PLASTIC PARTS FAILURE ANALYSIS & PRODUCT LIABILITY PREVENTION

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CONSULTEK
Topics

- Plastics Part Failures – Overview
- Four Key reasons behind part failures
- Types of Failures
- Analyzing Failures – Steps and Tools
- Case Studies
- Failure Analysis Checklist
- Concurrent Engineering Practices
- Product Liability & Prevention
- Q & A
Why do parts fail?

Plastics

vs.

Metal and other traditional materials
Plastics are viscoelastic.

Viscoelasticity: The tendency of plastics to respond to stress as if they were a combination of elastic solids and viscous fluids.

Viscoelastic behavior of plastics makes them sensitive to strain rate as well as temperature.
**Plastic is not Metal**

- **Designing Metal parts**

  Metals usually display largely unchanged mechanical behavior right up to the vicinity of their recrystallization temperature (> 300°C).

  For most applications – Designers can disregard effect of temperature, environment and long term effect of load. Rely on instantaneous stress-strain properties.

- **Designing Plastics Parts**

  Properties vary considerably under the influence of temperature, load, environment, and presence of chemicals.
• Synergistic effect – Most often overlooked
• Material Selection Challenge
  50 Primary Types
  500 Suppliers
  50,000 Grades
• Processing Nightmares
equipment/Tooling/personnel
• End-user education
• Concurrent Engineering
Figure 3.4. “Parallel” or “Concurrent Engineering” approaches to product design reduce development time, improves quality, and minimizes the potential for unanticipated production or performance problems.
Four Key factors

1. Material Selection
2. Design
3. Process
4. Service Conditions
Material Selection Challenge

• Large Data base ....... 50 major types – 500 suppliers – 50,000 Grades
• Standardization issues .... Tests, test specimen, testing organizations
• Difficulty in comparing data on equal basis
• Lack of multipoint measurement data
• Overzealous sales and marketing efforts
• Limited educational material availability
Material Selection

Material Selection Pitfalls

- Datasheet interpretation
- Synergistic effects
- Economics
- Supplier Recommendations
- Application checklist
Material Supplier Data Sheets

- Material supplier data sheet - purpose
- Origination of data sheets
- Meaning of reported values
- How are the values generated
- Interpretation of the data
- Application of the data for practical use
## Typical data sheet

### Table 2. Typical Properties of Delrin

#### Standard Delrin Products

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM</th>
<th>ISO</th>
<th>Unit</th>
<th>100</th>
<th>500</th>
<th>1000</th>
<th>1750</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Elongation at Break</td>
<td>D638</td>
<td>R527</td>
<td>%</td>
<td>30</td>
<td>15</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>-55°C</td>
<td></td>
<td></td>
<td></td>
<td>75</td>
<td>43</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td>-20°C</td>
<td></td>
<td></td>
<td></td>
<td>220</td>
<td>120</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>-10°C</td>
<td></td>
<td></td>
<td></td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>&gt;250</td>
</tr>
<tr>
<td>-2°C</td>
<td></td>
<td></td>
<td></td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>&gt;250</td>
</tr>
<tr>
<td>Shear Strength @ 22°C</td>
<td>D732</td>
<td></td>
<td>MPa</td>
<td>66</td>
<td>66</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Flexural Yield Strength (1.3 mm/min)</td>
<td>D790</td>
<td></td>
<td>MPa</td>
<td>92</td>
<td>97</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td></td>
<td></td>
<td></td>
<td>0.36</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Tensile Modulus (1.3 mm/min)</td>
<td>D628</td>
<td>R527</td>
<td>MPa</td>
<td>2800</td>
<td>7100</td>
<td>3100</td>
<td>3100</td>
</tr>
<tr>
<td>Flexural Modulus (1.3 mm/min)</td>
<td>D790</td>
<td></td>
<td>MPa</td>
<td>3000</td>
<td>4300</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td>Compressive Stress (1.3 mm/min)</td>
<td>D659</td>
<td></td>
<td>MPa</td>
<td>31</td>
<td>34</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Deformation under Load</td>
<td>D621</td>
<td></td>
<td>%</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Flexural Fatigue Endurance Limit</td>
<td>D671</td>
<td></td>
<td>MPa</td>
<td>32</td>
<td>31</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Tensile Impact Strength (22°C)</td>
<td>D302</td>
<td></td>
<td>kJ/m²</td>
<td>258</td>
<td>292</td>
<td>147</td>
<td>213</td>
</tr>
<tr>
<td>Impact (notched)</td>
<td>D326</td>
<td>R180</td>
<td>J/m²</td>
<td>96</td>
<td>64</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Impact (unnotched)</td>
<td>D250</td>
<td>R180</td>
<td>J/m²</td>
<td>65</td>
<td>70</td>
<td>58</td>
<td>58</td>
</tr>
</tbody>
</table>

1. Values listed are only to be used on a comparative basis between melt flow rates. Correlates, additives, and dies may affect rates in all but at all of these properties. Contact DuPont for specific data sheets.

### Notes:

- Values listed are only to be used on a comparative basis between melt flow rates. Correlates, additives, and dies may affect rates in all but at all of these properties. Contact DuPont for specific data sheets.

- All values reported in this table are based on ASTM methods. ISO methods may produce different test results due to differences in test methods used by different manufacturers. Contact DuPont for specific data sheets.

- Values for specific properties were determined at 0.7 kV/cm.
Typical Data Sheet

Product Data

R-5000, R-5100 NT15, R-5500

RADEL® R polyphenylsulfone resins offer exceptional hydrolytic stability, and toughness superior to other commercially-available, high-temperature engineering resins. They offer high deflection temperatures and outstanding resistance to environmental stress cracking. The polymer is inherently flame retardant, and also has excellent thermal stability and good electrical properties.

RADEL R resins are available as an opaque general purpose injection molding grade—R-5100 NT15, a transparent injection molding grade—R-5000, and a transparent extrusion grade—R-5500.

Typical Properties of RADEL R-5000, R-5100 NT15, and R-5500 Resins

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Test Method</th>
<th>U.S. Customary Units</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>D 638</td>
<td>10.1 kpsi</td>
<td>70 MPa</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>D 568</td>
<td>340 kpsi</td>
<td>2.3 GPa</td>
</tr>
<tr>
<td>Tensile Exogation at yield</td>
<td>D 638</td>
<td>1.2 %</td>
<td>1.2 %</td>
</tr>
<tr>
<td>Tensile Exogation at break</td>
<td>D 638</td>
<td>60-120 %</td>
<td>60-120 %</td>
</tr>
<tr>
<td>Flexural Strength(3)</td>
<td>D 790</td>
<td>13.2 kpsi</td>
<td>91 MPa</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>D 790</td>
<td>350 kpsi</td>
<td>2.4 GPa</td>
</tr>
<tr>
<td>Tensile Impact Strength</td>
<td>D 1822</td>
<td>190 ft-lb/in²</td>
<td>400 kJ/m²</td>
</tr>
<tr>
<td>Izod Impact, Notched</td>
<td>D 256</td>
<td>1.3 ft-lb/in</td>
<td>690 J/m</td>
</tr>
<tr>
<td>Deflection Temperature at 254°F</td>
<td>D 648</td>
<td>405 °F</td>
<td>207 °C</td>
</tr>
<tr>
<td>Flammability Rating(4)</td>
<td>UL-94 V-0</td>
<td>0.030 in</td>
<td>0.75 mm</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>D 696</td>
<td>31 ppm/°F</td>
<td>56 ppm/°C</td>
</tr>
<tr>
<td>Glass Transition Temperature</td>
<td>D 648</td>
<td>428 °F</td>
<td>220 °C</td>
</tr>
<tr>
<td>Dielectric Strength at 0.125 in</td>
<td>D 149</td>
<td>380 V/mil</td>
<td>15 kV/mm</td>
</tr>
<tr>
<td>Dielectric Strength at 0.001 in</td>
<td>D 150</td>
<td>&gt;6,000 V/mil</td>
<td>&gt;200 kV/mm</td>
</tr>
<tr>
<td>Dielectric Constant at 60 Hz</td>
<td>D 257</td>
<td>3.44</td>
<td>3.44</td>
</tr>
<tr>
<td>Volume Resistivity</td>
<td>D 257</td>
<td>9 x 10¹⁵ ohm-cm</td>
<td>9 x 10¹⁵ ohm-cm</td>
</tr>
</tbody>
</table>
| Steam Sterilization (5) w/Morpholine, cycles passed without cracking, crazing, or rupture | >1000 cycles | >1000 cycles |}

Chemical

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Absorption at 24 hours</td>
<td>0.37</td>
<td>%</td>
</tr>
<tr>
<td>Water Absorption at Equilibrium</td>
<td>1.10</td>
<td>%</td>
</tr>
</tbody>
</table>

General and Fabrication

<table>
<thead>
<tr>
<th>Property</th>
<th>R-5000</th>
<th>R-5100 NT15</th>
<th>R-5500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.29</td>
<td>1.30</td>
<td>1.29</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>1.672</td>
<td>opaque</td>
<td>1.672</td>
</tr>
<tr>
<td>Melt Flow at 699°F (365°C), 5.0 kg, g/10 min</td>
<td>17</td>
<td>17</td>
<td>11.5</td>
</tr>
<tr>
<td>Mold Shrinkage, %</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

(1) Actual properties of individual batches will vary within specified limits. Unless otherwise specified, properties were measured using one-eighth inch (0.2 mm) thick injection molded specimens.

(2) These flammability ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions.

(3) Measured by differential scanning calorimetry at a heating rate of 39°F (20°C) per minute.

(4) Steam Autoclave Conditions: Temperature - 270°F (132°C); Time - 50 minutes/cycle; Steam Pressure - 27 psig (1.9 MPa); Steaming Level - 100 psi (0.7 MPa); Steam Flow - 250 lbs/hr (113 kg/hr); Mold Temperature - 540°F (282°C); Mold Pressure - 150 lbs/in² (1 MPa); Mold Dimensions - 6 x 6 x 3 inches (15 x 15 x 7.5 cm); Mold Design - Flat Plate; Mold Material - Aluminum; Mold Coating - PTFE.

(5) at 5% strain
**Typical Data Sheet**

**General Purpose Polystyrene Resins**

**Properties**
- High heat resistance
- Excellent clarity
- Good moldability
- FDA compliance

**Process**
- Injection molding
- Extrusion
- Blow molding

<table>
<thead>
<tr>
<th>Properties</th>
<th>ASTM Method</th>
<th>Compression Molded</th>
<th>Injection Molded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Tensile Strength, psi</td>
<td>D 638</td>
<td>6200</td>
<td>7900</td>
</tr>
<tr>
<td>kgt/cm²</td>
<td></td>
<td>435</td>
<td>555</td>
</tr>
<tr>
<td>Ultimate Tensile Strength, psi</td>
<td>D 638</td>
<td>6200</td>
<td>7900</td>
</tr>
<tr>
<td>kgt/cm²</td>
<td></td>
<td>435</td>
<td>555</td>
</tr>
<tr>
<td>Yield Elongation, %</td>
<td>D 638</td>
<td>1.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Ultimate Elongation, %</td>
<td>D 638</td>
<td>1.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Tensile Modulus, psi</td>
<td>D 638</td>
<td>470,000</td>
<td>485,000</td>
</tr>
<tr>
<td>kgt/cm²</td>
<td></td>
<td>33,000</td>
<td>34,000</td>
</tr>
<tr>
<td>Izod Impact Strength, ft-lb/in</td>
<td>D 256</td>
<td>0.25</td>
<td>0.45</td>
</tr>
<tr>
<td>at a 23°C</td>
<td>D 785</td>
<td>1.3</td>
<td>2.4</td>
</tr>
<tr>
<td>cm kgf/cm of notch, 73°F</td>
<td></td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td>Hardness, Rockwell M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deflection Temperature Annotated</td>
<td>D 648</td>
<td>214</td>
<td>212</td>
</tr>
<tr>
<td>&quot;F&quot; at 264 psi</td>
<td></td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>&quot;C&quot; at 18.6 kgt/cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vicat Softening Point, °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melt Flow Rate, g/10 min</td>
<td>D 1525 (Rate B)</td>
<td>224</td>
<td>197</td>
</tr>
<tr>
<td>(Cond. 0)</td>
<td></td>
<td>1238</td>
<td>1238</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>D 752</td>
<td>2.4</td>
<td>1.04</td>
</tr>
</tbody>
</table>

*These are typical property values, intended only as guides, and should not be construed as sales specifications. Measured in ft-lb/in of notch at 73°F on compression molded samples.

**Handling Considerations, see reverse side**

---

**Dow Chemical U.S.A. • Olefins and Styrenics, Plastics Department • Midland, MI 48641**

*Trademark of The Dow Chemical Company*
Purpose of a data Sheet

• Compare property values of different plastics materials (Tensile strength of nylon vs. Polystyrene, Impact strength of ABS vs. Polycarbonate)
• Quality control guidelines for material manufacturers
• Purchasing/Material specifications
• Initial screening of various materials
Data Sheets Are **NOT** Meant to Be Used for

- Engineering design
- Final(ultimate) material selection

**Why?**

- Reported data generally derived from short term tests
- Usually from single point measurement
- Laboratory conditions
- Standard test bars
- Values are generally higher and do not correlate with actual use conditions
<table>
<thead>
<tr>
<th>Material</th>
<th>HDT</th>
<th>Continuous Use Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ryton R-4 (Polyphenylene Sulfide)</td>
<td>&gt;500 °F</td>
<td>338 °F</td>
</tr>
<tr>
<td>Ultem 4000 (Polyetherimide)</td>
<td>412 °F</td>
<td>122 °F</td>
</tr>
<tr>
<td>Delrin 100AL</td>
<td>325 °F</td>
<td>122 °F</td>
</tr>
</tbody>
</table>
HDT (DTUL) TEST
HDT Test
## Continuous use Temperature

UL’s relative Thermal Index based upon historical records

<table>
<thead>
<tr>
<th>Material</th>
<th>Generic Thermal Index °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon (type 6, 6/6, 6/10, 11)</td>
<td>65</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>80</td>
</tr>
<tr>
<td>Phenolic</td>
<td>150</td>
</tr>
<tr>
<td>PTFE</td>
<td>180</td>
</tr>
<tr>
<td>RTV Silicone</td>
<td>105</td>
</tr>
<tr>
<td>PET Film</td>
<td>105</td>
</tr>
</tbody>
</table>
Failure resulting from Selecting incorrect material from short term thermal test data

Figure 6-8 IPS salad bowls deformed and cracked due to washing in dishwasher
Material Selection Process

- Define requirements
- Narrow down choices...process of elimination...clear vs. opaque
- Rigid, flexible, elastomeric?
- Specific application? Medical?
- Material selection guidelines
- Specific property requirement...
Material Selection Process

- **Identify application requirements**
  Mechanical (Load, Stiffness, Impact etc.)
  Thermal (temperature range, Maximum use temperature, etc)
  Environmental considerations (Weather, UV, Moisture)

- **Identify the chemical environment**
  Define the chemical stress, temperature, contact time, type of chemical

- **Identify special needs**
  Regulatory (UL, FDA, NSF, etc.)
  Outdoor or UV exposure
  Light transmission, Fatigue and creep requirements

- **Define Economics**

- **Define Processing Considerations**
  Type of Process (Injection Molding, Extrusion, Blow Molding, Thermoforming, etc.)

- **Define Assembly requirements**
  Painting/Plating
  Shielding

- **Search history for similar commercial applications**
Identifying Application Requirements

- **Physical Properties**
  - Specific Gravity
  - Mold Shrinkage
  - Rheology

- **Mechanical Properties**
  - Tensile Strength
  - Tensile Modulus (Stiffness-Resistance to bending)
  - Tensile Elongation/Ductility
  - Impact strength
  - Fatigue Endurance (Resistance to high frequency cyclic loading)
  - Creep resistance (Resistance to long-term deformation under load)

- **Thermal Properties**
  - Deflection Temperature Under Load (DTUL,HDT)
  - Thermal Conductivity
  - Thermal expansion coefficient (Problems in Piping systems, Example Expansion Joints)
  - Continuous Use Temperature (Relative thermal Index)

- **Regulatory Performance**
  - Flammability (UL 94)
  - High Voltage Arc Tracking
  - FDA

Source: GE Plastics
• Environmental Considerations

    Exposure to UV, IR, X-Ray
    High humidity
    Weather Extremes
    Pollution: Industrial chemicals
    Microorganisms, bacteria, fungus, mold

    The combined effect of the factors may be much more severe than any single factor, and the degradation processes are accelerated many times.

    Published test results do not include synergistic effects…always existent in real-life situations.
Identifying Application requirements (Cont.)

- Chemical Behavior/Chemical resistance

Resistance of Thermoplastics to various chemicals is dependent on:

- Time (of contact with chemical)
- Temperature
- Stress (Molded-in or External)
- Concentration of the chemical

- Chemical Exposure may result in:

- Physical Degradation - Stress cracking, Crazing, Softening, Swelling, Discoloration
- Chemical Attack – Reaction of chemical with polymer and loss of properties
Chemical Exposure
<table>
<thead>
<tr>
<th>Property</th>
<th>Thermoplastics</th>
<th>Thermosets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low temperature</td>
<td>TFE</td>
<td>DAP</td>
</tr>
<tr>
<td>Low cost</td>
<td>PP, PE, PVC, PS</td>
<td>phenolic</td>
</tr>
<tr>
<td>Low gravity</td>
<td>polypropylene methylpentene</td>
<td>phenolic/nylon</td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>phenoxy glass</td>
<td>epoxy-glass</td>
</tr>
<tr>
<td>Volume resistivity</td>
<td>TFE</td>
<td>DAP</td>
</tr>
<tr>
<td>Dielectric strength</td>
<td>PVC</td>
<td>DAP, polyester</td>
</tr>
<tr>
<td>Elasticity</td>
<td>EVA, PVC, TPR</td>
<td>silicone</td>
</tr>
<tr>
<td>Moisture absorption</td>
<td>chlorotrifluoroethylene</td>
<td>alkyd-glass</td>
</tr>
<tr>
<td>Steam resistance</td>
<td>polysulfone</td>
<td>DAP</td>
</tr>
<tr>
<td>Flame resistance</td>
<td>TFE, P1</td>
<td>melamine</td>
</tr>
<tr>
<td>Water immersion</td>
<td>chlorinated polyether</td>
<td>all</td>
</tr>
<tr>
<td>Stress craze resistance</td>
<td>polypropylene</td>
<td>silicones</td>
</tr>
<tr>
<td>High temperature</td>
<td>TFE, PPS, P1, PAS</td>
<td>phenolic</td>
</tr>
<tr>
<td>Gasoline resistance</td>
<td>acetal</td>
<td>epoxy-glass</td>
</tr>
<tr>
<td>Impact</td>
<td>UHMW PE</td>
<td>melamine-glass</td>
</tr>
<tr>
<td>Cold flow</td>
<td>polysulfone</td>
<td>epoxy</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>TFE, FEP, PE, PP</td>
<td>allyl diglycol carbonate</td>
</tr>
<tr>
<td>Scratch resistance</td>
<td>acrylic</td>
<td>phenolic-canvas</td>
</tr>
<tr>
<td>Abrasive wear</td>
<td>polyurethane</td>
<td>urea, melamine</td>
</tr>
<tr>
<td>Colors</td>
<td>acetate, PS</td>
<td></td>
</tr>
</tbody>
</table>
Material selection using multi-point data

- Data sheets with single point measurement readily available
- Data sheets with multi point data - ask supplier

Multi-point data

- Isochronous stress-strain curves
- Multi point (Load-energy-time) Impact data
- Multi point thermal data

![Isochronous Stress/Strain Curves at 160°C (320°F)](image)
New Application Checklist

This checklist includes critical considerations for new part development. Its use will help provide a more rapid and more accurate recommendation.

Name ___________________________ Date ___________________________

Customer: ___________________________ Part: ___________________________

Project timing: ___________________________ Design force: ___________________________

Current product: ___________________________ Use performance: ___________________________

Comments: ___________________________

Part Function — What is the part supposed to do?

______________________________

Appearance

Clear

☐ water clear
☐ very clear
☐ generally clear, maximum haze level: ____________
☐ transparent color, maximum haze level: ____________

Comments: ___________________________

Opaque

☐ high gloss
☐ medium gloss
☐ low gloss

☐ from the plastic
☐ from paint
☐ from the mold

Comments: ___________________________

Colors desired:

☐ from the plastic
☐ from paint
☐ from both

Criticality of color match: ____________ %

☐ daylight
☐ transverse light
☐ fluorescent light
☐ all (no metamersism allowed)

Comments: ___________________________

Critical appearance areas — please attach sketch

Gate blemishes: ☐ None ☐ Invisible ☐ Minor ☐ OK

Sheet marks: ☐ None ☐ Invisible ☐ Minor ☐ OK

Cold lines: ☐ None ☐ Invisible ☐ Minor ☐ OK

Comments: ___________________________

Critical structural areas — please attach sketch

Comments: ___________________________

Monsanto Plastics
Where the best end products begin.
### Required Physical Characteristics — Please attach sketch

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>not too important</th>
<th>from plastic</th>
<th>from design</th>
<th>from both</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength (load bearing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creep resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Details:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied load/stress</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency (if cyclic)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating lifetime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comments:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Impact resistance              |                  |              |             |           |
| Room temp.                     | acceptable        | min.         |             |           |
| Low temp. °C/F                 | acceptable        | min.         |             |           |
| Comments:                       |                  |              |             |           |

| Dimensional tolerances         |                  |              |             |           |
| Deflection (under stress)      | acceptable        | max.         |             |           |
| Expansion (thermal)            | acceptable        | max.         |             |           |
| Shrinkage (mold)               | acceptable        | max.         |             |           |
| Creep                          | acceptable        | max.         |             |           |
| Comments:                       |                  |              |             |           |

| Electrical Properties          |                  |              |             |           |
| Dielectric constant            | acceptable        | min.         |             |           |
| Dissipation factor             | acceptable        | max.         |             |           |
| Volume resistivity             | acceptable        | min.         |             |           |
| Dielectric strength            | acceptable        | min.         |             |           |
| Comments:                       |                  |              |             |           |

| Chemical resistance            |                  |              |             |           |
| (List chemicals, frequency & duration of exposure, part stress/strain level, and type of resistance required.) | | | | |
| Comments:                       |                  |              |             |           |

| Permanence                     |                  |              |             |           |
| Color stability, indoor        |                  |              |             |           |
| Color stability, outdoor       |                  |              |             |           |
| Property retention, outdoor    |                  |              |             |           |
| Comments:                       |                  |              |             |           |

**Required Physical Characteristics — Continued**

**Miscellaneous**

- Rockwell hardness
  - Target: _____________
  - Min.: _____________
  - Max.: _____________

- Others:
  - __________________________________________
  - __________________________________________
Regulatory Approvals Required?

☐ Underwriters Laboratory, Inc.
  ☐ U.L. 94
  ☐ RTI
  ☐ Electrical ___ °C
  ☐ Mechanical ___ °C
  ☐ Thickness ___ °C

☐ National Sanitation Foundation
  ☐ Type

☐ Federal Specifications (Mil. Specs.)
  ☐ Type

☐ Canadian Standards Administration
  ☐ Type

☐ Food and Drug Association
  ☐ Type

☐ U.S. Pharmacopeia
  ☐ Type

☐ Automotive Specifications
  ☐ Type

☐ Other:
  ☐ Type

Comments:

__________________________________________________________________________

Process

☐ Extrusion
  ☐ Profile extrusion
  ☐ Sheet extrusion — monolayer
  ☐ Sheet extrusion — co-extruded
  ☐ Thermoforming
  ☐ Extrusion/blow molding

Comments:

__________________________________________________________________________

☐ Injection Molding

Comments:

__________________________________________________________________________

☐ Secondary Operations
  ☐ Decorating
    ☐ Painting
    ☐ Plating
    ☐ Hot stamping
    ☐ Laminating
  ☐ Assembly
    ☐ Gluing
    ☐ Sonar welding
    ☐ Vibrational welding
    ☐ Mechanical assembly

Comments (What is attached to what, difference in types of plastic, etc.?)

__________________________________________________________________________

Customer Part Testing Requirements

__________________________________________________________________________

Final Comments

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
Why Reinvent the Wheel?

Search history for similar commercial applications
## Material Selection

### Previous Applications

Before addressing a detailed material selection process, it is often worthwhile to determine if a similar part has been made before, and if so, from which material it was made. If such an application exists, it may be advisable to conduct further investigation into the specifics of the particular application to see whether newer or more appropriate materials can now be used.

Since it is impossible to list all applications—some grades are used for a multitude of parts in many industries—a relatively limited number has been listed.

This Application Matrix provides an overview of some typical applications in some of the numerous market segments served by GE Plastics.

For further information on a particular grade, please contact your local GE Plastics’ representative.

---

<table>
<thead>
<tr>
<th>Products</th>
<th>Automotive Interior</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYCOLAC ABS Resin</td>
<td>Instrument clusters; glove box lids; pillar trim; vents; speaker grilles; elbow trim; pedals; seat covers and knobs; steering wheel covers; interior trims; doors, covering</td>
</tr>
<tr>
<td>CYCOLYD PC/ABS Resin</td>
<td>Dashboard components and interior, center consoles; glove box lids; pillar trim; vents; grilles; armrests; sunroof frames; parcel shelves</td>
</tr>
<tr>
<td>ENBURAN PBT Resin</td>
<td>Dashboard and door panels</td>
</tr>
<tr>
<td>GELOY ASA Resin</td>
<td>Seat belts; boot panels; speaker grilles; dashboard components; instrument panels and switches; center consoles; hound covers; instrumentation levers</td>
</tr>
<tr>
<td>GESAN SAN Resin</td>
<td>DASHBOARD components; instrument clusters; center consoles; armrests; seat covers; sunroof panels; armrests; a rearview mirror; front; parts; a car stereo; rear view mirrors; armrests; hound covers; sunroofs; armrests; door panels; seats; a car radio</td>
</tr>
<tr>
<td>Products</td>
<td>Appliances</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CYCOLAC ABS Resin</td>
<td>Bathrooms and kitchen appliances; vacuum cleaners; injection moldable plastic</td>
</tr>
<tr>
<td>CYCOLOY PC/ABS Resin</td>
<td>Coffee makers, blenders, irons, steamer irons, coffee kettles, rice cookers, tea kettles,</td>
</tr>
<tr>
<td>ENDURAN PBT Resin</td>
<td>Small appliances: toaster, coffee maker, toaster, oven, refrigerator, dishwasher</td>
</tr>
<tr>
<td>GELoy ASA Resin</td>
<td>Glass products; small kitchen appliances; small appliances; small appliances;</td>
</tr>
<tr>
<td>GESAN SAN Resin</td>
<td>Small appliances: toaster, coffee maker, toaster, oven, refrigerator, dishwasher</td>
</tr>
<tr>
<td>LEXAN PC Resin</td>
<td>Structural components; small appliances; small appliances; small appliances;</td>
</tr>
<tr>
<td>NORYL Modified PPO Resin</td>
<td>Vending machines; coffee machines; filter system; compactors; small appliances;</td>
</tr>
<tr>
<td>NORYL GTK PPE/PA Resin</td>
<td>Laundry washers and dryers; small appliances; small appliances; small appliances;</td>
</tr>
<tr>
<td>SUPERC PPS Resin</td>
<td>Hot water, heating systems, small appliances; small appliances; small appliances;</td>
</tr>
<tr>
<td>ULTEM PEI Resin</td>
<td>Small appliances; small appliances; small appliances; small appliances; small appliances;</td>
</tr>
<tr>
<td>VALOX PBT Resin</td>
<td>Various housings such as small appliances; small appliances; small appliances;</td>
</tr>
<tr>
<td>XENOY PC/PBT Resin</td>
<td>Small appliances; small appliances; small appliances; small appliances; small appliances;</td>
</tr>
</tbody>
</table>

1:18 • Material Selection
Material Selection using Web

- Matweb  [www.matweb.com](http://www.matweb.com)  
  MatWeb, Your Source for Materials Information

- Ides  [www.ides.com](http://www.ides.com)  
  The Plastics Industry at Your Fingertips!

- Plaspec  [www.plaspec.com](http://www.plaspec.com)
Failure resulting from improper material selection

Figure 4.25: Impact polystyrene ballpoint pen barrel that cracked first or second time pen was used
Designing Plastics Parts

• With exception of few basic rules in designing plastic parts, the design criteria changes from material to material & application to application

• Challenge: Economics, functionality, manufacturability and aesthetics

• Compromise & trade offs lead to failures

• Systematic approach to developing new product
Most Common Mistakes in Design of Plastics

- Non-uniform wall thickness
- Sharp corners, lack of radius
- Draft angle considerations
- Thread design
- Lack of Creep considerations
- Lack of Environmental considerations
- Direct conversion from other materials
Wall Thickness

Basic Rules

• Nominal Wall thickness - 0.250 or less
• Transition must be less than +/- 25% nominal wall thickness, gradual transition is the best
• Draft greater than 1 degree preferred
• Draft for textured parts +/- 1 degree for every 0.001 inch of textured depth

Wall thickness variations greater than 25% will exhibit high levels of molded-in stress, resulting in sinks, voids, and distortion.

(a) (b)

Figure 2-1 Distortion due to nonuniform cooling: (a) part as drawn and (b) part as molded

How does wall thickness variations affect material flow in the mold?

Higher the shrinkage, Greater the warp
Wall thickness related failures

Figure 4-13 A. Acetal valve body design problem—photograph of interior ([1] Fig. 1, reproduced with permission). B. Diagram showing voids in acetal valve of Fig. 4-13A ([1] Fig. 2, reproduced with permission). C. Diagram showing improved design of acetal valve ([1] Fig. 3, reproduced with permission)
THE DIVINE 66% RULE

The thickness of ribs should never exceed 66% of the nominal wall thickness.

If your ribs never exceed 50-66% of nominal wall thickness you will never have a problem with sink.
Radii

Rules:

- Avoid sharp corners at all costs
- Radii for inside corners: 50% nominal wall thickness  \( R_1 = \frac{W}{2} \)
- Radii for outside corners: 150% nominal wall thickness  \( R_2 = 1.5W \) or  \( R_2 = R_1 + W \)
Radii
Threads

- Threads must have radii....no flat or "V" notched at root and crest
- Pitch should be less than 1/32 in.
- Lead depth must be greater than 1/32 in.

**MOLDED-IN THREADS**

- **AVOID**
  - 1/32" Lead-In
- **PREFER**
  - 1/32" Lead-In

**Thread Profiles**

- American National (Unified)
- Acme
- Buttress

Designing with Clearance on Threads

<table>
<thead>
<tr>
<th>WRONG</th>
<th>RIGHT</th>
<th>WRONG</th>
<th>RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Thread Example" /></td>
<td><img src="image2.png" alt="Thread Example" /></td>
<td><img src="image3.png" alt="Thread Example" /></td>
<td><img src="image4.png" alt="Thread Example" /></td>
</tr>
</tbody>
</table>

Common thread profiles used in plastic parts.
Threads

Figure 2-36

Pipe Threads

Not Recommended

Tapered threads create large hoop stress.

Bulge

Metal or Plastic Pipe

NPT

L

Bulge

Plastic Fitting

Recommended

Plastic Pipe

NPT

Metal Fitting

Plastic Pipe

Straight Thread

“O”-Ring Compression Seal

Plastic Fitting

Standard NPT tapered pipe threads can cause excessive hoop stresses in the plastic fitting.
Identifying Application Requirements (cont.)

• Environmental Considerations

Exposure to UV, IR, X-Ray
High humidity
Weather Extremes
Pollution: Industrial chemicals
Microorganisms, bacteria, fungus, mold

The combined effect of the factors may be much more severe than any single factor, and the degradation processes are accelerated many times.

Published test results do not include synergistic effects...always existent in real-life situations.
Steps for Robust Part Design Process

Part Design → Material Selection → Structural Analysis

Mold Flow Analysis → Rapid Prototype → Design Review I

Single Cavity Prototype → Design Review II Tolerance Analysis → Tooling Protocol Mold Cooling Analysis

Mold Construction Phase → Mold Sampling/Pilot Run DOE/CPK Study Establish Process Parameters → Final Part Evaluation & Acceptance
Most Common Process Induced Failures

- Drying of material
- Cold or overheated material
- Under or Over Packing
- Improper additive/ regrind mixing and utilization
Materials Drying

Why do we need to dry Plastics Materials?
All Plastics, when exposed to atmosphere, will pick up moisture to a certain degree depending upon the humidity and type of the polymer.

<table>
<thead>
<tr>
<th>Hygroscopic</th>
<th>Non Hygroscopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymers with high affinity for moisture</td>
<td>Polymers with very little or no affinity for moisture</td>
</tr>
<tr>
<td>Moisture is absorbed into the pellet over time until equilibrium is reached</td>
<td>No absorption of moisture into the pellet. May pick up surface moisture.</td>
</tr>
<tr>
<td>Nylon, ABS</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>Polyester</td>
<td>PVC, Polypropylene</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>Acetal</td>
</tr>
<tr>
<td>Desiccant Dryer</td>
<td>Hot Air Dryer</td>
</tr>
</tbody>
</table>

- Hygroscopic Pellet
- Moisture is absorbed into the Pellet
- Non-Hygroscopic Pellet
- Surface Moisture
Is Your Material Dry?

Dry air vs. Dry Material

Checks the efficiency of the dryer

Checks Material dryness
What is important….Barrel temperature or Melt temperature?

Optimum **MELT TEMPERATURE** is the key to successful molding

Factors affecting melt temperature

- Barrel temperature settings
- Screw speed
- Screw back pressure
- Residence time
- Cycle time

Too Cold?

Too Hot?

Cold or Overheated material

EX: PVC
Nozzle

Use as short a nozzle as possible

Nozzle bore diameter as large as possible

Use proper tips
Additives and Regrind

- Loss of properties
- Additives depletion (Antioxidant, Stabilizer)
- Fines
- Inadvertent mixing
- Missing additives

Table 2.3 - Effect of Remolding on the Properties of Fiberglass Reinforced Celcon® Acetal

<table>
<thead>
<tr>
<th>Property</th>
<th>1st Molding</th>
<th>3rd Molding</th>
<th>5th Molding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile yield strength, MPa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>110</td>
<td>92.5</td>
<td>85.6</td>
</tr>
<tr>
<td>percent retention</td>
<td>—</td>
<td>81.7</td>
<td>75.6</td>
</tr>
<tr>
<td>Tensile modulus, MPa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>8,280</td>
<td>7,660</td>
<td>6,970</td>
</tr>
<tr>
<td>percent retention</td>
<td>—</td>
<td>92.6</td>
<td>84.2</td>
</tr>
<tr>
<td>Flexural modulus, MPa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>7,250</td>
<td>6,830</td>
<td>6,350</td>
</tr>
<tr>
<td>percent retention</td>
<td>—</td>
<td>94.1</td>
<td>87.6</td>
</tr>
</tbody>
</table>
PROCESS RELATED FAILURE

Figure 15-4. Shrinkage voids created by insufficient time and pressure to freeze the gate during injection molding process. (Courtesy BASF Corporation.)

Molding defects

Poor mixing
Service Conditions

Failures due to:

- “Reasonable” misuse......Examples
  
  Trash Container, Ladder, Exposure to solvents, Compacts disks in cars

- Use of product beyond its intended lifetime

- Unstable/Unintentional/Unanticipated service condition

- Thermal, Chemical, Environmental, Physical, Biological, Mechanical

- Examples of unintentional service......coffee can lid, cash drawer, one time short service...bags, cups

- Examples of unexpected service......underground animals

- Service conditions beyond reasonable misuse

- Simultaneous application of two stresses operating synergistically

Figure 9-10: PE-coffe can over-used beyond its intended service; a rectangular hole was cut in the container, leading to cracks at the corners (Fig. 1), reproduced with permission.
Service condition related failures

Failure resulting from ignoring installation instructions
Types Of Failures

- Mechanical
- Thermal
- Chemical
- Environmental
Mechanical Failures arise from the applied external forces.

- Brittle Failure
- Ductile Failure
- Fatigue failure
- Creep & Stress relaxation
Brittle & Ductile failures

Brittle Failure

Brittle failures are characterized by a sudden and complete catastrophic failure in which rapid crack propagation is observed without appreciable plastic deformation. Brittle failures, once initiated require no further energy for the crack to propagate.

Ductile failure

Ductile failures are characterized by gradual tearing of the surfaces when applied forces exceed the yield strength of the material. For the crack resulting from the ductile mode of failure, additional energy must be provided to propagate the crack by some type of external loading. Ductile failure is slow and non catastrophic in nature and the failed specimen generally shows gross plastic deformation in terms of stress whitening, jagged and torn surfaces, necking ( reduction in cross sectional area) and some elongation.
IMPACT PROPERTIES

- Impact properties relate to the toughness of the material.
- Toughness is the ability of material to absorb applied energy.
- Impact resistance is the resistance to breakage under shock loading.
- Impact energy is the crack initiation at surface plus crack propagation.

Brittle (no yielding) vs. Ductile failure (definite yielding with cracking).
Notch sensitive plastics (PS, PMMA) are more prone to brittle failure.

Ductile - Brittle Transition Temperature

Figure 2-21: Brittle fracture of poorly fused polyethylene garden hose vs. ductile failure of well fused polyethylene ([24] Fig. 3, reproduced with permission)
Creep & Stress Relaxation

- Creep is a non-reversible deformation of material under load over time. Stress relaxation is gradual decrease in stress with time under a constant deformation.

- Creep failure (Creep rupture) occurs when polymer chains can no longer hold the applied load and stress reaches levels high enough for microcracks to form. In case of stress relaxation, at a constant deformation the movement of the polymer chain reduces the force necessary for a given deformation.
Thermal Failures

High & Low Temperatures (Temperature Extremes)

Thermal Expansion & Contraction

Thermal degradation

Misinterpretation of published data

(HDT vs. Continuous use temp.)

Figure 6-8 IPS salad bowls deformed and cracked due to washing in dishwasher
Chemical Failures

Chemical reactions - Chemical attack

Environmental Stress Cracking - Chemical reaction in presence of stress

Hydrolysis

Chemical compatibility factors*

- Exposure Time
- Temperature
- Chemical Concentration
- Molded-in Stresses
- External Stresses

* Synergistic Effects

Degradation from prolonged contact with Gasoline
Environmental Failures

- UV radiation – Indoor/Outdoor
- Ozone
- Oxidation
- Weather-Temperature extremes
- Acid rain
- Humidity and moisture
- Pollution
- Biological
Analyzing Failures
Failure Analysis Steps & Tools

- 1. Visual examination.
- 2. Identification analysis.
- 4. Heat reversion Technique
- 5. Microstructural analysis (Microtoming).
- 6. Mechanical testing.
- 7. Thermal analysis
- 8. Non Destructive Testing (NDT) techniques
- 9. Fractography
- 10. Simulation testing
Visual Examination

- Magnifying Glass & Good Lighting
- Handling evidence
- Cavity Numbers, compare with good parts
- Gate size and location, Sharp corners, Voids
- Visual defects, burn marks, contamination
- User Abuse, Gouge marks, Cuts
- Sectioning parts
- Surface….Smooth, Jagged, Shiny?
- UV effect
One of the most Common Reasons for product failure is simply the use of wrong material

<table>
<thead>
<tr>
<th>Reasons</th>
<th>Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Type</td>
<td>FTIR</td>
</tr>
<tr>
<td>Grade</td>
<td>Melt Index, DSC</td>
</tr>
<tr>
<td>Re grind</td>
<td>Melt Index</td>
</tr>
<tr>
<td>Material degradation</td>
<td>Melt index, Viscosity tests</td>
</tr>
<tr>
<td>Missing ingredients</td>
<td>Deformation, LC, GCMS, PYMS, NMR</td>
</tr>
<tr>
<td>Unwanted substances</td>
<td>SEM-EDX</td>
</tr>
</tbody>
</table>
Four Most Common Techniques

- FTIR
- DSC
- Ash Content (Burn-off test) or TGA
- Viscosity tests
Plastics Technology Labs was requested to perform Differential Scanning Calorimetry Analysis (DSC) on two samples.

The results of the DSC testing are as follows:

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Peak Tm (°C)</th>
<th>ΔHm (J/g)</th>
<th>Nylon Type by Tm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon Wire Ties - P</td>
<td>266</td>
<td>75.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Nylon Wire Ties - G</td>
<td>265</td>
<td>74.0</td>
<td>6.6</td>
</tr>
</tbody>
</table>

The Tm is the temperature at which a crystalline polymer melts.

ΔHm is the amount of energy a sample absorbs while melting.

Copies of the scans used to determine these results are attached.

If you have any questions, please feel free to call.
**Viscosity**

<table>
<thead>
<tr>
<th>Brookfield Viscosity (cP)</th>
<th>Relative Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P</strong></td>
<td></td>
</tr>
<tr>
<td>54.5</td>
<td>43.1</td>
</tr>
<tr>
<td>54.6</td>
<td>43.1</td>
</tr>
<tr>
<td>54.6</td>
<td>43.1</td>
</tr>
<tr>
<td>54.6</td>
<td>43.1</td>
</tr>
<tr>
<td>54.6</td>
<td>43.1</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>43.1</strong></td>
</tr>
<tr>
<td><strong>G</strong></td>
<td></td>
</tr>
<tr>
<td>71.0</td>
<td>47.4</td>
</tr>
<tr>
<td>71.0</td>
<td>47.4</td>
</tr>
<tr>
<td>71.8</td>
<td>47.0</td>
</tr>
<tr>
<td>71.0</td>
<td>47.4</td>
</tr>
<tr>
<td>71.6</td>
<td>47.8</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>47.6</strong></td>
</tr>
</tbody>
</table>

P = Poor (Bad Lot)
G = Good Lot
Standard RV = 47 to 51
Pyrolysis
Stress Analysis

- Photoelastic Method
- Brittle Coatings Method
- Strain gage Method
- Chemical (Solvent Stress Analysis)
Photoelastic Pattern

We quantify this information.
How to quantify the results…..

- Qualitative……Visual, Best guess, interpretation variations
- Quantitative….reliable, measurable values, ASTM D 4093
- Manual measurement techniques
- **Equipment** : Polariscope or Polarimeter with compensator and Calibrated wedge
Instruments for Photoelastic Analysis (DIY)

Figure 6-7. Light box for stress-optical sensitivity examination.
Annealing to reduce Molded-in Stresses
Brittle-Coating Method

- Brittle-coating method is a useful technique for measuring localized stress in the part. Brittle coatings are specially prepared lacquers that are usually applied by spraying on actual part.

- Small cracks appear on the surface of the part as a result of external loading.

- The brittle-coating technique is not suitable for detailed quantitative analysis like photoelasticity.

- Helps pinpoint the location of stress in the part.
In order to measure residual stress with these standard sensors, the locked-in stress must be relieved in some fashion (with the sensor present) so that the sensor can register the change in strain caused by removal of the stress. This was usually done destructively in the past -- by cutting and sectioning the part, by removal of successive surface layers, or by trepanning and coring.

With strain sensors judiciously placed before dissecting the part, the sensors respond to the deformation produced by relaxation of the stress with material removal. The initial residual stress can then be inferred from the measured strains by elasticity considerations.
The Hole-Drilling Method

• The most widely used modern technique for measuring residual stress is the hole-drilling strain gage method of stress relaxation, illustrated on the right.
Chemical Method

- Most plastics, when exposed to certain chemicals while under stress, show stress cracking. Molded parts can be stress analyzed to determine the level of molded-in or residual stress using these techniques.
- **ABS**  Acetic acid immersion test
  **ASTM D 1939**
- **PVC**  Acetone immersion test
  **ASTM D 2152**
- **Polycarbonate Solvent Stress Analysis**
  **GE Plastics test method T-77**
Polycarbonate Solvent stress Analysis – Critical Stress

- Critical Stress level is defined as the stress level at which a given solvent will craze a polycarbonate part when exposed for a specified time period.

Critical stress level.....Methanol.......................3400 psi
Critical stress level.....Ethyl acetate......................500 psi

- Solutions ranging from 0 to 50% by volume of ethyl acetate in Methanol are used for this test using 3 minute immersion test.
Polycarbonate Solvent Stress Analysis

Typical Results

- Typical test results

---

Polycarbonate Stress Analysis Report Page 1 of 1

Testing: Solvent Stress Analysis
Test Method: GE Plastics Test Method (T--) Project #: P20015083
Customer: Conductor
Attention: Vishu Shah
Analyst: T. Keith
Date: November 28, 2000

Material: Polycarbonate Connector Tubes
Test Conditions: 22°C / 50%RH
Sample Preparation: As Received
Test Duration: 3 Minutes
Solvant: Methanol / Ethyl Acetate (MeOH / EtOAc)

<table>
<thead>
<tr>
<th>Critical Stress (MeOH / EtOAc)</th>
<th>Clear New as Molded</th>
<th>Clear Old as Molded</th>
<th>Clear New Annealed</th>
<th>Clear Old Annealed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200 psi (7/29)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>1100 psi (60.31)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>1000 psi (67.33)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>800 psi (63.37)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>670 psi (59.50)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Samples have a stress level of < 1100 psi, < 1150 psi, < 570 psi, < 520 psi.

12 samples of opaque finished ports showed a stress level of < 520 psi. There were two instances of the port breaking at a stress level of 570 psi. This accounts for the rating of < 500 psi.

Following the test specification above, the following was performed:

A set of three specimens from each test group was immersed in each solution for a period of three minutes. The samples were then removed and placed in distilled water at room temperature for two hours. The samples were then visually analyzed for stress cracking.

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11 Prime Street, Northfield, MA 01360
Phone (413) 689-9935, Fax 689-2393
www.plastics.com
Heat Reversion Technique

All plastics manufacturing processes introduce some degree of stress in the finished product. By reversing the process, by reheating the molded or extruded product, the presence of stress can be determined.

The degree and severity of warpage, blistering, wall separation, fish-scaling, and distortion in the gate area of the molded parts indicate stress level.

Note: No quantitative measurements possible.
Microstructural Analysis

Microtoming is a technique of slicing an ultra thin section from a molded plastic part for microscopic examination.

- Under packed parts……voids
- Contamination
- Color dispersion
- Filler dispersion such as glass fibers
- Degree of bonding
- Molded-in stresses using polarizer
Mechanical Testing

- Tensile, Impact, compression etc using actual defective parts
- Compare with “Good” parts
- Grind-up defective parts and mold test bars for physical testing
Thermal Analysis

- **DSC**
  Melting point, Glass transition temperature, Crystallinity
  Level of anti-oxidant in polymer

- **TGA**
  Quantitative determination of additives

- **TMA**
  Thermal expansion, Chemical blowing agent
Fractography

Electron Microscopy - SEM

Branching
Look for cracks on the failed part. The cracks that end before they reach the edge of the part are AWAY from the origin. These cracks typically exhibit branching.

River marks
River marks may be visible on the fracture edge. A magnifying lens may be used to locate these markings. The pattern shown in the inset illustrates the river markings 'pointing' toward the fracture origin.

Source: Eastman
Wallner Lines
These wavelike bands radiate from the fracture origin.

Source: Eastman
Fatigue striations emanating from fracture origin of polycarbonate latch handle
Simulation Testing

Exposing parts similar to the one that has failed to chemicals and other environment to learn about probable cause for failure.
The Case
Company ABC approached Polymer Solutions Incorporated (PSI) for us to determine if any differences existed between two different polyacetal samples, labeled as Sample A and Sample B.

The Approach
In order to arrive at this conclusion, PSI used several analytical techniques to compare and contrast the two samples:
- Melt Rheology
- Nuclear magnetic resonance (NMR) spectroscopy
- Fourier transform infrared (FTIR) spectrometry
- Extraction and additive analysis
- Capillary gas chromatography (GC)

Conclusion
From the data sets it was concluded that Sample A and Sample B are indistinguishable.

Source: Polymer solutions
Case Studies

Water Filter Housing

The failure appears as a circumferential crack that completely separated the bottom cap from the housing. This failure caused extensive water damage in the property where it was installed.

Source: Madison Group
Outdoors Degradation of High Density Polyethylene

MFR Test

This large difference between specified and tested MFR is due to the molecules breaking because of material degradation.

The formation of carbonyls and byproducts associated with oxidation. The FTIR performed at the surface of the part shows stronger absorption bands compared to the FTIR at the core. Therefore, the level of oxidation at the surface is much higher than the oxidation at the core of the part.

Source: Madison Group
# Failure Analysis Checklist

<table>
<thead>
<tr>
<th>Category</th>
<th>Questions/Remarks</th>
</tr>
</thead>
</table>
| **Material**           | What material is it?  What Grade?  
Color Number? Lot Number? Any regrind?  
How Much? |
| **Design**             | Fail in same place?  Knit Line location? Part to print comparison?  
Sharp corners? Uniform wall thickness? |
| **Application History**| Did it ever work?  When did it happen?  
How many parts?  Chemical exposure? |
| **Secondary Ops.**     | How is it joined?  Failure mode? Performance?  
Procedure details? |
| **Environment**        | Appearance differences?  Weathering effects?  
Chemical Exposure?  Compatibility checked? |
| **End-Use**            | In-Use?  In-storage?  Accidental?  Abuse? |

Source: GE Plastics
Identifying Plastics Materials

- Simple methods
- Advance methods
SIMPLE METHODS OF IDENTIFICATION

• Useful for identifying basic polymer and differentiating between the different types of polymers within the same family.
• Requires no special equipment or in-depth knowledge of analytical chemistry
• Simple step by step identification procedure using flow chart
Simple methods

Thermoplastic
- Visual
- Sp. gravity or Float test
- Burn test
- Copper wire test
- Melting point test
- Solubility test
- Pyrolysis
- Solvent extraction

Thermoset
- Visual
- Burn test
- Solubility test
- Pyrolysis
- Solvent extraction
BURN TEST OBSERVATIONS

- Does the material burn?
- Color of flame
- Odor
- Does the material drip while burning?
- Nature of smoke and color of smoke
- The presence of soot in the air
- Self-extinguishes or continues to burn
- Speed of burning – fast or slow
Product Liability

The manufacturer may be held liable if:

• 1. The product is defective in design and is not suitable for its intended use.
• 2. The product is manufactured defective and proper testing and inspection was not carried out.
• 3. The product lacks adequate labeling and warnings.
• 4. The product is unsafely packaged.
• 5. The proper records of product sale, distribution, and manufacturer are not kept up-to-date.
• 6. The proper records of failure and customer complaints are not maintained.

• INSTRUCTIONS, WARNING LABELS, AND TRAINING
• TESTING AND RECORDKEEPING
Key Points

• Product design
• Reliability Testing
• Document Control
• Warning Labels
• Record Retention
• Recall Procedures
• Liability Incidents and Investigation
• Litigation Teaching
Local Failure Analysis Laboratories

- **KARS' ADVANCED MATERIALS, INC.**
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  (714) 892-8987 Fax: (714) 894-0225  kars@karslab.com

Seal Laboratories Inc.
250 N. Nash Street, El Segundo CA 90245  PH: 310-322-2011
www.seallabs.com

CRT Laboratories, Inc.
1680 N. Main Street, Orange, CA 92867  PH: 800-597-LABS
www.crtlabs.com

OCM Test Laboratories, Inc.
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Anaheim, CA 92807

Phone Number: 714-630-3003 Ext. 222
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  4 Mill Street * Bellingham * Massachusetts 02019 * USA
  Tel: +1 (508) 966-1301 * Fax: +1 (508) 966-4063
This four-course certificate program provides practical instruction applicable to materials, processing, product design and tooling. The program is targeted to technical and non-technical audiences desiring to acquire basic knowledge, expand their horizon, enhance their career or simply take as a refresher course. The main emphasis is on practical aspects of Plastics Engineering Technology without being extremely technical so that the knowledge achieved can be applied in day-to-day applications.

PLASTICS: THEORY AND PRACTICE  
WINTER

PLASTICS PART DESIGN FOR INJECTION MOLDING/ 
TOOLING FOR INJECTION MOLDING  
Spring

SCIENTIFIC INJECTION MOLDING  
FALL

WWW.CEU.CSUPOMONA.EDU
Any Questions?
Thank You

FOR SUPPORTING SO. CAL.