>
<th>PP + 40% Talc</th>
<th>PP + 40% Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>0.91</td>
<td>1.25</td>
<td>1.22</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>32</td>
<td>30</td>
<td>84</td>
</tr>
<tr>
<td>Notched Izod Impact (J/m)</td>
<td>47</td>
<td>34</td>
<td>108</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>1.5</td>
<td>3.8</td>
<td>7.5</td>
</tr>
</tbody>
</table>

**HIGH ASPECT RATIO**

Fibers (Glass)

Aspect Ratio = 50 - 250

**HIGH ASPECT RATIO - WARP**

Shrinkage X1 & X2 ≠ X3 ➞ Warp

**HIGH ASPECT RATIO - FLAT**

Shrinkage X1 = X2 = X3 ➞ Flat Part
**Engineered Plastics Workshop**

**IMPROVEMENTS IN SGF PP**

**40% Glass PP**

- Tensile Strength (MPa):
  - Short Glass: 84
  - eXtra Performance: 114
  - Long Glass (VLF): 124

- Flexural Modulus (MPa):
  - Short Glass: 7500
  - eXtra Performance: 8200
  - Long Glass (VLF): 8400

**Impact Strength (kJ/m²):**

- Short Glass: 12.1
- eXtra Performance: 15.8
- Long Glass (VLF): 22.6

**HIGH ASPECT RATIO**

- Carbon Fibers:
  - Specific Gravity: 1.30, 1.61, 1.45
  - Tensile Strength (MPa): 93, 186, 265
  - Notched Izod Impact (J/m): 53, 133, 91
  - Flexural Modulus (GPa): 3.8, 13.8, 30.3

**Aspect Ratio = 50 - 250**

Tough or Strong? Short or Long? Dialing in Mechanical Properties - Karl Hoppe
FIBER COMPARISON - PP

<table>
<thead>
<tr>
<th></th>
<th>PP 40% GF</th>
<th>PP 40% VLF</th>
<th>PP 30% CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>6900</td>
<td>8250</td>
<td>9000</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>85</td>
<td>120</td>
<td>90</td>
</tr>
<tr>
<td>Notched Izod Impact (kJ/m²)</td>
<td>12.1</td>
<td>22.8</td>
<td>6</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.21</td>
<td>1.21</td>
<td>1.00</td>
</tr>
</tbody>
</table>

FIBER COMPARISON – PA 6/6

<table>
<thead>
<tr>
<th></th>
<th>PA 6/6 60% VLF (Long Fiber)</th>
<th>PA 6/6 35% Carbon Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>19.3</td>
<td>19.0</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>275</td>
<td>244</td>
</tr>
<tr>
<td>Tensile Elongation (%)</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.71</td>
<td>1.29</td>
</tr>
</tbody>
</table>

FIBER COMPARISON – PPS

<table>
<thead>
<tr>
<th></th>
<th>PPS 40% Glass</th>
<th>PPS 20% Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>15.1</td>
<td>15.8</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>169</td>
<td>172</td>
</tr>
<tr>
<td>Tensile Elongation (%)</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.68</td>
<td>1.40</td>
</tr>
</tbody>
</table>

CARBON FIBER APPLICATION

Brake Rotor Measuring Probe

<table>
<thead>
<tr>
<th></th>
<th>Casting replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution:</td>
<td>Carbon fiber reinforced PPA</td>
</tr>
<tr>
<td>Benefits:</td>
<td>High strength</td>
</tr>
<tr>
<td></td>
<td>High stiffness</td>
</tr>
</tbody>
</table>
STANDARD COMPOUNDING PROCESS

Raw Materials → Finished Product

- Blender
- Cooling
- Extruder
- Pelletizer
- Classifier

EXTREME ASPECT RATIO - VLF

- Fiber Extruder/Die Puller Pelletizer
- Long Glass Fiber, Aspect Ratio = 300+
- Fiber length: 3 mm
- Fiber length: 12 mm

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Specific Gravity</th>
<th>Tensile Strength (MPa)</th>
<th>Notched Izod Impact (J/m)</th>
<th>Flexural Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Glass</td>
<td>1.22</td>
<td>84</td>
<td>108</td>
<td>7.5</td>
</tr>
<tr>
<td>Long Glass</td>
<td>1.22</td>
<td>124</td>
<td>228</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Tough or Strong? Short or Long? Dialing in Mechanical Properties - Karl Hoppe
Secret to success: the fiber skeleton

PA 66 + 60% VLF
Seat Belt Tension Housing

Dialing in Mechanical Properties - Karl Hoppe
MOLDING CONSIDERATIONS

General guidelines:
1. General purpose screw OK (low compression preferred)
2. Reduce shear: low back pressure and rpm’s
3. Reverse barrel temperature profile

Preferred:
- Three Piece Screw Tip Ring Valve
  - 100% “Free Flow” design
  - All components made from high quality, high purity cast steel

Avoid starting with long fiber and finishing with short fiber!

HIGH TEMPERATURE POLYMERS

<table>
<thead>
<tr>
<th>Amorphous</th>
<th>Semi-Crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyetherimide (PEI)</td>
<td>Polyetheretherketone (PEEK)</td>
</tr>
<tr>
<td>Polylthethersulfone (PES)</td>
<td>Polyphenylene Sulfide (PPS)</td>
</tr>
<tr>
<td>Polysulfone (PSU)</td>
<td>Polyphthalalamide (PPA)</td>
</tr>
<tr>
<td>Amorphous Nylon</td>
<td>Polyamide (PA/Nylons)</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>Polytbutylene Terephthalate (PBT)</td>
</tr>
<tr>
<td>Acrylic (PMMA)</td>
<td>Polyethylene Terephthalate (PET)</td>
</tr>
<tr>
<td>Acrylonitrile Butadiene Styrene (ABS)</td>
<td>Acetal (POM)</td>
</tr>
<tr>
<td>Styrene Acrylonitrile (SAN)</td>
<td>Polylactic Acid (PLA)</td>
</tr>
<tr>
<td>High Impact Polystyrene (HIPS)</td>
<td>Polypropylene (PP)</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Polyethylene (HDPE, LDPE, LLPE)</td>
</tr>
</tbody>
</table>

Commodity • Engineered • High Performance
Chemical Structure

Polyethylene
\[ T_g \sim -5 \, ^\circ F \]

Polyimide
\[ T_g \, 482 \, ^\circ F \]

Amorphous Materials

Flexural Modulus Vs. Temperature

Semi-Crystalline Materials

Flexural Modulus Vs. Temperature

Elevated Temp Properties

Multiple Temperature Tensile Stress/Strain
**ULTRA PERFORMANCE PRODUCTS**

![Graph showing tensile strength of different resins](image)

- **PEI**: Green
- **PPS**: Yellow
- **PPA**: Red
- **PEEK**: Orange

**High Temp Resins**

- **50% GF**
- **50% VLF**
- **40% CF**
- **40% UP CF**

**HIGH TEMPERATURE APPLICATION**

**Surgical Head Restraint**

**Problem:** Stable under MRI/CT energy

**Solution:** Carbon fiber reinforced PEEK

**Benefits:**
- High stiffness
- Creep resistance
- Resistance to autoclave

**SUMMARY**

**Modifiers**
- Polymer Blends - overcome morphology deficiencies
- Impact Modifiers - increase impact but reduction in strength/stiffness

**Fillers**
- Performance driven by aspect ratio

**High Temperature**
- Range of polymers offer array of performance

*Overall: Combinations of technologies result in balancing of properties and requirements*

---

**Thank You!**

rtpcompany.com  •  rtp@rtpcompany.com
Answers to Your Burning Questions: Flame Retardants and Regulations

Jesse Dulek  |  Product Development Engineer
jdulek@rtpcompany.com
(507) 474-5502

11:00 p.m.
FLAME RETARDANT (FR) MATERIALS

Definition

Materials that do not ignite readily or propagate flames under small to moderate fire exposures

- Materials are combustible
- Fire retardants reduce the intensity and spread of fire
- Reduces smoke and toxic by-products of combustion

Fire Triangle

GOALS OF FLAME RETARDANT COMPOUNDS

- Increase resistance to ignition
- Reduce rate of flame spread
- Reduce rate of heat release
- Reduce smoke emission

End Goal:
- Meet FR specifications
- Make the world a safer place!

MARKETS FOR FR THERMOPLASTICS

Segmentation of FR Consumption by Value

- Building 34%
- E&E 39%
- Transportation 12%
- Textile: Adhesive: 15%

- Electrical Parts
- Electronic Enclosures
- Wire and Cable
- Appliances
- Transportation
- Building and Construction
Thermoplastic Flammability

- Flame Retardant Additive Chemistries and Mechanisms

Regulatory Landscape

Testing Standards

Case studies

Flammable
- Polyolefins
- Nylons
- Polycarbonate
- Polymers
- Styrenics
- TPEs

Inherently Flame Resistant
- Polysulfones
- Polyphenylene Sulfide
- Polyetheretherketone
- Polyetherimide
- Fluoropolymers

CHALLENGES OF FLAME RETARDING PLASTICS

<table>
<thead>
<tr>
<th>Material</th>
<th>LOI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetal</td>
<td>0</td>
</tr>
<tr>
<td>Cotton</td>
<td>0</td>
</tr>
<tr>
<td>PTFE</td>
<td>0</td>
</tr>
<tr>
<td>PP</td>
<td>0</td>
</tr>
<tr>
<td>PA</td>
<td>0</td>
</tr>
<tr>
<td>PEEK</td>
<td>0</td>
</tr>
<tr>
<td>PET</td>
<td>0</td>
</tr>
<tr>
<td>Nylon 6/6</td>
<td>0</td>
</tr>
<tr>
<td>PBT</td>
<td>0</td>
</tr>
<tr>
<td>PET</td>
<td>0</td>
</tr>
<tr>
<td>SAN</td>
<td>0</td>
</tr>
<tr>
<td>PMMA</td>
<td>0</td>
</tr>
<tr>
<td>ABS</td>
<td>0</td>
</tr>
<tr>
<td>PP</td>
<td>0</td>
</tr>
<tr>
<td>PE</td>
<td>0</td>
</tr>
<tr>
<td>TPE</td>
<td>0</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
</tr>
<tr>
<td>PS</td>
<td>0</td>
</tr>
<tr>
<td>PVC</td>
<td>0</td>
</tr>
<tr>
<td>PVDF</td>
<td>0</td>
</tr>
<tr>
<td>TPI</td>
<td>0</td>
</tr>
<tr>
<td>PSU</td>
<td>0</td>
</tr>
</tbody>
</table>

LIMITING OXYGEN INDEX

0 10 20 30 40 50 60 70 80 90 100

LOI %

COMMON TYPES OF FR ADDITIVES

Halogenated FR’s
- Brominated
- Chlorinated

Halogen Free FR’s
- Metal hydroxides
- Phosphorous Based
- Melamine Based

Flame Retardant Additive Usage, 2011

- Bromine 22%
- Chlorine 12%
- Phosphorus 10%
- Inorganics 44%
- Other 8%
**HALOGENATED FR MECHANISM**

- Halogenated technology inhibits the chemical reaction in the gas/vapor phase
- Various molecules that efficiently get large amounts of free radicals to the gas phase

<table>
<thead>
<tr>
<th>Additive Type</th>
<th>Polymeric Type</th>
</tr>
</thead>
</table>
| • Higher Halogen Content  
• Lower Loadings  
• High Thermal Stability | • Melt Blendable  
• Less effect on physical properties  
• Enhanced Flow |

Halogenated flame retardants are compatible in most resin systems with the exception of Acetal

**NON-HALOGEN MECHANISMS**

**Phosphorous**

- Various forms  
- Contributes to the condensed phase char formation

**Hydrated Minerals**

- Produce water during combustion process, dilute flammable vapors  
- Insulative char formation

**Melamine Cyanurate**

- Endothermic decomposition  
- Physical removal of flame from surface

<table>
<thead>
<tr>
<th>Resin Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyolefins, Polyamides, Polymers, Poly carbonate and alloys</td>
</tr>
<tr>
<td>Polyolefins, Polyamides</td>
</tr>
<tr>
<td>Polyamides, used as a synergist for other Phosphorous technologies</td>
</tr>
</tbody>
</table>

**HALOGEN VS. HALOGEN-FREE**

<table>
<thead>
<tr>
<th>Halogenated</th>
<th>Halogen Free</th>
</tr>
</thead>
</table>
| • Lower Cost  
• Better Processing  
• Better Efficiency  
• Better Physical Properties | • Evolving Economics  
• Improved Processability  
• Wide Variety of Products  
• Low Smoke  
• Lower Toxicity  
• Less Corrosive  
• Lower Specific Gravity |

**CHOOSING A FR SYSTEM**

How do we decide which FR mechanism to use?

- Resins System  
- FR Specification  
- Part Function  
- Fillers/Additives  
- Regulatory Concerns  
  - Halogen, RoHS, etc
OVERVIEW

Thermoplastic Flammability
  – Flame Retardant Additive Chemistries and Mechanisms

Regulatory Landscape
Testing Standards
Case studies

EVOLUTION OF HALOGEN-FREE TECHNOLOGIES

• More “self-policing”/customer driven bans
• New FR standards
• Green Movement
• More Effective/Economical FR Chemicals
• Increased Performance
• Competition in the Market

HALOGEN RESTRICTIONS

OEM Driven Ban on Halogenated Chemicals
  • HP, DELL, IBM etc.

Eco Labels
  • Blue Angel, White Swan, Ecolabel etc.

IMPACT OF HALOGEN-FREE

• Resin Limitations
• Physical Properties
  • Strength/Impact
  • Flow
  • Heat Resistance
  • Resin Dependent
• Flammability
• Cost
• Reduction in Specific Gravity
**Mechanical Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>RTP 205 FR</th>
<th>RTP 205 FR Halogen Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength, psi</td>
<td>21000</td>
<td>19500</td>
</tr>
<tr>
<td>Tensile Modulus, psi E6</td>
<td>1.65</td>
<td>1.45</td>
</tr>
<tr>
<td>Tensile Elongation, %</td>
<td>2.4%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Flexural Strength, psi</td>
<td>33000</td>
<td>31500</td>
</tr>
<tr>
<td>Flexural Modulus, psi E6</td>
<td>1.55</td>
<td>1.45</td>
</tr>
<tr>
<td>Impact Notched, ft-lb/in</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Impact Un-notched, ft-lb/in</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>HDT @ 264 psi</td>
<td>470</td>
<td>470</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.68</td>
<td>1.41</td>
</tr>
<tr>
<td>Flammability</td>
<td>V-0 @ 1/32</td>
<td>V-0 @ 1/32</td>
</tr>
</tbody>
</table>

**Thermoplastic Flammability**
- Flame Retardant Additive Chemistries and Mechanisms

**Regulatory Landscape**

**Testing Standards**

**Case studies**

**INDUSTRY AND MARKET DRIVEN**

**Electrical and Electronics (E&E)**
- UL 94
  - V, 5V, HB
- UL 746
  - HA1, HWI, CTI

**UL94 RATINGS**

**UL94 Ratings**
- HB
- V-2
- V-1
- V-0
- 5VB
- 5VA

*Ratings in order of difficulty to meet!*

Answers to Your Burning Questions: Flame Retardants and Regulations - Jesse Dulek
UL94 RATINGS

HB
• Handheld electronics
• Cell Phone

V-2
• Low-voltage, attended
• Electric shaver

V-1/V-0
• High-voltage, un-attended
• Electronic connectors

5VB/5VA
• Electronic enclosures

UL94 - HB

Classification Criterion

3.0 mm to 13.0 mm thickness
• slower than 40 mm/minute or…
• combustion ceases prematurely

< 3.0 mm thickness
• slower than 75 mm/minute or…
• combustion ceases prematurely

** In general most thermoplastics meet this criteria **

UL94 - VB

<table>
<thead>
<tr>
<th>Classification Criteria</th>
<th>V-0</th>
<th>V-1</th>
<th>V-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bar specimens</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Maximum flame time per specimen per flame application, sec</td>
<td>10</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Maximum total flame time 5 specimens, 2 ignitions, sec</td>
<td>50</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Specimen drips, ignites cotton</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Maximum afterglow time per specimen, sec</td>
<td>30</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Burn to holding clamp</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>

**Thickness dependent ratings**

UL94 VERTICAL BURN DEMO

Flame Retardant – V-0
Non-Flame Retardant – No Rating

Answers to Your Burning Questions: Flame Retardants and Regulations - Jesse Dulek
**RTP COMPANY UL CERTIFICATION**

RTP Company has 600+ UL Yellowcards
- Continuous expansion of UL listed products

UL Certified Laboratory under Client Test Data Program (CTDP)
- Short term properties to UL94
- Long term thermal aging (RTI)

RTP Company offers custom UL certifications to achieve full commercialization
- Quick turnaround
- Compress your Time to Market!

**AEROSPACE**

**FAR 25.853**
- Flammability:
  - 15-Second Horizontal Burn
  - 12-Second Vertical Burn
  - 60-Second Vertical Burn

- Smoke Density:
  - $D_s@4\text{min} < 200$
  - ABDD031 or BSS 7238 or ASTM E-662

- Ohio State University Heat Release:
  - Calorimetry Test Measures Peak and Total Heat Release
  - $<$100/100, $<$65/65, & $<$55/55 are common

**OEM Driven Requirements**
- Toxic Gas Emission:
  - Varies by OEM
  - ABDD031 or BSS 7239

**BUILDING / INDUSTRIAL**

- Requirements focus on:
  - Low Smoke, Heat Release, Burn Rate, Flame Spread
- Various standard that apply:
  - UL2043, UL723/ASTM E84, ASTM E1354, NFPA 701, FM 4996, CAL TB133

- Applications
  - Wall coverings, Furniture, Plenum, Pallets, Storage systems, Roofing, Floor coverings, Ventilation

**RECAP**

**Designing for an FR application**

**Regulatory Landscape**
- RoHS, Halogen Restrictions

**Specifications**
- UL94, FAR, ASTM, etc.

**Part Function**
- Performance Requirements, Application Environment, etc.

**Economics**
- Price is a Property
OVERVIEW

Thermoplastic Flammability
- Flame Retardant Additive Chemistries and Mechanisms

Regulatory Landscape

Testing Standards

Case studies

FR MEETS TRANSPARENCY

Market
Consumer

Application
LED Lens Cover

Problem
UL 94 V-0, High Light Transmission, UV, Light Diffusion, RoHS Compliance

Solution
PC – Transparent, Flame retardant, Specialty pigment package

Benefit
Provided ample diffusion of high powered LED lights with a proprietary pigment technology while achieving the required flame performance

FR MEETS OUTDOORS / UV

Market
Consumer

Application
Marine Connector

Problem
Strength/Impact, UV Resistance, Specialty color, UL94 V-0, F1

Solution
PC/PBT – Glass reinforced, UV stabilized, Flame retardant

Benefit
Product was able to pass the required drop impact testing and stringent UL outdoor and flammability ratings

FR BREAKS THROUGH THE CEILING

Market
Industrial

Application
Speaker Unit

Problem
Plenum location, UL 2043, UL94 5VA, Rigidity

Solution
Polypropylene -- Glass fiber reinforced, Halogen free flame retardant

Benefit
Provided structural requirements needed for function and stringent UL flame resistance
Thank You!

Jesse Dulek
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(507) 474-5502
Live in the Wall Section:
Product Design Principles for Structural Composites

Barbara Matousek  |  CAE Analyst
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(507) 474-5301

12:45 p.m.
Live in the Wall Section

Product Design Principles for Structural Composites

Barbara Matousek
CAE Analyst

DESIGN FOR INJECTION MOLDING

- Materials
- Molding Process
- Tool Design
- Good Part Design

WHAT WE WILL COVER

- Material Issues/Concerns with Structural Composites
- Part Design Guidelines – Common Mistakes
- Warpage
- Structural Failures
### AMORPHOUS VS. SEMI-CRYSTALLINE

<table>
<thead>
<tr>
<th>Property</th>
<th>Amorphous</th>
<th>Semi-Crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Random</td>
<td>Ordered</td>
</tr>
<tr>
<td>Melting Point</td>
<td>Broad</td>
<td>Sharp</td>
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<tr>
<td>Solvent Sensitivity</td>
<td>Often</td>
<td>Solvent Resistant</td>
</tr>
<tr>
<td>Impact Resistance</td>
<td>Impact</td>
<td>Fatigue</td>
</tr>
<tr>
<td>Shrink</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Dimensional Stability</td>
<td>Better</td>
<td>More Difficult</td>
</tr>
<tr>
<td>Control</td>
<td>Stability</td>
<td>Dimensional</td>
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</table>

### AMORPHOUS VS. SEMI-CRYSTALLINE

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Acetals</td>
</tr>
<tr>
<td>PC</td>
<td>Nylons</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>Polymesters (PET, PBT)</td>
</tr>
<tr>
<td>Thermoplastic Urethanes</td>
<td>PP</td>
</tr>
<tr>
<td>PSU</td>
<td>PE</td>
</tr>
<tr>
<td>PEI</td>
<td>PEEK</td>
</tr>
</tbody>
</table>

### LIVE IN THE WALL SECTION

Many plastics are anisotropic

Plastics are non-Newtonian

### ISOTROPIC VS. ANISOTROPIC

**Isotropic:** Material properties (including shrink) are **uniform** in flow and cross-flow direction

**Anisotropic:** Material properties (including shrink) are **not uniform** in every direction
**FILLER & REINFORCEMENT GEOMETRY**

- Spherical
- Platelets
- Acicular
- Flake
- Fibrous
- Fibrillated Fiber

**FILLER/REINFORCEMENT CLASSIFICATION**

<table>
<thead>
<tr>
<th>Type</th>
<th>Geometry</th>
<th>Aspect Ratio</th>
<th>Classification</th>
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</thead>
<tbody>
<tr>
<td>Glass Beads</td>
<td>Spherical</td>
<td>1</td>
<td>Filler</td>
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<tr>
<td>Clay</td>
<td>Platelet</td>
<td>1-3</td>
<td>Filler</td>
</tr>
<tr>
<td>Calcium Carbonate</td>
<td>Platelet</td>
<td>1-3</td>
<td>Filler</td>
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<tr>
<td>Talc</td>
<td>Platelet</td>
<td>2-5</td>
<td>Filler</td>
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<tr>
<td>Wollastonite</td>
<td>Acicular</td>
<td>5-20</td>
<td>Transition</td>
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<tr>
<td>Mica</td>
<td>Flake</td>
<td>30-50</td>
<td>Transition</td>
</tr>
<tr>
<td>Milled Glass</td>
<td>Fibrous</td>
<td>10-50</td>
<td>Transition</td>
</tr>
<tr>
<td>Glass Fiber</td>
<td>Fibrous</td>
<td>50+</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>Fibrous</td>
<td>50+</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>Nickel Coated Carbon Fibers</td>
<td>Fibrous</td>
<td>50+</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>Fibrous</td>
<td>50+</td>
<td>?</td>
</tr>
<tr>
<td>Aramid</td>
<td>Fibrillated Fiber</td>
<td>50+</td>
<td>Reinforcement</td>
</tr>
</tbody>
</table>

**PROPERTIES AFFECTED BY ADDITIVES**

- Tensile Strength
- Impact Strength
- Specific Gravity
- Viscosity
- Thermal Conductivity
- Specific Heat
- Shrinkage

**STRESS-STRAIN OF POLYMERS**

- Fiber-filled Resin
- Yield
- Unfilled Resin
Dilemma:
Fiber filled materials are not isotropic.
How do we account for this variation in mechanical properties during design?

Recommendations:
When possible do analysis that considers fiber orientation – Moldflow followed by FEA.
For FEA that doesn’t use flow simulation inputs, use 60-80% of the modulus/strength to account for property variations.
Plastics are non-Newtonian.

Viscosity varies not only with temperature but with shear rate.

**Shear Rate:** Velocity gradient in a flowing material.

**Shear:** Friction between moving plastic and the mold wall.

**INJECTION MOLDING PROCESS**

- Plastic Velocity at Wall = 0
- This gradient indicates shear rate.
- Max Plastic Velocity

**VISCOSITY OF POLYMERS**
Important things that will affect viscosity:

- Wall Thickness
- Velocity
- Temperature

Many plastics are anisotropic.

Plastics are non-Newtonian.

WHAT WE WILL COVER

- Material Issues/Concerns with Structural Composites
- Part Design Guidelines – Common Mistakes
  - Warpage
  - Structural Failures

COMMON PART DEFECTS

- Hesitation/Partialling
- Air/Gas Traps
- Weld Lines
  - Related to Fill Pattern
- Warpage
- Sinks and Voids
- Structural Weakness or Failure
**COMMON PART DEFECTS**

- Hesitation/Partialling
- Air/Gas Traps
- Weld Lines
- Warpage
- Sinks and Voids
- Structural Weakness or Failure

**Related to Fill Pattern, Cooling, and Packing**

**COMMON PART DEFECTS**

- Hesitation/Partialling
- Air/Gas Traps
- Weld Lines
- Warpage
- Sinks and Voids
- Structural Weakness or Failure

**Related to Cooling and Wall Thickness**

**HESITATION/RACETRACKING**

**HESITATION/GATE LOCATION**
HESITATION/GATE LOCATION

EFFECT OF WALL THICKNESS

Cooling time [s] vs. Wall Thickness [mm]

Fill Pressure [psi] vs. Wall Thickness [mm]

Specialized molding machines

CORING OUT

Core out thick sections to eliminate thick masses in the part.
**“CORE OUT” - EXAMPLES**

- Poor design
  - Sink marks
  - Void

- Suggested alternatives
  - Cores from both sides if possible
  - Match outside configuration to inside cores

**PART DESIGN GUIDELINES**

- Keep nominal wall < 5mm (0.200”)
- Avoid large variations in thickness
- Avoid abrupt changes in thickness
- Make thickness transitions gradual to avoid stress concentrations

**PART DESIGN GUIDELINES**

- Constant nominal wall simplifies fill pattern
- Constant nominal wall minimizes stress and warp
- Avoid gating near areas with thickness variation

**EXAMPLE**
Sinks and voids are both caused by wall sections that are too thick.

- Sinks are cosmetic flaws and voids can be structural weak points.

**RECOMMENDED RIB DESIGN**

- 2-3 T (min) with ¼” min and 0.010” (min) thickness
- 0.50 T Semi-crystalline
- 0.75 T Amorphous or filled

**RECOMMENDED GUSSET DESIGN**

- 0.50 T Semi-crystalline
- 0.75 T Amorphous or filled
- 2T and 4T thickness
**RECOMMENDED BOSS DESIGN**

- Material Issues/Concerns with Structural Composites
- Part Design Guidelines – Common Mistakes
- Warpage
- Structural Failures

**WARPAGE**

- Shrinkage itself doesn’t cause warp.
- Warp is caused by variations in shrinkage.

**Three Primary Causes**

1. Non-uniform Cooling
2. Orientation Effects
3. Differential Area Shrinkage
**NON-UNIFORM COOLING**

When the mold is hotter on one side than on the other side, the hotter side will take longer to cool so it will shrink more.

**ORIENTATION EFFECTS**

Some plastics shrink differently in the direction of flow than across flow.

Shrink Rate \( x \neq \) Shrink Rate \( y \)
Live in the Wall Section: Product Design Principles for Structural Composites - Barbara Matousek
ORIENTATION EFFECTS
EXAMPLE

ORIENTATION EFFECTS
EXAMPLE

EXAMPLE CONCLUSIONS

Design to Avoid Orientation Effects

- Primary cause of warp is orientation due to a non-uniform fill pattern
- Different gate location will not improve the fill pattern or improve orientation warp
- Reducing the warp will require either major part design changes or a material change

- Uniform wall thickness to allow simple fill pattern
- No major thin sections that could result in hesitation or racetracking
REDUCING ORIENTATION EFFECTS

- Gate for the most uniform flow
- Adjust molding conditions (often higher temps and faster injections will help)
- Adjust wall thickness
- Use more uniformly shrinking material (or sometimes a lower viscosity material)

DIFFERENTIAL AREA SHRINKAGE

- Variations in cooling rate result in variations in shrinkage
- Slower cooling results in higher crystallinity and more shrink
- Faster cooling results in less crystallinity and less shrink

DIFFERENTIAL AREA SHRINKAGE

- Thick walls take longer to cool than thin walls resulting in non-uniform shrink
- More densely packed areas take longer to cool resulting in non-uniform shrink
ORIGINAL GATE LOCATION – FILL PATTERN

ORIGINAL GATE LOCATION - WARP

WARP DUE TO DIFFERENTIAL SHRINKAGE

WARP DUE TO ORIENTATION EFFECTS
The primary cause of the warp is differential shrinkage.

So the part bends towards the non-rib side as it cools.
OPPOSITE GATE LOCATION - WARP

CONCLUSIONS

• The primary cause of the warp is differential shrinkage due to wall thickness variations
• A different gate location will improve the fill pattern but it will not improve differential shrinkage warp
• Wall thickness changes and packing pressure profiles may reduce warp

PART DESIGN TO AVOID DIFFERENTIAL SHRINKAGE

• Uniform wall thickness to allow uniform cooling rate
• Balance thin ribs onto both sides of nominal wall

REDUCING DIFFERENTIAL AREA SHRINKAGE

• Uniform wall thickness
• Lower shrink materials
• Adjust the wall thickness/rib structure
• Packing profile during molding
• Tooling inserts such as beryllium copper
• Move gate to allow packing of thick areas
WHAT WE WILL COVER

• Material Issues/Concerns with Structural Composites
• Part Design Guidelines – Common Mistakes
• Warpage
• Structural Failures

STRUCTURAL WEAKNESS OR FAILURES

Mechanical failures happen when the loading of the part exceeds the capability of the material in a specific area

COMMON STRUCTURAL FAILURES

• Stress concentrators (such a sharp edges or corners)

   High stresses/warpage potential

   Better…but

   Best

   B

   B

   A

COMMON STRUCTURAL FAILURES

• Stress concentrators (such a sharp edges or corners)
• Weld lines
COMMON STRUCTURAL FAILURES

- Stress concentrators (such as sharp edges or corners)
- Weld lines
- Poor fiber orientation
- Poor properties due to voids
- Wrong material

DESIGN TO AVOID STRUCTURAL FAILURES

- Work with material supplier
- Radius corners and edges
- Thicker is not always better
- Gate to allow flow that orients fiber in the principal direction of the structural load

OTHER STRUCTURAL CONSIDERATIONS

- Fatigue
- Creep
- Moisture, UV, temperature and other environmental concerns

OTHER TOOLING CONSIDERATIONS

- Draft
- Surface Finish
- Undercuts
- Venting
SUMMARY

• Understand your material needs and understand the material
• Design parts with relatively uniform wall thickness
• Keep the fill pattern simple

DESIGN FOR INJECTION MOLDING

Successful Part Design

Materials
Molding Process
Tool Design

Live in the Wall Section!

Thank You!
Taking Charge of Resistivity: An Introduction to Conductive Plastics Technology

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1:45 p.m.
Taking Charge of Resistivity: An Introduction to Conductive Plastics Technology

Steve Maki
Vice President Technology

OVERVIEW

Conductive Classification and Testing

Overview of Conductive Modifiers
- Migratory Anti-Stats
- Inherently Dissipative Polymers
- Carbon (Powder, Fiber, Nanotubes)

More Specialized Technology
- EMI Shielding

Wrap Up and Questions

CONDUCTIVE CLASSIFICATION

- Antistatic
  - Cleanliness
  - Prevent Dirt & Dust build up

- Static Dissipative
  - Protect Delicate Electronics
  - Prevent Explosions

- Conductive (Current-Carry Devices)
  - Electrical Contacts
  - Electrical Circuits

- Shielding
  - Provide Protection against RFs

STATIC DECAY TESTING

- Static Decay Rate
  - Measures seconds to decay
  - 6000V to 50V
  - 12% Relative Humidity

- Standards/Specifications
  - MIL PRF 81705 D
  - NFPA 56A
  - Numerous Others
Surface Resistivity (ohms/square)
Surface Resistance (ohm)

Standards/Specifications
- ASTM D257
- ESD STM11.11
- IEC 60079-0
- Numerous others

SURFACE RESISTIVITY TEST
- Small Samples
- Irregular Part Shapes
- In-Field Test
- Units = ohms/square

SURFACE RESISTIVITY TEST
- Flat Specimen
- Precise Measurement
- Units = ohms/square

SURFACE RESISTANCE TEST
- Surface Resistance Meter
  - Point to Point
  - Measuring small & critical areas on part
  - Units = ohm
**VOLUME RESISTIVITY TEST**

\[ \rho = \frac{R}{A} \]

- \( \rho \): Volume Resistivity
- \( R \): Resistance
- \( A \): Cross-sectional Area
- \( l \): Length

Units = ohm-cm
ASTM D-257

**OVERVIEW**

Conductive Classification and Testing

- Migratory Anti-Stats
- Inherently Dissipative Polymers
- Carbon (Powder, Fiber, Nanotubes)

Overview of Conductive Modifiers

- EMI Shielding
- Thermal Conductivity

More Specialized Technologies

Wrap Up and Questions

**CONDUCTIVE MODIFIERS**

- Migratory Antistats
- Inherently Dissipative Polymers (IDPs)
- Metallic Additives
- Carbon Black
- Carbon Fiber
- Carbon Nanotubes

**PERCOLATION CURVE**

Conductivity Percolation Curve

- Volume Resistivity (ohm-cm)
- Additive Loading Percentage
MIGRATORY ANTI-STATIC AGENTS

- Migrating surfactant based – not bonded to resin
- Temperature & humidity dependent
  - Best at room temperature & high humidity
- Colorable
- Liquids & semi-solids with low boiling points
- Compatible only with low temp. resins
  - Olefins, Styrenics, PVC
- Economical/commodity materials

INHERENTLY DISSIPATIVE POLYMERS (IDP)

- All-polymeric, based on IDP
  - Typically consist of PE oxide
  - Other block dictates compatibility
  - Forms a co-continuous morphology with the base resin
- Over 20 different resin systems
  - Limited process temps (< 520 ºF)

PermaStat® TECHNOLOGY BENEFITS

- Permanent ESD protection – not dependent on migration, humidity or temperature
- Clean Technology – non sloughing with FDA and Biocompatible grades available
- Transparent grades available and fully colorable
- Base resin properties retained
- PermaStat PLUS® can meet ATEX requirements

TYPICAL APPLICATIONS

- Reticle Boxes
  - ABS, PMMA
- Inhalers
  - ABS, PP, PMMA
- Gas Cap
  - POM
- ATEX IBC
  - PE
WHAT IS ATEX?

ATMOSPHERE EXPLOSIVE
- Potentially explosive environments

Began as a European Directive
- Standardize compliance procedure
- Now seen in US and other countries (IECEx)

ATEX TESTING

Actual requirements defined by customer
All tests are on actual parts
Tests could include:
- Surface Resistance (almost always included)
- Relative Thermal Index (RTI)
- Chemical Resistance
- Impact (Low temperature)
- Ultra Violet (UV)
- High Humidity Aging Testing
- Flame Retardant (FR)

Need to fully identify all requirements for proper material selection

ATEX SURFACE RESISTANCE

Specific test
- Isolation resistance <1 Gohm at 50% R.H.
- Tested at 500 V

Different from the standard surface resistance or resistivity widely used in the plastic industry
- IEC 60093
- ASTM D 257
- ESD STM11.11

No real correlation

ATEX MARKETS

Mining
Personal protective equipment
Food, chemicals, and paint industries
Hand-held equipment
Industrial equipment (pneumatic, hydraulic, venting systems, pumps)
Characterized by:

- Structure
- Size of particles
- Porosity
- Surface Chemistry

Permanent
- Black color only
- Sloughing / Marking / Crayoning
- Economical
- Dissipative or conductive
  - SR $10^3$ to $10^9$ ohm/sq
  - VR $10^0$ to $10^6$ ohm-cm

CARBON BLACK APPLICATIONS

- Electronic device trays
  - PP, PS, PC
- Pipette tips
  - PP
- Storage bins & totes
  - PP
- Fuel filler tubes
  - PE

CARBON / GRAPHITE FIBER

- Non-sloughing
- Colorable
- Anisotropic shrinkage
- Reinforcing
- Dissipative or conductive
  - SR $10^2$ to $10^6$ ohm/sq
  - VR $10^{-1}$ to $10^4$ ohm-cm

- Chopped Fiber
  - ¼” long “bundles”
- Milled Fiber
  - pulverized
CARBON FIBER APPLICATIONS

Full Line components
- PPA, Nylon, Acetal

Chip transport/Storage trays
- PC, PSUL, PES

Card printer chassis
- PC

CARBON NANOTUBES (CNT)

- > 90% graphite
- Hollow
- 10 nanometer diameter
- High L/D ratio

CNT SIZE DIFFERENCE

A carbon fiber surrounded by CNTs

PRIMARY BENEFITS OF CNTS

- Uniform electrical conductivity – prevent hot spots and protect sensitive electronics
- Effective at low loadings – clean product with low SG and good surface finish
- Isotropic Properties – non reinforcing, behaves like neat resin
- Ability to use regrind – maintains conductivity with additional processing
**ELECTRICAL CONDUCTIVITY**

**SEM (2000x) of typical CNT compound**
- Smooth surface finish
- Uniform shading is a direct result of uniform electrical conductivity

**SEM (2000x) of typical CF compound**
- Rough surface finish
- White shading indicates a point of high conductivity - "Hot spot"
- Possible conductive particle generation site

**HOT SPOTS**

- Fewer Hot Spots
- Lower Voltage Retention
- Reduced Tribocharging

**ELECTRONICS INDUSTRY APPLICATIONS**

- Hard disc drive (HDD) handling components
- Silicon wafer handling components
- Semiconductor chip trays
- ESD shipping trays

**OVERVIEW**

- Conductive Classification and Testing
- Overview of Conductive Modifiers
  - Migratory Anti-Stats
  - Inherently Dissipative Polymers
  - Carbon (Powder, Fiber, Nanotubes)
- More Specialized Technology
  - EMI Shielding
- Wrap Up and Questions
Electromagnetic Interference = EMI

Emitting from a source or received by a device.

Frequency range of 1 kHz to 10 GHz.

Faraday Cage Principle:
- Barrier that reflects or conducts signals to ground.

Shielding provides “Immunity.”

EMI shields protect sensitive devices.

Electrically Conductive modifiers:
- Carbon Powder
- Carbon fiber
- Graphite
- Stainless steel fiber
- Nickel-coated carbon fiber
- Other metallic additives
**ADDITIVE COMPARISON**

**Stainless Steel Fiber**
- Non-Reinforcing
- Equivalent shrinkage to neat resin
- Moderate shielding performance
- Colorable

**Nickel-Coated Carbon Fiber**
- Reinforcing
- High shielding performance
- Higher cost
- Less colorable

**COAXIAL TRANSMISSION LINE TEST**

- ASTM D 4935
- Direct Measurement on Flat Specimens
- Fast and Repeatable
- Relative Ranking
- Frequency range of 30 MHz to 1.5 GHz
- Units = Decibels of SE

**REVIEW OF SHIELDING OPTIONS**

- VR is key parameter
- SR is misleading
- SE dependent on filler loading and wall thickness
- Easily Grounded

- SR key parameter
- Other surfaces insulative
- SE depends on coating conductivity & thickness
- Care in grounding required
- Can flake or chip off

- Uniform Conductivity
- SR easily measured
- Easily grounded
- Design limitations

**EMI APPLICATIONS**

- Shielding gasket
- TPO/SS

- Motor Housing
- PC/NCCF
### CONDUCTIVE MODIFIERS: PROS AND CONS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Migratory Antistats</td>
<td>• Economical</td>
<td>• Non-permanent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Process temperature limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Humidity dependent</td>
</tr>
<tr>
<td>Inherently Dissipative Polymer PermaStat®</td>
<td>• Permanent</td>
<td>• Limited to dissipative range</td>
</tr>
<tr>
<td></td>
<td>• Transparent availability</td>
<td>• Process temperature limited</td>
</tr>
<tr>
<td></td>
<td>• Colorable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• No loss of mechanical properties</td>
<td></td>
</tr>
<tr>
<td>Carbon Black</td>
<td>• Economical</td>
<td>• Sloughing</td>
</tr>
<tr>
<td></td>
<td>• Dissipative or conductive</td>
<td>• Black only</td>
</tr>
<tr>
<td></td>
<td>• Resists Tribocharging</td>
<td>• Lower impact strength</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>• Dissipative or conductive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reinforcing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Non-sloughing</td>
<td></td>
</tr>
<tr>
<td>Carbon Nanotubes</td>
<td>• Dissipative or conductive</td>
<td>• Anisotropy</td>
</tr>
<tr>
<td></td>
<td>• Superior Tribocharging performance</td>
<td>• Poor tribocharging</td>
</tr>
<tr>
<td></td>
<td>• Minimal effect on mechanical and viscosity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Low Liquid Particle Count (LPC)</td>
<td>• Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Black only</td>
</tr>
<tr>
<td>Metallic Additives</td>
<td>• EMI/RFI shielding</td>
<td>• Limited colorability</td>
</tr>
<tr>
<td></td>
<td>• Highly conductive</td>
<td>• Higher specific gravity</td>
</tr>
</tbody>
</table>

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Questions?

Thank you!

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Wear in the World of Plastics

Ben Gerjets | Product Development Engineer
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2:30 p.m.
“My application is wearing out!”

Fatigue?  Chemical Attack?

Abrasion?  Weather/UV Resistance?

Be Specific!

Wear – Sliding wear of thermoplastic compounds against a contact surface (steel, aluminum, other thermoplastics, etc.)

Friction – Reducing/controlling the friction in a sliding or moving system.

Internally Lubricated Thermoplastics
AGENDA

I. Wear Definitions & Test Methods
II. Friction Definitions & Test Methods
III. Additive Technologies
IV. Application Examples
V. Extreme Conditions – Ultra Wear

WEAR DEFINITIONS

Tribology
The Science of the mechanisms of friction, lubrication, and wear of interacting surfaces that are in relative motion

Recall: Sliding surfaces
Wear = Loss of material over time

Adhesive Wear Mechanism
• The primary mechanism for thermoplastic wear
• Characterized by transfer of material from one part to the other caused by frictional heat
WEAR DEFINITIONS

**Abrasive Wear Mechanism**
- Caused by a hard material scraping or abrading away at a softer material
- Characterized by grooves cut or gouged into the surface
  - Three Body

WEAR TESTING

**Question:** How do you simulate an application and test a material for *long-term* wear resistance?

**Answer:** RTP uses ASTM D-3702 wear test to quantify the amount of material a sample loses over time under specific conditions (pressure, speed, temperature).

**ASTM D-3702 “Thrust Washer” Wear Test**
- **Adjustable:**
  - Counter-surface (thrust washer)
  - Pressure
  - Velocity
  - Temperature

The best use of this test is to perform comparative screening of multiple candidate materials.

**WEAR TESTING**

- RTP Company has six thrust washer wear testing machines in our wear lab located in Winona, MN
- Equipment is available to perform customer requested testing
- A test isn’t always just a test
  - Conditions matter!
Wear factor (K): Used to quantify wear resistance.
Lower Value = Better Wear Resistance!

\[ K = \frac{W}{(F \times V \times T)} \]

- \( K \) = Wear Factor: \( \text{in}^3\cdot\text{min}/\text{ft-lb-hr} \) \( \cdot 10^{-10} \) or \( \text{mm}^3/\text{N-m} \) \( \cdot 10^{-8} \)
- \( W \) = Volume wear: \( \text{in}^3 \) or \( \text{mm}^3 \)
- \( F \) = Force: \( \text{lb} \) or \( \text{N} \)
- \( V \) = Velocity: \( \text{ft/min} \) or \( \text{m/sec} \)
- \( T \) = Elapsed time: \( \text{hr} \) or \( \text{sec} \)

100 Hour Test!

**WEAR TESTING**

**Standard Conditions:**
- Steel thrust washer
- 40 psi \( \cdot \) 50 ft/min
- Ambient temp
- 100 hour test

**PV = (Pressure \cdot Velocity)**

Conditions often used together to characterize severity of a wear environment

2,000 PV = (40 psi \( \cdot \) 50 ft/min)

**Typical testing done at 2,000 to 10,000 PV**

**Question:** Does an equivalent PV always result in the same data?

**Answer:** No…Wear factor will change based on individual conditions
**WEAR TESTING**

**Question:** What happens when PV is increased? Does Wear Factor (K) also increase?

![Graph showing wear factor vs. PV (load)](image)

- PV (lbf·ft²/in³·min) vs. Wear Factor ($\text{in}^2/\text{ft}·\text{in}^2/\text{ft}·\text{min}$)
- Wear per ASTM D 3702 against C1018 Steel

**AGENDA**

I. Wear Definitions & Test Methods

II. Friction Definitions & Test Methods

III. Additive Technologies

IV. Application Examples

V. Extreme Conditions – Ultra Wear

---

**FRICITION DEFINITIONS**

**Coefficient of Friction (μ)**

Ratio of the force of friction between two bodies and the force pressing them together

\[ \mu = \frac{F}{N} \]

- Static coefficient of friction ($\mu_s$) = $F_x / F_y$
  - $F_x$ = Force to initiate motion
  - $F_y$ = Normal force holding surfaces together

- Dynamic coefficient of friction ($\mu_k$) = $F_x / F_y$
  - $F_x$ = Force to sustain motion
  - $F_y$ = Normal force holding surfaces together
FRICTION DEFINITIONS

- In most non-plastic materials
  - $\mu_s > \mu_k$
- Thermoplastics are somewhat unique
  - $\mu_k > \mu_s$
- May cause “slip/stick” – Glide Factor℠
- If $\mu_k >> \mu_s$ you may have squeaking

FRICTION TESTING

ASTM D 1894 “sled test”
- Coefficient of friction testing
- Does not determine wear resistance
- Can show slip/stick

RTP Modified ASTM D3702 Friction Test
- Oscillating motion used to measure friction coefficients and Glide Factor℠
- Glide Factor℠ is used to quantify the difference between $\mu_s$ and $\mu_k$ in order to reduce/eliminate stick/slip
- Used to generate friction data for optimal material selection in medical devices

TESTING REVIEW

Question: How does RTP measure wear resistance?
Answer: ASTM D3702 Thrust Washer wear test; Wear Factor (K)

Question: How does RTP measure Friction?
Answer 1: ASTM D1894 “Sled Test” (Static and Dynamic Coefficient of Friction)
Answer 2: Modified ASTM D3702 Thrust washer friction test. (Glide Factor℠)
**AGENDA**

I. Wear Definitions & Test Methods  
II. Friction Definitions & Test Methods  
III. Additive Technologies  
IV. Application Examples  
V. Extreme Conditions – Ultra Wear

**ADDITIVE TECHNOLOGIES**

PTFE – Polytetrafluoroethylene (5-20%)

- Workhorse additive – solid white powder  
- Compatible with nearly all thermoplastic resins  

**Limitations**

- Fluorine content  
- Die plate-out  
- Relatively high loadings  
- Cost fluctuation

**PTFE Wear Mechanism**

Base Polymer Layer  
Exposed PTFE  
PTFE Layer  
Part – As Molded  
Part – After break-in period

Exposed PTFE shears to form layer
APPLICATION EXAMPLE

Laser Printer Fuser Gears

Requirements
- High Operating Temperatures
- Good wear Resistance

Solution
- Glass fiber reinforced and PTFE lubricated PPS

SILICONE – POLYDIMETHYLSILOXANE (1-3%)

- Boundary lubricant which migrates to the surface over time
  - Migration rate is viscosity dependent
  - Excellent friction reducer
  - Best in high speed/low load applications

Limitations
- Limited use in decorated parts
  - Poor adhesion of paint or print inks
- Bad for electrical applications
  - Can foul contacts
**PTFE + Silicone Wear Mechanism**

- SI Present as Molded
- Exposed PTFE
- SI + PTFE Layer

**Wear Resistance with PTFE and Silicone**

<table>
<thead>
<tr>
<th>Material</th>
<th>Unfilled</th>
<th>2% Silicone</th>
<th>20% PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>550</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>POM</td>
<td>175</td>
<td>95</td>
<td>40</td>
</tr>
<tr>
<td>PA 6/6</td>
<td>320</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Friction Reduction with PTFE and Silicone**

<table>
<thead>
<tr>
<th>Material</th>
<th>Unfilled</th>
<th>2% Silicone</th>
<th>20% PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>0.60</td>
<td>0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>POM</td>
<td>0.40</td>
<td>0.38</td>
<td>0.25</td>
</tr>
<tr>
<td>PA 6/6</td>
<td>0.55</td>
<td>0.45</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Specific Gravity Differences with PTFE and Silicone**

<table>
<thead>
<tr>
<th>Material</th>
<th>Unfilled</th>
<th>2% Silicone</th>
<th>20% PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>1.19</td>
<td>1.31</td>
<td>1.40</td>
</tr>
<tr>
<td>POM</td>
<td>1.41</td>
<td>1.40</td>
<td>1.52</td>
</tr>
<tr>
<td>PA 6/6</td>
<td>1.14</td>
<td>1.13</td>
<td>1.26</td>
</tr>
</tbody>
</table>
### ADDITIVE TECHNOLOGIES

#### Tensile Strength with PTFE and Silicone

- **Unfilled**
- **2% Silicone**
- **20% PTFE**

<table>
<thead>
<tr>
<th>Material</th>
<th>Unfilled</th>
<th>2% Silicone</th>
<th>20% PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>8,500</td>
<td>8,700</td>
<td>12,000</td>
</tr>
<tr>
<td>POM</td>
<td>8,700</td>
<td>8,500</td>
<td>12,000</td>
</tr>
<tr>
<td>PA 6/6</td>
<td>7,800</td>
<td>6,500</td>
<td>9,500</td>
</tr>
</tbody>
</table>

### APPLICATION EXAMPLE

#### Garage Door Opener Limit Switch

**Requirements**
- Dimensional stability
- Good strength and stiffness

**Solution**
- Silicone lubricated PC

![Contact Carrier](image)

Not Transparent! More on this later…

### APPLICATION EXAMPLE

#### Drug Delivery Pen Components

**Requirements**
- Good strength, dimensional stability, eliminate secondary lubricant application and no slip/stick.

**Solution(s)**
- Optimal Plastic “Friction Pairs” with low Glide FactorSM
- Fiber reinforced and internally lubricated PC or PBT
- Internally lubricated POM or PBT

---

**Engineered Plastics Workshop**

**Wear in the World of Plastics - Ben Gerjets**

107
ADDITIVE TECHNOLOGIES

PFPE – Perfluoropolyether Oil (< 1%)

- Thermally stable up to PEEK processing temps
- Differentiates RTP Company from others
- Synergy with PTFE
- Specific gravity benefits

Limitations
- Limited effectiveness in amorphous resins
- Needs PTFE “kick” to deliver optimum friction reduction

APPLICATION EXAMPLE

Agricultural Pump

Requirements
- Chemical and Wear Resistance

Solution
- PFPE lubricated PP

Universal Conveyor Roller

Requirements
- Strength, conductivity and wear resistance (must be silicone-free)

Solution
- Carbon fiber reinforced and PTFE/PFPE lubricated PPS
ADDITIVE TECHNOLOGIES

Additives Reduce Clarity!

- PC with APWA+
- PC with PTFE
- PC with PFPE
- PC with Silicone
- Natural PC

Graphite Powder (5-30%)
- Aqueous environments
- Excellent temperature resistance
- Black color

Molybdenum Disulfide - MoS₂ (1-5%)
- Nucleating agent in nylons: creates harder surface
- High affinity to metal:
  - Smoother mating metal surface = lower wear

Limitations
- Limited use
- Dark color limits colorability
- Sloughing type additives

APPLICATION EXAMPLE

Water Meter Valve

Requirements
- Dimensional stability, potable water contact - NSF listed

Solution
- Graphite lubricated PS and SAN
ADDITIVE TECHNOLOGIES

PTFE
Silicone
PFPE
Graphite
MoS₂
Fibers

Reinforcing Fibers and Wear Resistance

Glass Fiber
Carbon Fiber
Aramid Fiber

- Improved bearing capabilities/wear resistance
- Very abrasive
- Higher bearing capabilities
- Excellent thermal resistance
- Conductive
- Less abrasive
- Little strength improvement
- Very gentle to mating surface

Fibers protect the polymer, but may be abrasive against the mating material

Glass
Carbon
Aramid

APPLICATION EXAMPLE

Copier Bushings

Requirements
- High HDT and good wear resistance

Solution
- Aramid fiber reinforced and PTFE lubricated PPA

Engineered Plastics Workshop

Wear in the World of Plastics - Ben Gerjets
ADDITIVE TECHNOLOGIES

APWA PLUS:
All Polymeric Wear Alloy

A Unique Polymer Alloy Technology Offering:
• Improved wear and friction performance
  • Especially effective in plastic vs. plastic wear
• Good retention of base resin physical properties
• Lower specific gravity than PTFE
• Reduction/Elimination of plate-out associated with PTFE

ADDITIVE TECHNOLOGIES

Additive Synergies

10/10/10 – Carbon Fiber/Graphite Powder/PTFE
Typical additive package for high load bearing/high temp. applications

Aramid Fiber/PTFE
Excellent wear package that is gentle on the mating surface

Carbon Fiber/Ceramic Additive
Non-PTFE solution, good for very demanding conditions

ADDITIVE TECHNOLOGIES

Wear Performance of 10% PTFE Vs. APWA PLUS in PA6/6, PC, and POM

Tested against C1010 Steel

AGENDA

I. Wear Definitions & Test Methods
II. Friction Definitions & Test Methods
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IV. Application Examples
V. Extreme Conditions – Ultra Wear

Engineered Plastics Workshop

Wear in the World of Plastics - Ben Gerjets
### EXTREME CONDITIONS

**What happens when your application has a PV higher than 10,000?**

- High Temperature
- High Loads (500+ psi)
- High Speeds
- Chemical Resistance

**100 ft/min tests**
- 10,000 PV: 100 psi
- 25,000 PV: 250 psi
- 50,000 PV: 500 psi

**200 ft/min tests**
- 10,000 PV: 50 psi
- 25,000 PV: 125 psi
- 50,000 PV: 250 psi

### EXTREME CONDITIONS

**Ultra Wear Products Developed for Demanding applications**

- Transmission Seal
- High Load Thrust Washers
- Pipe Gaskets
- Off-Shore Drilling
- Construction Vehicles
- Oil and Gas Industry

### EXTREME CONDITIONS

**1. Develop a series of high performance RTP products ideal for “Ultra” testing**

<table>
<thead>
<tr>
<th>Resins</th>
<th>Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEE K</td>
<td>PPS PPA</td>
</tr>
<tr>
<td>• Carbon Fiber</td>
<td>• PTFE</td>
</tr>
<tr>
<td>• Graphite</td>
<td>• Ceramic</td>
</tr>
<tr>
<td>• Aramid Fiber</td>
<td>• MoS₂</td>
</tr>
</tbody>
</table>

**2. Compare RTP Ultra Products with industry leading wear resistant materials**

- Rulon® J
- Rulon® LR
- Torlon® 4301
- Torlon® 4630
- Vespar® SP-21
- Vespar® SP-211
- Stanyl® TW371

### EXTREME CONDITIONS

**PV=50,000 (500 psi @ 100 ft/min)**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Wear Factor (in³/min/ft-lb-hr)*10⁻¹⁰</th>
<th>Dynamic</th>
<th>Compound</th>
<th>Wear Factor (in³/min/ft-lb-hr)*10⁻¹⁰</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE 1</td>
<td>4</td>
<td>0.05</td>
<td>PPS-CF/Ceramic</td>
<td>134</td>
<td>0.06</td>
</tr>
<tr>
<td>PTFE 2</td>
<td>16</td>
<td>0.16</td>
<td>PPS-CF/PFPE</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PEEK-CF/Ceramic</td>
<td>26</td>
<td>0.12</td>
<td>PEEK-CF/PFPE</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PSF-1</td>
<td>43</td>
<td>0.14</td>
<td>PEEK-CF/PFPE</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PSF-2</td>
<td>56</td>
<td>0.15</td>
<td>PEEK-CF/PFPE</td>
<td>Wear Limit</td>
<td>NA</td>
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<tr>
<td>PSF-GF/TiC</td>
<td>79</td>
<td>0.16</td>
<td>PEEK-CF/TiC</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PANI</td>
<td>105</td>
<td>0.15</td>
<td>PPA-CF/TiC</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PEEK-AF/PFPE</td>
<td>119</td>
<td>0.15</td>
<td>PPA-CF/AF/TiC</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PEEK-CF/PFPE</td>
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<td>0.20</td>
<td>PA-46-TFE</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
<tr>
<td>PEEK-CF/GRPH/TFE</td>
<td>119</td>
<td>0.15</td>
<td>PPA-CF/AF/TiC</td>
<td>Wear Limit</td>
<td>NA</td>
</tr>
</tbody>
</table>

Wear per ASTM D-3702 against Steel
APPLICATION EXAMPLE

AC Compressor Scroll Seal

Requirements
- High temperature, chemical and wear resistance

Solution
- Carbon fiber reinforced and PTFE/Graphite lubricated PEEK

Transmission Seal Rings/Thrust Washers

Requirements
- Ability to survive extremely high PV conditions with external lubrication

Solution
- Carbon fiber reinforced, internally lubricated PEEK
WEAR AND FRICTION

Wear Factor (K) and friction coefficient (µK) for common tribological compounds:
www.rtpcompany.com/info/wear

Thank You!
Ben Gerjets
bgerjets@rtpcompany.com
(507) 474-6381

Wear in the World of Plastics - Ben Gerjets
Color - More than Meets the Eye

Jesse Dulek  l  Product Development Engineer
jdulek@rtpcompany.com
(507) 474-5502

3:15 p.m.
Color—More than Meets the Eye - Jesse Dulek

RTP COMPANY COLOR DIVISION

Color virtually all resins
- Engineering resins
- Styrenic resins
- Polyolefin resins

Color in multiple formats
- Masterbatches
- Precolored resins
- Cube blends

Advanced Color Development
- Custom colors
- Multiple light sources
- Regulatory knowledge
  - UL, FDA, USP, RoHS, etc.

GLOBAL COLOR CONSISTENCY

8 Color Labs
- USA, France, China, Singapore, Mexico

Color Control
- Consistent raw materials
- Consistent hardware
- Consistent software
- Global database

Speed
- Fast color matching service
- Transfers across regions
- Global color palette

Brief introduction to RTP Company Color Division

Color Fundamentals
- Three Sciences of Color
- Colorant Types & Limitations
- Evaluation & Control
- Effective Color Communication

Light Diffusion
- Types
- Applications

Questions
**COLORING OPTIONS**

**Masterbatches**
- Concentrated formulation of colorants and/or additives dispersed in a polymer carrier
- Usage defined by let-down ratio or percentage
- Most widely used form to color commodity resins

**Precolor**
- Colorants are added to the polymer and extruded
- Ready to use as-is

**Cube blend**
- Masterbatch is blended with resin (two or more pellet solution)

*Your Color – Your Way*

---

**PRODUCT FAMILIES**

Compounds formulated to meet performance requirements, from one property to multiple technologies

- Color
- Conductive
- Flame Retardant
- Thermoplastic Elastomers
- Structural
- Wear Resistant
- Film - Wiman
- Sheet - ESP™

---

**TOPICS**

Brief introduction to RTP Company Color Division

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**Light Diffusion**
- Types
- Applications

**Questions**

---

**COLOR SCIENCE**

**Biology**
- Color perception

**Physics**
- Light interactions

**Chemistry**
- Colorants

*Color—More than Meets the Eye - Jesse Dulek*
**How do we see color?**

Light Source → **Object** → **Observer**

**PHYSICS**

White light is made up of all wavelengths of visible light. It is separated into individual colors when light passes through a glass prism.

- **Appears blue**
- **Blue object**

- **Appears black**
- **Black object**

**ART OF COLOR**

Light behaves like a wave
SPECTRAL REFLECTANCE

• Spectral reflectance curves produced by spectrophotometer
• Graph shows light reflected from an object at each wavelength
• Each color has a unique spectral curve

CHEMISTRY – COLORANT TYPES

Inorganic Pigments
• Pigments from various metals or other substances from nature

Organic Pigments
• Pigments made synthetically

Dyes
• Synthetic substances that are soluble

ORGANIC VS. INORGANIC

Organic Pigments:
• Small particle size
• Difficult to disperse
• Limited heat stability (300 °C max)
• High color strength
• Light fastness
  • Evaluated on individual basis

Inorganic Pigments:
• Large particle size
• Easy to disperse
• Heat stable
• Weak color strength
• Improved light fastness

DYES

Soluble
• Migration concerns

High color strength

Transparent

Commonly used in:
• Styrenic Resins
• Engineering Resins
COLOR EVALUATION & CONTROL

Visual Color Evaluation
- Confirmed color vision
- Color standards for reference
- Controlled light
- Agreed upon color space

Instrumental Color Evaluation
- Calibrated instruments
- Color standards for reference
- Controlled light
- Agreed upon color space

ENVIRONMENTAL FACTORS

Observer
- Each person sees color uniquely

Light Source
- Different spectral distributions (D65, CWF, Incandescent)

Background
- Contrast difference makes colors appear different

Viewing Angle
- Most common 45°
  
  Keep viewing conditions CONSTANT

SPECIFICATION & TOLERANCES

Numeric Color Modeling

Numeric model provides
- 3 dimensional color space
- Quantify colors numerically
- Can be used for specification, identification, comparison

Several Color Spaces
- CIE 1931 Yxy
- CIE L*a*b* 1976
- CIE LCh
  - CMC l:c 1984

COMMON COLOR TERMS

Hue
- Color perceived

Chroma (Saturation)
- Vividness of a color

Lightness
- Measure of brightness
  (think about gray scale)

Tint: Hue has been lightened
- Pink is a tint of red

Shade: Hue has been darkened
- Maroon is shade of red
COLOR SPACE

CIE 1931 Yxy

- Uses numeric values Yxy
  - Y - Luminance
  - x,y - Chromaticity values
- Only x,y chromaticity values shown
- Hue changes around color gamut
- Chroma increases from center towards edge

COLOR SPACE

CIE L*a*b* Model (Traditional X-Y-Z coordinate system)

- Developed in 1976
- Most popular color space
- Uniform color space
- Identified by numeric values
  - \( L^* = \) lightness to darkness (0-100)
  - \( a^* = \) redness to greenness
  - \( b^* = \) yellowness to blueness
- \( \Delta E^* = \) total color shift (dimensionless)

\[ \Delta E^* = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \]

COLOR SPACE

CMC l:c (1984)

- Used for tolerancing
- l:c (lightness:chromaticity) values are typically 2:1
- Provides better agreement between visual and instrumental assessment
- Allows user to vary ellipse tolerance per application

TOLERANCES

- Tolerances developed around variation in raw materials, processing, customer goals for visual appearance

* Asymmetrical color tolerances are perfectly acceptable to use
COLOR COMMUNICATION

It’s important to specify all targets through color communication

APPLICATION REQUIREMENTS/TARGET

Application Requirements
- Resin/Compound
- Regulatory Restrictions
- Processing Method
- Secondary Operations

Color Target
- Physical Color
- Grass Green
- Pantone: 347
- L^* = 43
- a^* = -22.9
- b^* = 26.21

SATISFYING EXPECTATIONS

Color nomenclature
- Identifies both regulatory and formulation commitment

Lot control
- Ingredient traceability

Process control
- Defined manufacturing specifications
- Engineering review during development and continuous improvement
- Contributes to consistency

Color quality control
- Color meets defined requirements
- Physical properties
- Composition consistency

TOPICS

Brief introduction to RTP Company Color Division

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- Effective Color Communication

Light Diffusion
- Types
- Applications

Questions
LIGHT DIFFUSING

- Electronics, outdoor lighting & signage, automotive
- More consistent and pleasing light for consumers
- Eliminates Hot Spots
- LED Color Variation
- Protects/hides light source
- Expands Design Space
- Popular for LEDs
- PC, Acrylic

LIGHT DIFFUSION

- Two basic automotive applications...
  - Attenuation and color
  - HVAC Displays

- Various buttons

LIGHT DIFFUSION TYPES

- Brilliant
- Emergence & Chromergence
- Veil & Eclipse
- Pure

Or is it three?

- How do we eliminate projected “hot spots”?
- Light pipes are used to direct source lighting, balancing output to achieve a consistent harmonious display!
**BRILLIANT**

**Features**
- High opacity
- 95%+ reflectivity
- Spectrally neutral

**Common Uses**
- LED Reflectors
- Light boxes for LCD backlighting
- Illuminated pushbutton actuators
- Reflective light guides
- Light isolators

**EMERGENCE & CHROMERGENCE**

**Features**
- High contrast
- Easily backlit
- Tunable transmission
- Neutral or tuned
- Laser etch-able, paintable, printable

**Common Uses**
- Multi-shot graphics
- Illuminated Indicators
- Graphics with LED color correction
- Paint and laser etched graphics
  - in white and colors

**VEIL & ECLIPSE**

**Features**
- Wide angle diffuser
- High transmission and efficiency
- Laser etch-able, printable, paintable
- Neutral transmission and/or color

**Common Uses**
- LED hotspot elimination
- Hidden-until-lit graphics in color
- LED color tuning diffusers
- Substrate for surface decorated illuminated graphics

**PURE**

**Features**
- Very high light transmission
- Color tunable
- Available in wide variety of scatter angles
- from very narrow to wide angles

**Common Uses**
- Long light path light pipes
- LED color correcting lenses
- Point source softening elements
- Complex light distribution covers
SO HOW DO WE BEGIN?

- Data from LED bins used
- Actual LED on a PCB to be lighted at RTP
- Drawing with dimensions/thicknesses included
- OEM color and chromaticity specifications
- Painted clear chip if paint layer is involved
- Molded parts and data

RTP COMPANY TYPICAL PARAMETERS

- Luminance tolerance of +/- 5%
- Chroma tolerance of +/- 0.01 CIE 1931 x, y
- 1-4mm specimen thickness
- Spectrophotometer for standard quality assurance needs
- Spectroradiometer for development and, as needed, QA

OUR RESOURCES

- Standard Products
  - Translucent White, Color Options, and ‘clear or colorless’
  - Various levels of diffusion and optical performance
- OEM approvals on Lighting materials
- Specific Controls for manufacture and quality control
- Global Lighting Products Available
  - Local development with Global support
- Compounding Process for Lighting Materials
- Quality Assurance Controls for Lighting Materials

CHALLENGES TO OVERCOME

- Missing or incomplete information
  - Changing targets
  - Lessons learned
- Limited access to light source
  - Light source is critical
  - PCB source is preferred
- Not enough data points
  - Often best to offer 2 or more samples for expediency
  - Sample plaques maybe used to define goals
- Distance of light path and part geometry
### COMMUNICATION IS KEY

**How do we share information?**

- Luminance transmission
- Spectral transmission
- Most applications require reporting “Day and Night” performance
- X-Rite i17 Spectrophotometer
  - D65 SCI 10 degree, LAV
  - Black and white background defined thickness
- Minolta CS-2000
  - Preferred customer source
  - RTP source as alternative

### LIGHT DIFFUSION REVIEW

**Brilliant**
- Brilliant Emergence & Chromergence
- Veil & Eclipse
- Pure

### SUMMARY

- RTP Company supplies innovative colors and functional additives
- Color communication is crucial to color matching and tolerancing
  - Application is key to setting tolerance!
- Light diffusion applications and types
- Communication is key and we are here to help!

### QUESTIONS

Any Questions

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*Color—More than Meets the Eye - Jesse Dulek*
Thank You!

Jesse Dulek
jdulek@rtpcompany.com
(507) 474-5502
Everything You Need to Know about TPEs

Karl Hoppe  | Senior Product Development Engineer
khoppe@rtpcompany.com
(507) 474-5367

4:00 p.m.
DEFINITION

**THERMOPLASTIC ELASTOMER**

“...Having the property of softening or fusing when heated and of hardening again when cooled...”

“...Any of various elastic substances resembling rubber...”

Int'l Inst. of Synthetic Rubber Producers (IISRP) definition:

“Polymers, polymer blends or compounds which, above their melt temperatures, exhibit thermoplastic character that enables them to be shaped into fabricated articles and which, within their design temperature range, possess elastomeric behavior without cross-linking during fabrication. This process is reversible and the product can be reprocessed and remolded.”

AGENDA

- Establish a Definition
- Understanding how TPEs work
- TPE Types
- RTP Product offering
  - Additive Capability
  - Styrenic Based TPEs
  - TPV Alloys
  - Bondable Technology

GOALS:

- A basic understanding of various TPEs
- Relate this knowledge to the RTP TPE Product line

WHAT IS TPE

A diverse family of rubber like materials that, unlike conventional vulcanized rubber, can be processed and recycled like thermoplastic materials.

<table>
<thead>
<tr>
<th>Thermoset</th>
<th>Thermoplastic</th>
</tr>
</thead>
<tbody>
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<td></td>
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</tr>
</tbody>
</table>
TPEs are composed of hard and soft domains; they are multiphase materials in their solid state.

**Hard** phase contributes “plastic” properties such as:
- High-temperature performance
- Thermoplastic processability
- Tensile strength
- Tear strength

**Soft** phase contributes “elastomeric” properties:
- Low-temperature performance
- Hardness
- Flexibility
- Compression & tension set

The design temperature range of a TPE is bounded by the glass transition temperature of the rubbery phase and the glass transition or melt temperature of the hard phase.

By raising the temperature of the TPE above the glass transition or melting temperature of the **plastic phase**.

And applying shear forces typical of thermoplastic processes.
UNLIKE THERMOSET RUBBER...

By comparison, thermoset rubbers (TSRs) are single phase materials with non-reversible chemical (covalent) bond cross-links.

And are unaffected by shear forces.

Or increasing heat...

By increasing heat...
NEAT POLYMER VS COMPOUND

NEAT POLYMER
Created in a reactor, polymerizing thermoplastics chemically from feedstock.

COMPOUND
Using a mechanical mixing process to improve one or more neat polymers.

CLASSIFICATION & NOMENCLATURE
Performance (heat & oil resistance following ASTM, SAE, etc.)
Chemistry (styrenic, olefinic, urethane, etc.)
Structure
- Block copolymers
- Blends & alloys
- Dynamic vulcanizates

LINEAGE (ALPHABET SOUP)

TPE
TPO
“Plastomer”

SBC
TPU
TEO
COPE
PEBA

SBS
SEBS
SEPS
SEEPS
SIBS

POE
OBC
TPV

PVC/NBR

Most Commonly seen as compounds

BLOCK COPOLYMERS - MECHANISM
Block copolymer based TPEs are made of polymers that have both hard (semi-crystalline or glassy) blocks and soft (amorphous) blocks along the backbone:

s-s-s-s-h-h-h-h-s-s-s-s-h-h-h-

In the bulk, as they cool from the melt, the hard blocks will coalesce into crystalline or glassy domains creating physical crosslinks.

The soft blocks are left to form amorphous rubbery domains that provide the elastomeric bridges between the crystalline domains.

Everything You Need to Know about TPEs - Karl Hoppe
### BLOCK COPOLYMERS - EXAMPLES

Styrenic block copolymers “SBC”
- SBS, SEBS, SIS, SIBS, SEEPS (neat rubber)
- Rarely used in their neat form

Polyolefin elastomer “POE”
Thermoplastic urethane “TPU”
Copolyether-ester “COPE”
Polyether-block-amide “COPA” or “PEBA”

### BLENDS & ALLOYS - EXAMPLES

Styrenic block copolymers “SBC”
- SBS, SEBS, SIS, SIBS, SEEPS → Styreflex Compounds
- Most frequently compounded with PP, PE, or POE

Bondable TPES
- Polabond
- Nylabond

### FOCUS – SBC BASED TPE’S

<table>
<thead>
<tr>
<th>COMPOSITION</th>
<th>DESIGN FLEXIBILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIL (white mineral, other)</td>
<td>Hardness → Gels (Shore OOO) to 50D</td>
</tr>
<tr>
<td>SBC POLYMER(S) (type, MW, and structure)</td>
<td>Viscosity → Extrusion to ultra-high flow</td>
</tr>
<tr>
<td>FILLER (CaCO3, talc, none)</td>
<td>Clarity → Opaque to water clear</td>
</tr>
<tr>
<td>POLYPROPYLENE (lots of choices)</td>
<td>Properties → Tailored elasticity, strength</td>
</tr>
<tr>
<td>Stabs, pigments, etc</td>
<td>Feel → Super grippy to dry</td>
</tr>
<tr>
<td></td>
<td>Fillers → Throw in the kitchen sink</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>LIMITATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity→ Highly elastic to “dead”</td>
<td>Oil resistance→ High affinity for absorption</td>
</tr>
<tr>
<td>Versatility→ Broad range of customizations</td>
<td>High Temp→ Max CUT ~100C</td>
</tr>
<tr>
<td>Low temp and RT → Great CS and flexibility</td>
<td>High Temp #2→ Properties drop off as temp ↑</td>
</tr>
<tr>
<td>Cost→ General purpose to boutique compounds</td>
<td>Reputation→ A few bad apples . . .</td>
</tr>
<tr>
<td>Aesthetics→ Excellent moldability, consistency</td>
<td>Balance→ Formulations flexibility is capped by inverse requirements – no free lunch</td>
</tr>
<tr>
<td>Colorability→ Very bright colors possible</td>
<td>Bond to PP</td>
</tr>
</tbody>
</table>

### DYNAMIC VULCANIZATES - MORPHOLOGY

**Simple melt-mixing**
- Coarse morphology
  - TPO

**Dynamic vulcanization**
- Fine morphology
  - TPV
FOCUS – TPV’S

COMPOSITION
EPDM RUBBER  (non-vulcanized bale)
POLYPROPYLENE  (usually GP grades)
FILLER  (CaCO3 or talc, low %)
CURE PACKAGE  (phenolic, peroxide, etc)
Oil  (generally low % add)
Stabs, pigments etc

DESIGN FLEXIBILITY
Hardness  35A to 50D
Viscosity  Shear dependent flow
Clarity  Opaque, nat color vs cure pkg
Properties  Driven by hardness
Feel  Most “rubber-like” feel
Fillers  Crosslinked EPDM limits filler

STRENGTHS
“Industrial”  Higher temp property retention
Long term sealability (think auto)
Great inherent UV stability
Chemical and oil resistance
Rubber-like  Most similar TPE to rubber
Commoditized  Standard products and stocks
Bond to PP

LIMITATIONS
Customization  Technology and mfg limited
Aesthetics  Shear sensitivity and gate defects
RM flexibility  TPV does not drive inputs
Color  Opaque natural, cure technology driven
Regulatory vs Cost  Control capable, but “true” TPV has major cost implications

TPE ≠ RUBBER

Keep in mind:
This is a broadbrush of many (very) different technologies that make up generic “TPE”, relative to many (very) different technologies making up thermoset elastomers.

<table>
<thead>
<tr>
<th>PRO’s</th>
<th>CON’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recyclable</td>
<td>High Temp Performance</td>
</tr>
<tr>
<td>Mass Reduction</td>
<td>Material Cost</td>
</tr>
<tr>
<td>Manufacturing Cost</td>
<td>Elastomeric Properties</td>
</tr>
<tr>
<td>Design Flexibility</td>
<td>No in-house compounding</td>
</tr>
</tbody>
</table>

TPE’s are not a one to one replacement for Thermoset Elastomers
Proper material selection is highly dependent on the application requirements, design, and ability to take advantage of the strengths inherent to TPE or Thermoset Elastomers.

RELATIVE VALUE OF TPE’S

Performance = heat & oil resistance

Everything You Need to Know about TPEs - Karl Hoppe
THE PROBLEM WITH HARDNESS

TPE Strength and Hardness Comparison

THE PROBLEM WITH HARDNESS

WHY RTP?

RTP has been built on several basic principles:

- Independent, Value Added Custom Compounding
- Incorporating Specialty Additives into a Wide Variety of Base Resins
- Very Highly Focused on (and invested in) R&D, Technology, and Engineering

SBS • POE • TES • SBC • TPV • TPU • COPE • PEBA

TPE compounding requires the exact same approach – Only Different?

- Mix R&D / Engineering capability with ability to supply “volume” compounds
- Standard – Compounds common to the market
- TPE Alloys – Combining neat technologies to optimize performance
- Specialties – incorporating RTP additive expertise

STYRENIC BASED TPE’S

Styreflex™ 2700S & 2740S

Standard Products

Styreflex™ 2700 S Series - 30A to 80A unfilled
- Translucent to clear, low gravity, excellent elasticity
- Medical and FDA compliant grades available (MD and Z)

Styreflex™ 2740S Series - 30A to 80A filled SBC
- Opaque, higher gravity, FDA compliant grades available

Attributes
- Highly Elastic
- Highly Customizable
- Design Flexibility
- Broad Cost Spectrum
- Great RT Compression Set

2799 SX Design Flexibility

- Water clear
- Increased Elasticity
- Low Hardness + Strength
- EU food contact compliant
- Processing Tweaks
- Haptics (Touchy-Feely)
### VULCANIZE BASED TPE'S

#### Permaprene™ 2800B & 2840B Standard Products

**Permaprene™ 2800 B Series** - 45A to 50D TPV Products
- HF Grades preferred for cost & appearance improvement
- FDA compliant grades available in non-HF only

**Permaprene™ 2840 B Series** – 55A to 90A TPV VA/VE Option
- Higher Gravity, Lower temp, good extrusion, smoother feel

#### Attributes
- Broad temp range
- Improved chem resistance
- Easily Colorable
- Broad Cost Spectrum
- Great RT Compression Set

#### 2899 X Design Flexibility
- Targeted Viscosity
- Targeted Properties
- Improved UV (good to great)
- Application Tailoring
- Splitting the Difference
- Haptics (Touchy-Feely)

### NYLABOND™

#### Nylabond™ 6091 Series: Nylon Bondable TPVs
- Formulated specifically for melt bonding to Nylon 6 and 6/6
- Available in durometer levels of 55A to 85A
- TPV based product based on Santoprene® technology
- Market leading technology, unequalled property set
- Significant value in automotive – temp & chem resistance

#### Automotive Specifications
- GMW 15817 Type 1
- GMW 15817 Type 2
- MSAR 100 AAN
- MSAR 100 BAN
- MSAR 100 CAN
- VW 50123 Conformance
- Daimler DBL5562-30 Conformance
- SAE J200 callouts
- ASTM D4000 callouts

#### COMPETITION
- Tekbond 1158A, 1372A [Teknor Apex]
- Versaflex OM-6059, OM-6200 [GLS]
- Thermolast K CO PA, CO NY [Kraiburg]
- Starbond [Star Polymers]

### POLABOND™

#### Polabond 6042 Series: ABS, PC, and PC/ABS Bondable SEBS Alloys
- Excellent Bonding due to unique technology
- Great grip and feel, very durable
- Good aging properties relative to competitors
- Excellent processability and aesthetics
- Specialty versions available for unique applications

#### Polabond 6041 Series: 55A and 70A TPV based
- Excellent Bonding to PC, ABS, PMMA, RTPU
- Premium polar bonding product
- Excellent chemical resistance at high temps
- Superior weatherability

#### COMPETITION
- Various Tekbond Products [Teknor-Apex]
- Versaflex OM-3060, OM-1000 series [GLS]
- Thermaflex AD1 Grades [Kraiburg]
- Starbond [Star Polymers]

### ADDITIVE INCORPORATION

#### RTP’s Bread & Butter, Applied to TPE
- Strong Market Leadership
- Leverage Expertise and Resources
- Deliver Unique Solutions & Functionality

#### Color
- Precolor Anything
- Conductive Anything
- Structural Anything
- Wear Anything
- FR Anything

#### Conductive
- CoF modified TPEs
- FR TPEs

#### Structural
- Glass RTPU
- ATEX Bondables

#### Wear
- Wear TPU / COPE
- Density modified

#### FR
- 2-Shot
- ATP

#### Side Benefit - Uniquely Experienced with all TPE chemistries
- Technical acumen to create custom formulations and alloys
- Culture of customer co-development – create what you NEED
WHAT TO TAKE AWAY FROM TODAY

**Styreflex™ - SBCs**
- Common stand-alone TPE; 20A to 90A hardness
- 2700S – higher cost, lower gravity, translucent
- Bonds to PP; Custom tailoring possible
- Temp limited ~100°C

**Permaprene™ - TPV Alloys**
- 2800B-xx HF - TPV offset in most non-auto applications
- 45A to 50D hardness, can be FDA
- 2640B -xx - VA/VE where TPV over-engineered
- Good Chemical resistance, smooth feel, extrusion

**Nylabond™**
- 6091 – TPV based PA bonding, lots of auto approvals
- 6092 – in development, targeting Powertool market
- 6041 – TPV based Polar bondable, high performance
- 6042-xx HF – Cost effective, excellent bonding

**Specialty**
- Elastomeric + Any RTP core competency
- Conducive to “typical” RTP sales process

APPLICATION GUIDELINES

- What is the operating temperature range for my application?
- What chemical and/or environmental exposures might there be?
- What are the key performance requirements for the application (beyond just shore hardness)?